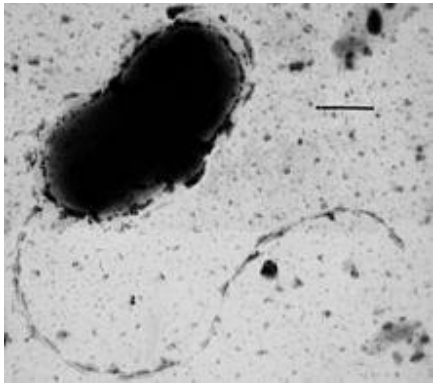

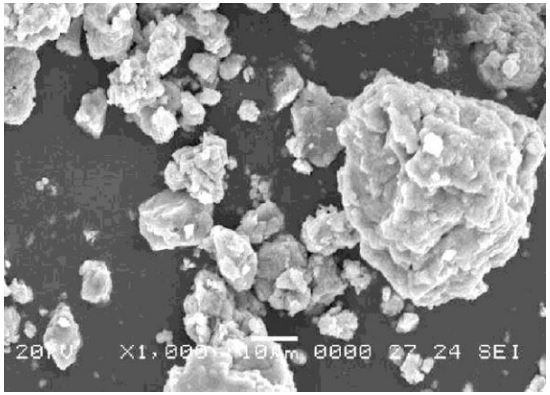


# Enhanced *In Situ* Bioremediation of Cadmium and Lead Impacted Groundwater

**Andrew Madison, Christopher Hemingway, Marie Lewis & Stuart Mitchell (Golder Associates Inc.)**

**2017 Battelle Symposium on Bioremediation and Sustainable Environmental Technologies**

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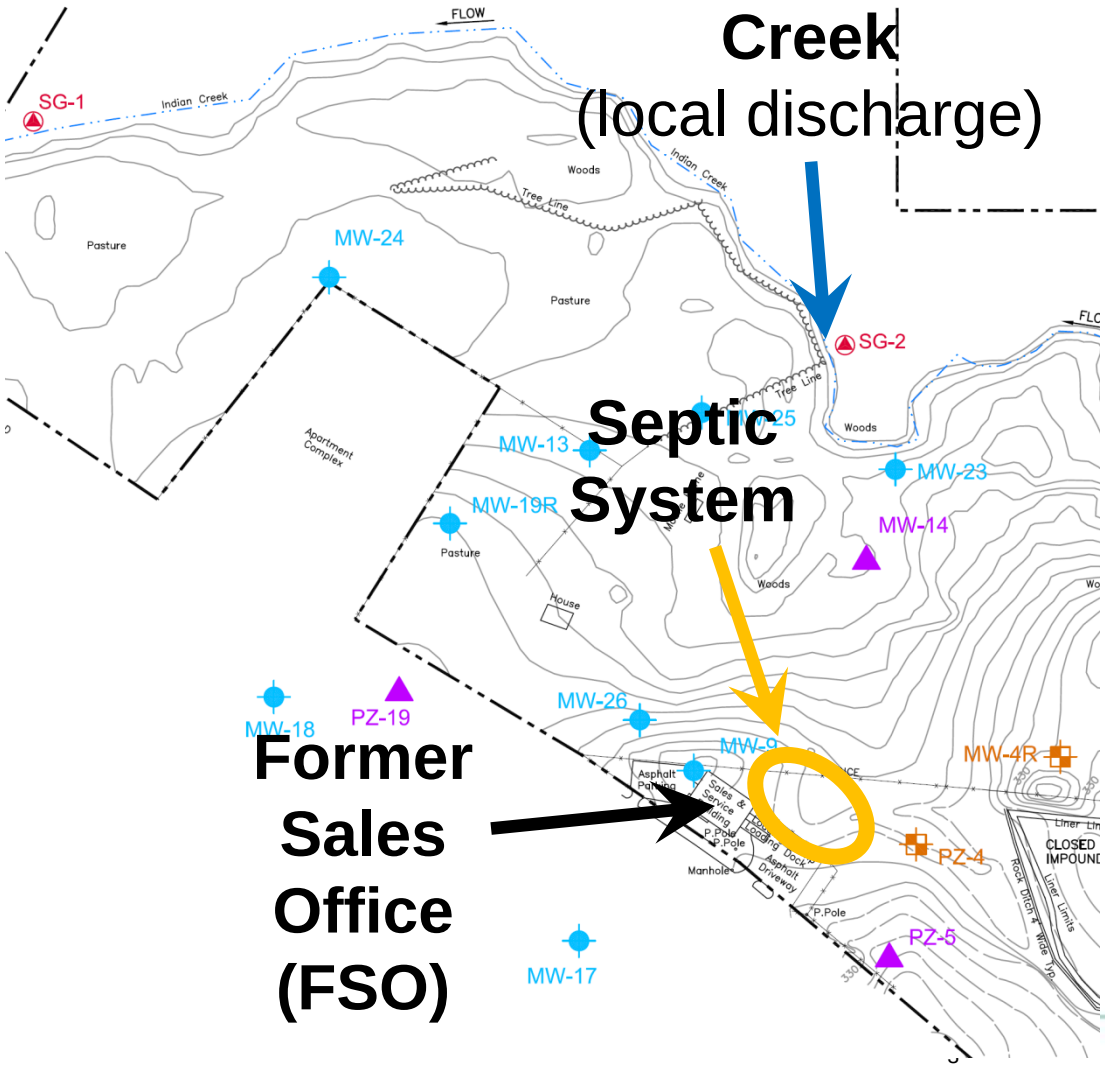
# Objective

- Develop and implement an efficient and cost-effective treatment strategy to reduce concentrations of cadmium and lead in groundwater prior to discharge to a local creek.

# Site Background




- Former lead-acid battery manufacturing facility
- Septic system of the Former Sales Office (FSO) introduced cadmium (Cd), lead (Pb) and increased acidity to groundwater
- Septic system and piping was removed in 1991
- Cd impacts have been observed in a local creek that borders the Site and is downgradient of the FSO

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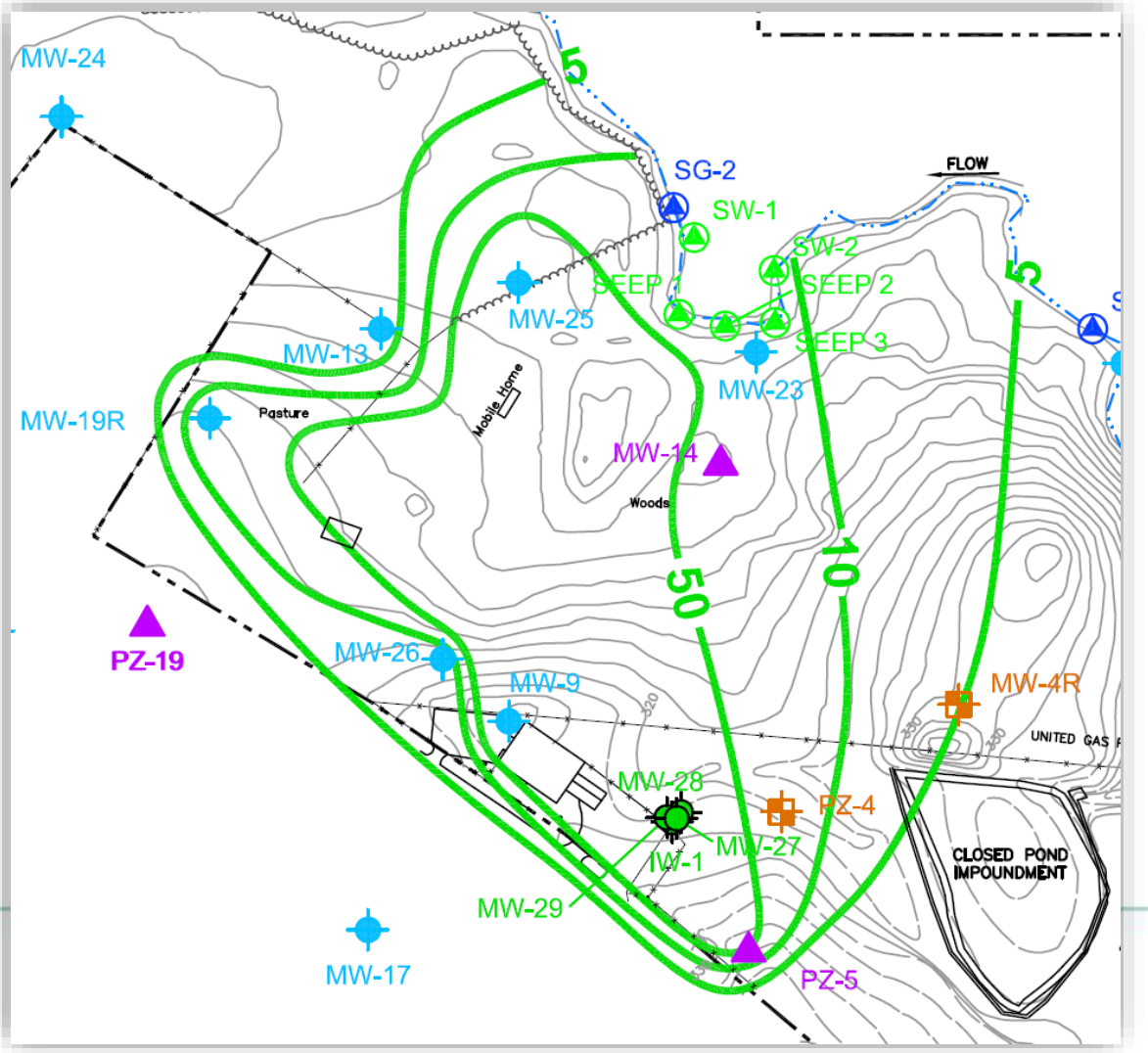
# Site Background – Cd Impacts

## Cd Isoconcentration Contours (µg/L)



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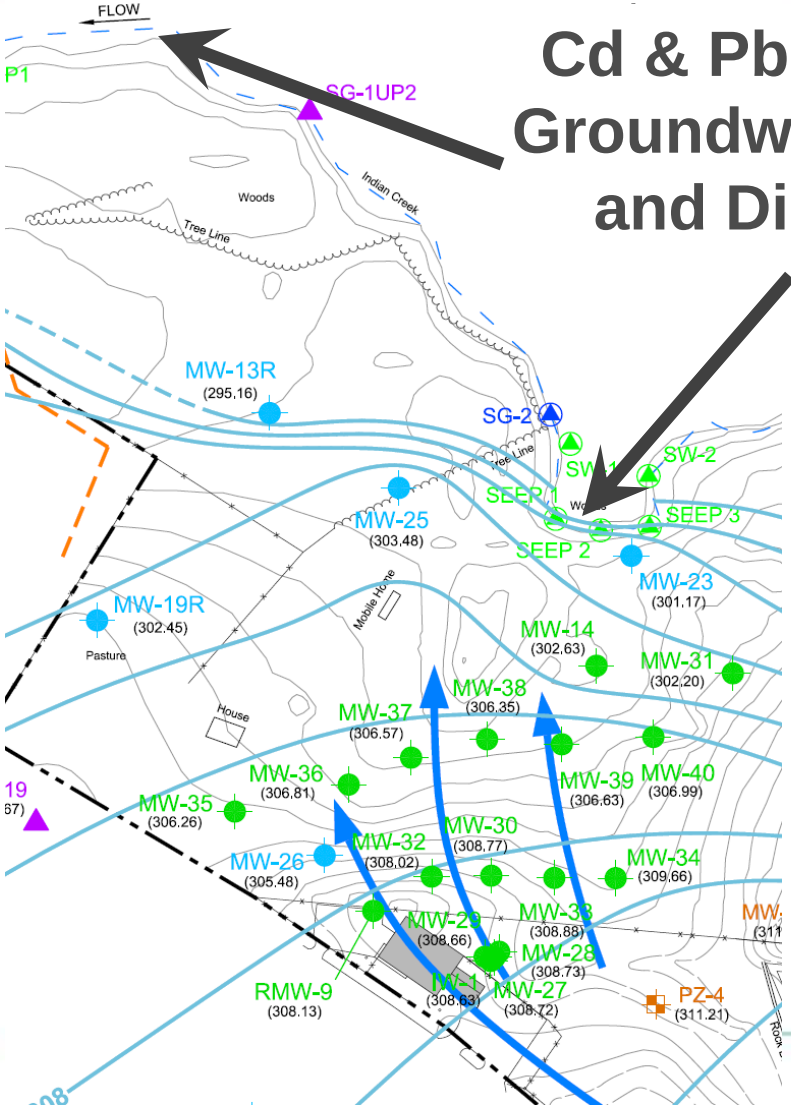
# Site Background – Creek Impacts




## Cd & Pb Impacted Groundwater Seeps and Discharge



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# Site Geochemical Setting

- Mobility of Cd is controlled by chemical speciation which is dependent on **pH** and **redox state** (measured by oxidation reduction potential [ORP])

- Geochemical modeling of current Site conditions indicated that Cd was highly soluble:
  - 80% of total Cd was present as $Cd^{2+}$
  - 20% of total Cd was present as $CdSO_4$ (original form)

- Indigenous microorganisms were limited by the lack of available organic carbon

- System was anaerobic and electron acceptors (oxygen, iron-oxides, manganese-oxides) were limited; however groundwater had elevated levels of sulfate

# Remedial Design

- Goal:
  - Stimulate indigenous sulfate reducing microorganisms to generate sulfide to precipitate Cd and Pb as insoluble metal sulfide species (CdS, PbS and mixed Cd- and Pb-iron sulfides)

- Process:
  - Intrinsic microbes obtain energy from the oxidation of the injected organic carbon substrate (i.e., lactate)
  - By providing organic carbon, microbial reduction of sulfate to sulfide will be enhanced

$$(CH_2O)_n + SO_4^{2-} \rightarrow S^{2-} + CO_2 + H_2O$$

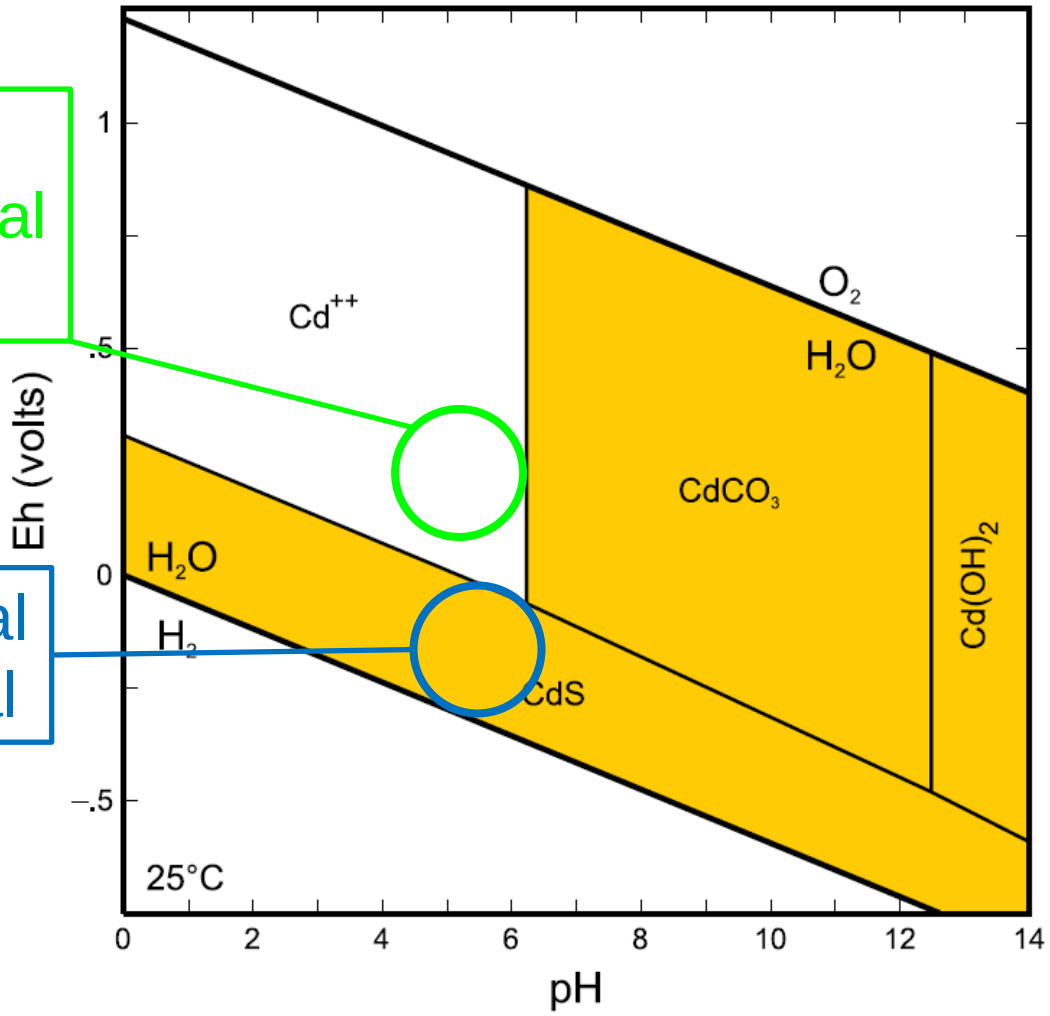
$$\downarrow$$

$$Cd^{2+} \rightarrow \boxed{CdS_{(s)}}$$

# Remedial Design – Redox Manipulation

Baseline Geochemical Setting

Geochemical Setting Goal



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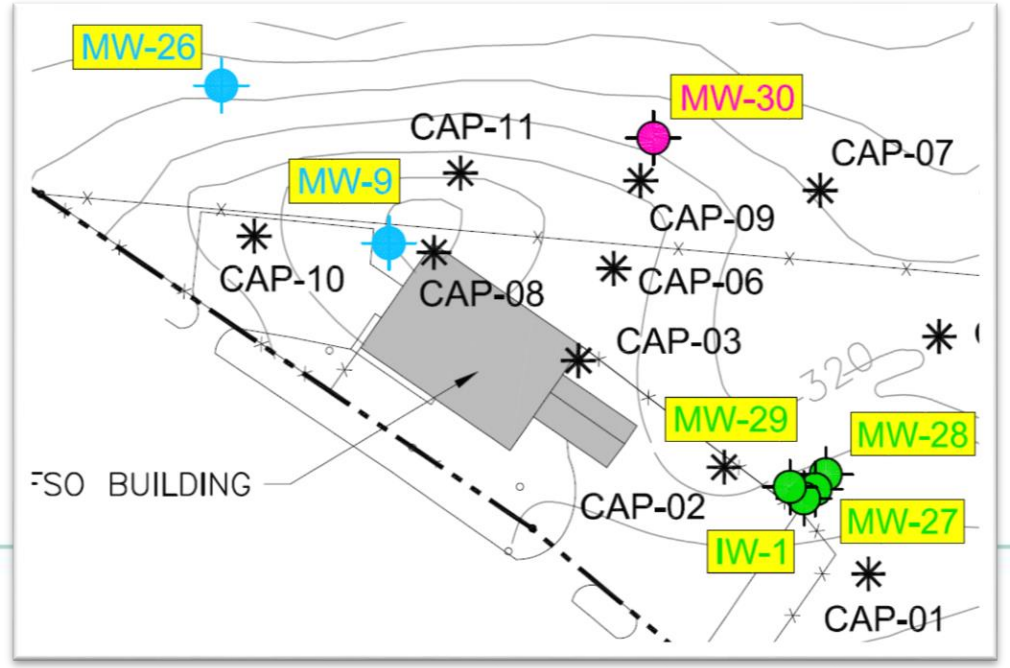
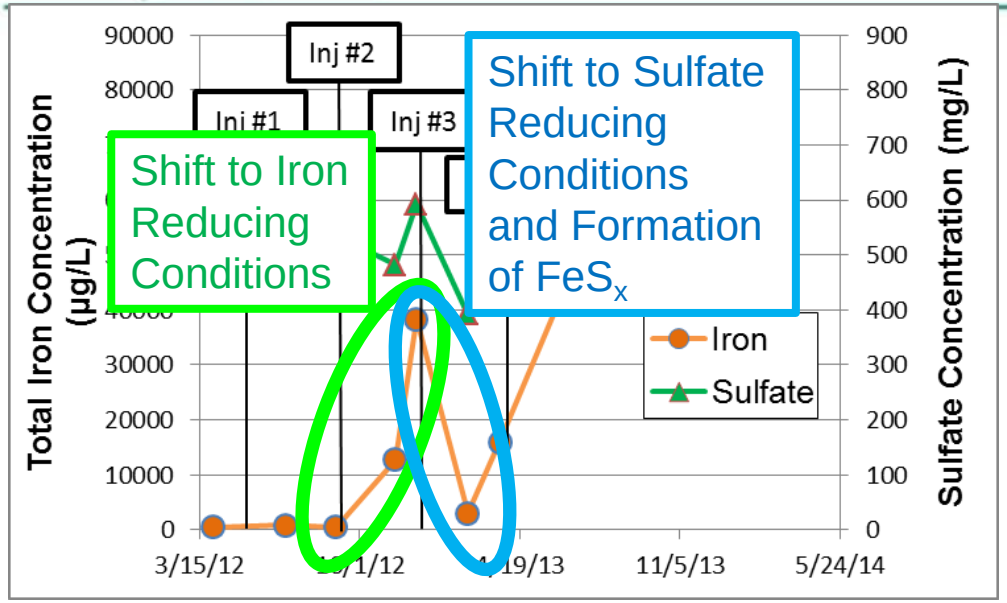
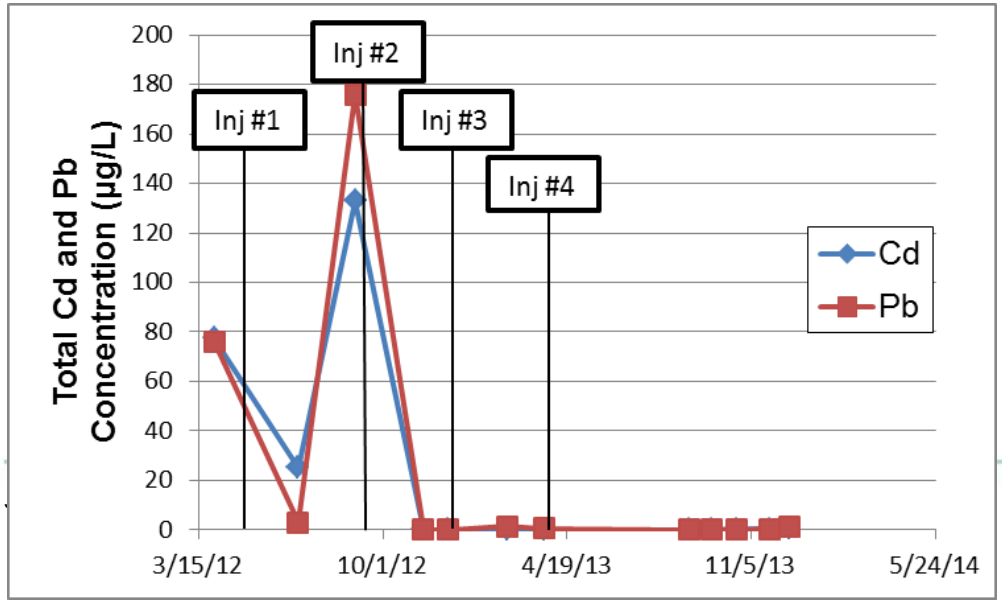
# Pilot Study Implementation

- Installed 1 injection well and wells along primary flowpaths
- Bromide tracer injection to confirm flowpaths and evaluate effects of dispersion and dilution of the amendment
- 4 Quarterly lactate ($NaC_3H_5O_3$) injections in IW-1
  - 75 kg of lactate in 1,000 gallons of potable water



# Pilot Study Results




- Natural geochemical conditions can be favorably modified by lactate addition
- Promoted microbially-mediated sulfate reduction sufficient to sequester Cd and Pb in the immediate area of injection
- For >18 months following injections, geochemical changes were stable and Cd and Pb concentrations remained less than MCLs

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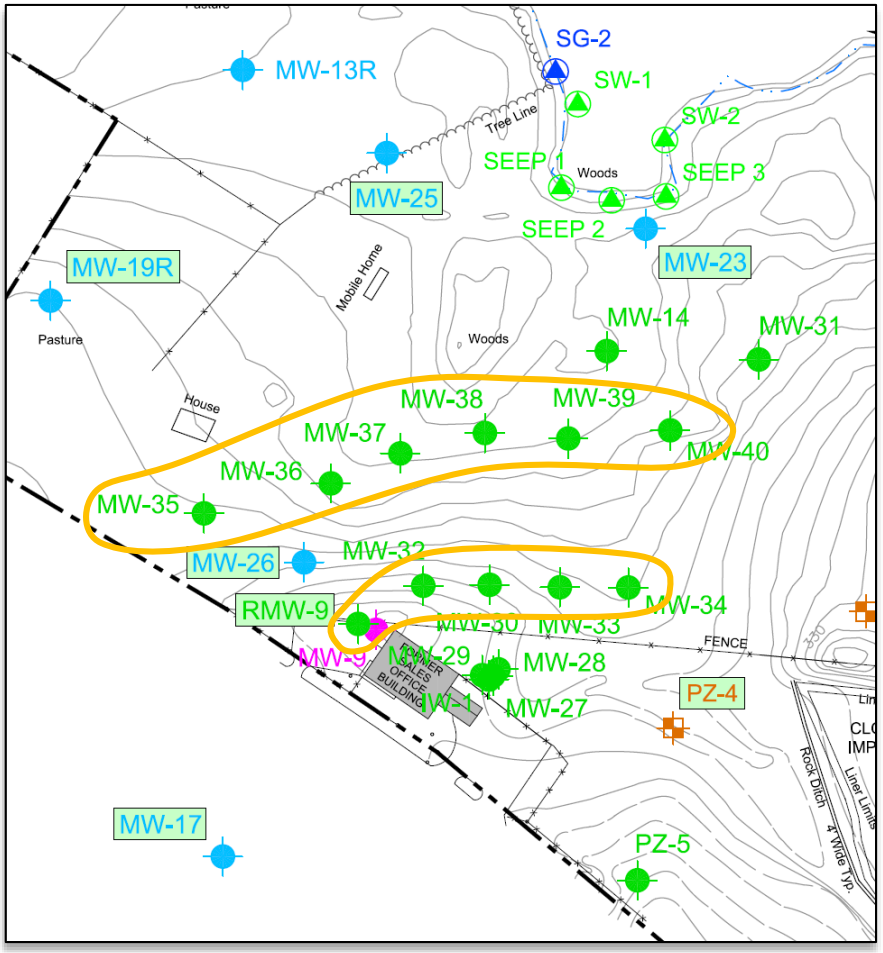
# Full-Scale Remedy Implementation

- Installed 2 rows of injection and monitoring wells downgradient of source area
- 7 quarterly lactate injections in 9 injection wells (June 2015 – December 2016)



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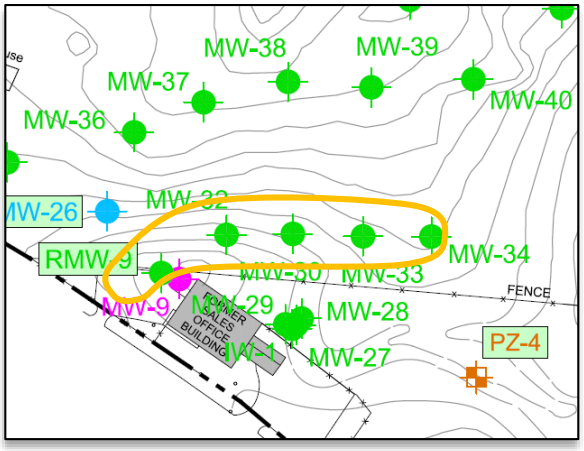
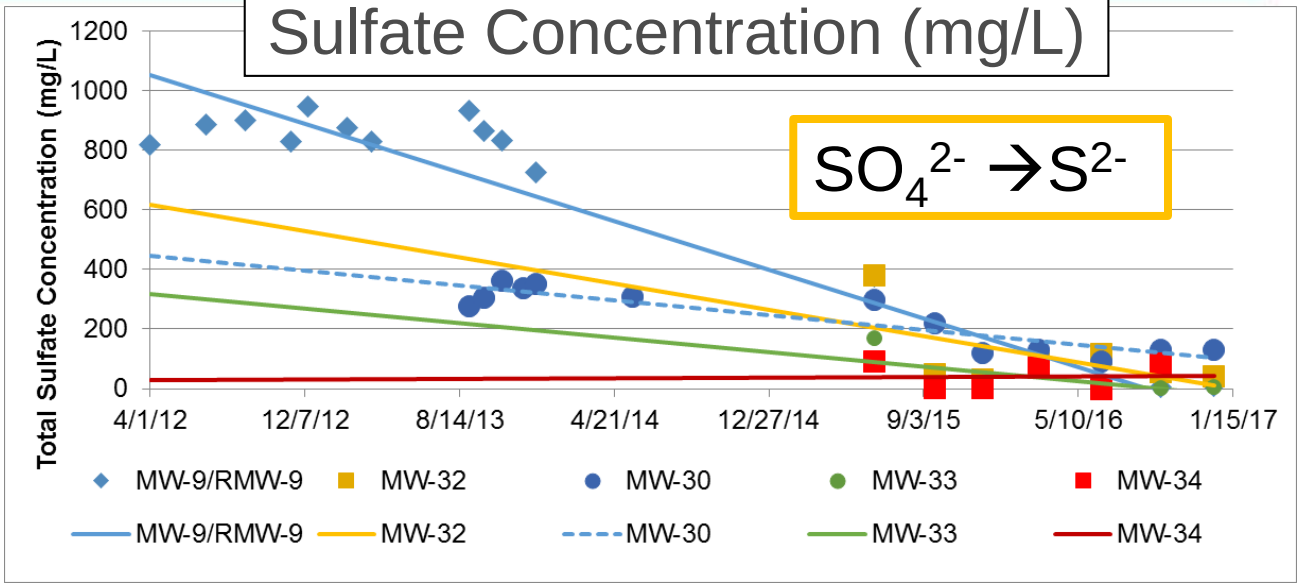
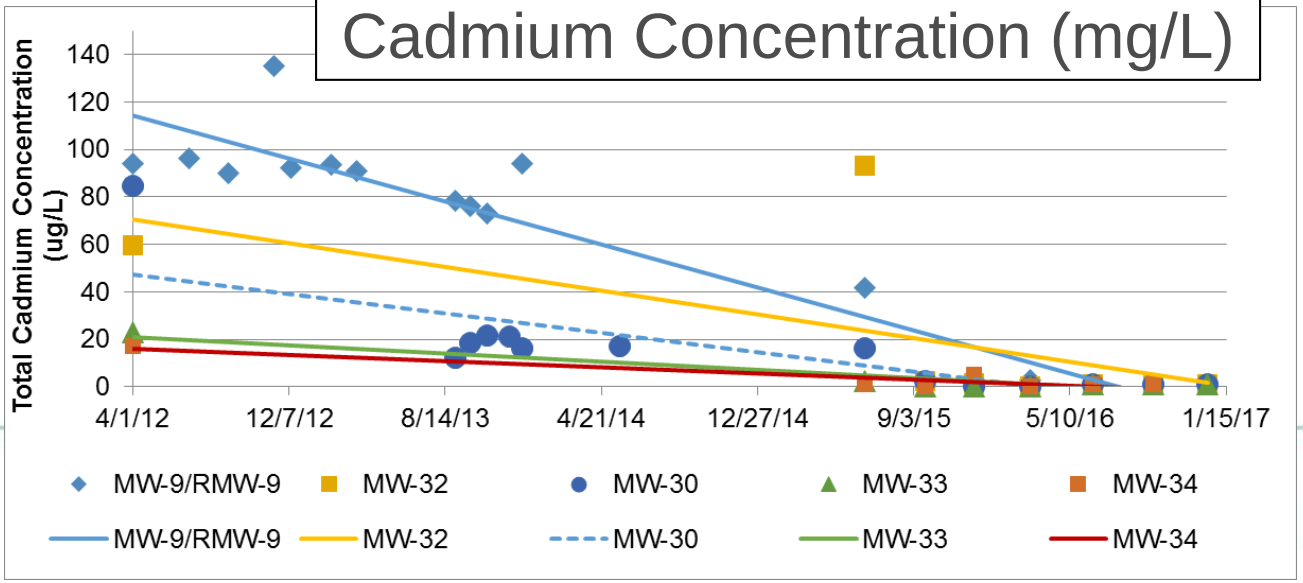
# Full-Scale Remedy Results – First Row




## Sulfate Concentration (mg/L)




## Cadmium Concentration (mg/L)



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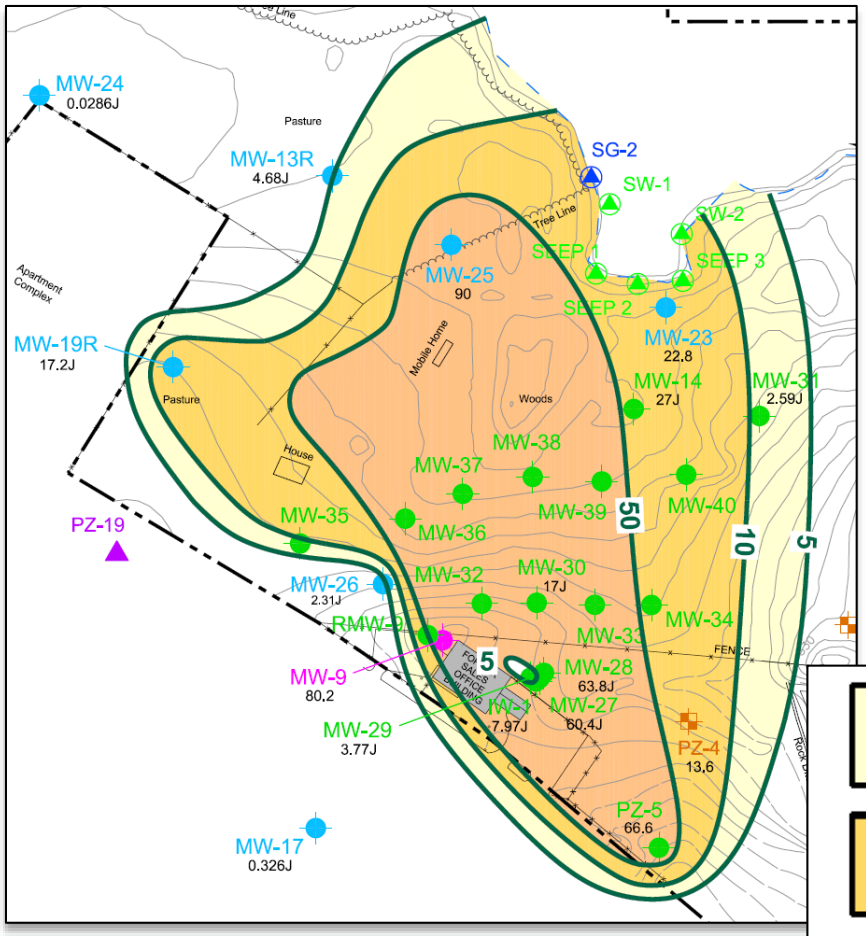
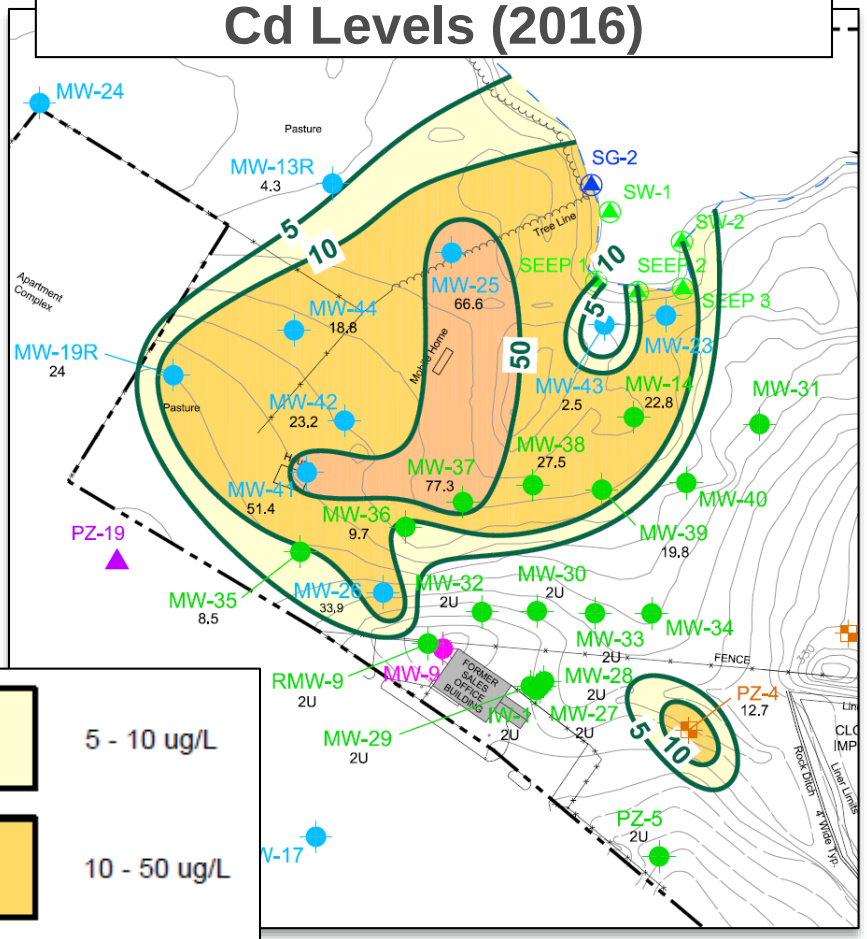
# Full-Scale Remedy Results - Plume

## Baseline Cd Levels (2014)




## Post-remedy Implementation Cd Levels (2016)




June 9, 2017

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# Summary

- Natural geochemical conditions can be favorably modified by addition of an organic carbon amendment
- Promoted microbially-mediated sulfate reduction sufficient to sequester Cd and Pb downgradient and within the injection area
  - No observed buildup of toxic $S^{2-}$
- Strong understanding of flow regime critical to remedy success
- Reduction of Cd and Pb within former source area to below MCLs and, most importantly, surface water quality criteria.
- Cost-effective remedial approach for Cd- and Pb-impacted groundwater
  - Applicable to other metals that form metal-sulfides or adsorb to sulfide minerals

# Questions?