Naval Facilities Engineering Command
SOUTHWEST

Surprises and Mysteries from the Installation and Performance of 2,000-feet of Biobarriers in Brackish Water Naval Air Station North Island, San Diego, CA

Michael Pound, Vitthal Hosangadi, Ryley Robitaille, Pamela Chang

Project Team

Michael Pound

Vitthal Hosangadi, PE*
Ryley Robitaille, PE

Pamela Chang

** Presenting*

Presentation Overview

1. Background

2. Objectives

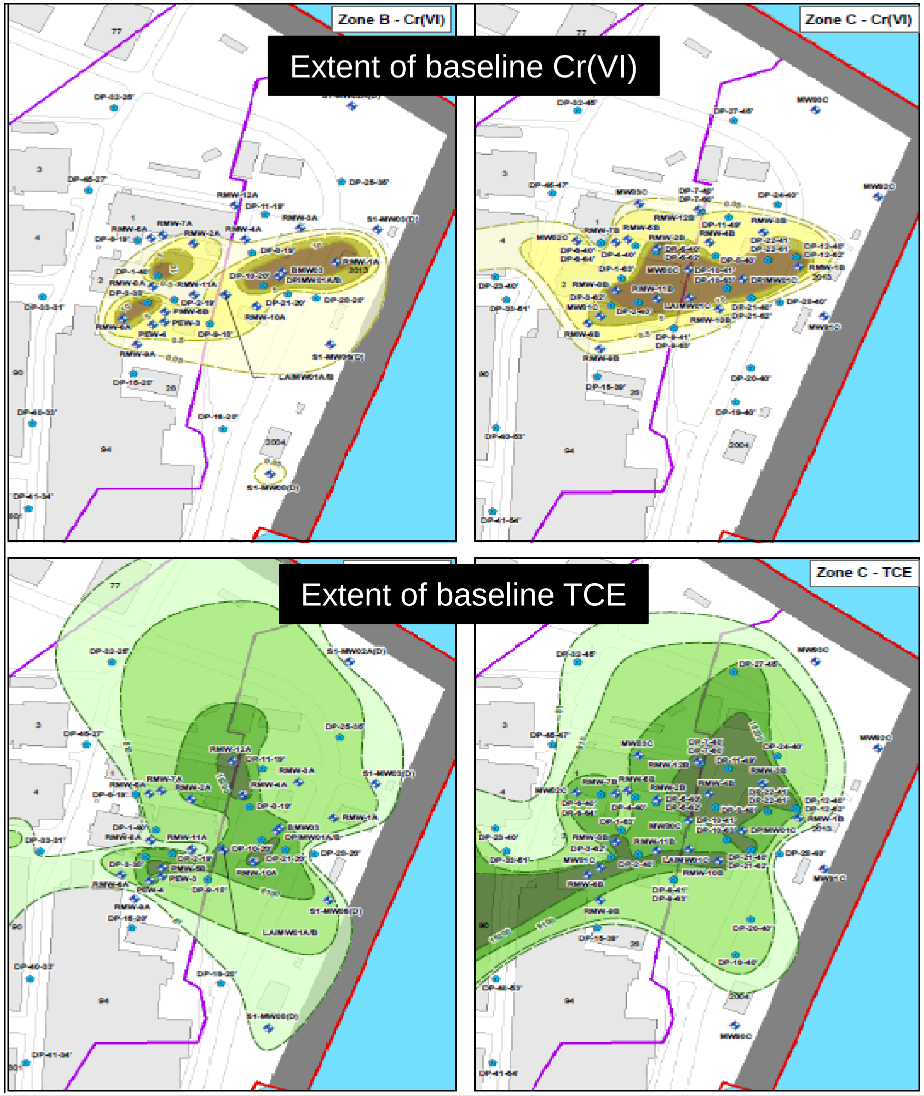
3. Approach

4. Results

5. Summary and Conclusions

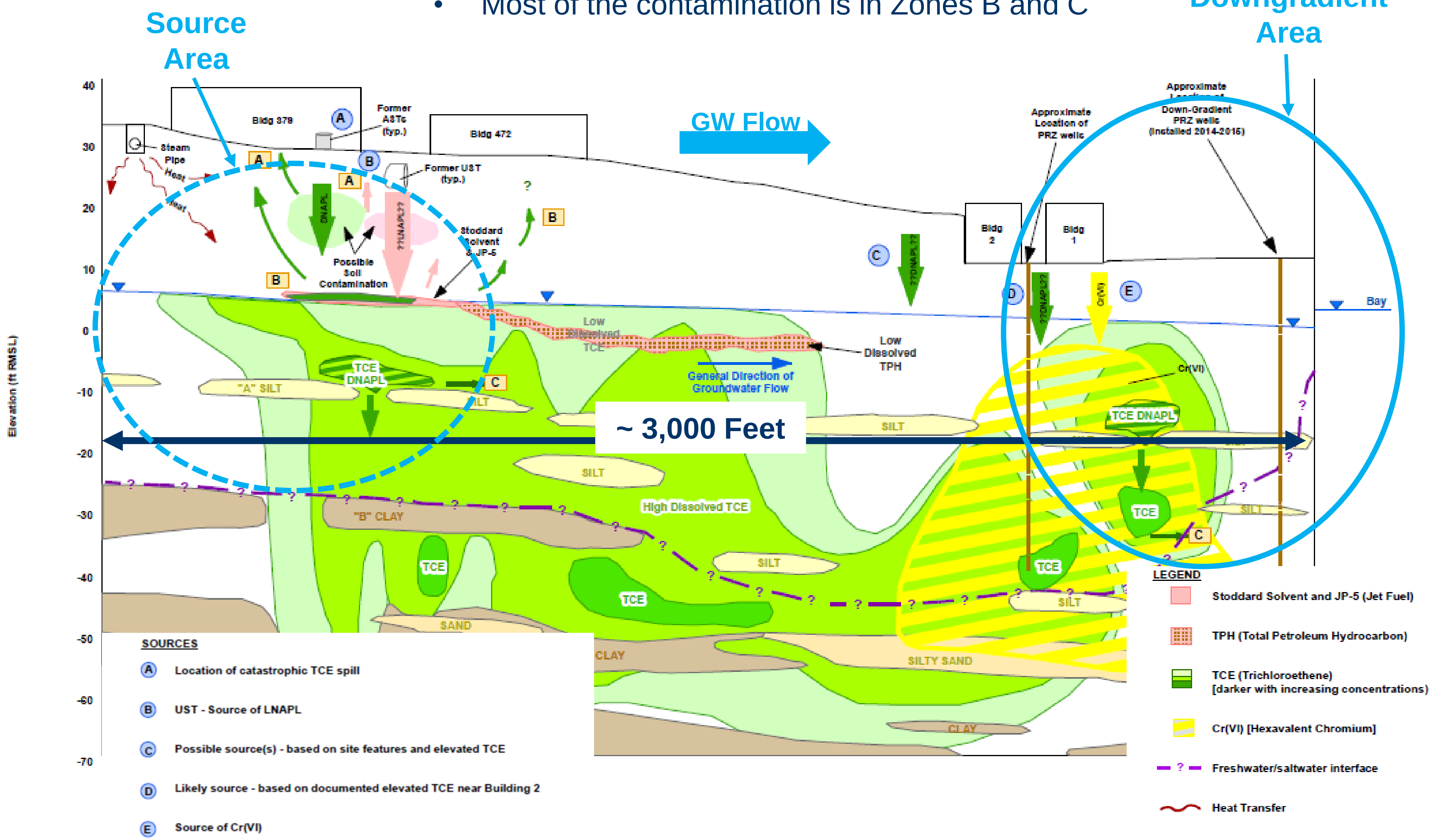
1. Background – NASNI OU 20

- Cr(VI) and TCE in groundwater
- Elevated levels of Cr(VI) > 140 mg/L and TCE >100 mg/L
- Cr(VI) and TCE present in close proximity to San Diego Bay
- A Time Critical Removal Action was implemented



1.1 Background: OU 20 Conceptual Site Model

- 4 water bearing Zones – A through D
- Most of the contamination is in Zones B and C



2. Objectives

- Present an overview of lessons learned from implementation of multiple bio-barriers used to remediate the downgradient edge of a plume with multiple challenges:
  - Multiple contaminants - cVOCs and Cr(VI)
  - Elevated levels of contaminants [>100 mg/L for TCE and >140 mg/L for Cr(VI)]
  - Brackish water with high TDS
  - Complicated lithology in saturated zone
  - Large/long plume (>1/2-mile long, hundreds of feet wide)
  - Located in a very busy part of NASNI (near two active piers)
  - Multiple buried utilities

3.1 Overall Approach

- Due to proximity of contaminants to Bay, Navy elected to implement a Time Critical Removal Action

- Selected approach would need to:
  - Be effective for both elevated Cr(VI) and TCE – single technology
  - Account for high traffic/buried utilities
  - Minimize number of mobilizations
  - Minimize impacts to site activities

- Ultimately, an in-situ approach was selected: Enhanced In Situ Bioremediation (EISB)

3.2 Approach – Bench/Field Scale Testing of EISB

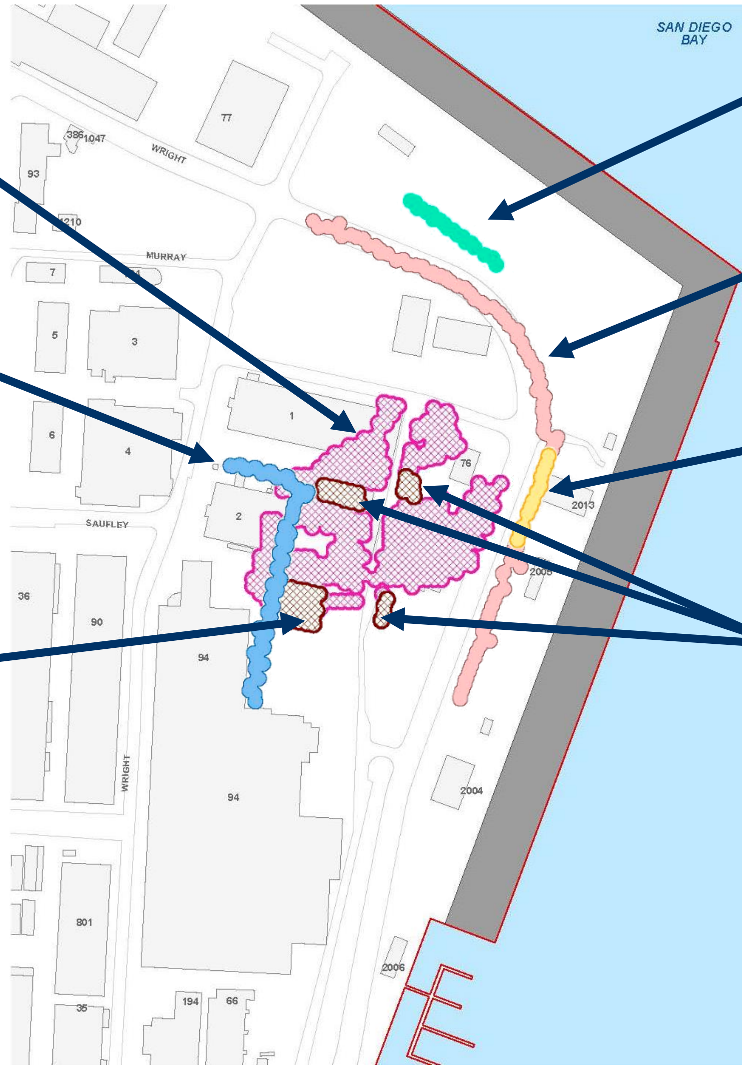
- **Bench-scale Testing**
  - –Assessed several organic and inorganic amendments before identifying Emulsified Vegetable Oil (EVO) for bioremediation of cVOCs
  - –For Cr(VI), the EVO was supplemented with a proprietary abiotic reductant
  - –Bioaugmentation completely reduced Cr(VI) in as little as one day, allowing co-bioaugmentation and complete biological reductive dechlorination of TCE within 35 days
- **Field-scale Testing**
  - –Conducted at three locations each with liquid atomized injection (LAI) and direct-push injection (DPI)
  - –Microbial culture was injected simultaneously
  - –DPI required less distribution time, lower flow rates, and lower pressures
  - –Reduction in TCE was not observed until Cr(VI) concentrations were reduced to under 10 mg/L

3.3 Approach - TCRA Injection Design

DPI – Phase I (Q2/Q3 2012)

UGPRZ – Phase I (Q2/Q3 2012)

DPI – Phase II (ZVI) (Q4 2015)



DDPRZ – Phase II (Q4 2015)

DGPRZ – Phase II (Q4 2015)

DGPRZ – Phase II (Lactate) (Q4 2015)

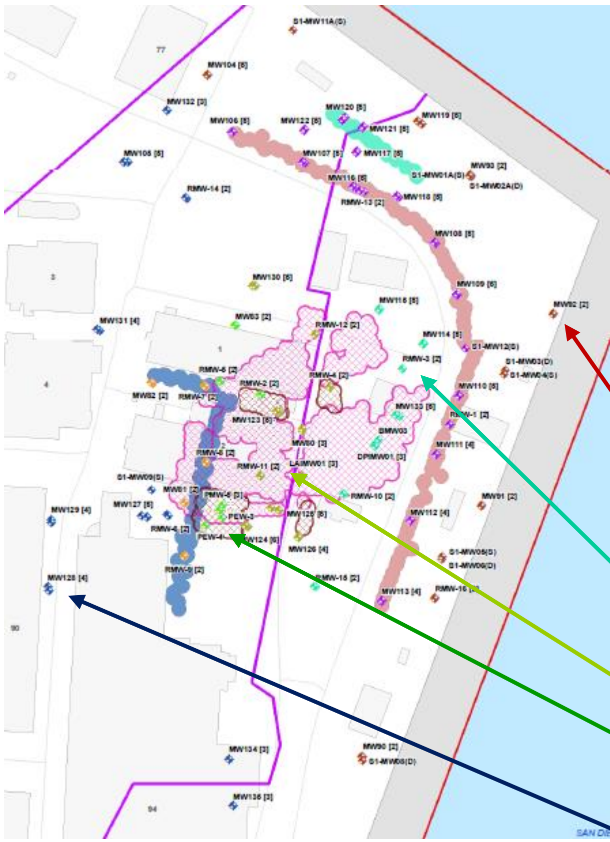
DPI – Phase II (Q4 2015)

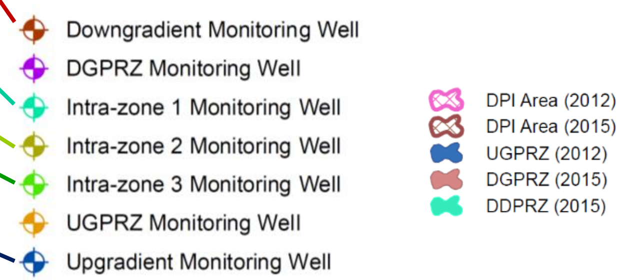
3.4 OU 20 GW TCRA – By The Numbers

Parameter	Value	Unit
Length of Plume	3,000	Feet
Width of Plume	1,275	Feet
Total Length of PRZs	2,400	Feet
Monitoring Wells	217	Screens
Injection Wells	376	Screens
CPT/Hydropunch®	388	Depths
DPIs	413	Locations
EVO	46,255	Gallons
Microbial Culture	1,121	Liters
Total Injectate Volume	697,150	Gallons

3.5 Approach - Post-Injection Monitoring Activities

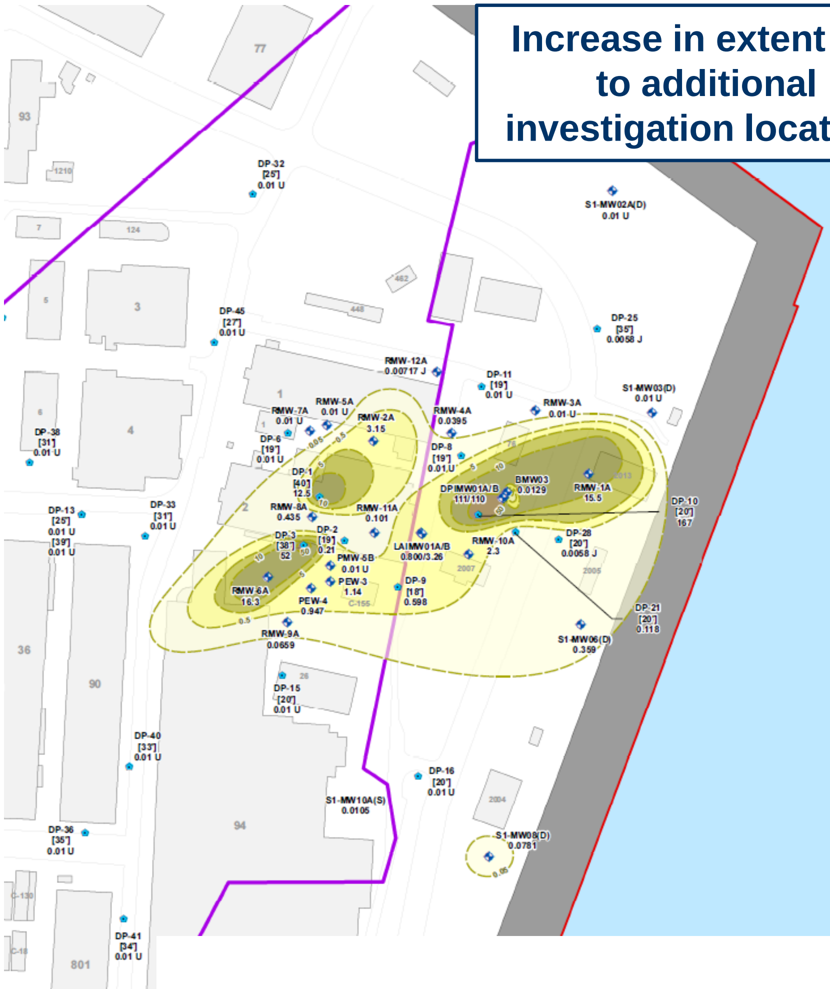
Summary of monitoring well locations



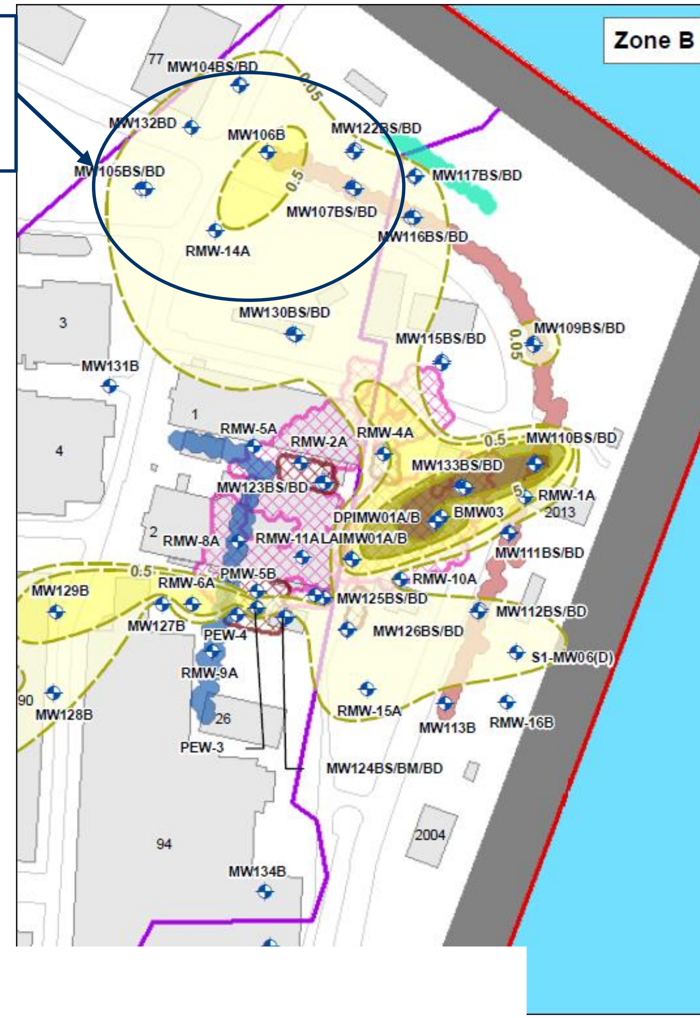


- **9 rounds of post-injection monitoring have occurred between 2012 and 2017**
- **Laboratory analyses have varied depending upon the location of monitoring wells relative to plumes and injection locations**
  - **VOCs, Cr(VI), total organic carbon (TOC), DHC, volatile fatty acids (VFAs), dissolved gases (methane, ethane, ethene), nitrate/sulfate**

4.1 Extent of Cr(VI) Over Time – Zone B

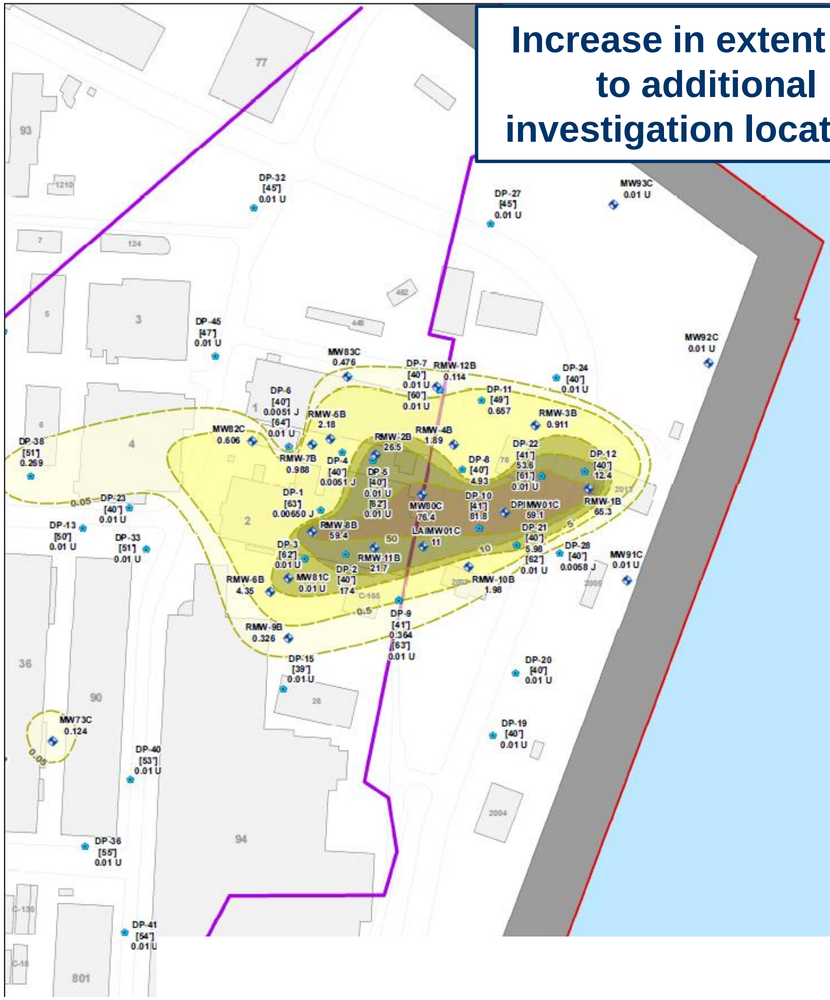


Increase in extent due to additional investigation locations



Levels and areal extents of Cr(VI) have decreased significantly

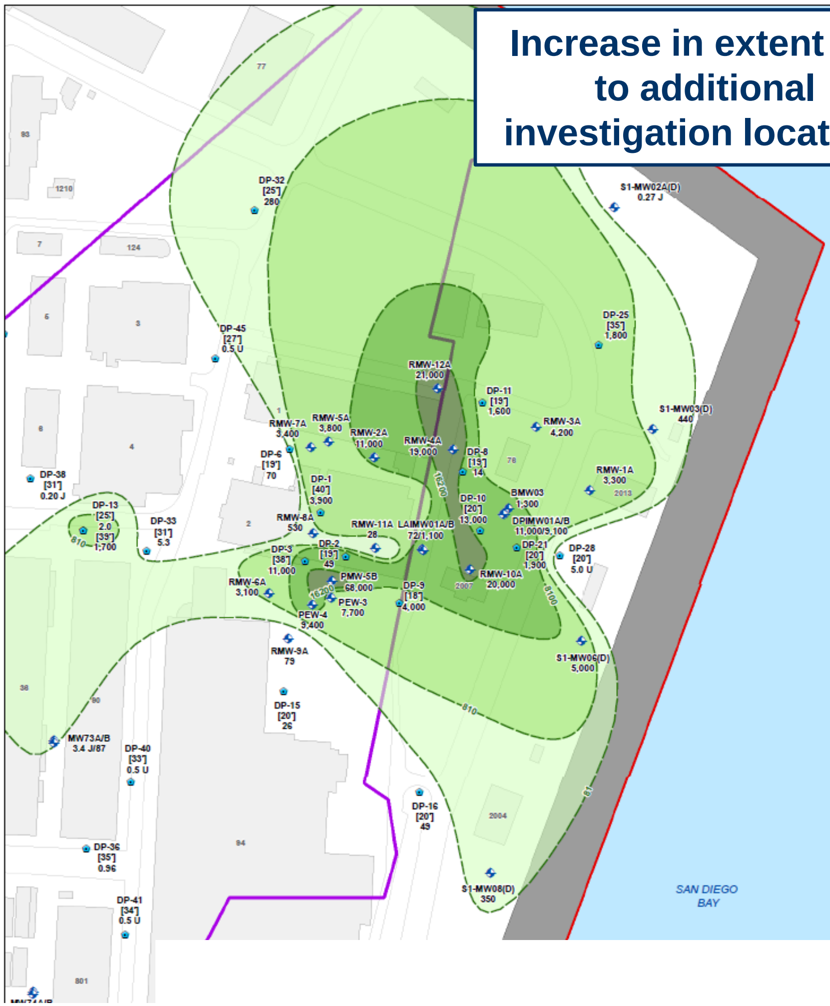
4.2 Extent of Cr(VI) Over Time – Zone C



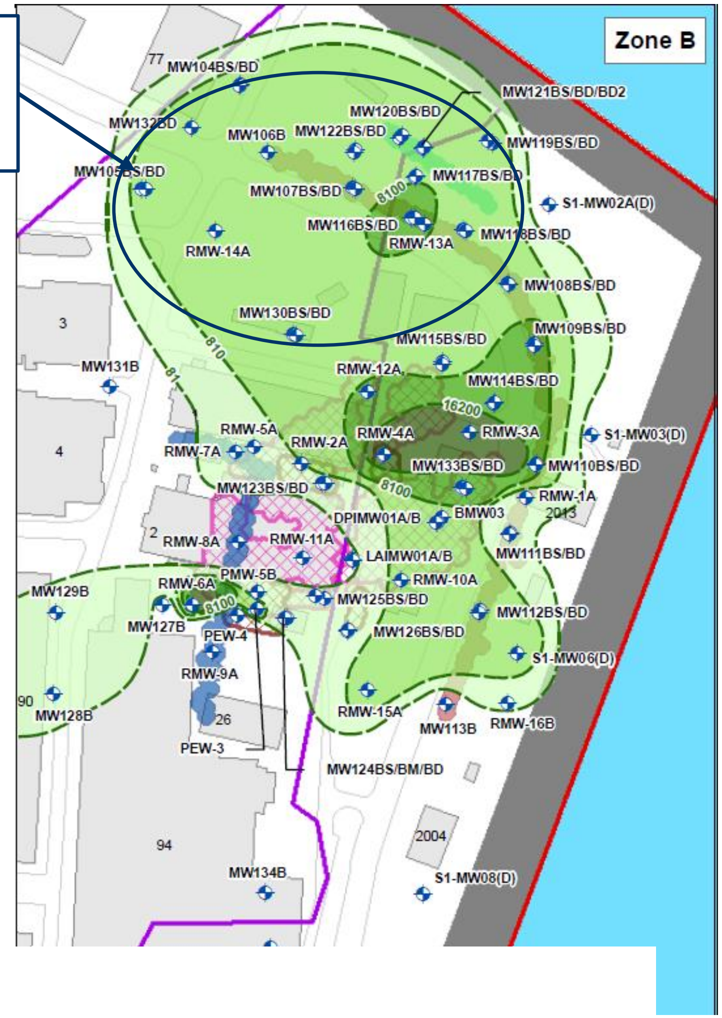
Increase in extent due to additional investigation locations

Levels and areal extents of Cr(VI) have decreased significantly

4.3 Extent of TCE Over Time – Zone B

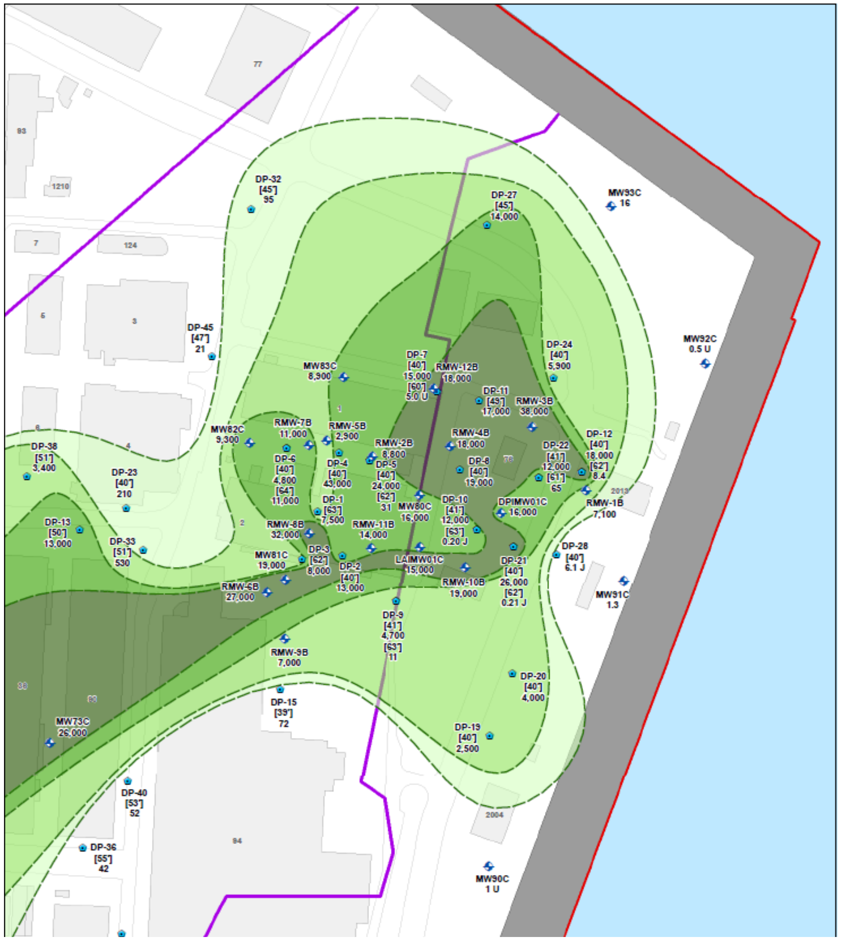


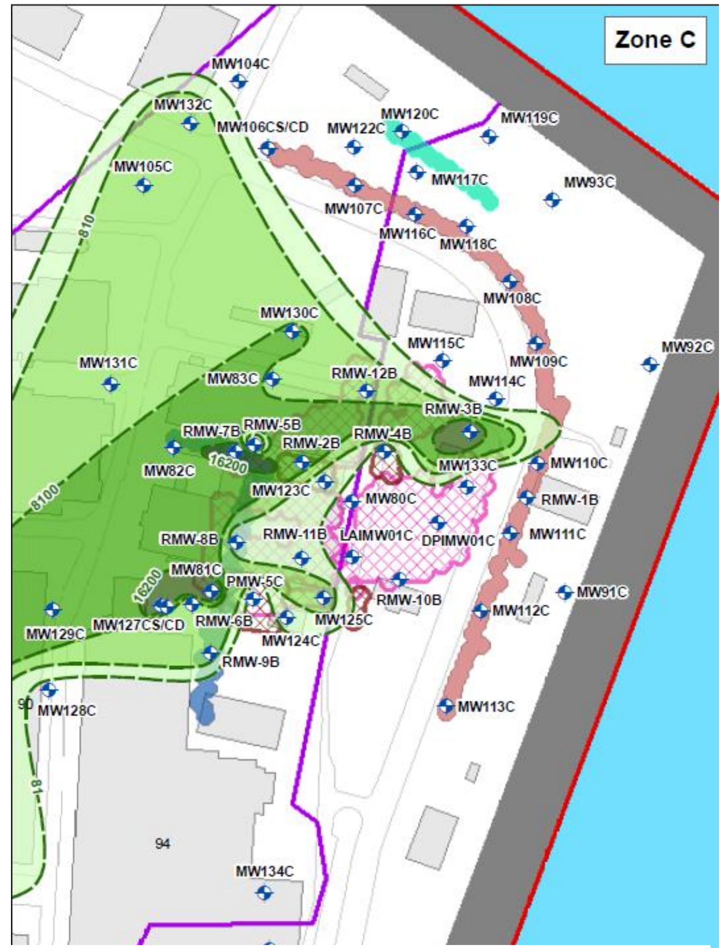
Increase in extent due to additional investigation locations



Levels and areal extents of TCE have decreased significantly

4.4 Extent of TCE Over Time – Zone C

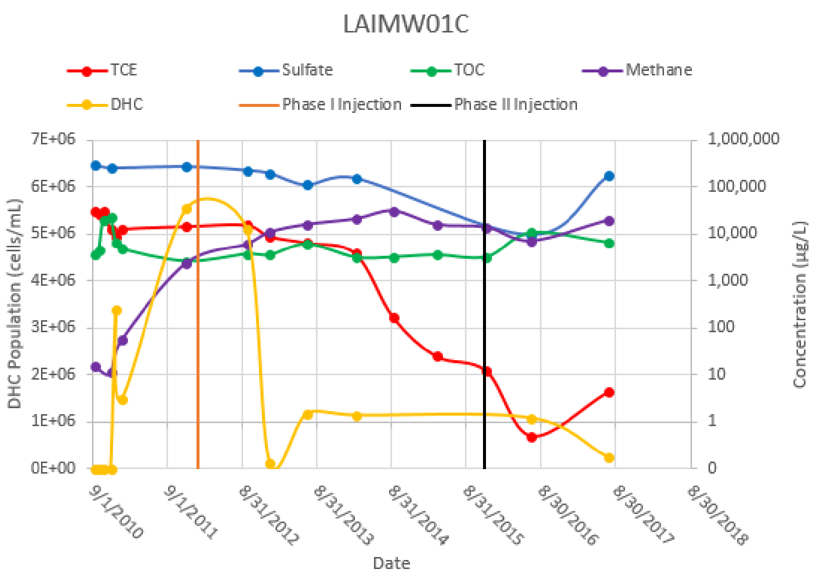




Levels and areal extents of TCE have decreased significantly

4.5 Monitoring Results at a Typical Well

Summary of LAIMW01C - Geochemical Results



- TCE biodegraded with a robust microbial population (a population >10^4 cells/mL is recommended)
- In a reducing environment, sulfate can be a terminal electron acceptor (reduced to sulfide)
- Good correlation between sulfate and TCE concentrations, as well as microbial population
- TOC used to track presence of the electron donor (EVO), but as mentioned previously, not always a reliable indicator
- Methane is produced when CO_2 is used as a terminal electron acceptor: Strong correlation between increasing methane concentrations and decreasing TCE concentrations

4.6 Progress to Date

- Levels of Cr(VI) and TCE have decreased significantly since Phase I injections (2012)

- Areal extents have decreased in Zones B and C (the primary zones targeted)

- Some assumptions and conventional wisdom were confirmed, but there were some surprises or mysteries along the way

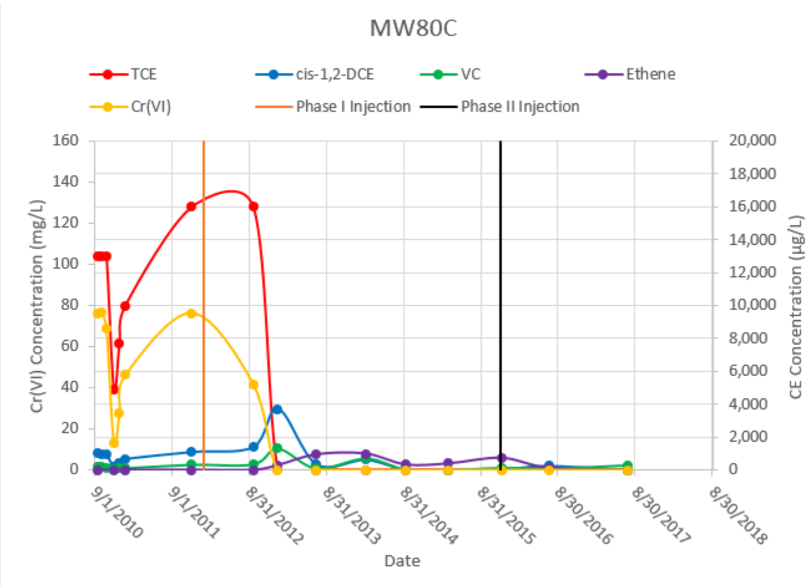
4.7 Questioning Conventional Wisdom

#1 – EISB works for elevated levels of TCE (>100 mg/L) and for elevated Cr(VI) (>140 mg/L) *(EISB often not considered effective for high levels)*

#2 – EISB works in saline environments at NASNI *(EISB often not considered effective for coastal/saline environments)*

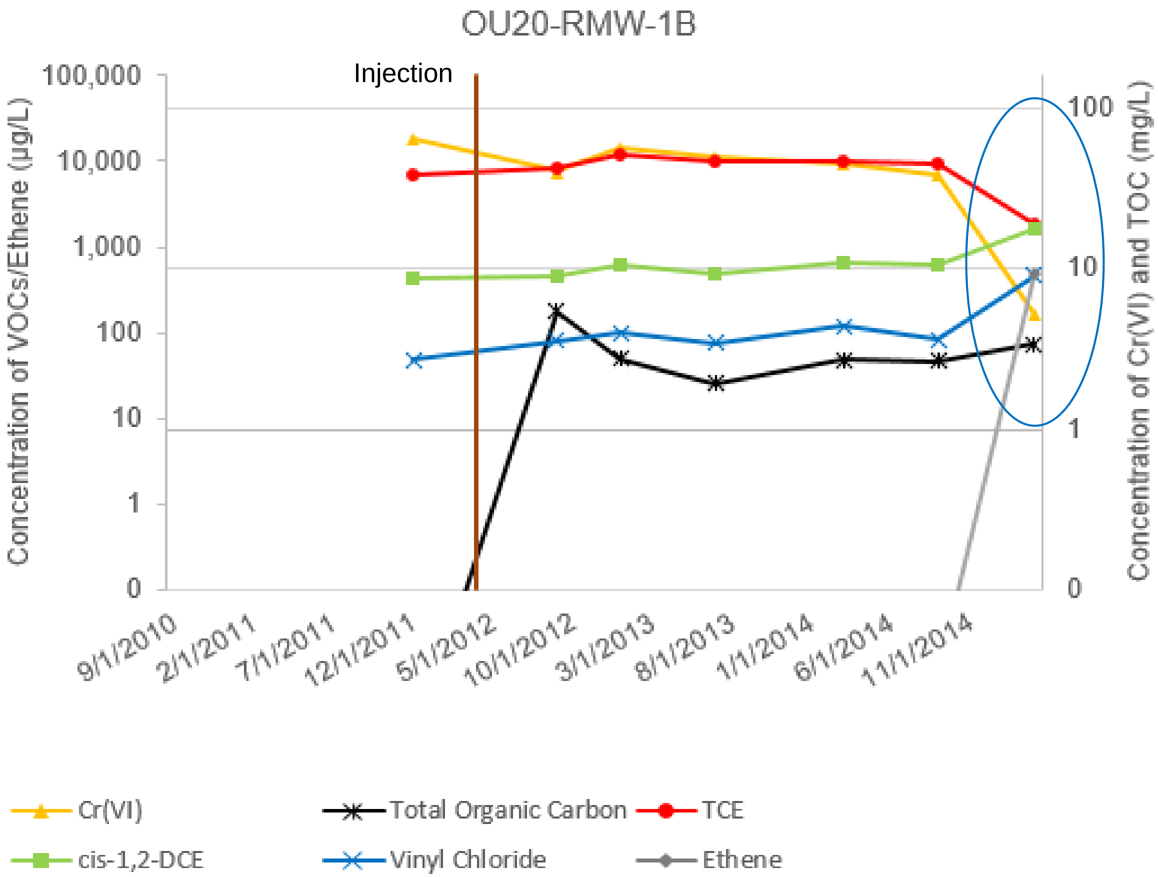
4.8 Inhibition of TCE Biodegradation due to Cr(VI)

Summary of MW80C: CE and Cr(VI) Results



- Decreases in TCE correlated with increases in daughter products *cis*-1,2-dichlorothene and vinyl chloride
- Similarly, decreases in daughter products correlated with an increase in ethene
- **TCE began to biodegrade following reduction of Cr(VI) to below 10 mg/L (consistent with bench-scale findings and conventional wisdom)**

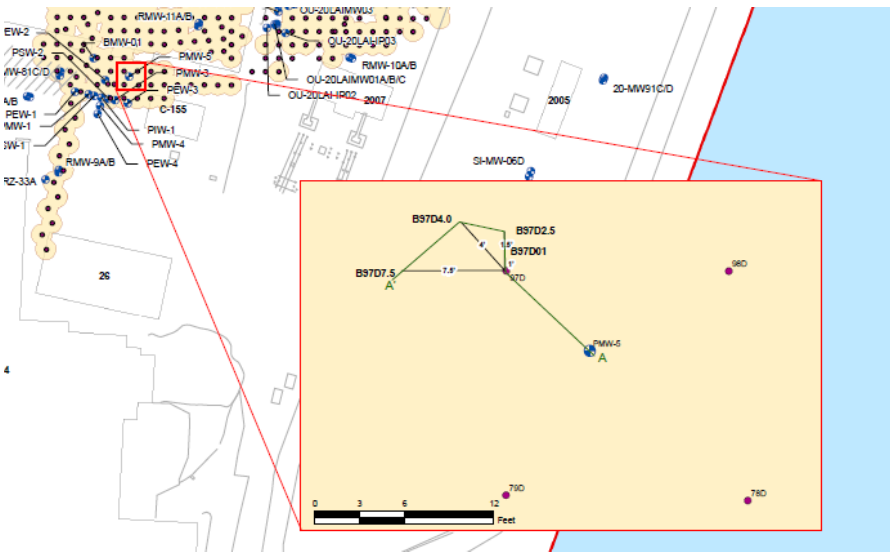
4.9 EVO Longevity/Transport & Effect of Tidal Fluctuations



- Significant decrease in Cr(VI) and TCE, coupled with *cis*-1,2-DCE and VC increase in 2015
- This was 3 years after injections, which occurred 60 feet upgradient
- Sulfate (not shown) – 1,000 mg/L
- **Lessons learned – tidal fluctuations did not impact performance (some stakeholders were skeptical during design phase)**

4.10 TOC Levels in Groundwater

Location of soil investigation samples



- Initial sampling indicated TOC was not consistently observed in groundwater
- This raised questions about EVO distribution
- Soil investigation to evaluate the extent of the distribution and migration of EVO
- TOC was detected in soil samples, and black-colored soils and fermented EVO odors were noted in all soil borings
- Majority of EVO was sorbed to the soil matrix within a few feet of the injection point, which can serve as a source of dissolved electron donor for years
- **Lessons learned: Dissolved TOC in groundwater may not necessarily be a reliable indicator of EVO distribution <u>(tracers being considered for future)</u>**

4.11 Methane Generation

Summary of CH_4/H_2S Results Within Select DGPRZ Wells

Location	Dissolved CH_4 (µg/L)	CH_4 (ppm_v)	H_2S (ppm_v)
MW120BD	33,000	>4,268	99.9
MW110A	11,000	>4,268	11.5
MW116BD	--	1,017	2.2
MW107C	13,000	>4,268	99.9

- Methane readings were taken with an at monitoring wells within the DGPRZ several months after Phase II injections
- Many wells showed >1,000 ppm CH_4 in zones where injection had occurred
- High levels of H_2S also detected in several wells
- **Lessons learned: high levels of methane can be generated during EISB (considering addition of antimethanogenic formulations to limit methane production)**

4.12 EVO Coagulation in UGPRZ Wells

Coagulated EVO from UGPRZ Injection Wells

- EVO can coagulate in an injection well ("crud") – present several years after initial injection
- This may hinder upcoming replenishment
- Dissolution of the crud was attempted on a bench scale with water, trisodium phosphate (TSP), and Dawn detergent
- Cold water did not dissolve the crud, but hot water did until it cooled
- Some foam was observed from samples mixed with TSP
- **Lessons learned: <u>Hot water will be used to dissolve the crud and drive the EVO out into the formation prior to replenishment</u>**

4.13 Future Activities

- Replenishment of Phase I UGPRZ wells: 3Q 2018
- DPIs to address residual elevated Cr(VI) and TCE: 3Q 2018
- Recirculation zone to address elevated Cr(VI) under a busy road (using new and existing wells): 3Q/4Q 2018
- Other electron donors being evaluated
- Tracers (Rhodamine WT) being considered as an additional measure of amendment distribution

5. Summary and Conclusions

- EISB is effectively remediating elevated TCE and Cr(VI) [> 100 mg/L and 140 of mg/L] in brackish water at NASNI
- Good correlation between reductive dechlorination of TCE and sulfate/methane concentrations
- EVO distribution not affected by tidal fluctuations (close to Bay)
- Reductive dechlorination of TCE did not occur until Cr(VI) dropped below 10 mg/L
- TOC is not the best indicator of EVO distribution in groundwater
- Minimum longevity of EVO in the saturated zone is at least 3 years, transport of at least 60 feet
- Significant methane concentrations in groundwater
- EVO can coagulate in injection wells over time, but can be dissolved by adding hot water

QUESTIONS?