



REGENESIS[®]

In-Situ Treatment for Hexavalent Chromium Using ISCR Enhanced Bioremediation in Saturated Clay Soils Results in No Further Action

Owen Miller
Senior Design Specialist
REGENESIS

Overview

- Site History and Background
- Treatment Evaluation
- Chromium Geochemistry
- Pilot Test Treatment
- Full-Scale Remedy
- Conclusions

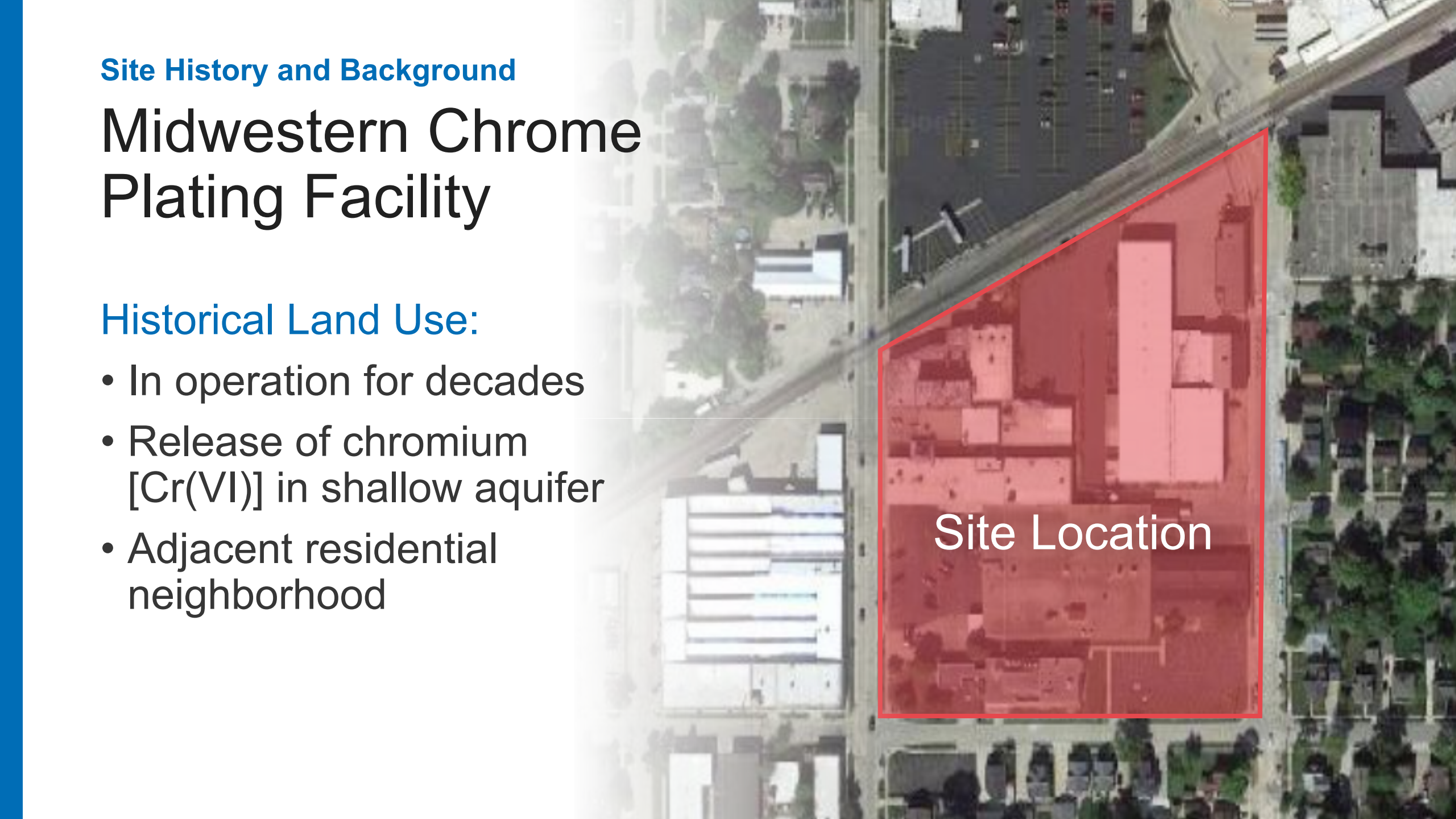


Site History and Background

Midwestern Chrome Plating Facility

Historical Land Use:

- In operation for decades
- Release of chromium [Cr(VI)] in shallow aquifer
- Adjacent residential neighborhood

An aerial photograph of an industrial area. A large, irregularly shaped area in the center-right is highlighted with a semi-transparent red overlay. The text "Site Location" is written in white within this red area. The surrounding area includes various industrial buildings, parking lots, and some greenery.

Site Location

Site History and Background

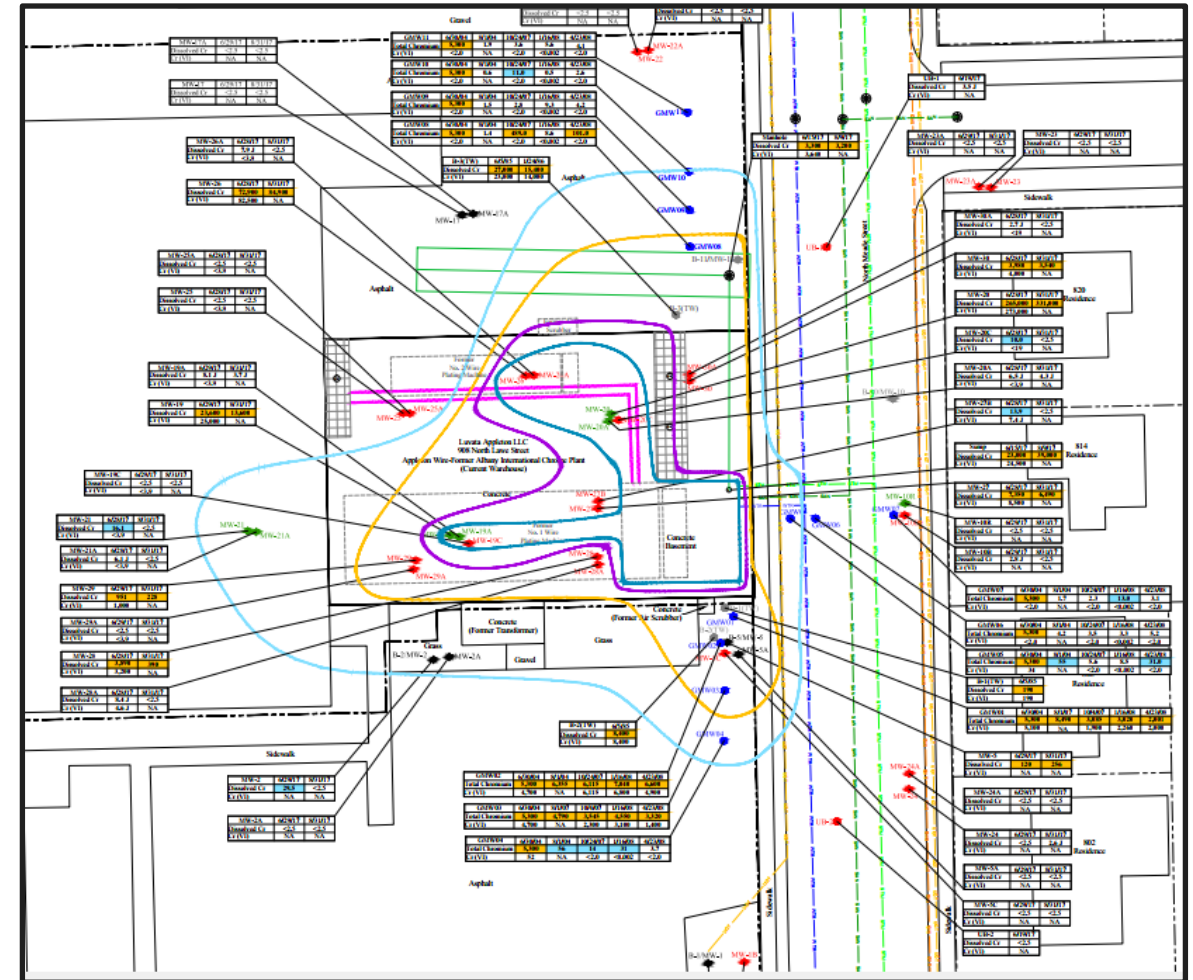
Midwestern Chrome Plating Facility

Site Conceptual Model

- Widespread and radial plume
- Concs. Range widely:
 - 250 ppb to >300 ppm

Site Challenges

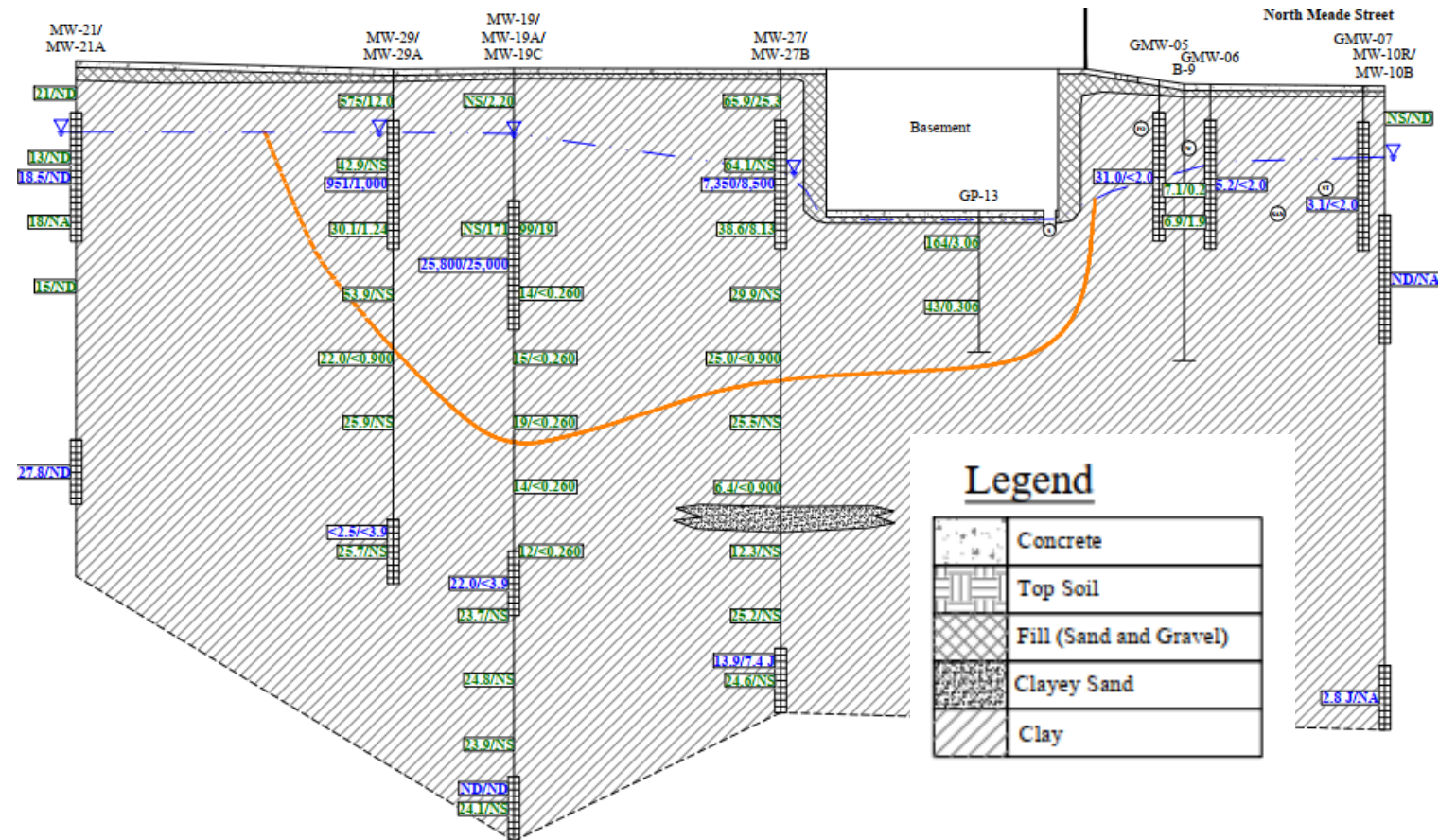
- Limited access due to existing infrastructure
- Low permeability (low K)
- Wide range of impacts



Site History and Background

Site Hydrogeology

- Glacial geology
- Low K clays with interbedded sand
- Shallow water table
 - (~5 ft bgs)
- Oxidic geochemistry
 - (150 to 200 mV ORP)
- Impacts >20 ft bgs



Treatment Evaluation

Treatment Evaluation

Treatment Needs

- Effective in low K and inside building
- Address range of concs
- Immediate and long-term treatment

Treatment Evaluation

- Pump and Treat? X
- Excavation? X
- In-Situ Metals Immobilization? ✓
 - In-Situ treatment within existing infrastructure



Chromium Geochemistry

In-Situ Metals Immobilization

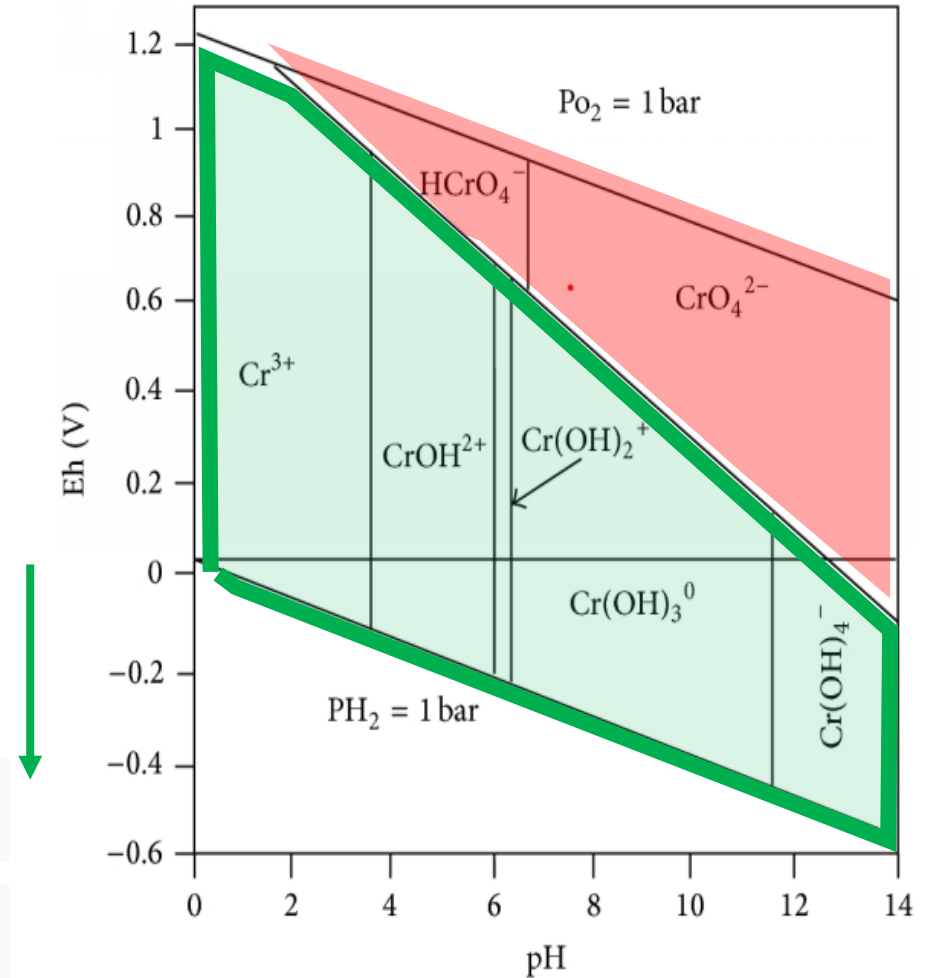
- Starts with fundamental geochemistry

Chromium Geochemistry

- **Hexavalent** – CrO_4^{2-}
- **Trivalent** – Cr(OH)

Eh-pH Diagram

- Cr(IV) compounds are not stable under normal environmental conditions
- Once Cr(III) hydroxide is formed it remains stable



How to Treat Hex Chrome?

- Simple Treatment = Provide Electrons
 - In-Situ Chemical Reduction (ISCR) and Enhanced Anaerobic Bioremediation
- Recall Eh-pH diagram – once formed Cr (III) is stable precipitate under most conditions
- Treatment Chemistry Example



↓
Cr⁺⁶

↓
Cr⁺³

*With excess iron, chromium can also form trivalent mixed iron chromium hydroxides $\text{Fe}_x\text{Cr}_{1-x}(\text{OH})_3$

Pilot Test Treatment

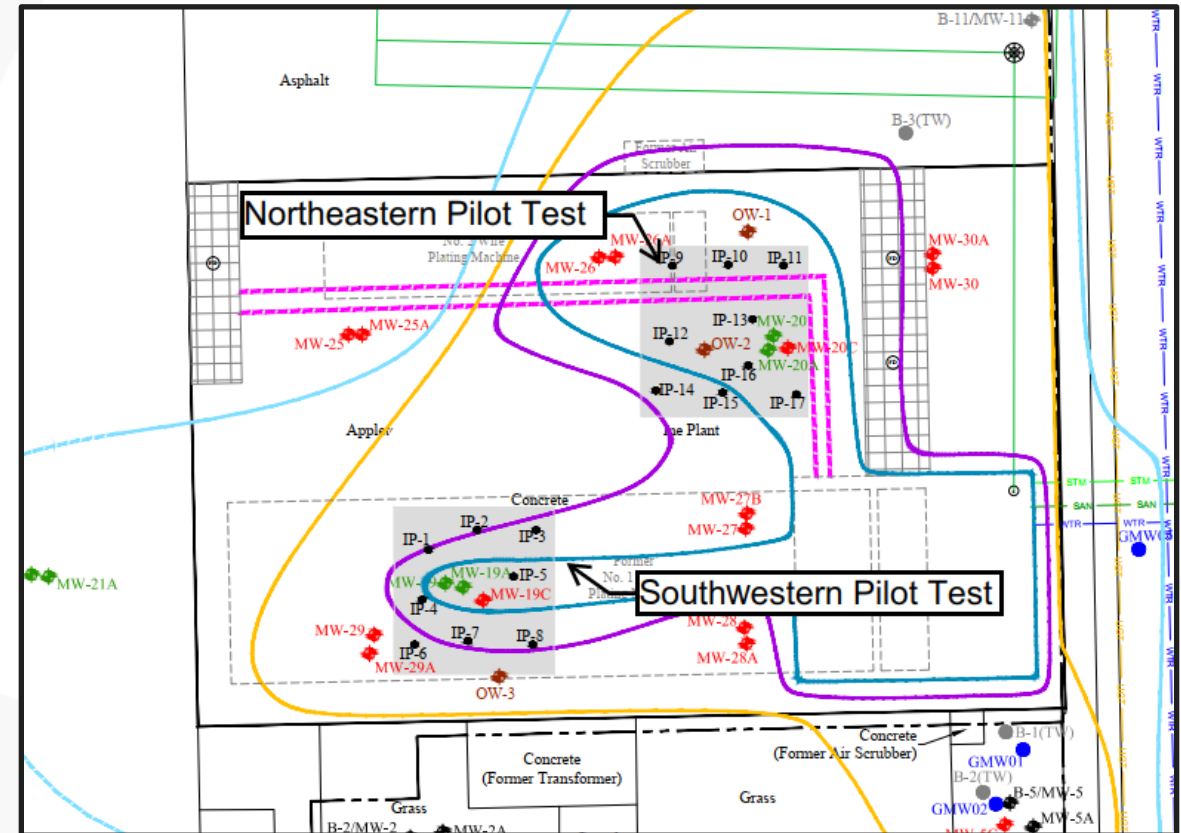
Pilot Test Treatment

Objectives:

- Demonstrate aquifer can accept fluids via in-situ injections
- Determine optimal ISCR and Anaerobic Bio combination

Scope of Work:

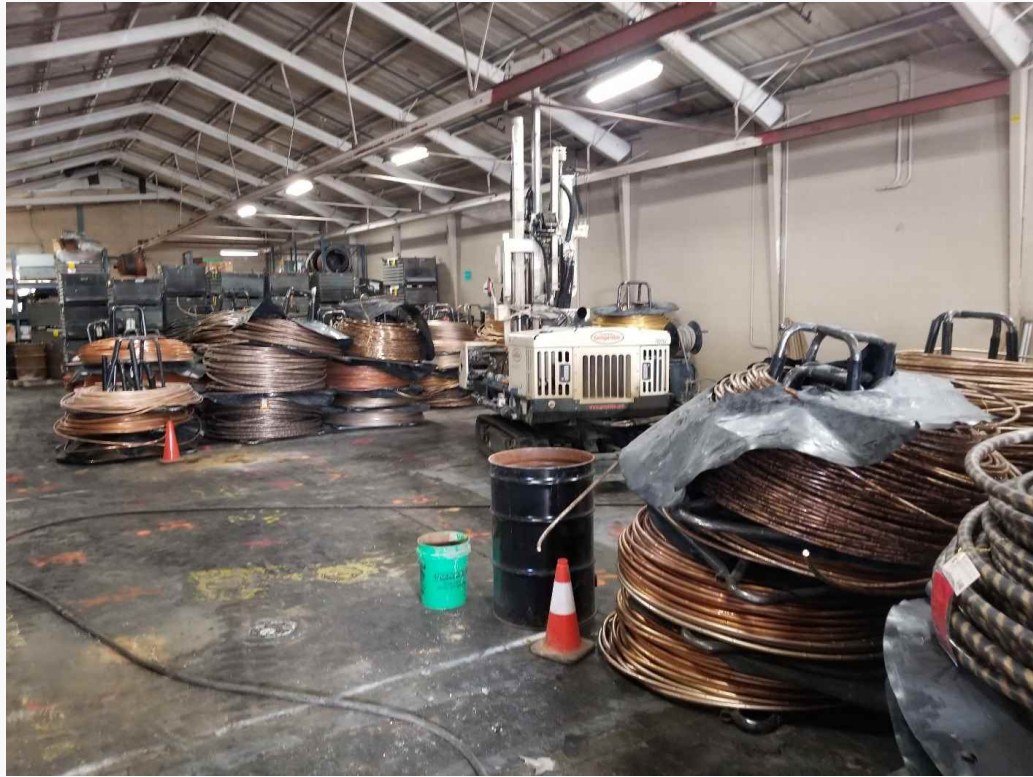
- Southwestern Pilot:
 - ISCR via viscous microscale ZVI slurry
- Northeastern Pilot:
 - Anaerobic bio using colloidal, emulsified electron donor
 - ISCR via Divalent Iron (DVI)



Pilot Test Treatment

Pilot Test Injections

Injections Inside Building



ZVI Slurry Injections



Pilot Test Treatment

Pilot Test Performance

Southwestern Pilot Test

- As anticipated, ISCR effective for treatment
- Immediate reductions within 3 months
- *Total hex chrome reduction of ~19 mg/L*

Northeastern Pilot Test

- Anaerobic bioremediation effective for treatment
- Immediate reductions within 3 months
- Total hex chrome reduction of ~117 mg/L

MW-19/19R		Dissolved Metals (µg/L)		
	Sample Date	Chromium	Manganese	Iron
Pre-Pilot Test	4/23/18	18,900	<11.3	<155
Post-Pilot Test	7/16/18	172	948	22,400
	8/20/18	97.6	1640	88,200
	1/21/19	16.1	608	12,200

MW-20/20R		Dissolved Metals (µg/L)		
	Sample Date	Chromium	Manganese	Iron
Pre-Pilot Test	4/23/18	296,000	<11.3	<155
Post-Pilot Test	7/16/18	161,000	99.1	929 J
	8/20/18	174,000	73.1	156
	1/21/19	179,000	37.1	<35.4

Pilot Test Takeaways

Pilot Test Takeaways

- Anaerobic bioremediation treatment has greater removal than ZVI slurry (distribution)
- DVI and ZVI slurry are not optimal reductants
 - DVI (Ferrous Iron) was fully consumed during pilot test
 - ZVI Slurry – less than ideal distribution (surfacing)

	Microscale ZVI	Oil Emulsion/ Soluble Iron
Reactivity	Good	Good
Delivery	High pressures induce fractures	Low viscosity and low- pressure injection
Persistence	Good	Limited
Ease of Use	Requires high pressure pumps	Good

Full-Scale Remedy

Full-Scale Optimization

Leverage the same electron donor for full scale treatment

- Excellent distribution within low K formation

Incorporate ZVI based ISCR

- Boost treatment strength

Optimize ZVI Amendment

- Use colloidal, sulfidated ZVI (S-MZVI)
- Enhanced distribution, longevity and reactivity compared to slurry ZVI

Colloidal ZVI suspension



Low pressure sandbox demo



Commodity ZVI Slurry



Depiction of subsurface fractures



Full Scale Remedy

Full Scale Results

- 99% reduction achieved and maintained in all monitoring wells
- Treatment effective across entire concentration spectrum
- Treatment removal increased by ~150%

NFA Granted

- Regulators issued closure for hex chrome following full-scale remedy
 - PFAS investigation ongoing

Monitoring Well Identification	Screen Interval	Remediation Status	Sample Date	Dissolved Metals			Field Parameters					
				Chromium	Manganese	Iron	Temperature	pH	Specific Conductance	Oxidation Reduction Potential	Turbidity	Dissolved Oxygen
Reporting Units				µg/L	µg/L	µg/L	Celsius	S.U.	mS/cm	mV	NTU	mg/L
NR 140 Enforcement Standard (ES)				100	300	300*						
NR 140 Preventative Action Limit (PAL)				10	60	150*						
MW-20/20R	5.1 - 15.1	Pre	06/28/17	265,000	NA	NA	NA	NA	NA	NA	NA	NA
			08/31/17	331,000	NA	NA	NA	NA	NA	NA	NA	NA
			04/23/18	296,000	<11.3	<155	15.73	7.21	2.70	282	50.4	NA
		Post Pilot Test	07/16/18	161,000	99.1	929 J	20.33	7.10	2.73	78	47.8	8.76
			08/20/18	174,000	73.1	156	19.93	7.54	2.52	103	0.0	10.05
			01/21/19	179,000	37.1	<35.4	17.09	8.20	2.55	126	1.9	5.02
		Post Full-Scale	04/10/20	7.0	114	9,250	17.90	7.48	1.41	-114	149	1.47
			06/30/20	10.9	166	23,000	20.62	6.98	2.25	-102.7	934	1.01
			09/29/20	16.7	178	17,800	20.36	7.09	2.15	-78.4	57.8	0.69
			09/29/20	22.8	179	17,200	NA	NA	NA	NA	NA	NA
			12/29/20	<3.9	160	1,950	15.24	7.02	2.41	-81.9	235.4	4.09
			03/17/21	145	328	23,100	16.41	7.14	2.17	-51.2	59.96	2.58
			07/07/21	4.9 J	130	10,700	20.68	7.14	2.10	-80.6	36.16	4.60
DUP-1												
MW-20R												

Conclusion

- **In-Situ Metals Immobilization for Cr(VI) is highly effective**
 - Offers immediate and long-term treatment without site disruption
- **Combining ISCR and Anaerobic Bioremediation is recommended**
 - Leverage both treatment technologies when possible
 - Multiple pathways to increase efficiency
- **ISCR selection is key for optimization**
 - ZVI based ISCR is recommended – greater strength and quicker transformation to trivalent chromium
 - Mobility, reactivity, longevity and overall treatment is enhanced with colloidal iron

Questions?



Owen Miller

**Senior Design Specialist
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omiller@regenesiscorp.com