 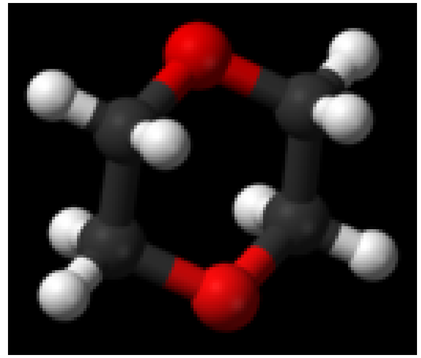 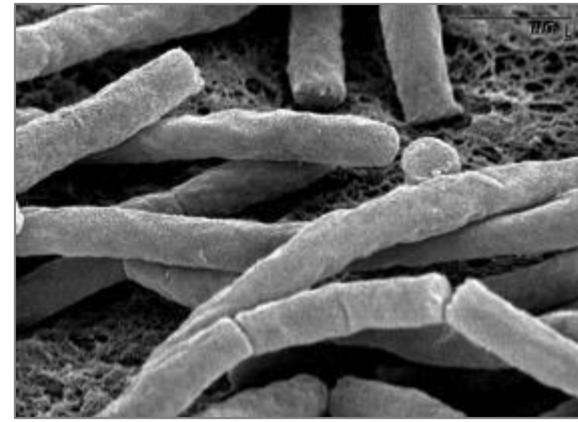

Evaluation and Enhancement of Intrinsic 1,4-Dioxane Biodegradation

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2017 Battelle Symposium on Bioremediation and Sustainable Environmental Technologies

Study Objective

- Evaluate the potential for intrinsic, *in situ* biodegradation of 1,4-dioxane using a multiple lines of evidence (MLOE) framework

Traditional Analyses

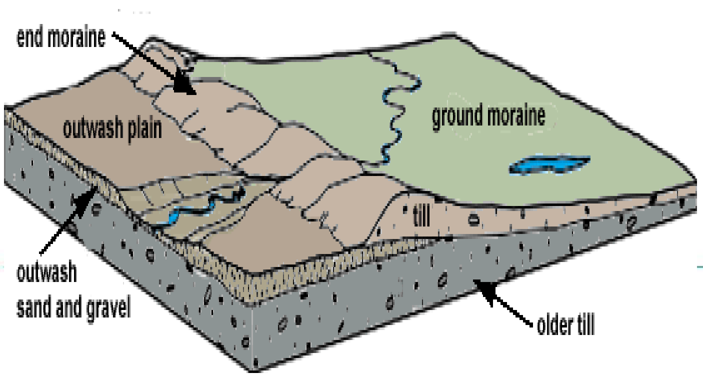
- Temporal and spatial data trends
- Geochemical indicator parameters
- Source and plume mass estimates
- Numeral fate and transport plume modeling

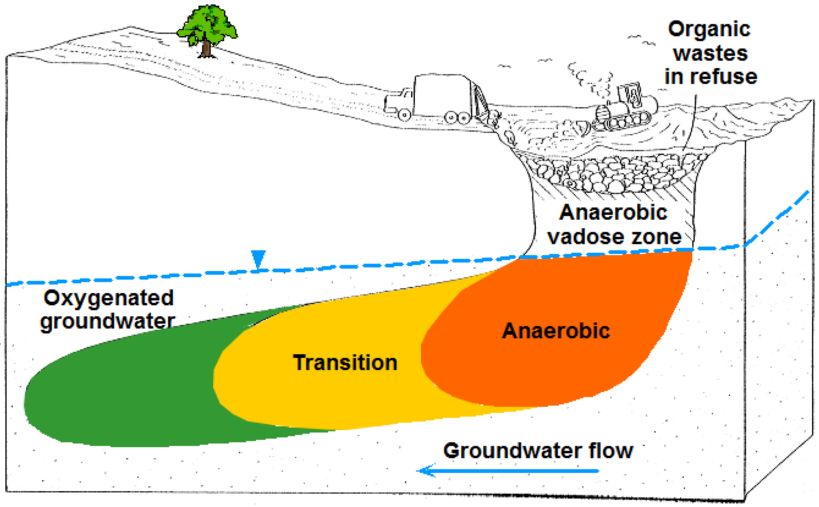
Molecular Analyses

- Nucleic acid-based biomarkers
- Microcosms
- Isolate 1,4-dioxane-degrading bacteria
- Compound-specific isotope analysis (CSIA)

Site History

- Former municipal and industrial landfill (1968 – 1979)
- Underlain by thick glacial outwash deposits (sands and gravels interbedded with till and lacustrine clay)
- Aquifer(s) are unconfined to semi-confined with average advective flow ~1 ft/day

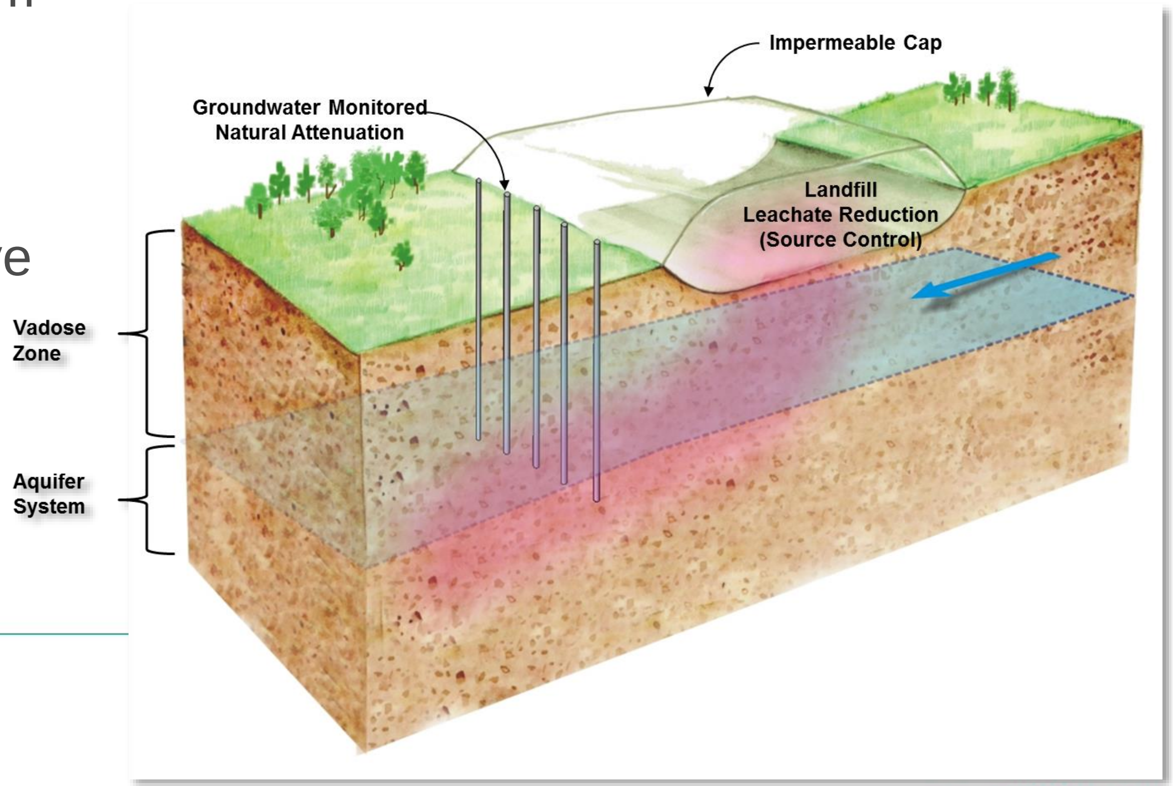




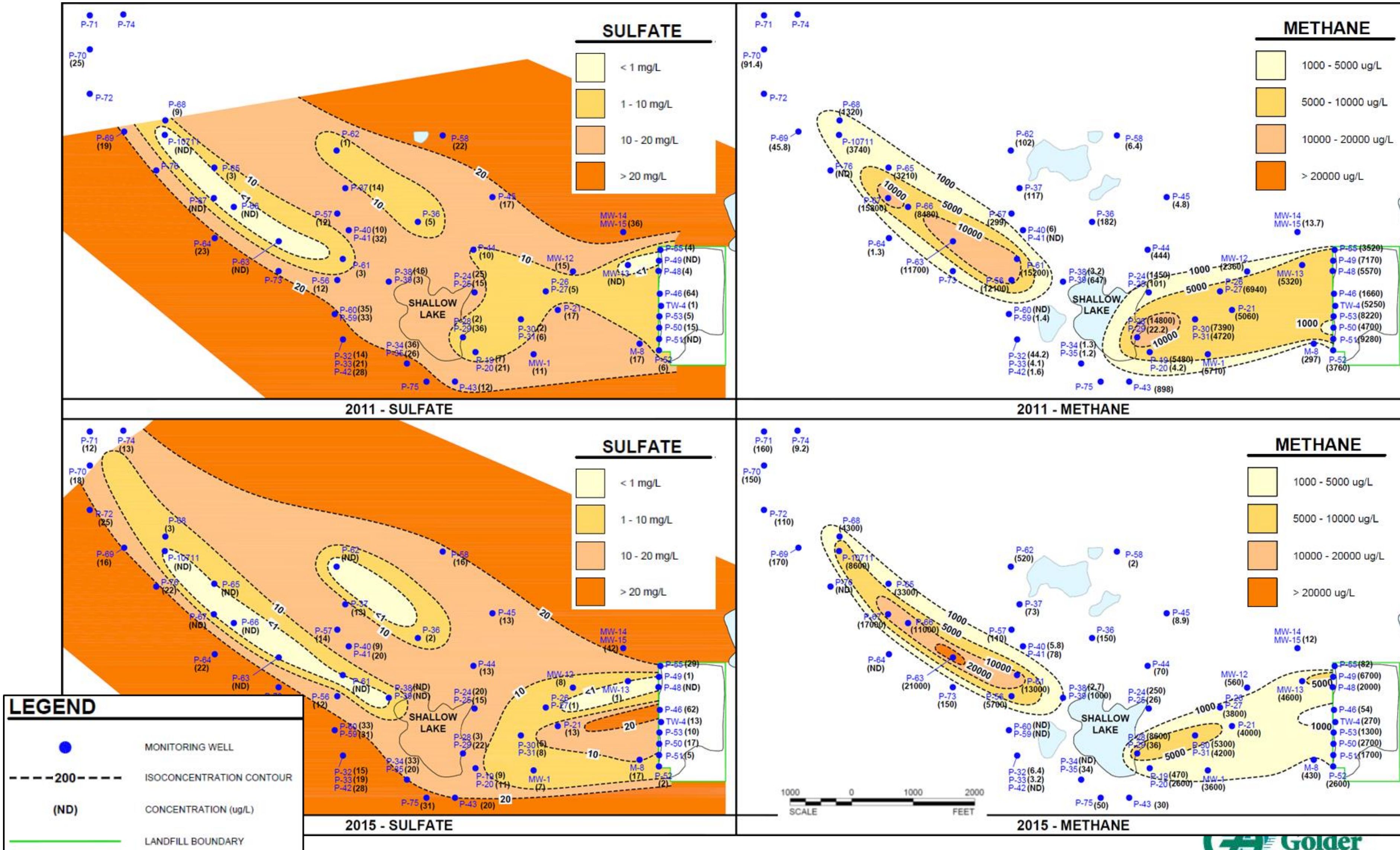
Conceptual Site Model

- Large, dilute plume comprised of 1,4-dioxane (up to 420 µg/L) and tetrahydrofuran ([THF] up to 340 µg/L)
- Main plume is 90 – 150 feet thick thinning to <50 feet beyond ~10,000 feet downgradient

- Source control- Low-perm cap with active gas collection
- Long-term groundwater monitoring from extensive well network



Shifting Geochemical Conditions – Enhancing Biodegradation



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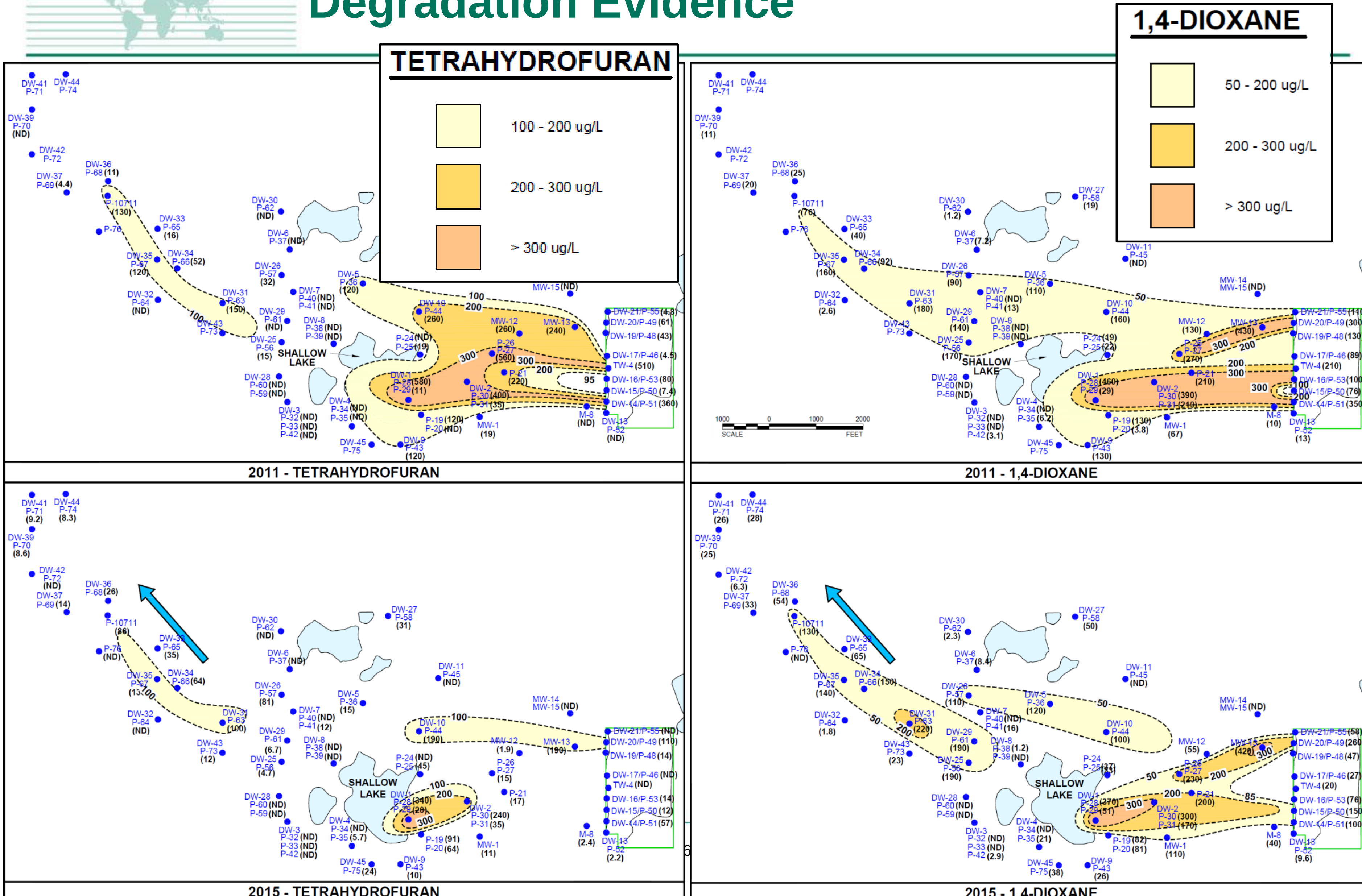
Degradation Evidence

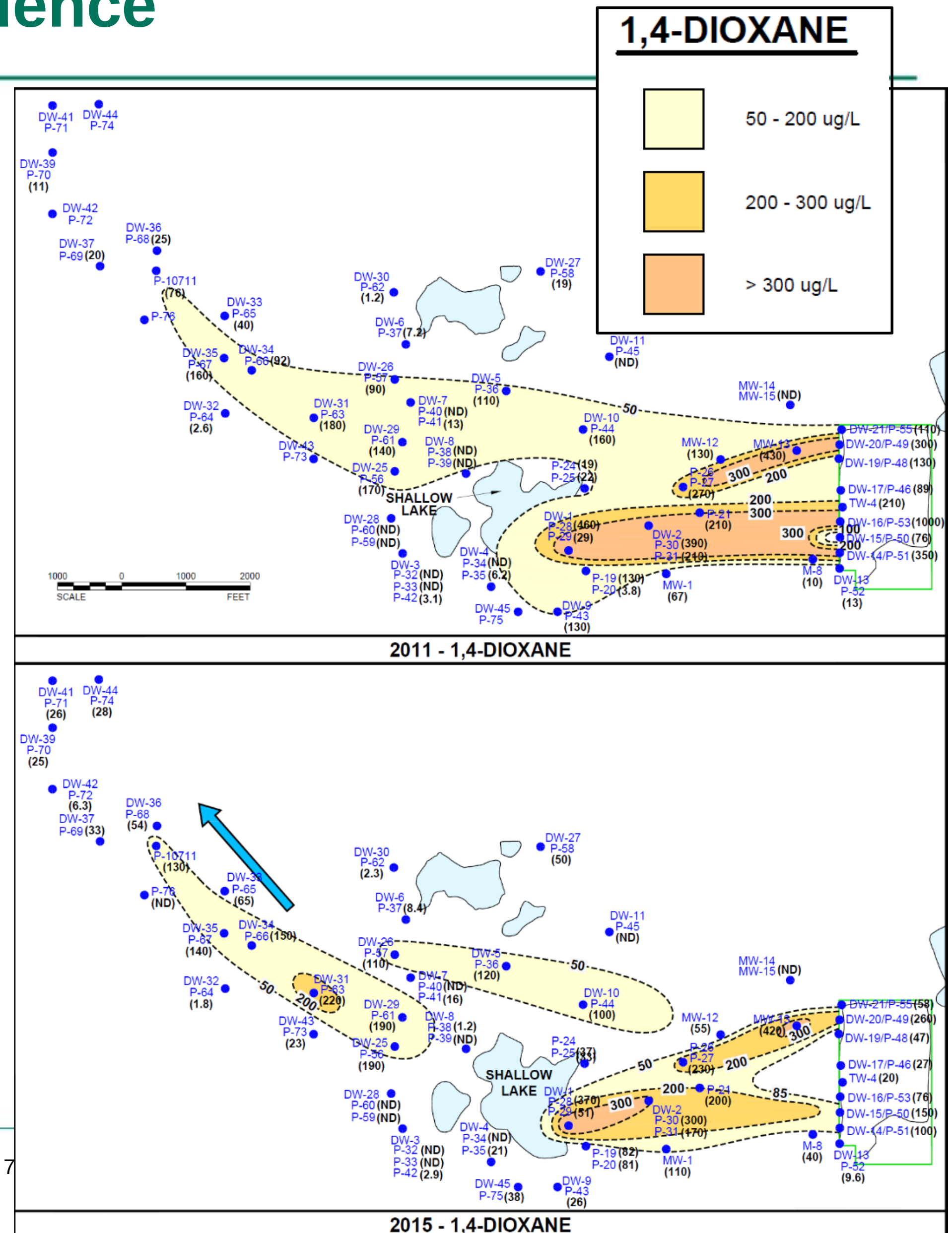


Associates

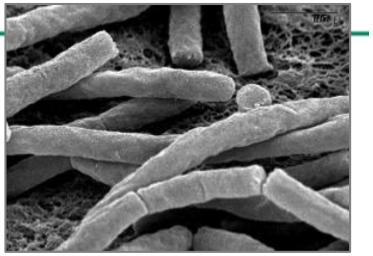
Degradation Evidence

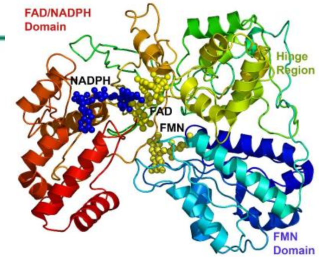
Contaminant	Near Source Mass % Reduction	Total Plume Mass % Reduction
1,4-Dioxane	82%	38%
THF	92%	80%

- Declining source GW concentrations since 2004
- 1,4-Dioxane and THF source and plume mass reductions
- Numerical F&T modeling could reproduce the plume only when 1,4-dioxane degradation was included



Application of Molecular Tools



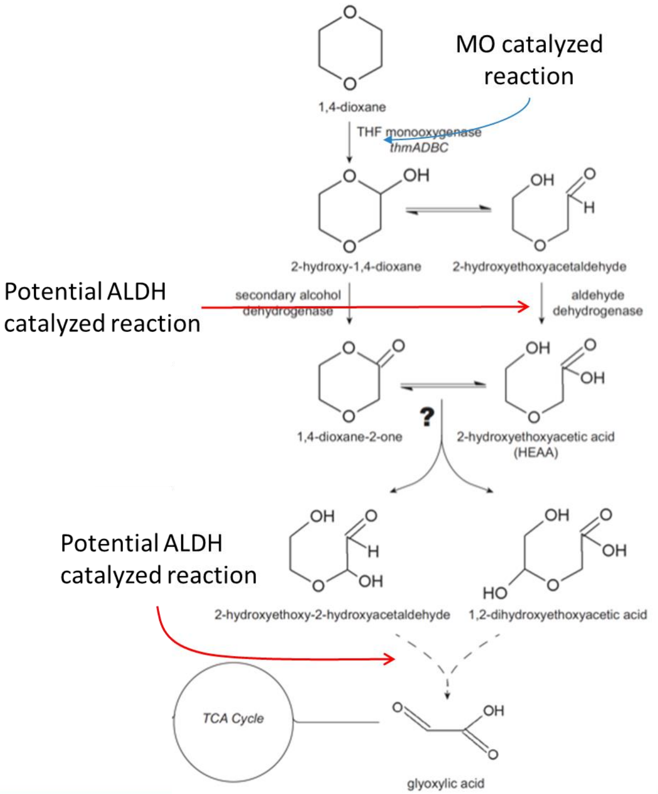


1,4-Dioxane Metabolism Biomarkers

- Dioxane monooxygenase (DXMO)
  - Indicates aerobic metabolism of 1,4-dioxane
- Aldehyde dehydrogenase (ALDH)
  - Catalyzes key step in metabolism of 1,4-dioxane breakdown product

1,4-Dioxane Cometabolism Biomarkers

- Soluble methane monooxygenase (sMMO)
- Propane Monooxygenase (PRMO)
- THF monooxygenase (THFMO)
- Toluene monooxygenase



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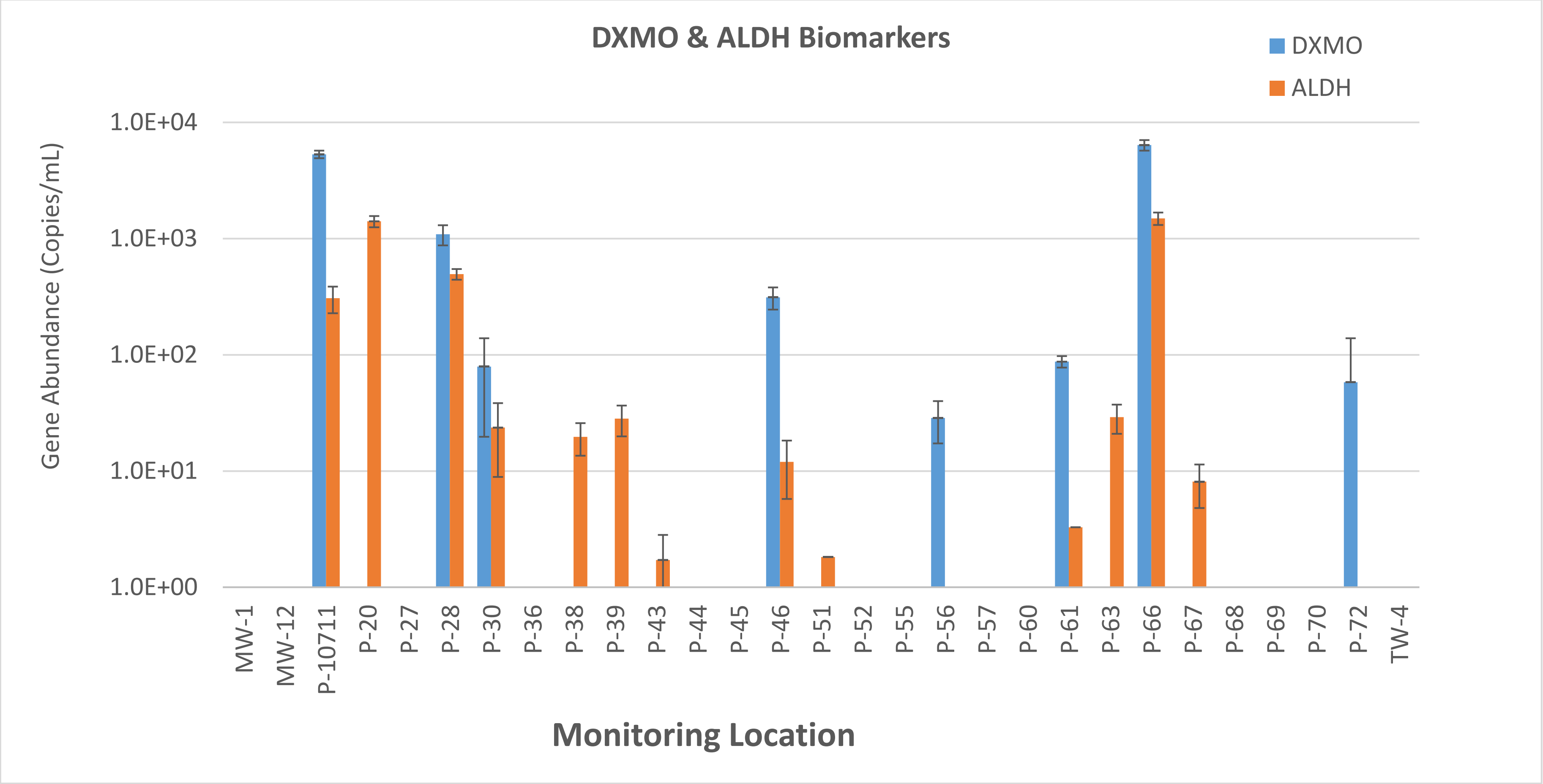
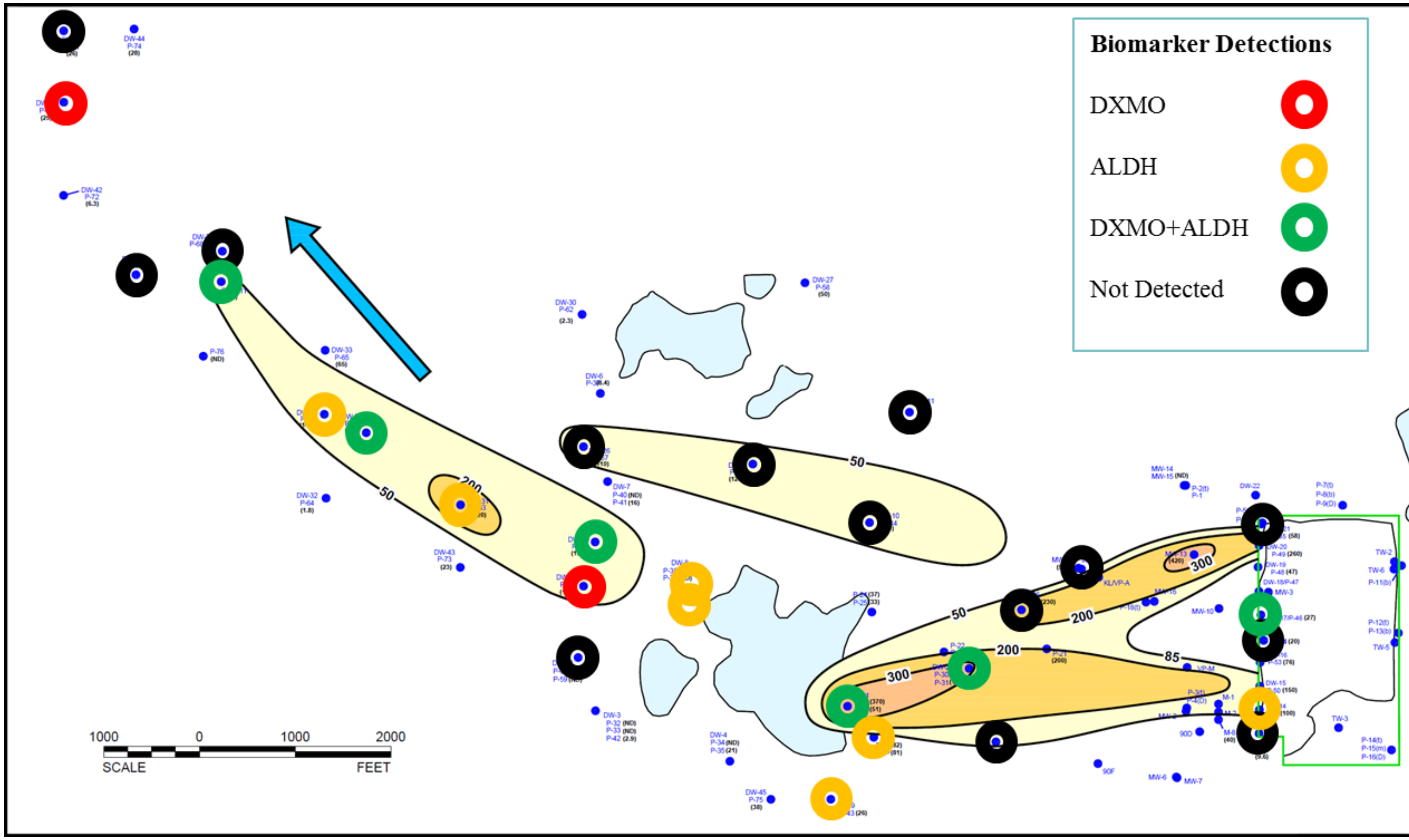
DXMO and ALDH Biomarker Abundance



ALDH and DXMO present together in high abundance in 6 wells

DXMO and ALDH Biomarker Results



Presence of DXMO and ALDH biomarkers tracks the receding plume

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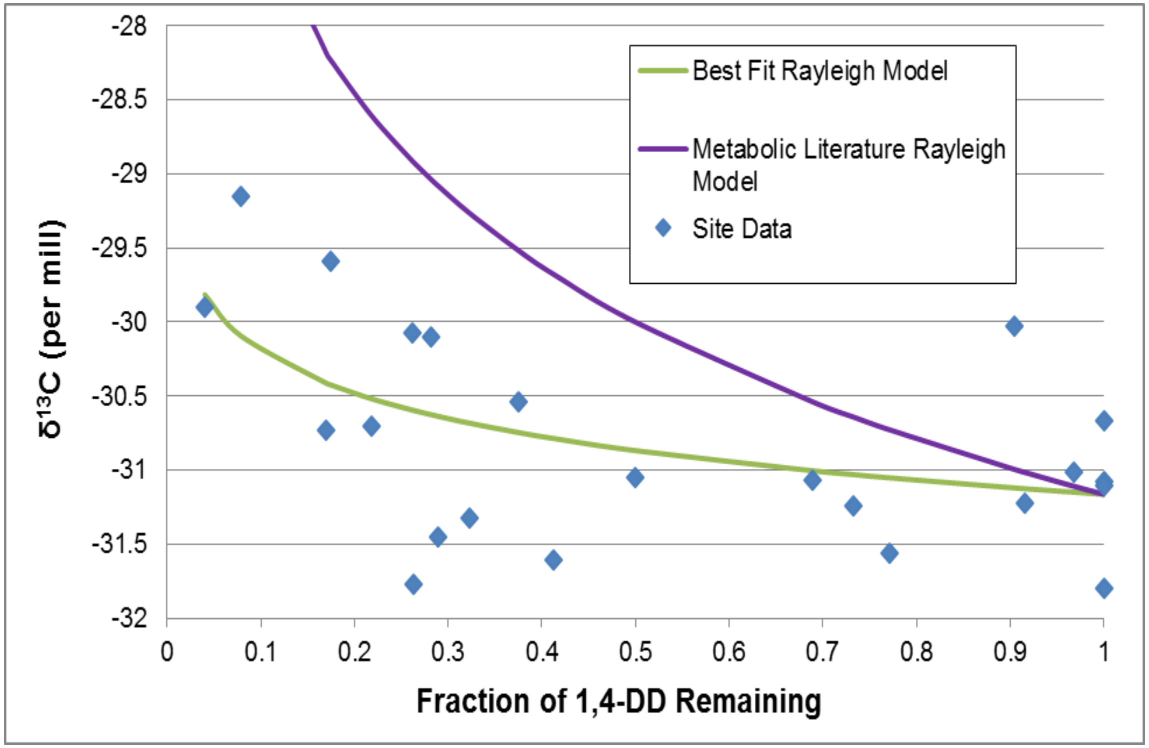
Compound Specific Isotope Analysis (CSIA) for 1,4-Dioxane Biodegradation

$$\varepsilon \ \ln f = 1000 \times \ln[(1000 + \delta_{x,t}) / (1000 + \delta_0)]$$

1,4-Dioxane

$\delta^{13}C$ (‰)



CSIA results for laboratory pure culture (purple; (Pornwongthong et al., 2011; Pornwongthong et al., In review)) and site-specific (green) biodegradation of 1,4-dioxane.

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Supporting Evidence of 1,4-Dioxane Degradation

Traditional Analyses

- Spatial and temporal groundwater trends demonstrate decreasing GW 1,4-dioxane concentrations
- 1,4-Dioxane source mass near the landfill decreased by 82% and total plume mass decreased by 38%
- Groundwater modeling indicates the plume cannot be explained by dispersion and dilution alone → Requires degradation

Molecular Analyses

- Presence of DXMO and ALDH directly tracks with the plume
- Enrichment of ^{13}C in 1,4-dioxane with increasing downgradient distance

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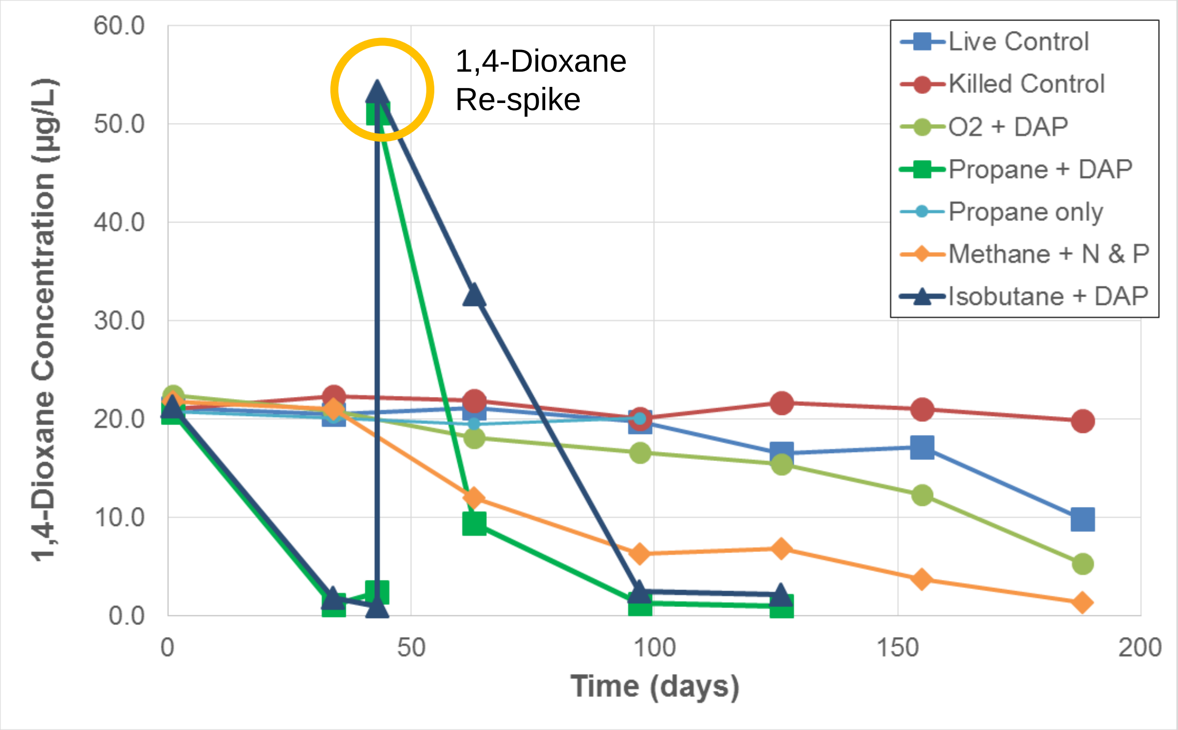
Microcosm Treatability Study

Objective: Enhance/stimulate intrinsic biodegradation of 1,4-dioxane gas (O_2, alkane gas) and nutrient amendment (DAP) addition.

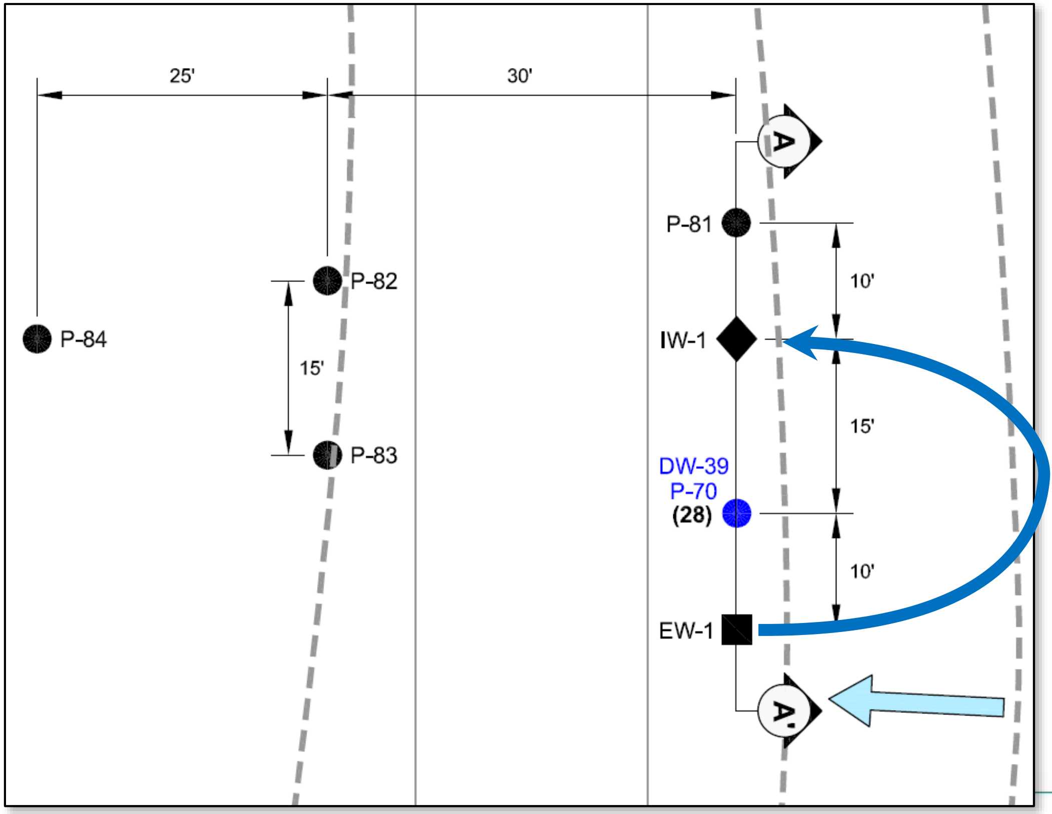


"Laboratory Evaluation of Alternative Substrates for Enhancing the Cometabolic Biodegradation of 1,4-Dioxane and Tetrahydrofuran". Session B9. 1-Dioxane Treatment Technologies I

Proposed Field Pilot-scale Study

Objective:

Evaluate the efficacy and feasibility of enhancing intrinsic 1,4-dioxane biodegradation addition of oxygen, propane and/or nutrient amendments.



Phase I
(Stimulate Metabolic Degradation)

- Infuse extracted groundwater with oxygen, amend with DAP and re-inject to treatment zone

Phase II
(Stimulate Cometabolic Degradation)

- Infuse extracted groundwater with oxygen, propane amend with DAP and re-inject to treatment zone

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Questions?