

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

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Background/Objectives. The Escambia Wood Treating Company (ETC) site is a former wood-preserving facility located in Pensacola, Florida that operated from 1942 through 1982. ETC treated wood products with coal tar creosote and PCP. Process waste water including spent creosote and PCP were disposed in an unlined waste pond. NAPL migrated from the waste pond vertically to over 100 ft bgs. The site is underlain by complex sequence of sand, gravel, silt and thin lenses of clay in three defined zones; surficial, low permeability (LPZ) and main producing zones. This aquifer is the primary municipal drinking water supply. A dissolved SVOC plume (primarily naphthalene), up to a quarter-mile wide and one-mile long, and 200 ft deep extends downgradient from the ETC source area. An active railroad switching yard is located adjacent to and downgradient of the on-site source area.

Approach/Activities. In situ bioremediation with aerobic biobarriers was selected in the Feasibility Study to remedy the extended plume. A pilot study was prepared for beneath the rail yard to evaluate the site-specific oxygen transfer efficiency and effectiveness of the remedy. Three bundled horizontal wells were used to infuse oxygen into the LPZ. The pilot study included pulsing oxygen into the infusion wells during two phases, including a 30-day period in July 2009 and a 90-day period in June 2010.

A 1,450 foot horizontal bore was advanced to a depth of 100 ft bgs. Three 2-inch diameter injection wells, each 170 foot long, were installed within the bore using horizontal directional drilling (HDD). The screens were constructed with different slots and materials (stainless steel, ADS HDPE flex pipe) to assess optimal well construction materials. Performance monitoring wells were installed at depths of 55, 71 and 91 feet and at distances of 5, 15, and 20 feet from the injection wells. Oxygen was produced on-site using a pressure-swing adsorption oxygen generator. The 90% oxygen was injected from a storage tank at mass injection rates up to 113 pounds/day per injection well. The oxygen was pulsed into the horizontal infusion wells at variable durations to assess optimization of bioremediation. Pilot test results were attained through groundwater monitoring of downgradient wells, including SVOC analyses, qPCR analyses of aerobic bacteria (bioflow filters and biotrap), continuous downwell DO and ORP field monitoring, and general chemistry parameters before, during, and after pilot testing.

Results/Lessons Learned. The pilot study produced essential information for the upcoming full scale aerobic biobarrier design based on additional horizontal oxygen infusion wells. The use of a carrier casing and biopolymer drilling fluids during HDD contributed to a successful installation. The oxygen feed system ran flawlessly and was easily adjusted via a remote PLC system. During the one month pilot study, DO increased

from near 0 to at least 52.5 mg/L at a depth of 91 feet. Solubility was calculated at 56 mg/L for this depth. DO increased to 10 mg/L or higher at depths of 55 and 71 feet. A corresponding increase in oxidation-reduction potential up to 200 mV and a tenfold increase in dissolved carbon dioxide were also measured. Laboratory analyses showed up to 4 orders magnitude increase in aerobic bacteria, with an overall reduction in dissolved naphthalene of 50 to 95 percent during oxygen infusion. The test demonstrated that a successful aerobic barrier was created throughout the 55-foot water column and outward to at least 20 feet, with a minimum DO of 10 mg/L. The data indicate that an oxygen reservoir was created, oxygen demand was significantly reduced, and periodic pulse injections are effective in maintaining highly aerobic conditions. Post pilot test monitoring has attested to the longevity of elevated DO in the LPZ, and limited naphthalene rebound from the source.

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Oxygen Injection Systems

June, 2011 • Reno



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in a Changing World



ESCAMBIA WOOD TREATING SITE

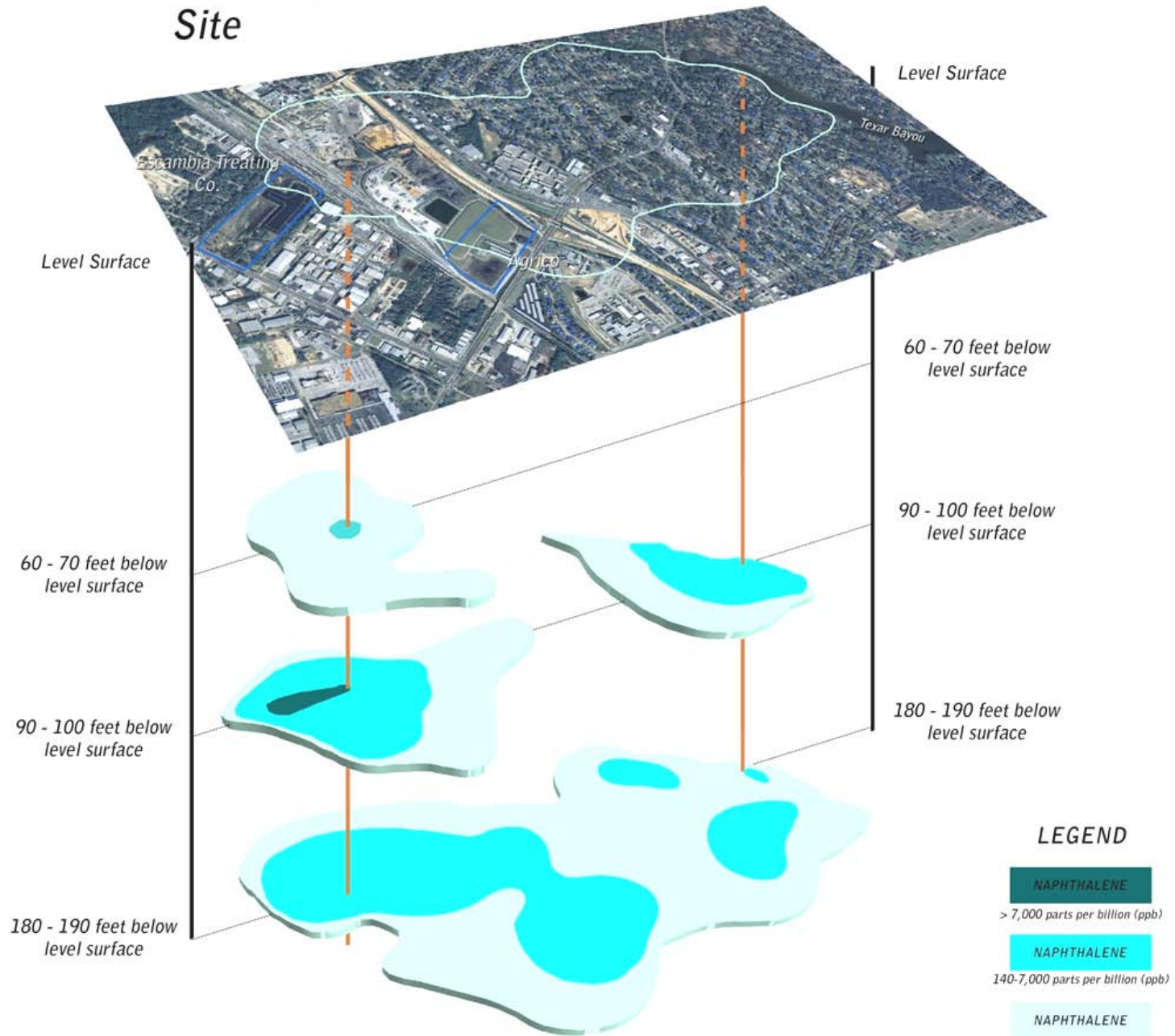
Background

- 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

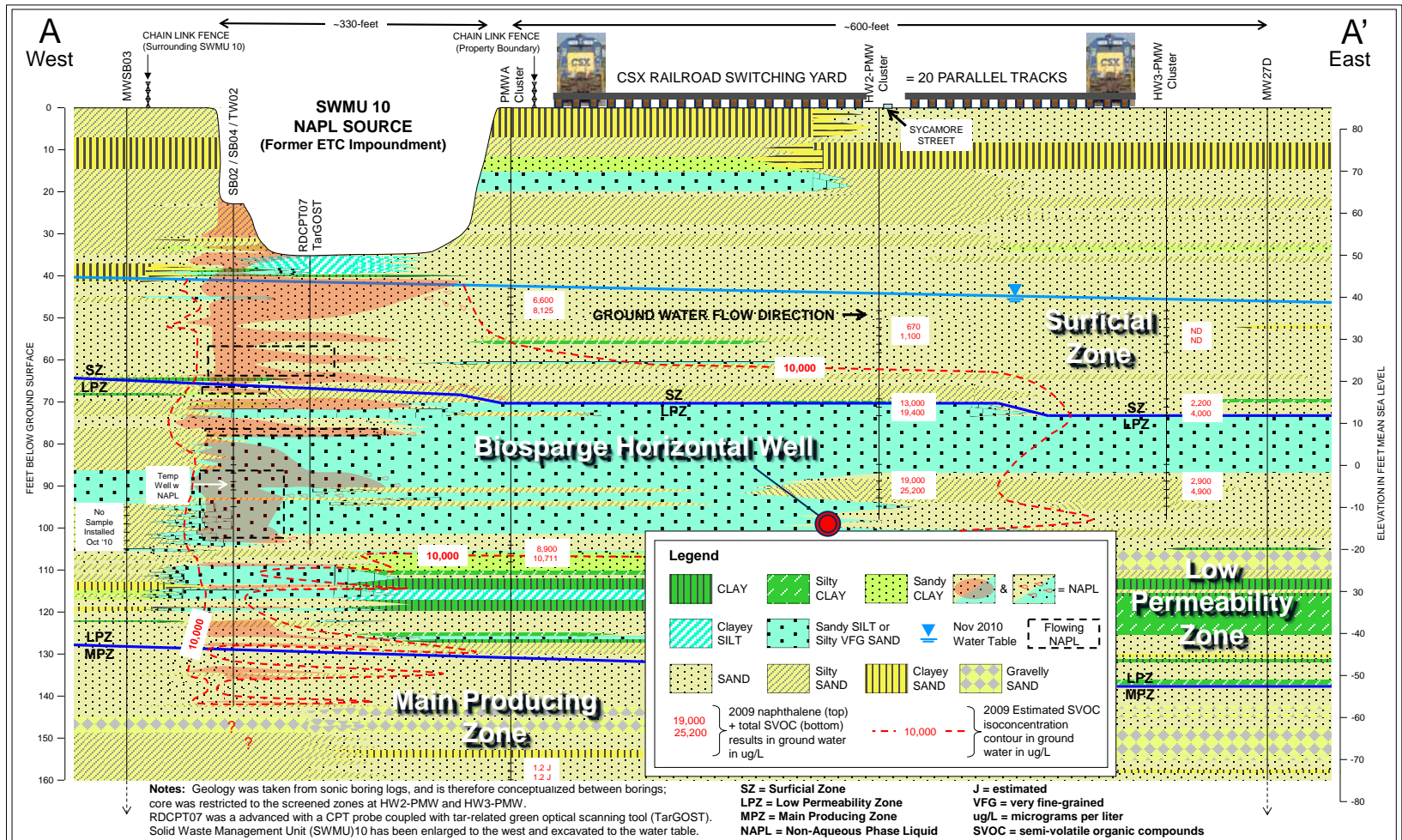
BACKGROUND



Composite Depth Naphthalene Plume

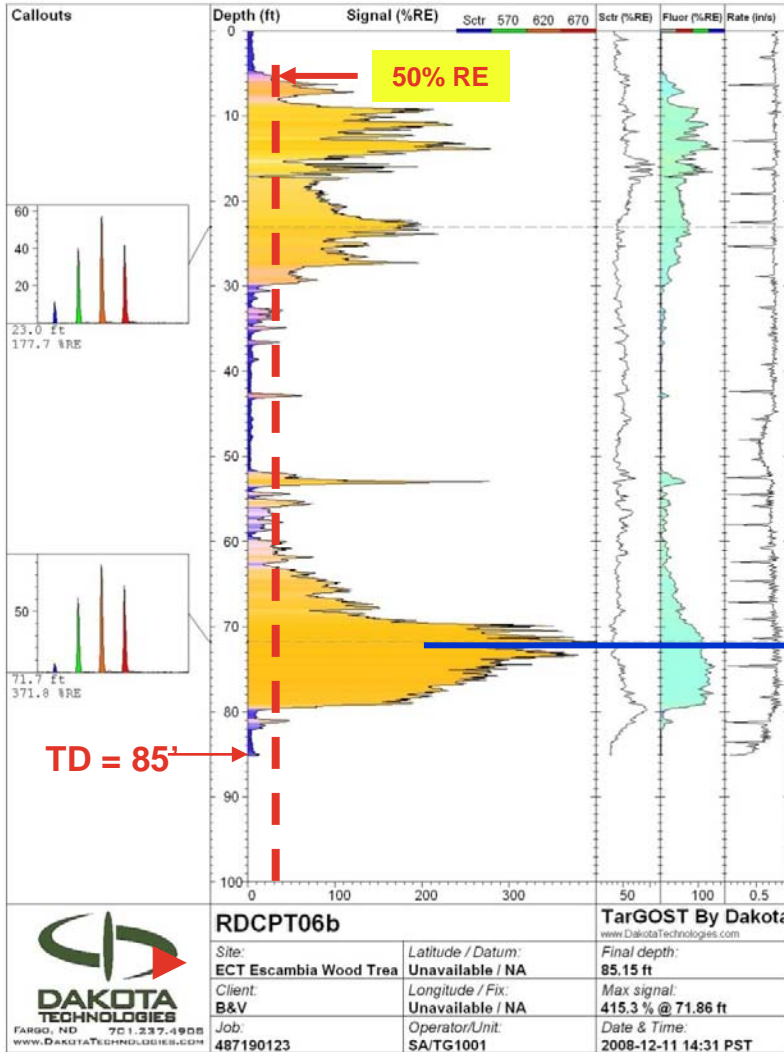


Site Conceptual Model



Source Zone DNAPL

TarGOST Source Boring (CPT Rig)



DNAPL at 70 ft bgs



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

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



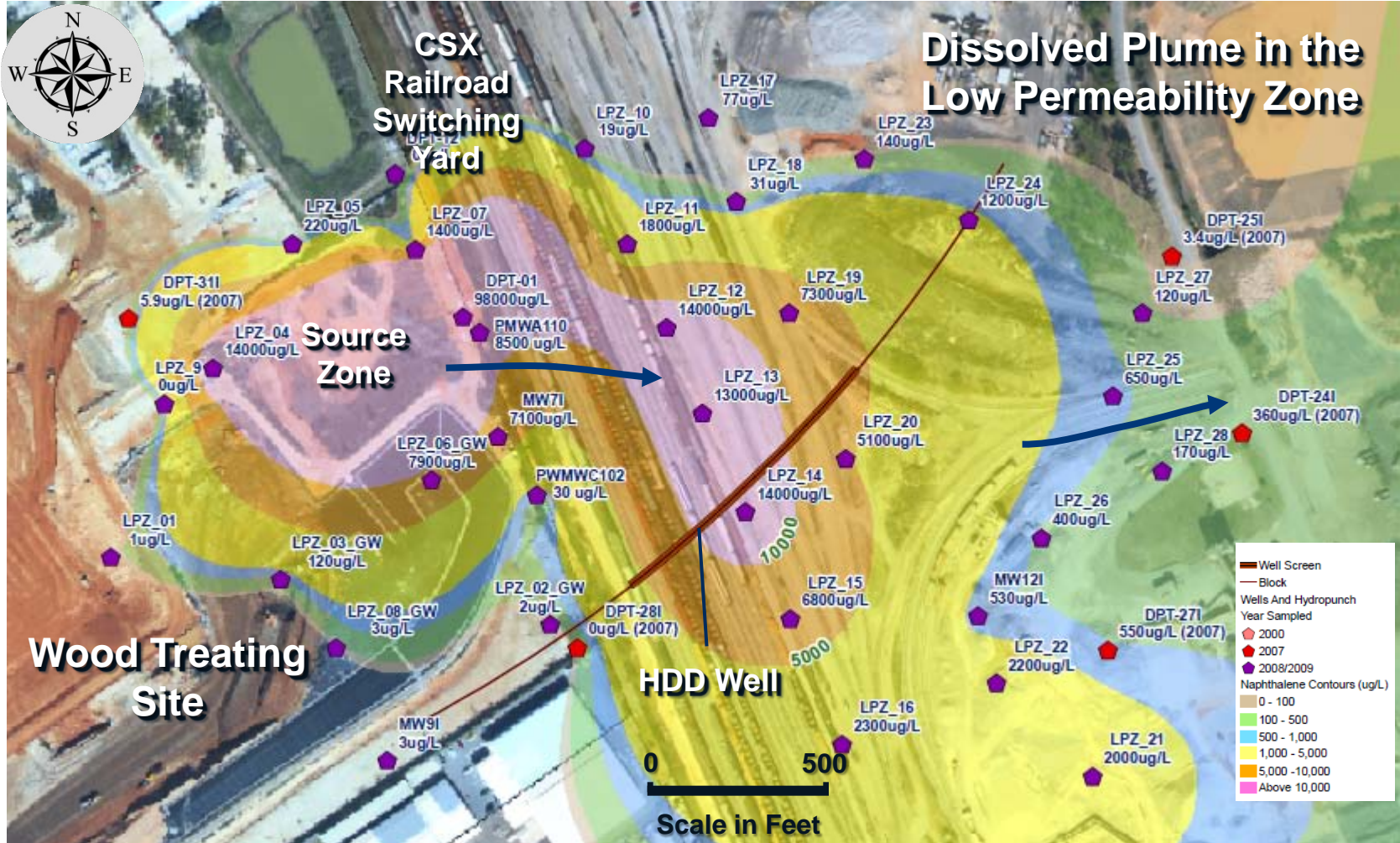
Biosparge Pilot Test Setup



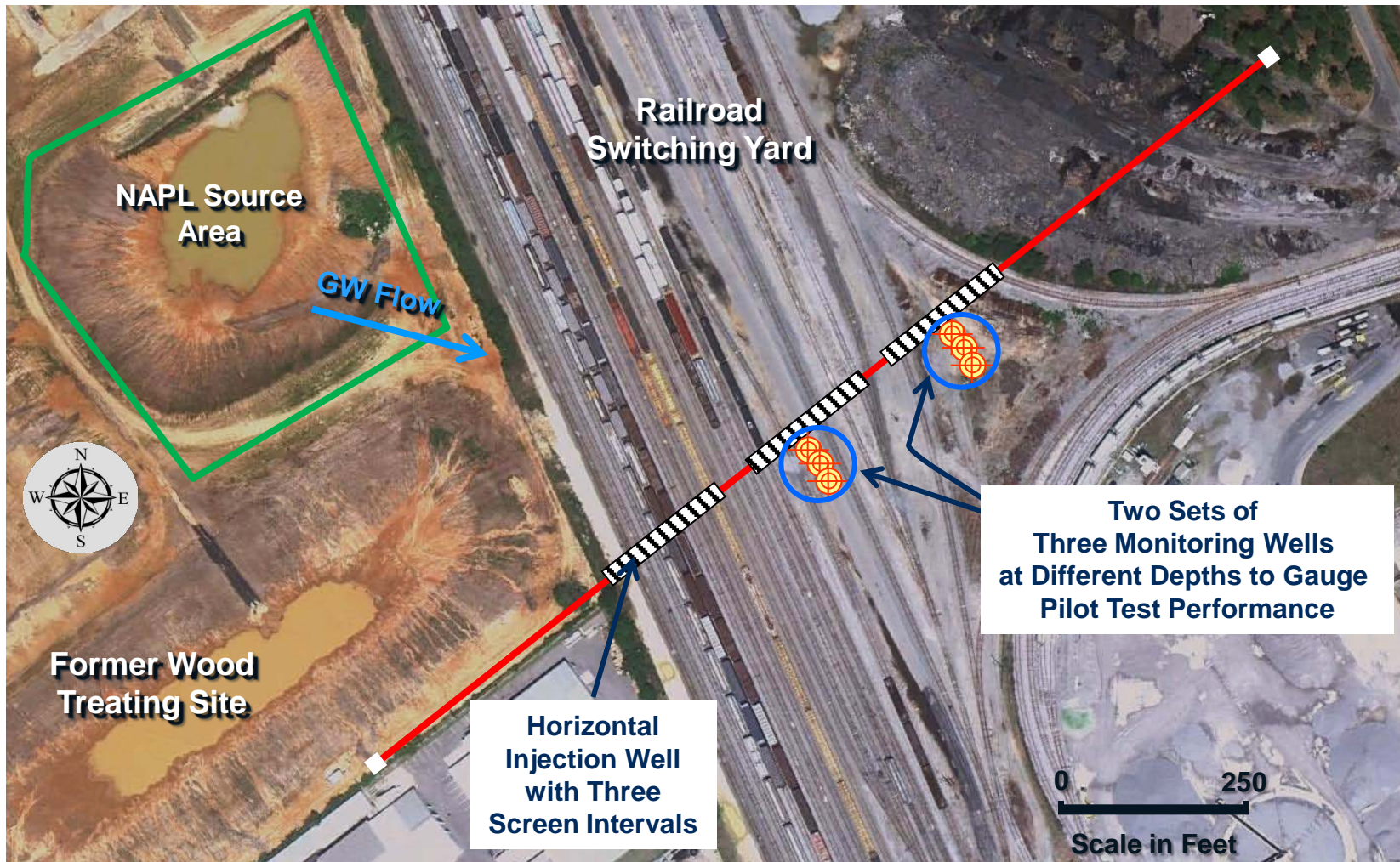
BIOSPARGE PILOT TEST GOALS

- 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**

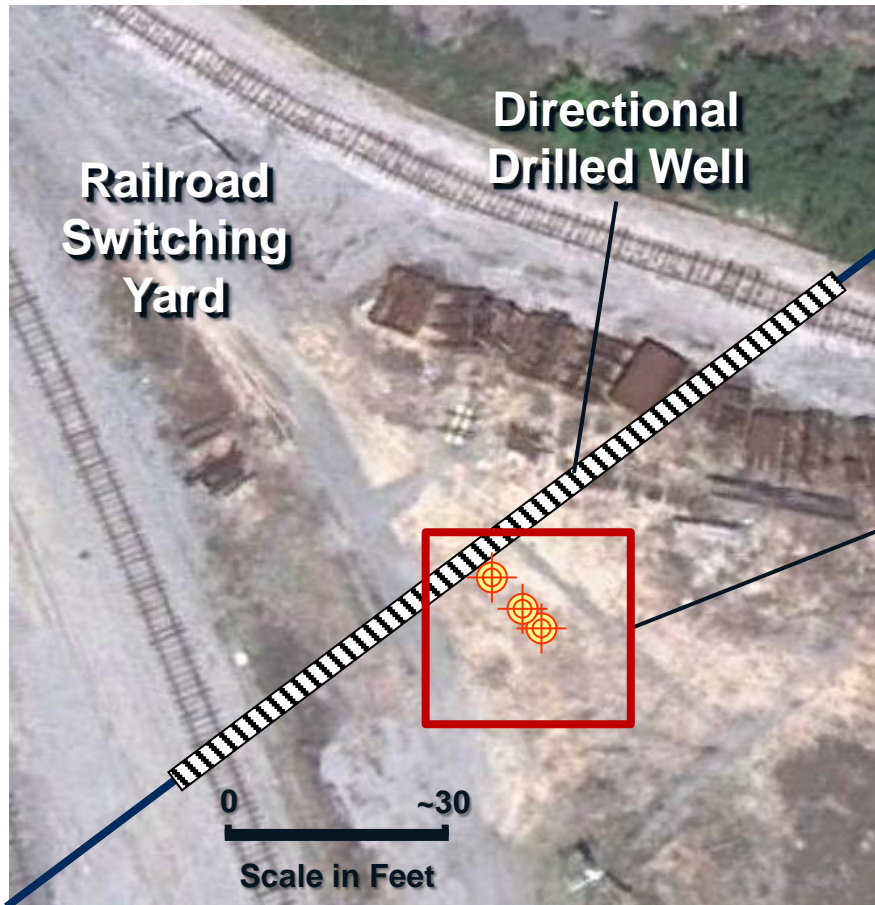
NAPHTHALENE PLUME



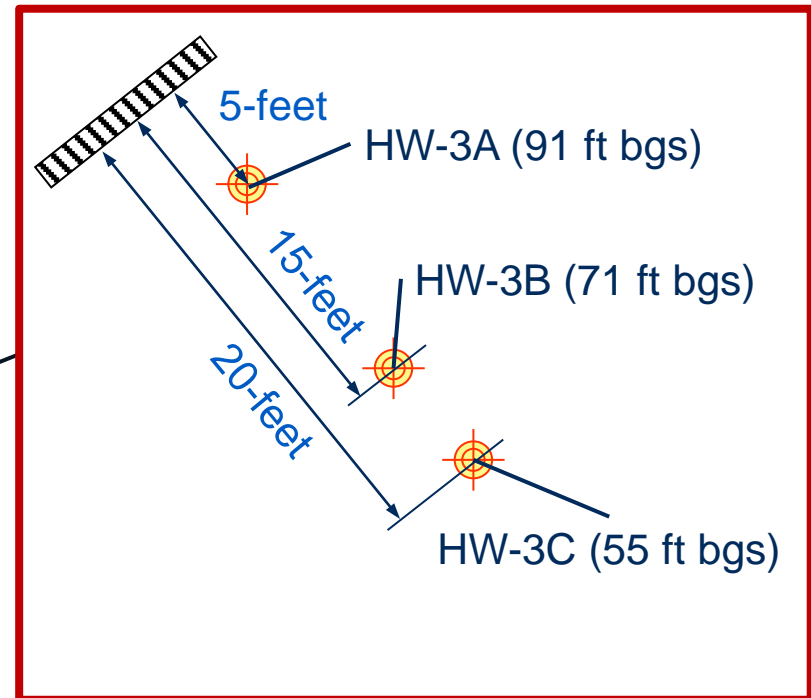
LAYOUT OF *IN SITU* BIOSPARGE PILOT TEST



Performance Monitoring Wells



HW-3 Performance Monitoring Array



In Situ Biosparge Pilot Study Components

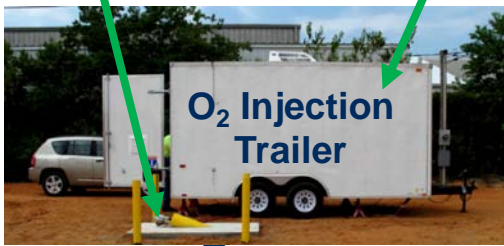
Bundle of 3 Injection Wells



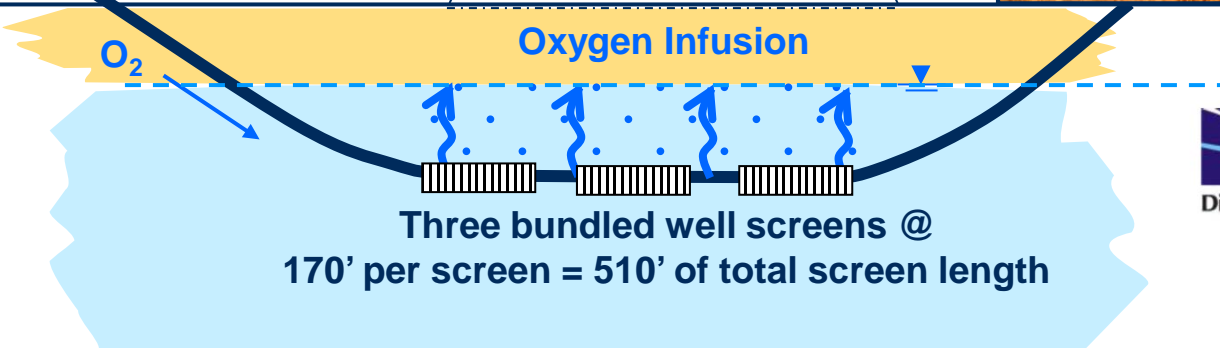
Air Conversion to >90% Pure O₂



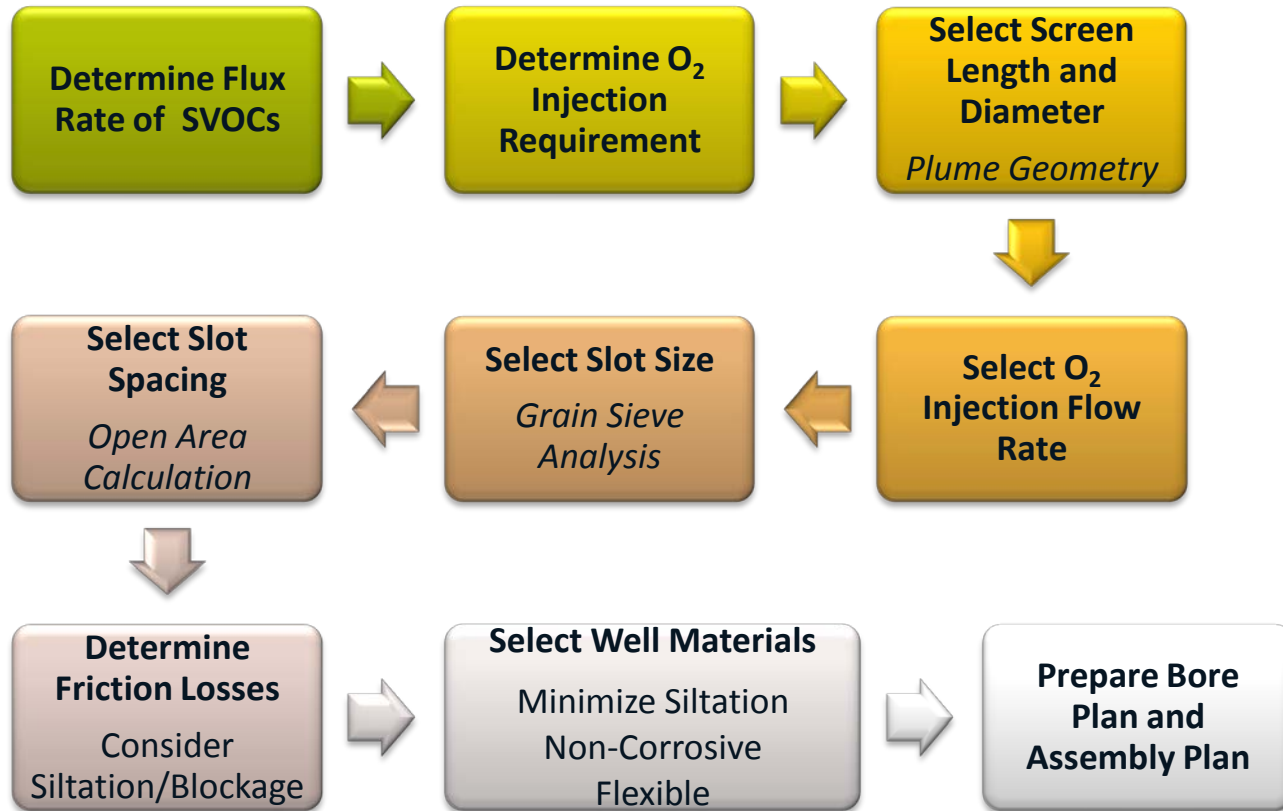
Horizontal Directional Rig drilling the 1,450 ft long bore to 100 ft bgs, and installing the bundle of three (3) injection well screens.



[CSX]
Railroad Switching Yard with 20 Parallel Tracks



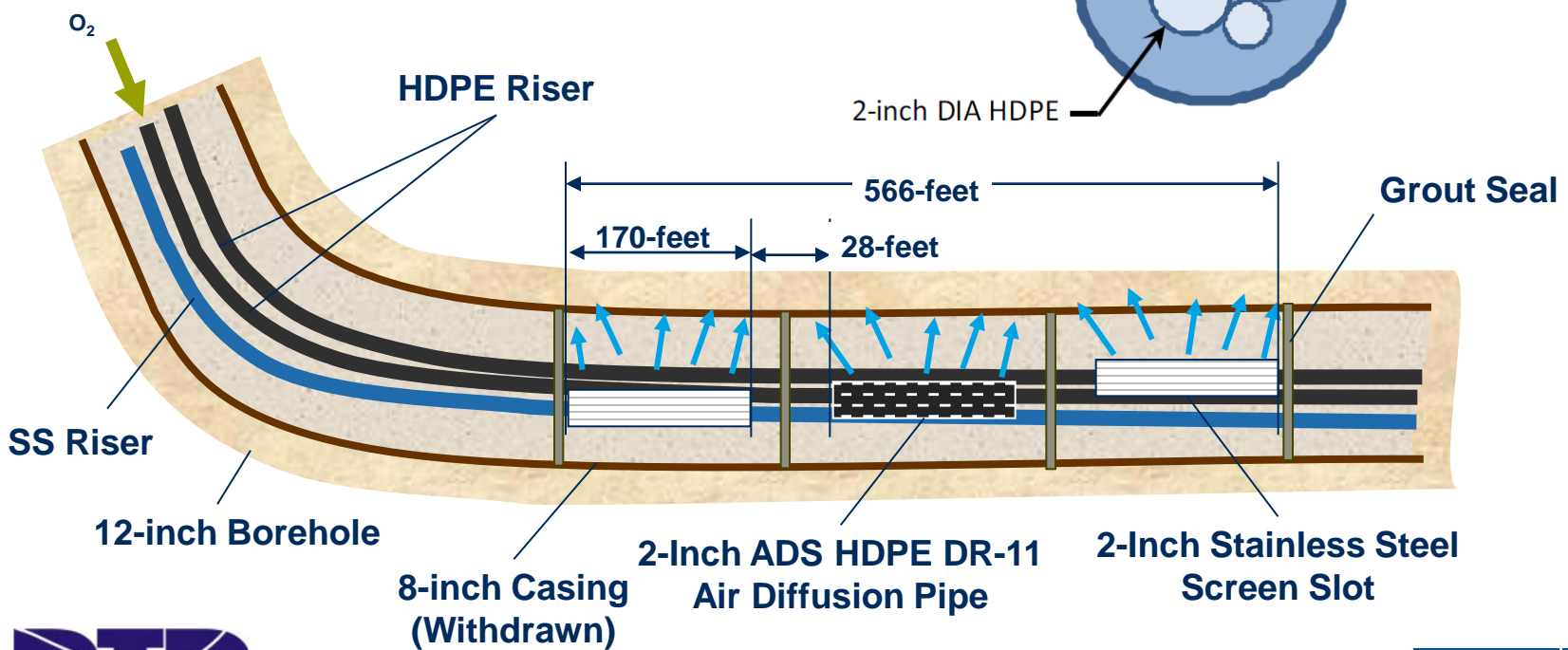
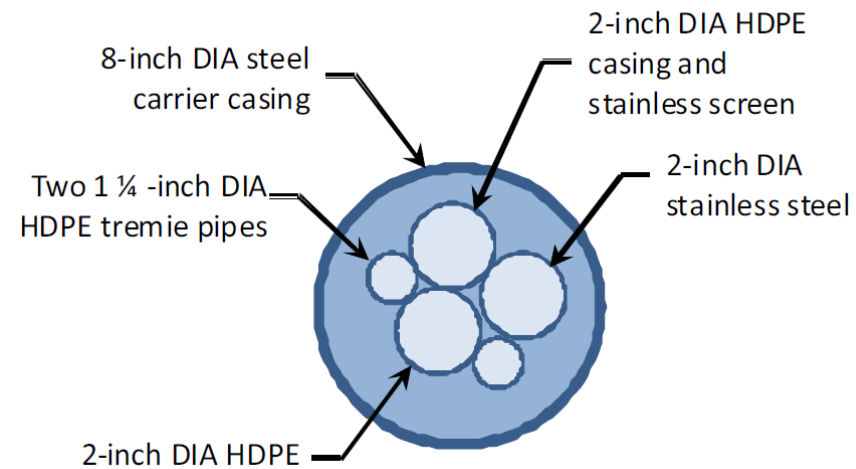
Pilot Scale Biosparge Wall Design



BioSparge Well Construction

Screen Construction

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



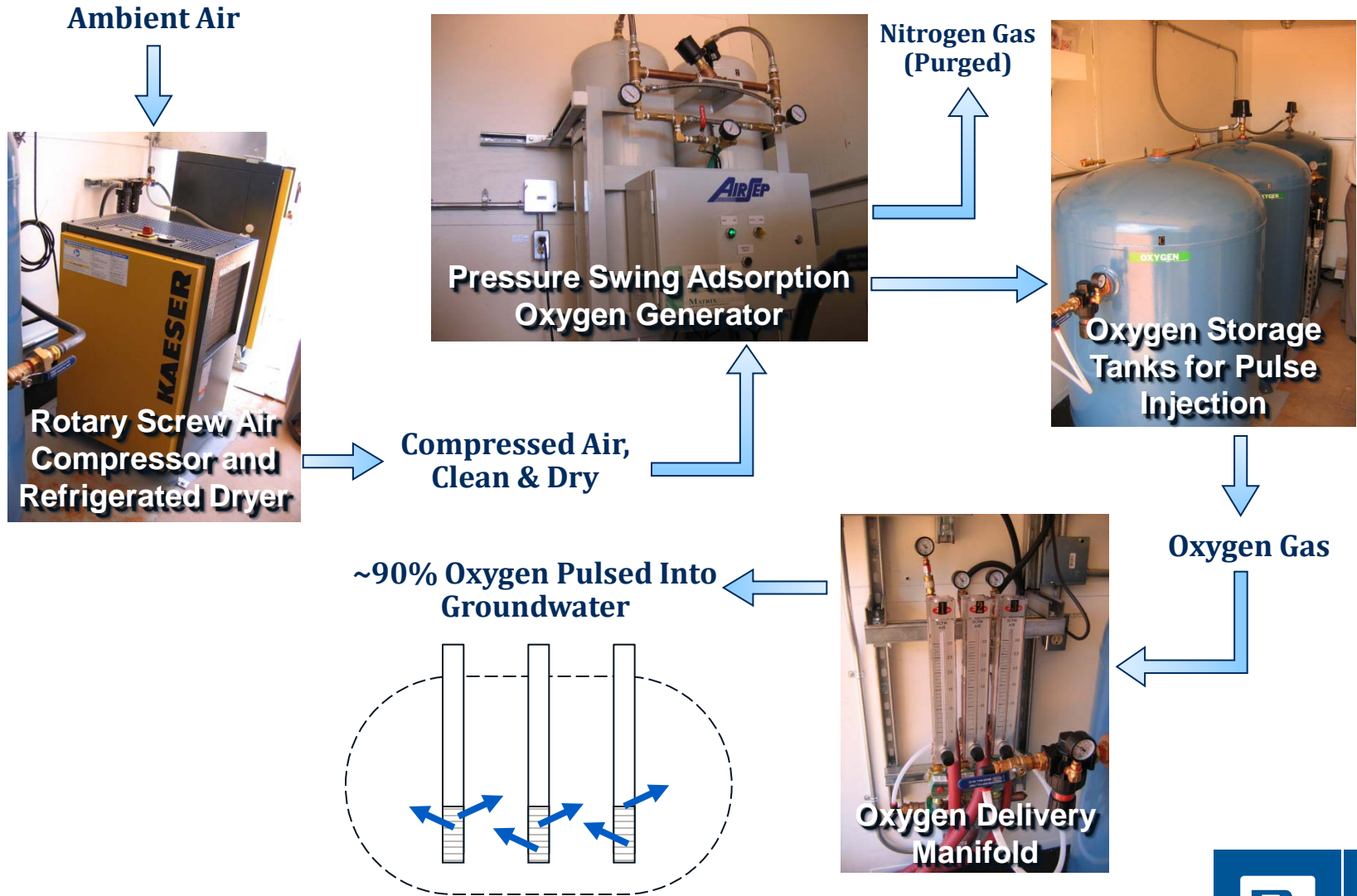
Oxygen Injection Trailer



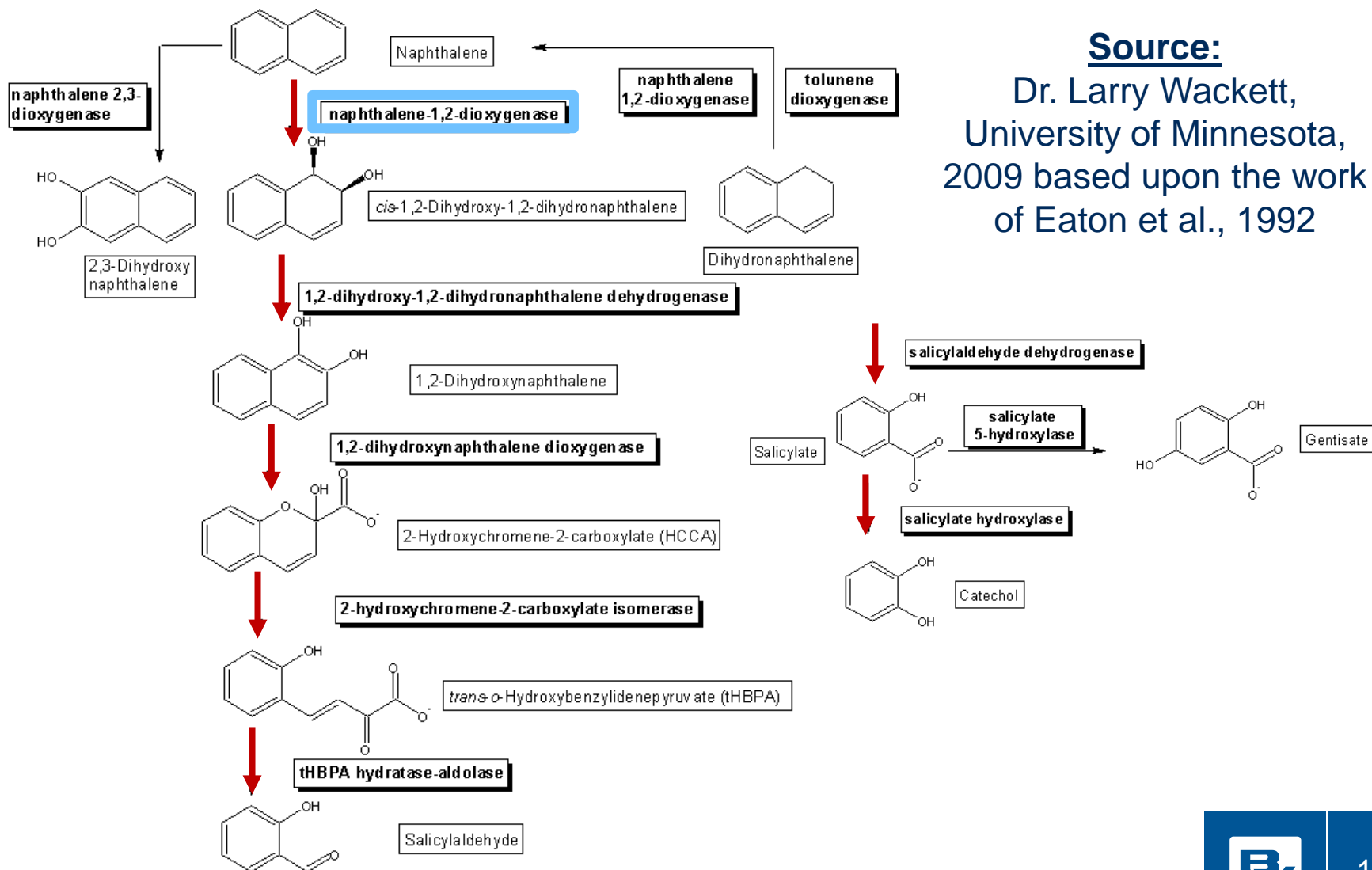
- The Matrix Oxygen Injection System produces **O₂ gas on-site for pulse injection** into groundwater contaminant plumes at controlled rates or volumes.
- DO saturation levels up to **40 mg/L**.
- Dispersion of oxygen with control of radius of influence and oxygen mass transfer
- Used at over 250 remediation 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



Source:

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

Results

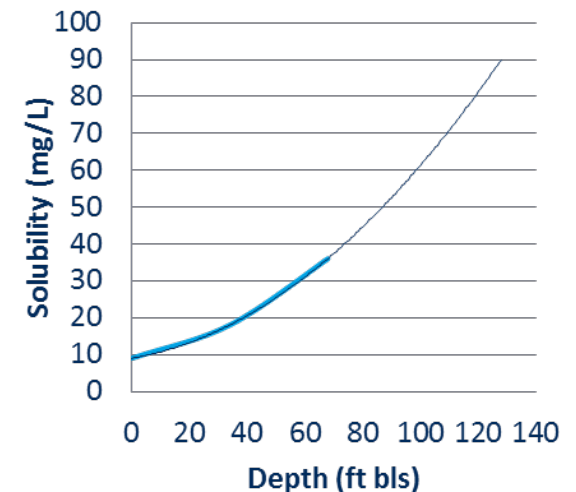
Verification of Dissolved Oxygen Front

Used stable luminescent **optical dissolved oxygen** probes

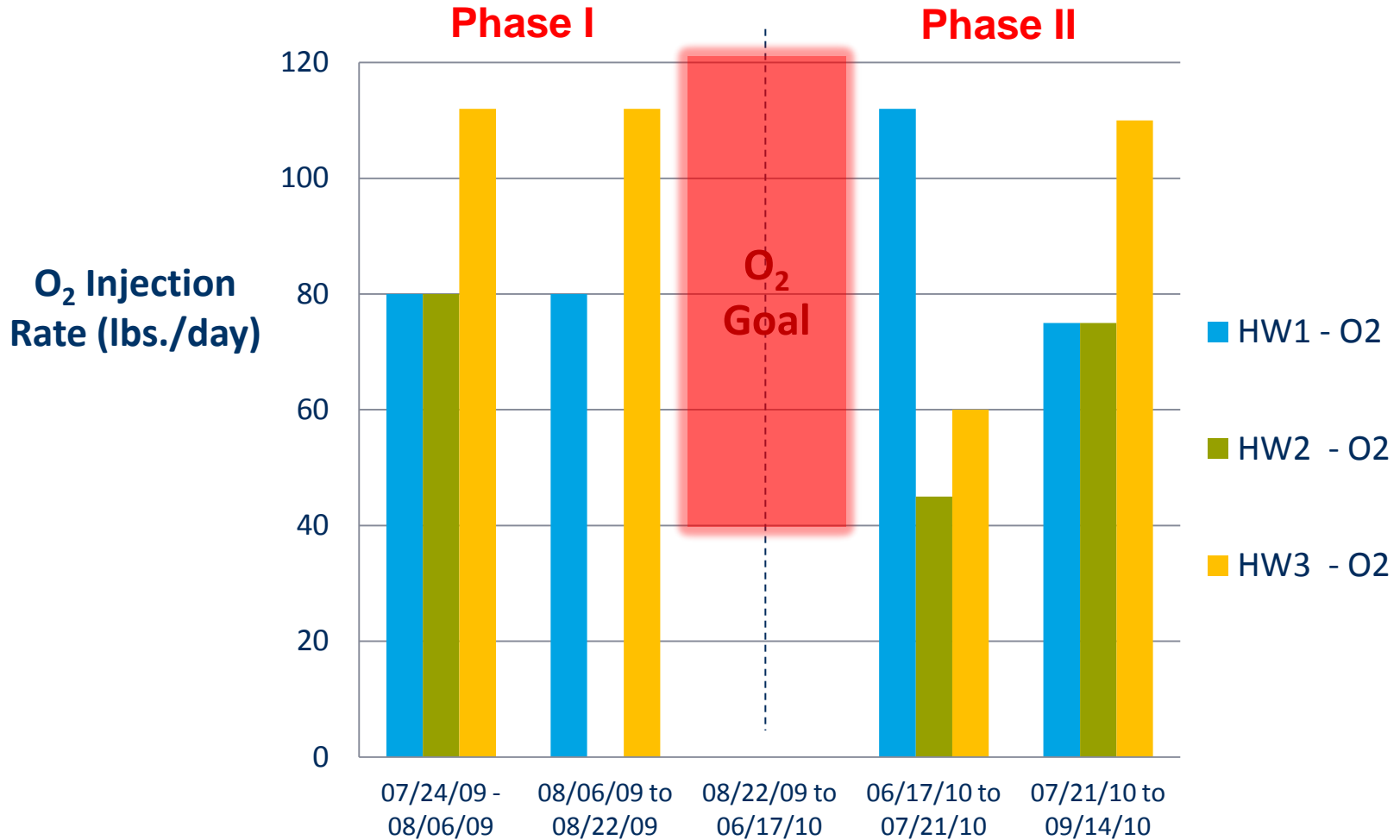
- **Continuous downwell monitoring with Trolls for 30-days** in the 6 performance monitoring wells for DO, ORP, pH, conductivity, and temperature.
- DO Measurement a **critical parameter**
- Oxygen is not consumed as part of an electrochemical reaction, and optical sensors do not require sample flow 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

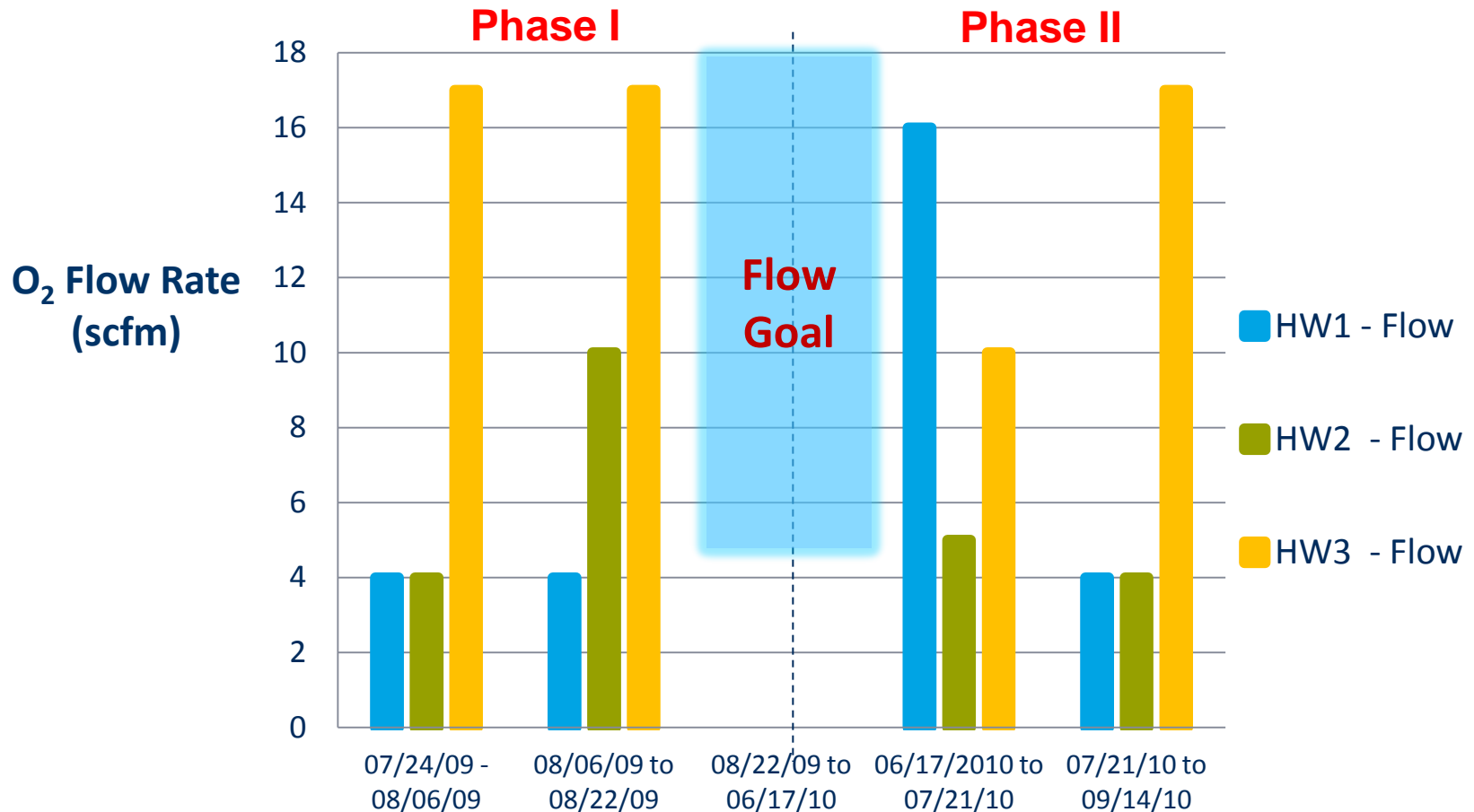


Phase 1 and 2 Pilot Scale Oxygen Feed Rates



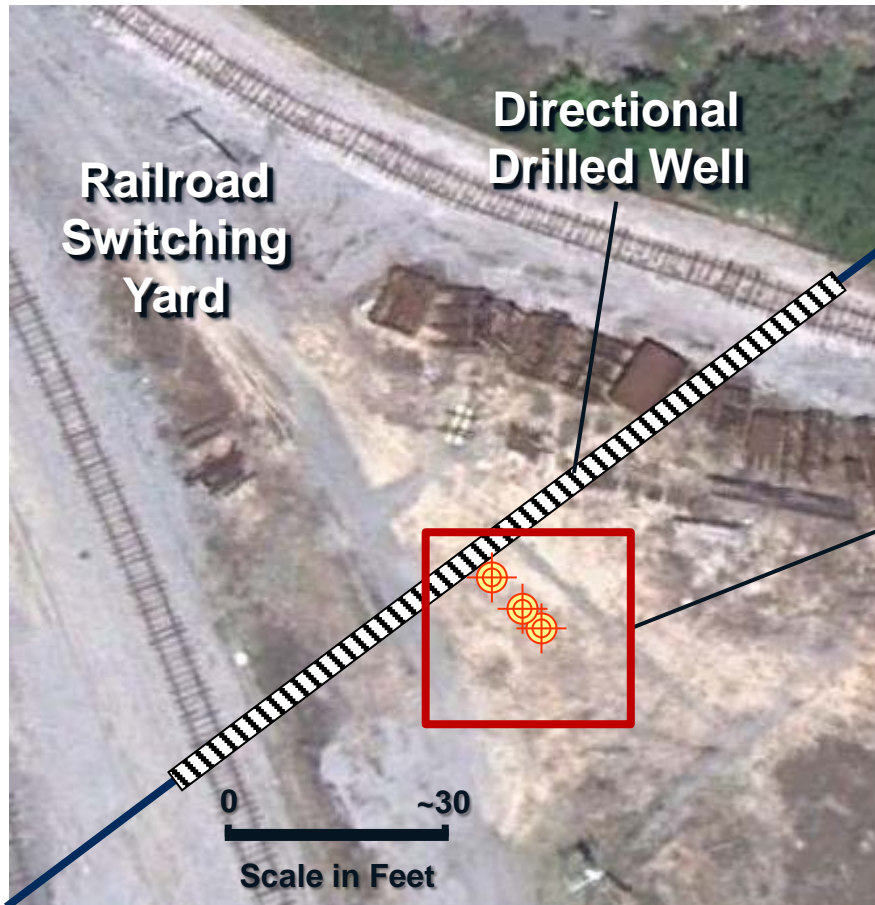
- *In situ* DO target = 10 mg/L (minimum goal of 5 mg/L)

Phase 1 and 2 Pilot Scale Flow Results

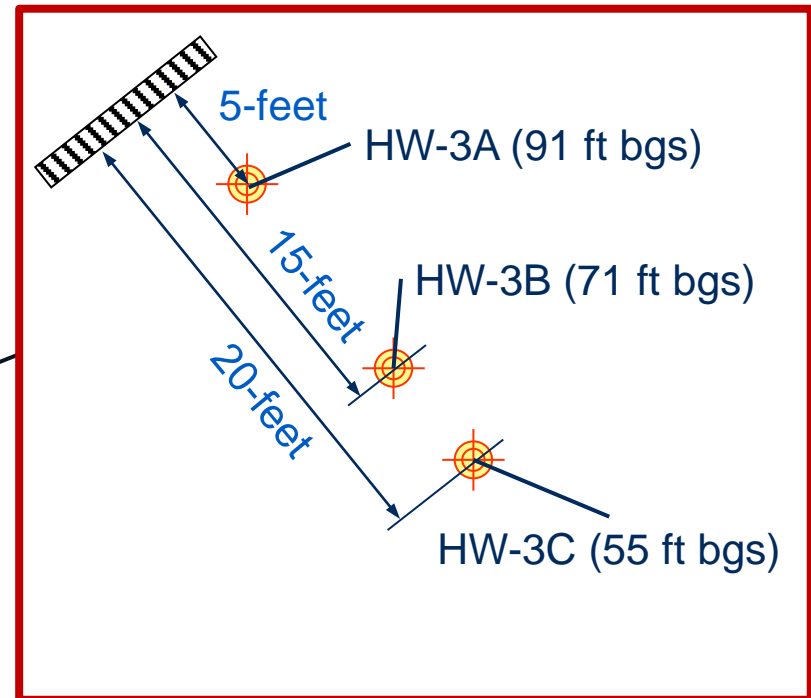


- 0.03 to 0.1 scfm/foot of screen
- Pressures ranged from 30 to 53 psig

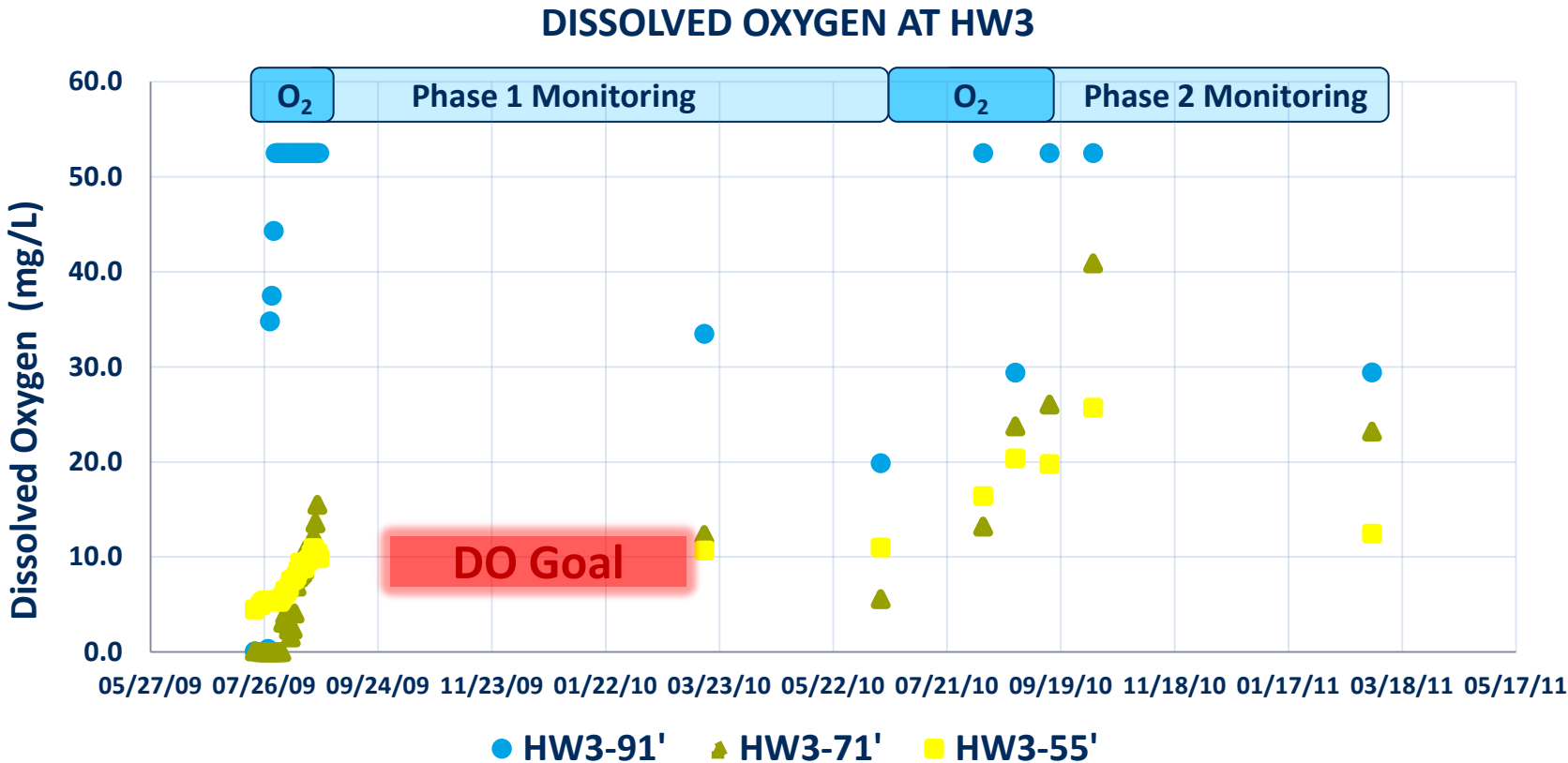
Performance Monitoring Wells



HW-3 Performance Monitoring Array



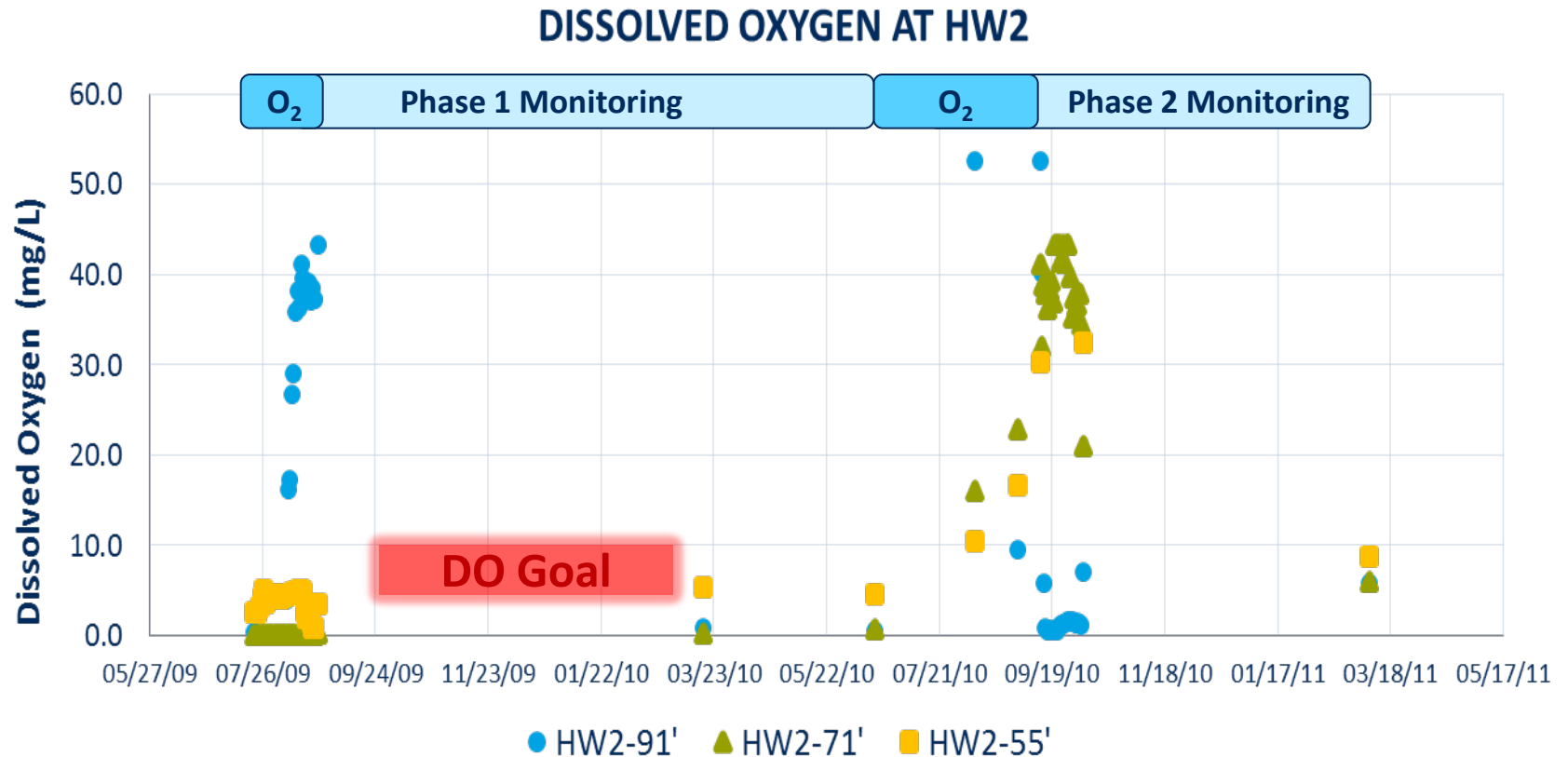
Phase 1 and 2 Pilot Scale DO Results – HW3



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

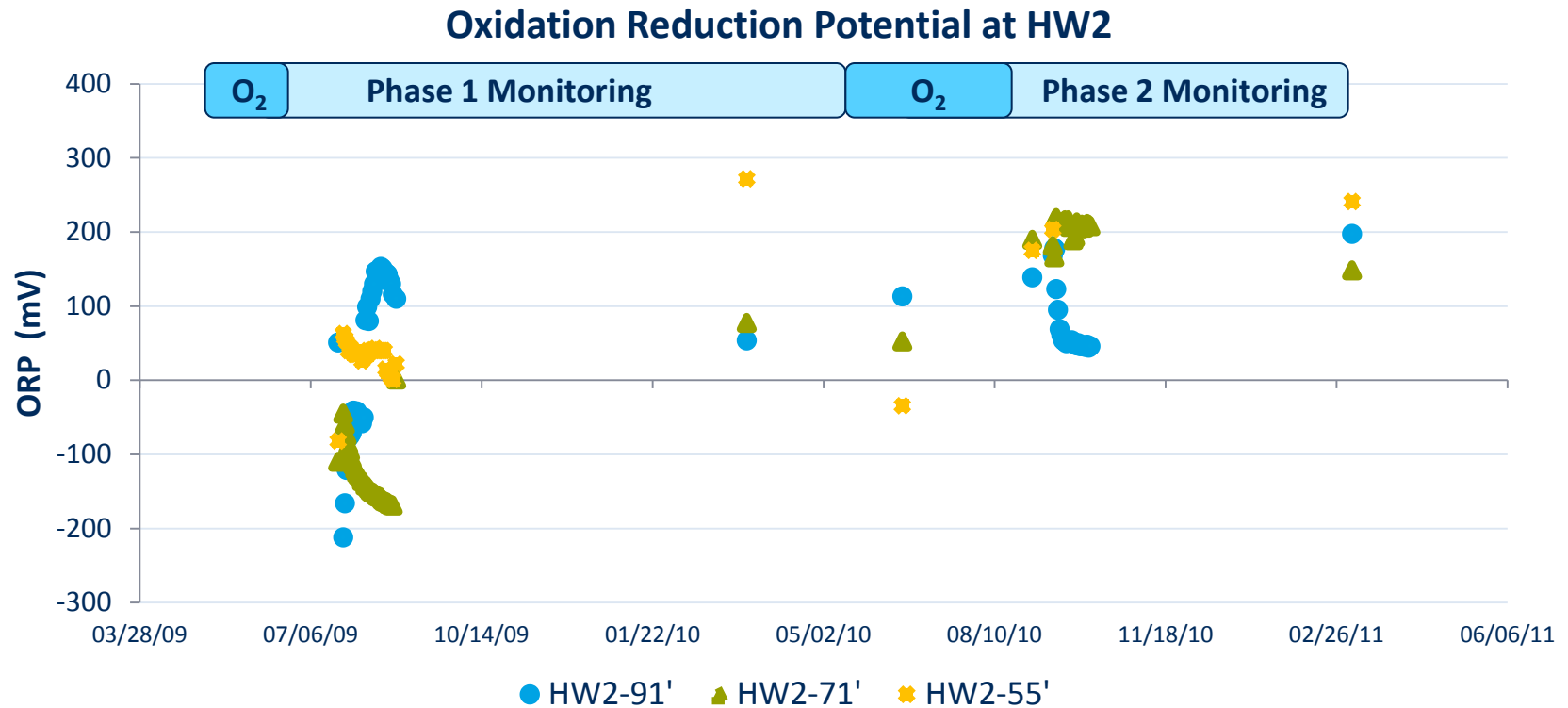


Phase 1 and 2 Pilot Scale DO Results – HW2



- 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

Sampling for *In Situ* Microbial Population



Bio-Flo Samplers

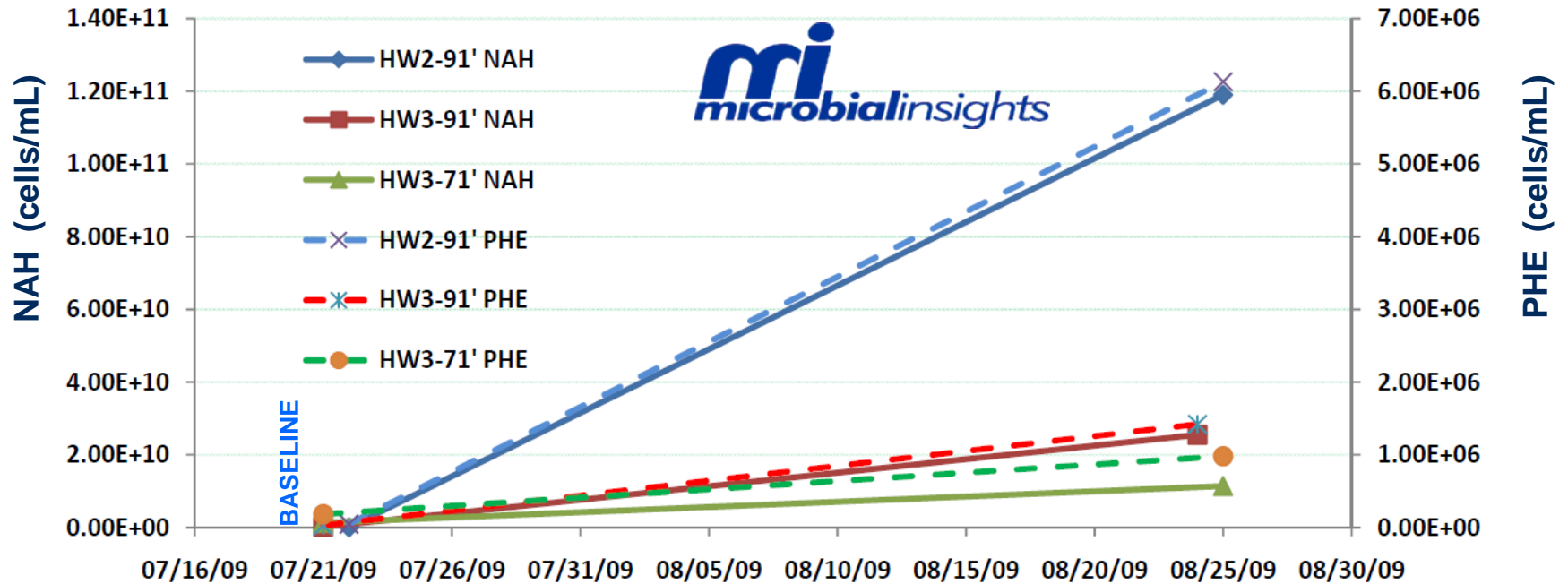
- Field sample collection
- Used to record baseline & post-pilot test populations of degraders
- 1 to 2 Liters
- Microbes live on solid surface



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)

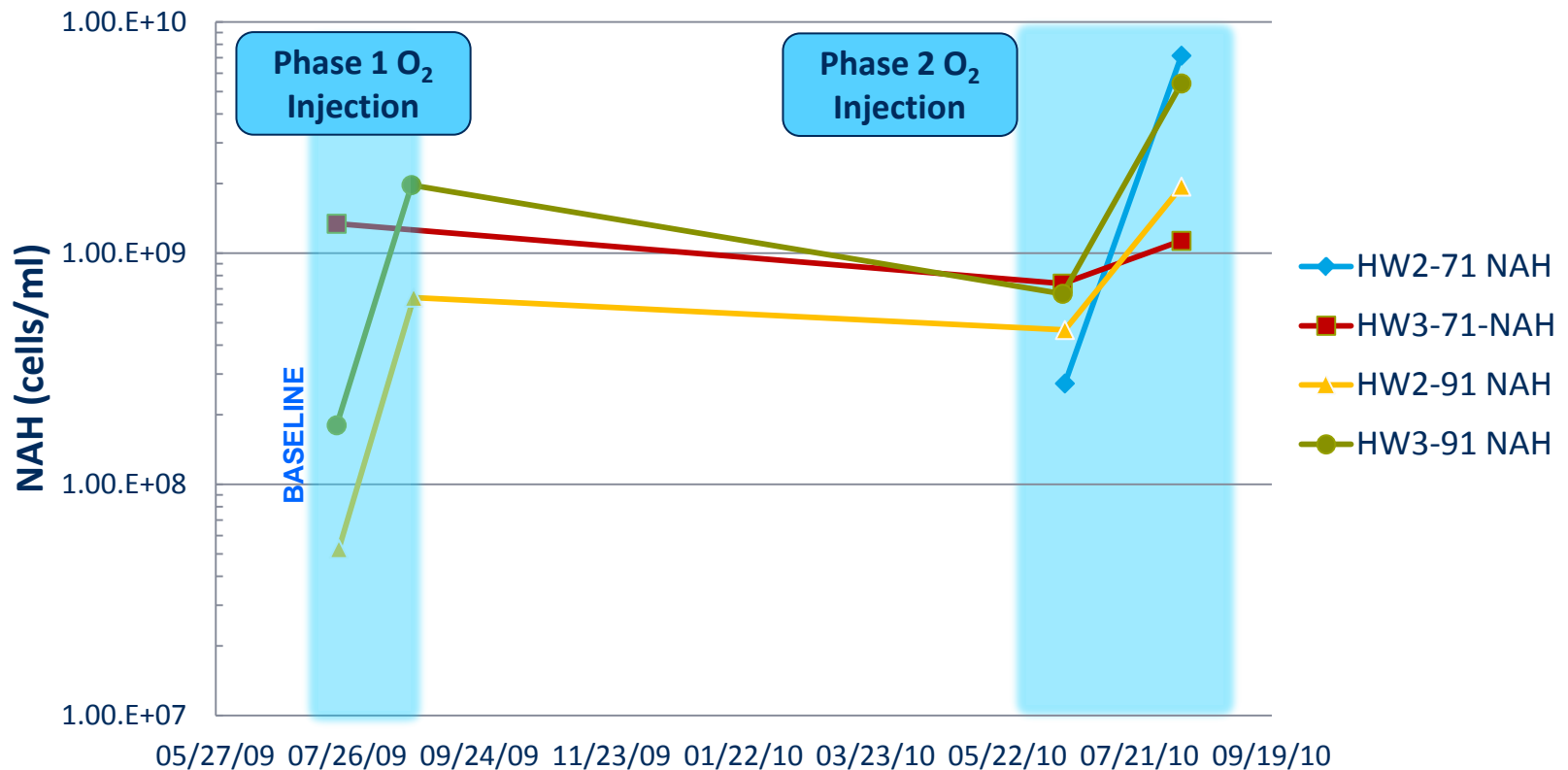
Downwell Microcosm Study - Phase 1 Injection



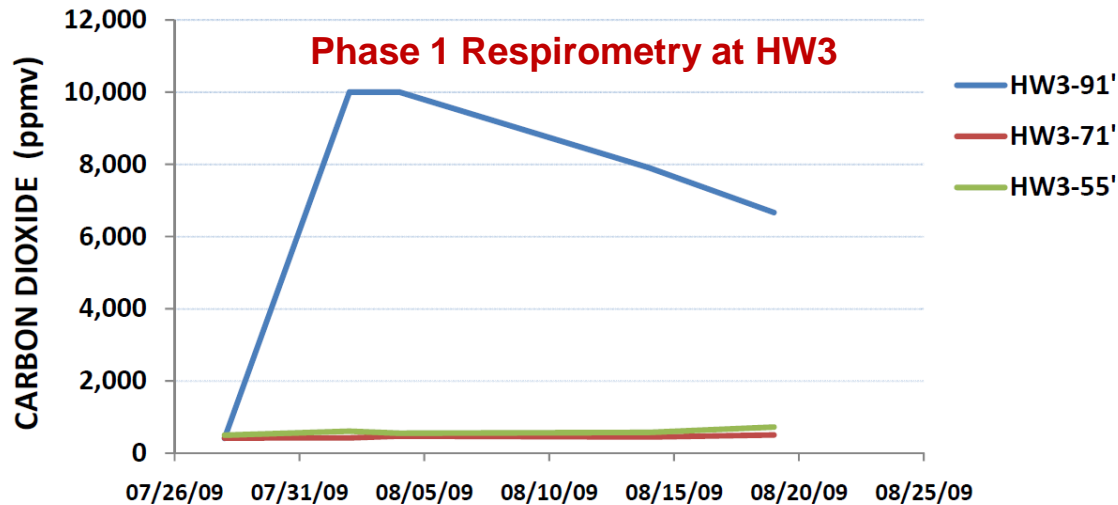
- Microcosm study consisted of Bio-trap cylinders installed in 3 HW-3 wells for one month
- Baseline results from Bio-Flo Sampler

NAH = Naphthalene Dioxygenase PHE = Phenol Hydroxylase

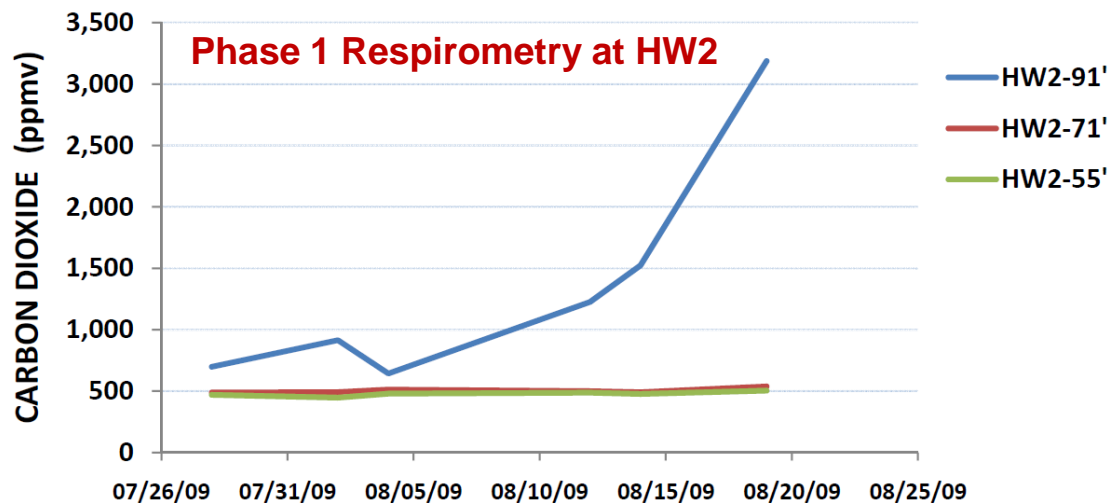
NAH Indicator Gene Populations by qPCR



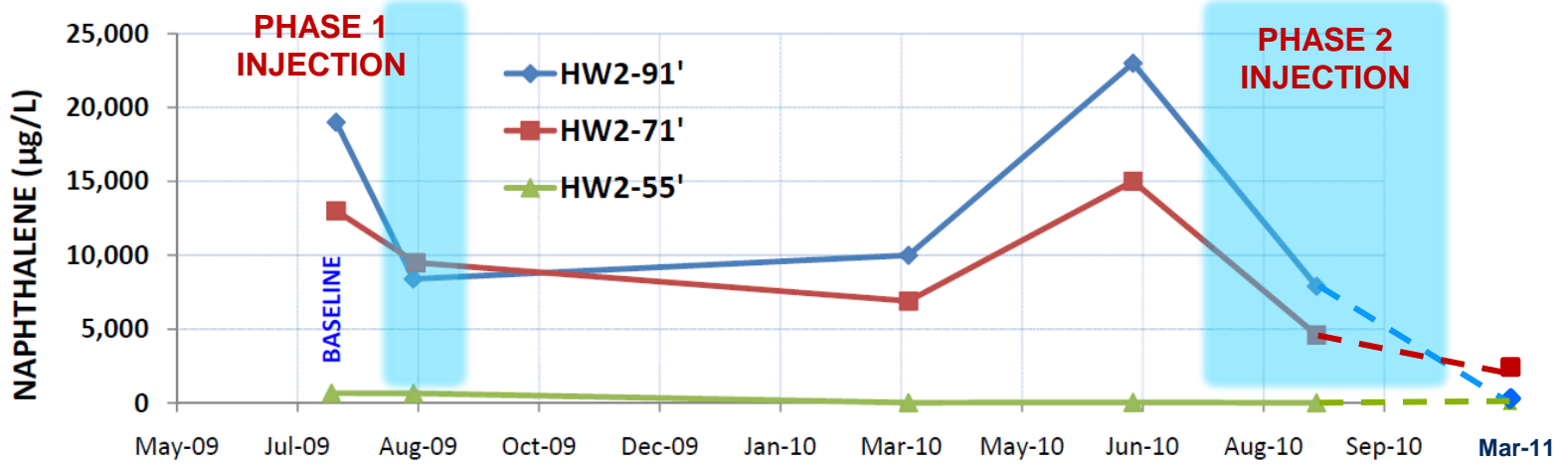
Phase 1 Pilot Scale Respirometry Data



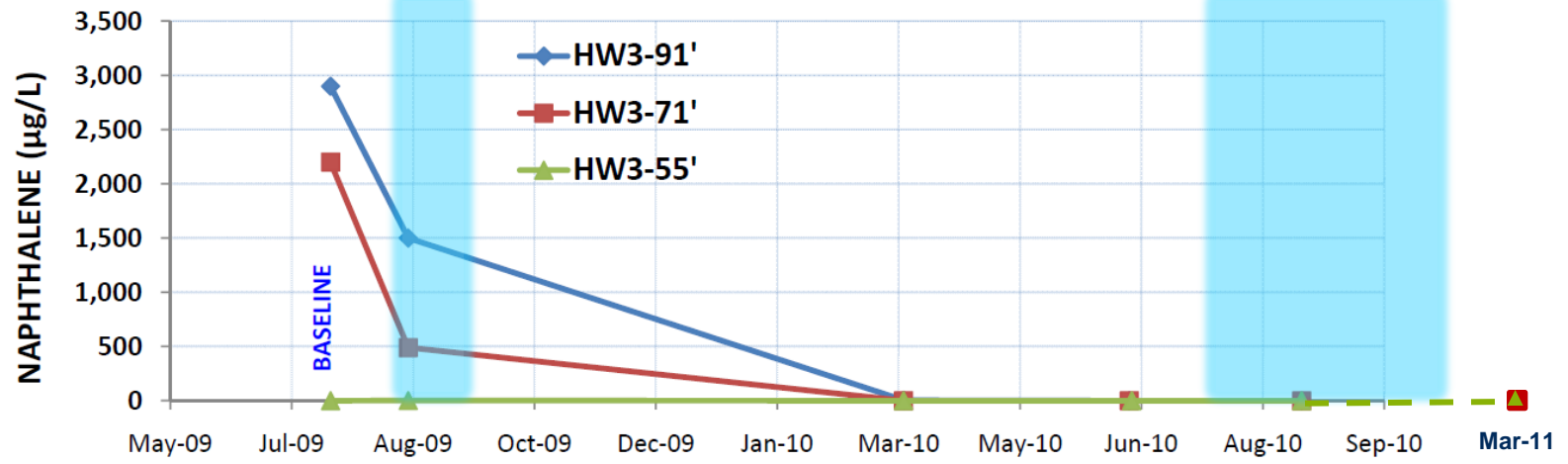
- Wellhead CO₂ Analysis
- 500 ppmv is background value in air



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 very 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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