CDM

Determining Success and Lessons Learned

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NEWMOA Enhanced In Situ Bioremediation Workshop

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Acknowledgements

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- Nathan Smith (CDM)
- Neil Smith (CDM)

Presentation Outline

- Introduction – focus on chlorinated ethenes
- Case Study – Fast release electron donor
- Case Study – Slow release electron donor

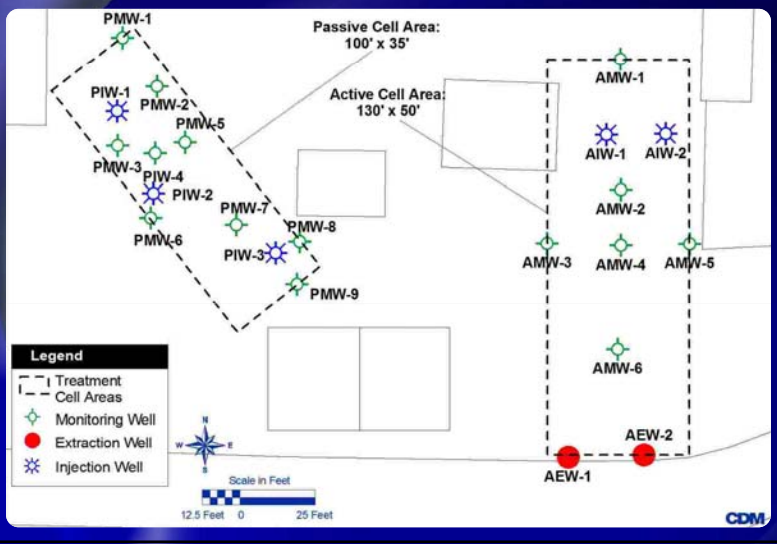
Case Study #1 – Fast Release Electron Donor

- The passive treatment zone
  - Inject DHC-containing bioaugmentation culture into passive injection wells
  - Bacterial transport by ambient groundwater flow
- The active recirculation treatment zone
  - Groundwater continuously injected and extracted
  - DHC-containing bioaugmentation culture added through the reinjection wells
  - Transport occurs by forced advection

Demonstration Site
NWS Seal Beach Site 70

- Selected Seal Beach Site 70 for demonstration
  - TCE source area has concentrations as high as 190 mg/L during demonstration
  - Water table occurs at 15 to 20 ft bgs
  - Shallow aquifer zone extends to 50 ft bgs; highest contamination concentrations present to ~35 ft bgs
  - Ambient groundwater velocity ~25-30 ft/yr
  - Sulfate ranges from 1,500 to 9,000 mg/L
  - Scale-up area is centered within the source area and is ~ 400 ft by 150 ft
  - Bioremediation/bioaugmentation being implemented as the remedial action for this site

Treatment Cell Construction



Treatment Cell Injection System - Construction

- Perform "pre-conditioning" to establish appropriate redox conditions prior to bioaugmentation
- Injection strategy: approx. 3,000 gallons of 1% lactate into each treatment cell
- Active cell (started April 2008)
  - Quarterly injections conducted until bioaugmentation (January 2009)
- Passive cell (started September 2008)
  - Injections performed monthly

Pre-conditioning Results

Active Cell Summary

- Moderately reducing conditions achieved near reinjection wells; cis-DCE increasing; sulfate decreasing
- DHC functional gene vcrA not present

Passive Cell Summary

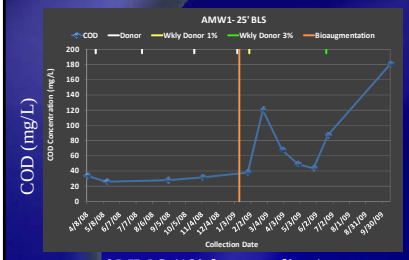
- Significant donor in all injection wells and in several monitoring wells; redox conditions moderately reducing; sulfate decreasing
- Concentrations of c-DCE low
- DHC functional gene vcrA not present

Bioaugmentation Activities

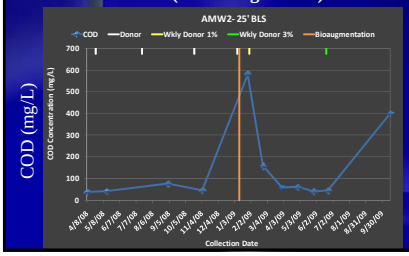
- Bioaugmentation performed week of January 12, 2009
  - Donor Injection performed week of January 5 in both cells
  - SDC-9™ culture used for inoculation
  - 80-L of SDC-9 inoculated into each cell, equally split between injection wells in each cell
- Electron donor injection strategy modified in active cell
  - Weekly injections performed beginning February 2009
  - Injection mass and volume increased beginning June 25, 2009
    - 3% lactate; 1,000 gallons/well
- Monthly injections continued as planned in passive cell
- Monthly sampling from January through June; quarterly event late September / early October

Active Cell Electron Donor Results

AMW-1 (25' upgradient)

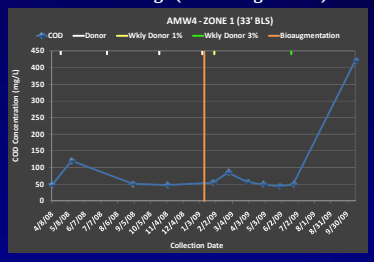


AMW-2 (18' downgradient)



COD (mg/L)

AMW-4 33' bgs (28' downgradient)

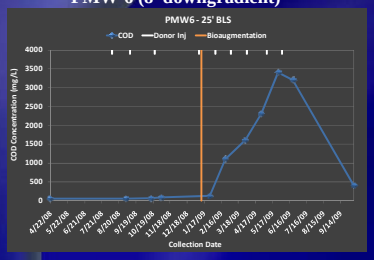


COD (mg/L)

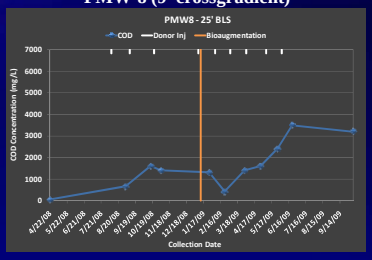
COD Donor Wkly Donor 1% Wkly Donor 3% Bioaugment

Passive Cell Electron Donor Results

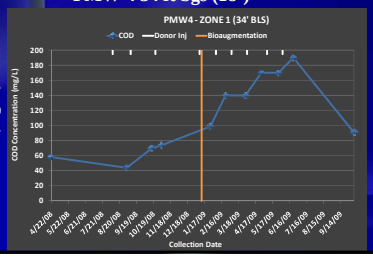
PMW-6 (8' downgradient)



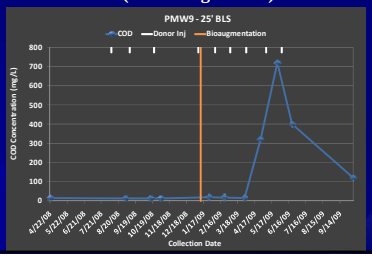
PMW-8 (9' crossgradient)



PMW-4 34 ft bgs (18')



PMW-9 (13' downgradient)



Electron Donor Summary

Active Cell

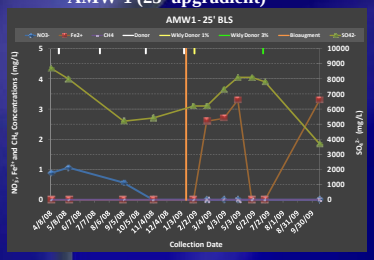
- Good electron donor distribution along cell axis to at least 28 feet downgradient
- Little increase in electron donor observed beyond 25-30 ft. from injection wells
- Highest concentrations in the deep zone

Passive Cell

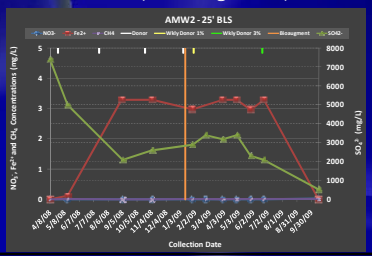
- Electron donor increased following lactate injections in CMT wells at least 25 feet from injection well
- Electron donor increased in downgradient wells with consistent monthly injections
- Electron donor is order of magnitude higher in middle zone of CMT wells compared to deepest zone

Active Cell Electron Acceptor Results

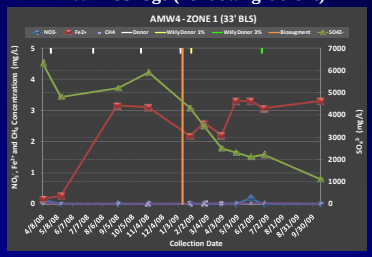
AMW-1 (25' upgradient)



AMW-2 (18' downgradient)

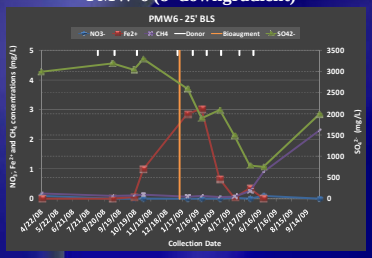


AMW-4 33' bgs (28' downgradient)

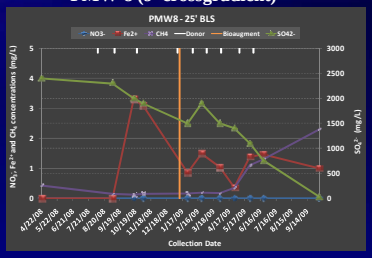


Passive Cell Electron Acceptor Results

PMW-6 (8' downgradient)



PMW-8 (9' crossgradient)



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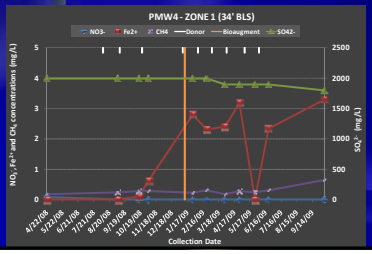
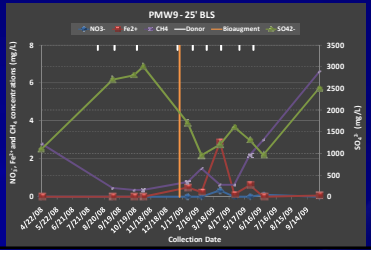


PMW-9 (13' downgradient)



Electron Acceptor Summary

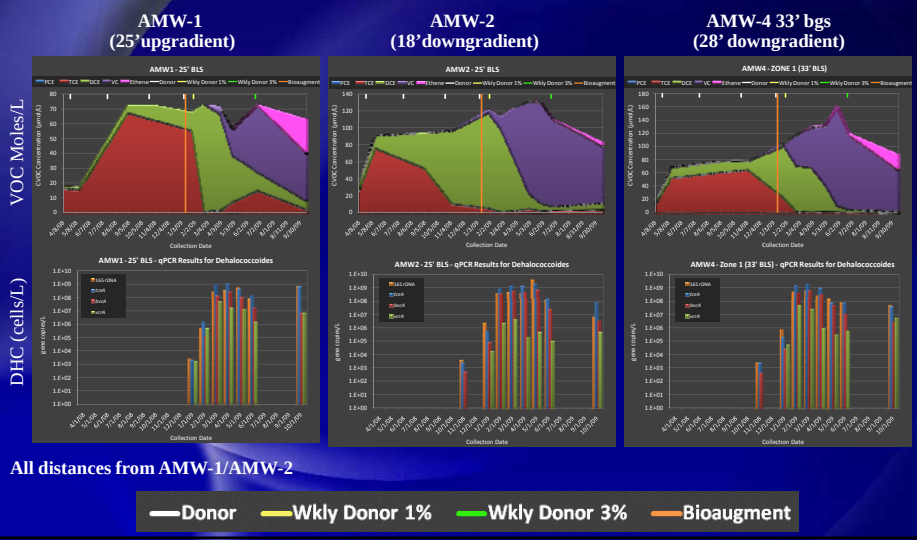
Active Cell

- Sulfate reducing to methanogenic conditions achieved 25-30 feet down-gradient of injection wells
- Redox conditions relatively unchanged downgradient of CMT wells

Passive Cell

- Sulfate reducing conditions achieved in upgradient portion of cell
- Methanogenic conditions achieved in downgradient portion of cell

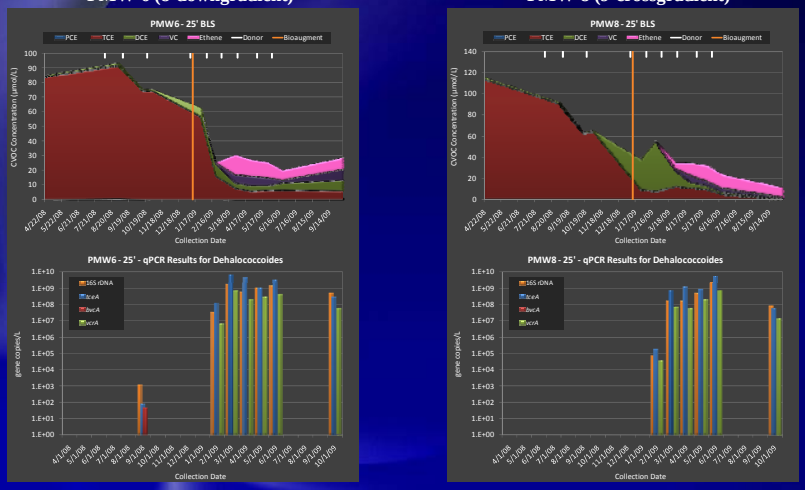
Active Cell



Passive Cell

PMW-6 (8'downgradient)

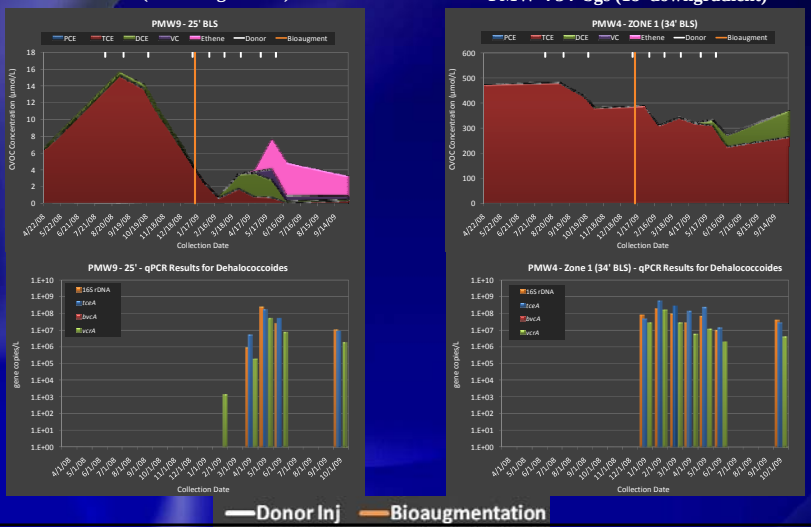
PMW-8 (9'crossgradient)



Passive Cell

PMW-9 (13'downgradient)

PMW-4 34' bgs (18' downgradient)



Active Cell Summary

- DHC distribution rapid (observed at ~30 ft downgradient within 1 month)
- Difficult to distribute donor > 30 ft downgradient
  - Lactate injection modified in June to increase electron donor in cell
- Primarily sulfate reducing conditions where donor distributed
- DHC growth correlates with donor distribution (30 ft)
- Complete transformation to DCE and VC with some ethene 30 feet downgradient less than 3 months after bioaugmentation
- No dechlorination beyond 30 feet downgradient

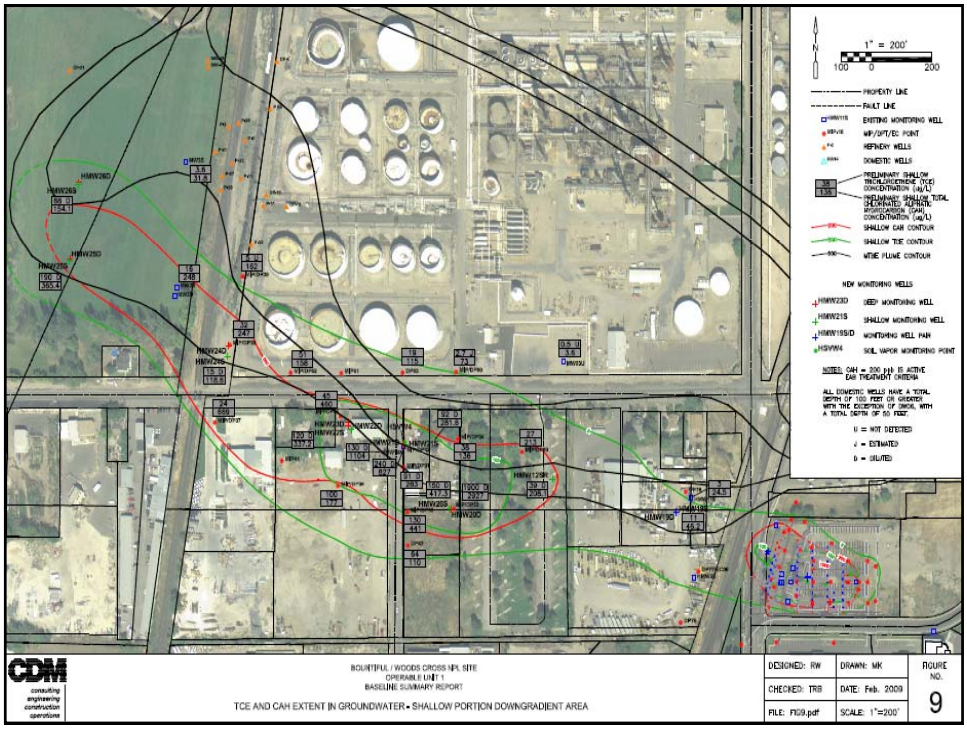
Passive Cell Summary

- TCE present at higher concentrations in deepest zone of treatment cell
- Effective lateral donor distribution throughout cell; vertical distribution to deeper zones is not uniform
- Full dechlorination to ethene in downgradient part of cell
  - Good electron donor distribution and methanogenic conditions
  - DHC (and vcrA) not observed until February 2009, but populations of DHC/vcrA have been sustained since then
- Little dechlorination occurring in upgradient portion of cell despite presence of DHC and vcrA, and methanogenic conditions
  - Possible inhibition due to co-contaminants

Conclusions

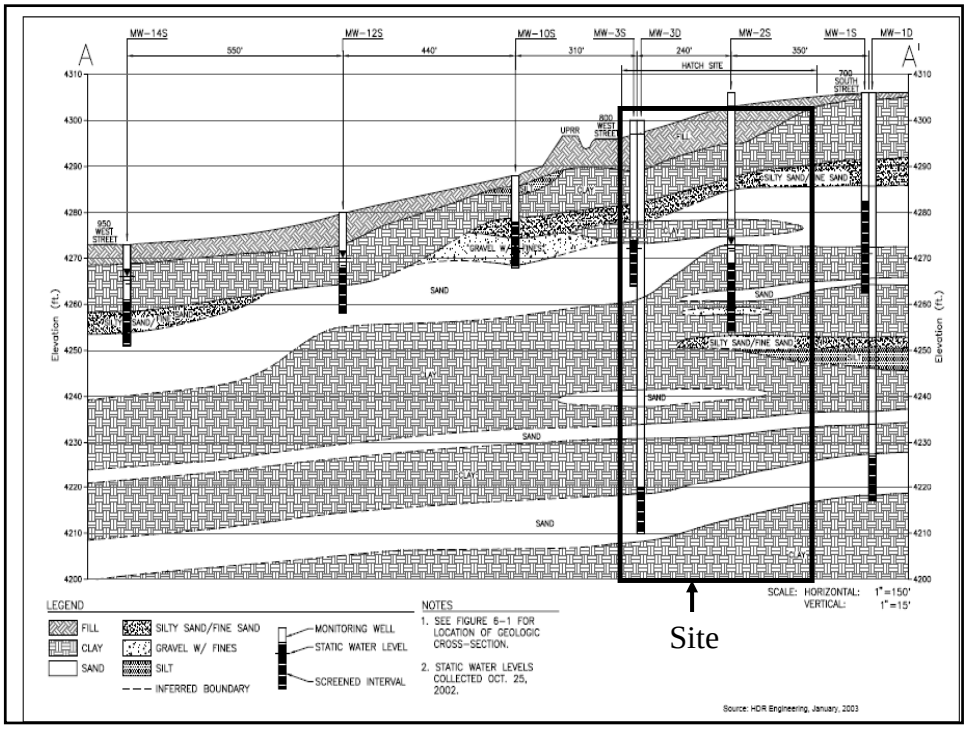
- Similar electron donor distribution achieved in both passive and active cells
  - More donor was required and more operational issues were encountered with active approach
- Dechlorination to ethene observed in both treatment cells as a function of donor distribution
- DHC was distributed to similar distances from injection points in both treatment cells, and populations were sustained as a function of donor distribution
- Better overall distribution throughout the treatment cell was achieved using the passive approach

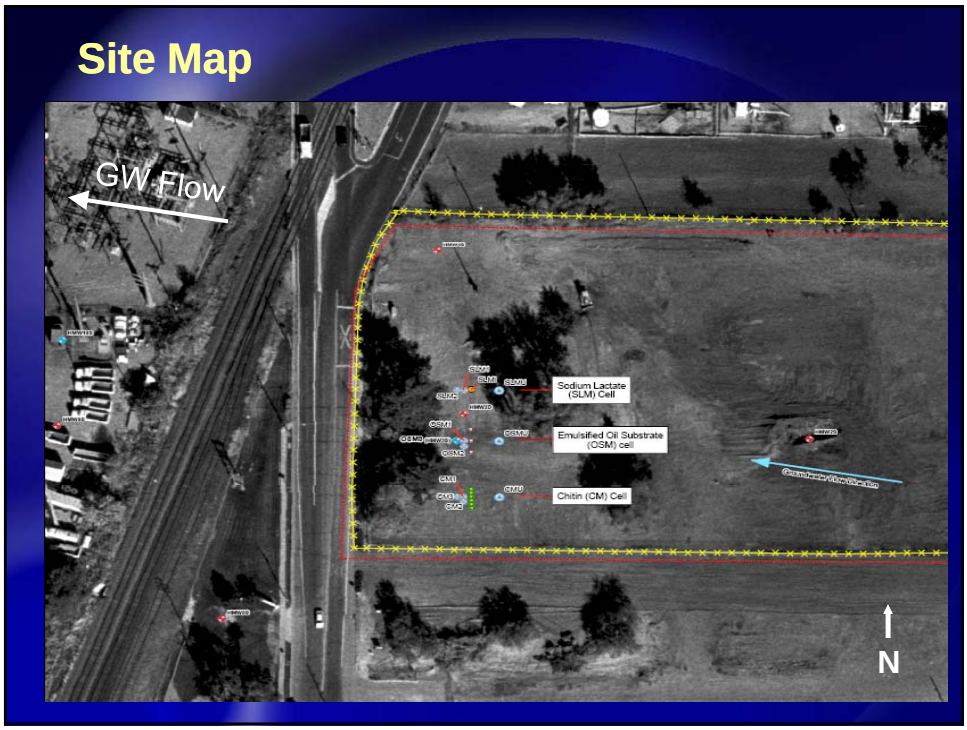
CASE STUDY #2



Site Hydrogeology - RI

- Water table generally encountered at 25-30 ft bgs
- Sand and gravel zones present to 35-40 ft
- Clay aquitard present below sand and gravel unit; laterally continuous and up to 20 ft thick
- Separate sand/gravel aquifer unit below clay, which was not contaminated

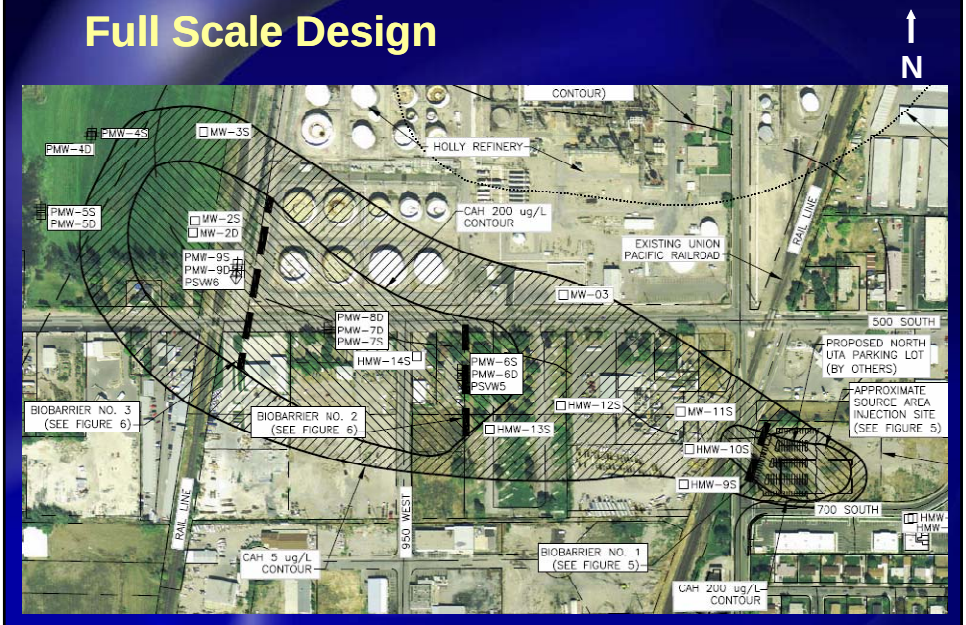

MW-14S
MW-12S
MW-10S
MW-3S
MW-3D
MW-2S
MW-1S
MW-1D
A
A'
550'
440'
310'
240'
350'
HATCH SITE
700 SOUTH STREET
800 WEST STREET
950 WEST STREET
UPRR
FILL
SILTY SAND/FINE SAND
GRAVEL W/ FINES
SAND
CLAY
Elevation (ft.)
4310
4300
4290
4280
4270
4260
4250
4240
4230
4220
4210
4200
LEGEND
FILL
CLAY
SAND
SILTY SAND/FINE SAND
GRAVEL W/ FINES
SILT
INFERRED BOUNDARY
MONITORING WELL
STATIC WATER LEVEL
SCREENED INTERVAL
NOTES
1. SEE FIGURE 6-1 FOR LOCATION OF GEOLOGIC CROSS-SECTION.
2. STATIC WATER LEVELS COLLECTED OCT. 25, 2002.
SCALE: HORIZONTAL: 1"=150'
VERTICAL: 1"=15'
Site
Source: HDR Engineering, January, 2003


Site Map
GW Flow
Sodium Lactate (SLM) Cell
Emulsified Oil Substrate (OSM) cell
Chitin (CM) Cell
N

Full Scale Design – ROD Selected Remedy

- Treat >200 µg/L total chlorinated solvents using enhanced anaerobic bioremediation (EAB)
- Treat remainder of plume with monitored natural attenuation
- Source area treatment using grid pattern of injection wells
- Downgradient plume treatment - installation of one to three biobarriers
- Pre-drilling characterization to refine well design

Full Scale Design

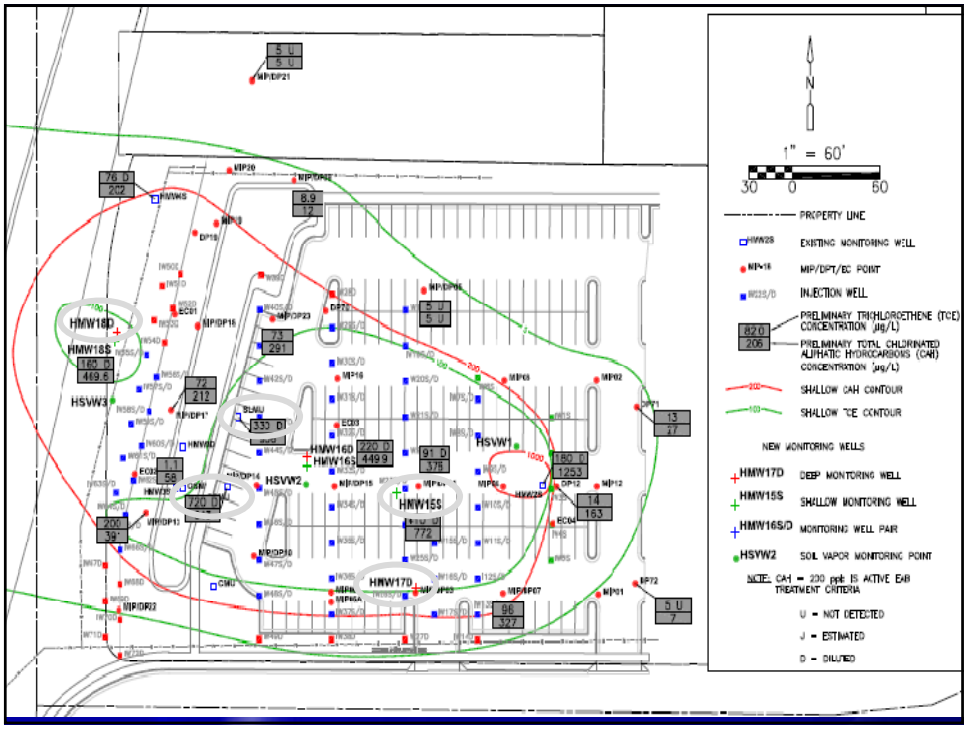


Pre-RA Characterization Results: Contaminant Distribution

- MIP results showed responses at depths greater than 40 ft throughout the source area and downgradient plume
- DPT sampling confirmed MIP results as source concentrations greater than 15,000 ppb were found below 40 ft
- Downgradient concentrations were greater than 3,000 ppb in one location

Pre-RA Characterization: Hydrogeology

- Clay layer at 35 ft bgs was found to be laterally discontinuous
- Modified DPT/EC approach was used to investigate hydrogeology below 60 ft.
- Below 35 ft, layers of sand and gravel exist to 80 feet bgs, with intermittent thin clay layers present in some areas.
- A several foot thick clay layer was found at depths of approximately 80 ft throughout the source area.



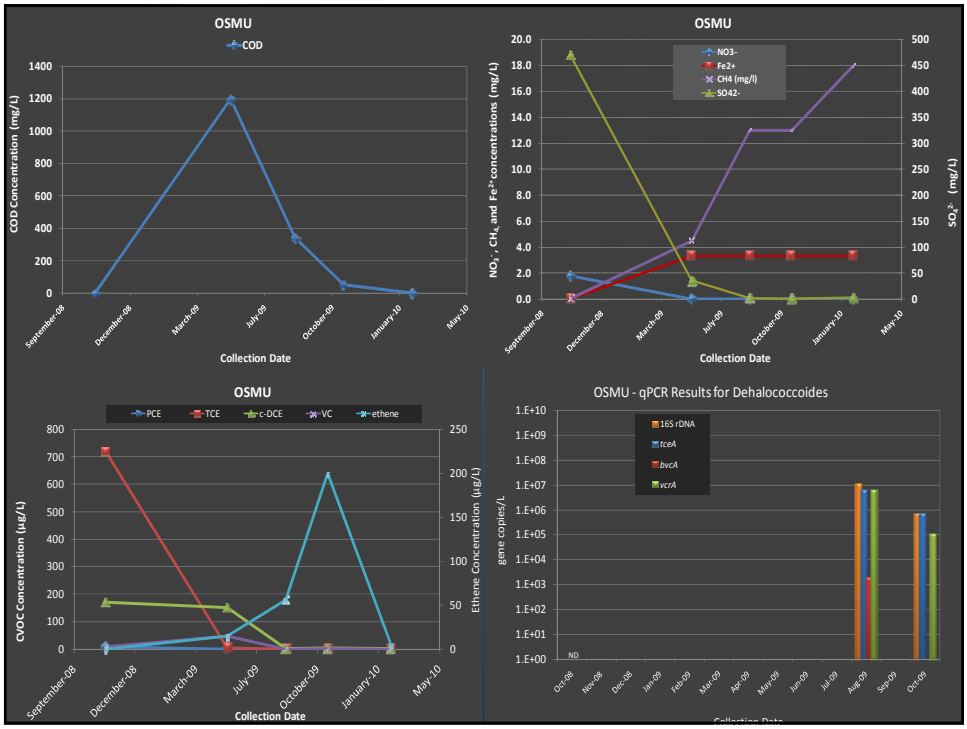
Emulsified Oil Injections

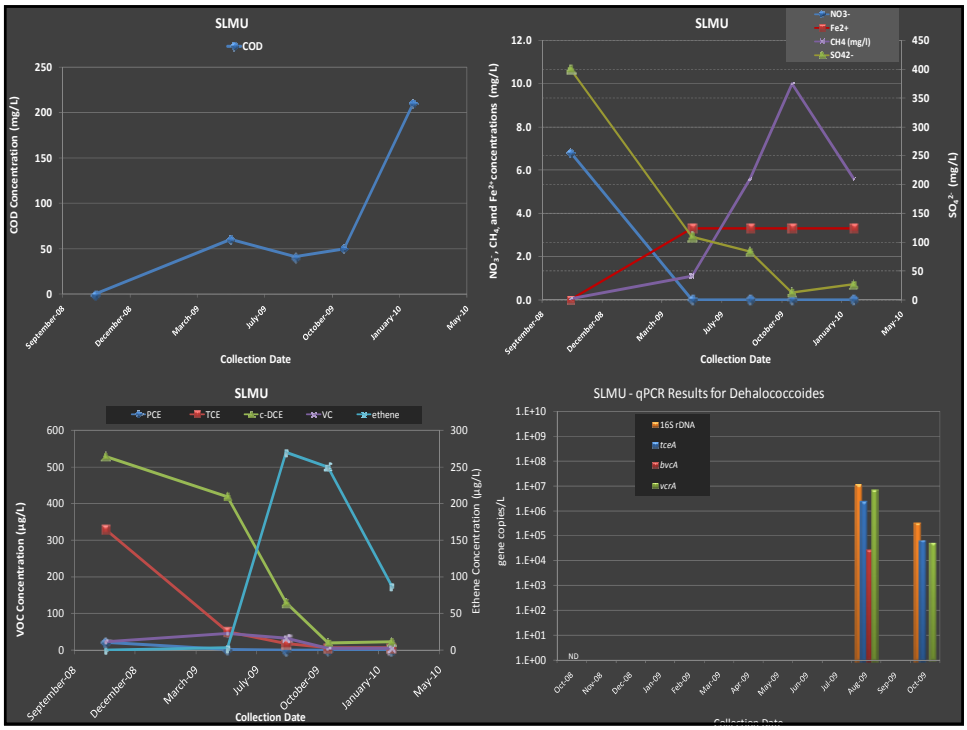
- Target injections of 1,500 gal 2% EOS into each of 121 injection locations
  - Source area – 37 paired wells and 12 individual wells
  - Biobarrier – 12 paired wells and 11 individual wells
- Injections conducted from December 2008 through February 2009

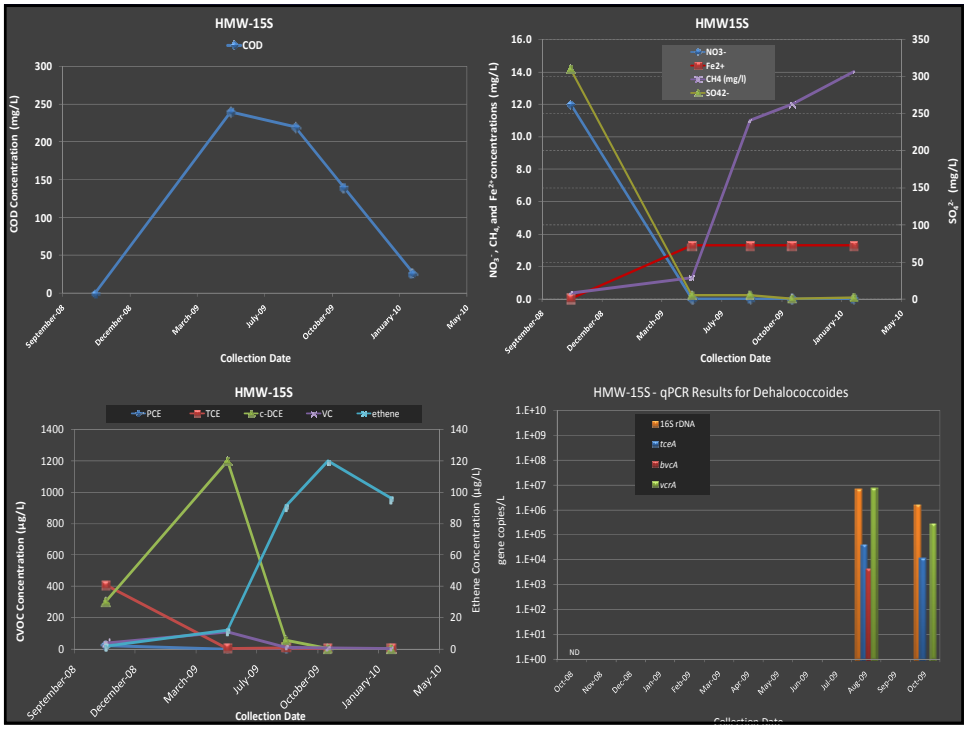
- Manifold system in heated trailer allowed for injection in up to 12 wells simultaneously

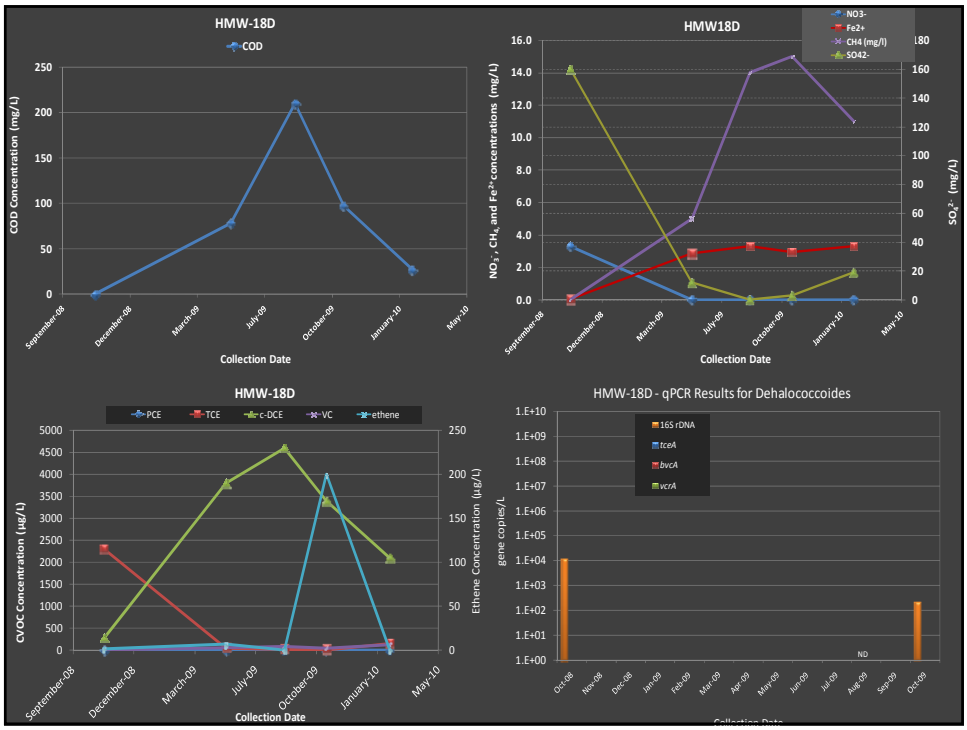
Bioaugmentation

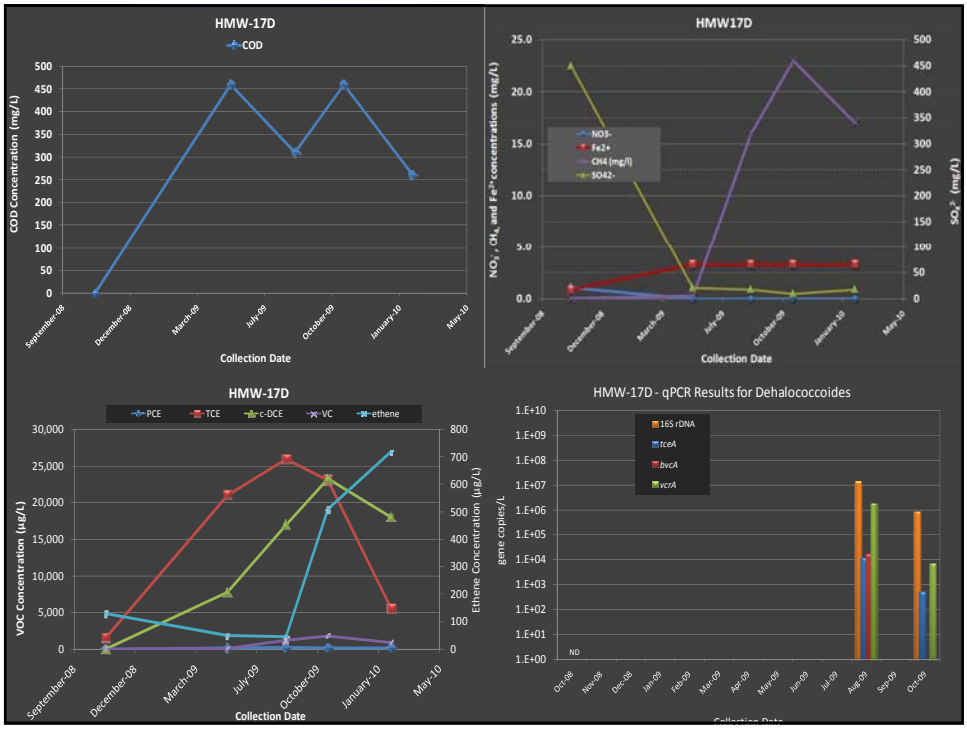
- Pilot study area had active dechlorinating culture
- Following completion of emulsified oil injections, original plan was to transfer culture from pilot area to wells throughout the source area and biobarrier in phases
- After preliminary transfers were completed, it was determined that dechlorinating bacteria were growing following biostimulation alone in most areas


OSMU
COD
COD Concentration (mg/L)
Collection Date
OSMU
NO3-
Fe2+
CH4 (mg/l)
SO42-
NO3- , CH4 and Fe2+concentrations (mg/L)
SO4 2- (mg/L)
Collection Date
OSMU
PCE
TCE
c-DCE
VC
ethene
CVOC Concentration (µg/L)
Ethene Concentration (µg/L)
Collection Date
OSMU - qPCR Results for Dehalococcoides
16S rDNA
tceA
bvcA
vcrA
gene copies/L
ND


SLMU
COD
COD Concentration (mg/L)
Collection Date
SLMU
NO3-
Fe2+
CH4 (mg/l)
SO42-
NO3- , CH4 and Fe2+concentrations (mg/L)
SO4 2- (mg/L)
Collection Date
SLMU
PCE
TCE
c-DCE
VC
ethene
VOC Concentration (µg/L)
Ethene Concentration (µg/L)
Collection Date
SLMU - qPCR Results for Dehalococcoides
16S rDNA
tceA
bvcA
vcrA
gene copies/L
ND


HMW-15S
COD
COD Concentration (mg/L)
Collection Date
HMW15S
NO3-
Fe2+
CH4 (mg/l)
SO42-
NO3-, CH4 and Fe2+concentrations (mg/L)
SO42- (mg/L)
Collection Date
HMW-15S
PCE
TCE
c-DCE
VC
ethene
CVOC Concentration (µg/L)
Ethene Concentration (µg/L)
Collection Date
HMW-15S - qPCR Results for Dehalococcoides
16S rDNA
tceA
bvcA
vcrA
gene copies/L
ND


HMW-18D
COD
COD Concentration (mg/L)
Collection Date
HMW18D
NO3-
Fe2+
CH4 (mg/l)
SO42-
NO3-, CH4 and Fe2+concentrations (mg/L)
SO42- (mg/L)
Collection Date
HMW-18D
PCE
TCE
c-DCE
VC
ethene
CVOC Concentration (µg/L)
Ethene Concentration (µg/L)
Collection Date
HMW-18D - qPCR Results for Dehalococcoides
16S rDNA
tceA
bvcA
vcrA
gene copies/L
ND



Summary of Results

- Complete dechlorination occurring in many portions of the source area after 15 months
- Injection of EOS likely mobilized previously sorbed contaminants, especially in area of HMW-17D
- High concentrations of *Dehalococcoides* in many areas of the site (many naturally-occurring)
- Large percentages of TCE already degraded throughout the source area
- Observed degradation as fast as 40 day half life, even with slow release electron donor

Path Forward

- Sodium lactate was injected in hotspot near HMW-17D
- Second EOS injection was completed in June-July 2010 for source area and first biobarrier
- Design and construction of downgradient biobarriers to start early 2011
  - Challenge for installation is progression toward artesian conditions for downgradient area
  - Alternative emplacement methods may be needed

Questions and Answers

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