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

Ernest Mott-Smith, P.E.
Cal Butler, P.G.
Tim Turner, P.E.

Erik Spalvins, EPA Region 4
David Keefer, EPA Region 4
Sean R. Carter, Matrix Oxygen Injection Systems

BLACK & VEATCH FEDERAL SERVICES DIVISION

October, 2011 • Orlando
Florida Remediation Conference

BLACK & VEATCH

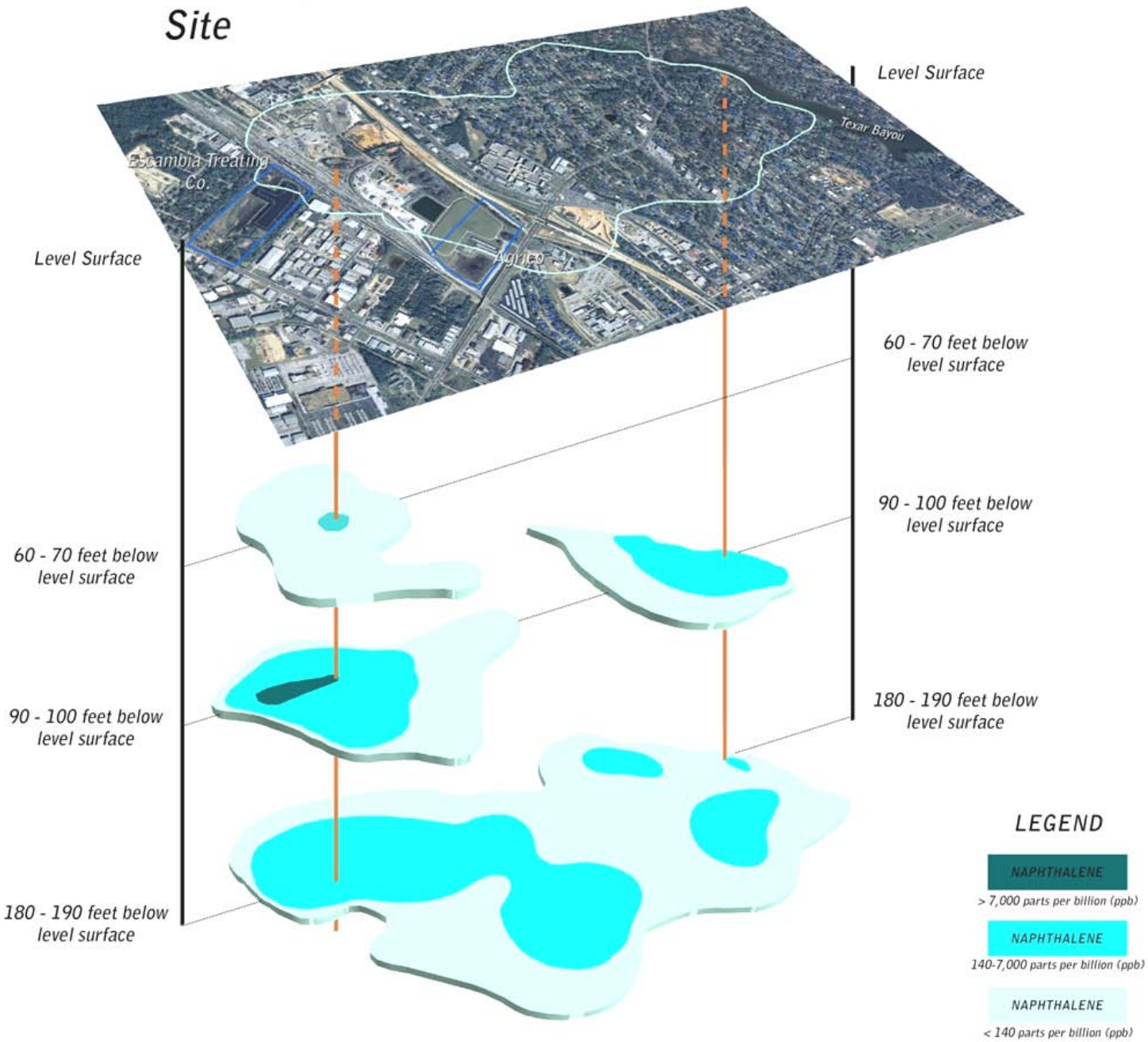
ESCAMBIA WOOD TREATING SITE

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

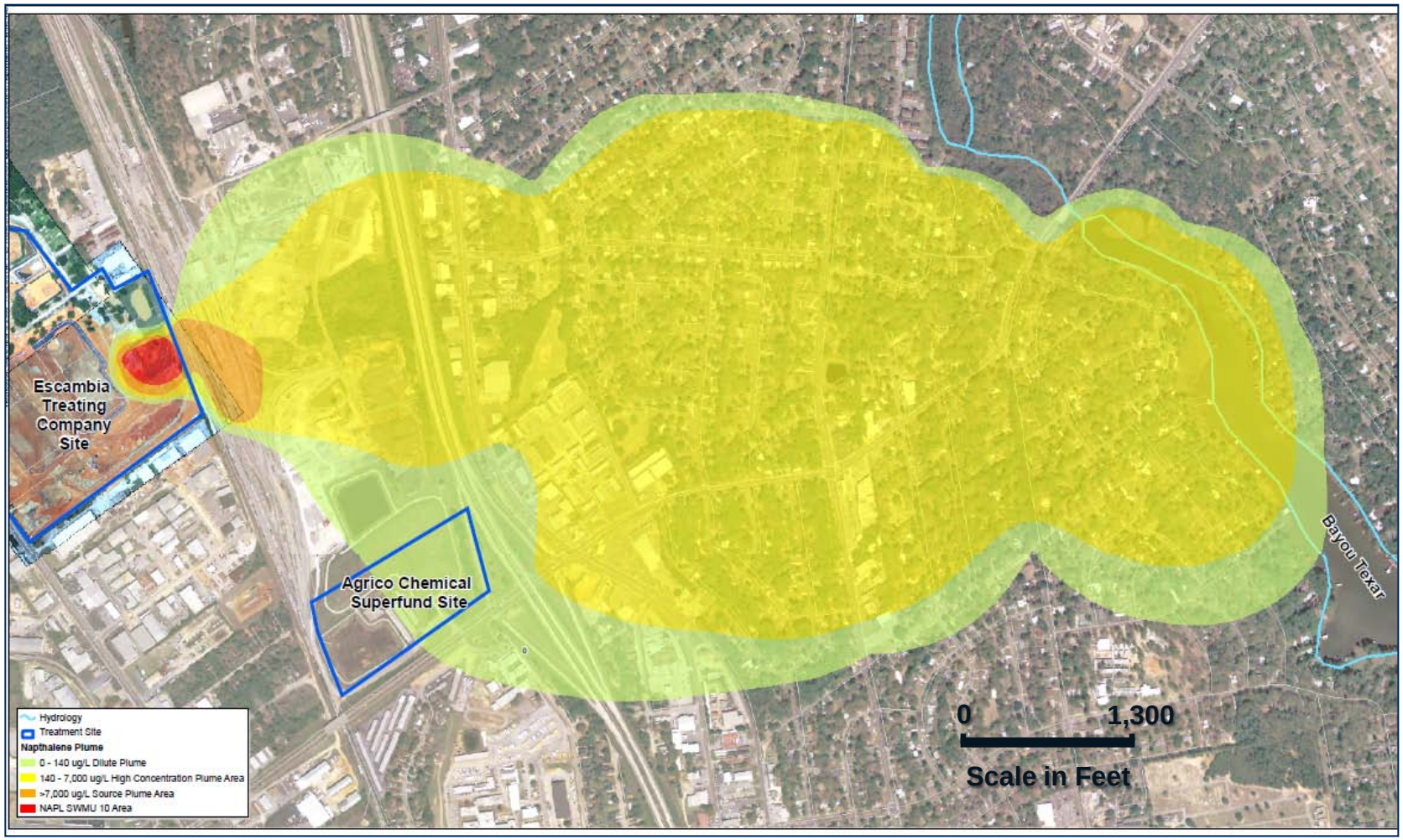


ESCAMBIA WOOD TREATING SITE – JAN 2009

Relocation of Mount Dioxin and Source Area Locations

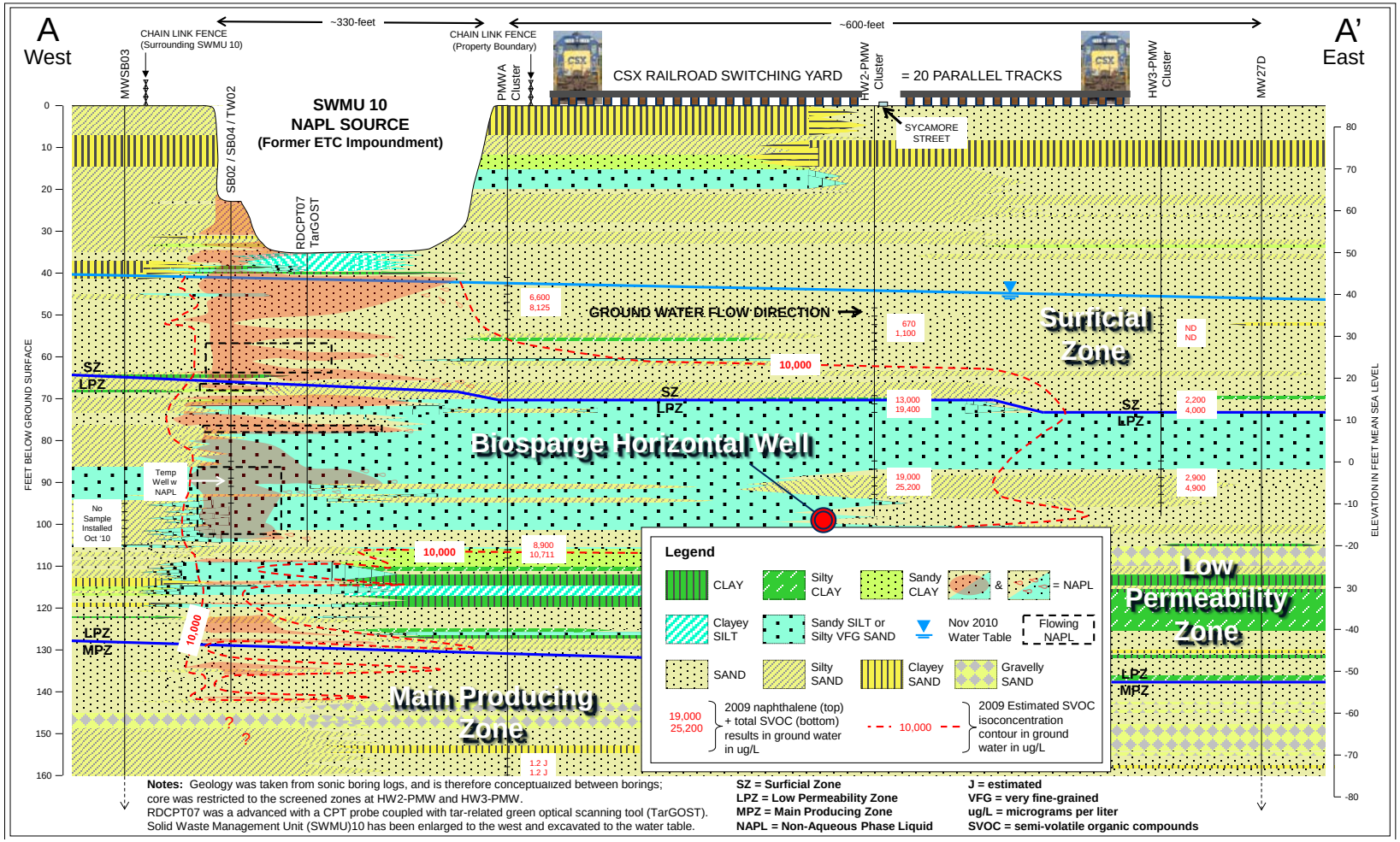
BACKGROUND

Composite Depth Naphthalene Plume



BACKGROUND

Site Conceptual Model



Notes: Geology was taken from sonic boring logs, and is therefore conceptualized between borings; core was restricted to the screened zones at HW2-PMW and HW3-PMW.
RDCPT07 was a advanced with a CPT probe coupled with tar-related green optical scanning tool (TarGOST).
Solid Waste Management Unit (SWMU)10 has been enlarged to the west and excavated to the water table.

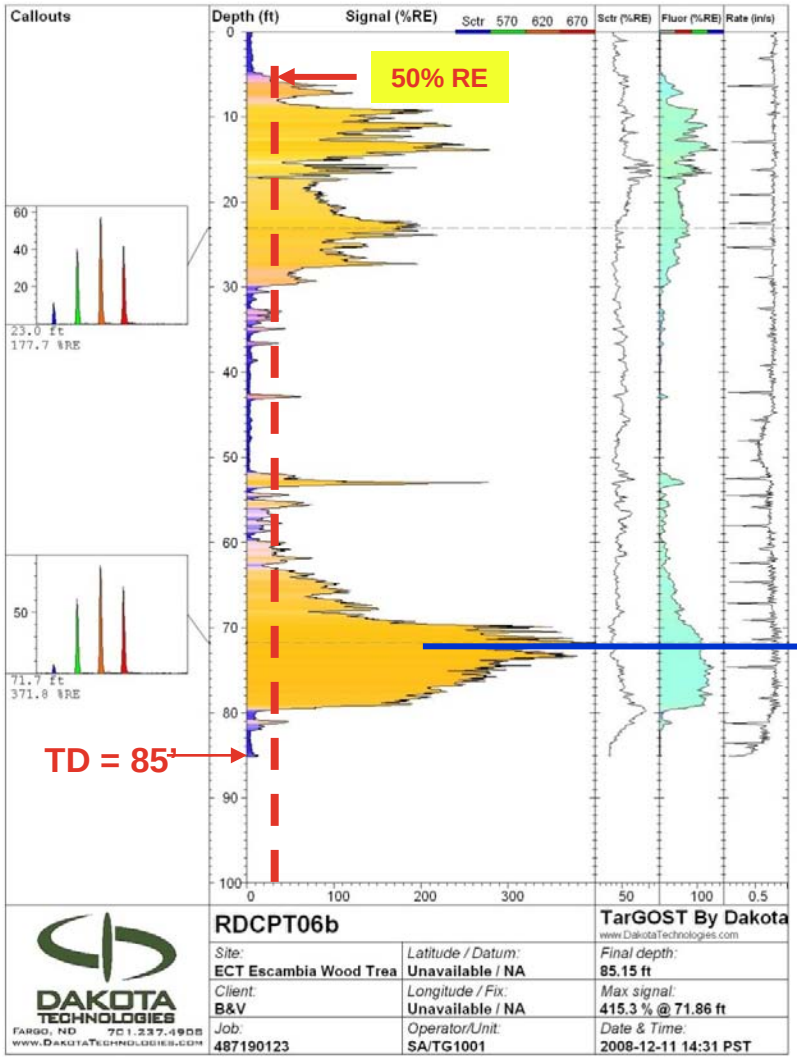
SZ = Surficial Zone
LPZ = Low Permeability Zone
MPZ = Main Producing Zone
NAPL = Non-Aqueous Phase Liquid

J = estimated
VFG = very fine-grained
ug/L = micrograms per liter
SVOC = semi-volatile organic compounds

BACKGROUND

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.

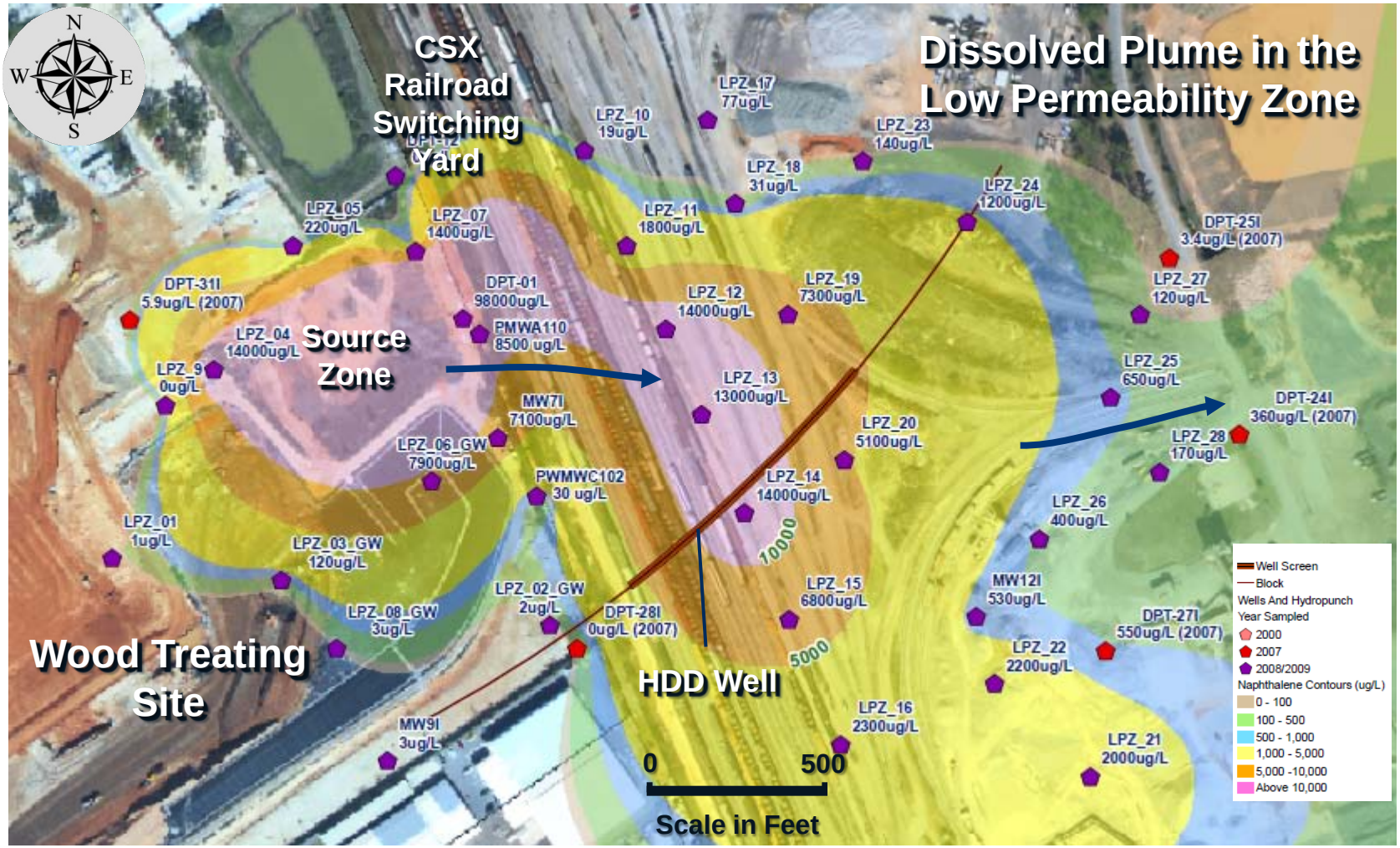
BACKGROUND

Biosparge Pilot Test Setup

BIOSPARGE PILOT TEST GOALS

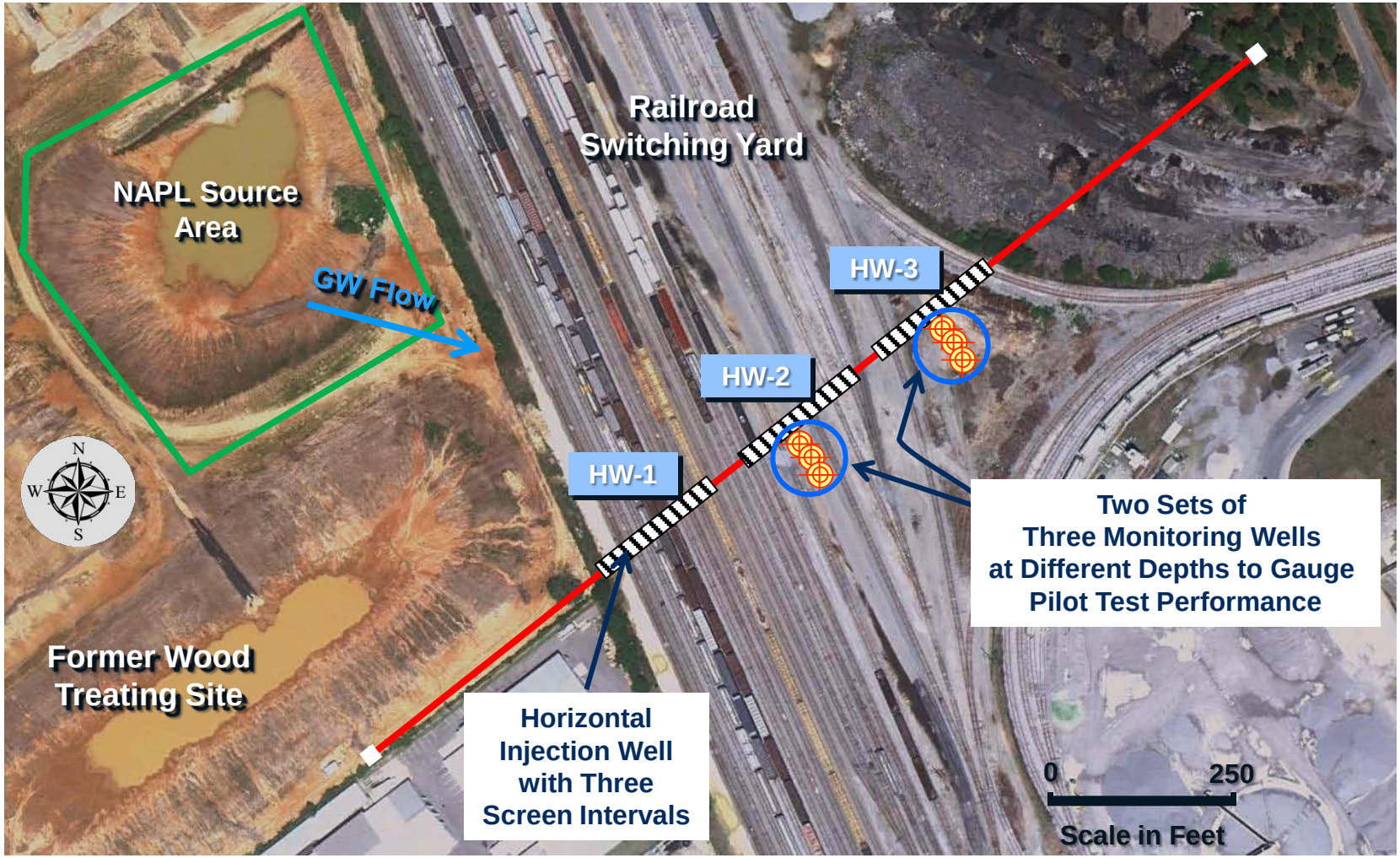
1. Demonstrate viability of directional drilling under railroad yard
2. Compare the effectiveness of different well materials
3. Evaluate the ability to disperse oxygen effectively through a horizontal well
4. Determine design basis for flows and pressures
5. Measure and assess dissolved oxygen dispersion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

NAPTHALENE PLUME

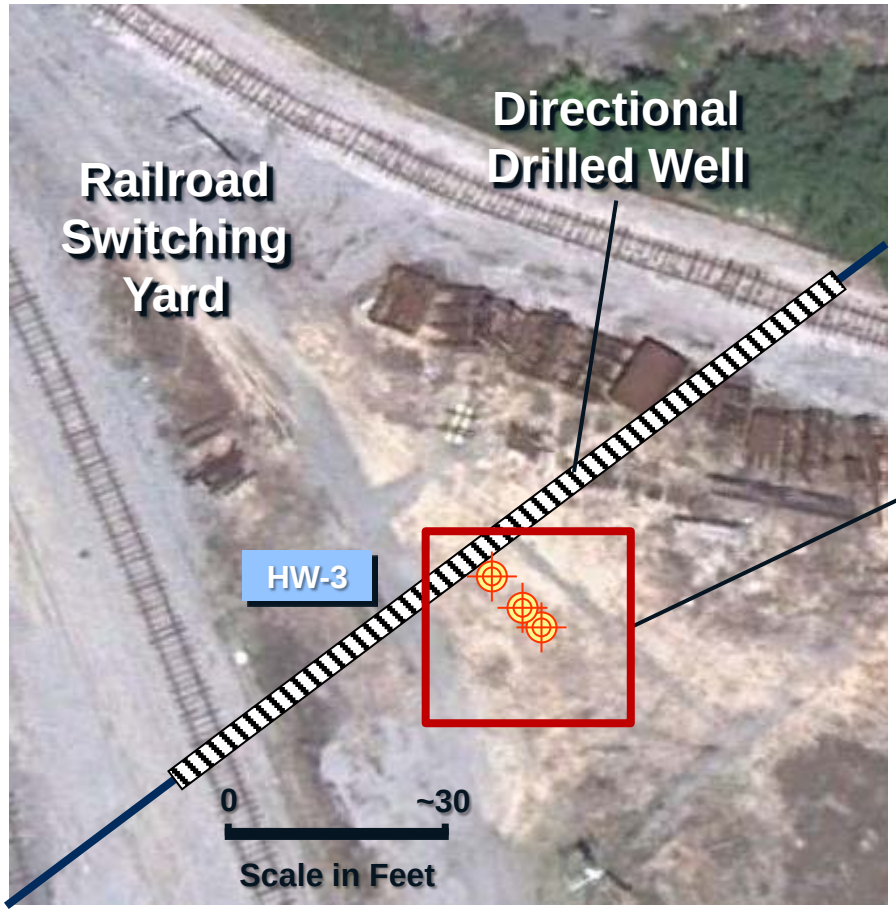


BIOSPARGE PILOT TEST SET-UP

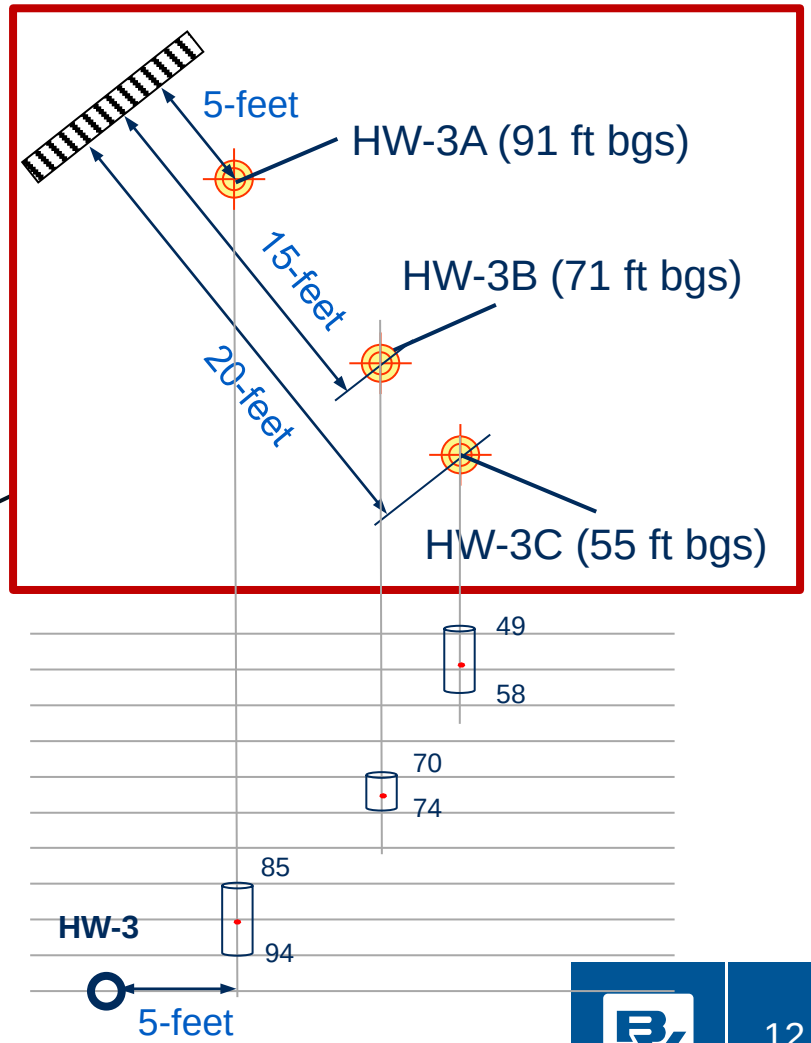
LAYOUT OF *IN SITU* BIOSPARGE PILOT TEST



Performance Monitoring Wells



HW-3 Performance Monitoring Array



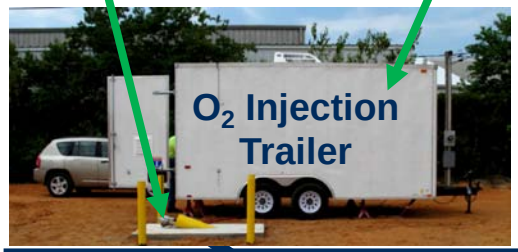
BIOSPARGE PILOT TEST SET-UP

In Situ Biosparge Pilot Study Components

Bundle of 3 Injection Wells

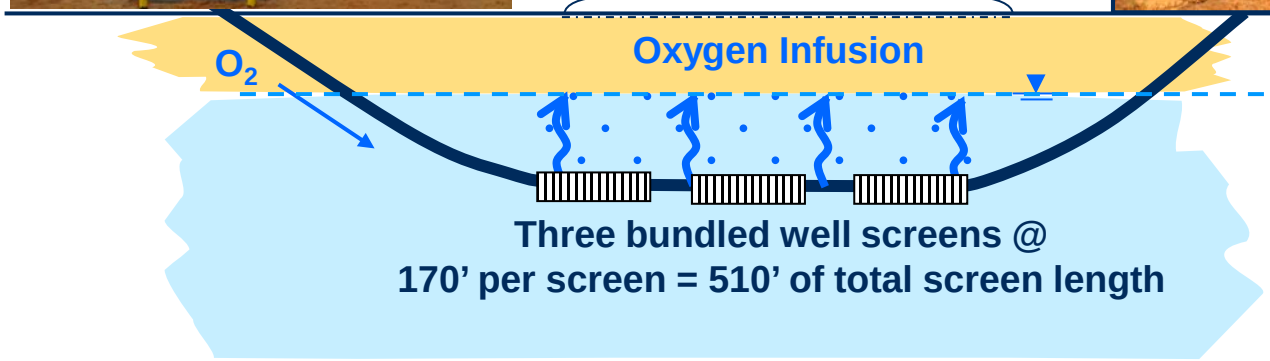
Air Conversion to >90% Pure O_2

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

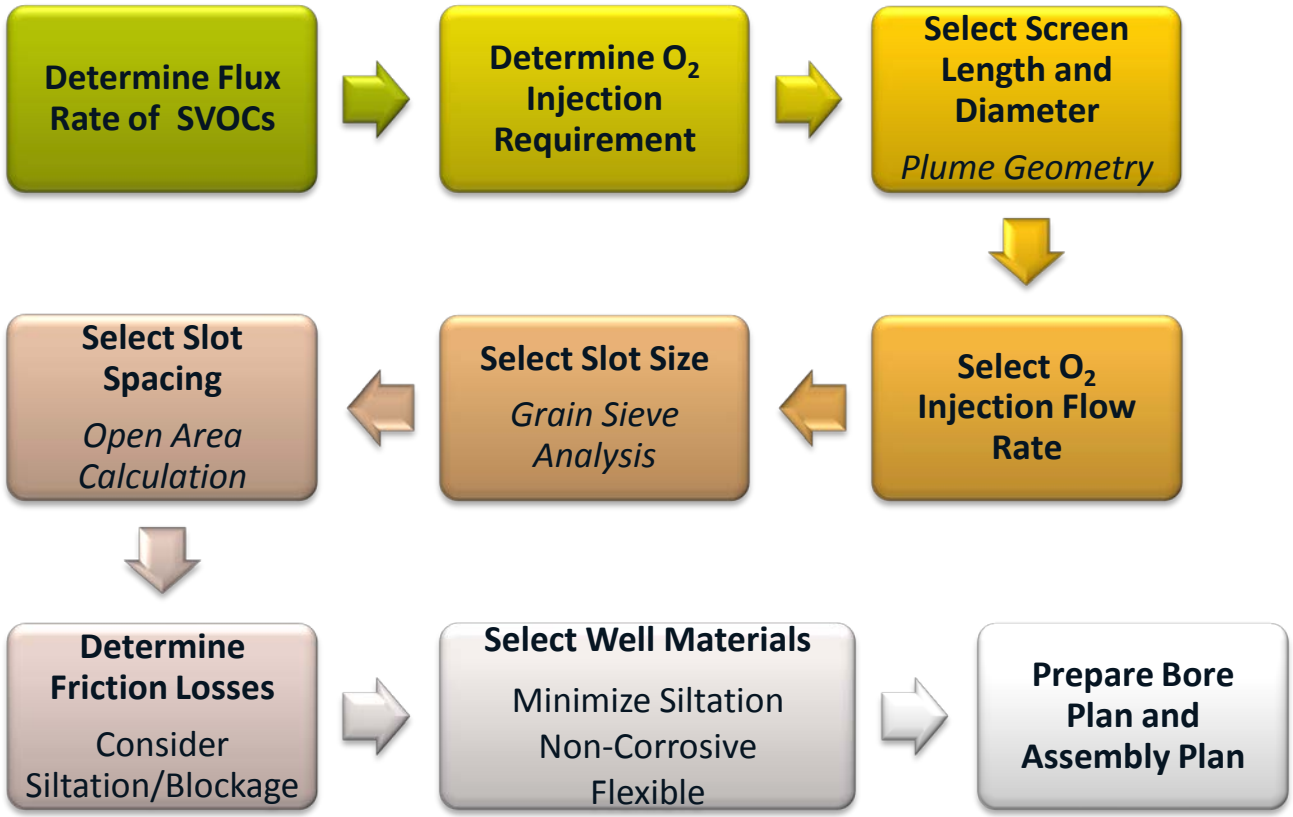
Railroad Switching Yard with 20 Parallel Tracks



Directed Technologies Drilling Incorporated

BIOSPARGE PILOT TEST SET-UP

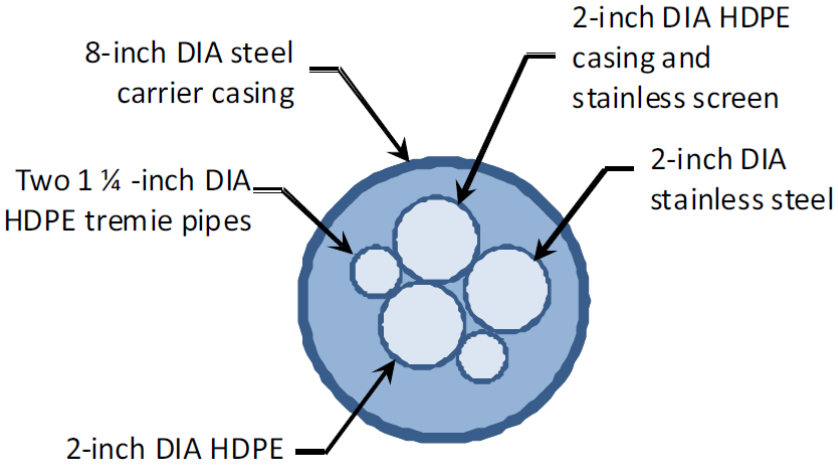
Pilot Scale Biosparge Wall Design

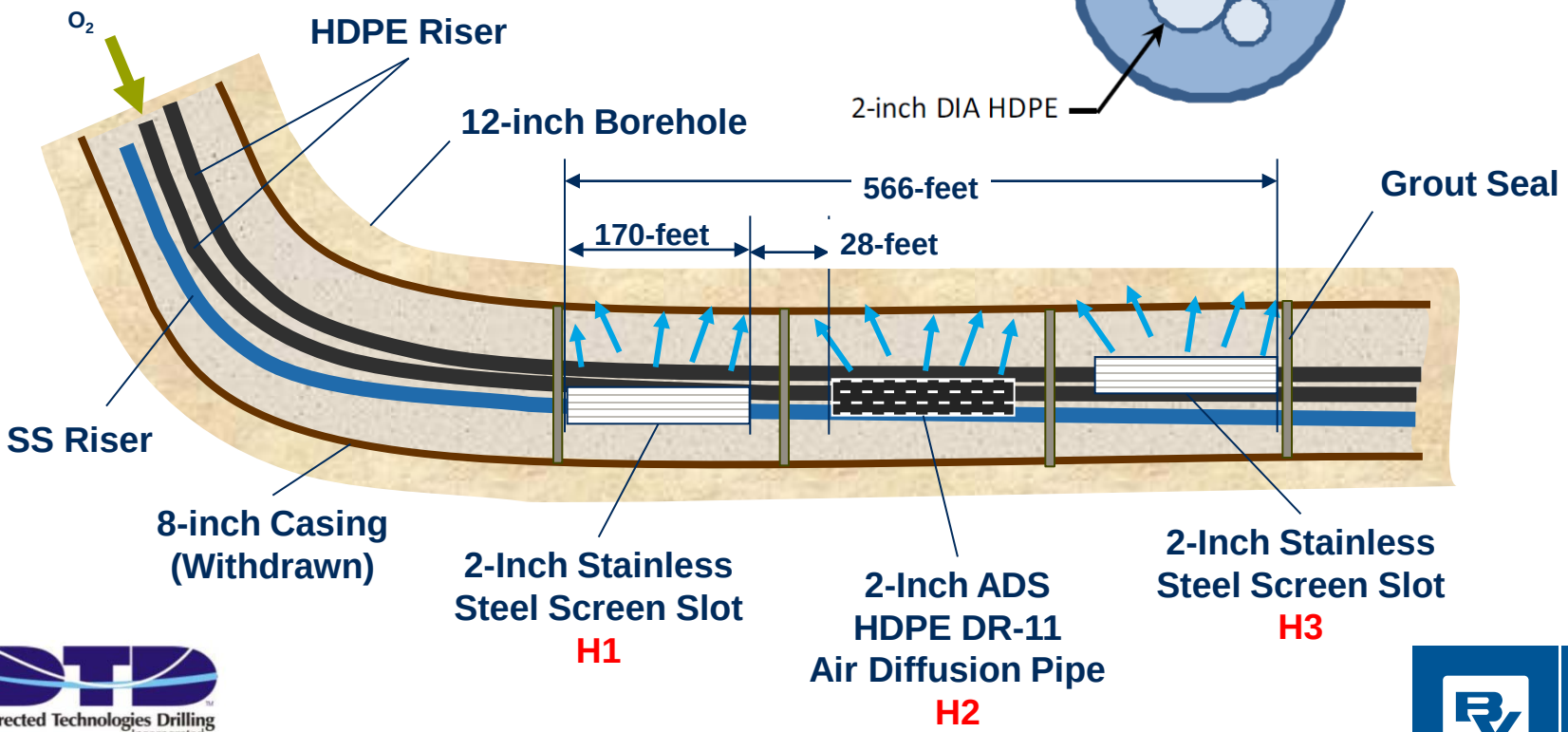


BioSparge Well Construction

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).





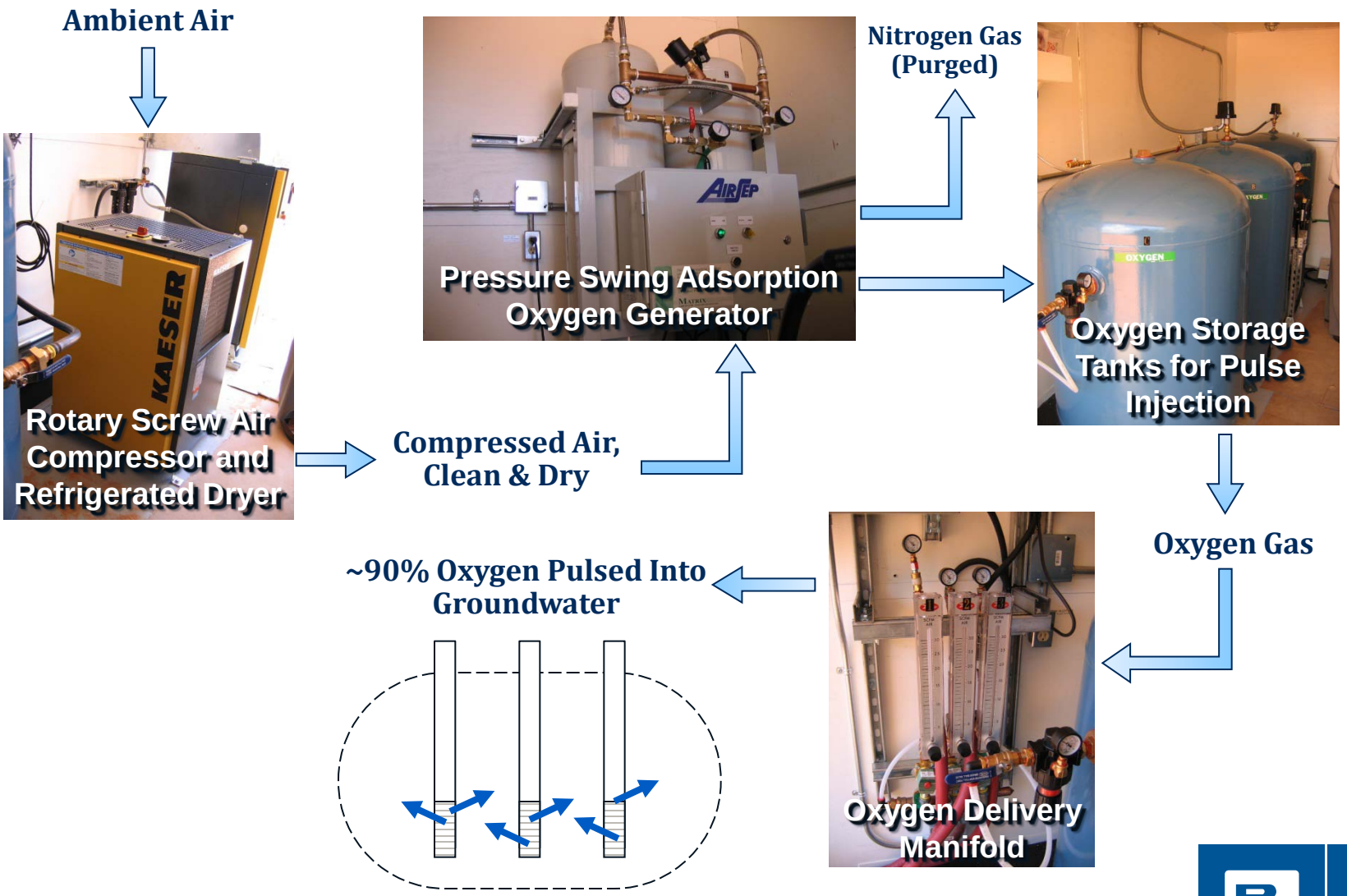
Directed Technologies Drilling Incorporated

Oxygen Injection Trailer

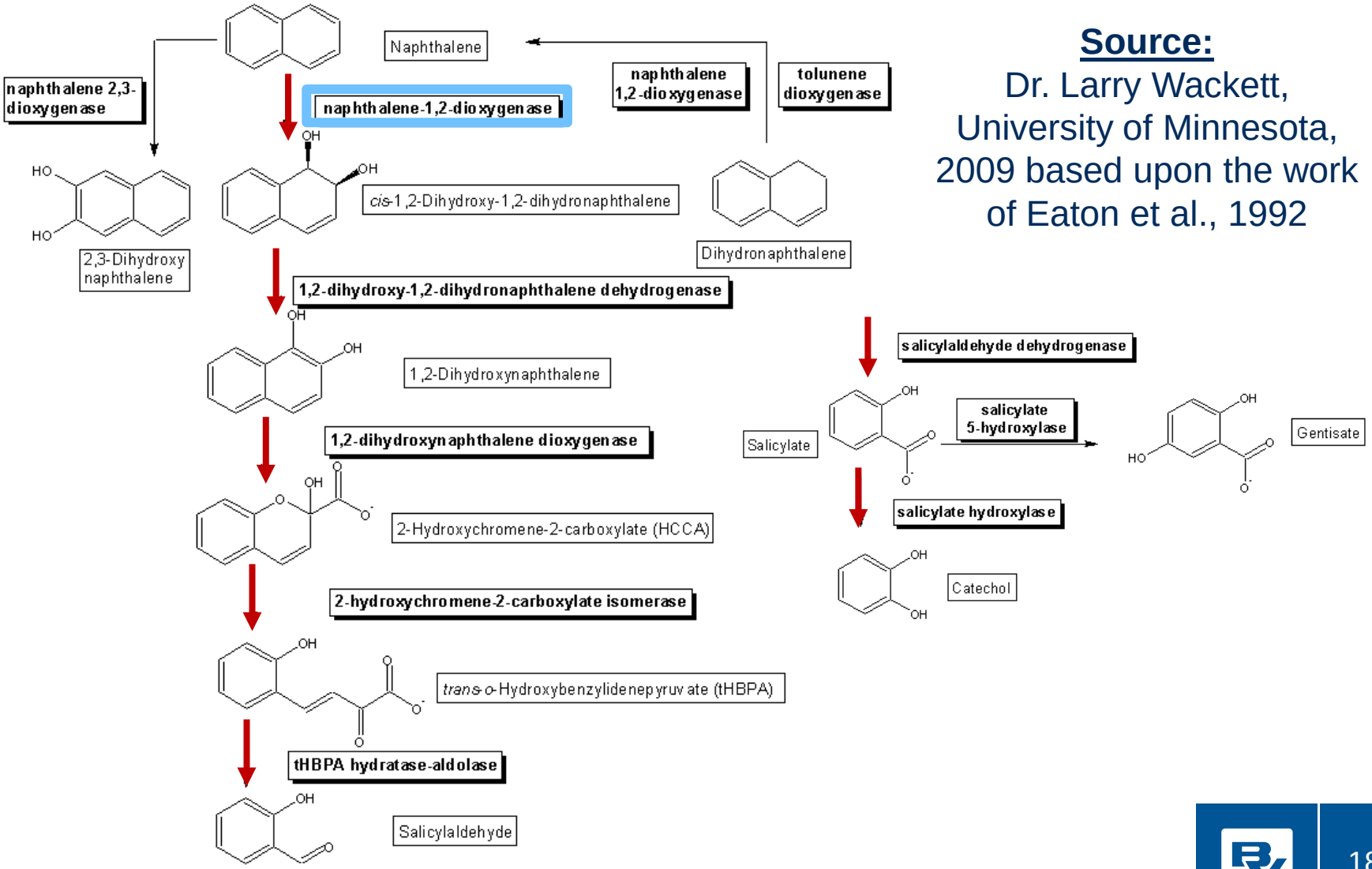
MATRIX

- 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



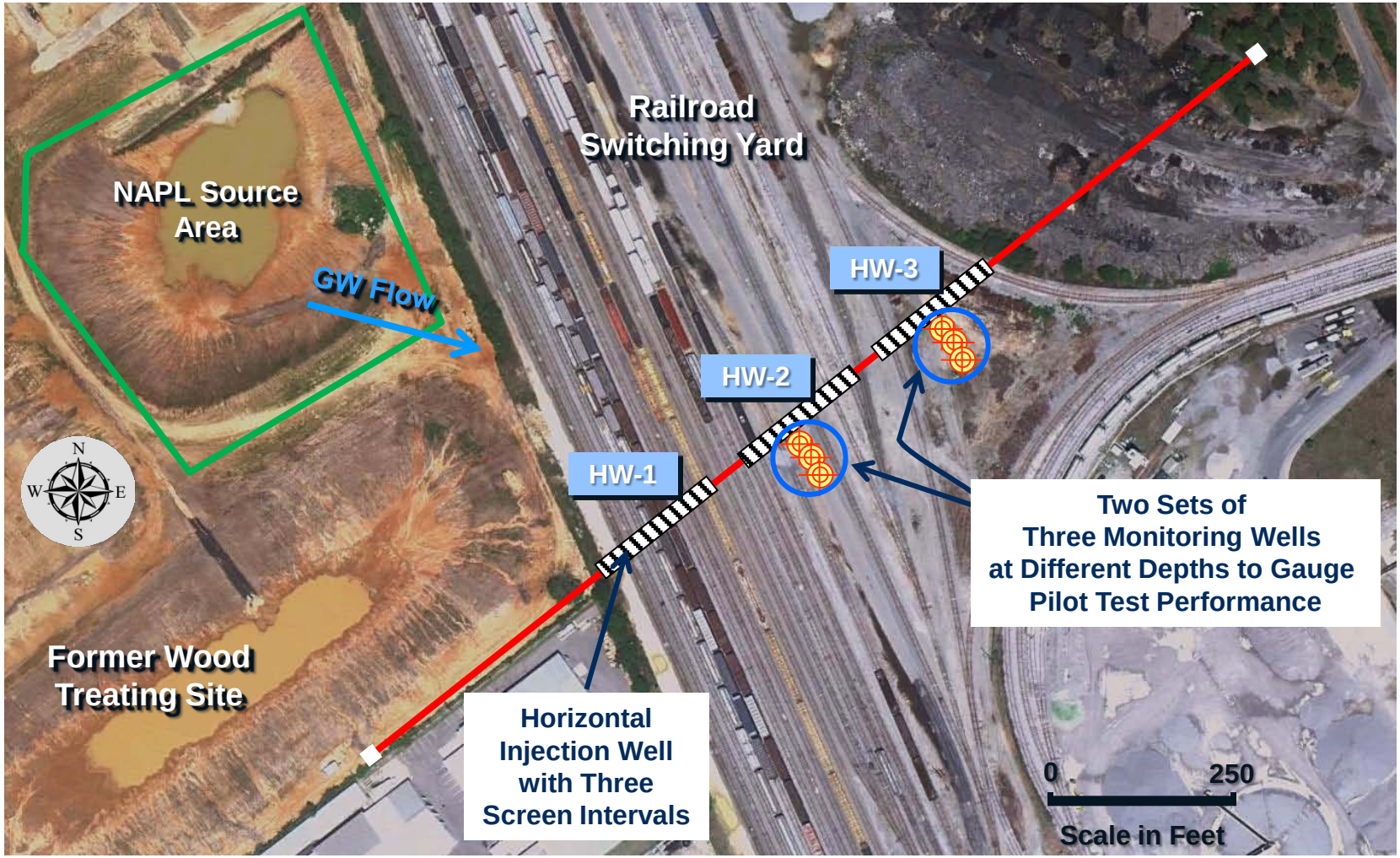
Naphthalene Aerobic Degradation Pathway



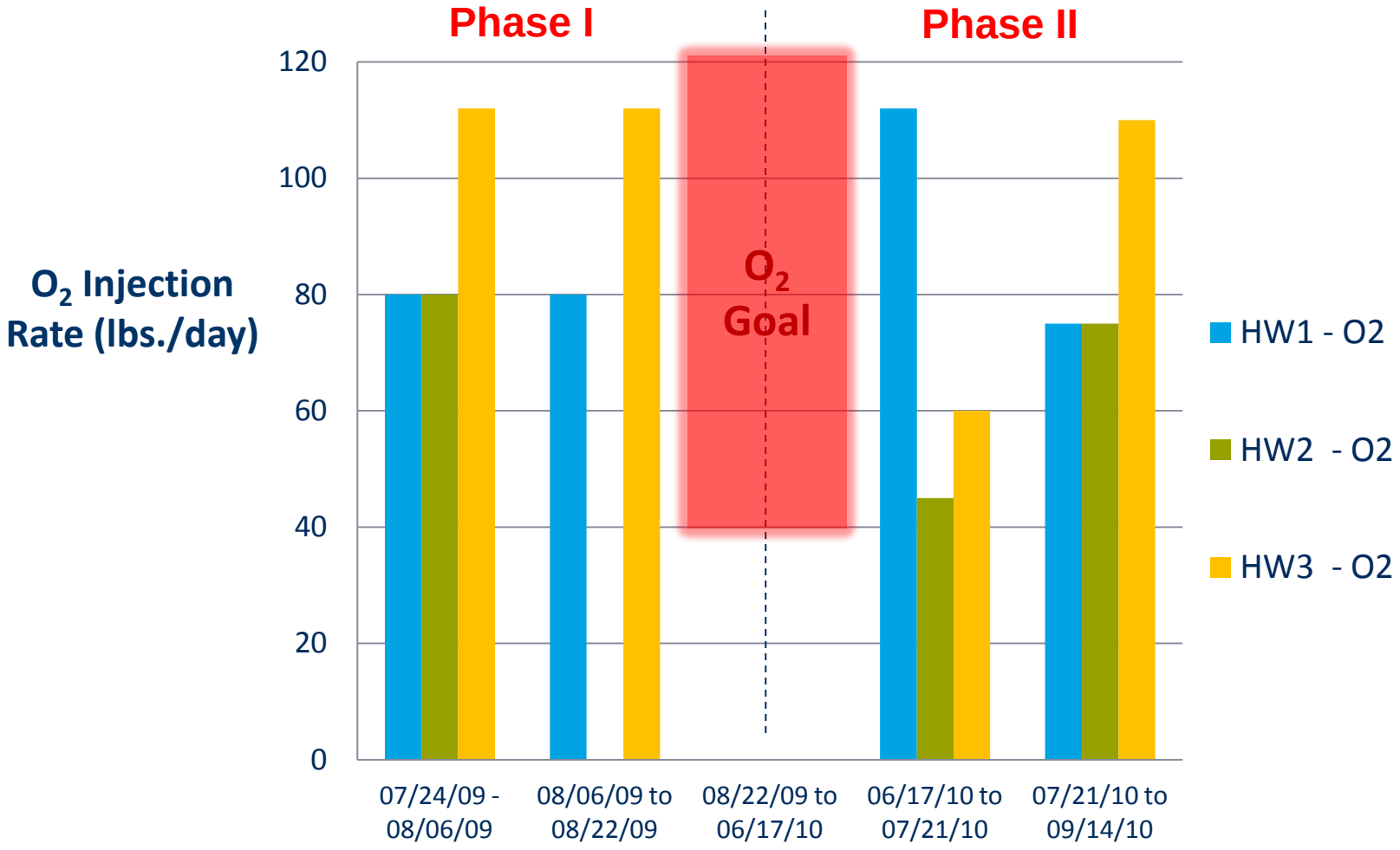
Source:
Dr. Larry Wackett, University of Minnesota, 2009 based upon the work of Eaton et al., 1992

Results

LAYOUT OF *IN SITU* BIOSPARGE PILOT TEST

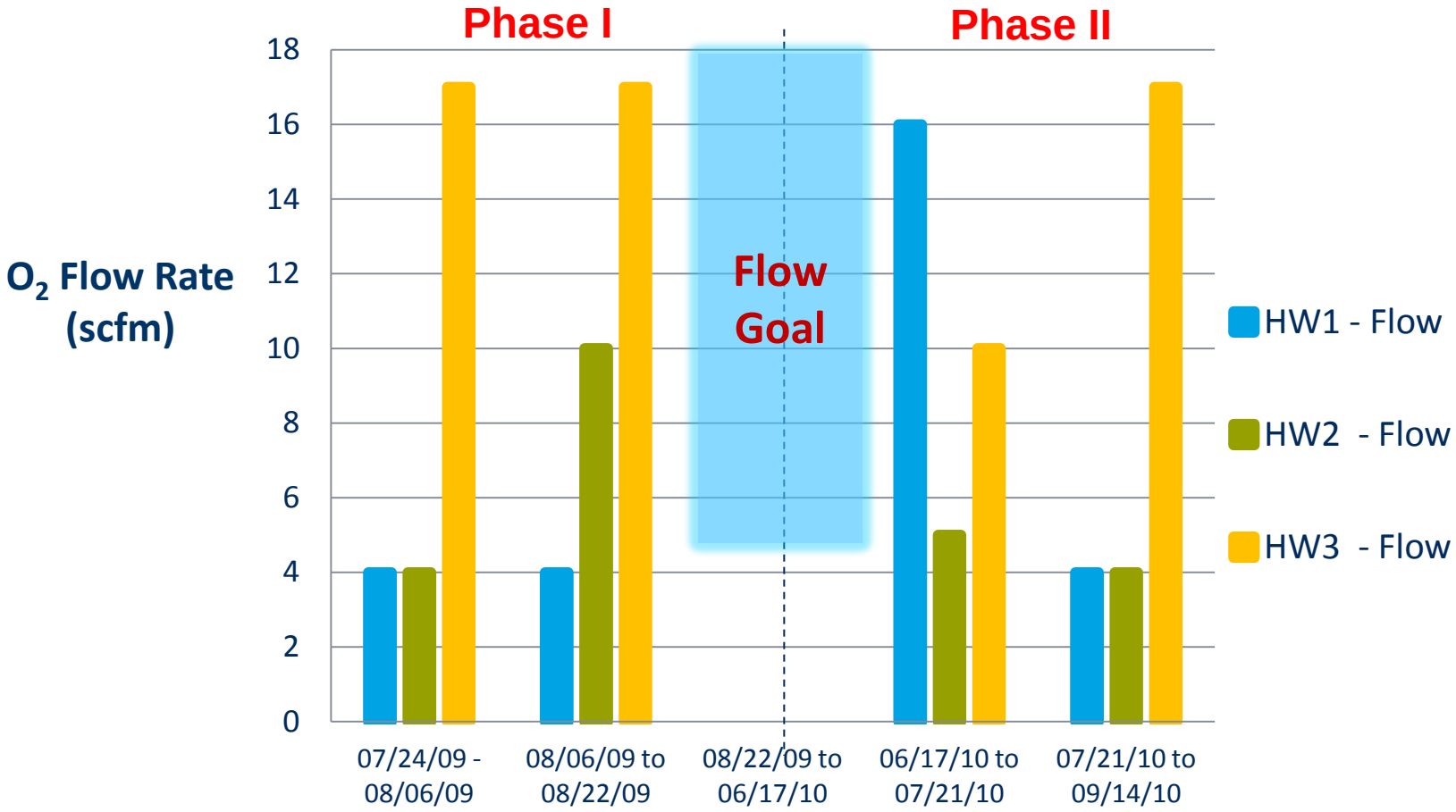


Phase 1 and 2 Pilot Scale Oxygen Feed Rates



- *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., $Fe^{+2} \rightarrow Fe^{+3}$)
  - Decreases in natural organic matter (and potential increased metal mobility)
- **Decreases in TOC or COD**

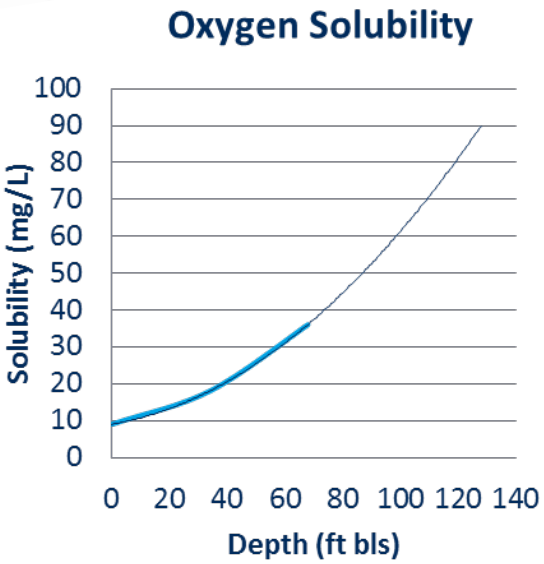
What Results are Indicators of Biological Degradation?

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

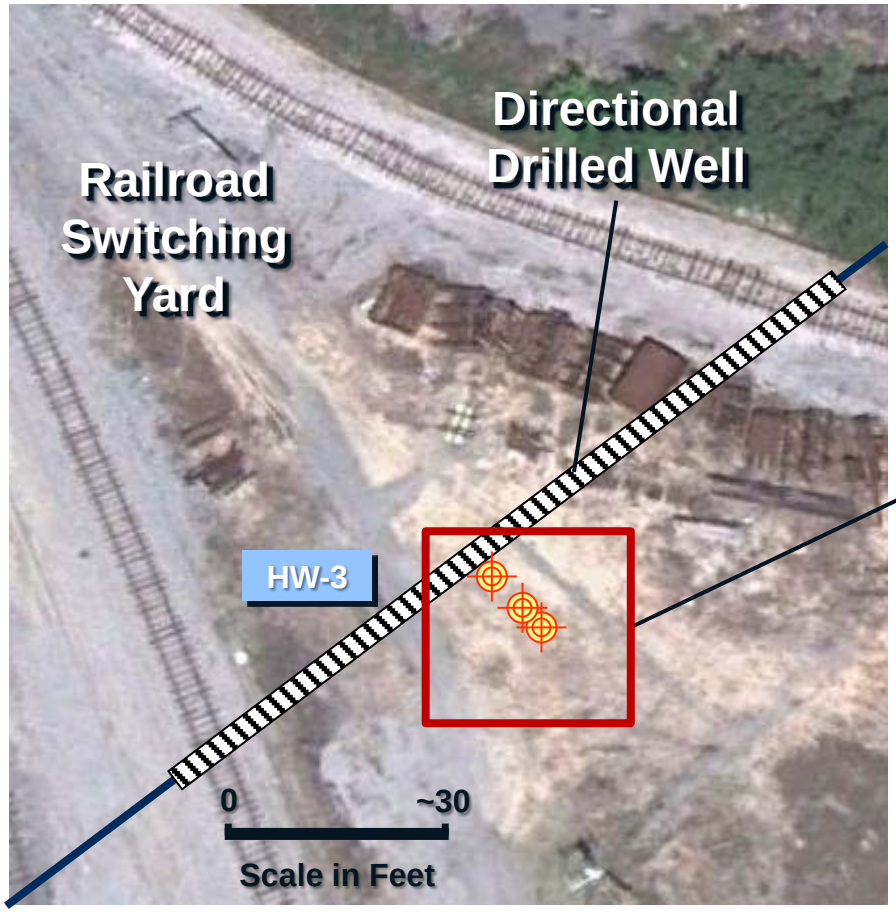
Verification of Dissolved Oxygen Front

Used stable luminescent optical dissolved oxygen probes

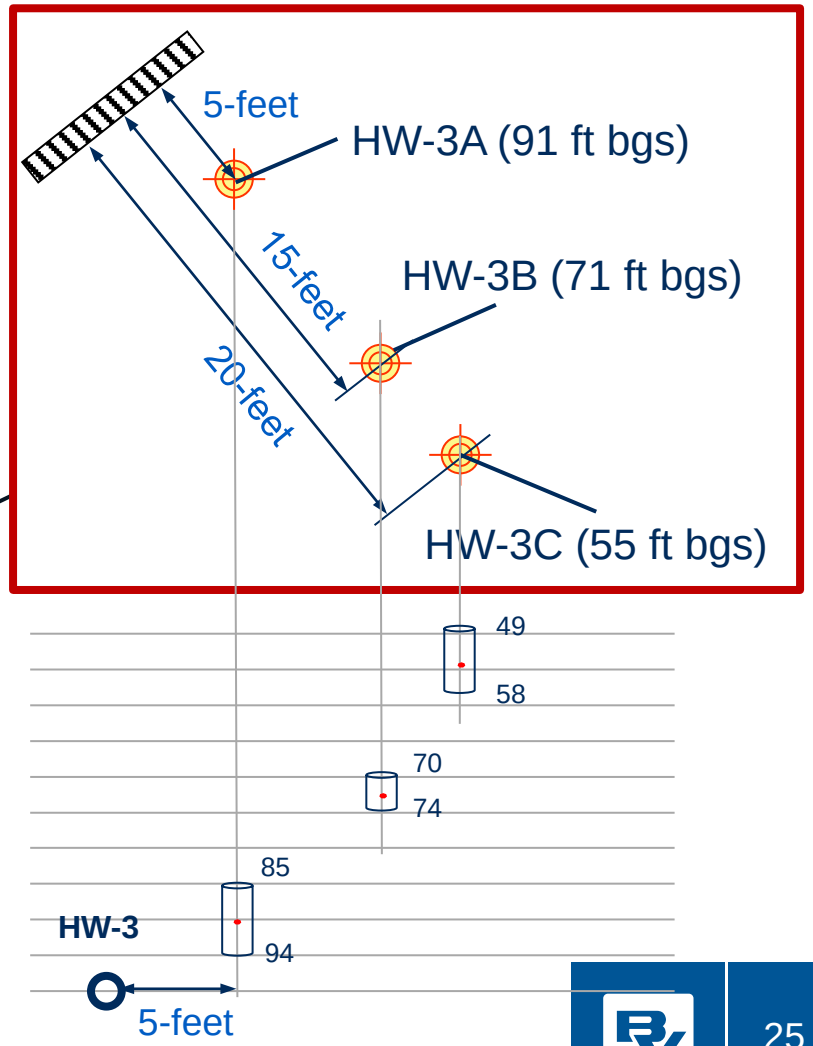
- Continuous downwell monitoring with Trolls for 30-days in the 6 performance monitoring wells for DO, ORP, pH, conductivity, and temperature.
- DO Measurement a critical parameter
- Oxygen is not consumed as part of an electrochemical reaction, and optical sensors do not require sample flow or stirring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



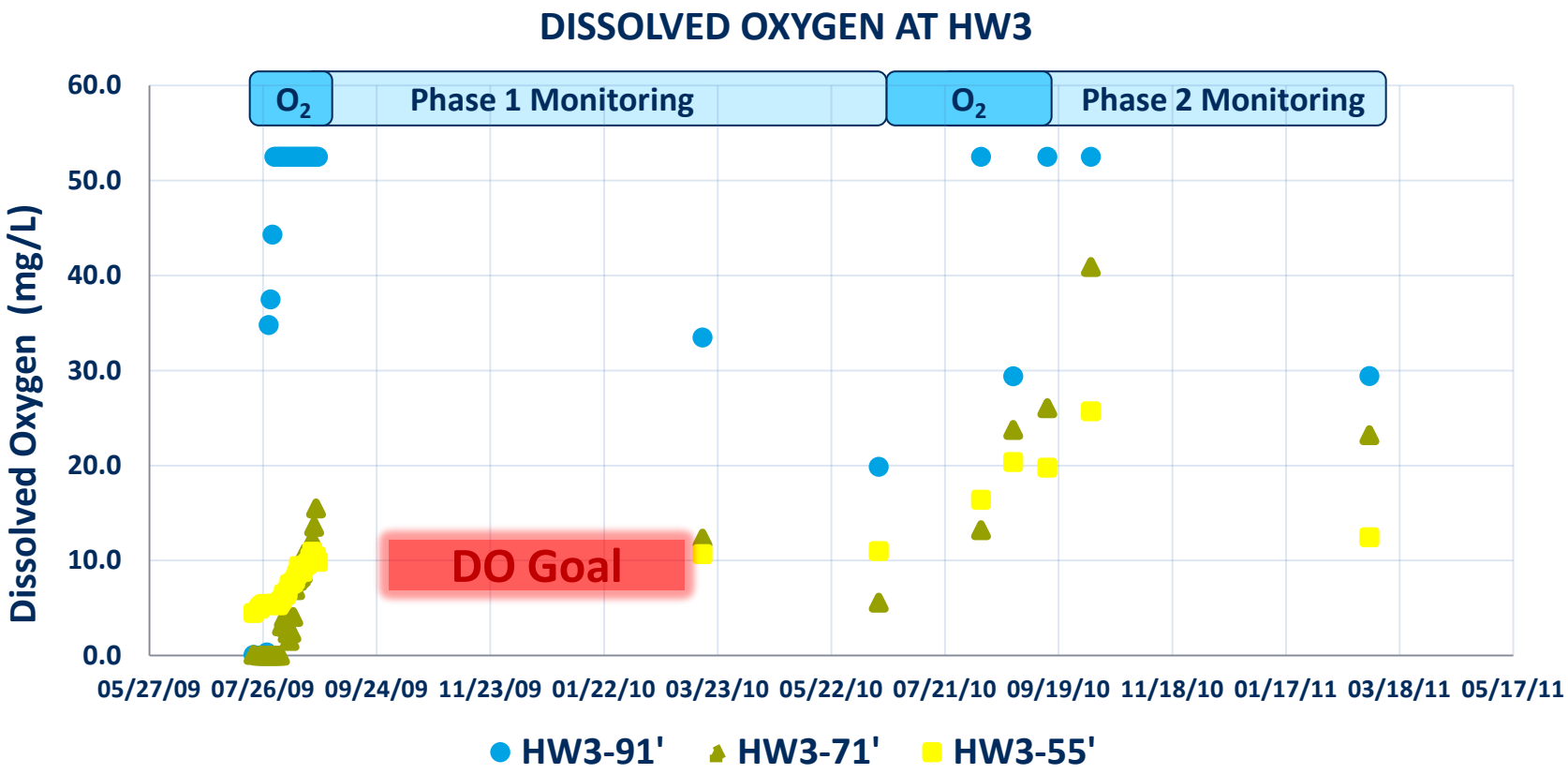
Performance Monitoring Wells



HW-3 Performance Monitoring Array

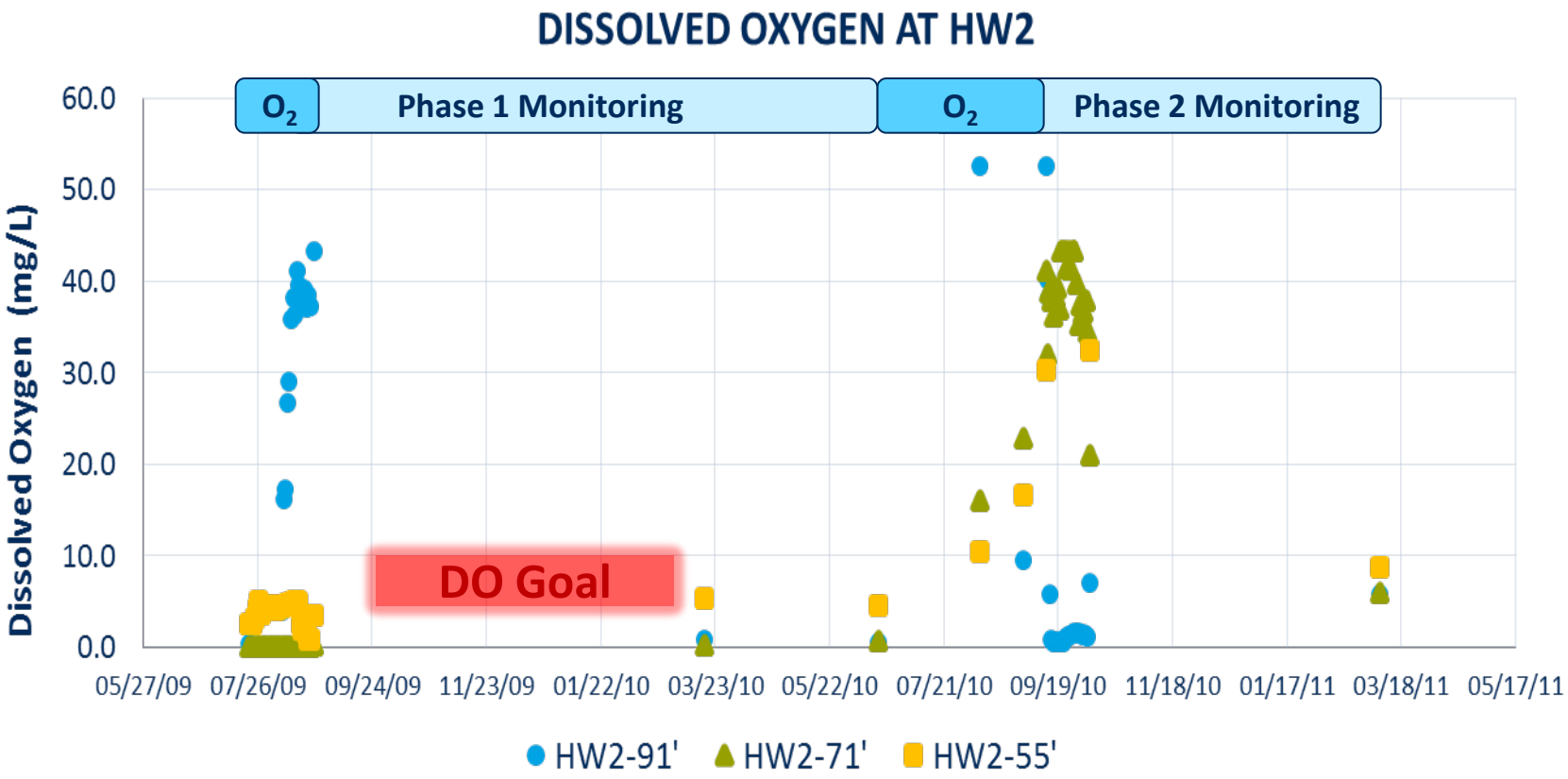


Phase 1 and 2 Pilot Scale DO Results – HW3



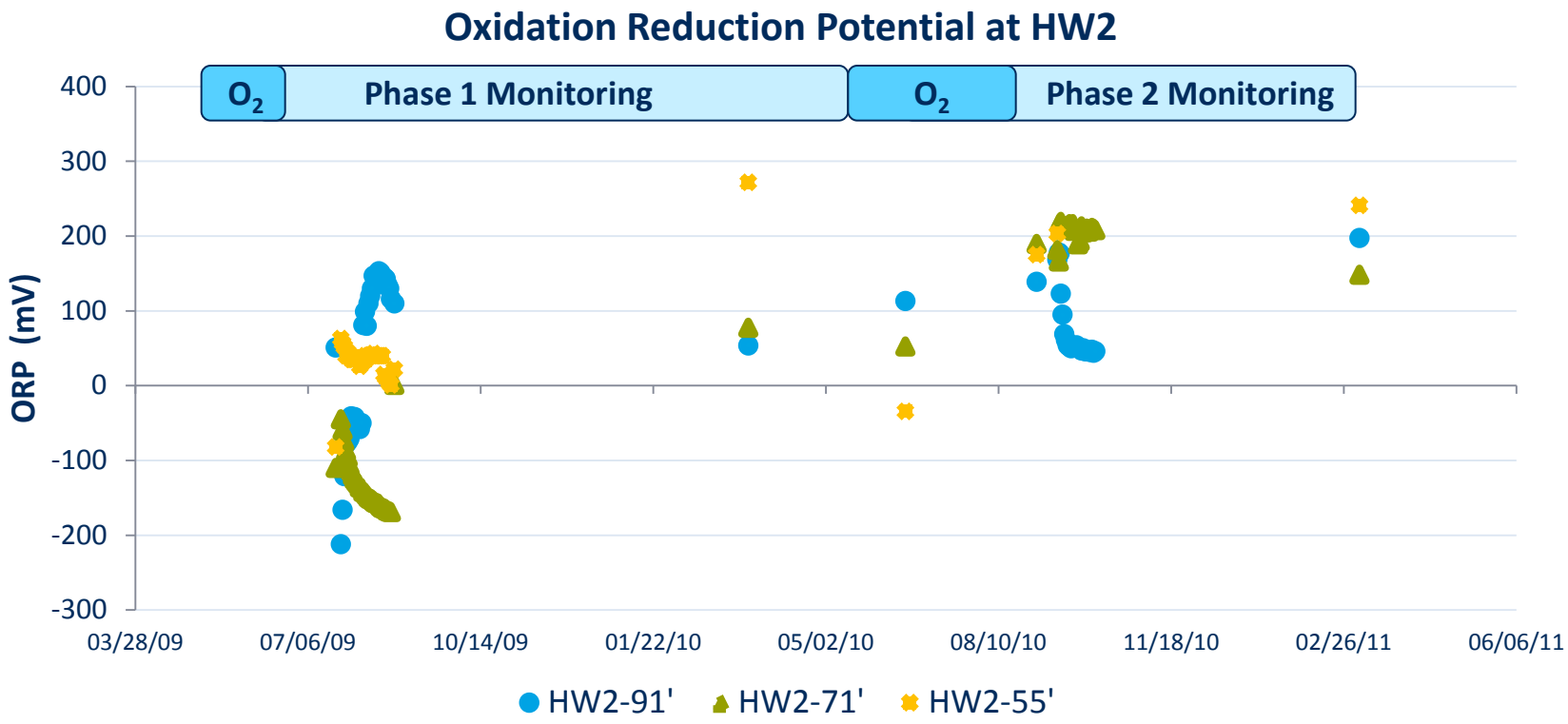
- Phase 1 = 30 days injection
- Phase 2 = 89 days injection

Phase 1 and 2 Pilot Scale DO Results – HW2



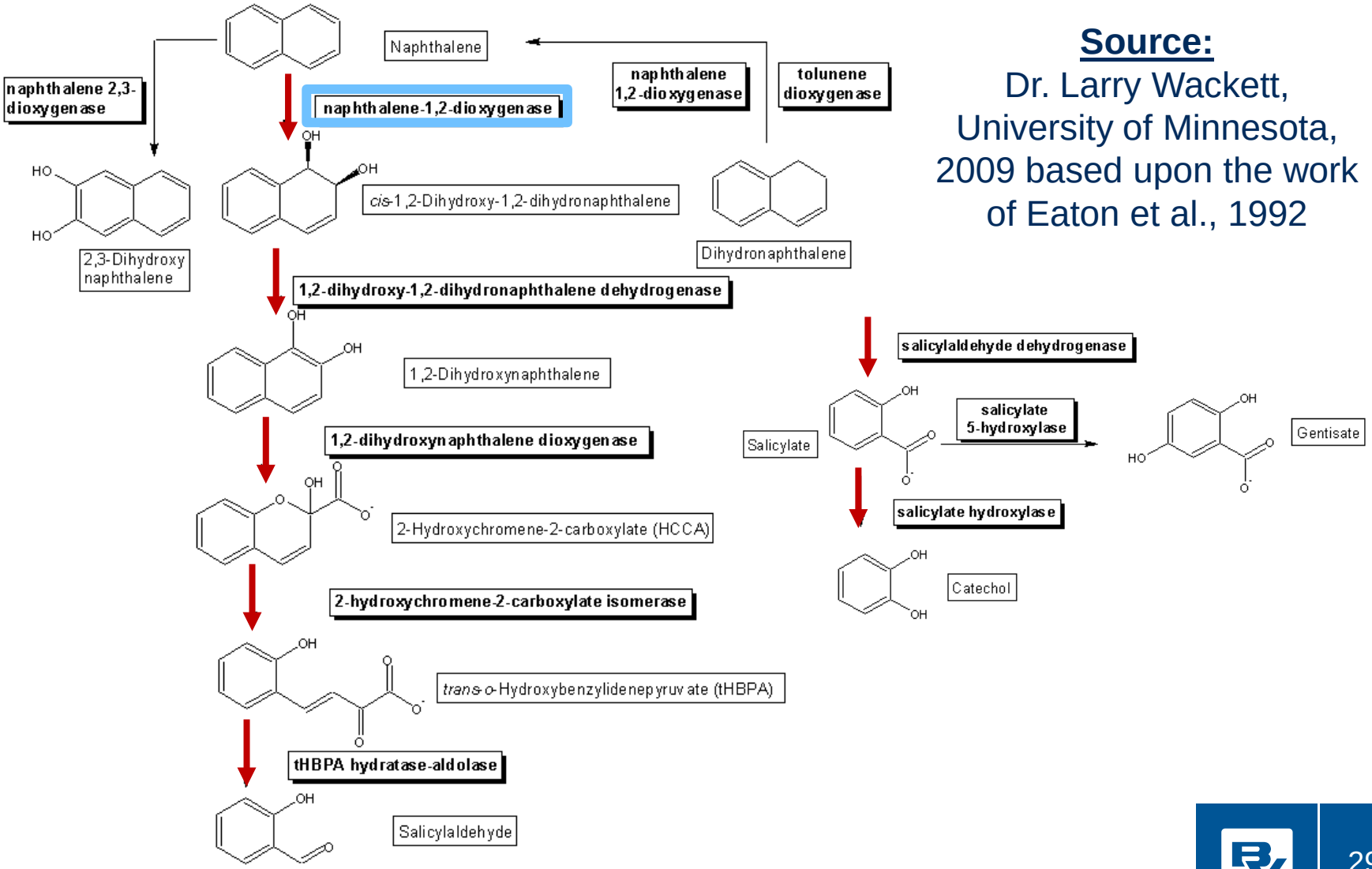
- Phase 1 = 30 days injection
- Phase 2 = 89 days injection

Phase 1 and 2 Pilot Scale ORP Results



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

Naphthalene Aerobic Degradation Pathway



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

Sampling for *In Situ* Microbial Population

Bio-Flo Samplers

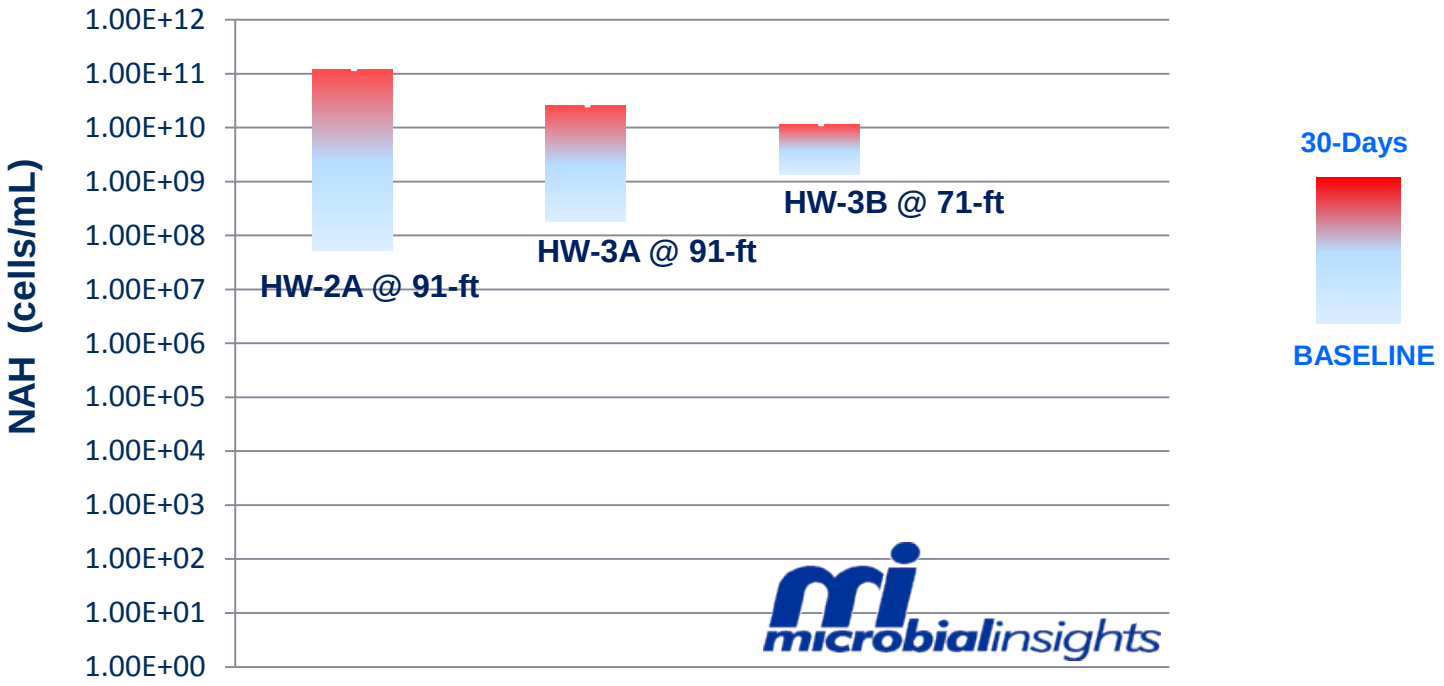
- Field sample collection
- Used to record baseline & post-pilot test populations of degraders
- 1 to 2 Liters
- Microbes live on solid surface

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)

microbialinsights

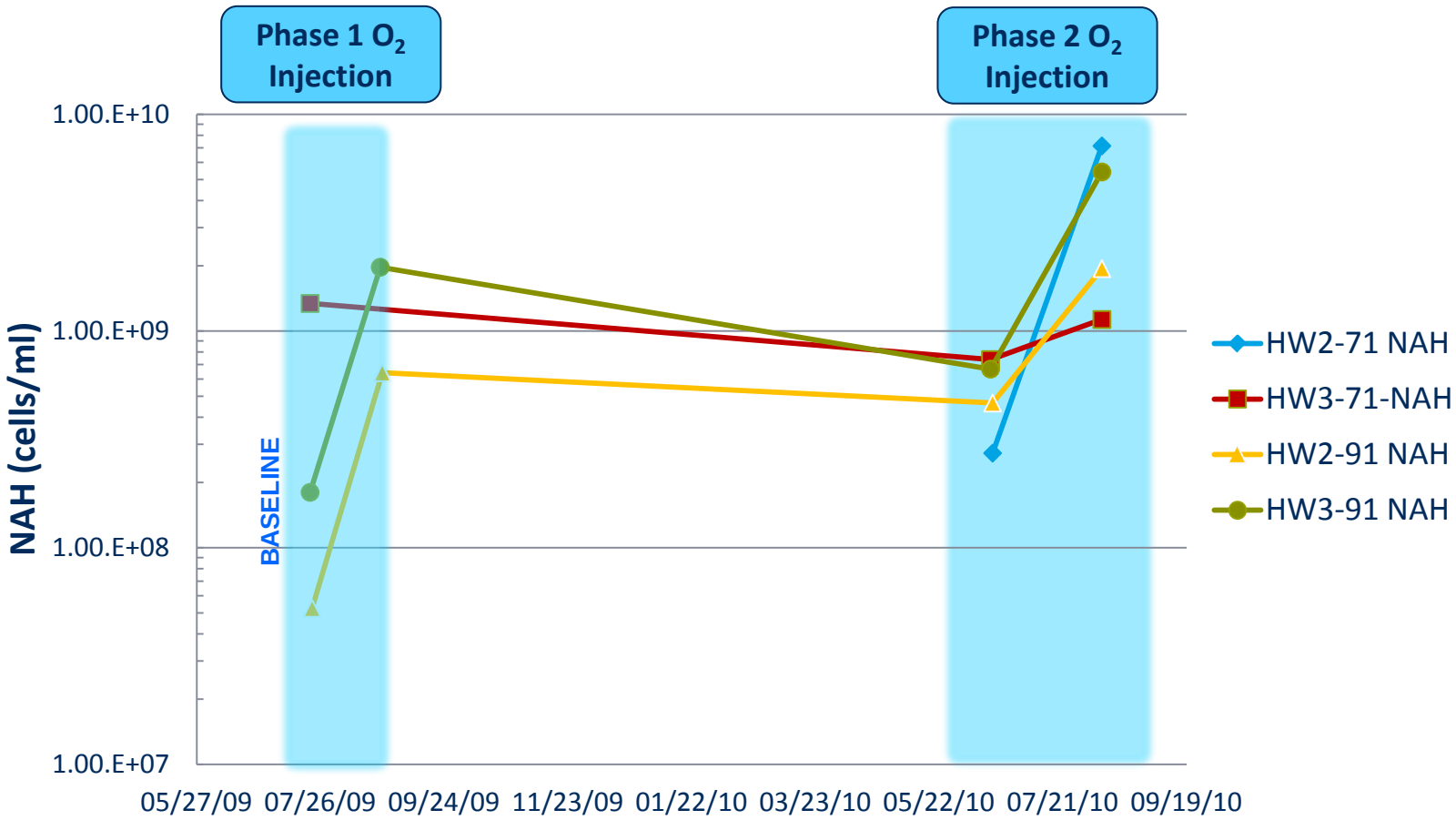
Downwell Microcosm Study - Phase 1 Injection



- 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

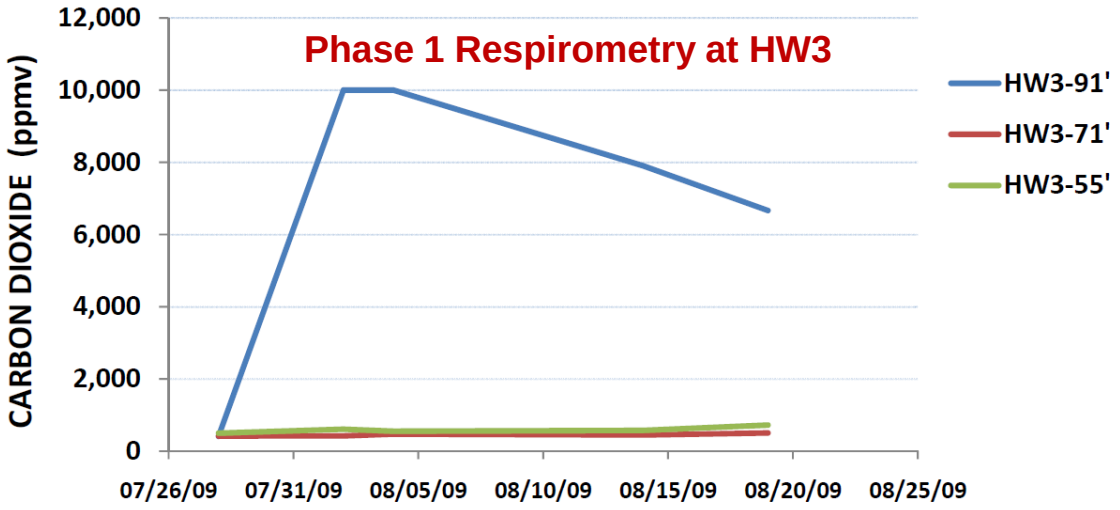
NAH Indicator Gene Populations by qPCR

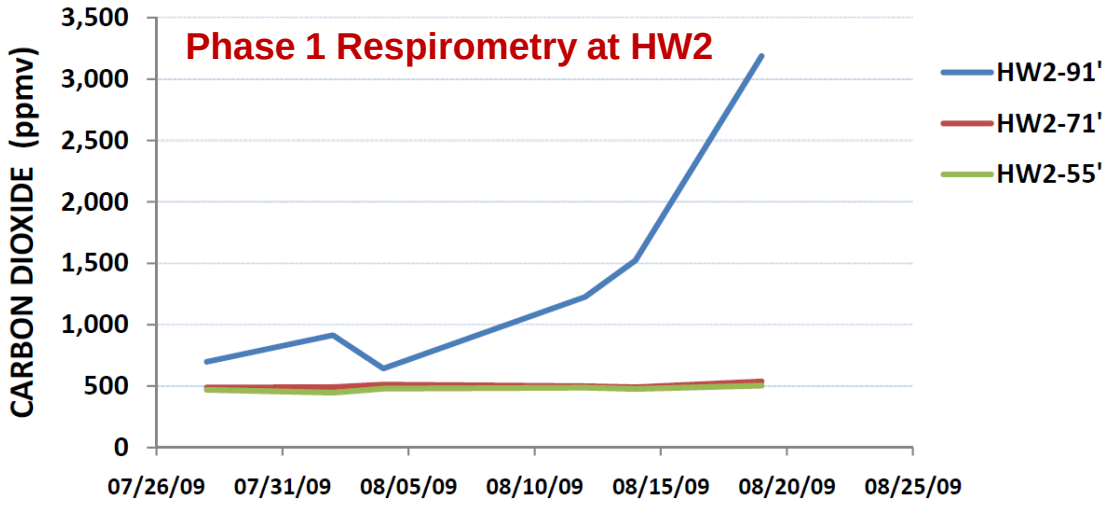


Bio-Flo Sampling

NAH = Naphthalene Dioxygenase

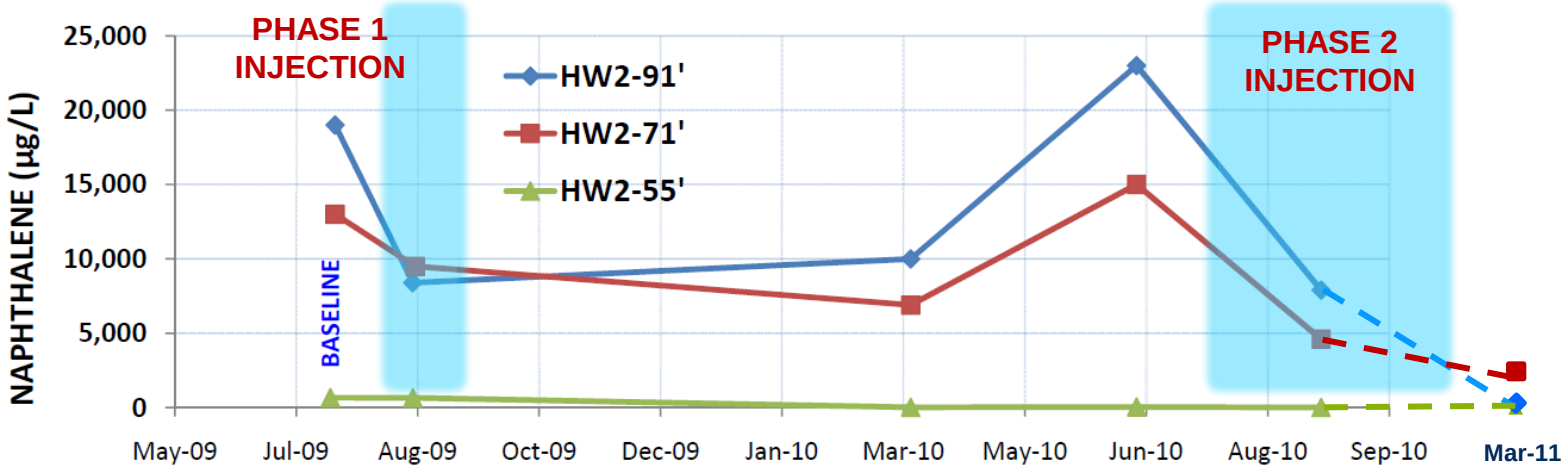
Phase 1 Pilot Scale Respirometry Data



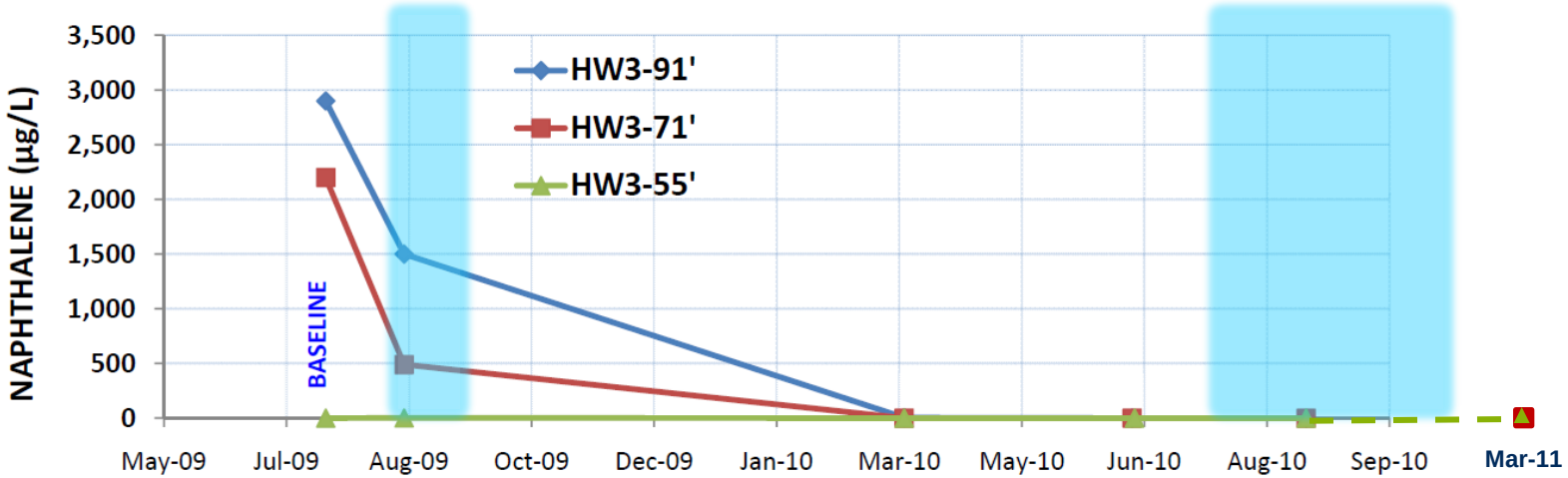


- Wellhead CO_2 Analysis
- 500 ppmv is background value in air

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

Contact Information:

Timothy R Turner, PE
Black & Veatch Special Projects Corp.
1120 Sanctuary Parkway, Suite 200
Alpharetta, Georgia 30004
770-521-8125

Building a World of Difference
in a Changing World