

Metals Reducing Compound for Reduction/Anaerobic Degradation Enhancement Compounds:

1. Daniel Nunez, Regenesis
2. Propionic acid, 2-[2-[2-(2-hydroxy-1-oxopropoxy)-1-oxopropoxy]-1,2,3-propoanetriyl ester Glycerol esters of fatty acids and polylactates (MRC[®], Glycerol Tripolylactate with Metal Control Agent)
3. MSDS & Technical Data Sheet - Attached
4. Number of Field-scale Applications to Date: 200+ sites.
5. Case Studies – Attached
6. MRC[®] is a controlled release metals remediation product that removes dissolved hexavalent chromium from groundwater via in situ immobilization (precipitation and/or sorption to soil particles). MRC consists of an organosulfur compound esterified to a carbon backbone. This organosulfur ester is embedded in a polylactate matrix, making MRC a thick, viscous liquid. Upon injection into an aquifer, the organosulfur compound, which is the active metals immobilization agent, is slowly released when the ester bonds in MRC are cleaved via hydrolysis by water and microbial enzymatic action. Similar processes also cause MRC to slowly release lactic acid, which acts as an electron donor and carbon source for naturally occurring bacteria and creates the optimal conditions for metals immobilization by the organosulfur compound. MRC has been on the market over 10 years. There are no known adverse health and safety issues with this product.

**Metals Remediation Compound (MRC[®])
MATERIALS SAFETY DATA SHEET**

Last Revised: August 31, 2007

Section 1 – Material Identification

Supplier:



REGENESIS

1011 Calle Sombra

San Clemente, CA 92673

Phone: 949.366.8000

Fax: 949.366.8090

E-mail: info@regenesiS.com

Chemical Name: Propionic acid, 2-[2-[2-(2-hydroxy-1-oxopropoxy)-1-oxopropoxy]-1,2,3-propoanetriyl ester

Chemical Family: Organic Chemical

Trade Name: MRC[®], Glycerol Tripoly lactate with Metal Control Agent

Product Use: Used to remediate contaminated groundwater (environmental applications)

Section 2 – Chemical Identification

<u>CAS#</u>	<u>Chemical</u>
201167-72-8	Glycerol Tripoly lactate
444618-64-8	Sorbitol Cysteinate
50-21-5	Lactic Acid
56-81-5	Glycerol

Section 3 – Physical Data

Melting Point:	Not Available (NA)
Boiling Point:	Not Determined (ND)
Flash Point:	ND
Density:	1.3 g/cc
Solubility:	Acetone and DMSO
Appearance:	Viscous amber gel/liquid
Odor:	Strong Amine/Sulfur Smell
Vapor Pressure:	None

Section 4 – Fire and Explosion Hazard Data

Extinguishing Media: Use Water Spray, Carbon Dioxide, Dry Chemical Powder or Appropriate Foam.

Water May be used to keep exposed containers cool. For large quantities involved in a fire, one should wear full protective clothing and a NIOSH approved self contained breathing apparatus with full face piece operated in the pressure demand or positive pressure mode as for a situation where lack of oxygen and excess heat are present.

Section 5 – Toxicological Information

Acute Effects: May be harmful by inhalation, ingestion, or skin absorption. May cause irritation. To the best of our knowledge, the chemical, physical, and toxicological properties of the glycerol tripoly lactate have not been investigated. Listed below are the toxicological information for glycerol and lactic acid.

RTECS# MA8050000
Glycerol

Section 5 – Toxicological Information (cont)

Irritation Data:	SKN-RBT 500 MG/24H MLD	85JCAE-,207,1986
	EYE-RBT 126 MG MLD	BIOFX* 9-4/1970
	EYE-RBT 500 MG/24H MLD	85JCAE-,207,1986
	SKN-RBT 5MG/24H SEV	85JCAE -,656,86
	EYE-RBT 750 UG SEV	AJOPAA 29,1363,46
Toxicity Data:	ORL-MUS LD50:4090 MG/KG	FRZKAP (6),56,1977
	SCU-RBT LD50:100 MG/KG	NIIRDN 6,215,1982
	ORL-RAT LD50:12600 MG/KG	FEFRA7 4,142,1945
	LC50: > 570 MG/1H	BIOFX* 9-4/1970
	IHL-RATLC50:>570 MG/M3/1H	RCOCB8 56,125,1987
	IPR-RAT LD50: 4420 MG/KG	ARZNAD 26,1581,1976
	IVN-RAT LD50: 5566 MG/KG	ARZNAD 26,1579,1978
	IPR-MUS LD50: 8700 MG/KG	NIIRDN 6,215,1982
	SCU-MUS LD50: 91 MG/KG	JAPMA8 39,583,1950
	IVN-MUS LD50: 4250 MG/KG	DMDJAP 31,276,1959
	ORL-RBT LD50: 27 GM/KG	BIOFX* 9-4/1970
	SKN-RBT LD50:>10GM/KG	NIIRDN 6,215,1982
	IVN-RBT LD50: 53 GM/KG	JIHTAB 23,259,1941
	ORL-GPG LD50: 7750 MG/KG	FMCHA2-,C252,91
	ORL-RAT LD50:3543 MG/KG	FMCHA2-,C252,91
	SKN-RBT LD50:>2 GM/KG	FAONAU 40,144,67
	ORL-MUS LD50: 4875 MG/KG	JIHTAB 23,259,41
ORL-GPG LD50: 1810 MG/KG	FMCHA2-,C252,91	
ORL-QAL LD50: >2250 MG/KG		
Target Organ Data:	Behavioral (headache), gastrointestinal (nausea or vomiting), Paternal effects (spermatogenesis, testes, epididymis, sperm duct), effects of fertility (male fertility index, post-implantation mortality).	

Only selected registry of toxic effects of chemical substances (RTECS) data is presented here. See actual entry in RTECS for complete information on lactic acid and glycerol.

Section 6 – Health Hazard Data

Handling: Avoid continued contact with skin. Avoid contact with eyes.

In any case of any exposure which elicits a response, a physician should be consulted immediately.

First Aid Procedures

Inhalation: Remove to fresh air. If not breathing give artificial respiration. In case of labored breathing give oxygen. Call a physician.

Ingestion: No effects expected. Do not give anything to an unconscious person. Call a physician immediately.

Skin Contact: Flush with plenty of water. Contaminated clothing may be washed or dry cleaned normally.

Eye Contact: Wash eyes with plenty of water for at least 15 minutes lifting both upper and lower lids. Call a physician.

Section 7 – Reactivity Data

Conditions to Avoid: Strong oxidizing agents, bases and acids

Hazardous Polymerization: None known.

Further Information: Hydrolyses in water to form Lactic Acid and Glycerol.

Section 8 – Spill, Leak or Accident Procedures

After Spillage or Leakage: Neutralization is not required. This combustible material may be burned in a chemical incinerator equipped with an afterburner and scrubber.

Disposal: Laws and regulations for disposal vary widely by locality. Observe all applicable regulations and laws. This material may be disposed of in solid waste. Material is readily degradable and hydrolyses in several hours.

No requirement for a reportable quantity (CERCLA) of a spill is known.

Section 9 – Special Protection or Handling

Should be stored in plastic lined steel, plastic, glass, aluminum, stainless steel, or reinforced fiberglass containers.

Protective Gloves: Vinyl or Rubber

**Eyes: Splash Goggles or Full Face Shield
Area should have approved means of washing eyes.**

Ventilation: General exhaust.

Storage: Store in cool, dry, ventilated area. Protect from incompatible materials.

Section 10 – Other Information

This material will degrade in the environment by hydrolysis to lactic acid and glycerol. Materials containing reactive chemicals should be used only by personnel with appropriate chemical training.

The information contained in this document is the best available to the supplier as of the time of writing. Some possible hazards have been determined by analogy to similar classes of material. No separate tests have been performed on the toxicity of this material. The items in this document are subject to change and clarification as more information becomes available.



REGENESI



Metals Remediation Compound (MRC®)

MRC Proves Effective Against Hexavalent Chromium

SITE SUMMARY

Shallow groundwater in an industrial area of Berkeley, CA, was contaminated with hexavalent chromium (Cr (VI)) as a result of plating waste releases during the late 1970s. Stellar Environmental Solutions, Inc. (SES) was retained as the consultant to the responsible party. Groundwater monitoring since 1993 shows an elongated plume extending downgradient of the source area. Primary source area removal actions (soil excavation and disposal) occurred between 1993 and 1999. In 1999, monitored natural attenuation (MNA) was accepted as a remedial strategy for the approximately 1,000-foot-long chromium plume. Data collected in 2000 suggested that the Cr (VI) plume was generally attenuating as predicted. However, “hot spot” areas were identified and it was documented that the plume was migrating faster than anticipated along some preferential pathways. In addition, a public works project (a skateboard park) was constructed within the footprint of the plume in 2000-2001. During construction, inadvertent dewatering discharges of Cr (VI)-contaminated water were detected in the storm drain resulting in heightened regulatory concern over the site. Further complications developed in 2003 when cracks in the concrete base of the skateboard park allowed groundwater seepage, creating increased concerns within the community at large. In order to augment or accelerate the relatively slow Cr (VI) natural attenuation process already underway, a pilot study using Metals Remediation Compound (MRC®) was initiated in early 2003.



Figure 1. Metals Remediation Compound

REMEDIATION APPROACH

- **Remediation Objective:** Determine the efficacy of *in situ* Cr (VI) reduction with MRC.
- **Application Type:** 15 point barrier (direct-push injection)
- **Product:** MRC
- **Quantity Applied:** 960 lbs
- **Application Rate:** 8 lbs/ft
- **Product Cost:** \$9,120

SITE CHARACTERISTICS

General

- **Name:** Confidential
- **Location:** Berkeley, CA
- **Industry:** Active Plating and Engraving Facility
- **Barrier Length:** 150 ft
- **Treatment Thickness:** 8 ft (8-10 ft bgs)
- **Soil Type:** stiff clay to sand and gravel
- **Groundwater Velocity:** 10-80 ft/yr
- **Groundwater Flow Direction:** West to Northwest
- **Depth to Groundwater:** Approximately 7 ft

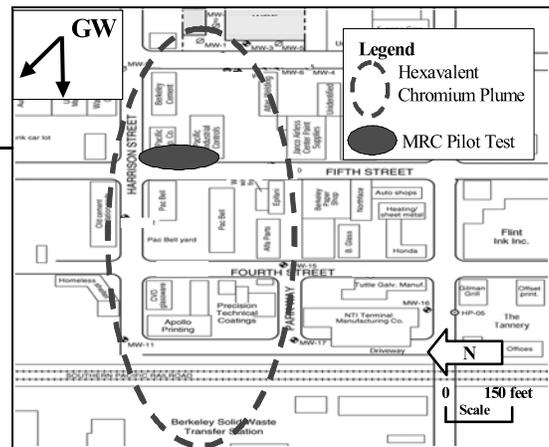


Figure 1. Site and Site Vicinity Map

RESULTS

The presence of MRC can be traced through the concentration of total organic acids (sum of lactic, pyruvic, acetic, butyric, and propionic, acids), which act as non-conservative tracers for the product. An increase in total organic acids in downgradient wells is characteristic of successful MRC distribution, and chromium should decrease in wells affected by MRC. Unexpectedly, nine months following the MRC application, organic acids were not detected in MW-18, the downgradient well closest to the MRC barrier (Figure 3). It was hypothesized that the effects of uncharacterized, localized groundwater flow may be to blame. Further site characterization suggested that localized groundwater flowed more toward the northwest (instead of due west) causing chromium breakthrough between injection points and extending into MW-18 (Figure 3). Additional bore-hole sampling by SES, in a tight grid near the injection areas confirmed this hypothesis as increased organic acid concentrations were detected in sampling locations (BH-07, BH-01, BH-03 and BH-04) more to the northwest of the MRC injection points.

In wells where total organic acids reached a concentration of at least 50 mg/L (e.g. BH-01, BH-03, BH-04, BH-07), total chromium concentrations were reduced to low levels (e.g. 20 ug/L in BH-01, BH-03 and BH-07) and hexavalent chromium concentrations were non-detect (<10 ug/L). Conversely, in areas not influenced by the action of MRC due to unanticipated groundwater flow direction changes (e.g. BH-02, BH-08, and MW-18), total organic acids were non-detect and total and hexavalent chromium concentrations were no different than nearby contaminated, untreated areas.

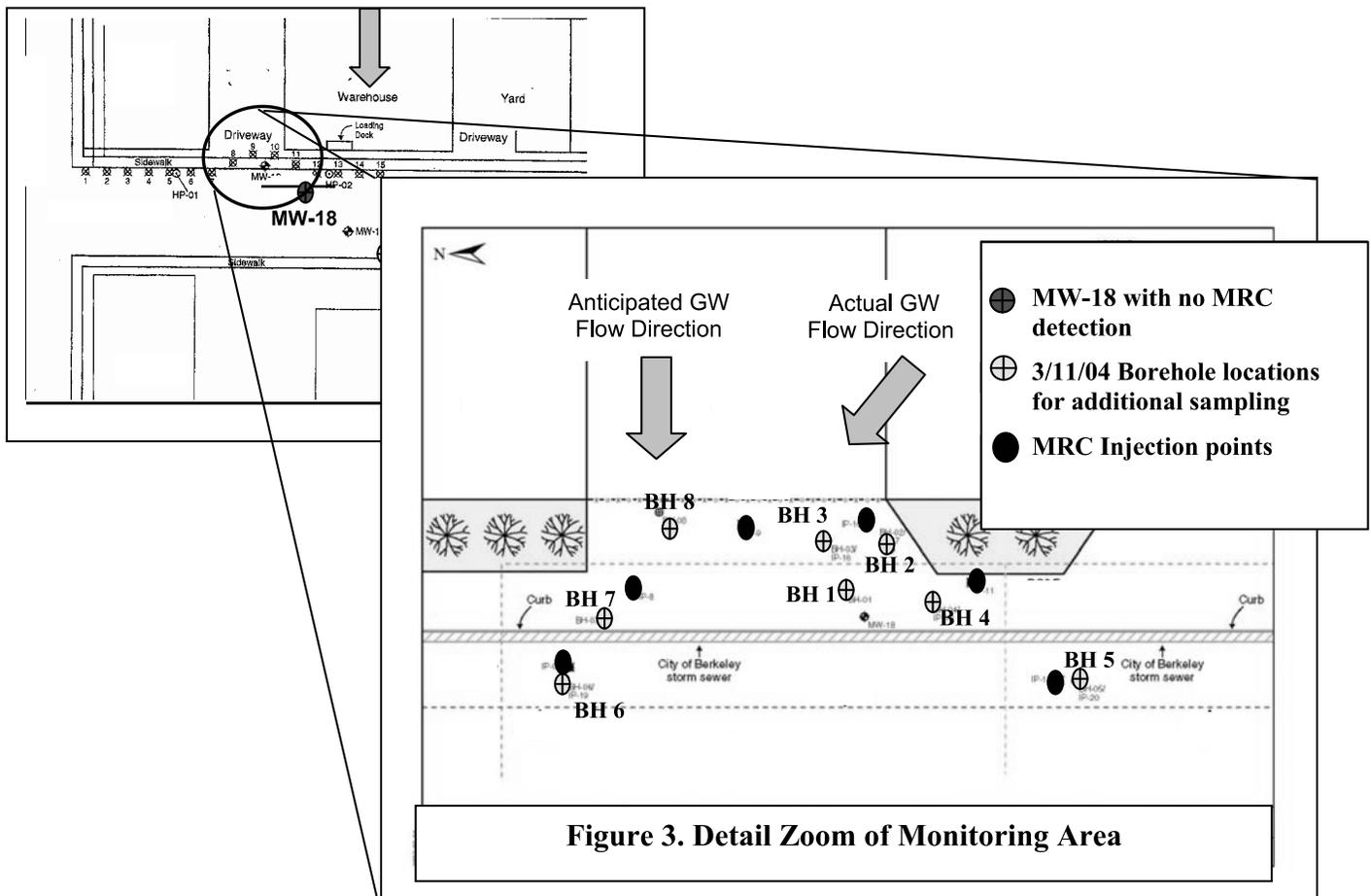
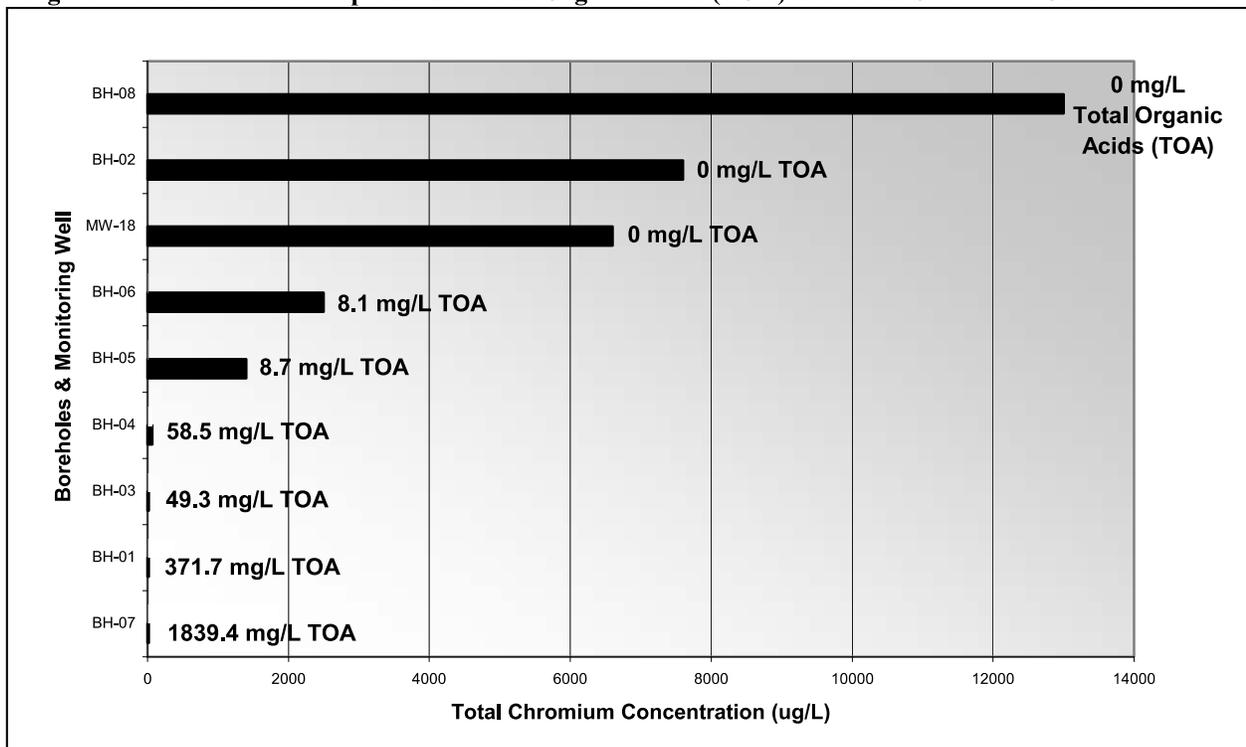


Figure 4. Inverse Relationship Between Total Organic Acids (TOA) and Total Chromium Concentrations



CONCLUSION

This pilot study demonstrates the efficacy of *in situ* chromium reduction with MRC when proper distribution in the subsurface is achieved. Results from follow-up sampling demonstrated a strong correlation between increased total organic acid concentrations and reduced total and hexavalent chromium concentrations. In boreholes impacted by MRC (total organic acids greater than 50 mg/L), total chromium concentrations were 20-67 ug/L, while, in areas where total organic acids were not measured, total and hexavalent chromium were as high as untreated background levels (5000 ug/L). Due to the initial effectiveness of MRC and in light of the additional groundwater flow direction information, a second MRC application is scheduled to address the areas of chromium breakthrough. The initial results from this site provide convincing evidence that the application of MRC to hexavalent chromium contaminated groundwater results in significant chromium reduction.

CONTACTS

Consultant: Stellar Environmental Solutions, Inc.
 Richard S. Makdisi
 Phone: (510) 644-3123
rmakdisi@stellar-environmental.com

Regenesis: Jack Peabody
 Northwest Regional Manager
 Phone: (925) 944 – 5566
jpeabody@regenesis.com



REGENESI**S**

Metals Remediation Compound (MRC[®])

MRC Treats Chromium and Replaces Pump and Treat System

SITE SUMMARY

Wastewater discharge from an industrial plating facility resulted in hexavalent chromium contamination of a groundwater aquifer. Under the oversight of the U.S. EPA's CERCLA (Superfund) program and the Texas Commission on Environmental Quality (TCEQ), a pump and treat system was installed and operated from 1990 until August 2003 when pumping was stopped on parts of the site. To provide chromium treatment in the absence of the active system, a remediation technology was needed that could effectively reduce the total unfiltered chromium groundwater concentration to 100 ug/L. An injectable controlled release compound, Metals Remediation Compound (MRC[®]), was chosen to immobilize dissolved chromium, including hexavalent chromium, from groundwater. MRC was chosen for groundwater remediation due to its ability to provide a rapid, effective, and low-cost solution. Remediation was initiated through an MRC pilot test, which resulted in a substantial decrease in the groundwater concentration of total unfiltered chromium in areas around treated wells. As a result of this success, a full-scale injection of MRC was performed. During the full-scale project (monitoring on-going), MRC has continued to reduce the total unfiltered chromium concentration toward the project goal of 100 ug/L. The pump and treat system has been completely shut down and the results continue to provide convincing evidence that the application of MRC to treat hexavalent chrome is a viable alternative to costly and operations/maintenance intensive mechanical systems.



Figure 1: Barrier Application

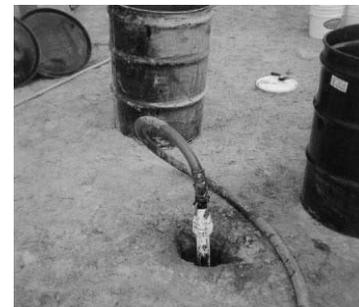


Figure 2: MRC Application into an Existing Well

REMEDIATION APPROACH

- **Remediation Objective:** Reduce concentrations of total unfiltered chromium to 100 µg/L
- **Application Type:** Multiple Barrier (Sonic Drilling/Air Rotary Drilling)
- **Product:** MRC

Table 1: Application Details

Application Scale	Starting Date	Quantity Applied	Product Cost	Application Rate
Pilot Scale	8/22/03 (day 0)	2,880 lbs.	\$27,360	6 lbs/ft
Full Scale	12/16/03 (day 116)	15,840 lbs.	\$126,720	12 lbs/ft

SITE CHARACTERISTICS

General

- **Name:** Confidential
- **Location:** Odessa, TX
- **Industry:** Industrial Plating Facility

Hydrogeology

- **Treatment Area:** 350,000 ft²
- **Soil Type:** Fine Sand
- **Groundwater Velocity:** 0.24 ft/day
- **Groundwater Flow direction:** Northeast
- **Depth to Groundwater:** 60 ft

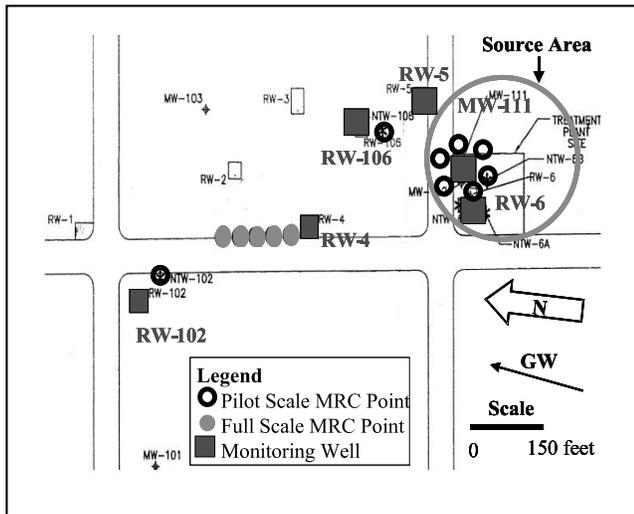


Figure 3a: Plume Area Site Map

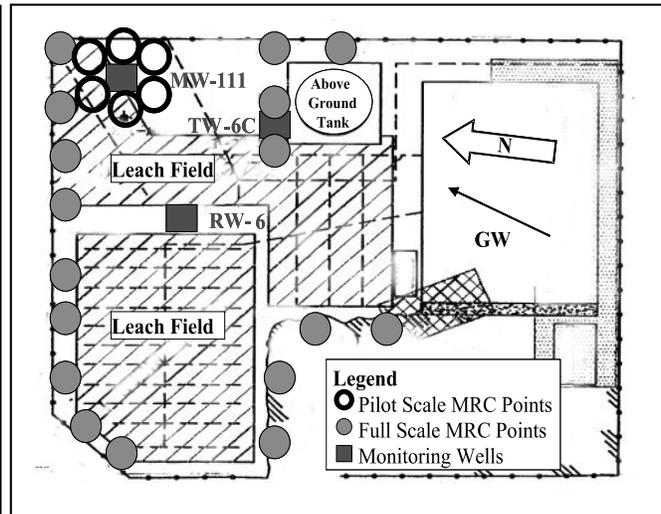
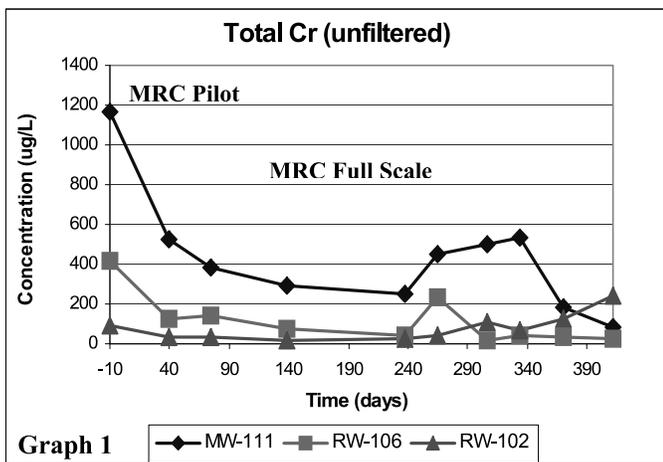
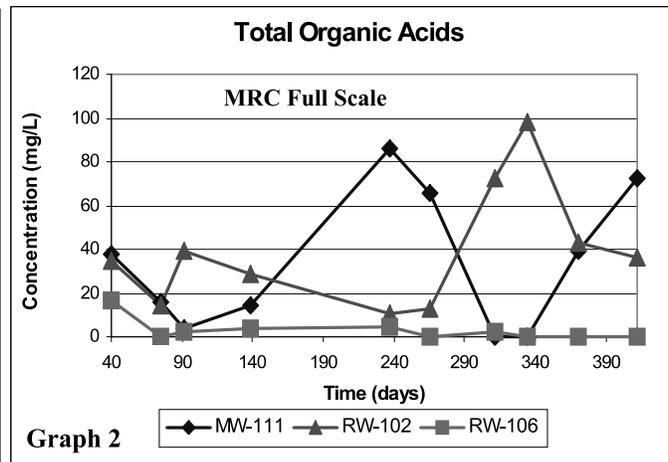


Figure 3b: Source Area Site Map

RESULTS



Graph 1



Graph 2

Plume Results (MW-102 and RW-106)

Results in Graph 1 are provided in total unfiltered chromium concentrations, as specified by the regulatory guidelines. Unfiltered total chromium samples may contain metals present as particulate matter, while filtered samples are more representative of dissolved metals. Results in Graph 2 are presented as total organic acids (TOA), which are the sum of MRC metabolic products lactic, pyruvic, acetic, propionic, and butyric acids.

Pilot scale treatment results in targeted plume wells RW-106, and RW-102 (Figure 3a) indicated a rapid reduction in total unfiltered chromium at 42 days post-MRC injection, in conjunction with detections of elevated TOA. Total unfiltered chromium in RW-106 was reduced to below the regulatory goal of 100 ug/L by day 138 and has remained beneath the goal, with the exception of a single monitoring event on day 265 that was linked to pumping in the source area. Well RW-102 has remained beneath the regulatory goal for the majority of the project period, but rose to 239 ug/L on day 412. Although total unfiltered chromium levels are above the 100 ug/L goal in RW-102, hexavalent chromium, the more toxic form of chromium, was reduced from a pre-injection level of 107 ug/L to <10 ug/L by day 40 and has remained < 10 ug/L thereafter (Table 1). Thus, hexavalent chromium has been reduced, but the trivalent solid has not yet precipitated. Graph 2 shows that RW-102 has consistently elevated levels of TOA, indicating the MRC is affecting this well and providing the reducing conditions necessary for chromium precipitation. In contrast to treated wells RW-106 and RW-102, untreated plume wells RW-4 and RW-5 show fluctuating total unfiltered chromium levels (between approximately 50 and 200 ug/L) and no increases in TOA.

Source Results (MW-111)

Well MW-111, in the heart of the source area and part of the MRC pilot study (Figure 3b), showed a decrease in total unfiltered chromium levels from 1170 ug/L pre-injection to 86 ug/L at day 412, a 93% reduction (Graph 1). Graph 2 shows that total unfiltered chromium decreases occurred in conjunction with increases in TOA from MRC. The continued decrease is significant since, historically, total unfiltered chromium in well MW-111 has fluctuated between 1,000 and 12,000 ug/L. Other source area wells not treated by the MRC application show no decreases in total unfiltered chromium or increases in TOA.

Table 1. – Hexavalent Chrome Measurements for Various Wells

	Pre MRC Treatment Concentration (3/2003, day -162)	Post MRC Pilot Concentration (10/2003, day 42)	Post MRC Full Scale Concentration (1/2004, day 138)	Recent Sampling (10/2004, day 370)	Percent Reduction
MW-111	2620	<10	<10	<10	99%
RW-106	690	<10	<10	<10	99%
RW-102	107	<10	<10	<10	91%
RW-5 (untreated)	41	90	92	40	2%
RW-4 (untreated)	119	70	34	96	19%

Hexavalent Chrome Reduction

The results in Table 1 show the reduction of hexavalent chromium in groundwater as a result of MRC influence. In the source well MW-111, as well as plume well RW-106 and RW-102, levels were reduced by 91-99% approximately one month after injection and remained non-detect. Untreated wells RW-4 and RW-5 showed minimal reduction of Cr (VI).

Table 4: Oxidation-Reduction Potential (ORP) in MRC Treated and Untreated Wells

	Baseline (8/03) ORP (mv)	Minimum ORP (mv) Value Over Monitoring Period
RW-5	212	59
RW-4	201	-5
RW-111	248	-202
RW-106	232	-294
RW-102	230	-235

Table 5: Total Organic Acids (sum of lactic, pyruvic, acetic, butyric, and propionic acids) in MRC Treated and Untreated Wells

	Baseline (8/03) Total Organic Acids (mg/L)	Maximum Total Organic Acid (mg/L) Value Over Monitoring Period
RW-5	Assumed Non-Detect	Non-Detect
RW-4	Assumed Non-Detect	Non-Detect
RW-111	Assumed Non-Detect	85.8
RW-106	Assumed Non-Detect	16.6
RW-102	Assumed Non-Detect	72

Oxidation-Reduction Potential and Total Organic Acids

The action of MRC can also be traced through oxidation-reduction potential (ORP - Table 4) and total organic acids (TOA - Table 5). A reduction in ORP and an increase in TOAs are characteristic of the presence of MRC. These trends were displayed when comparing treated wells RW-111, RW-106, and RW-102 to untreated wells RW-4 and RW-5. The ORP difference in wells RW-4 and RW-5 averaged 180 mV, while treated wells RW-111, RW-106, and RW-102 showed an average of 480 mV. In addition, TOAs in RW-4 and RW-5 remained non-detect, while treated wells showed an increase.

CONCLUSION

As a result of MRC influence, hexavalent and total unfiltered chromium have decreased to close to or beneath target concentrations in treated wells. As a result, the pump and treat system has been shut down, for a net savings of \$183,000 in the first year. Based on the successes of the pilot and full scale MRC applications, a re-application to the untreated portions of the source area is being investigated.

CONTACTS

Regenesis: Rick Gillespie
 (972) 377-7288
 (972) 377-7298
 E-mail: rgillespie@regenesis.com

The Large Scale Treatment of Hexavalent Chromium Cr(VI) by the Injection of MRC[®]

CASE SUMMARY

The phased remedial work undertaken by Provectus Group at a contaminated industrial site in Birmingham has demonstrated that the combination of remediation techniques including source removal and the injection of Metals Remediation Compound (MRC[®]) into the contaminated saturated zone has significantly reduced the concentrations of hexavalent chromium (Cr(VI)) within soils and groundwater.

Provectus Group has successfully completed a complex remediation project at an industrial site approximately 2.0km south-west of Birmingham city centre. Historical processes at the site included a range of metal treatment services including internal and cylindrical grinding, honing and polishing, and the electro-chemical deposition of metals from aqueous solutions.

The industrial history of the site has been established since 1904 with the most recent activities and layout being established since 1951.

Site investigation works undertaken between June 2004 and April 2006 confirmed the presence of extensive hexavalent chromium (Cr(VI)) contamination, together with limited nickel, zinc, copper and hydrocarbon contamination within the near surface soils and groundwater. The chromium contamination identified was directly linked to a series of process dipping tanks located in the northern part of the existing industrial building.

Aqueous phase Cr(VI) can be quickly converted to its non-toxic, insoluble trivalent state, Cr(III), through the use of a benign organosulfur compound known as Metals Remediation Compound (MRC[®]) manufactured by RegenesiS (based in Bath, Somerset, UK). The phase transfer from Cr(VI) to Cr(III) prevents continued plume migration and effects a permanent solution under natural aquifer conditions. The stability of the end-point is highlighted by the observation that this is essentially an acceleration of the natural weathering pattern of Cr(VI) in an aquifer, and that given time, the contamination would naturally attenuate to the same end-point. The process is therefore not prone to reversal under natural conditions.

Metals Remediation Compound (MRC[®])

MRC's active compound is an ester of cysteine (a sulfur-containing amino acid) on a carbon backbone molecule of glycerol and sorbitol. A cysteine-based product such as MRC is well suited for *in situ* Cr(VI) immobilization, since it has a strong affinity for metal contaminants and does not alter the properties of the subsurface. The active compound in MRC (sorbitol hexacysteinate) is embedded in a polylactate matrix that provides a carbon source and electron donor for subsurface bacteria. This combination of materials makes MRC a viscous but injectable material that slowly releases the cysteine ester to a contaminated aquifer via hydrolysis by water or enzymatic action by microbes. MRC's slow-release property allows for a longevity of 12 to 18 months in an aquifer, allowing for an effective approach to metals immobilization.

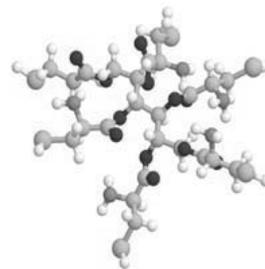


Figure 1.
Core Molecular Structure of MRC[®]

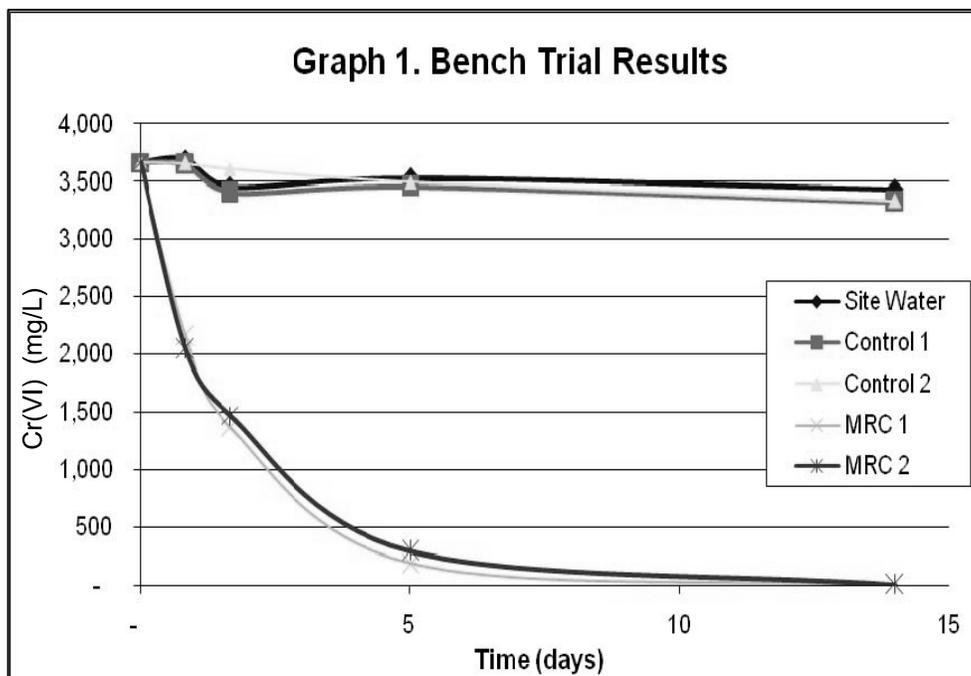
BENCH SCALE TRIAL

A bench scale treatability study was initiated to determine the potential effectiveness of MRC to immobilise Cr(VI) from groundwater prior to applying it on-site. The study included duplicate control samples and MRC test samples consisting of clean sub-soil and site water to try and replicate subsurface conditions. In addition, a sample of site water was used as a control for comparative purposes. Table 1 describes the compositions of each bottle. The study was conducted over a 14-day period during which 4 samples were taken. The headspace of each bottle was purged with nitrogen and anaerobic conditions were maintained throughout the trial.

Table 1. Composition of Test Trials

Test Bottle	Site Water (mL)	Clean Soil (g)	Deionised Water (g)	MRC (g)
Site Water	500	--	--	--
Control 1		250	50	--
Control 2			50	--
MRC 1			--	50
MRC 2			--	50

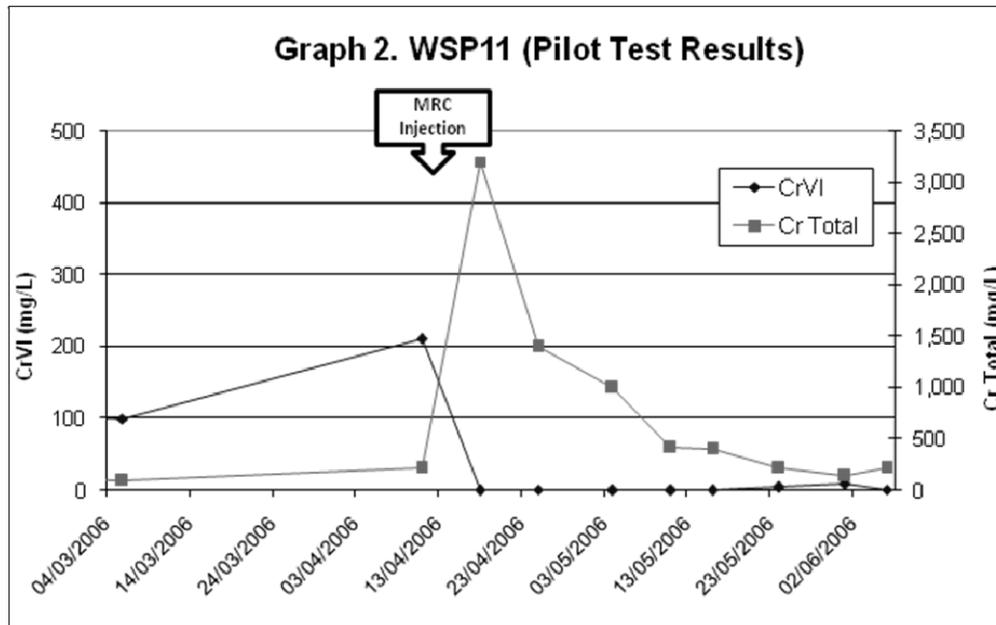
The reduction of Cr(VI) throughout the bench scale study can be seen in Graph 1. The site water and duplicate controls maintained a Cr(VI) concentration of approximately 3,500 mg/L throughout the 14-day trial. Whereas, immediate reduction was observed in the MRC duplicate samples; concentrations were reduced from 3,660 mg/L to less than 10 mg/L within two weeks, a 99% reduction. As a result, in-situ injection of MRC was chosen to be pilot tested on-site to assess its effectiveness within the soil matrix.



PILOT TEST APPLICATION

A pilot study was conducted in the area of the highest recorded Cr(VI) concentrations to provide site specific effectiveness of the proposed treatment technology. An area of 64m² was treated utilising 16 direct-push injection points at 2.0m spacing.

Rapid reduction of Cr(VI) was apparent one week after the MRC injection as concentrations declined from 210 mg/L to 1 mg/L (Graph 2). Concentrations remained reduced throughout the 8 week monitoring period achieving a reduction of 99%. The increase in total chromium is indicative of the transformation of Cr(VI) to Cr(III) which then partitions into soil. The successful results of the pilot test prompted a full-scale application of MRC over the remaining plume.



FULL-SCALE APPLICATION

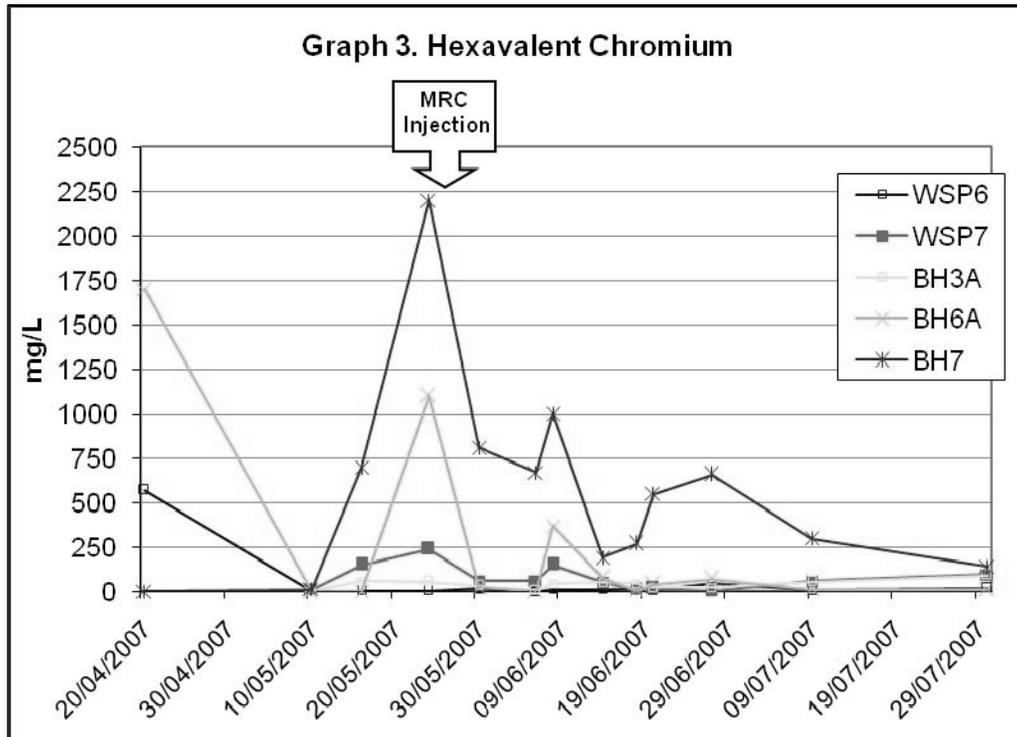
The full-scale remedial treatment design included the removal of former storage tanks and chrome dipping tanks and targeted excavation of impacted soils. This was followed by placement of MRC directly into the base of the excavation and in-situ injection of MRC across the existing plume. Excavation and injection activities were completed within the existing building that was retained for future use. A total of 840m³ of chromium-contaminated soil was removed and disposed of off-site. A combination of MRC and HRC Primer were added to the base of the excavation to treat any residual contamination. A total of 1,640kg MRC and 820kg HRC Primer were applied to the excavation using a mixing ratio of 2 parts MRC and 1 part HRC Primer.

The in-situ application included the direct-push injection of MRC and HRC Primer across the chrome-contaminated area using a grid design using 3m spacing. A total of 2,383kg MRC and 1,191kg HRC Primer was mixed and applied via 77 injection points.

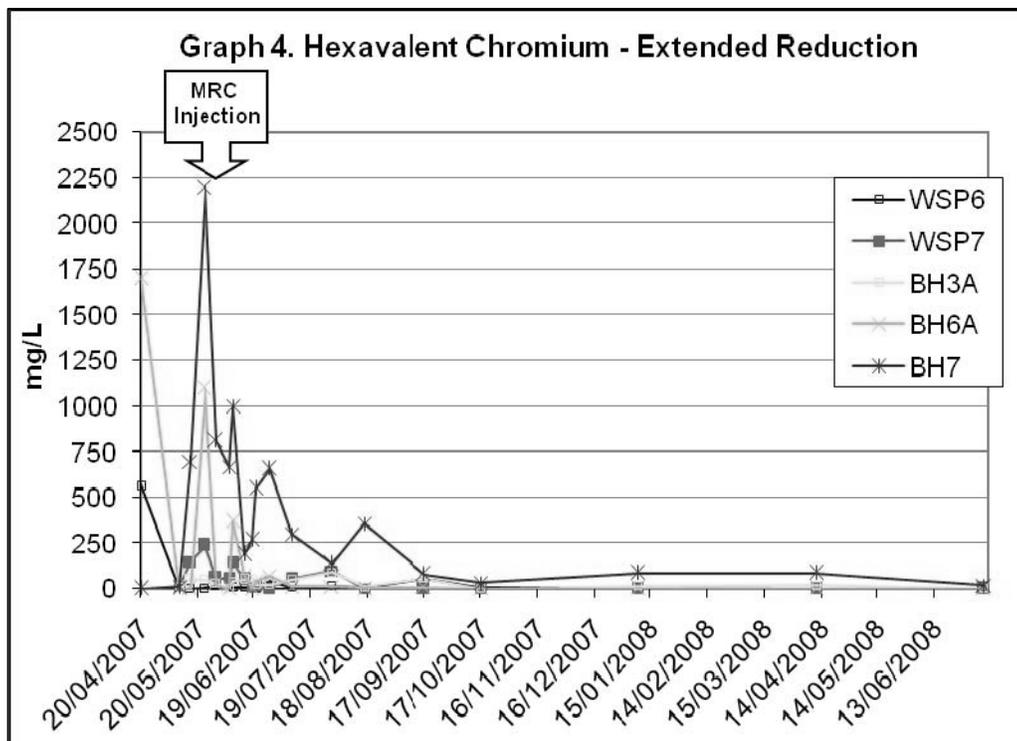
RESULTS

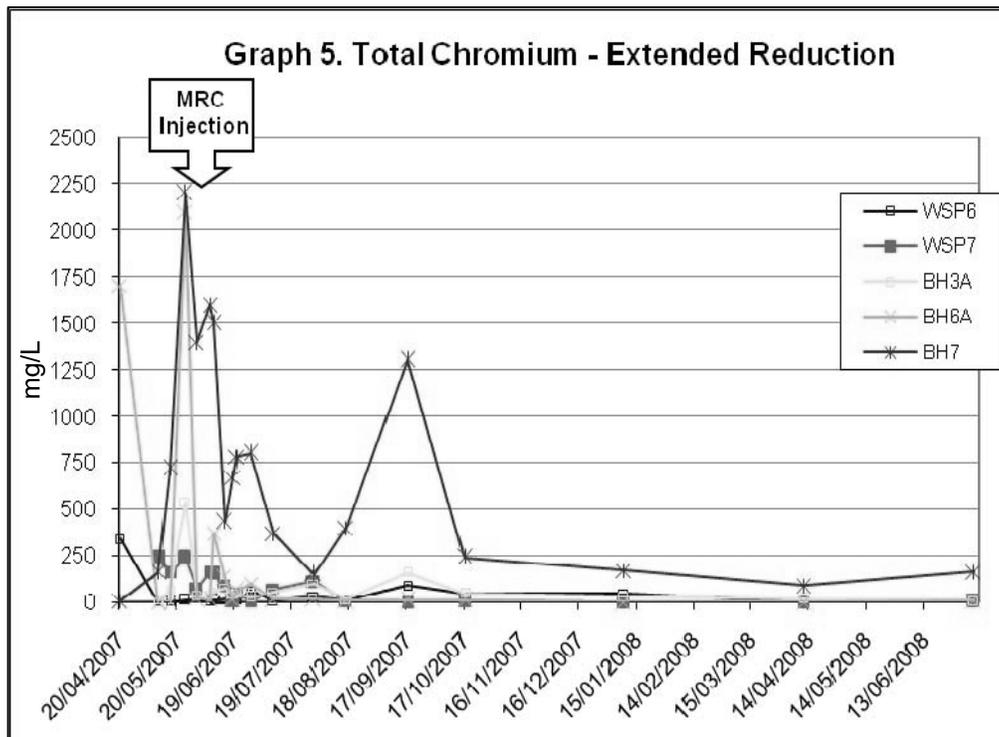
During the remediation works, an increase in Cr(VI) concentrations within the groundwater was observed caused by site disturbance from the excavation activities. Following the injection of MRC, a significant decline in Cr(VI) occurred. Most notable is the decline in BH7 from 2,200 mg/L to 810 mg/L within one week. Cr(VI) concentrations continued to decline over the following 2 months to below 250 mg/L (Graph 3).

A similar reducing trend was observed in total chrome in all wells. As a result of the excavation activities, total chrome temporarily increased to a high of 2,200 mg/L in well BH7. Concentrations were then reduced to below 200 mg/L within 15 weeks of the MRC application.



The extended results of the MRC application indicate that Cr(VI) was reduced to below 20 mg/L in all wells within the treatment area 15 weeks after the application (Graph 4). After one year, the Cr(VI) concentration has remained below 20 mg/L. Total chrome declined to below 250 mg/L and remains reduced one year after the MRC application (Graph 5).





CONCLUSION

High concentrations of hexavalent chromium (Cr(VI)) were identified as causing risk to human health under a former plating works site. Provectus Group identified MRC as the most viable remediation technology and both bench and pilot scale testing proved that MRC was effective at significantly reducing Cr(VI) concentrations. Full-scale application of MRC into excavations and by direct-push injection provided a rapid reduction in Cr(VI) and total chromium concentrations, which were shown to remain low over an extended monitoring period. The success of the in-situ treatment allowed for the existing structure to remain in-place and undamaged. Site closure was granted by the regulatory authorities which has allowed the site to be used for future industrial activities.

CONTACT

Gareth Leonard
 Regenesys Ltd.
 District Manager – UK & Scandinavia
 +44 (0) 1833 630 411 /gleonard@regenesys.com

Mark Harris
 Provectus Group
 Project Manager
 +44 (0) 1902 625 04 / mark.harris@provectusgroup.com



METALS REMEDIATION COMPOUND (MRC®)

MRC is a controlled release remediation product designed specifically for the treatment of hexavalent chromium (Cr(VI)) in groundwater. MRC removes dissolved hex-chrome via *in situ* immobilization and provides a substrate for the biodegradation of chlorinated solvents.

Background

Within a groundwater aquifer chromium can exist as either the trivalent, Cr(III), or hexavalent, Cr(VI) form. Cr(III) is considered to be essential to mammals for the maintenance of glucose, lipid, and protein metabolism. Conversely, in humans Cr(VI) is known to have an adverse affect on the lungs, liver, and kidneys. Groundwater can become contaminated with metals, including Cr(VI), through a variety of processes including: infiltration of leachate from landfills, land application of sewage sludge, seepage from industrial waste lagoons and spills/leaks from industrial plating and coating operations.

The Subsurface Environment

Within the subsurface environment, dissolved metals are affected by a number of geochemical factors including pH, electrical potential (Eh), complexation, sorption and ion exchange. The ability to manipulate and control these factors can directly influence the physical state, mobility, and presence of metals in groundwater through processes such as precipitation, oxidation/reduction, sorption, and complexation. MRC directly affects biogeochemical processes to remove Cr(VI) from groundwater quickly, effectively and at a relatively low cost.

How it Works

MRC is a controlled release metals remediation product that removes dissolved hexavalent chromium from

groundwater via *in situ* immobilization (precipitation and/or sorption to soil particles). MRC consists of an organosulfur compound esterified to a carbon backbone. This organosulfur ester is embedded in a polylactate matrix, making MRC a thick, viscous liquid. Upon injection into an aquifer, the organosulfur compound, which is the active metals immobilization agent, is slowly released when the ester bonds in MRC are cleaved via hydrolysis by water and microbial enzymatic action. Similar processes also cause MRC to slowly release lactic acid, which acts as an electron donor and carbon source for naturally-occurring bacteria and creates the optimal conditions for metals immobilization by the organosulfur compound.

Immobilization Mechanisms

MRC stimulates chromium immobilization using a two-part mechanism. First, there is significant evidence that the organosulfur compound in MRC is a direct chemical reductant for soluble hexavalent chromium and produces insoluble trivalent chromium. Secondly, MRC can stimulate hexavalent chromium reduction indirectly by providing lactic acid, which is rapidly metabolized by subsurface microbes and creates reduced species, like ferrous iron and sulfide, that are known to chemically reduce hexavalent chromium to the insoluble trivalent state.

Dual-Purpose Functionality

MRC can also be used to treat sites with mixed hexavalent chromium and chlorinated hydrocarbon contamination because it provides the substrates needed to facilitate dissolved hexavalent chromium immobilization and reductive dechlorination. The dual-purpose feature allows MRC to effectively treat sites with co-mingled plumes because it eliminates the need for separate technologies to treat metals and chlorinated compounds. The organic substrate and lactate present in MRC accelerates the *in situ* biodegradation rates of chlorinated hydrocarbons (CHs) via anaerobic reductive dechlorination processes. Indigenous microorganisms ferment the lactate given off by MRC and produce hydrogen. Microorganisms capable of reductive dechlorination use this hydrogen to progressively remove chlorine atoms from chlorinated hydrocarbon contaminants. In general, reductive dechlorination of ethenes occurs by way of sequential dechlorination from perchloroethene (PCE) to trichloroethene (TCE) to dichloroethene (DCE) then to vinyl chloride (VC) and finally to ethene. Reductive dechlorination is one of the primary attenuation mechanisms by which chlorinated solvent groundwater plumes can be stabilized and/or remediated.

MRC offers a safe, simple and effective means of *in situ* Cr(VI) treatment at contaminated groundwater sites.



MRC® PERFORMANCE

IN THE LAB

MRC was tested for the immobilization of hex-chrome in a simulated aquifer experiment. Results of hex-chrome treatment:

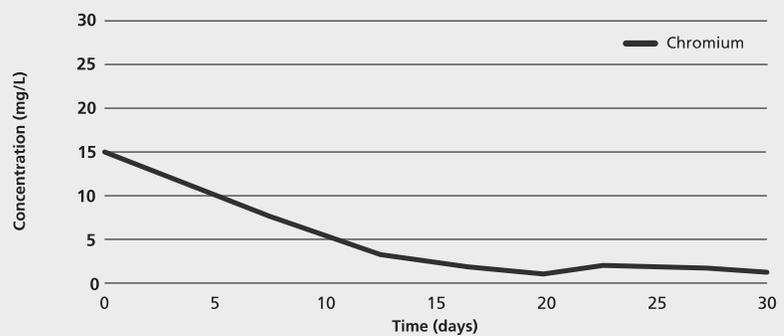
Results of Chromium Treatment

Over a 30 day period:

- Chromium was reduced from 15 mg/L to 0.4 mg/liter

After 30 days of operation, flushing was started to assess the stability of the hex-chrome. Three pore volumes of oxygenated water were flushed through the aquifer simulation vessel (ASV) for 30 days and concentrations of dissolved hex-chrome did not rebound or increase.

Figure 1: Chromium Immobilization with Regenes Metals Remediation Compound (MRC)

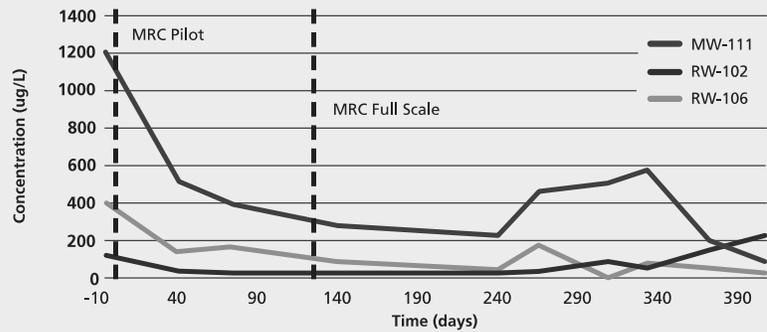


IN THE FIELD

Superfund Site Replaces Pump and Treat (P&T) with MRC

A P&T system was installed at a site in Texas to treat chromium in tight soils. After 13 years of operation, the P&T system was deemed ineffective in treating the remaining chromium and the system was shutdown. MRC was chosen to further reduce concentrations of unfiltered chromium. Figure 2 shows the reduction of unfiltered chromium as a result of MRC influence. Hexavalent and total unfiltered chromium have decreased to close to or beneath target concentrations. The use of MRC resulted in a net savings of \$183,000 during the first year of treatment.

Figure 2: Total Cr (unfiltered)



REGENESIS

Advanced Technologies for Groundwater Resources

Metals Remediation Compound **MRC**[®]

TECHNICAL BULLETIN 5.0

Cr(VI) Reduction: MRC vs. HRC

Metals Remediation Compound (MRC[®]) is an organosulfur compound embedded in a polylactate matrix designed to immobilize metals from groundwater. Hydrogen Release Compound (HRC) is a polylactate compound without the organosulfur compound originally designed for the reduction of chlorinated solvents.

Hexavalent chromium (Cr(VI)) is used in a variety of industrial processes. Highly soluble and toxic, Cr(VI) is used in wood treating, plating, tanning, as well as the power industry. Both MRC and HRC have proven to be effective in removing Cr(VI) from groundwater by reducing it to its trivalent form, Cr(III), which has limited solubility. However, the mechanisms by which MRC and HRC reduce Cr(VI) are slightly different. The organosulfur compound in MRC is an abiotic reductant and reacts with Cr(VI) directly in the initial stages, whereas HRC releases lactate to biologically reduce Cr(VI). In general, the rate of abiotic Cr(VI) reduction is faster than that of biological Cr(VI) reduction.

An investigation was conducted at Hanford, a Cr(VI)-contaminated DOE site with a plume migrating towards the Columbia River. Sediment was collected from the Hanford site and exposed to 1,000 ppb Cr(VI) and either HRC or MRC. In less than 1 week, MRC had reduced Cr(VI) to undetectable concentrations whereas it required 3 weeks for HRC to reduce Cr(VI) to undetectable concentrations (Hazen *et al.*, 2004).

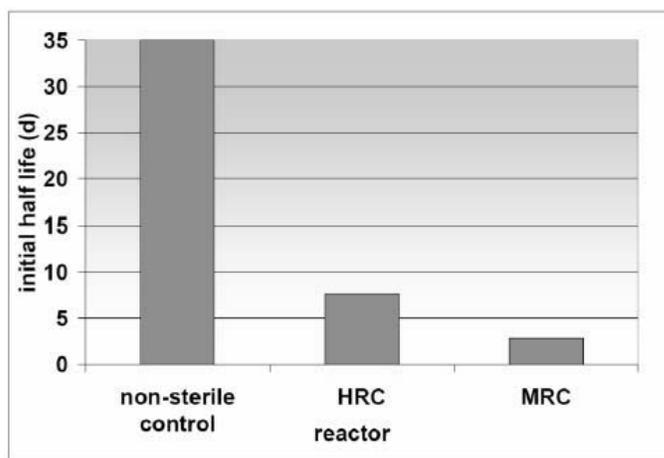


Figure 1: Half-life calculations for HRC, MRC, and non-sterile reactors

A similar investigation was carried out at a former chrome plating facility in Sacramento, California. HRC and MRC were used in soil reactor experiments to examine their potential for stimulating dissolved Cr(VI) reduction and precipitation. Contaminated water with 12,000 µg/L of Cr(VI) was placed into three 32-gallon reactors filled with soil from uncontaminated on-site borings and then treated with HRC, MRC, or no amendment (non-sterile control). The results can be seen in the Figures 1 and 2.



REGENESIS

The Cr(VI) half-lives for MRC for the first 12 days was 3 days for MRC, which was less than half that of HRC at 7 days. By contrast, the non-sterile control had total chromium half-lives of 35 days.

MRC and HRC reactors showed respectively, 100% and 73% reduction in Cr(VI) concentrations over the same 12 days. The non-sterile control was reduced by 25% over this time span.

These experiments demonstrate that while both HRC and MRC are effective at reducing dissolved Cr(VI) concentrations in groundwater, the abiotic reduction of Cr(VI) due to the organosulfur compound in MRC can result in much quicker results that do not rely on native microbial populations.

While the difference in Cr(VI) reduction rates may not seem significant in bench-scale studies, in a full scale application the disparity could potentially be extrapolated to additional weeks or months of treatment. As well, the addition of an abiotic reductant decreases the reliance on microbiological factors increasing the overall efficiency of reduction.

References

Hazen T.C. et al. (2004) "Functional Microbial Changes During Lactate and HRC-Stimulated Bioreduction of Cr(VI) in Hanford 100H Sediments." *Fourth International Conference on the Remediation of Chlorinated and Recalcitrant Compounds*. Battelle, Columbus, OH.

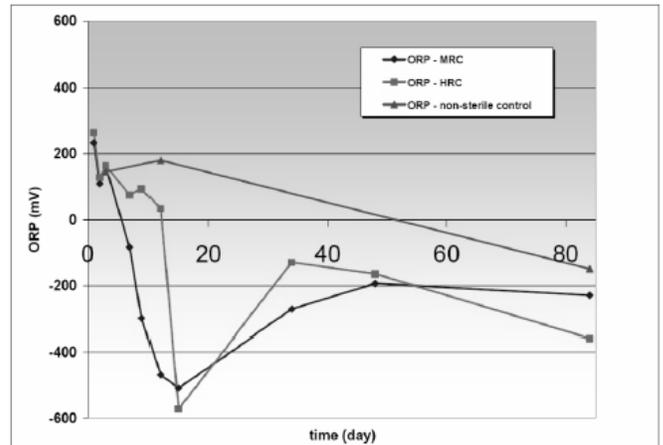


Figure 2: ORP measurements taken from MRC, HRC, and non-sterile reactors



REGENESIS

Metals Remediation Compound **MRC**[®]

TECHNICAL BULLETIN 1.0

Environmentally Safe

Metals Remediation Compound (MRC[®]) consists of an organosulfur compound esterified to sorbitol, a 6 carbon polyalcohol. The esterified organosulfur compound is embedded in a polylactate matrix. The organosulfur compound, sorbitol, and lactate are either food-grade or are approved for use as food additives. Thus, MRC is made from materials that are non-toxic.

Lactic acid occurs naturally in milk and foods (such as sauerkraut) and is also formed in the muscles during exercise. In the subsurface environment, lactic acid degradation products (e.g. pyruvic, acetic, propionic, and butyric acids) are eventually completely converted to methane or CO₂ and water, leaving no residue. In a review of EPA regulations there is no reference to maximum contaminant levels (MCLs) for lactic acid or its derivatives pyruvic acid, propionic acid, butyric acid, and acetic acid (see HRC technical bulletin #1.3.2).

Sorbitol is a sweet tasting, viscous solution that is generally chemically inert. These features and properties make sorbitol an ideal and preferred ingredient in many products. Sorbitol is on the list of food additives generally recognized as safe, which is distributed by the Food and Drug Administration (FDA) (See Link Below).

The organosulfur compound is a sulfur-containing amino acid that occurs naturally in foods and can also be manufactured by the body. This organosulfur compound is also on the Generally Recognized as Safe (GRAS) list distributed by the FDA

Related Links:

<http://www.cfsan.fda.gov/~dms/eafus.html>



REGENESIS

All Rights Reserved 2004- RegenesiS, San Clemente, CA 92673 (949-366-8000)