



Air Sparge Pilot Study in the DNAPL Source Zone at Launch Complex 34



Edith M. Johansen and Michael J. Deliz, (NASA, Kennedy Space Center, Florida)

Mark J. Jonnet (mark.jonnet@tetrattech.com), James Lloyd, Mark Speranza (Tetra Tech, Pittsburgh, Pennsylvania)

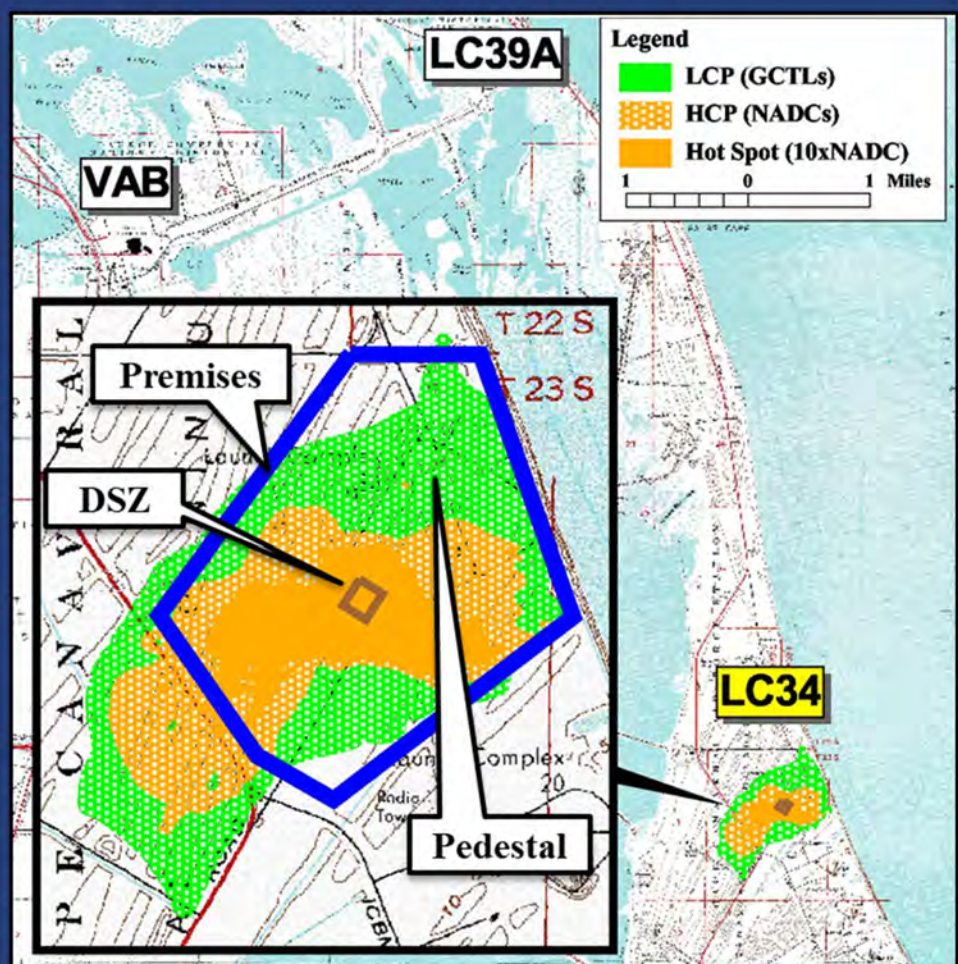
Launch Complex 34 History

- Construction of Launch Complex 34 (LC34) began in 1959.
- LC34 is located on a barrier island bounded by the Banana River and Atlantic Ocean.
- The Complex was designed to support NASA's Saturn 1 and 1B programs with seven launches between 1961 and 1968.
- Historical records suggest trichloroethene (TCE) used to flush rocket engines and for precision cleaning of spacecraft hardware.
- 1967: Apollo 1 cabin fire during a launch rehearsal test claimed the lives of astronauts Virgil "Gus" Grissom, Edward White and Roger Chaffee.
- 1972: Service structures and operational equipment was scrapped, leaving majority of on-site buildings and structures abandoned in-place.
- 1984: Declared LC34 part of the Man In Space National Historic Landmark.



Launch Complex 34 in the 1960s

Remedial Background

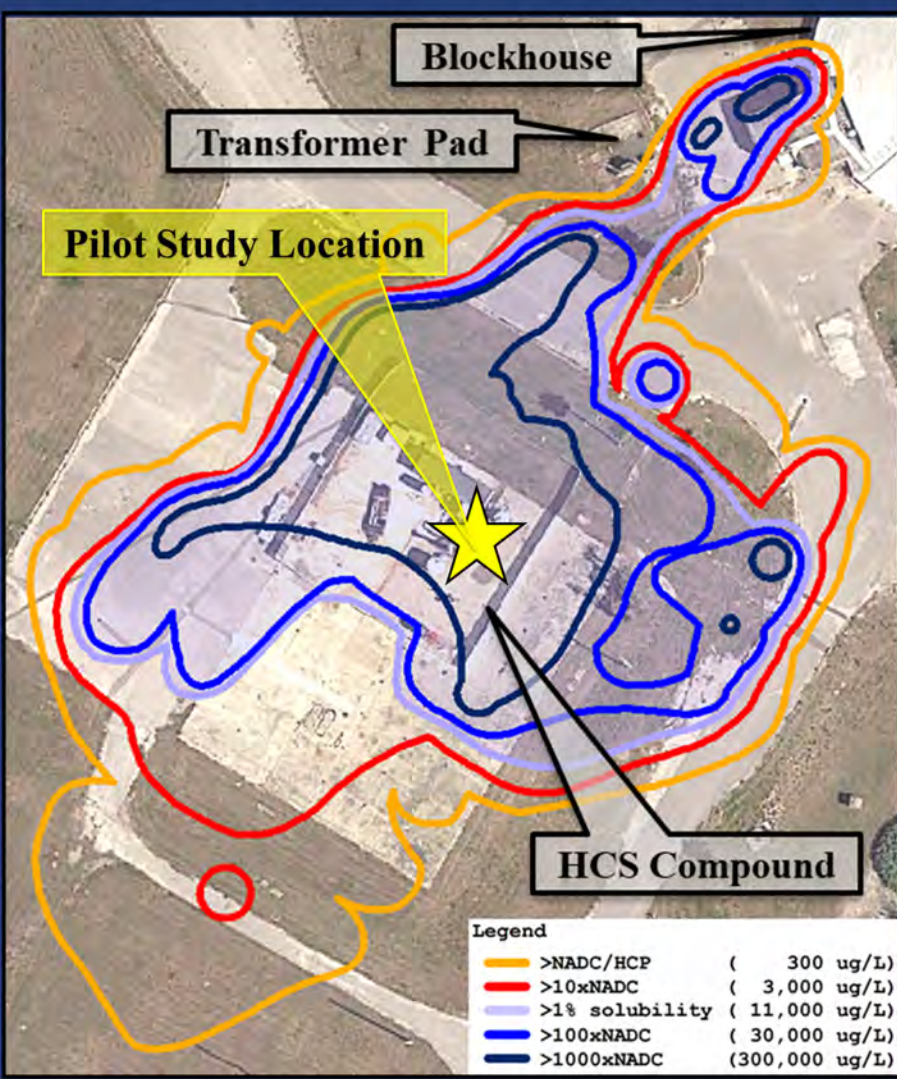


LC34 DNAPL Source Zone Location

- The Florida Department of Environmental Protection (FDEP) is the regulatory agency.
- 1990s: Environmental investigations revealed chlorinated solvent contamination including dense non-aqueous phase liquid (DNAPL) in groundwater in the vicinity of the Engineering Support Building (ESB).
- 1993 to 2003: In Situ remediation demonstration projects were conducted at the ESB.
- 2004: Groundwater long-term monitoring and corrective measures study (CMS) initiated.
 - The DNAPL source zone (DSZ) characterized as a 2-acre area to 75' below land surface (bls) encompassing the extent of TCE DNAPL determined by soil concentrations with TCE ≥ 300 mg/kg and the transition zone to 100 mg/kg. The corresponding pounds of TCE was calculated to be 74,000 and 12,000 lbs, respectively.
 - Recommended corrective action alternative was a hydraulic containment system (HCS) for the DSZ via pump and treat (P&T).
- HCS has operated since 2010 providing hydraulic containment via P&T for the DSZ.
- Recharacterization of the DSZ was conducted in 2019 to delineate TCE to 300 $\mu\text{g/L}$ to support optimization of HCS and for the DSZ Remedial Alternatives Evaluation (RAE).
 - Mass estimate showed that total TCE mass is 32,000 lbs. with 10,000 lbs. in the dissolved DNAPL phase (TCE > 11,000 $\mu\text{g/L}$).
- A preliminary RAE was conducted to evaluate aggressive technologies to substantially reduce mass in the remaining DSZ in a reasonable timeframe.

Pilot Study Background

- Preliminary RAE efforts showed a different approach was warranted for the DSZ based on:
 - Despite the extraction of approximately 276,413,135 gallons of groundwater and 83,139 lbs. of VOCs as of December 2021 (approximately 79% is TCE), the DSZ recharacterization showed its size was little changed and extended into fine-grained Layer 7.
 - Scaling up costs for aggressive DNAPL technologies used at other KSC sites (e.g., electrical resistance heating) indicated prohibitive expense without confidence of complete treatment.
 - Targeted DSZ treatment being more feasible, but an updated groundwater model indicated continued HCS operation may achieve site cleanup objectives faster.
- Path forward is to evaluate the next implementable technology in the treatment train for the DSZ.
- Air sparging is proposed as a potential alternative, in addition to other proposed alternatives in the RAE, based on the following reasons:
 - Over 90% of the mass is between 40 to 80 ft bls.
 - Air sparging has been successful in Layers 1, 2, and 3 outside of the DSZ at LC34.
 - Air sparging success is unknown in Layers 4 and 7 (both fine grained units).
 - Anticipate air sparging to be successful in Layers 5 and 6 (both sandy units).
 - If air sparging is successful in Layers 4 and/or 7, cost significantly less than other technologies.
- A pilot study was proposed in support the RAE alternative to evaluate whether air sparging is a feasible technology in the DSZ area.



Pilot Study Location with 2019 Recharacterization

Pilot Study Description

Project Objectives

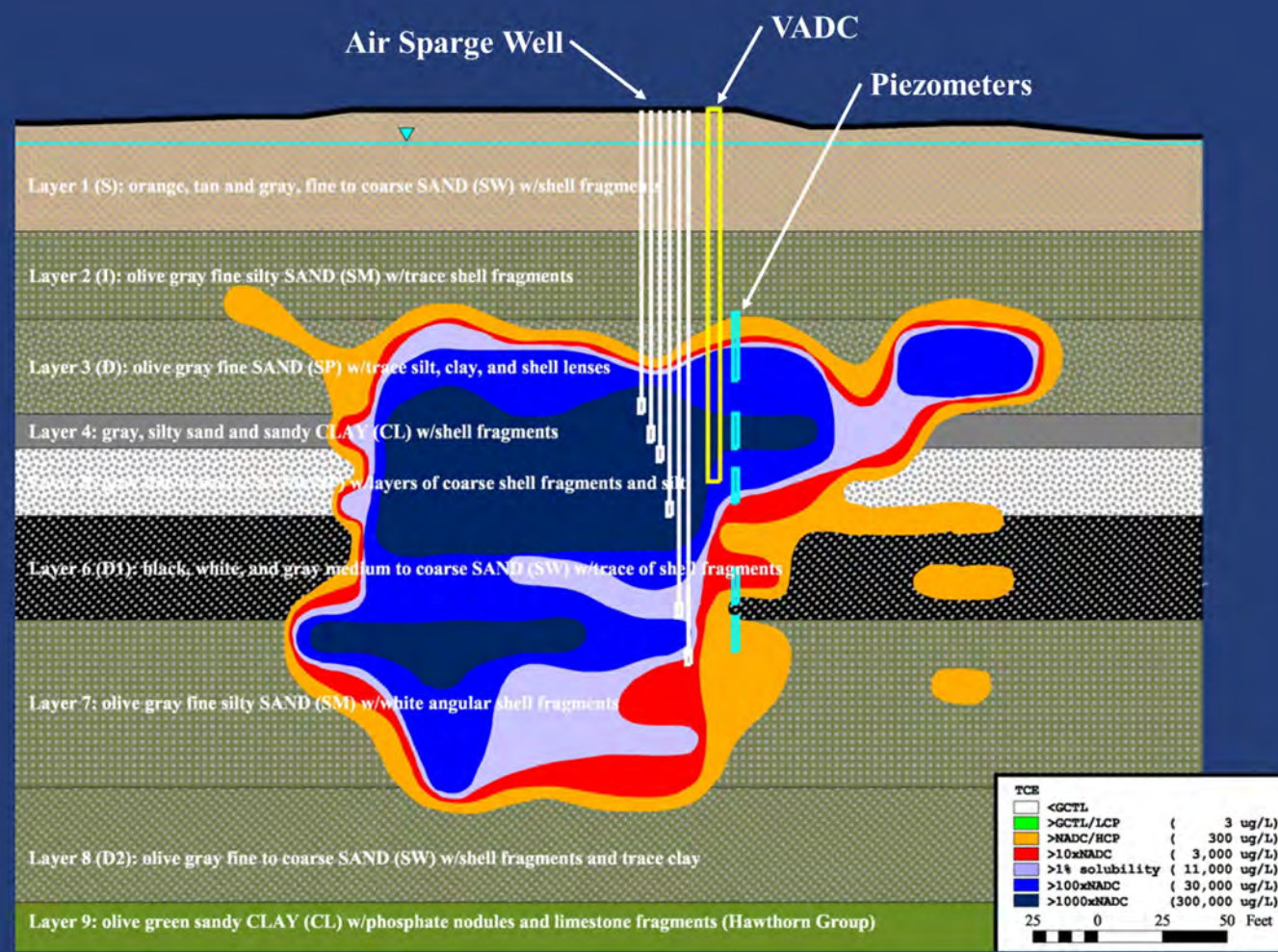
- Determine the potential for vertical and horizontal air distribution within and below Layer 4 (> 45 ft bls) and determine a radius of influence (ROI) within the various geologic layers.
- Evaluate the ability to capture vapors below Layer 4.
- Evaluate the treatability of the TCE source area.
- Determine whether full scale implementation is feasible.

Components

- Central cluster of 6 Air Sparge Wells (ASW)
- 4 Vertical Air Distribution Columns (VADC) to monitor and capture vapors below Layer 4
- 12 Vapor Monitoring Points (VMP) to monitor vapors in vadose zone
- 55 Piezometers (PZ) to monitor vertical and horizontal air distribution (i.e., dissolved oxygen)



Pilot Study Site Layout



Pilot Study Cross Section

Methods and Testing Objectives

Methods

- The Pilot Study consisted of seven tests to carry out the objectives.
- Tests generally ran for two weeks with a two-week shut-down period to allow sparged conditions to subside.
- Baseline conditions were recorded before each test which included:
 - Dissolved oxygen (DO), oxidation-reduction potential (ORP), pressure, and photoionization detector (PID) readings.
 - DO was the primary measurement of ROI while ORP, pressure, and PID were supporting lines of evidence.
- During testing, daily readings were collected including the baseline parameters.
 - Additionally, pressure and PID readings were taken at VADCs and VMPs.
- At the end of each test, air and groundwater samples were collected.
- DO measurements were converted to DO saturation for determining ROI.

Testing Objectives

- Data collected during each test were evaluated against the test-specific objectives.
- The DO saturation response (the difference between the average and the baseline reading) was compared to guidance to determine significant air sparge influence.
- Analytical results for air samples collected during each test were used to evaluate the magnitude of emissions to determine the need for off gas treatment.

Geotechnical Results for Fine-Grained Layers

Layer 4

- Soil description is bluish gray/Green Clay; little to some silt; trace to little sand; fine to very fine shell
- Clay content is 18.4%
- Hydraulic conductivity is 7.9×10^{-8} cm/sec

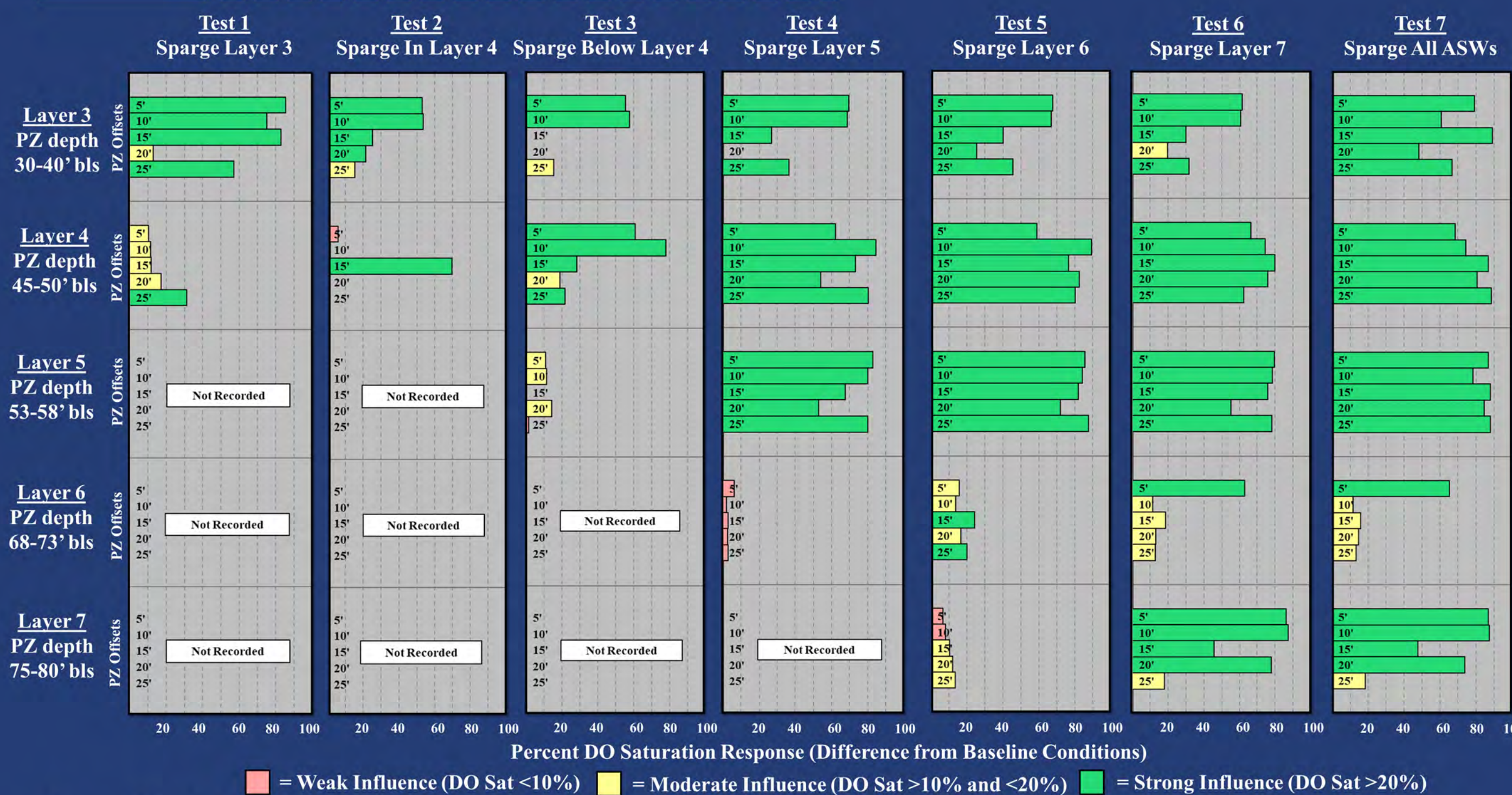


Layer 7

- Soil description is Gray/Greenish Gray Sand – Fine to very fine; little to some shell and silt; trace clay
- Clay content is 12.2%
- Hydraulic conductivity is 4.5×10^{-6} cm/sec



ROI Evaluation Using DO Saturation Results By Layer



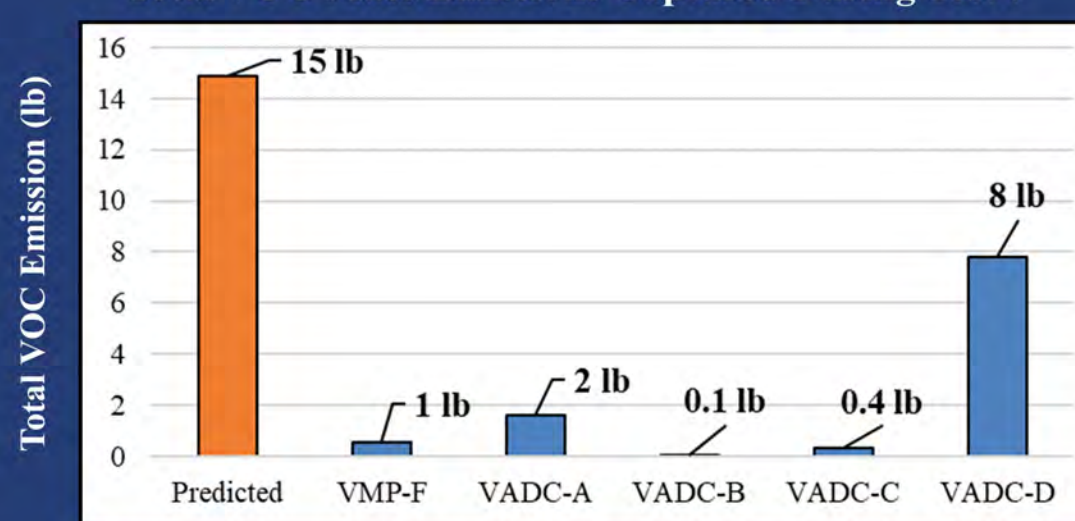
Vapor Emissions and Treatability

- Test 7 air data were used to calculate emissions over the course of the test (blue bars).
- Actual emissions were compared to predicted emissions using an emissions calculator (orange bar).
- Results show approximately 50% of predicted emissions were observed.
 - VADC-D captured the maximum vapors from all components tested.
- VADCs can capture significant portion of the emissions below Layer 4.
- VMPs captured less emissions; Layer 4 hindered potential volatilization into the vadose zone.

Results and Conclusions

- Conservative depth-specific ROIs determined from test-specific DO saturation response results.
- Other lines of evidence (ORP, pressure, and PID) generally confirmed the ROI results.
- Vapor capture below Layer 4 is crucial for successful full-scale implementation.
- Site-specific factors contributed to the results including:
 - Layer 4 is likely not a continuous layer creating preferential pathways.
 - Greater ROI observed when sparging deeper due to the air sparge "cone" effect and a higher chance of air dispersing into discontinuous geology.

Total VOC Mass Emissions Captured During Test 7



ROI Determination by Test

Test	Sparged Layer	ROI (ft)
Test 1	Above Layer 4	15
Test 2	In Layer 4	≤ 5
Test 3	Directly below Layer 4	10
Test 4	Layer 5	15-20
Test 5	Layer 6	≥ 5
Test 6	Layer 7	10-15
Test 7	All above layers	15-20