



# Bioremediation Monitoring Optimization to Key Bioremediation Indicators – KBI on a Large-Scale Recirculation System for a Thermal Enhanced Anaerobic Process

2019 Bioremediation Symposium  
Baltimore, Maryland

Martim Souza

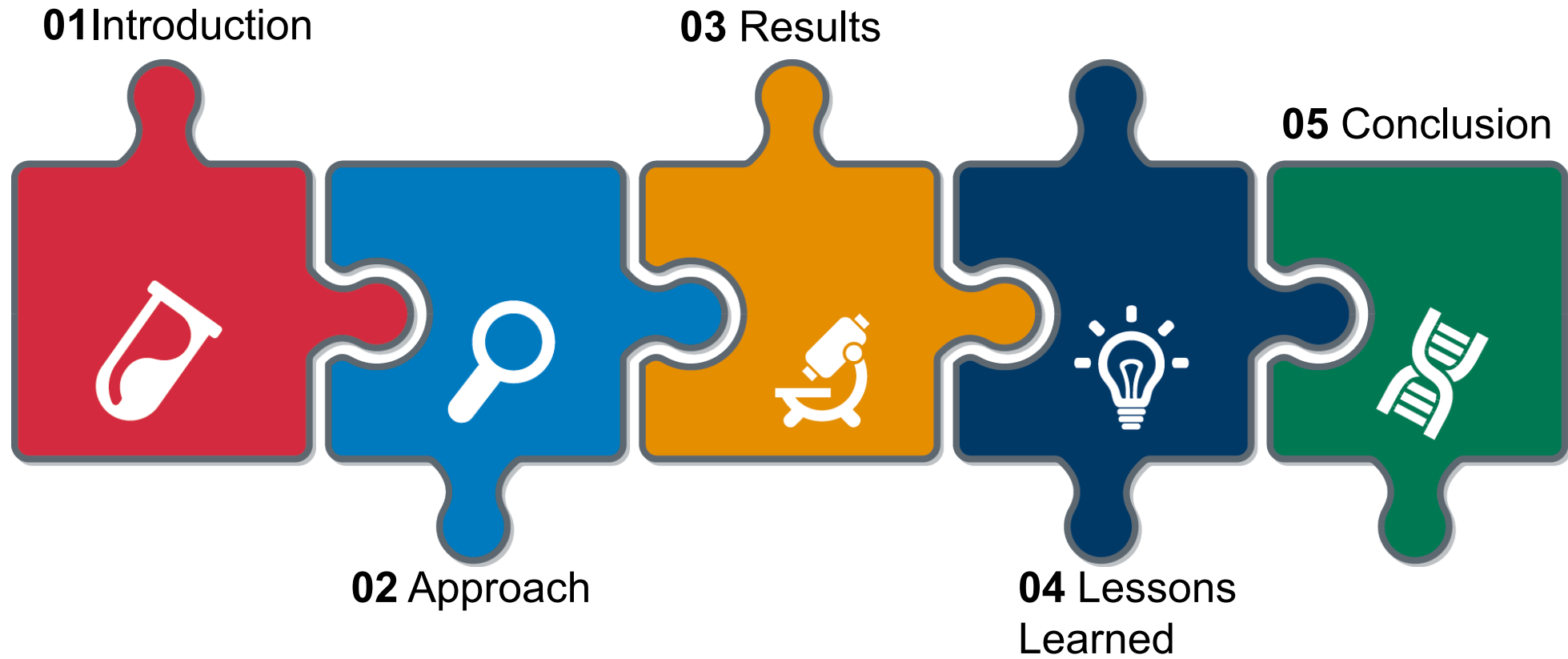
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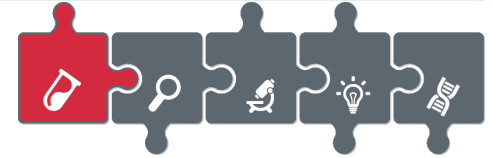
*The business of sustainability*



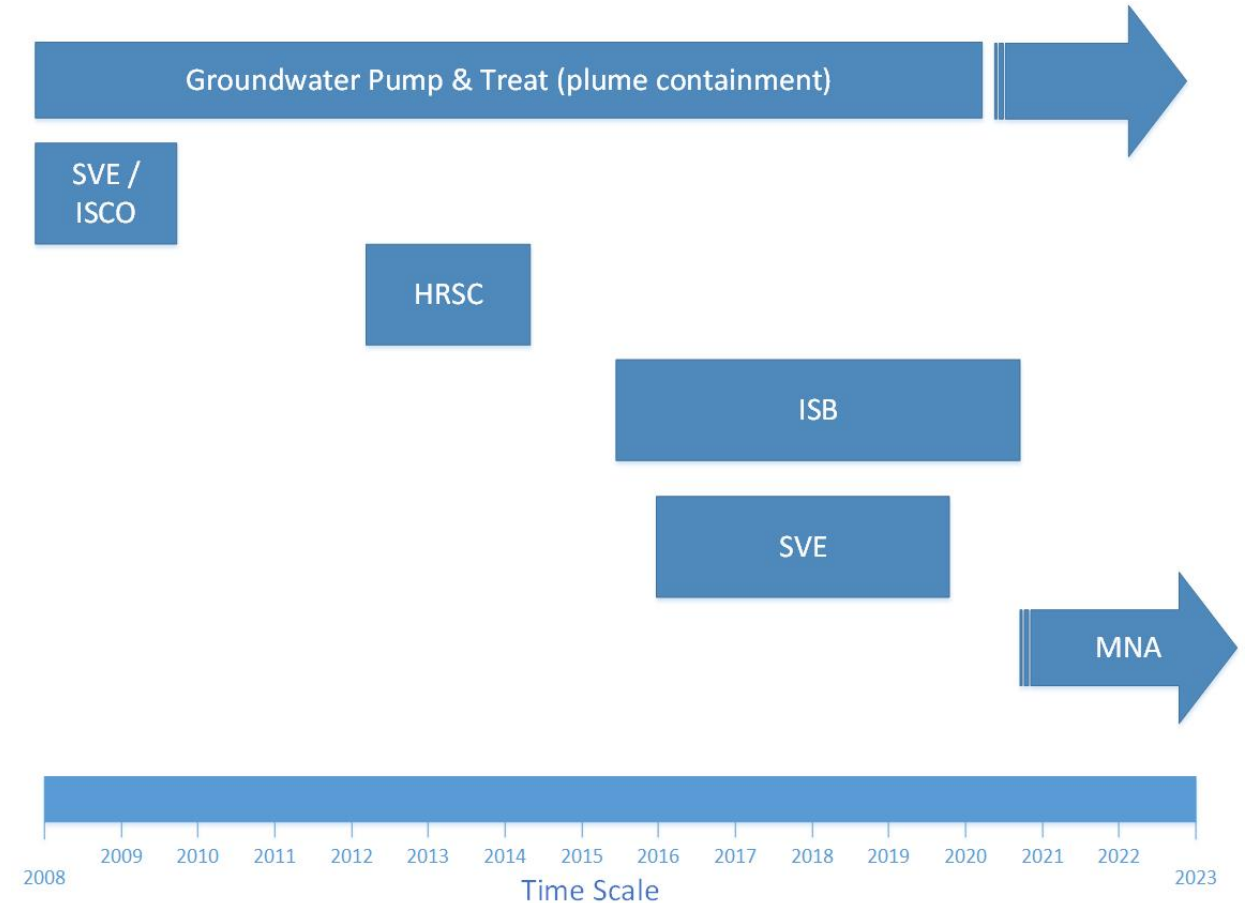
# Agenda Slide



# Introduction



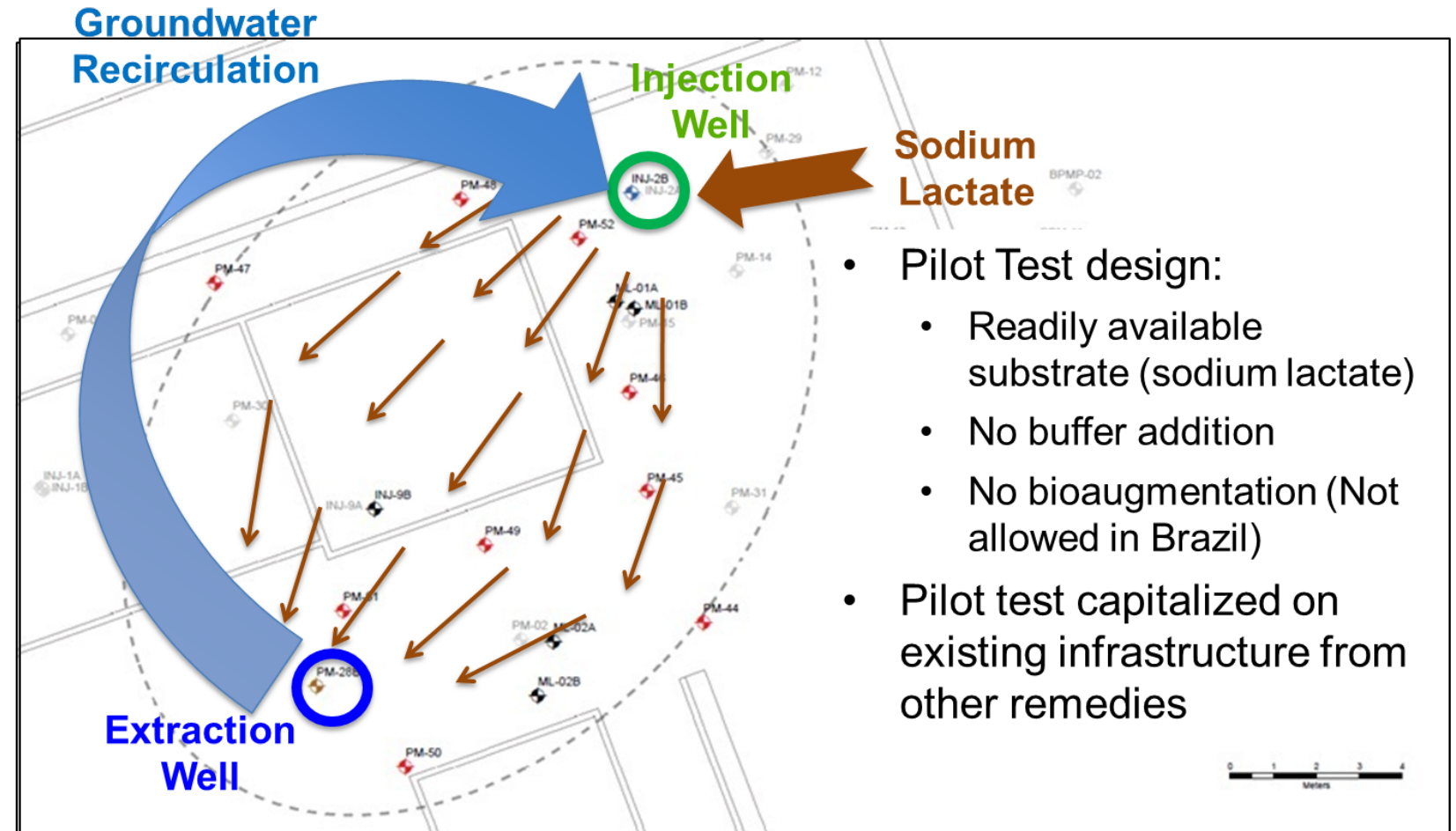
- Industrial Facility in São Paulo, Brazil
- Chlorinated solvent release
  - Chemicals of concern: PCE, TCE, cDCE, VC
- Remediation Technologies:
  - Hydraulic barrier (P&T)
  - Soil Vapor Extraction (SVE)
  - Thermally-enhanced anaerobic recirculation system (In Situ Bioremediation – ISB).
- Presentation Focus: ISB results and optimization based on Key Bioremediation Indicators – KBI



# Approach – ISB Pilot Test (2015)

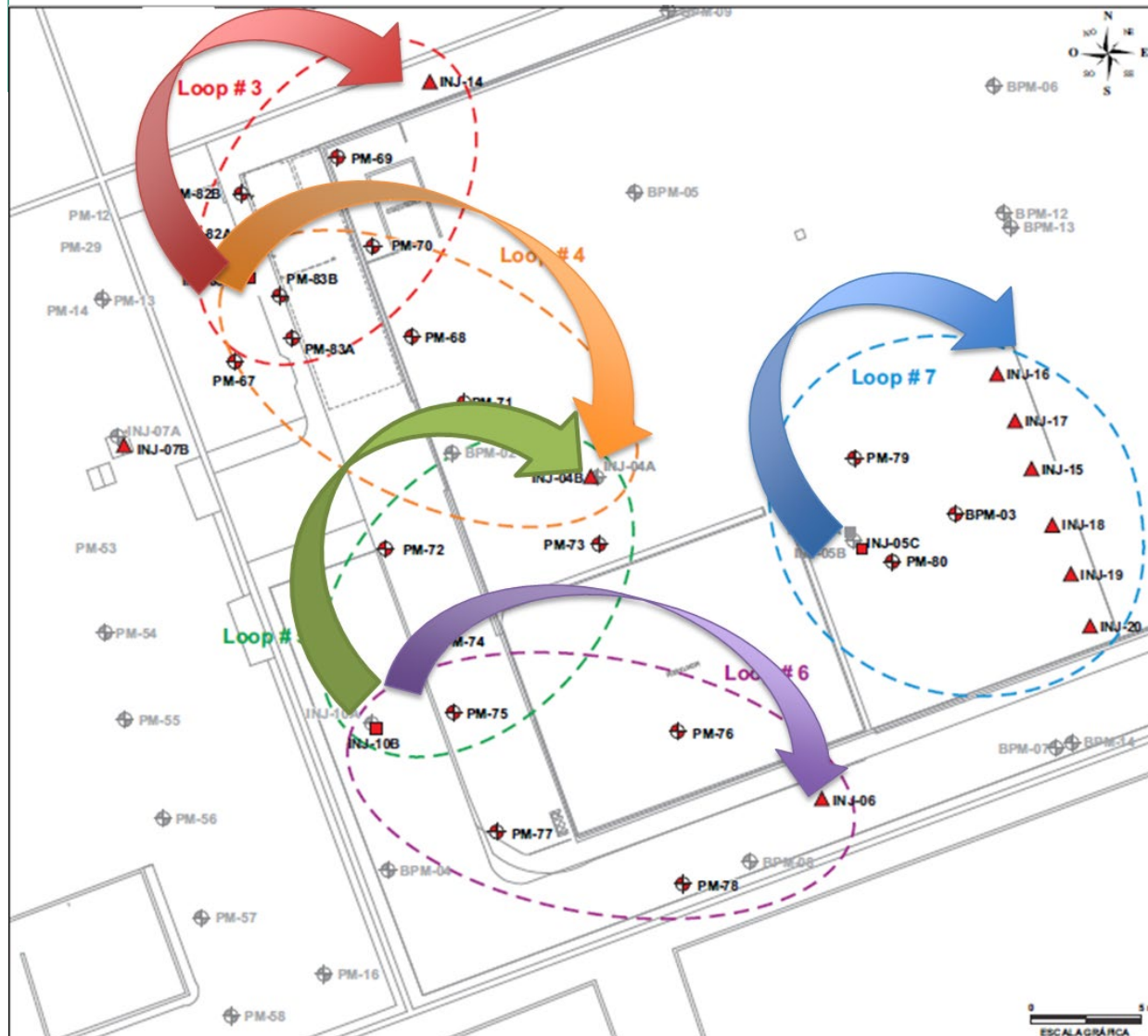
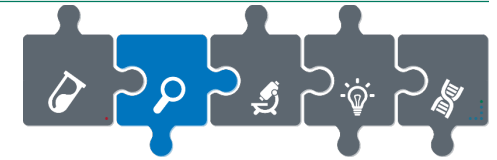


- Main Goal: stimulate complete reductive dechlorination of PCE
- Approach: One Recirculation ISB Loop
  - Monitored pilot test with CMT wells
  - 3.6m<sup>3</sup> recirculated groundwater (5.1 pore volumes)
- Carbon Substrate: Lactate
  - 4m<sup>3</sup> Sodium Lactate



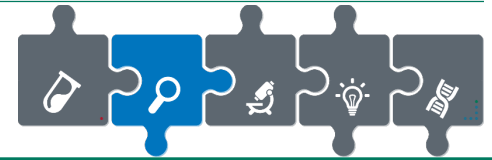
- Pilot Test design:
  - Readily available substrate (sodium lactate)
  - No buffer addition
  - No bioaugmentation (Not allowed in Brazil)
- Pilot test capitalized on existing infrastructure from other remedies

# Approach – ISB Expansion

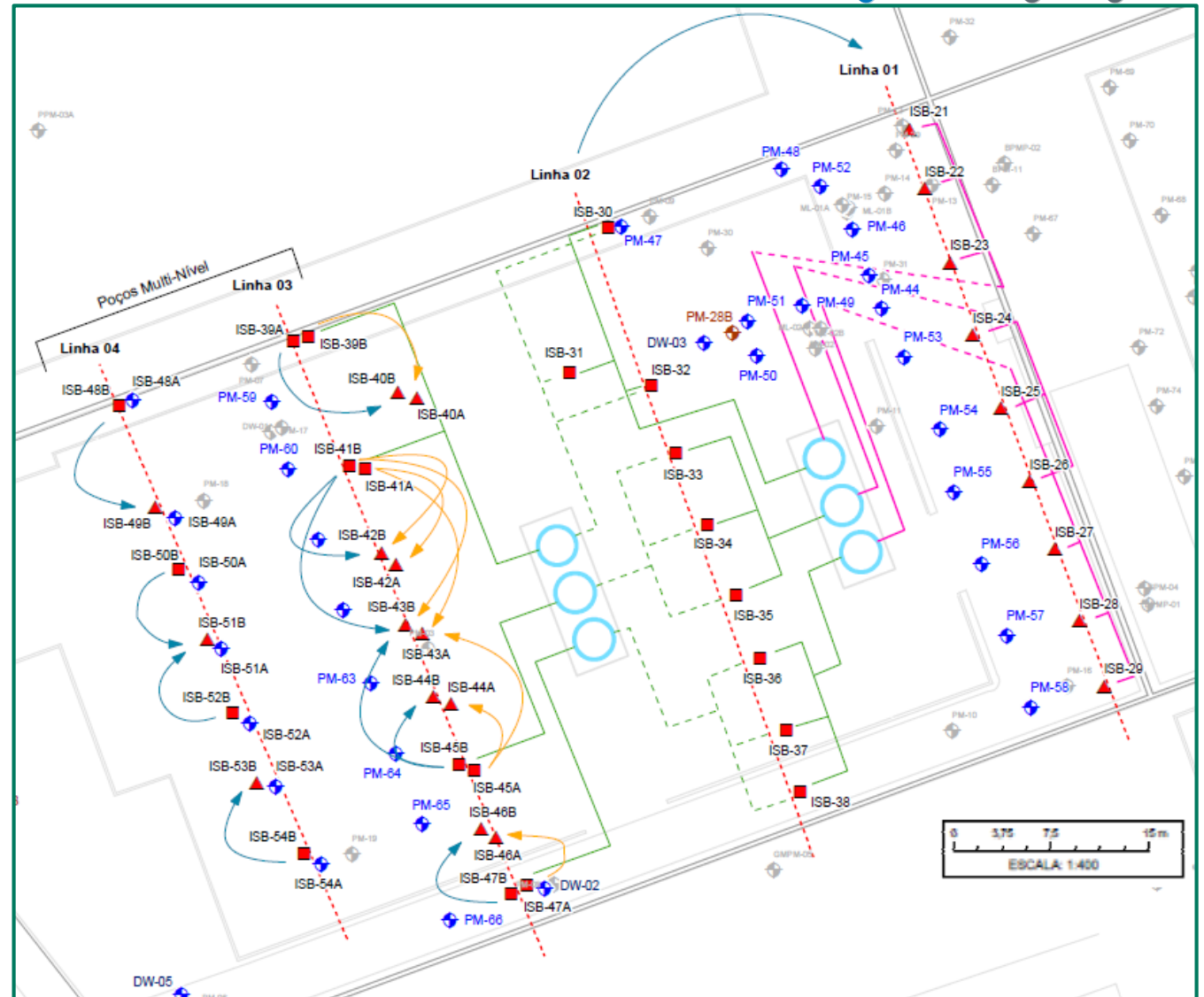


- Main Goal: implement ISB across larger area of site
- Approach: 5 ISB Recirculation Loops (approx. 1,200 m<sup>2</sup>)
- Carbon Substrate: Lactate
- System details:
  - 3 pumping wells
  - 9 injections wells
  - Monitored using transects of CMT wells

# Approach – ISB Second Expansion



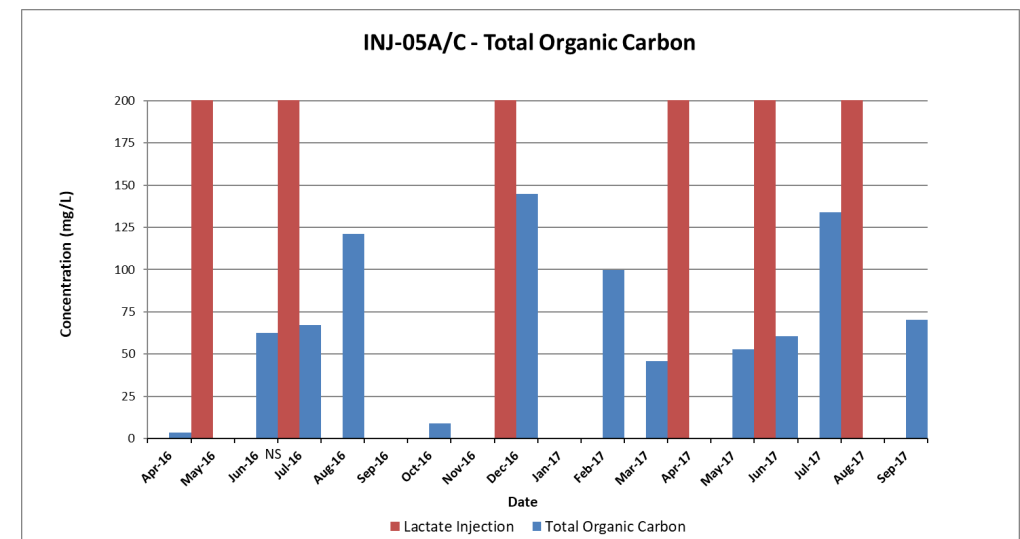
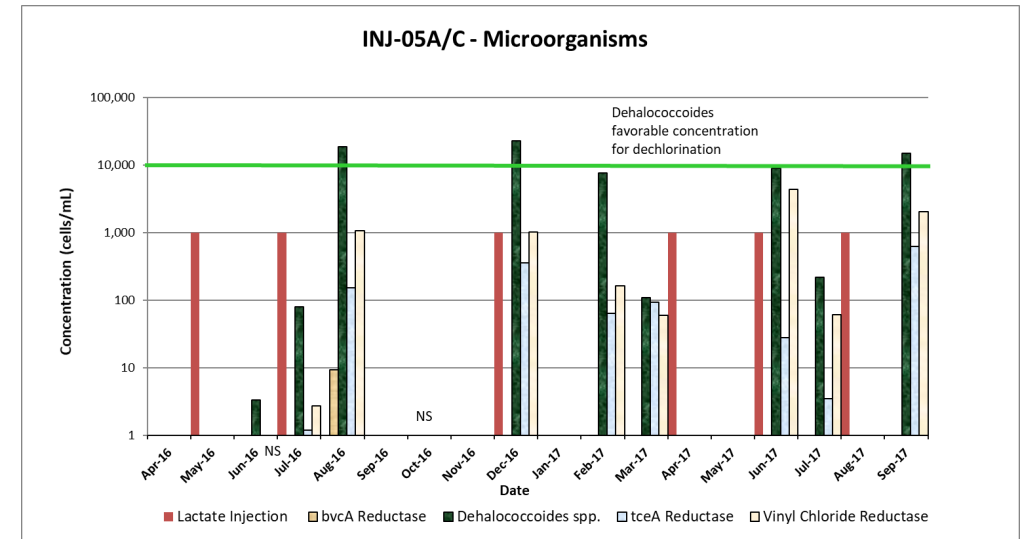
- Main Goal: Implement ISB across larger area and downgradient distribution
- Approach: 4 recirculation transects (approx. 3,200 m<sup>2</sup>)
- Carbon Substrate: Lactate
- System details:
  - Fully automated
  - 4 Hybrid Recirculation Transects
  - Upstream: upgradient-downgradient recirculation loops
  - Downstream: cross gradient recirculation loops
  - Recirculation water heated up to 35°C



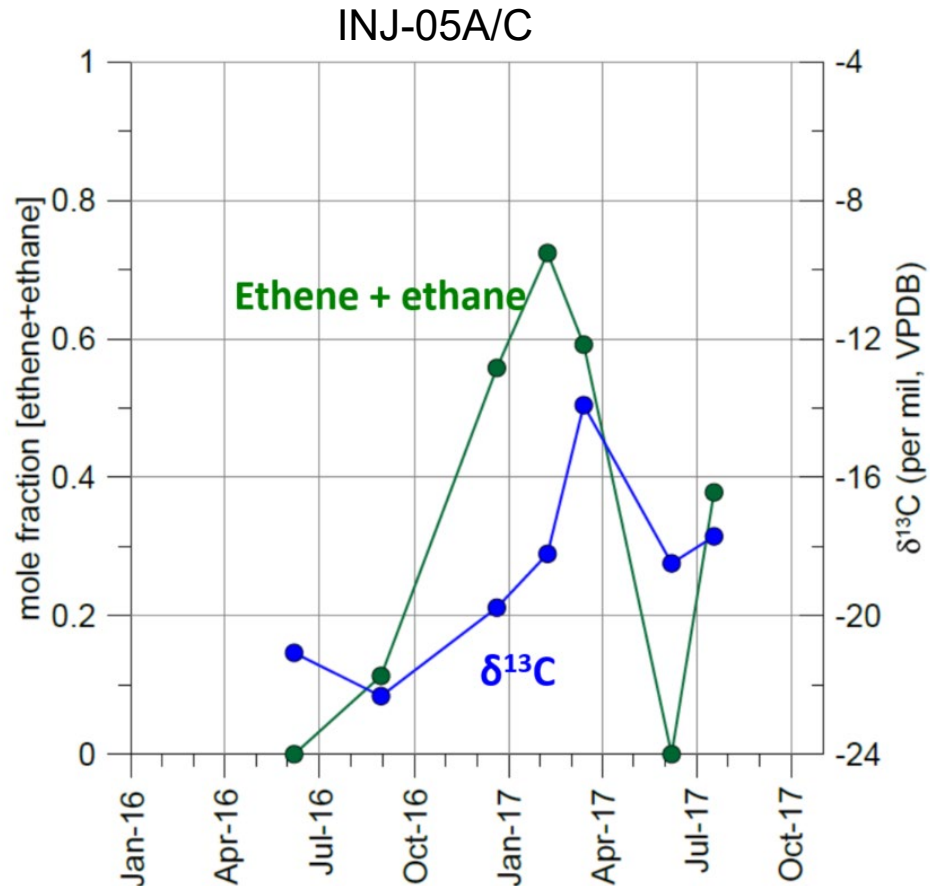
# Approach – Monitoring Program



- Initial monitoring program
  - **Compounds of Interest – COI:** PCE, TCE, cis-1,2-DCE and VC.
  - **Competing Electron acceptors - CEAs:** DO,  $\text{NO}_3^-$ ,  $\text{Fe}_2^+$ , Mn,  $\text{SO}_4^-$
  - **Dissolved Hydrogen Gases – DHG:** Ethane, Ethene and Methane
  - **Total Organic Carbon - TOC**
  - **Chloride and Bromide**
  - **Compound Specific Isotope Analysis – CSIA**
  - **qPCR Analysis:** *bvcA* Red., *Dehalococoides* sp., *tceA* Red. and VC Red.
  - **Field parameters:** pH, DO, ORP, EC, Temp



# Results - CSIA



Bennett, P. 2018, Project Notes – Haley Aldrich

## ■ CSIA - Mole fraction of ethene+ethane:

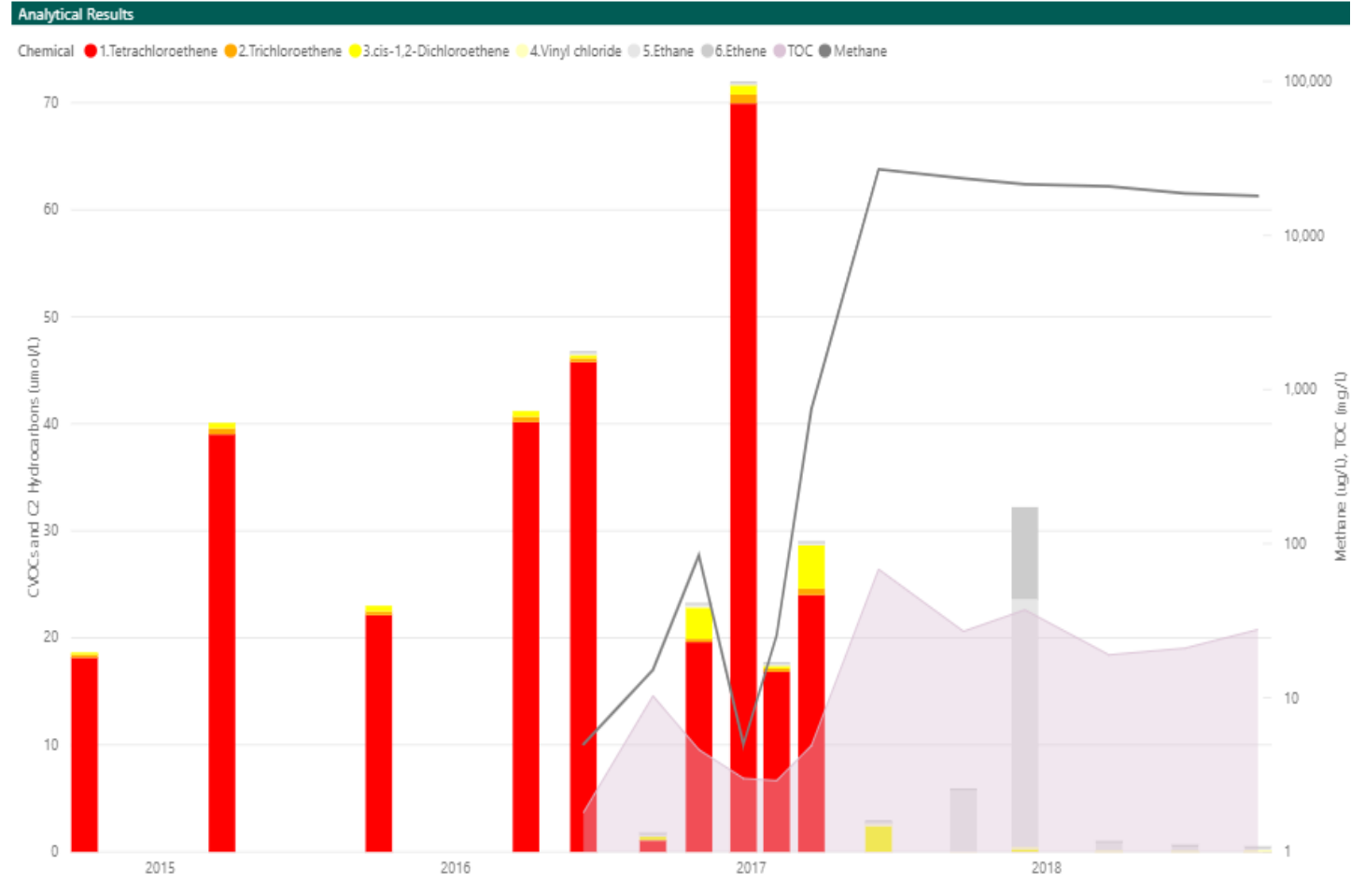
- $[\text{ethene+ethane}]/[\text{PCE+TCE+DCE+VC+ethene+ethane}]$ (in moles)
- Essentially equals fraction of PCE dechlorinated
- $\Sigma\delta^{13}\text{C}$  correlates with ethene and ethane
- Up to 70% conversion of PCE to non-chlorinated end products



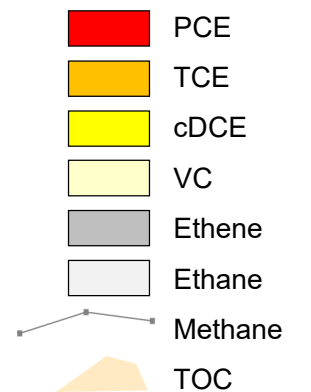
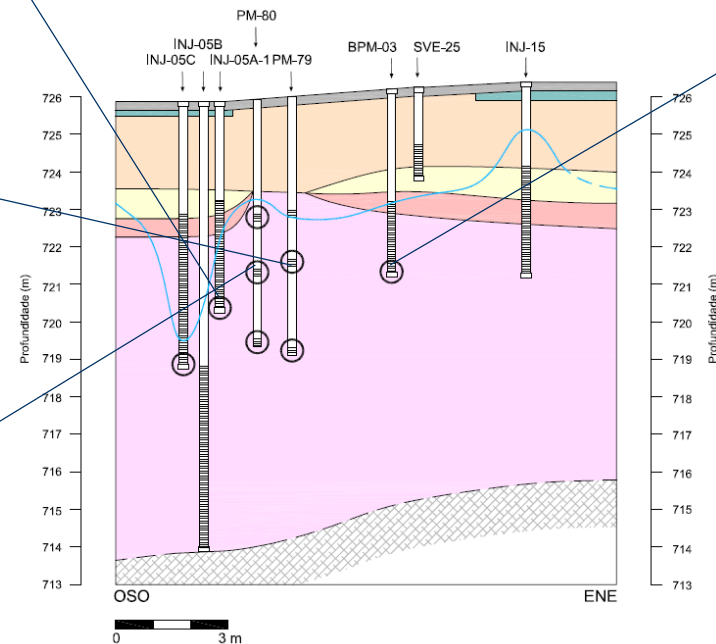
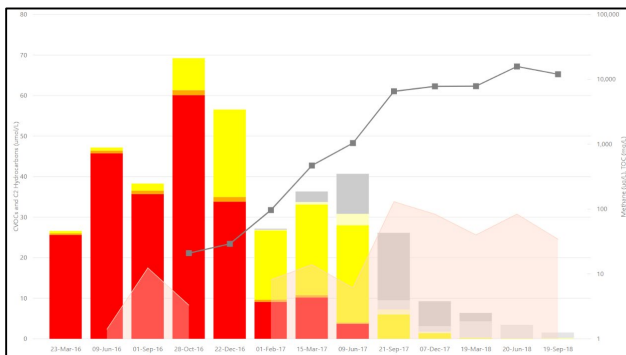
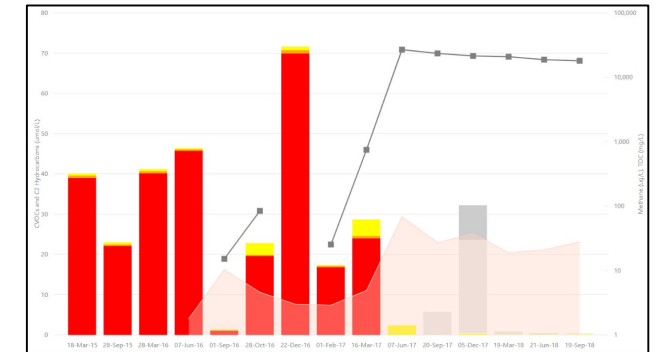
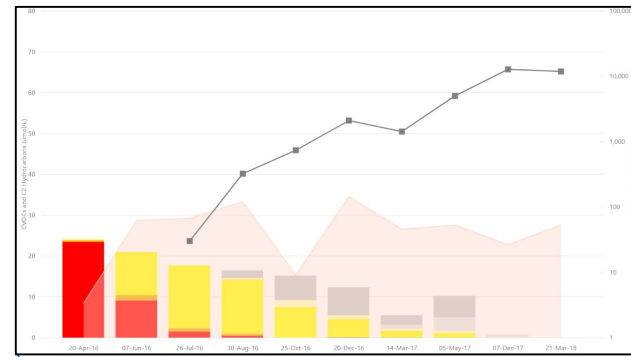
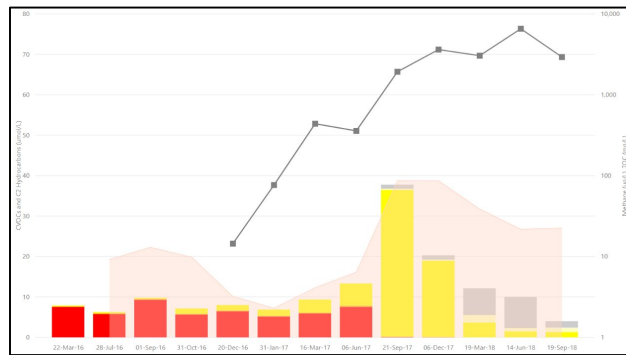
# Results



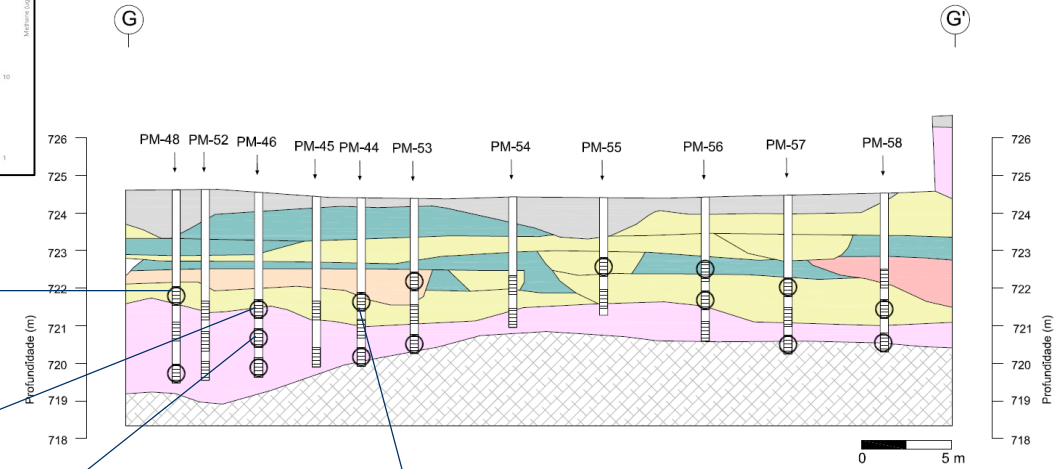
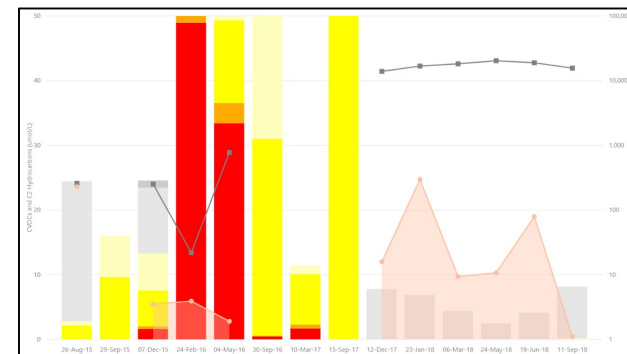
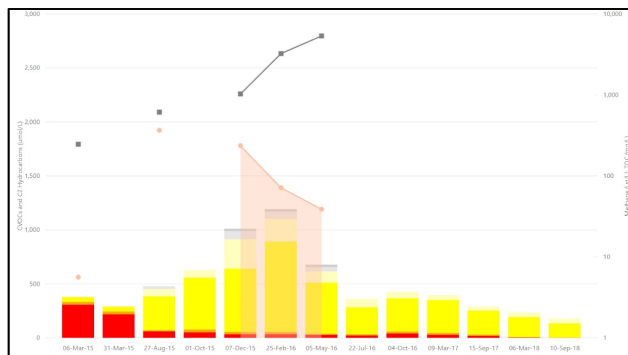
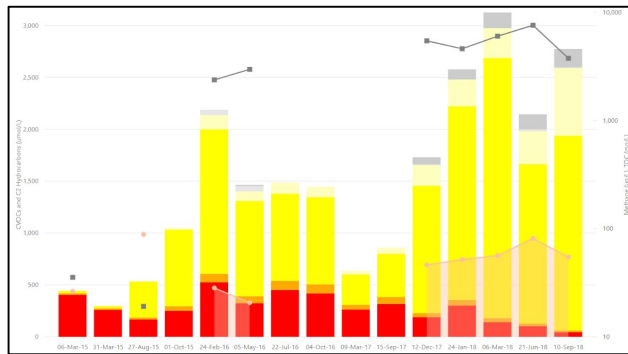
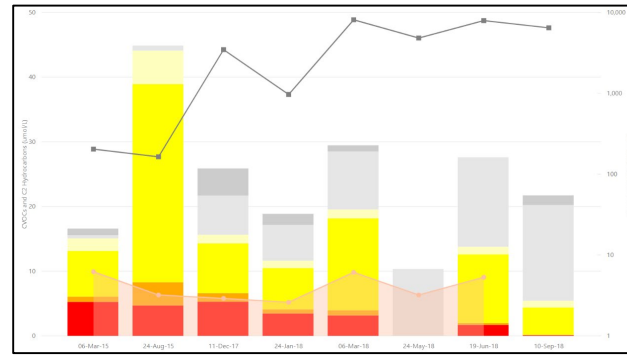
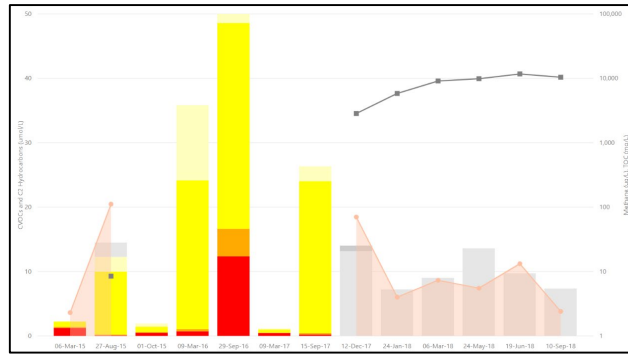
- Biodegradation, rate metrics is monitored by TOC and Methane concentrations;
- Lactate has a half life around 40 to 50 days;
- Substrate injections maintain optimum TOC and Methane concentrations;
- **Defined Key Bioremediation Indicators (KBI):** TOC, DHGs (Ethene, Ethane and Methane) and COI (PCE, TCE, cis-1,2-DCE and VC).



# Results



# Results

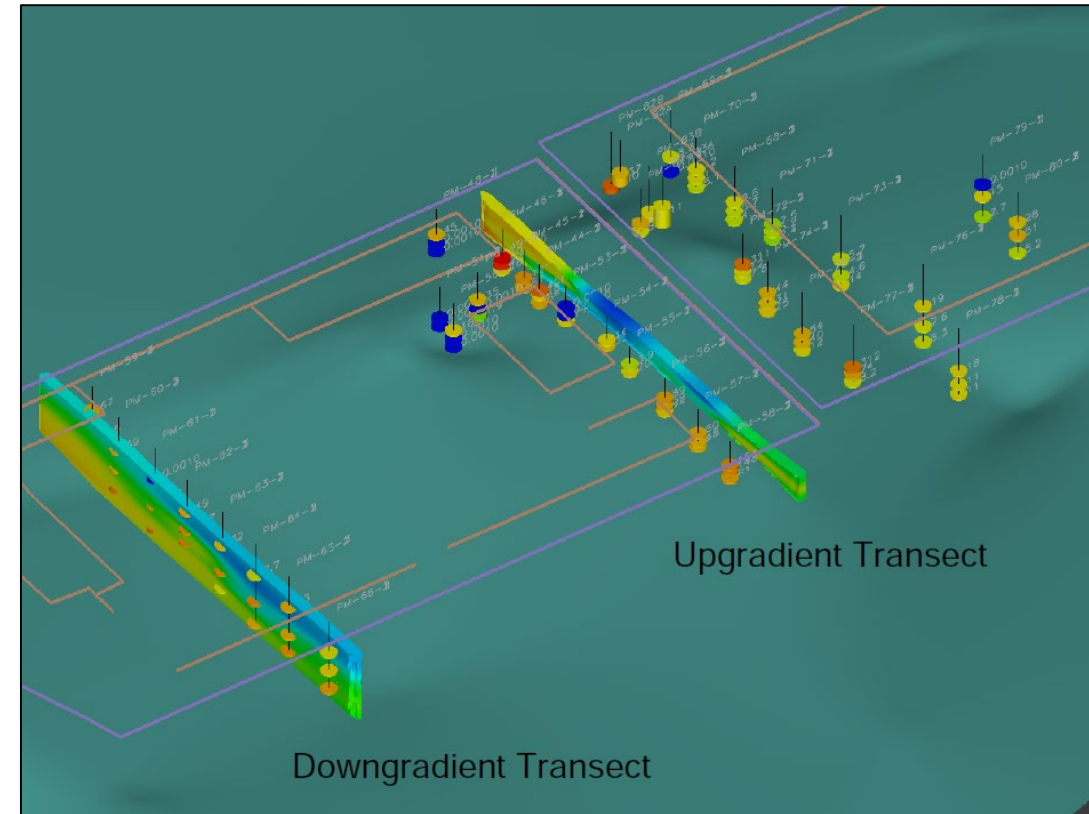
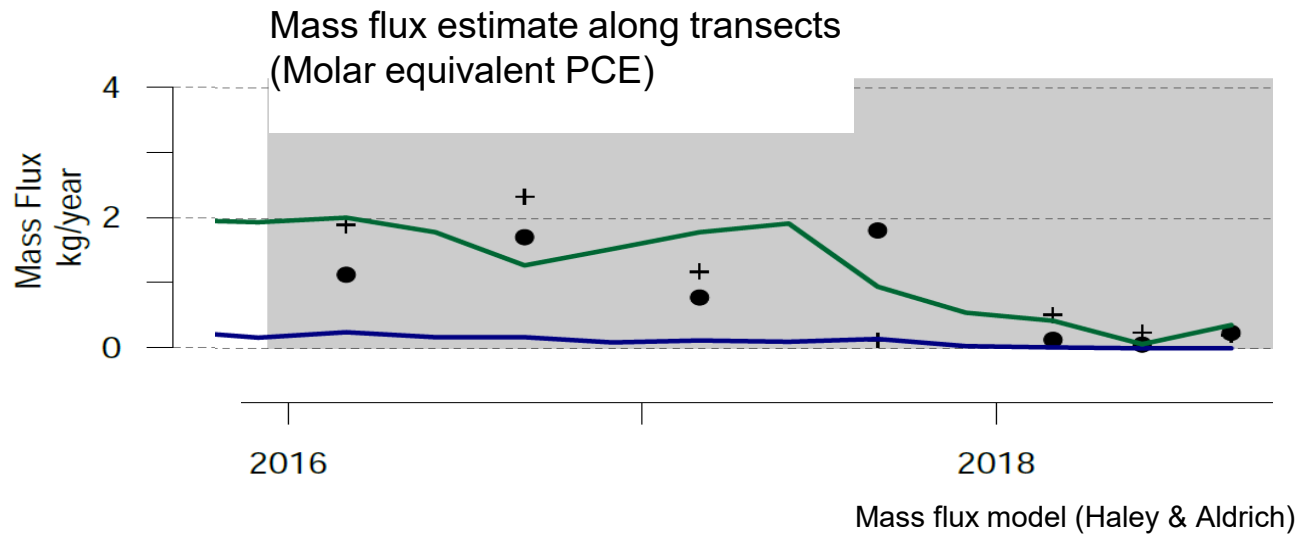


- PCE
- TCE
- cDCE
- VC
- Ethene
- Ethane
- Methane
- TOC

# Results



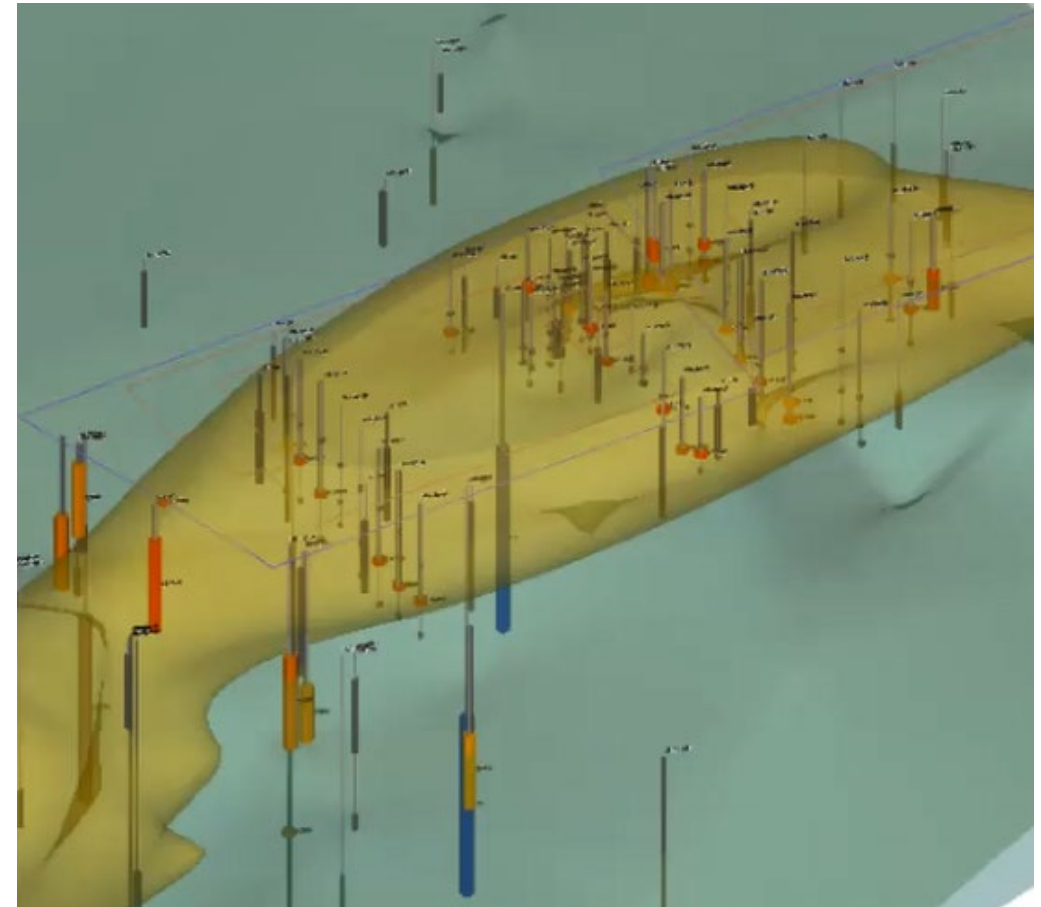
- In three years
  - 86% of wells reduced concentration below site specific cleanup criteria for all COI
  - 47% of wells below CETESB criteria for all COI
  - Mass Flux across CMT transects reduced 83%
  - Mass discharge from P&T system reduced 66%



# Results



- Focused on KBI reducing costs
  - Reduced sampling of electron acceptors, chloride and bromide, CSIA, and qPCR
- KBI Parameter Results
  - TOC increased 3,800% on yearly average concentration
  - Methane increased 4,100% on yearly average concentration
- TOC and Methane present in all wells with degradation
  - ISB operation can be optimized based on reduced KBI parameter list
- Monitoring only KBIs reduces monitoring costs 25%

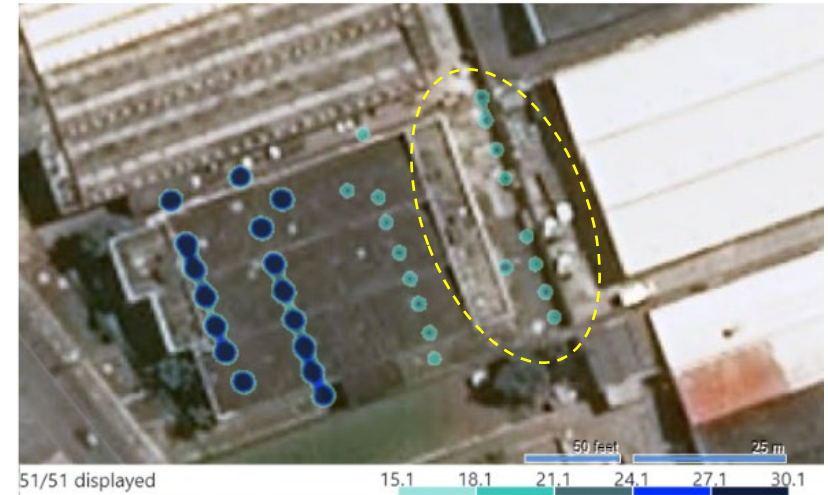


Methane Distribution in the treatment zone – 01/2018  
Shell of 1,000 ug/L – (Haley & Aldrich)

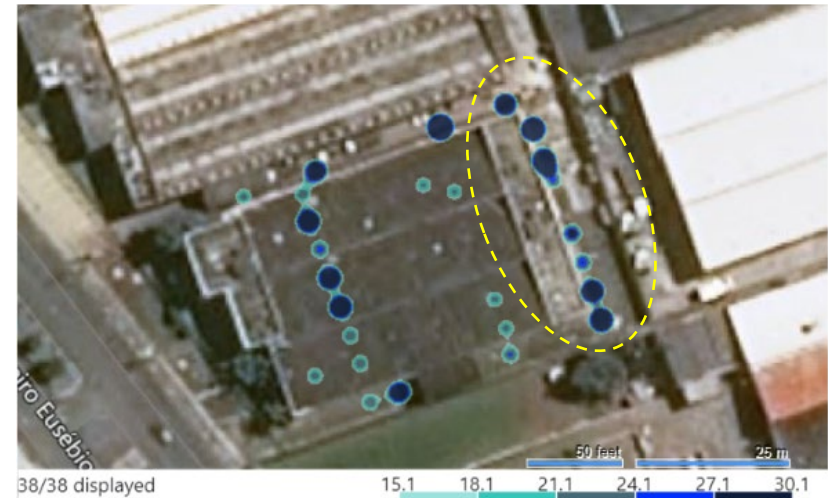
# Lessons Learned



- Challenges:
  - Complex Geology
    - Detailed site characterization to understand the stratigraphy and flow conditions
  - Low pH, but no buffering needed
  - Low cell count but reacted to carbon substrate
  - Heating raised groundwater temperature and accelerated degradation: 5.4°C increment
  - Define ideal lactate injection rates
    - Reach and maintain high TOC and methane concentrations



Baseline Average Temperature 21.7°C

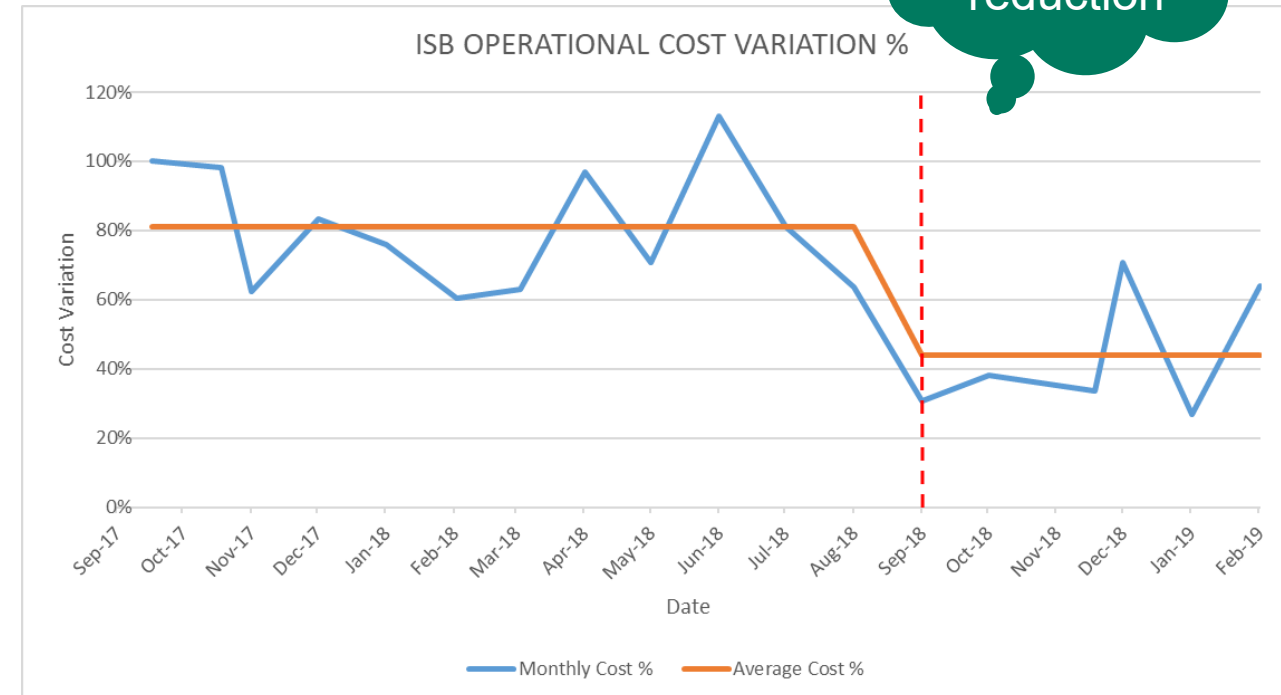


After heating Average Temperature 27.1°C

# Lessons Learned



- Shift system operation in order to reduce costs.
- Monitoring Optimized
  - Only monitor for KBI
    1. COI – PCE, TCE, cis-1,2-DCE VC
    2. DHGs – Ethene, Ethane and Methane
    3. TOC – Total Organic Carbon
    4. Reduced frequency of monitoring based on results
- Injection Schedule
  - Inject based on known decay of TOC and methane (Every 50 days)
  - Shift focus to areas with concentrations still elevated
- Recirculation system operation
  - Modify the recirculation to address areas with poor lactate distribution
  - Recirculation in pulsed operation



# Conclusion



- Although bioremediation is an universal process, it is still site specific
  - Effective for Chlorinated Ethenes remediation
  - Dehalococoides and associated bugs occurs and can be stimulated
- Perform a comprehensive site characterization to
  - Develop a Conceptual Site Model – CSM
  - Understand solution distribution issues
  - Concentrate the efforts on the parameters/indicators that matters and that are cost effective
- System optimization will add enormous value and cost savings
- Big Data vs Long term projects - manage it with the proper tools:
  - Automated operation / Remote control
  - Database
  - Dashboards
  - Visualization Models
  - Mass flux models



# Project Pictures



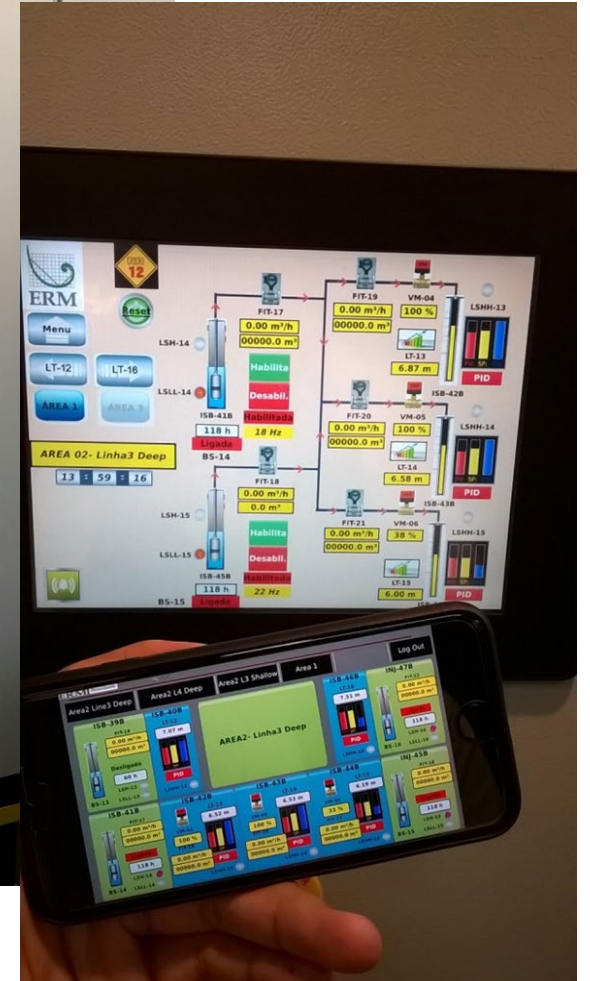
ISB system solution / mixing tanks  
Injection / extraction wells for groundwater recirculation amended with carbon solution



Detail of above ground recirculation wells infrastructure



Automated system control panel





*Manual lactate injection prior to system automation. Really hurry to start “bugging” the site!!!!*

**Thank you**

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**Thanks to the client**  
For the support and profound  
technical debates during the entire  
project.