

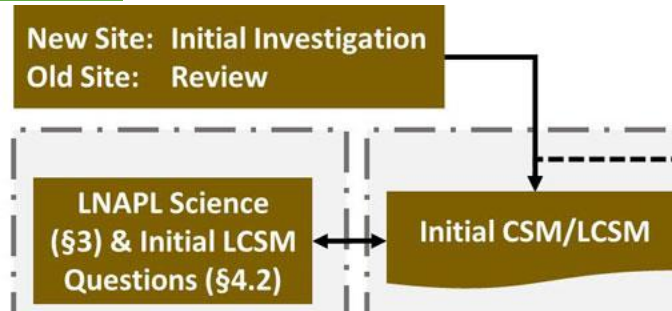


Building a Robust LCSM for Remediation Decision-Making: Next-Generation Tools

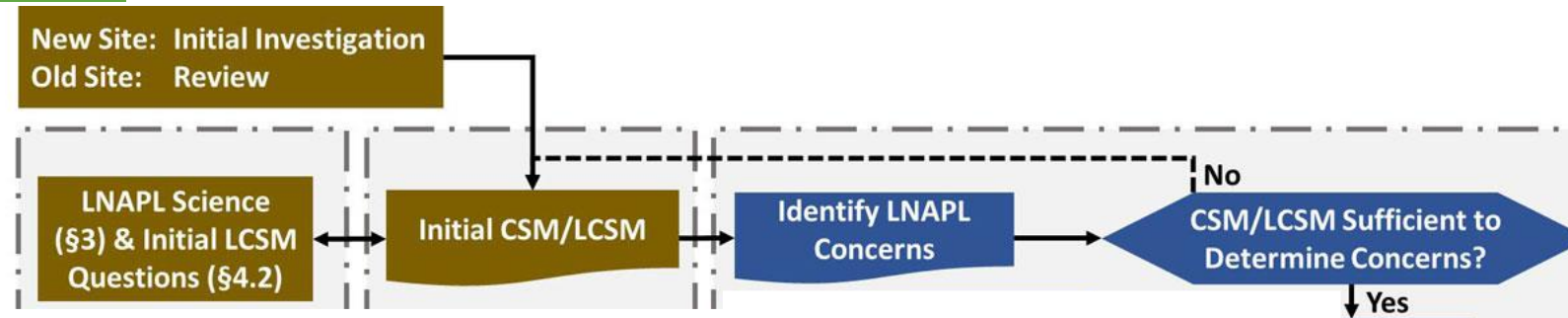
Ecometrix Incorporated

16 October 2025

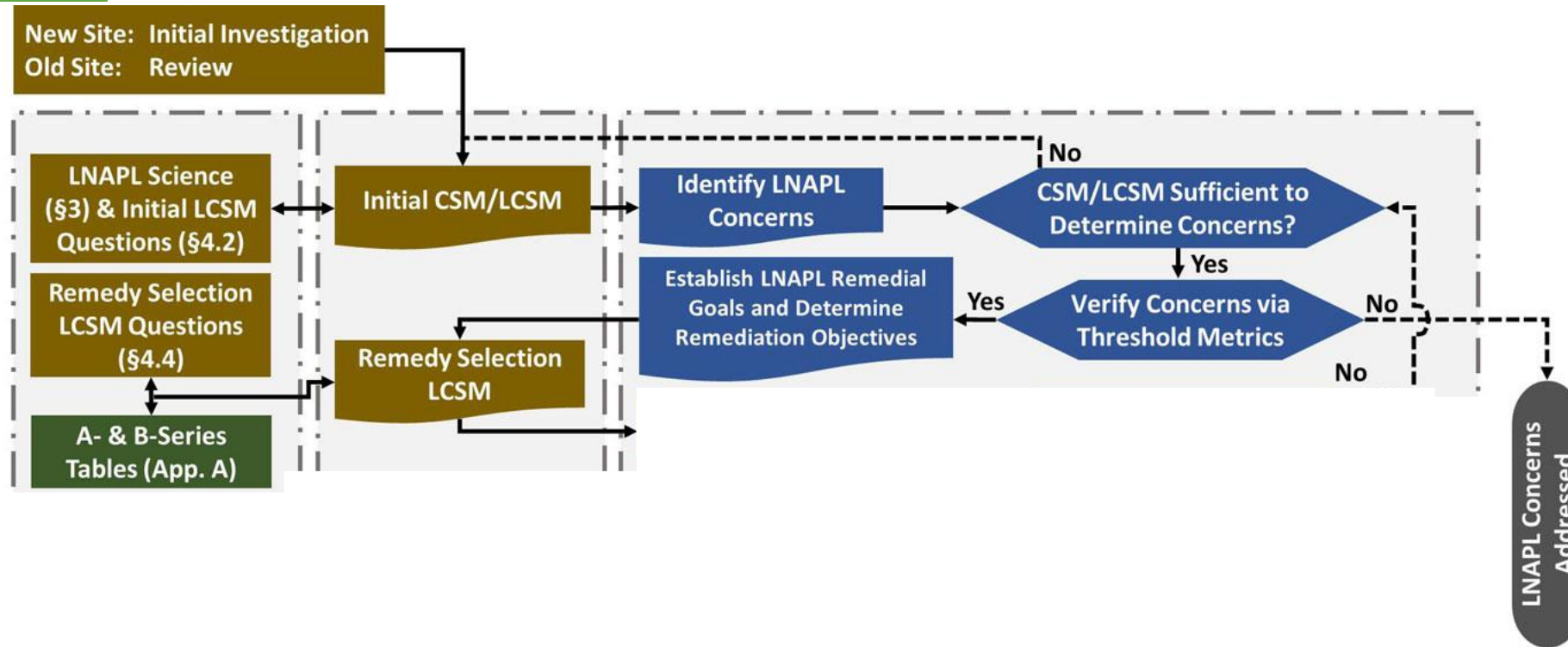
Evolution of the LCSM



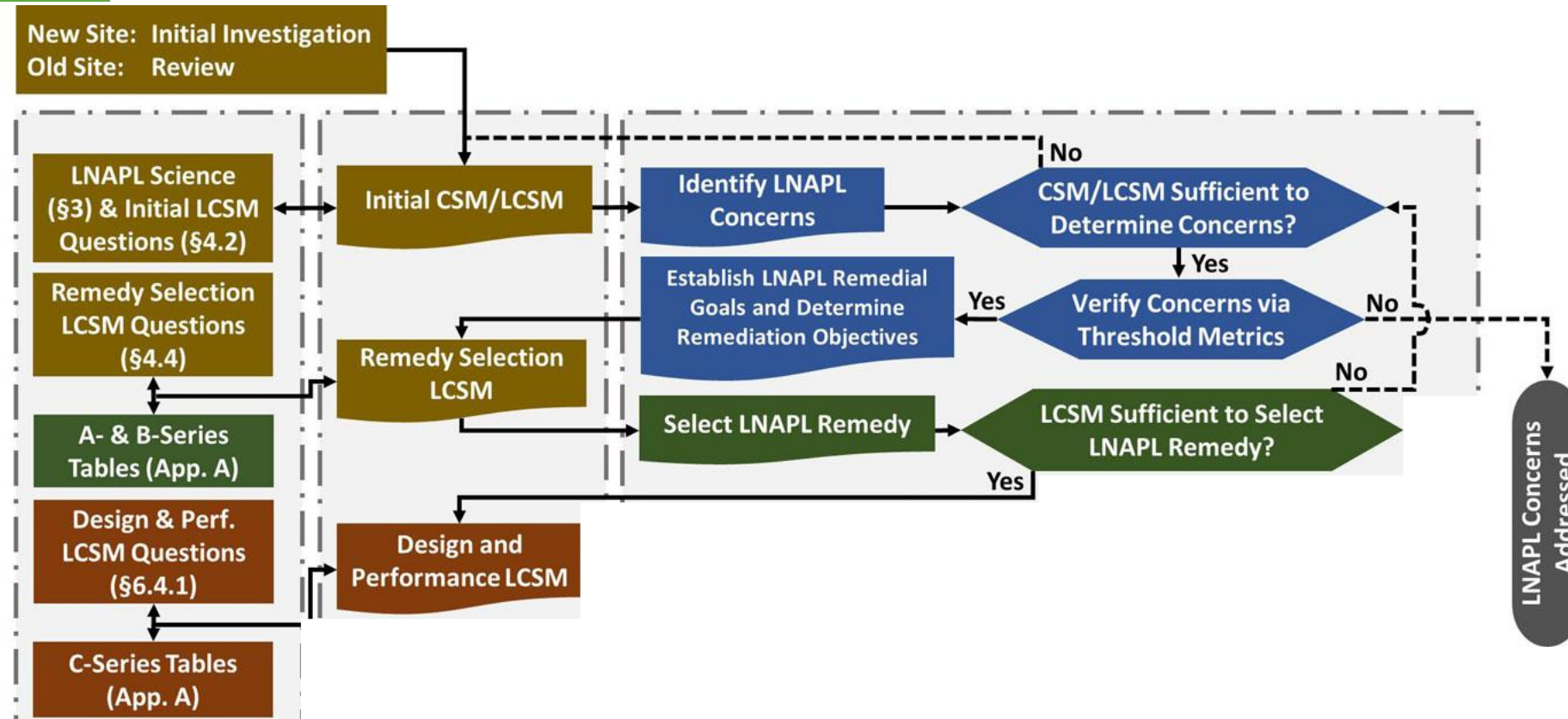
Evolution of the LCSM



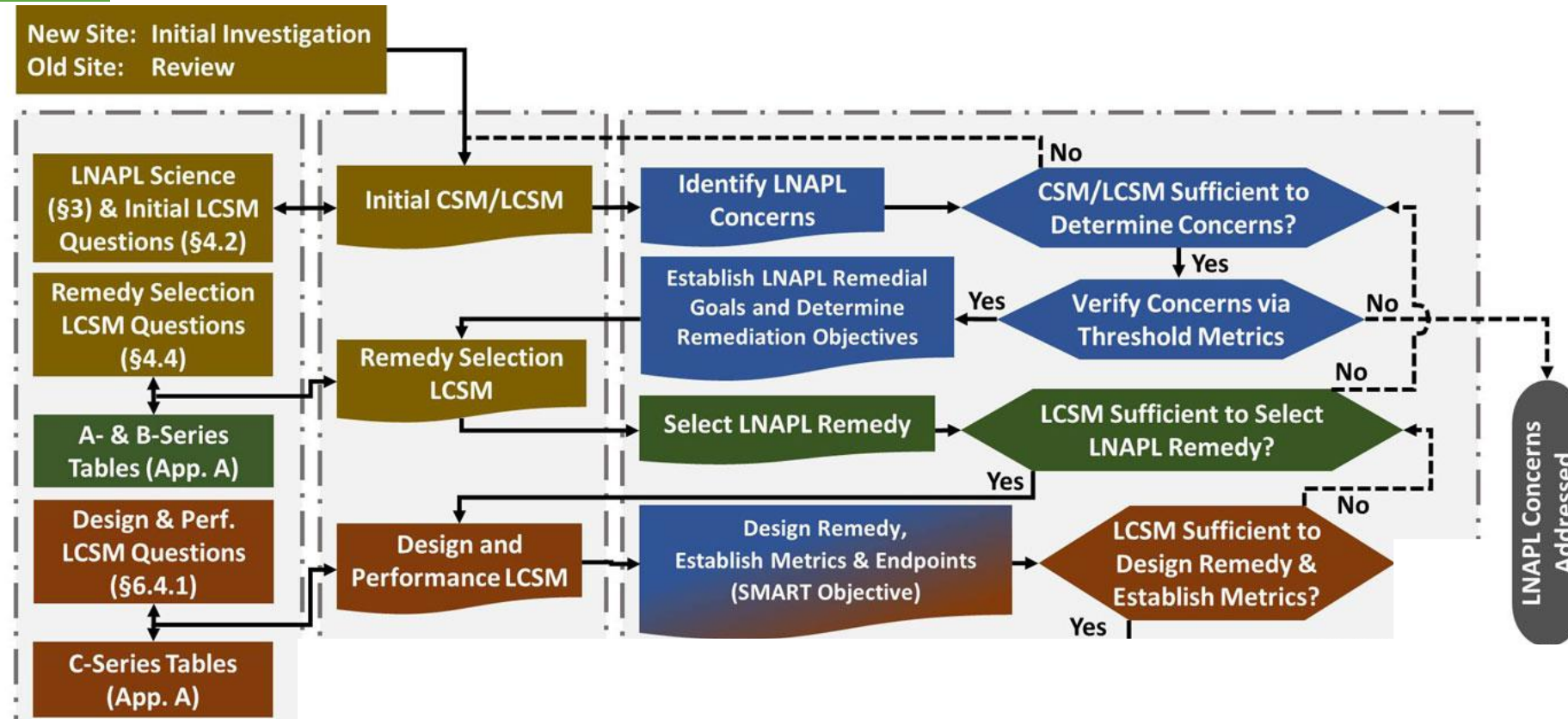
Evolution of the LCSM



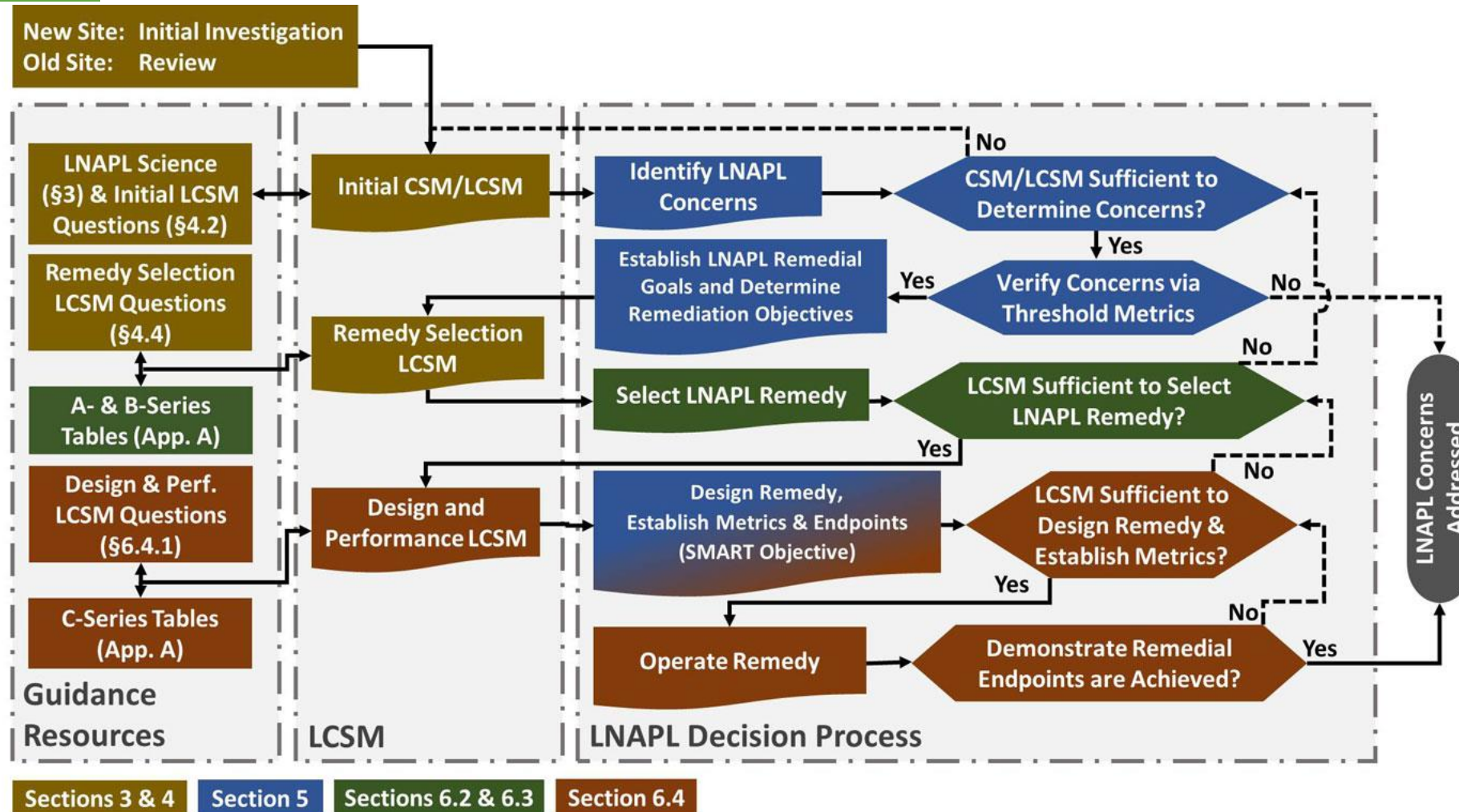
Evolution of the LCSM



Evolution of the LCSM



Evolution of the LCSM



Example of Refining an LCSM

Site Characteristics

- Upper bedrock is Paskapoo Formation
- Aged, complex, and discontinuous LNAPL body
 - Small number of wells where LNAPL is present
- The site has an initial LCSM
- Site managers want to refine the LCSM to support remedy selection

Can we estimate NSZD on a site-wide basis?

Can we refine the hydrogeology?

Is the LNAPL recoverable?

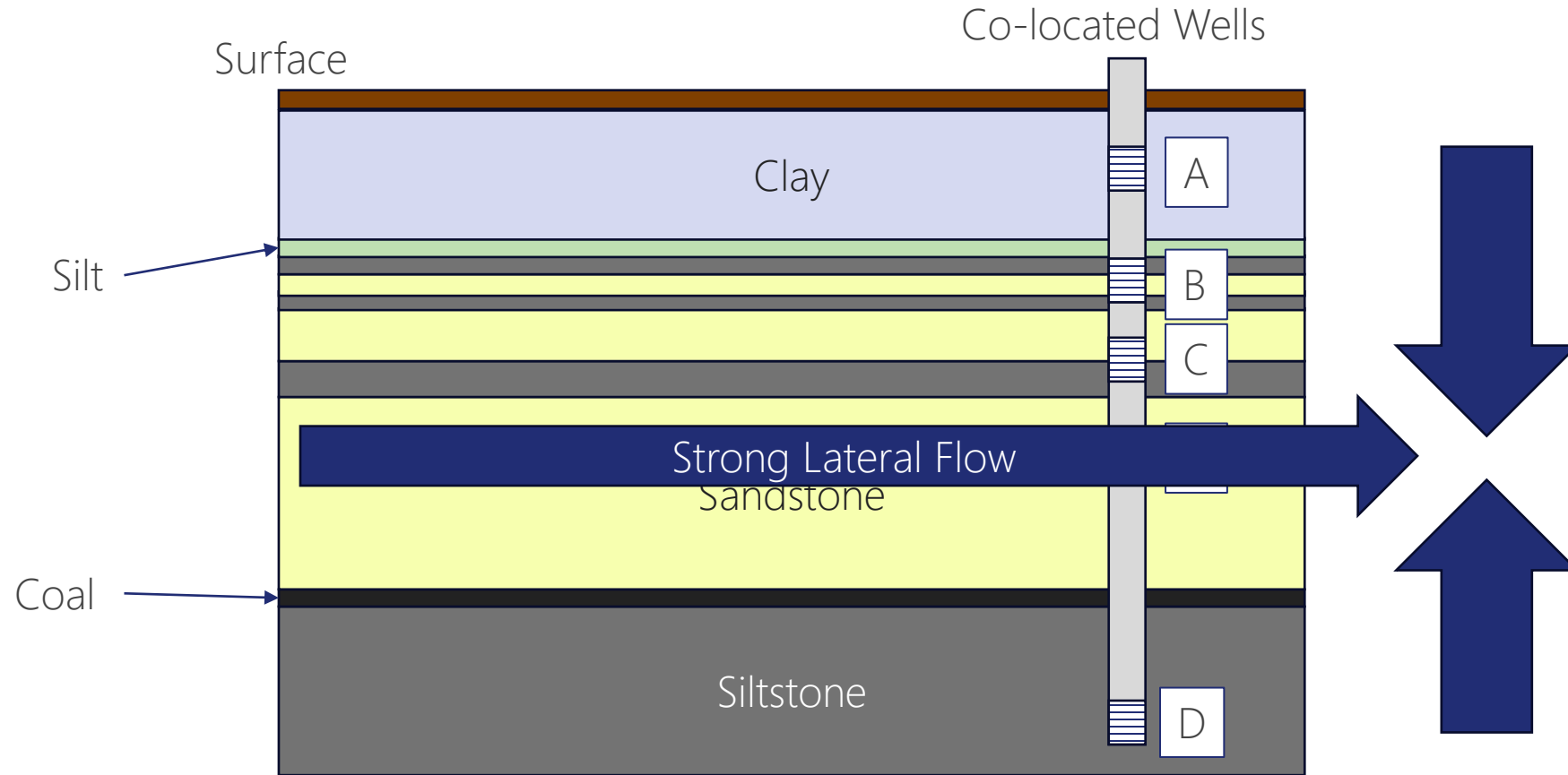
Is our LCSM detailed enough to screen technologies?

Site-specific LCSM Refinement Objectives

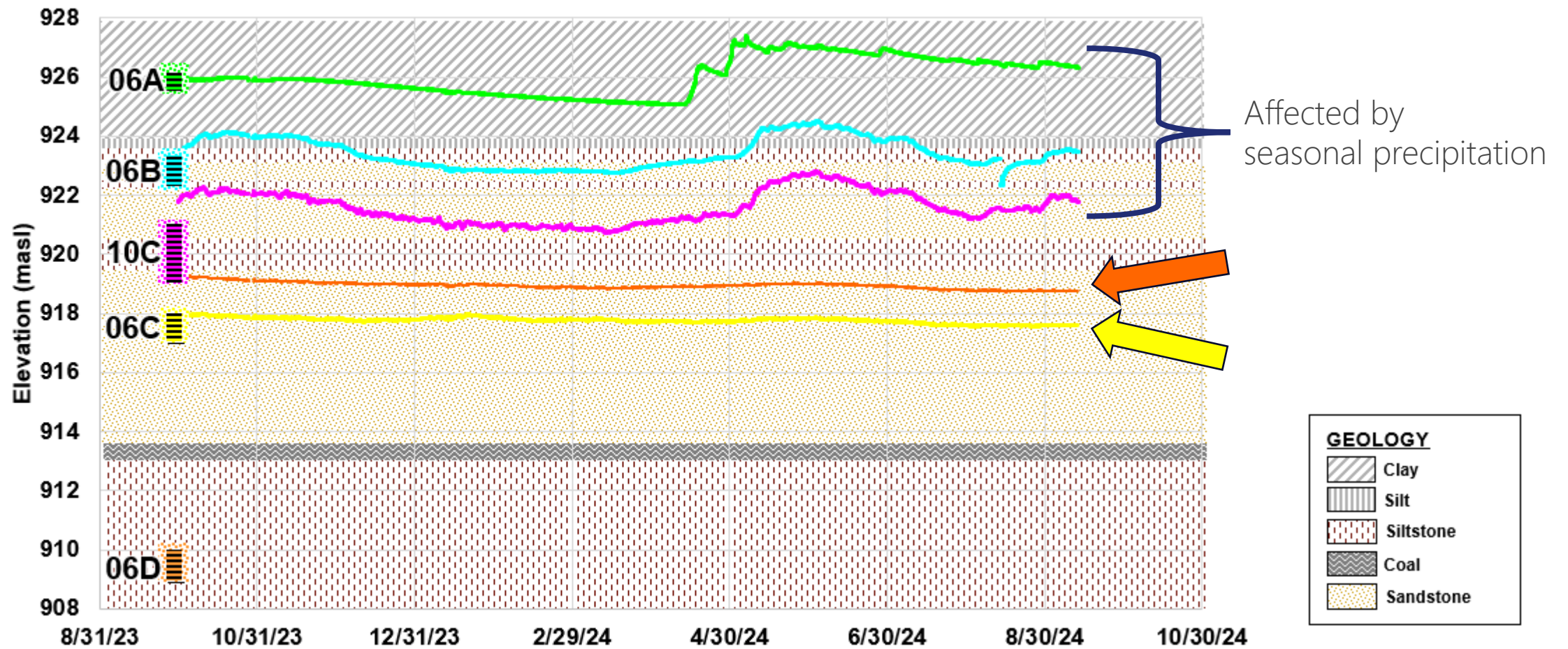
- Develop a process-driven understanding of LNAPL distribution
- Characterize weathering patterns
- Enhance prediction of behavior and future weathering using microbial metrics

Refinement 1: Process-based LNAPL Distribution

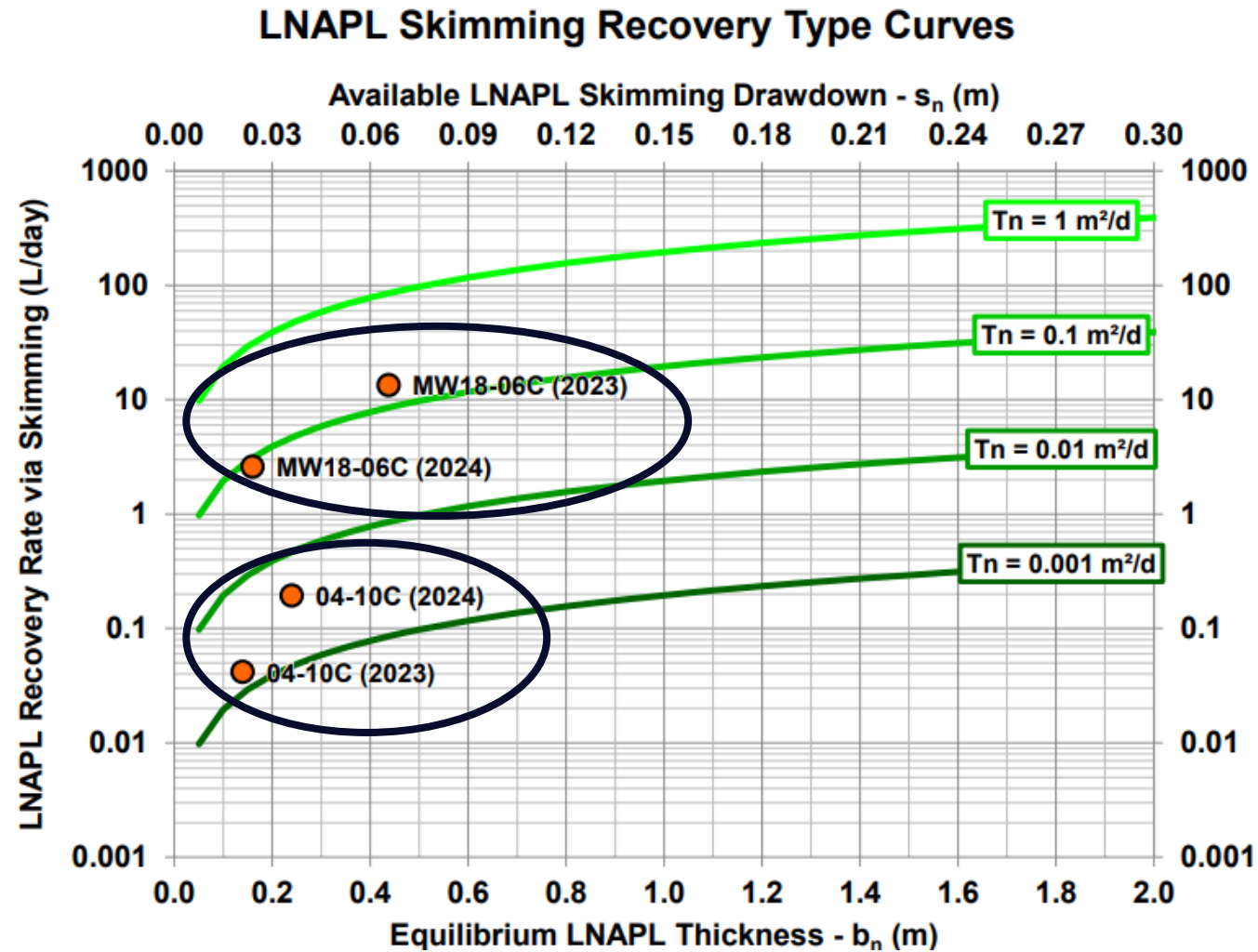
Refining the Hydrogeology



Long-term Water Levels



Transmissivity Testing

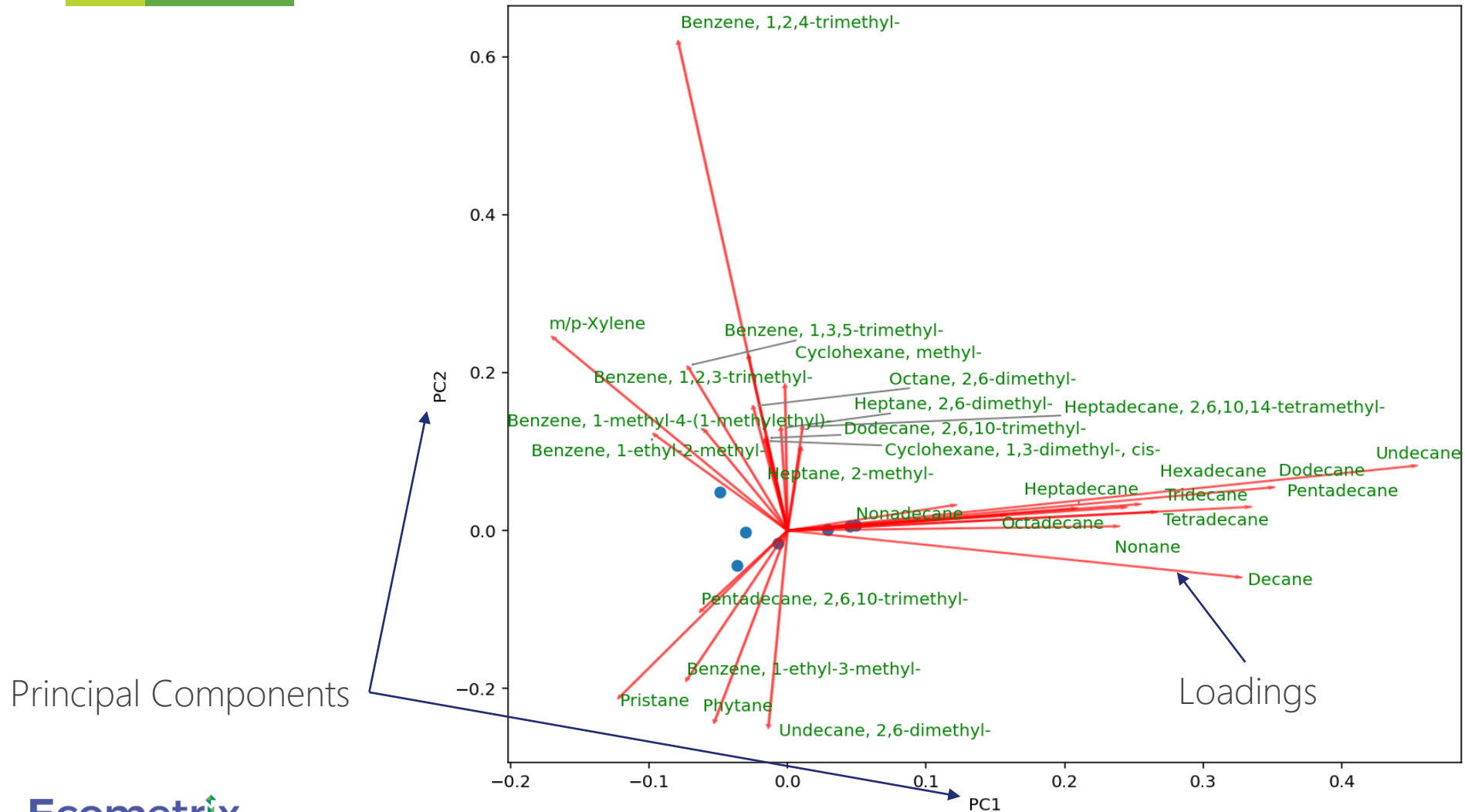


Refinement 2: Characterize Weathering Patterns

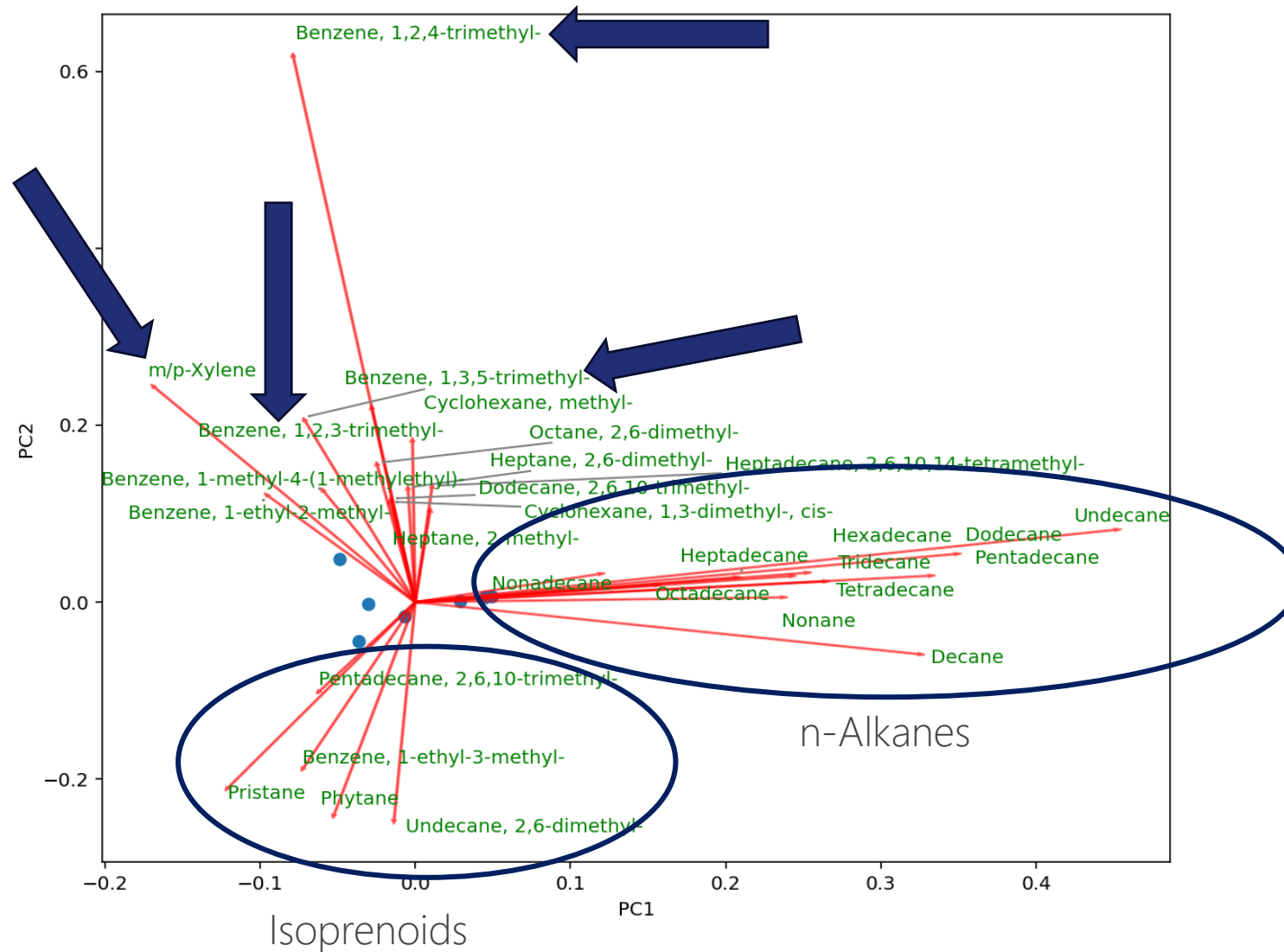
LNAPL Sample Compositional Analysis

- AECOM collected LNAPL samples
- We analyzed them with high-resolution GCMS
- Interpreted compositional differences using Principal Component Analysis (PCA)
- PCA is a statistical technique that simplifies complex datasets

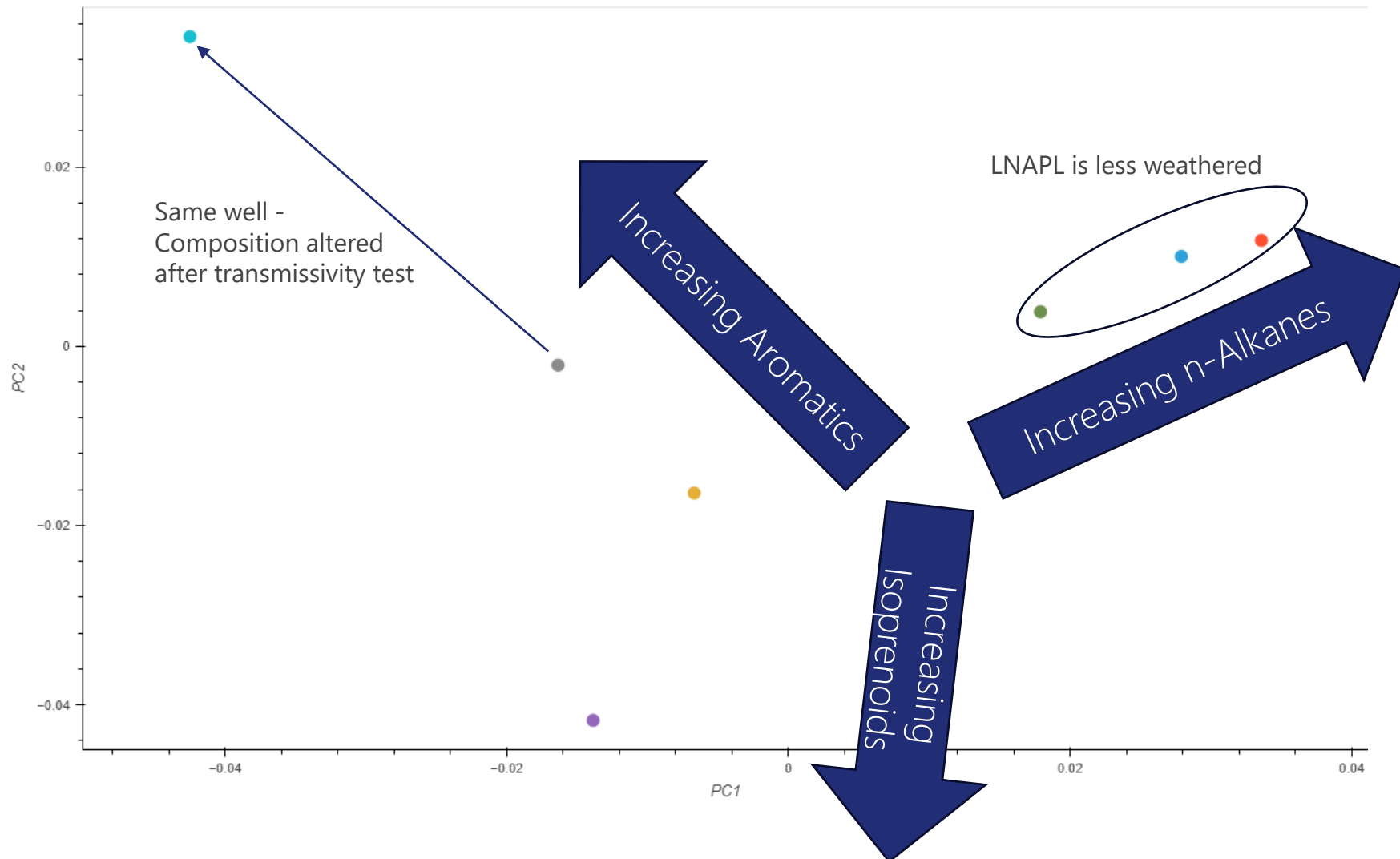
Biplot Visualization



Compositional Analysis

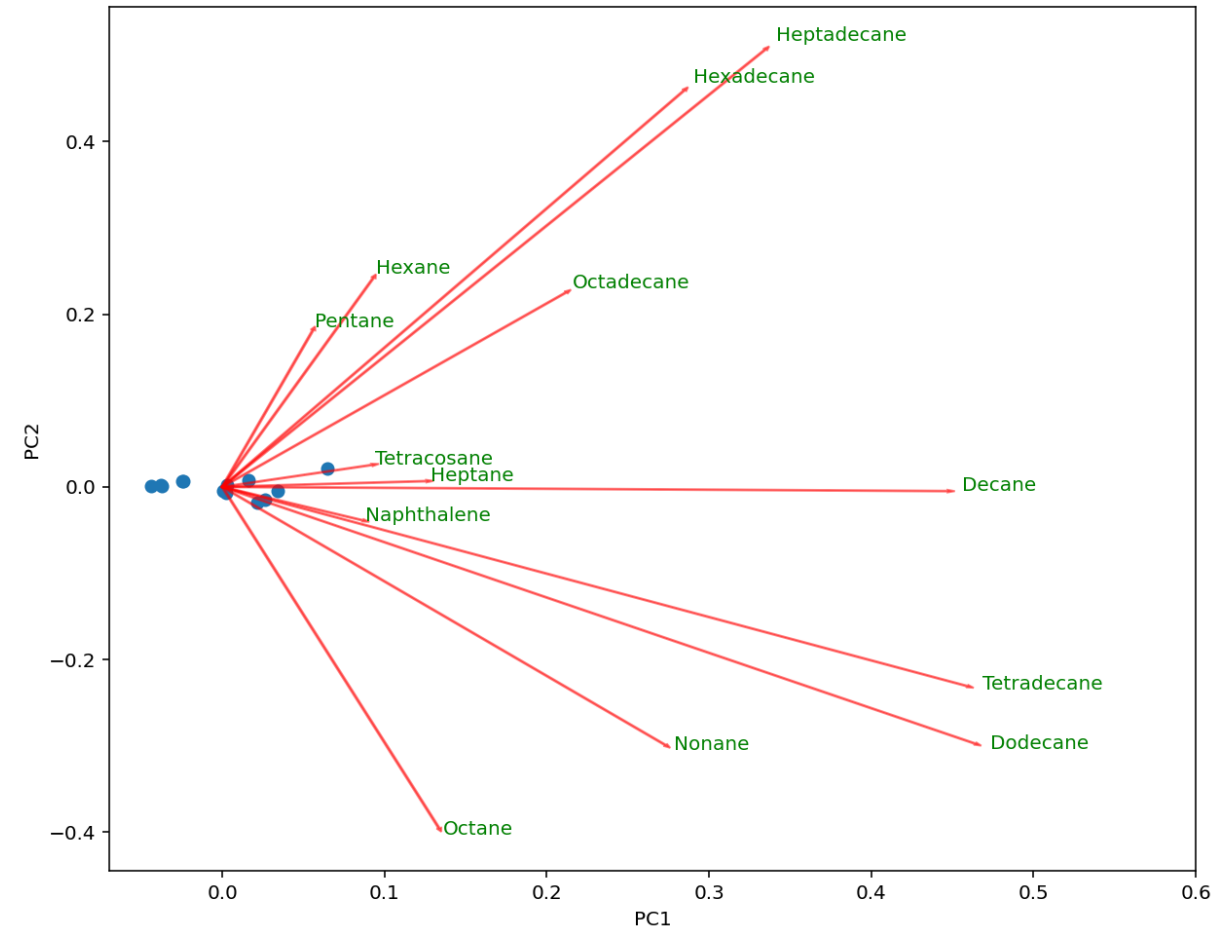


LNAPL Compositional Differences

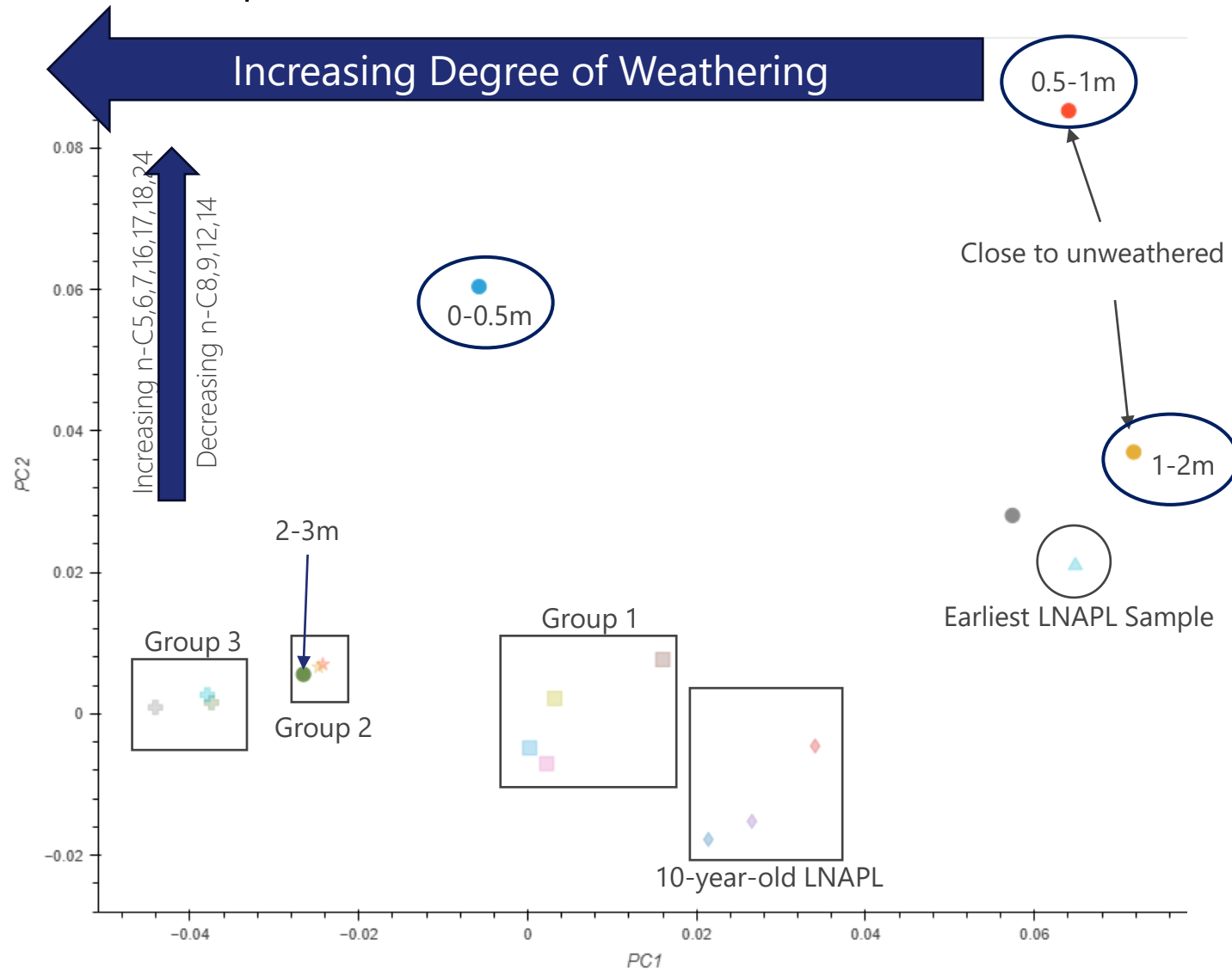


Incorporating Historical Data

- Historical data was available
- But, only for the n-Alkanes
- That's OK!
- Trained a model on that subset
 - Limited to the phase of weathering with n-alkane depletion

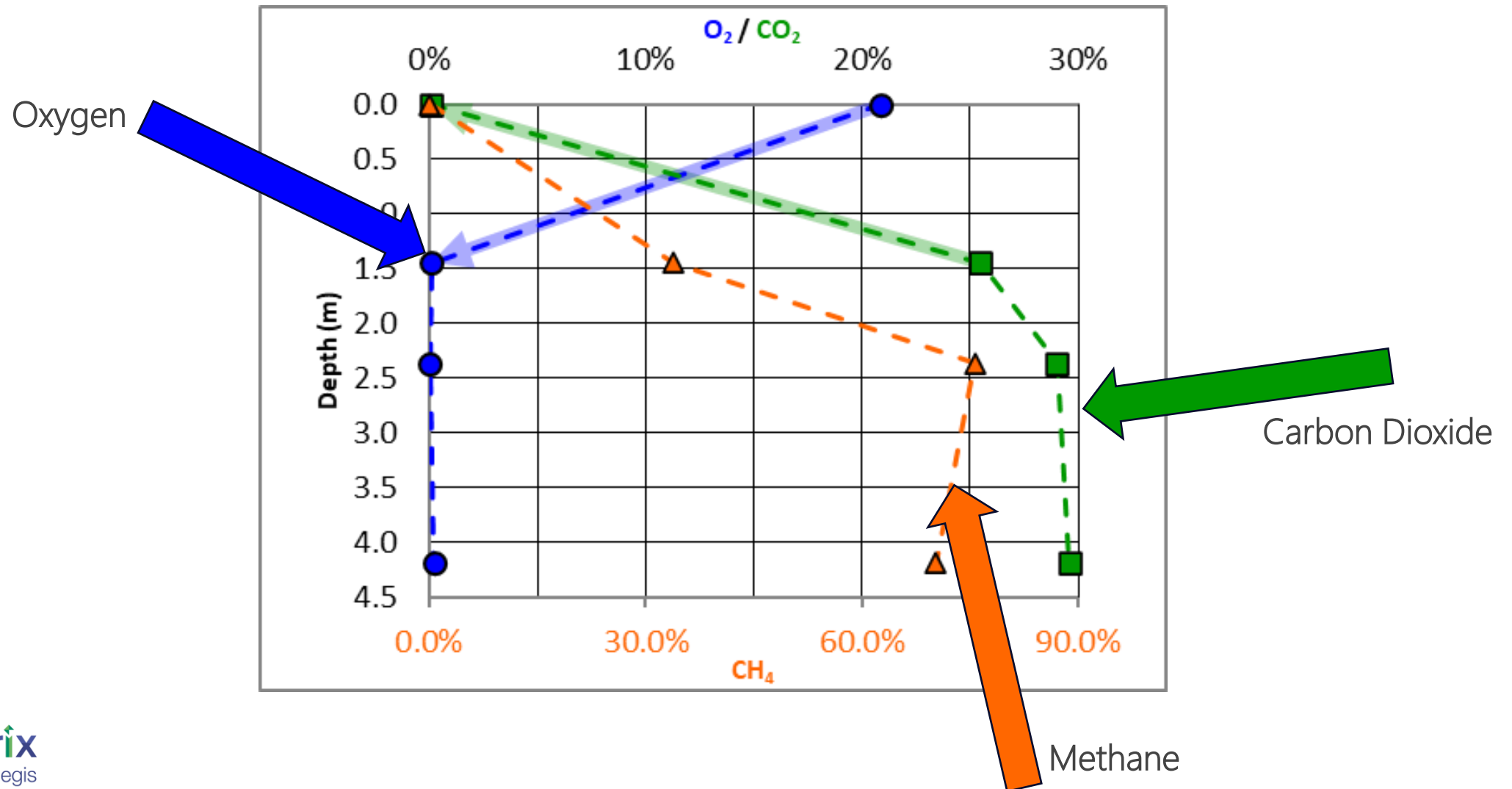


Grouping Soil Samples

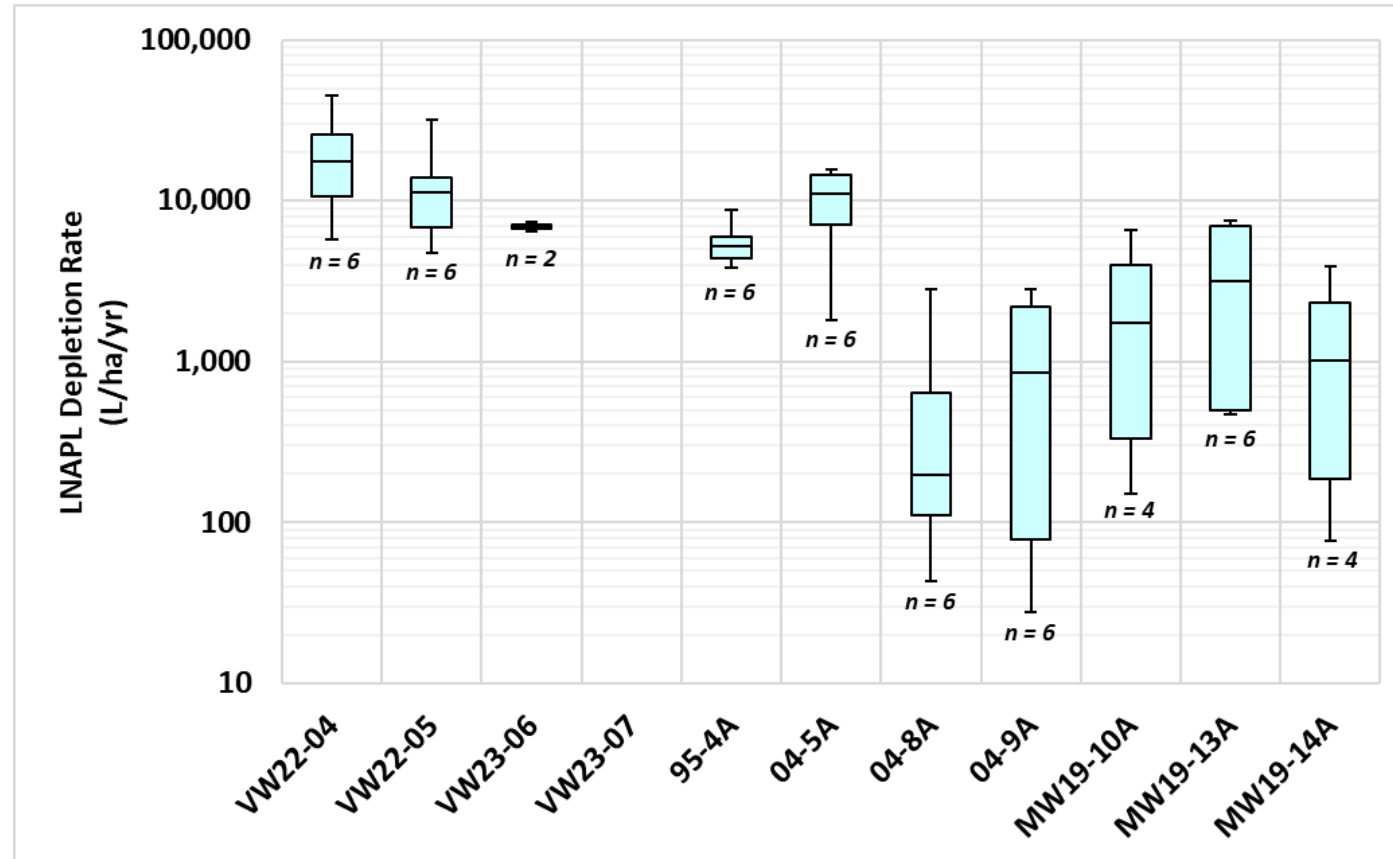


Refinement 3: Enhance Prediction of LNAPL Behavior and Future Weathering using Microbial Metrics

Soil Gas Gradient Measurements



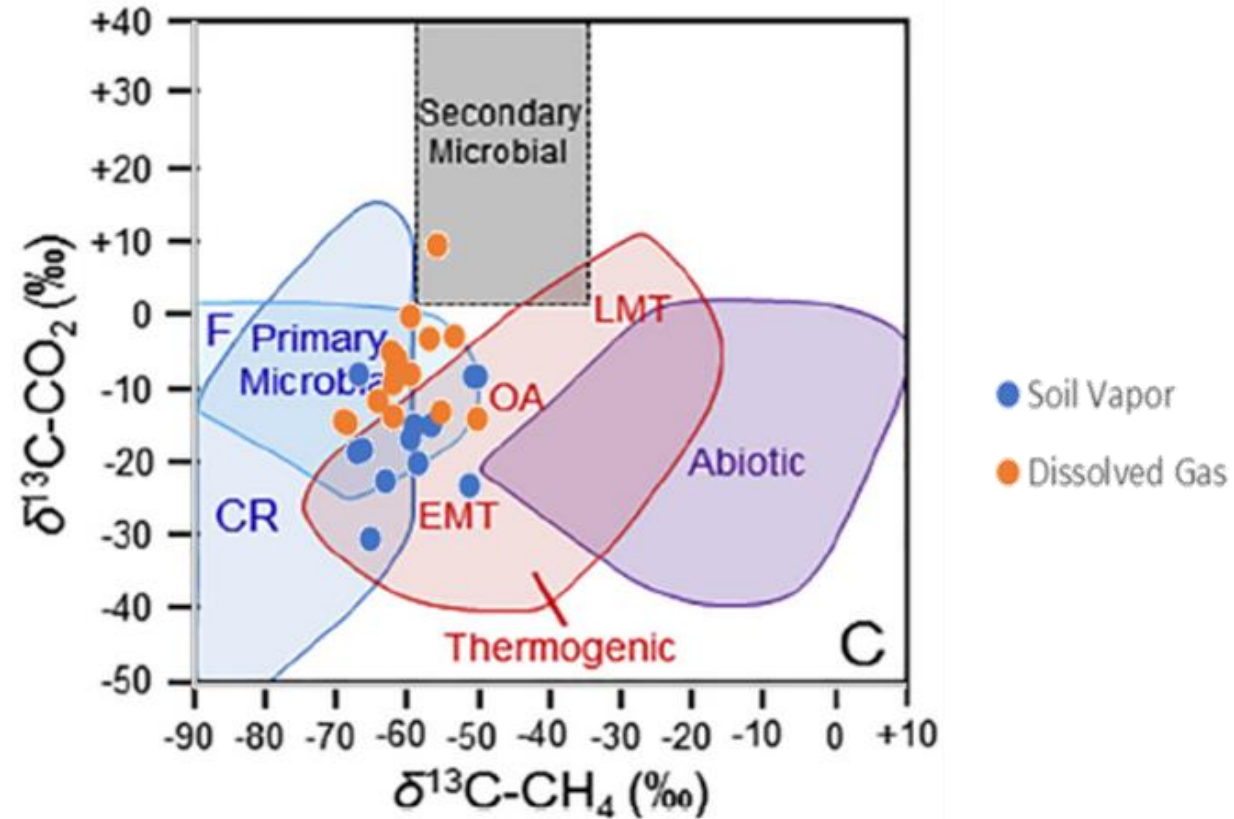
NSZD Rates



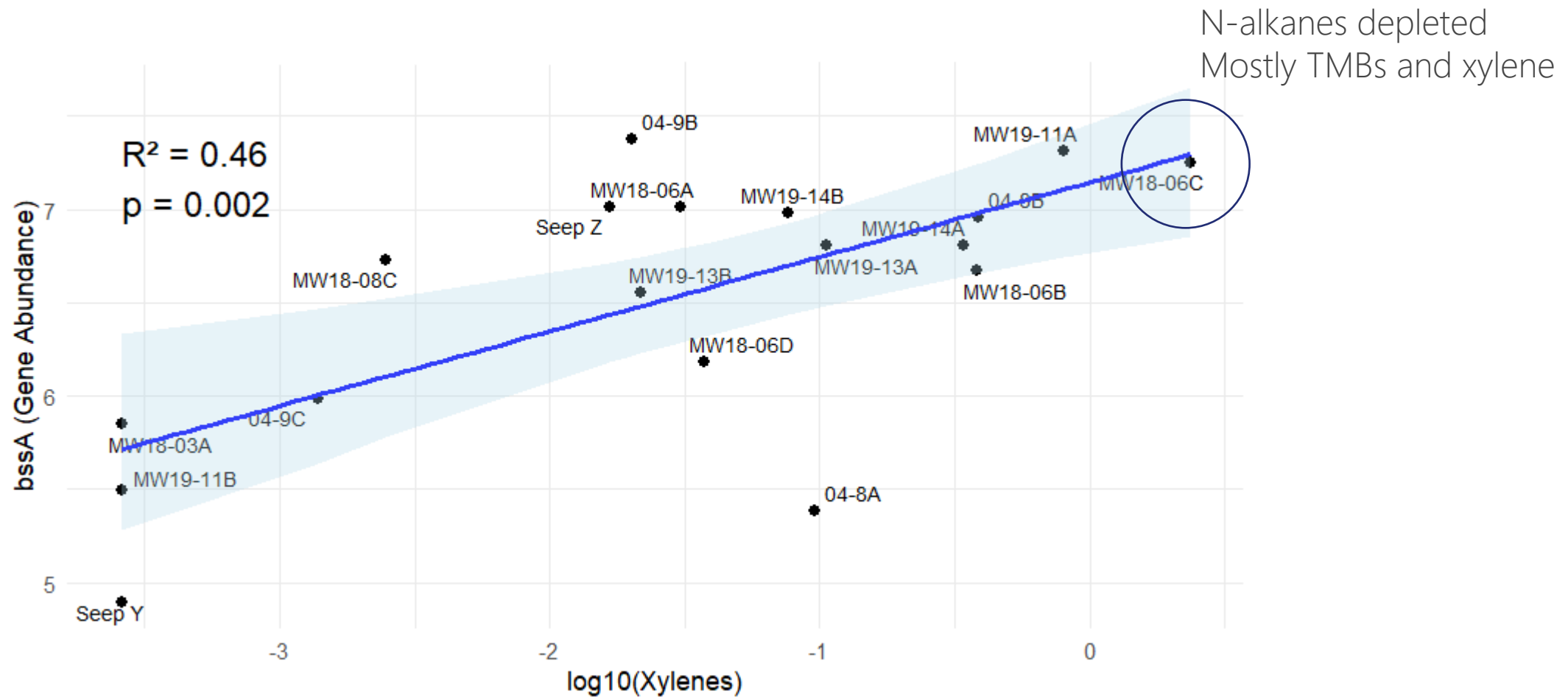
Calculated assuming decane as the contaminant

Assumed processes:
Methogenesis
Aerobic oxidation of methane
Direct aerobic oxidation

Isotope Fractionation Evidence



Microbial Metrics: Functional Gene Correlations



Multiple Lines of Evidence for NSZD

- Compositional analysis identifies how the LNAPL varies chemically
 - It weathers heterogeneously across the site
- Gas gradients suggest that NSZD due to bioremediation is occurring
 - Also estimated bulk rates of depletion
- Isotope fractionation suggests that biodegradation is the source of the carbon dioxide and methane
- Microbial metrics are providing evidence as to what members of the microbial community are contributing to NSZD
 - Community sequencing and additional metrics continue to be investigated

How is this Changing our LCSM?

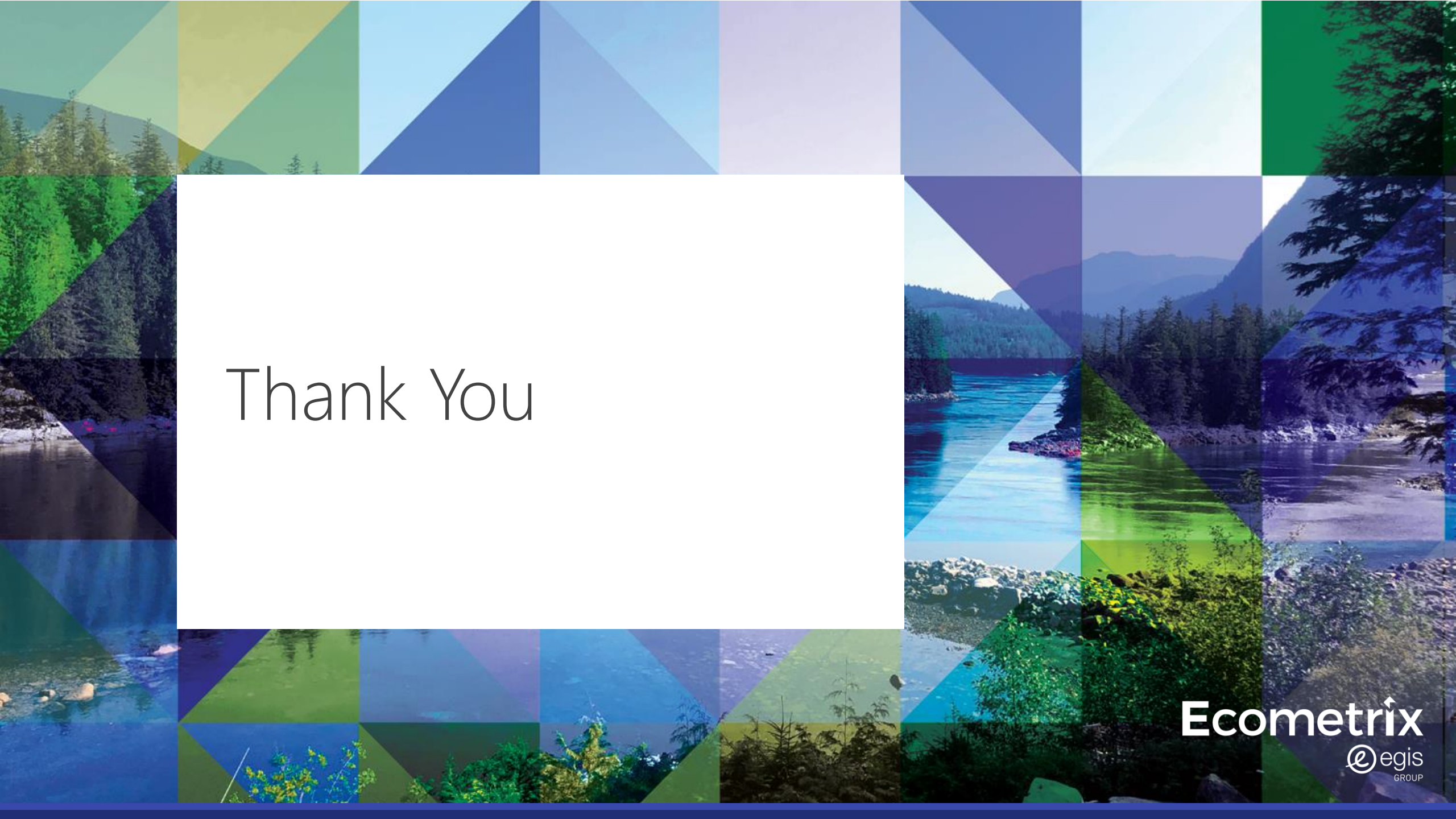
- Refining our understanding of the hydrogeologic conditions
- Updated model of how the LNAPL is weathering across the site
- Multiple lines of evidence helping establish NSZD rates for baseline comparison
- Gaps in the data that are critical to remedy selection for the site are being closed

Summary of Next-Generation Tools

Tool	What Does it Offer the LCSM?	How are we Using it?
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Key Takeaways

- The LCSM is a living document that should be refined over the project lifecycle
- LNAPL evolution over time is controlled by many interrelated local factors
 - Matrix properties
 - Hydrogeological conditions
 - NSZD
- High-resolution, advanced approaches can significantly improve the LCSM refinement process
- Advanced chemical and microbial techniques are powerful tools to help refine the LCSM for remedy selection



Thank You

Agenda



- Objectives
- Building a Robust LCSM (Go for images and work from ITRC)
- Example of Updating an LCSM

Evidence for Biodegradation

- DNA
- CSIA

Understanding the LNAPL Nature

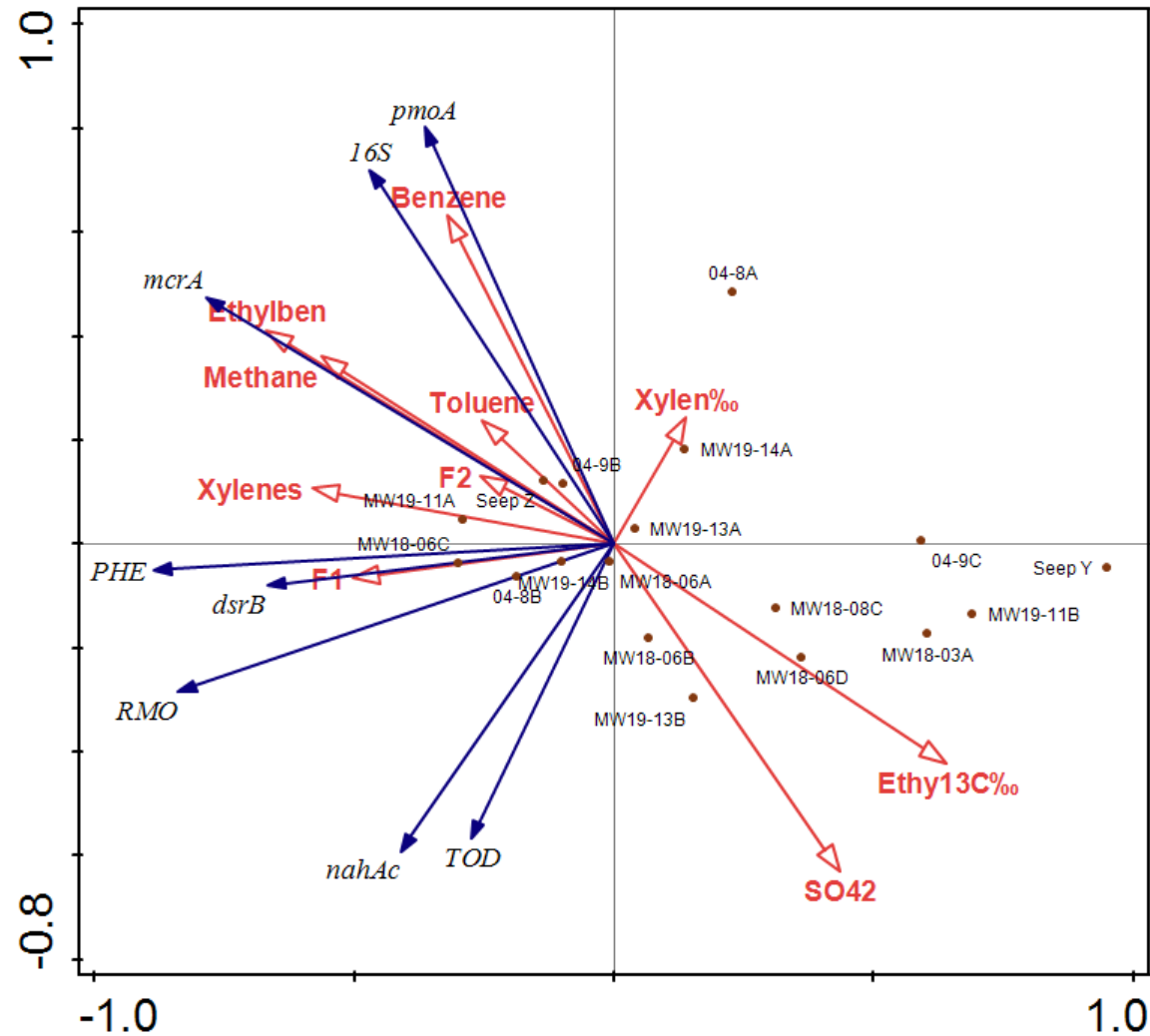
- Downward gradients at the site
- Upward gradient from the D zone
- Persistence of the NAPL
- Transmissivity of the units

LNAPL Persistence

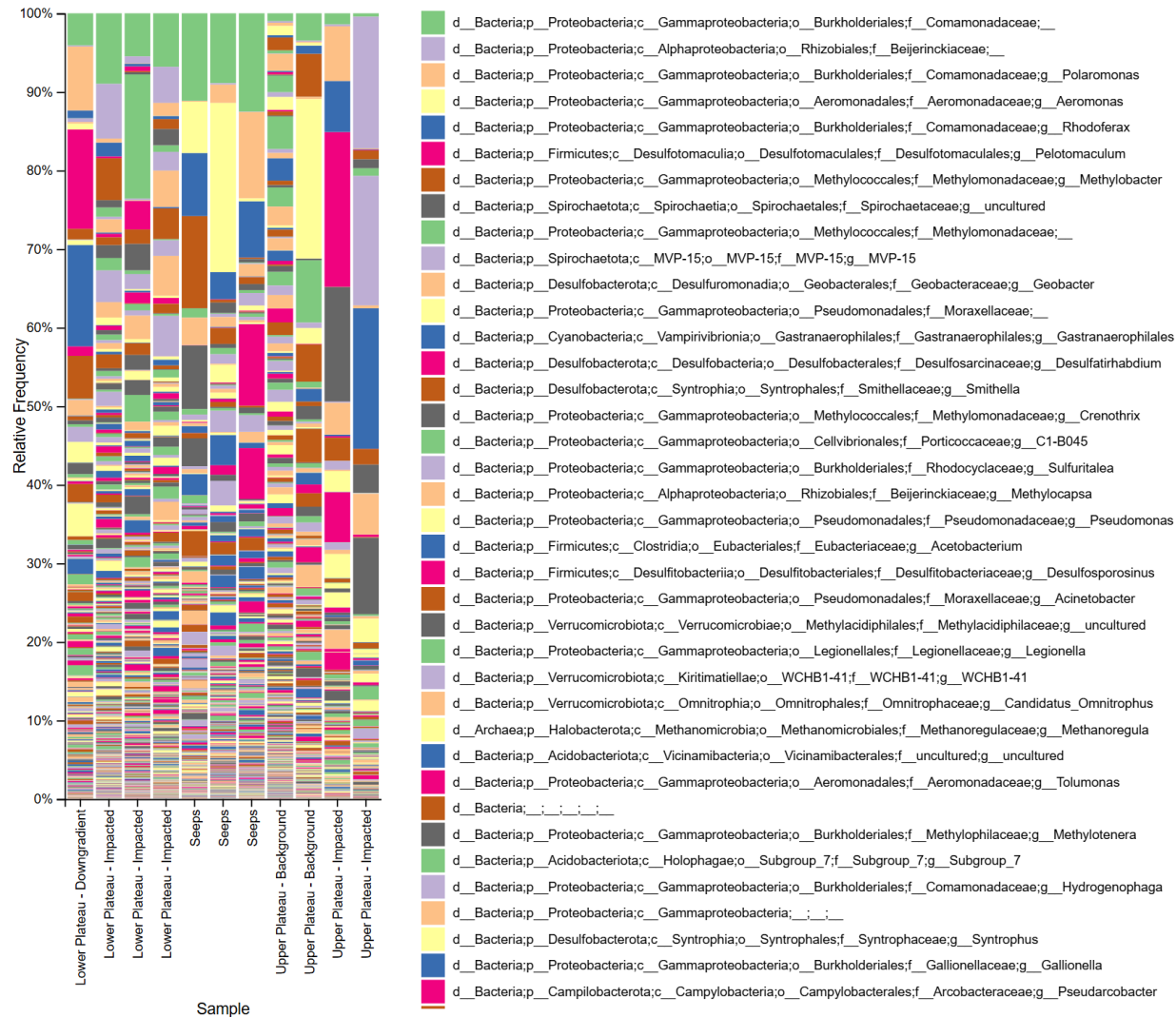
- LNAPL is consistently found in a small number of monitoring wells
- LNAPL
- How much could be removed hydraulically?

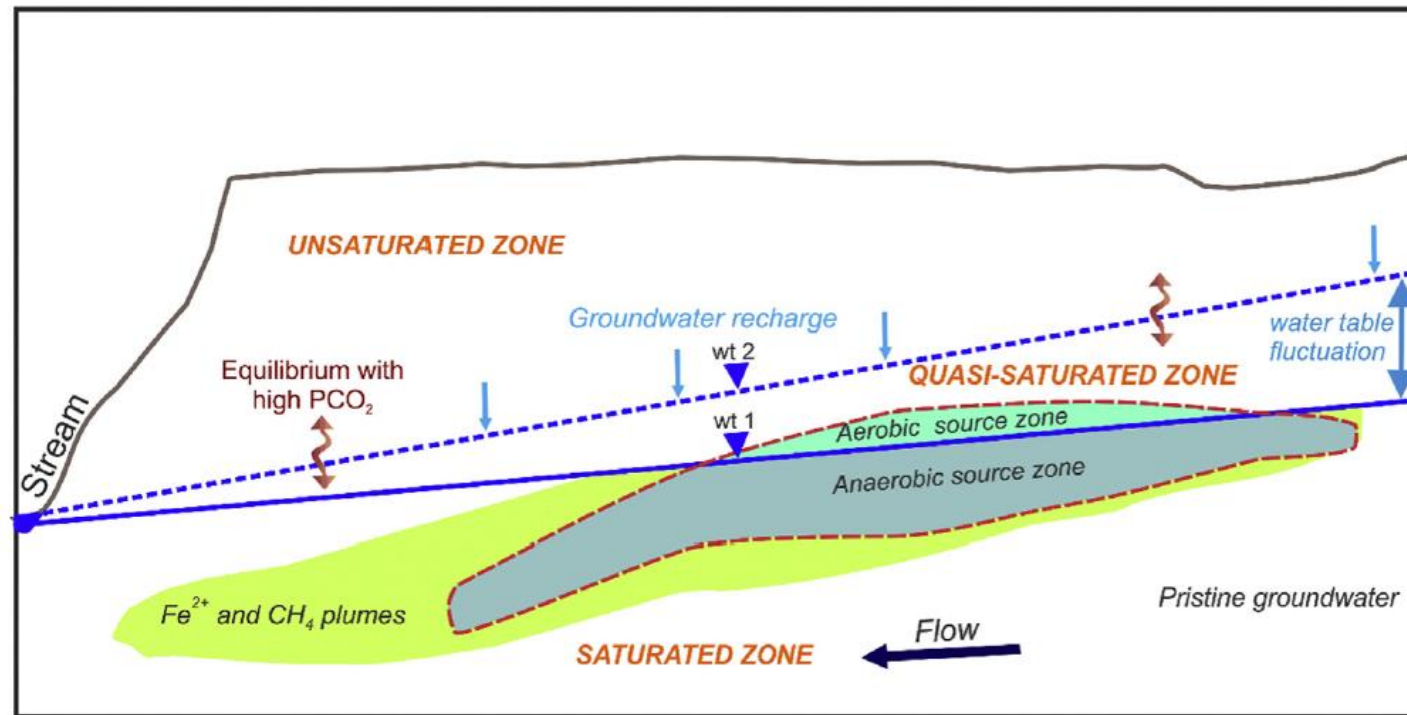


Functional Gene Analysis



Groundwater Microbial Diversity





PRISTINE GROUNDWATER

- Low mineralization in response to low residence time of groundwater and aquifer mineralogy simplicity, pH below 5 in response to equilibrium with high PCO_2 (Teramoto & Chang, 2019).

SOURCE ZONE

- Aerobic zone - the water table rise promotes the air entrapment and aquifer oxygenation. The oxygen is provided by diffusion of entrapped air. BTEX biodegradation is mediated by member of *Moraxellaceae* family (Hidalgo et al., 2019).
- Anaerobic zone - anoxic zone, where the biodegradation is mainly mineralized by iron reduction and methanogenesis. The bacterial community is composed of *Propionibacteriaceae*, *Enterobacteriaceae*, *Geobacteriaceae* and *Peptococcaceae* (Hidalgo et al., 2019). High concentration of Fe^{2+} , HCO_3^- and CH_4 associated to pH ranging from 5.5 to 6.2 (Teramoto & Chang, 2019).

Fe^{2+} AND CH_4 PLUMES

- Mainly oxidant and very low BTEX concentration. Moderated to low concentration of Fe(II) and methane produced during the hydrocarbon biodegradation. pH and alkalinity higher than pristine groundwater

Fig. 10. Simplified cross-section of the conceptual model showing the distribution of biogeochemical zones, defined by geochemistry, microbiology and isotopic data.

BTEX Fractionation in Groundwater

