

Injection of Oxygen in Deep Horizontal Wells for the Biostimulation of PAH Degradation at a Former Wood Treating Superfund Site

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Oxygen Injection Systems

October, 2011 • Orlando
Florida Remediation
Conference



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ESCAMBIA WOOD TREATING SITE

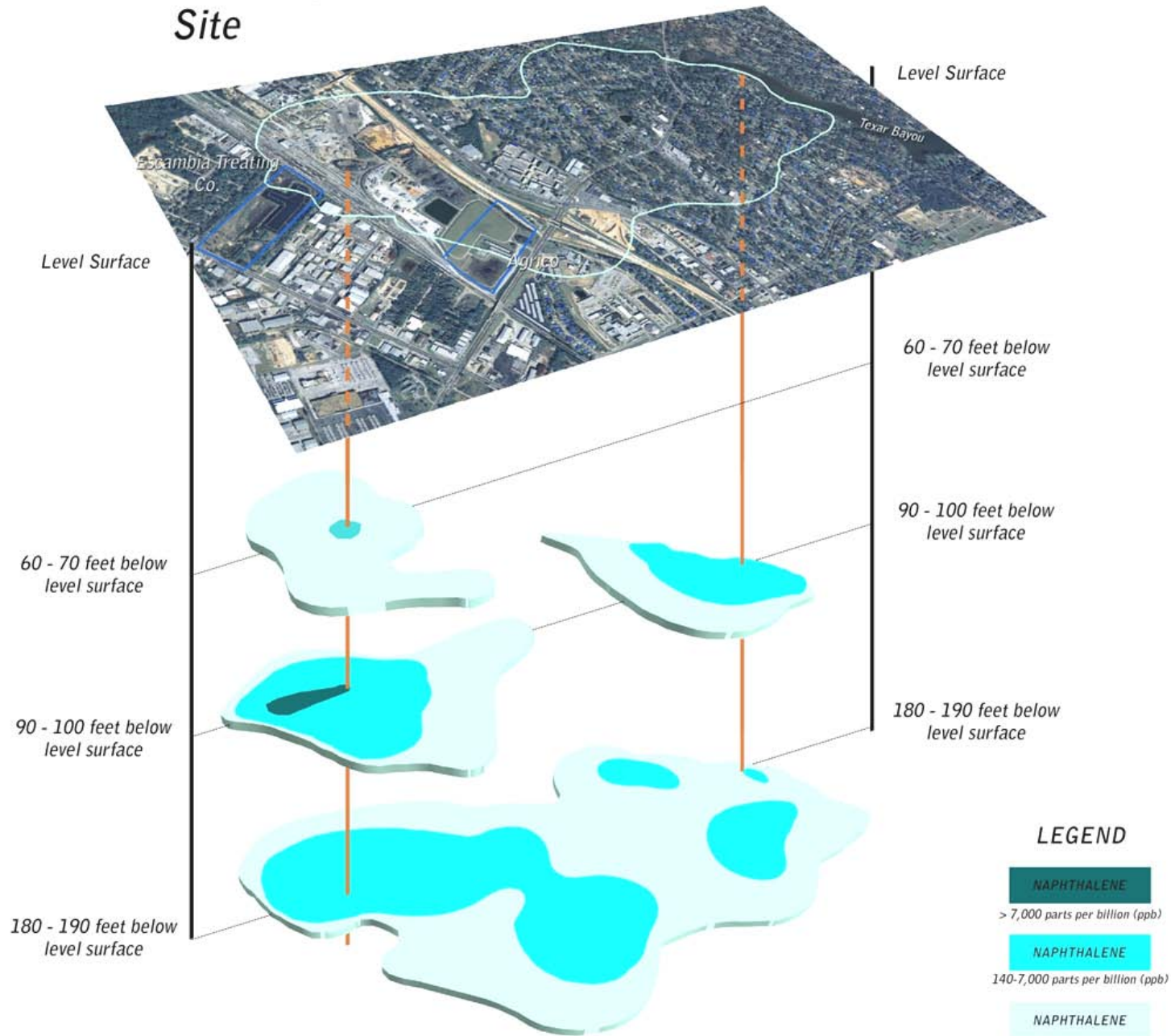
Background

- Former **wood treating facility** in Pensacola, FL that operated from 1942 to 1982
- Primary products were pressure treated utility poles.
- Primary contaminants are coal tar **creosote** compounds, **PCP** and **dioxin**
- Site is 26-acres, with over 60 acres of adjacent neighborhoods acquired.



Active Wood Treating Plant
circa 1975

Escambia Treating Co. Site

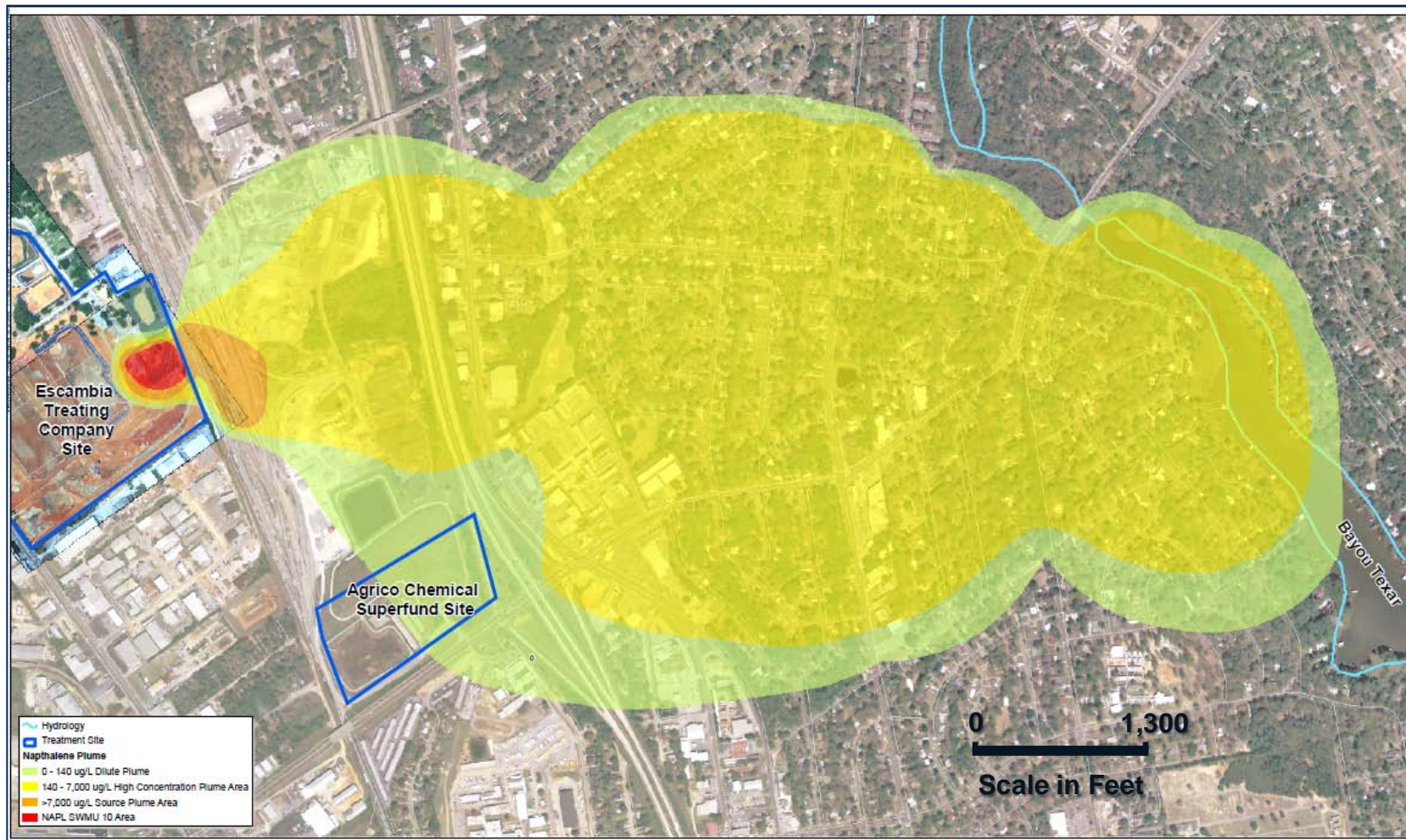


ESCAMBIA WOOD TREATING SITE – JAN 2009

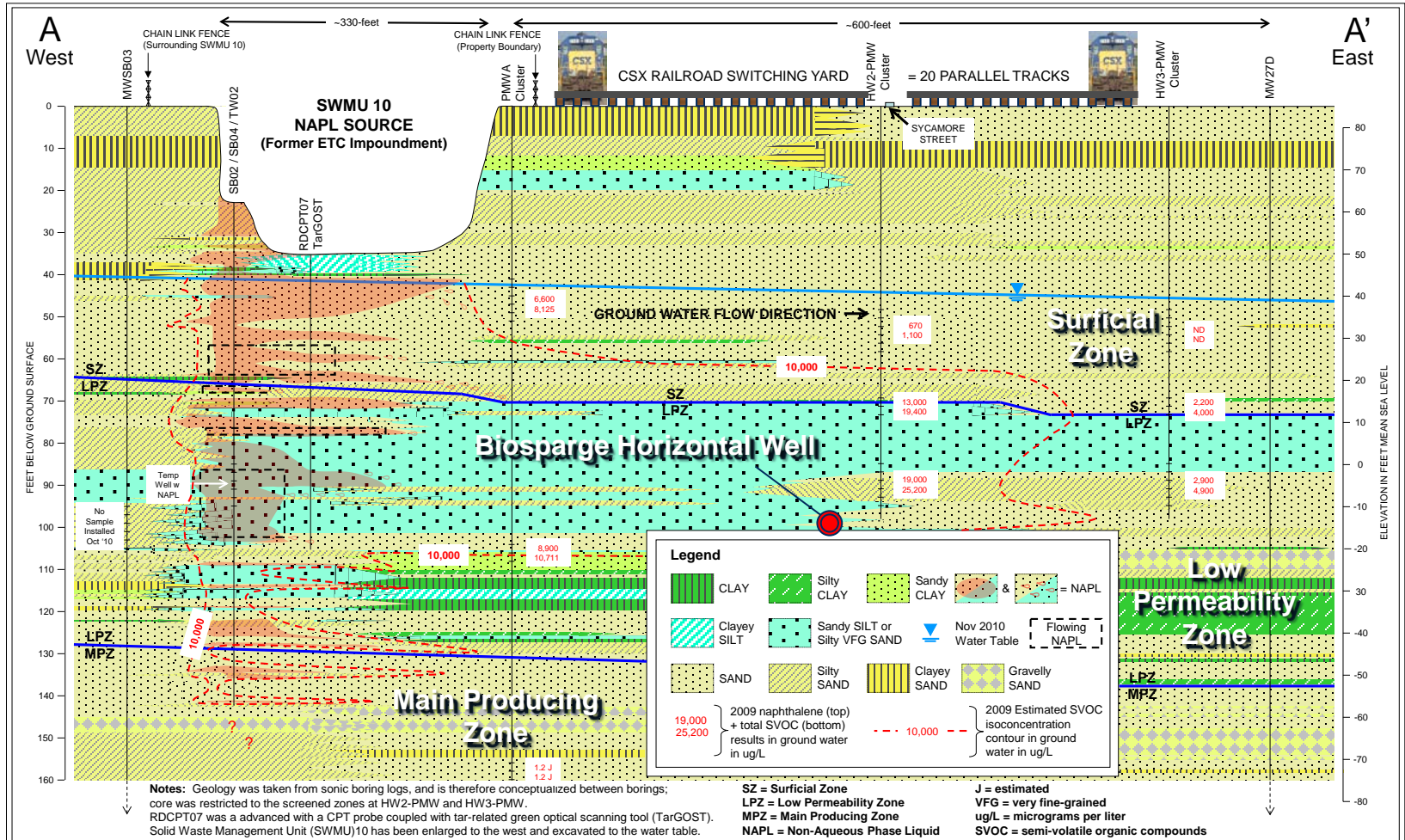


Relocation of Mount Dioxin and Source Area Locations

Composite Depth Naphthalene Plume

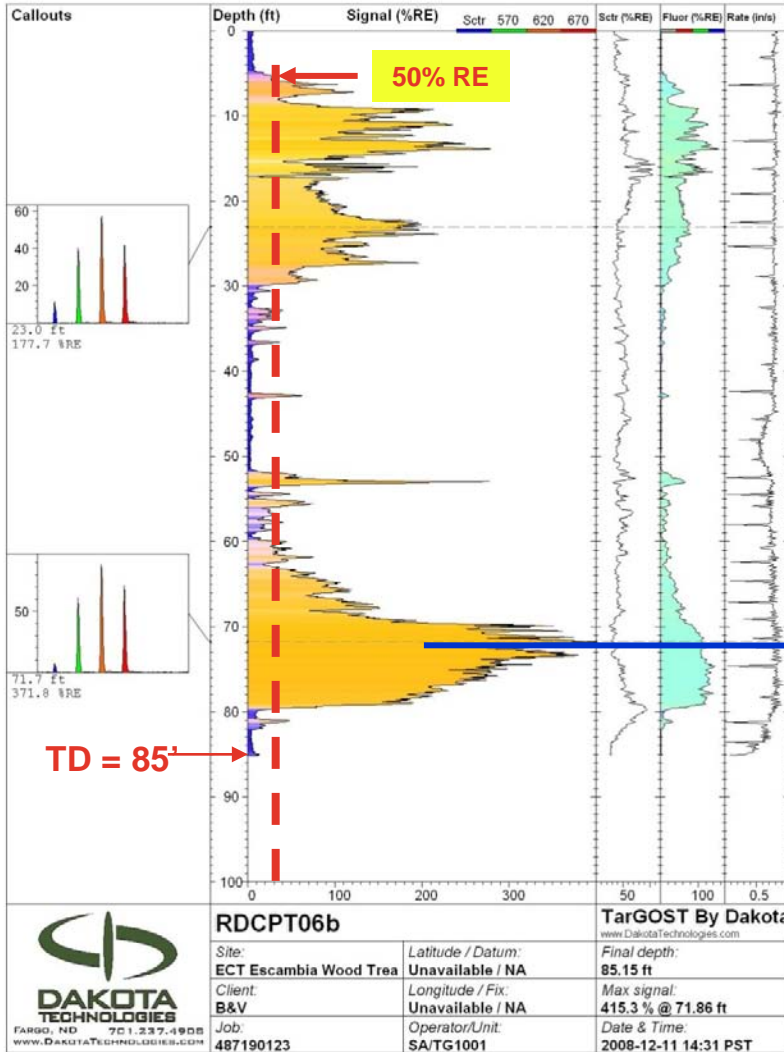


Site Conceptual Model



Source Zone DNAPL

TarGOST Source Boring (CPT Rig)



Adjacent confirmatory sonic bore; cores and plastic sleeves stained dark brown to black; strong naphthalene odor.

DNAPL at 70 ft bgs



Adjacent test well screened 70 to 75 ft bgs with free flowing creosote DNAPL.



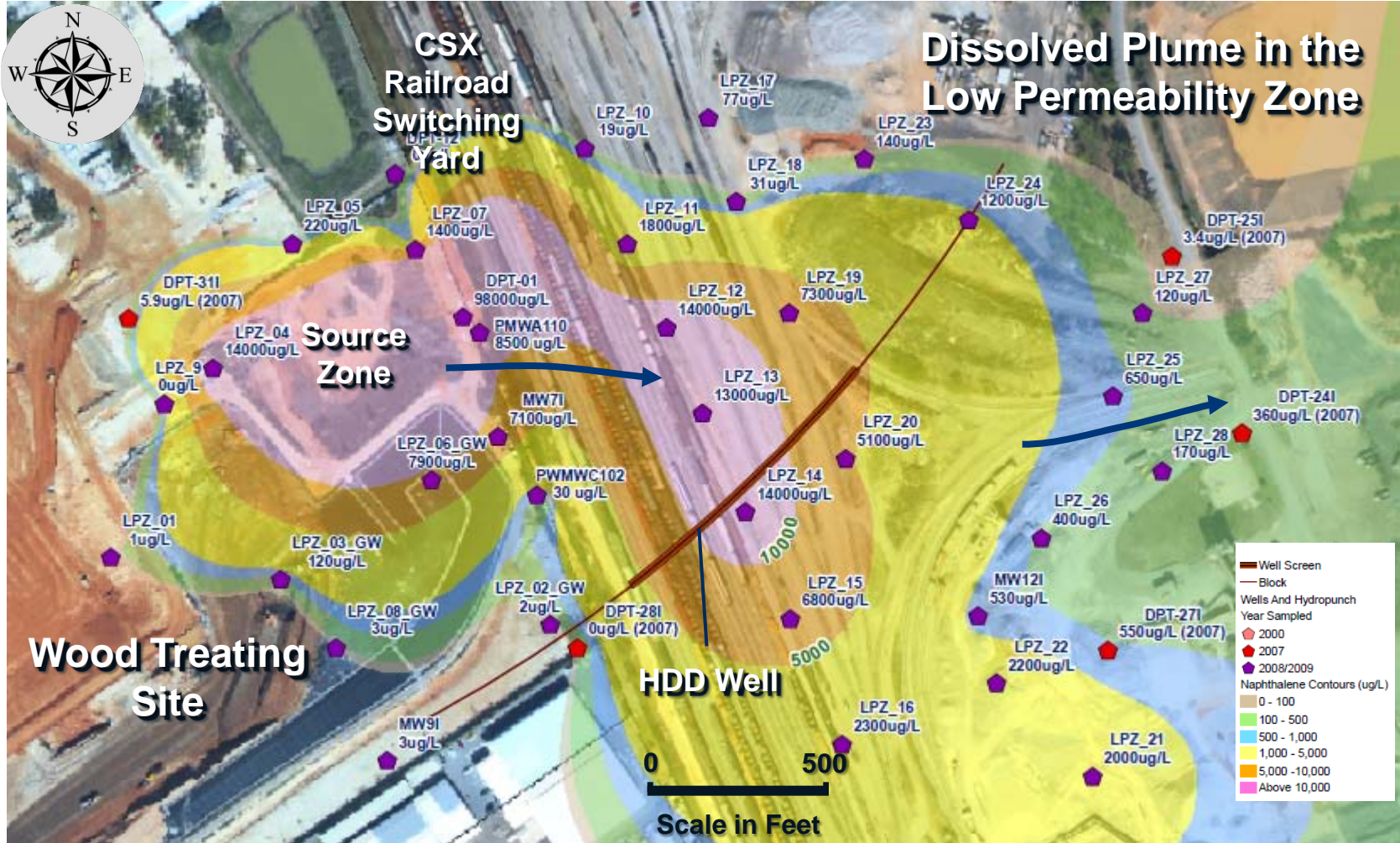
Biosparge Pilot Test Setup



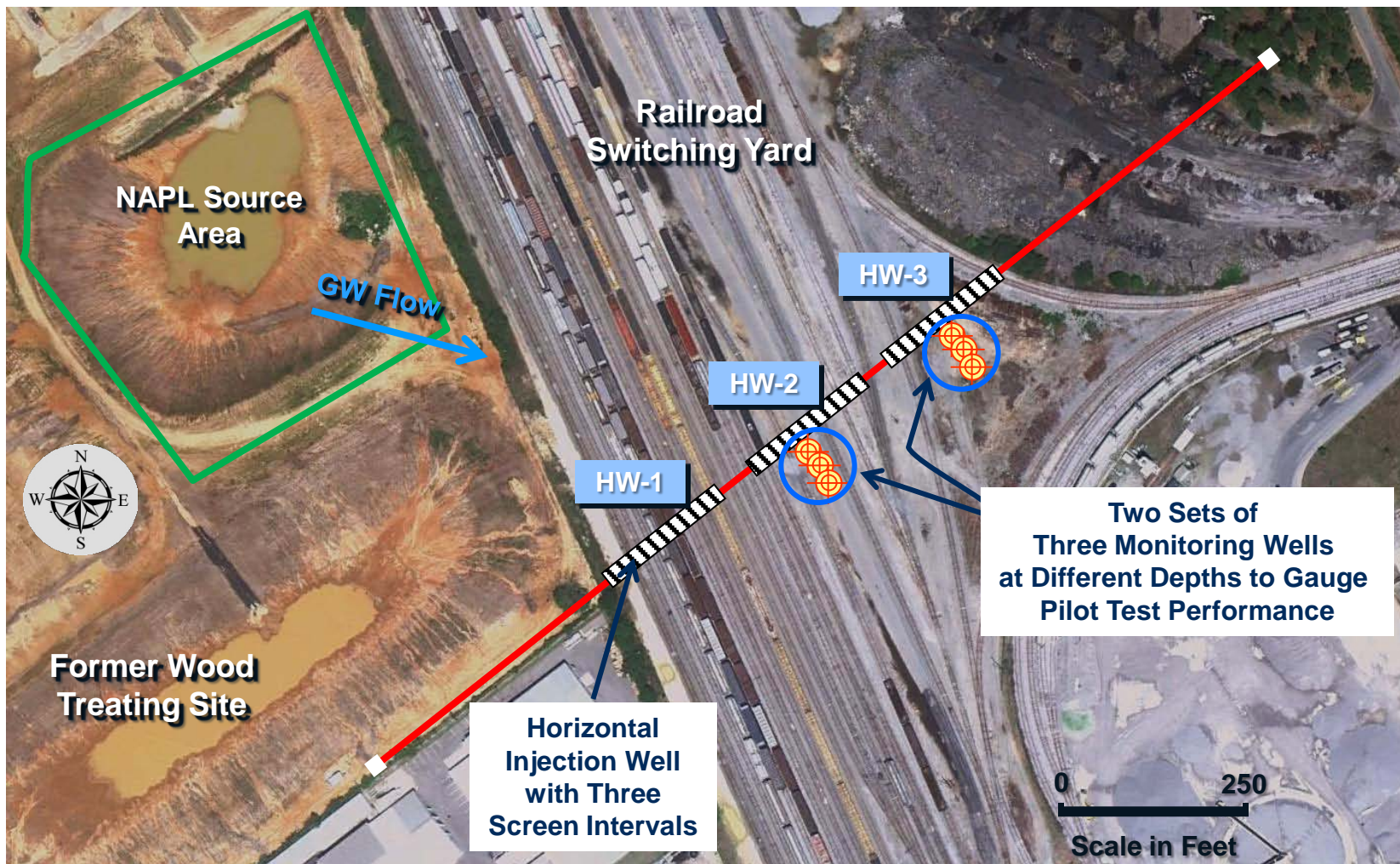
BIOSPARGE PILOT TEST GOALS

1. Demonstrate viability of directional drilling under railroad yard
2. Compare the effectiveness of different well materials
3. Evaluate the ability to disperse oxygen effectively through a horizontal well
4. Determine design basis for flows and pressures
5. Measure and assess dissolved oxygen dispersion outward and upward from the horizontal wells
6. Identify changes in microbial activity due to oxygenation of the plume

NAPHTHALENE PLUME

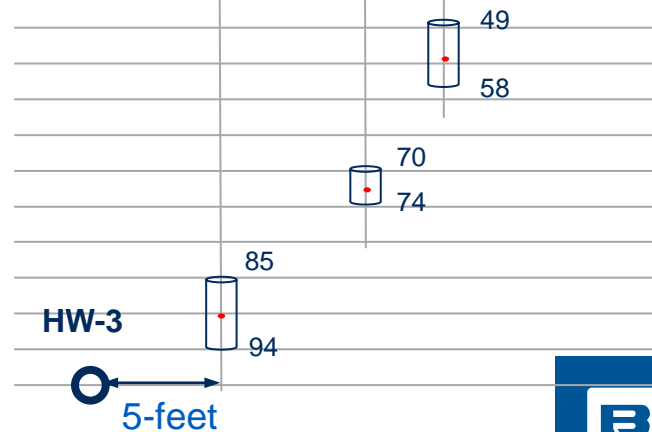
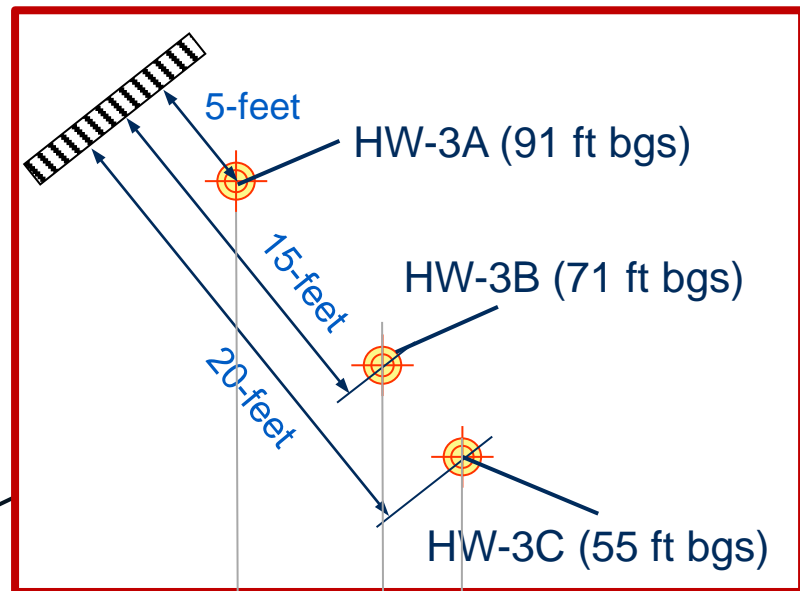
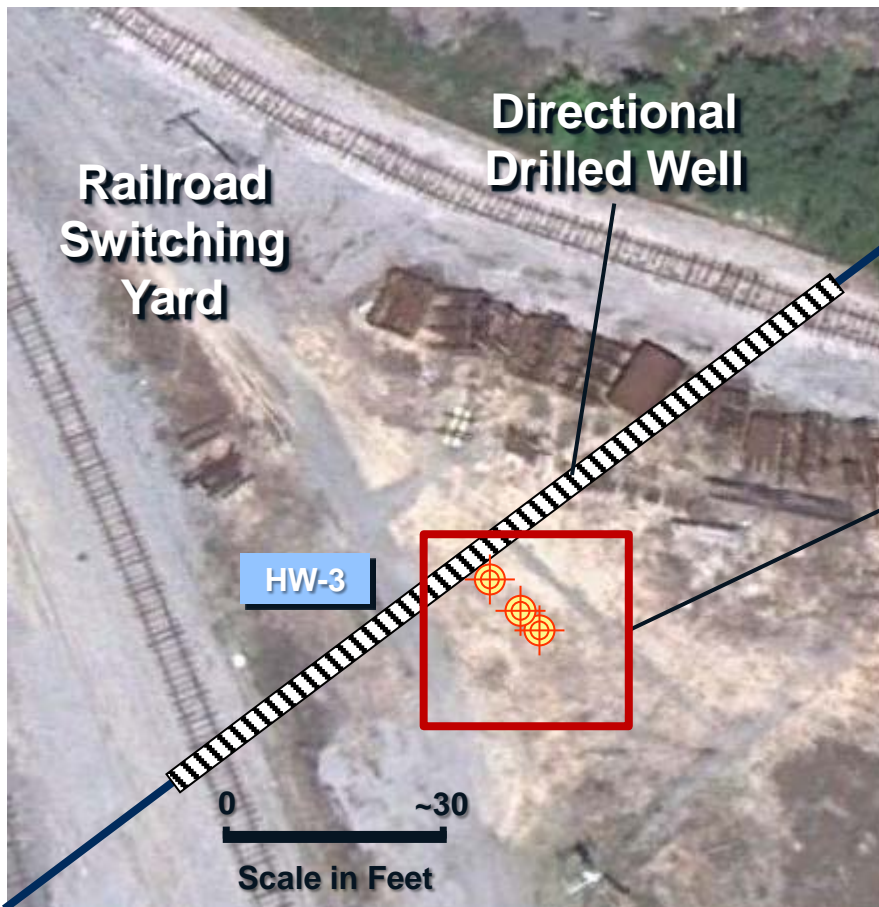


LAYOUT OF *IN SITU* BIOSPARGE PILOT TEST



Performance Monitoring Wells

HW-3 Performance Monitoring Array



In Situ Biosparge Pilot Study Components

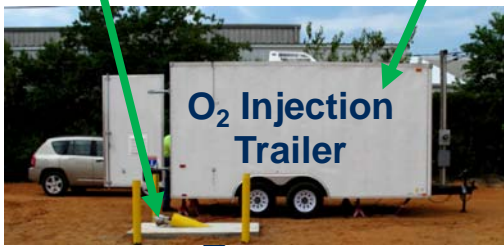
Bundle of 3 Injection Wells



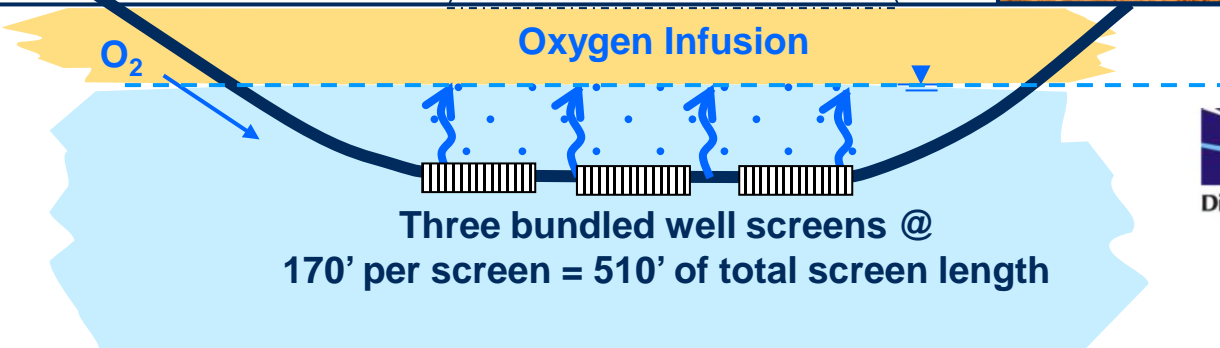
Air Conversion to >90% Pure O₂



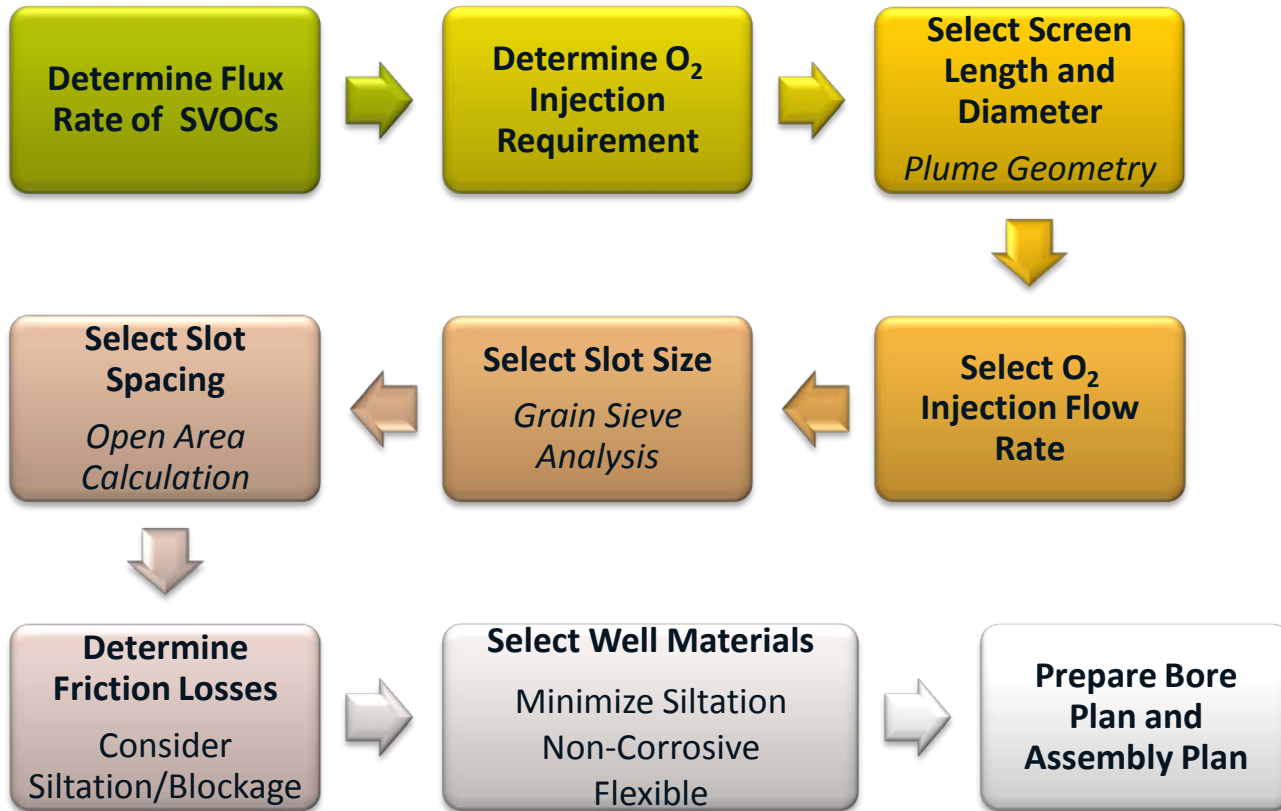
Horizontal Directional Rig drilling the 1,450 ft long bore to 100 ft bgs, and installing the bundle of three (3) injection well screens.



[CSX]
Railroad Switching Yard with 20 Parallel Tracks



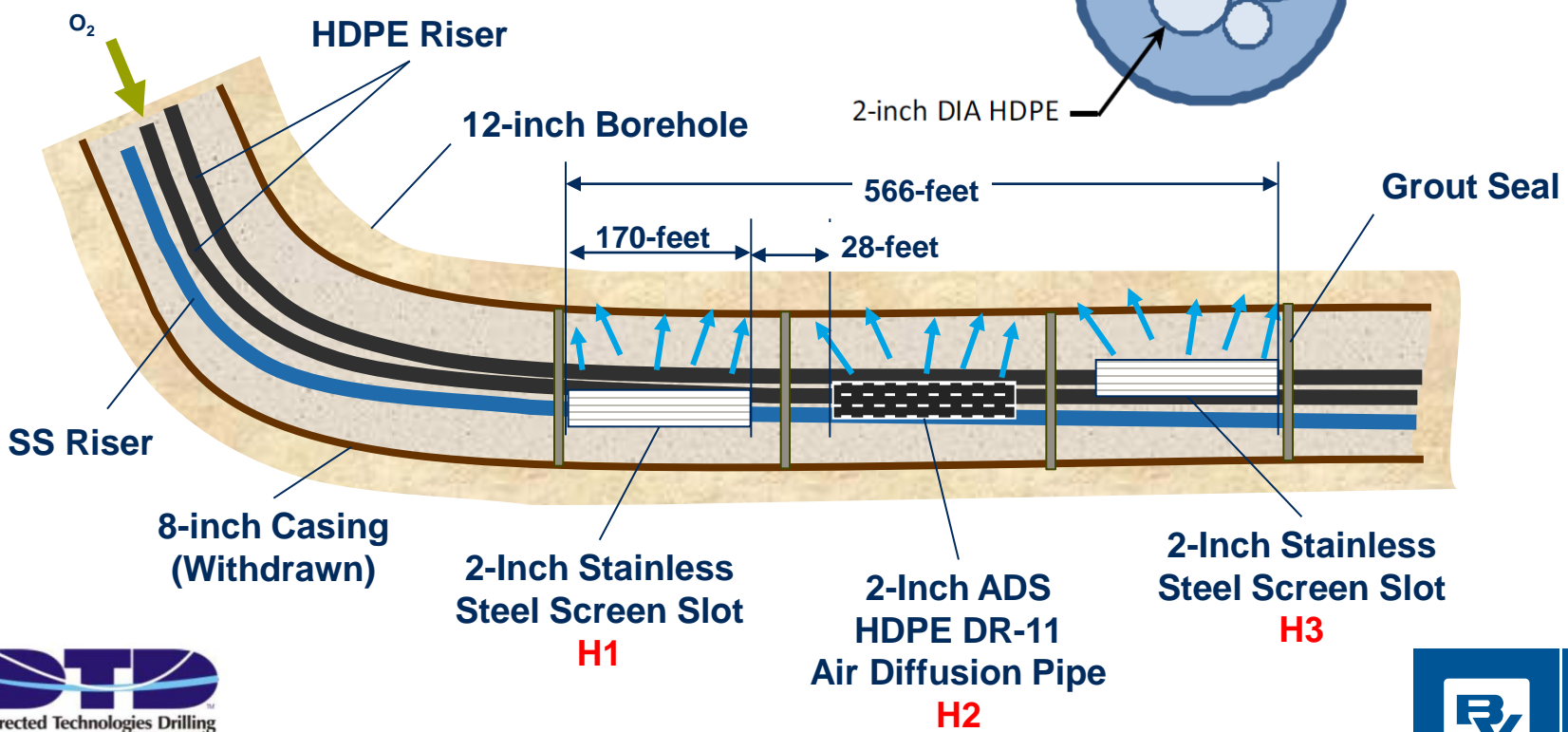
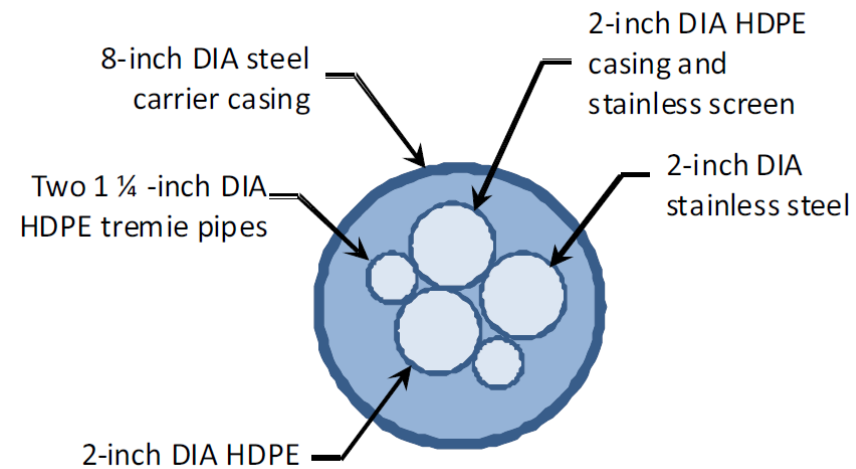
Pilot Scale Biosparge Wall Design



BioSparge Well Construction

Screen Construction

ADS piping is air cut microslits on 1-foot centers that delivers 0.2 scfm per foot of pipe (opens at 5 psig).



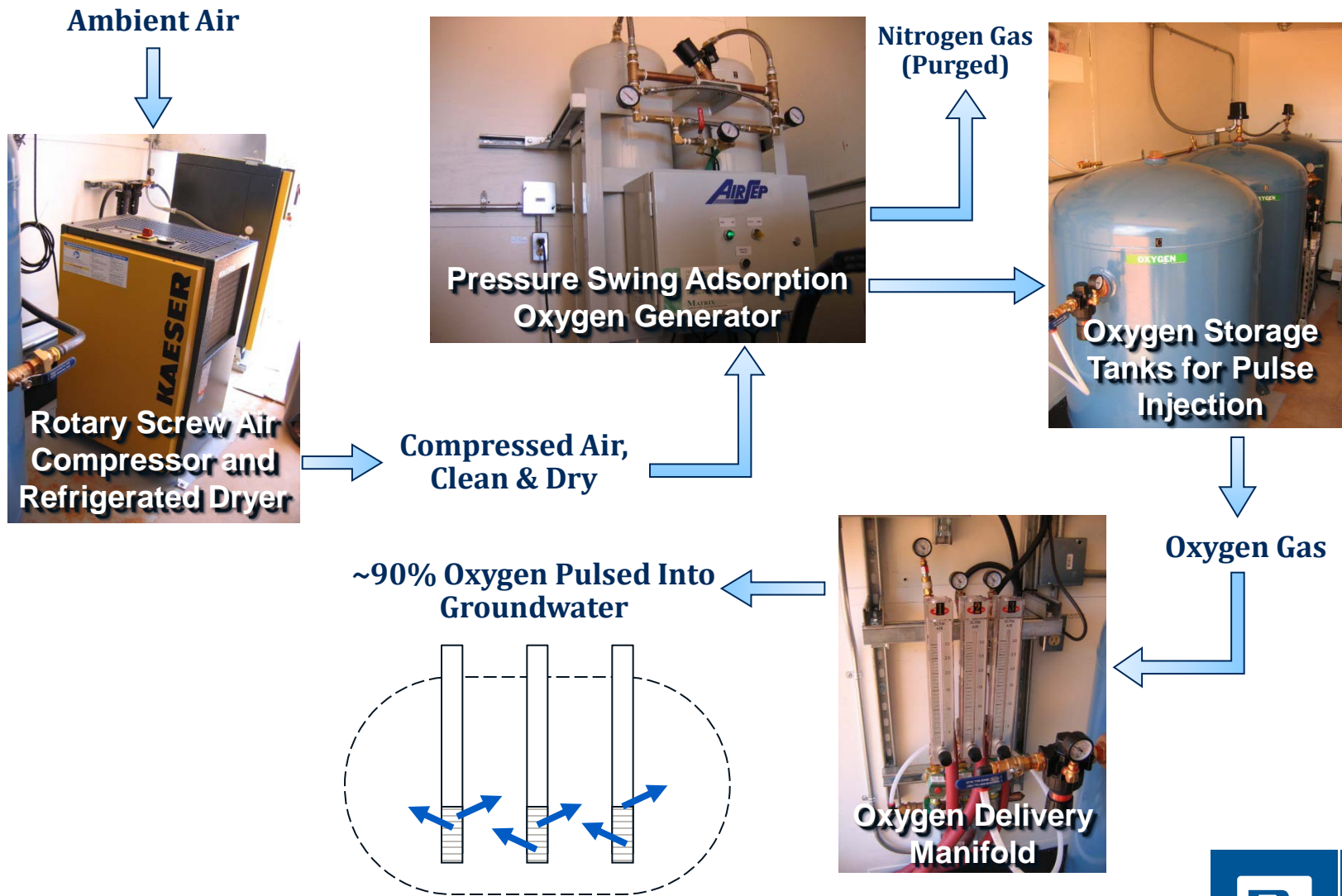
Oxygen Injection Trailer



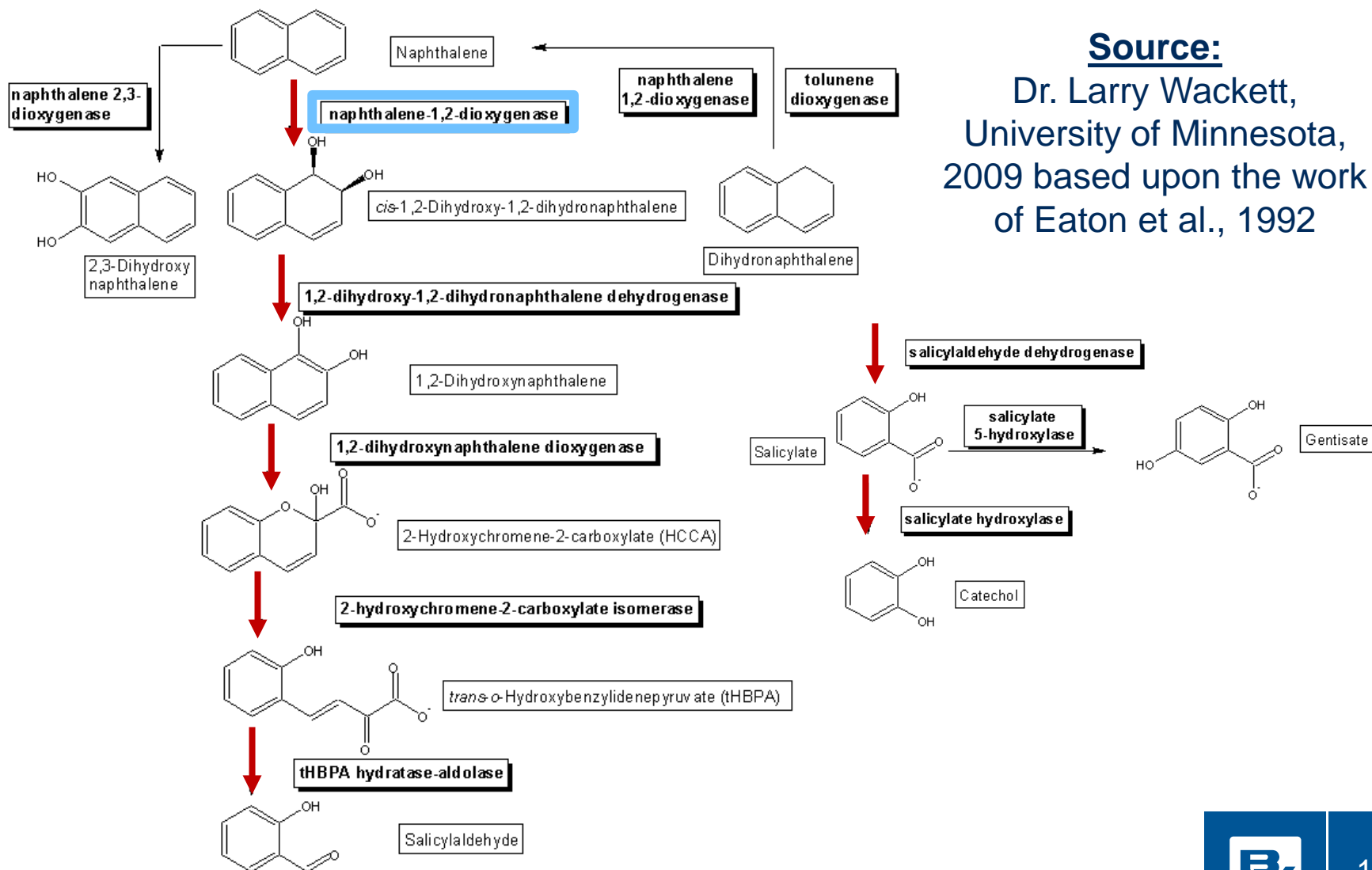
- The Matrix Oxygen Injection System produces **O₂ gas on-site for pulse injection** into groundwater contaminant plumes at controlled rates or volumes.
- DO saturation levels up to **40 mg/L**.
- Dispersion of oxygen with control of radius of influence and oxygen mass transfer
- Used at over 250 remediation sites over 14 years.
- U.L. certified PLC control system with touch screen display and remote access
- Pressure swing adsorption oxygen generator and rotary screw compressor
- License to operate under U.S. Patent No. 5,874,001.



Oxygen Injection Flow Schematic



Naphthalene Aerobic Degradation Pathway

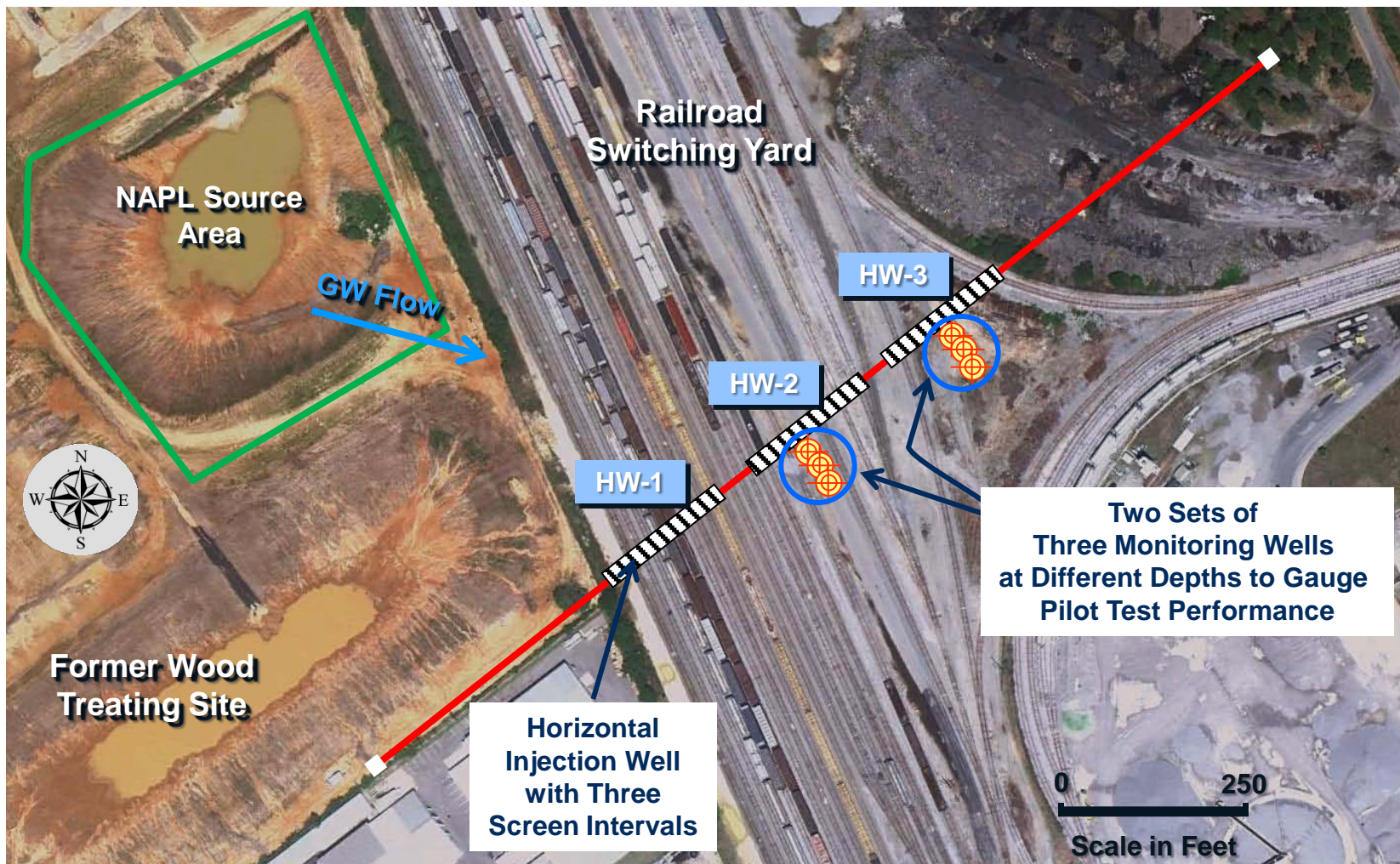


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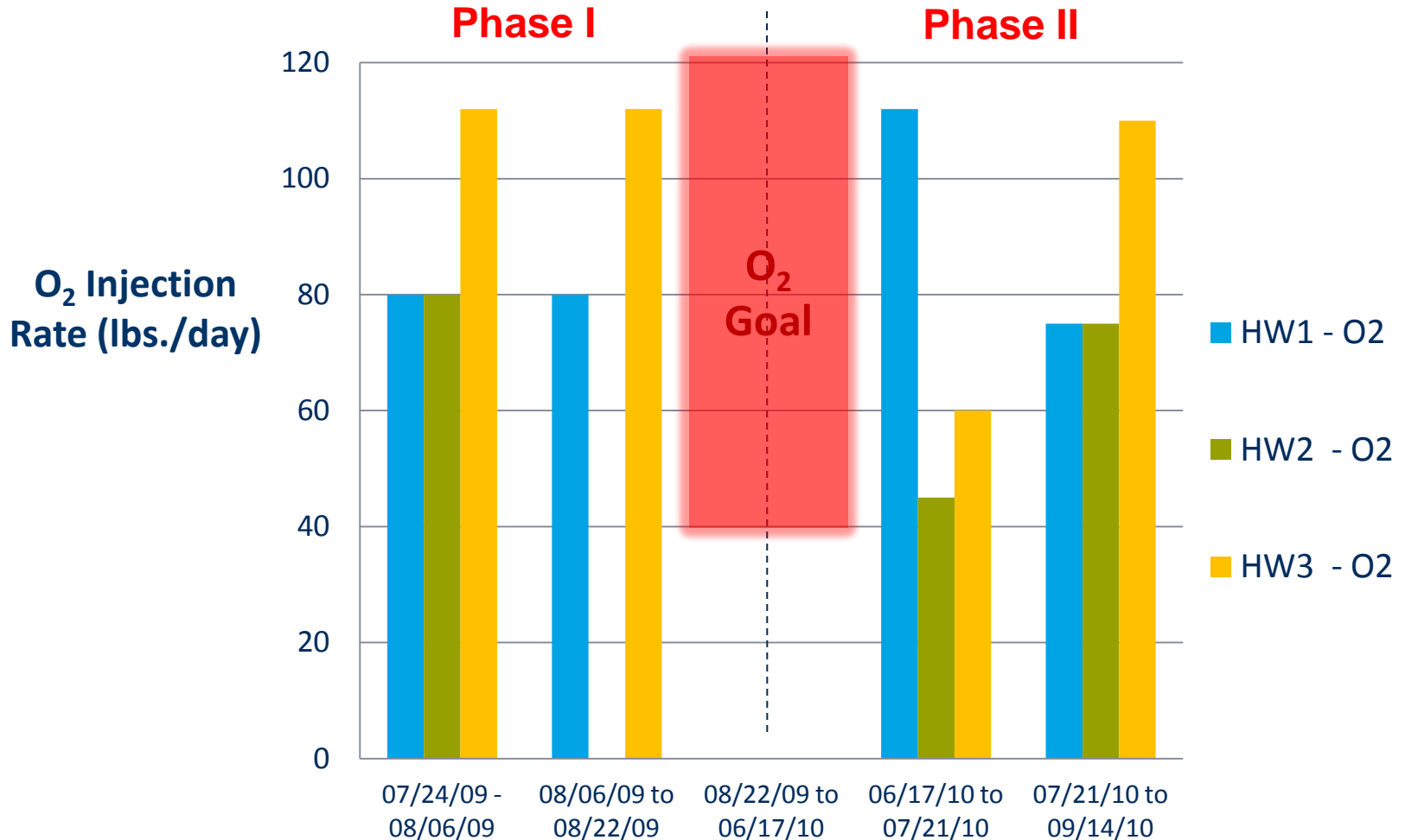
Dr. Larry Wackett,
University of Minnesota,
2009 based upon the work
of Eaton et al., 1992

Results

LAYOUT OF *IN SITU* BIOSPARGE PILOT TEST

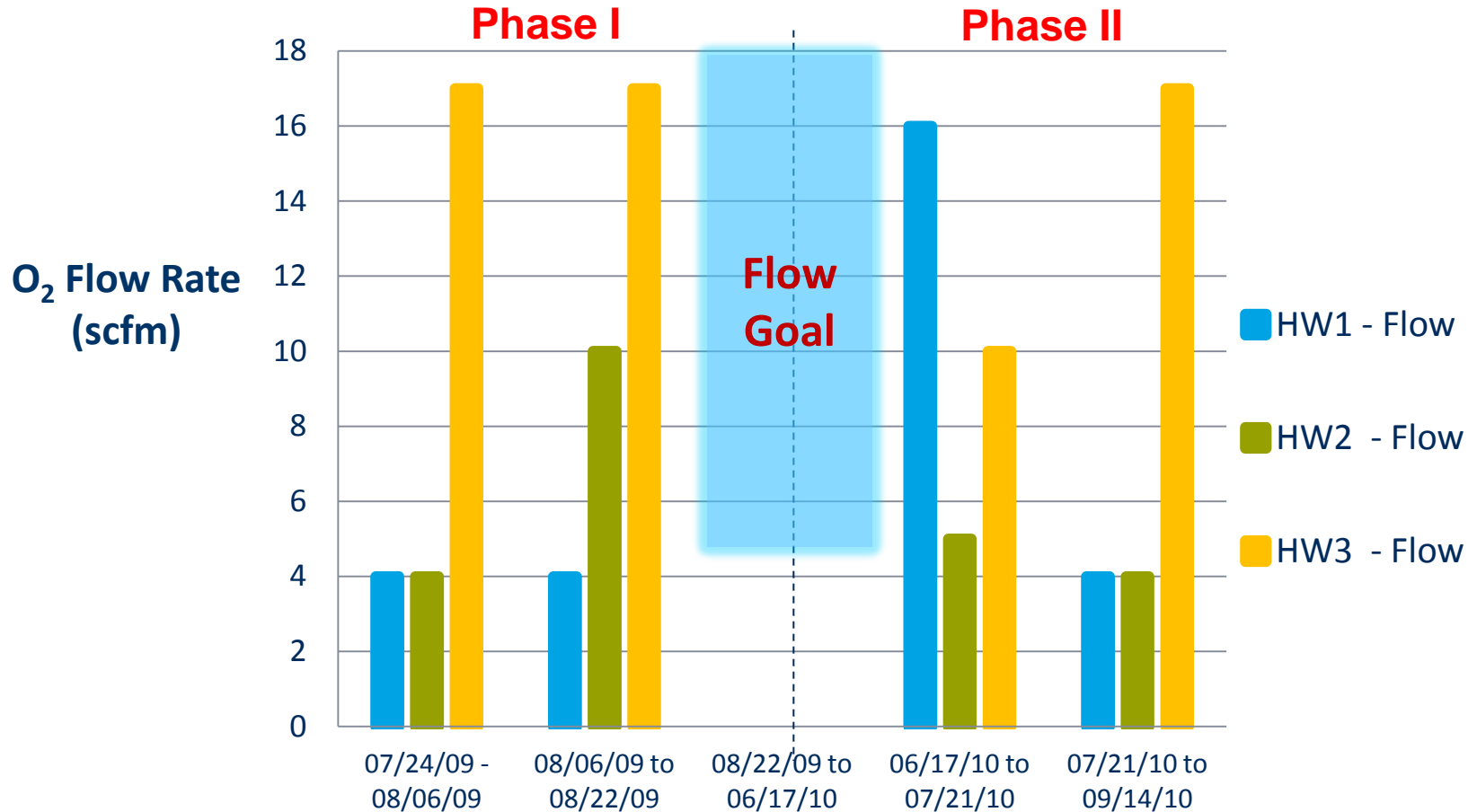


Phase 1 and 2 Pilot Scale Oxygen Feed Rates



- *In situ* DO target = 10 mg/L (minimum goal of 5 mg/L)

Phase 1 and 2 Pilot Scale Flow Results



- 0.03 to 0.1 scfm/foot of screen
- Pressures ranged from 30 to 53 psig

Performance Monitoring

What Results are Indicators of Increased Oxygen Influence?

- Increases in **DO and ORP**
- Changes in metal chemistry/mobility due to:
 - Changes in **oxidation states** (e.g., $\text{Fe}^{+2} \rightarrow \text{Fe}^{+3}$)
 - Decreases in natural organic matter (and potential increased metal mobility)
- Decreases in **TOC or COD**

What Results are Indicators of Biological Degradation?

- Increases in naphthalene degrading bacteria
- Increased CO_2 from aerobic respiration
- Decreased concentrations of naphthalene

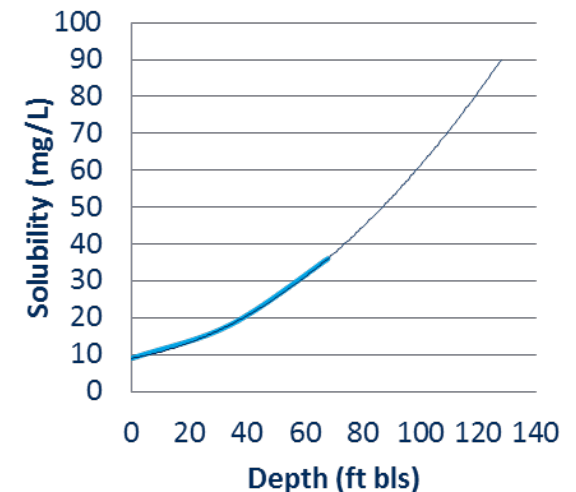
Verification of Dissolved Oxygen Front

Used stable luminescent **optical dissolved oxygen** probes

- **Continuous downwell monitoring with Trolls for 30-days** in the 6 performance monitoring wells for DO, ORP, pH, conductivity, and temperature.
- DO Measurement a **critical parameter**
- Oxygen is not consumed as part of an electrochemical reaction, and optical sensors do not require sample flow or stirring for accurate readings
- Accuracy from:
 - 0 to 20 mg/L (± 0.1 to 0.2 mg/L)
 - 20 to 50 mg/L ($\pm 10\%$)

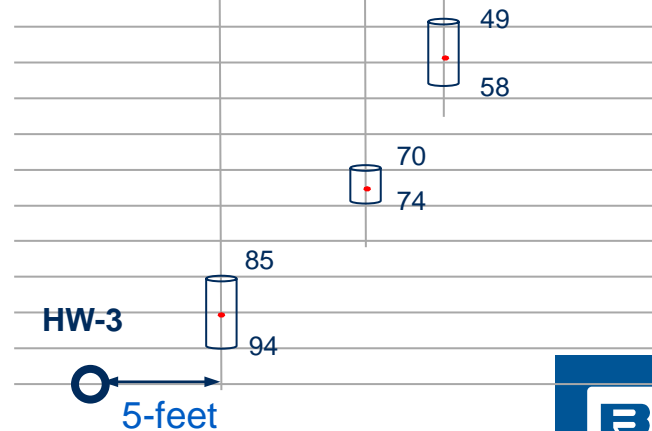
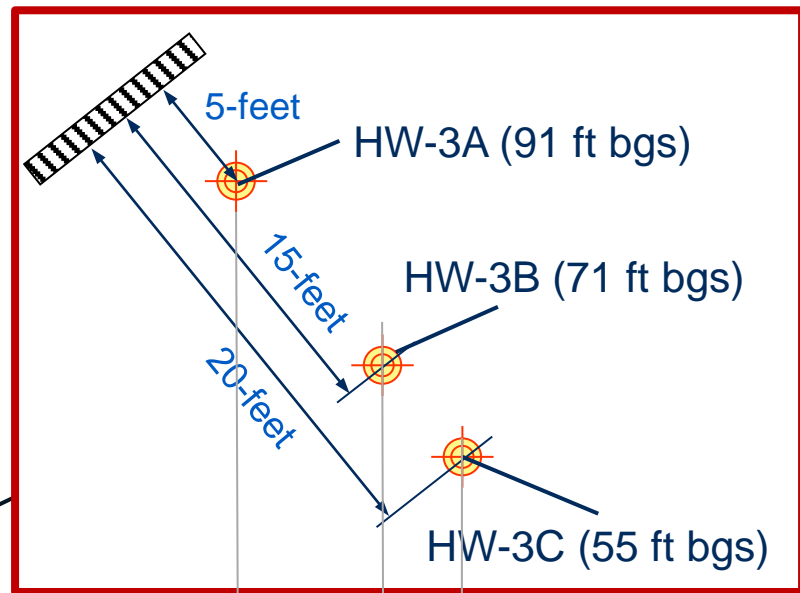


Oxygen Solubility

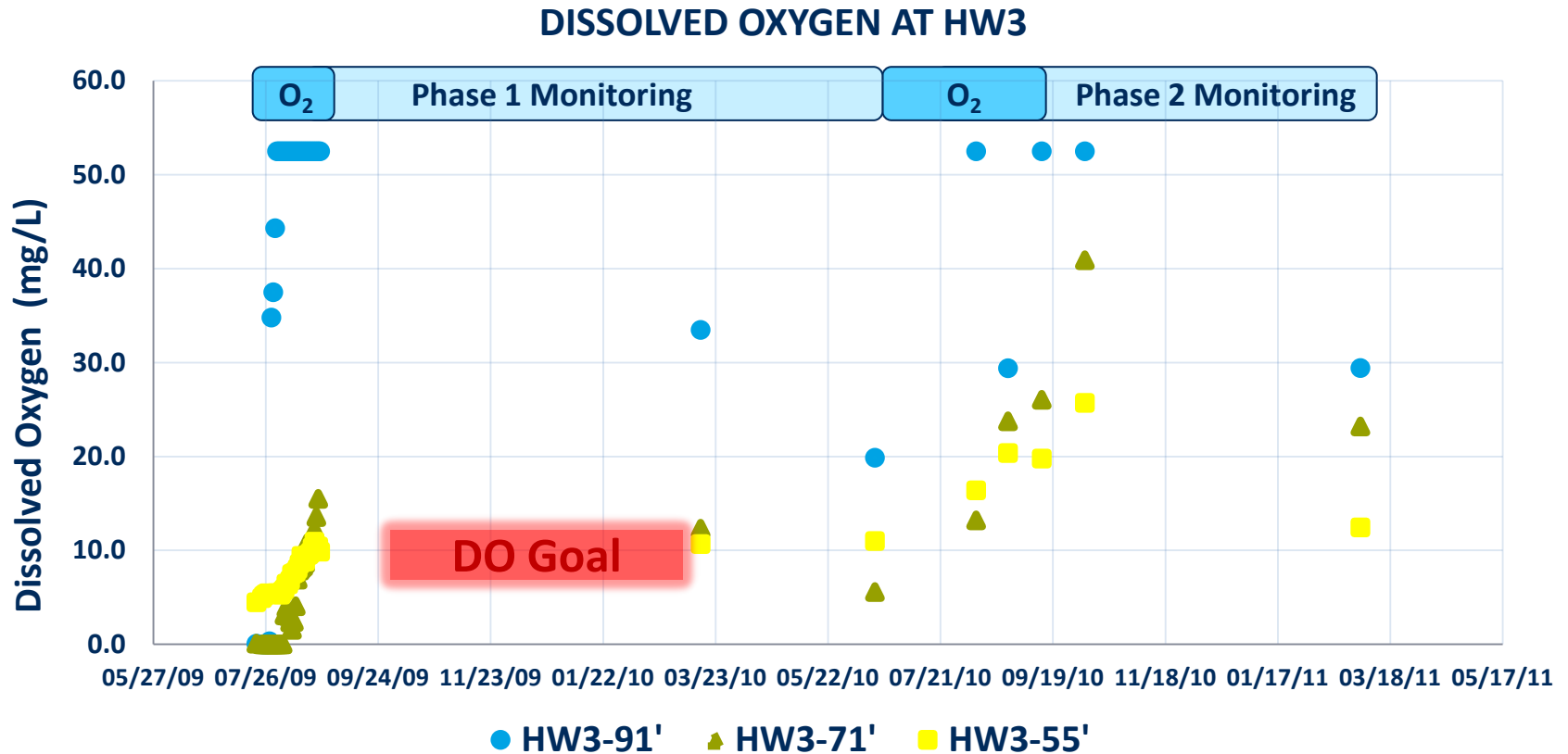


Performance Monitoring Wells

HW-3 Performance Monitoring Array

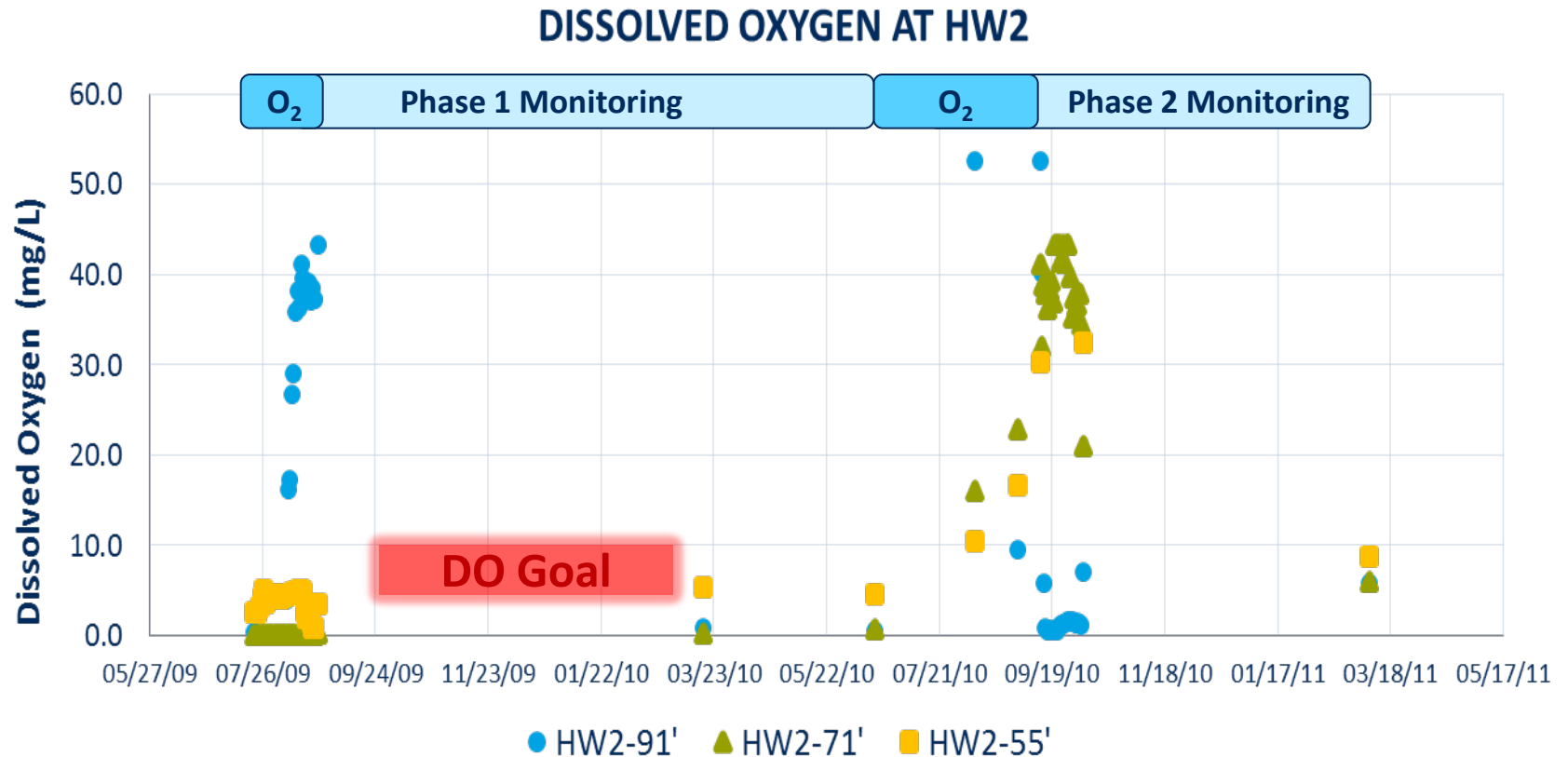


Phase 1 and 2 Pilot Scale DO Results – HW3



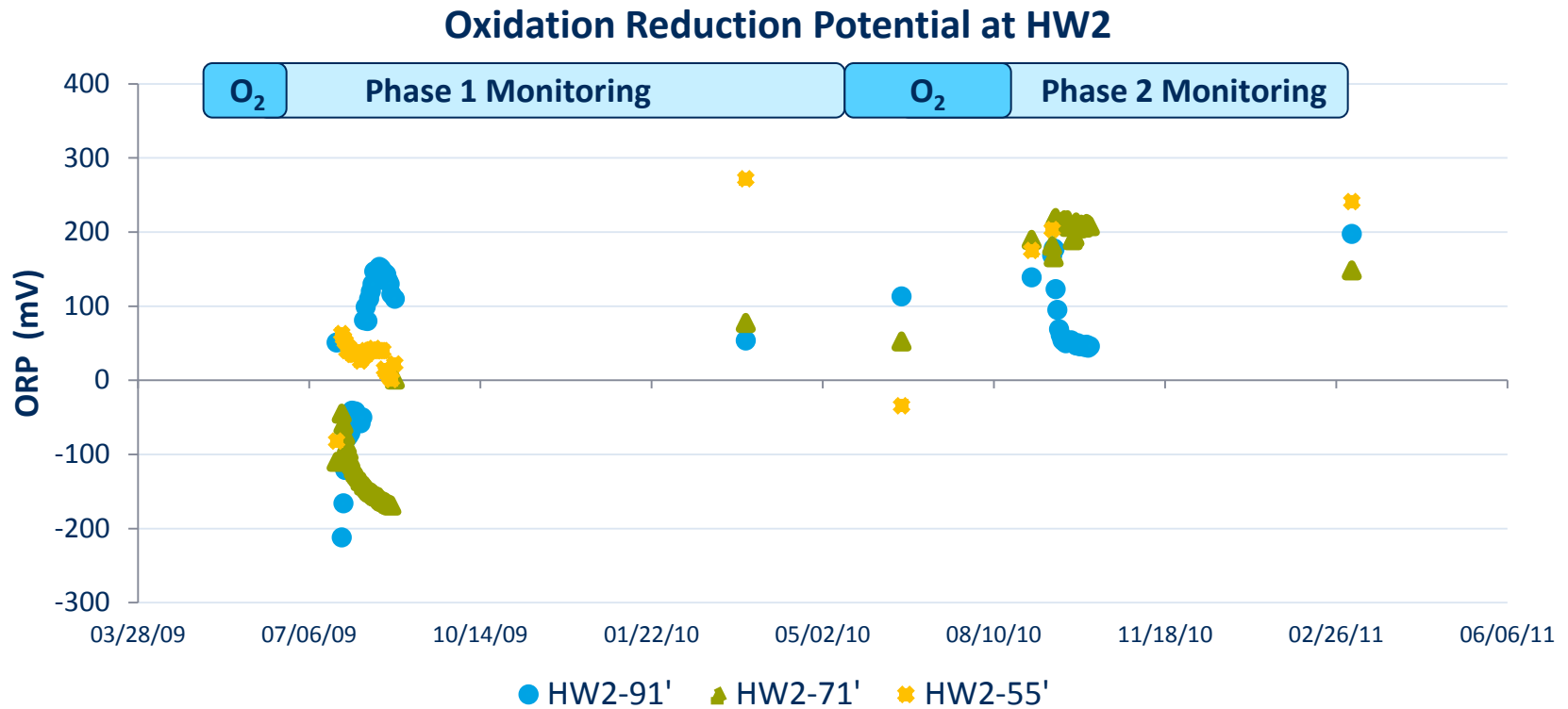
- Phase 1 = 30 days injection
- Phase 2 = 89 days injection

Phase 1 and 2 Pilot Scale DO Results – HW2



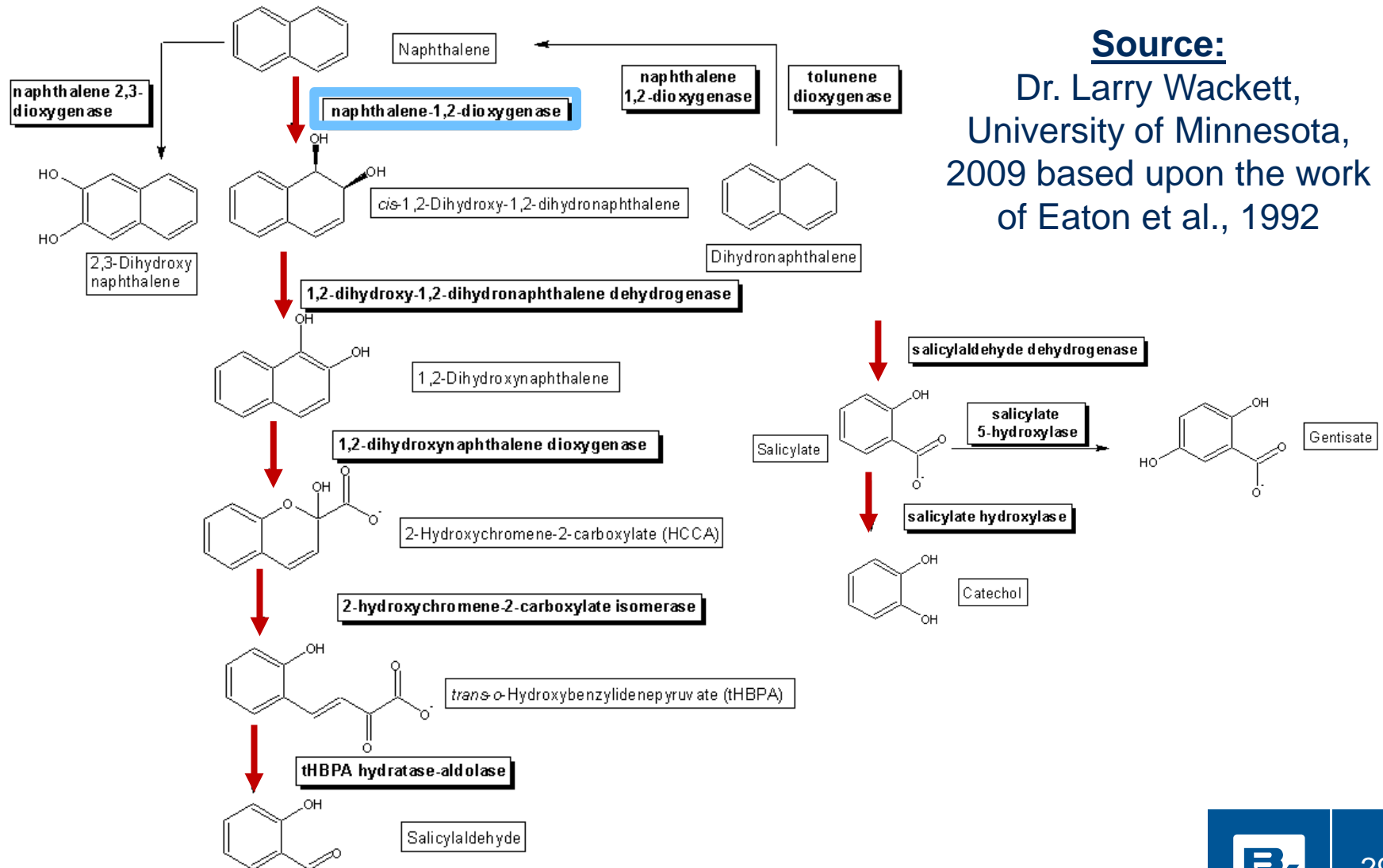
- Phase 1 = 30 days injection
- Phase 2 = 89 days injection

Phase 1 and 2 Pilot Scale ORP Results



- Phase 1 = 30 days injection
- Phase 2 = 89 days injection

Naphthalene Aerobic Degradation Pathway



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Sampling for *In Situ* Microbial Population



Bio-Flo Samplers

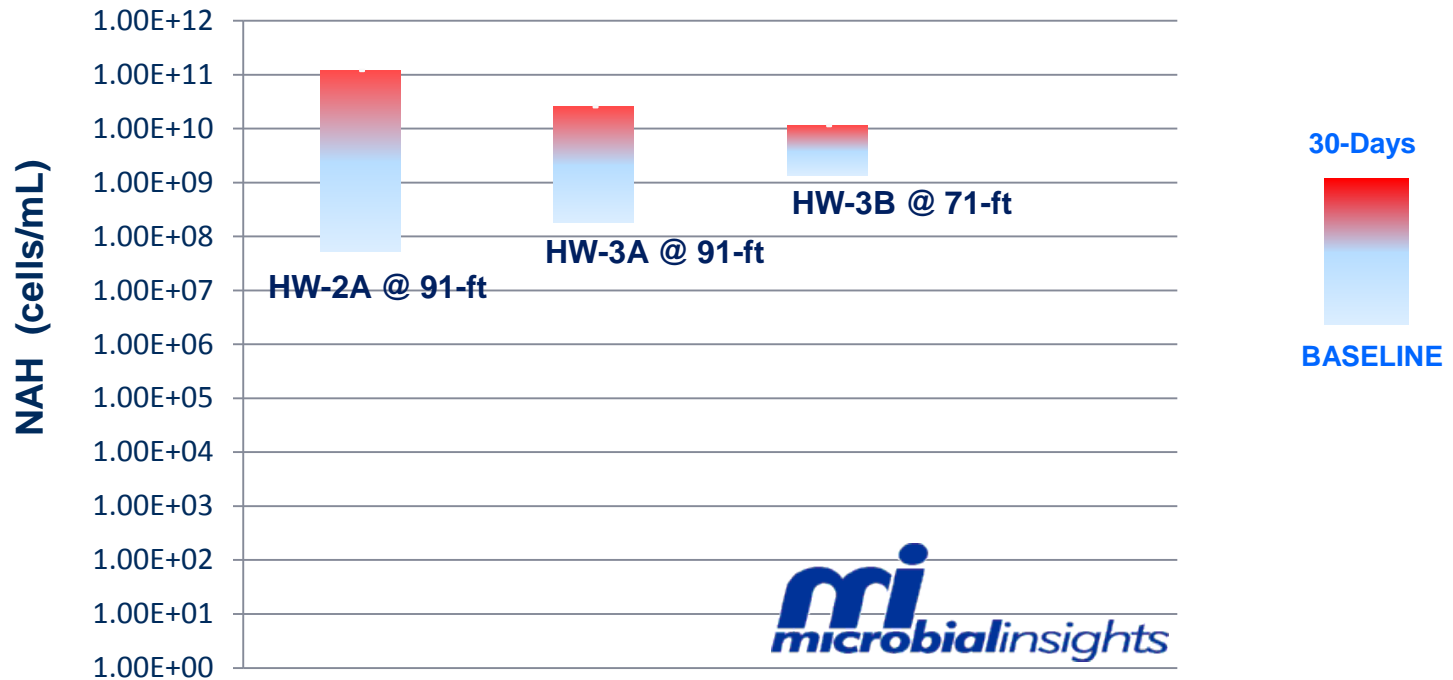
- Field sample collection
- Used to record baseline & post-pilot test populations of degraders
- 1 to 2 Liters
- Microbes live on solid surface



Bio-Trap® Samplers

- Contains beads of activated carbon with high surface area for microbial growth
- ~30-day incubation
- Unique sampling matrix, bio-sep beads, which mimics environmental conditions
- Can be analyzed using a variety of molecular based approaches (DNA, RNA and PLFA)

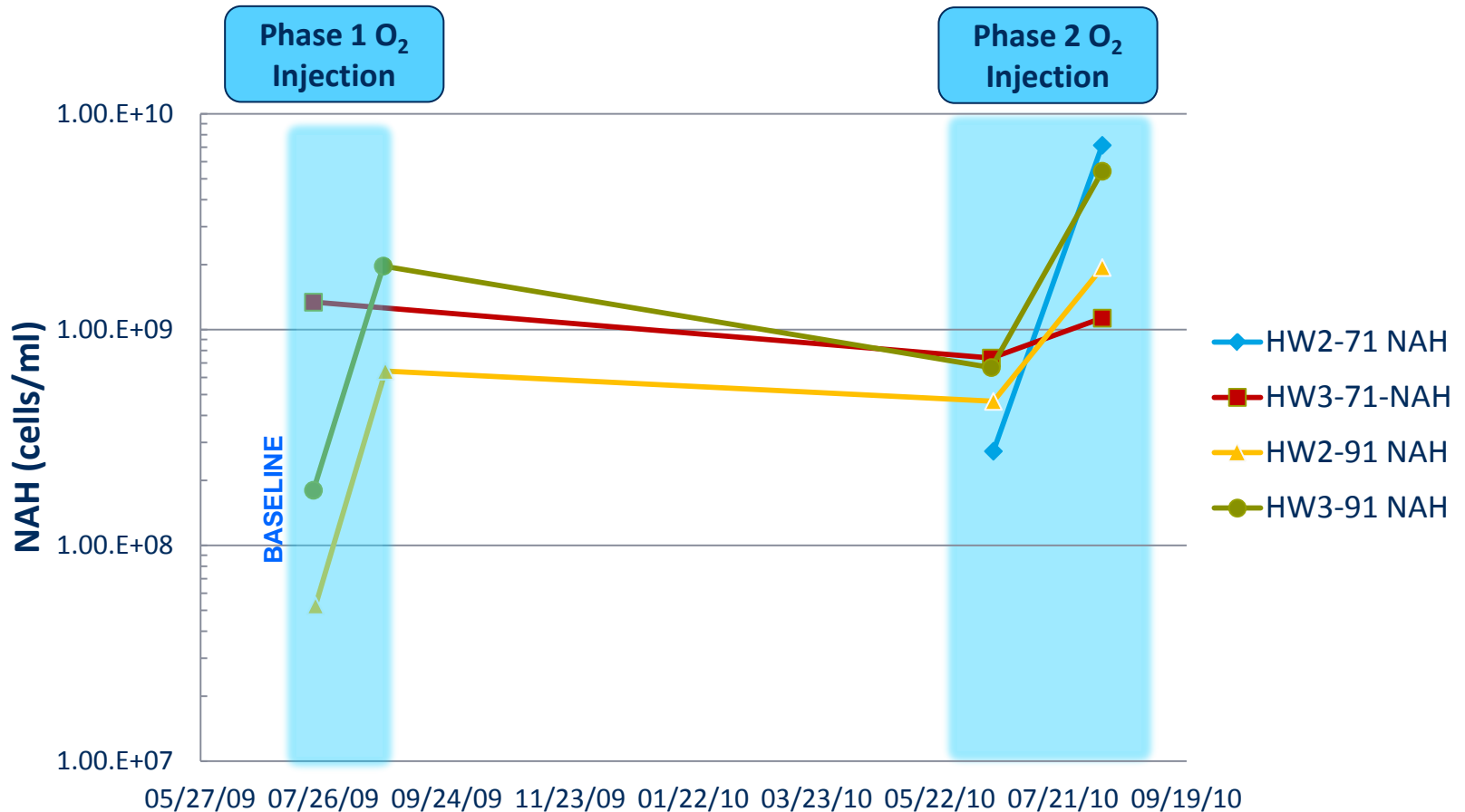
Downwell Microcosm Study - Phase 1 Injection



- Microcosm study consisted of Bio-Trap cylinders installed in 3 wells for one month (07/25/09 to 08/25/09)
- Baseline results from Bio-Flo Sampler

NAH = Naphthalene Dioxygenase

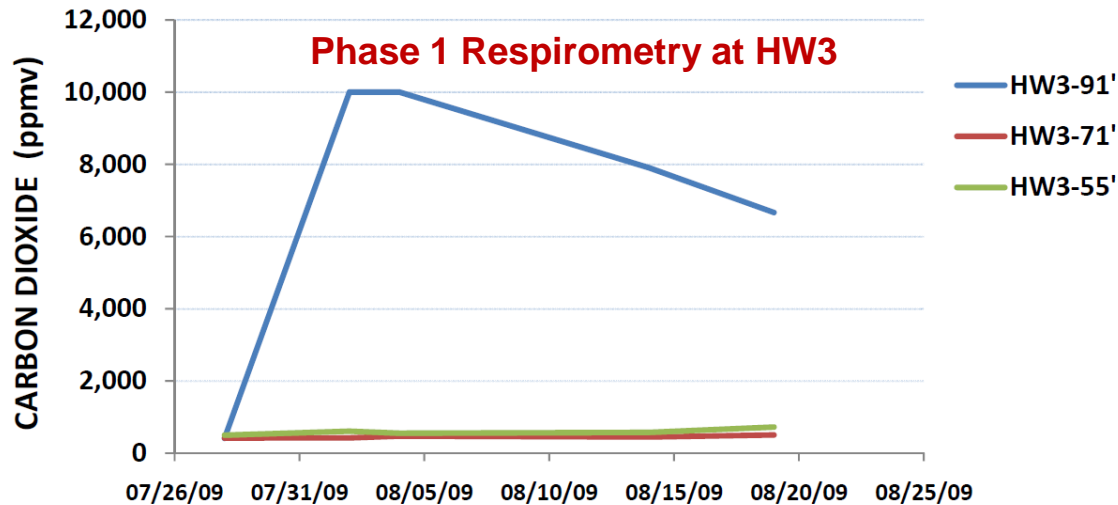
NAH Indicator Gene Populations by qPCR



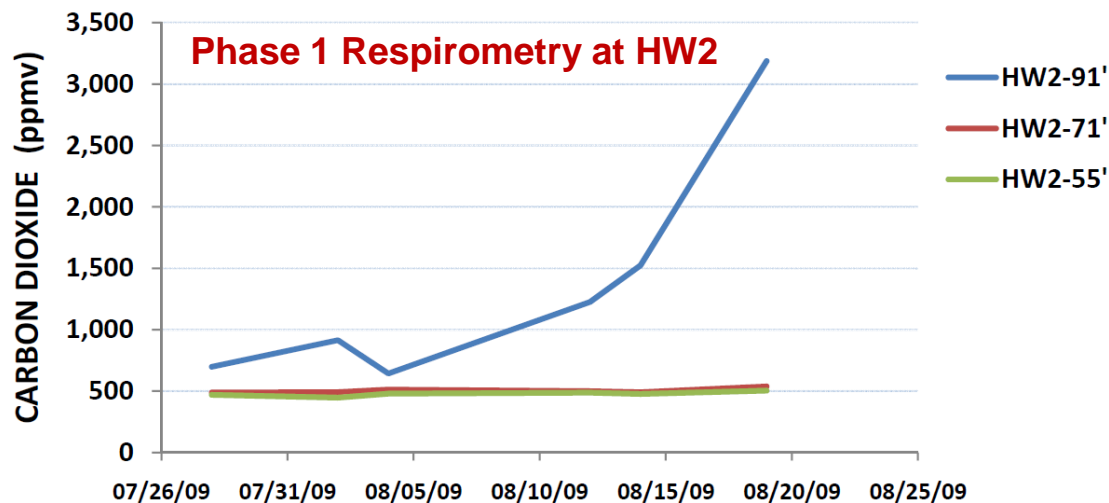
Bio-Flo Sampling
 NAH = Naphthalene Dioxygenase



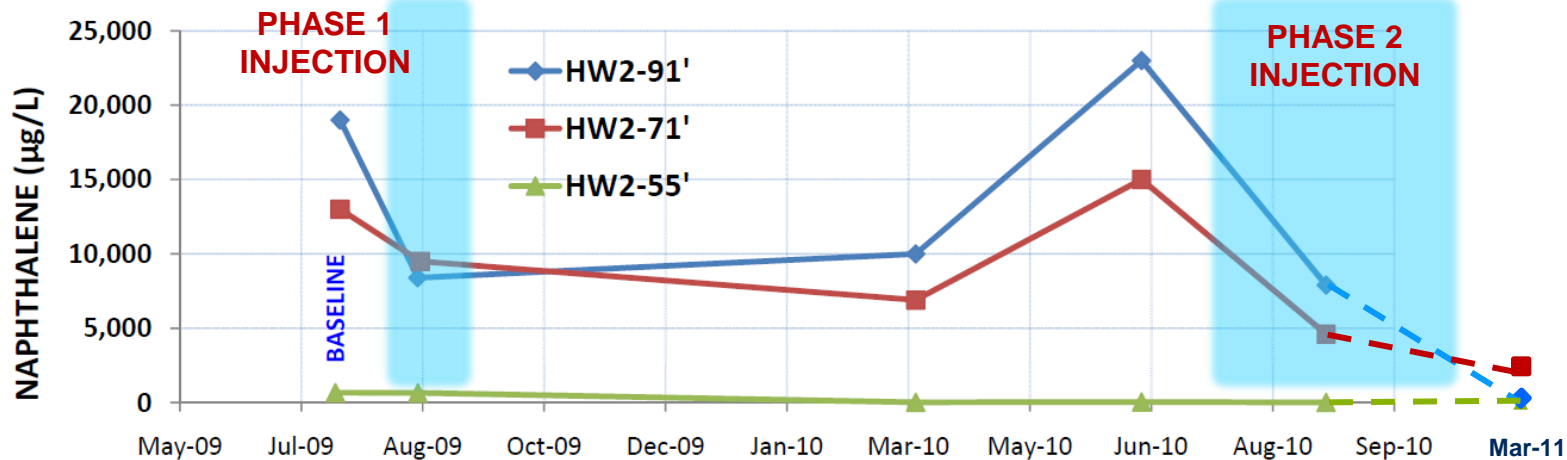
Phase 1 Pilot Scale Respirometry Data



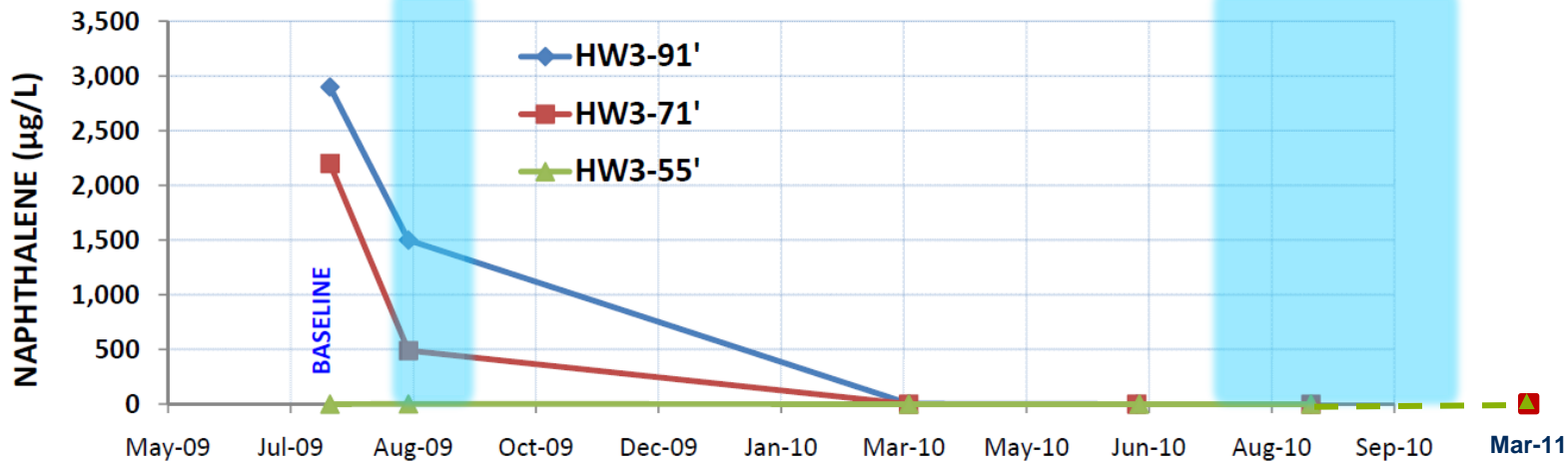
- Wellhead CO₂ Analysis
- 500 ppmv is background value in air



Naphthalene Analytical Sampling



NAPHTHALENE DEGRADATION OVER TIME AT HW2



NAPHTHALENE DEGRADATION OVER TIME AT HW3

Conclusions and Lessons Learned

- Directional drilling of 1450-ft long and 100-foot deep **cluster biosparge well** was quite successful.
- ADS Sparge pipe proved effective.
- Additional performance monitoring wells would greatly enhance determination of the lateral influence of dissolved oxygen and naphthalene-consuming bacteria.
- Vertical biosparging wells would serve to compare the HDD effectiveness and cost for full-scale operation.
- The optical DO downwell probes on the trolls maintained calibration through 90 days of operation.
- **Good convergence of data** for pilot test success:
 - ✓ **Analytical results**
 - ✓ **Field DO and ORP data**
 - ✓ **Bacterial microcosm results**
 - ✓ **Respirometry**



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