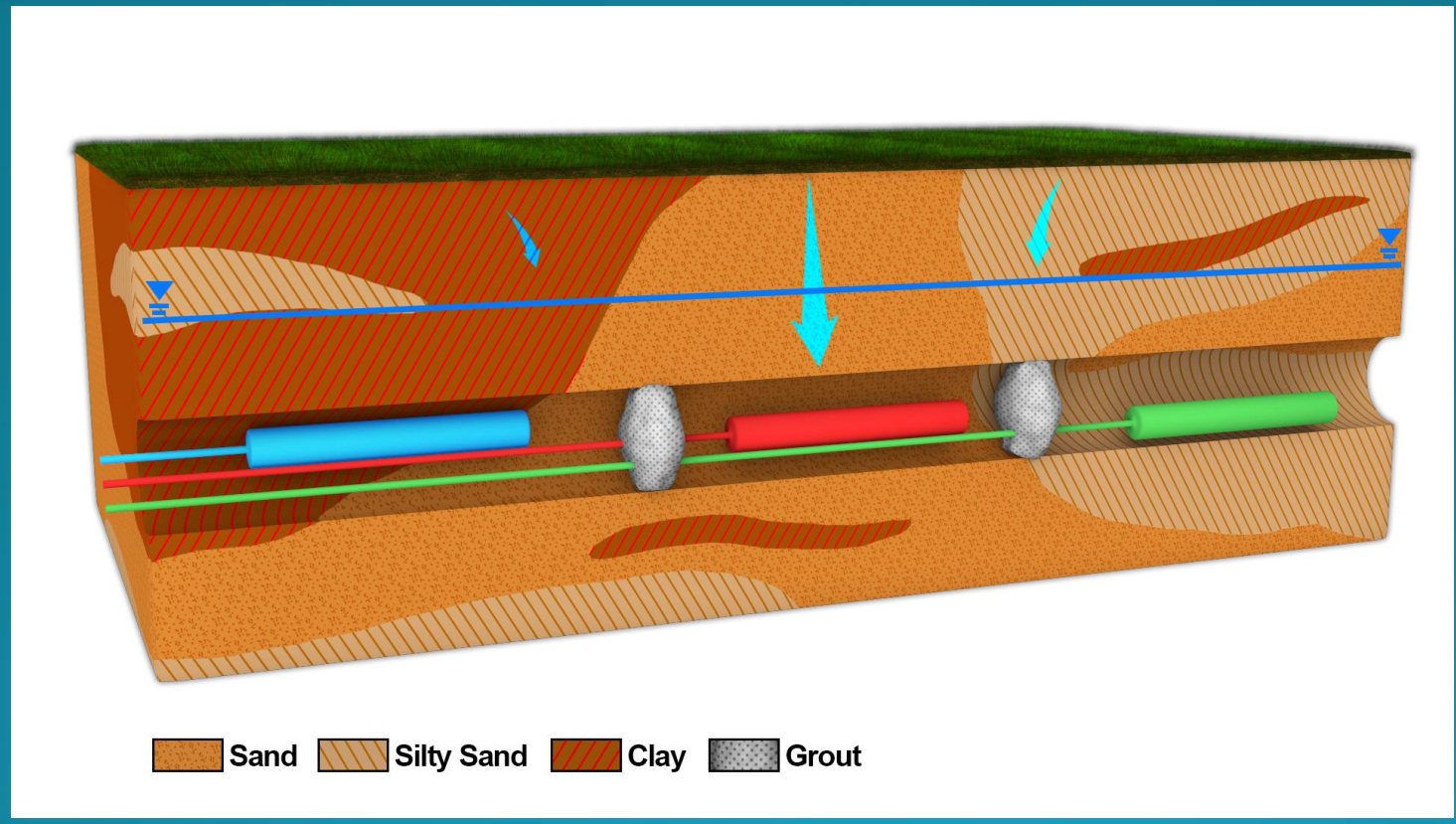
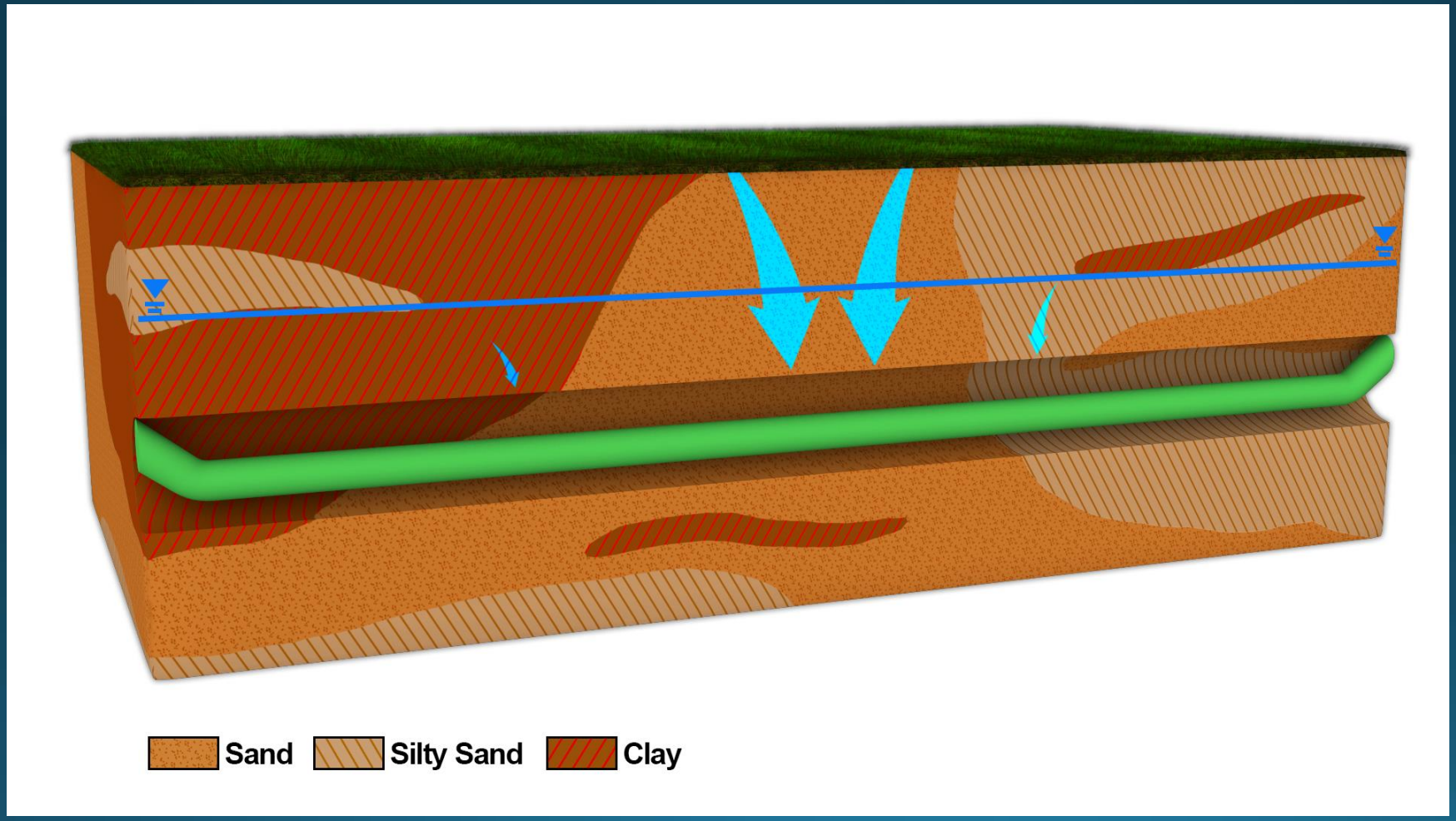
Vertebrae™ Horizontal Nested Well Systems

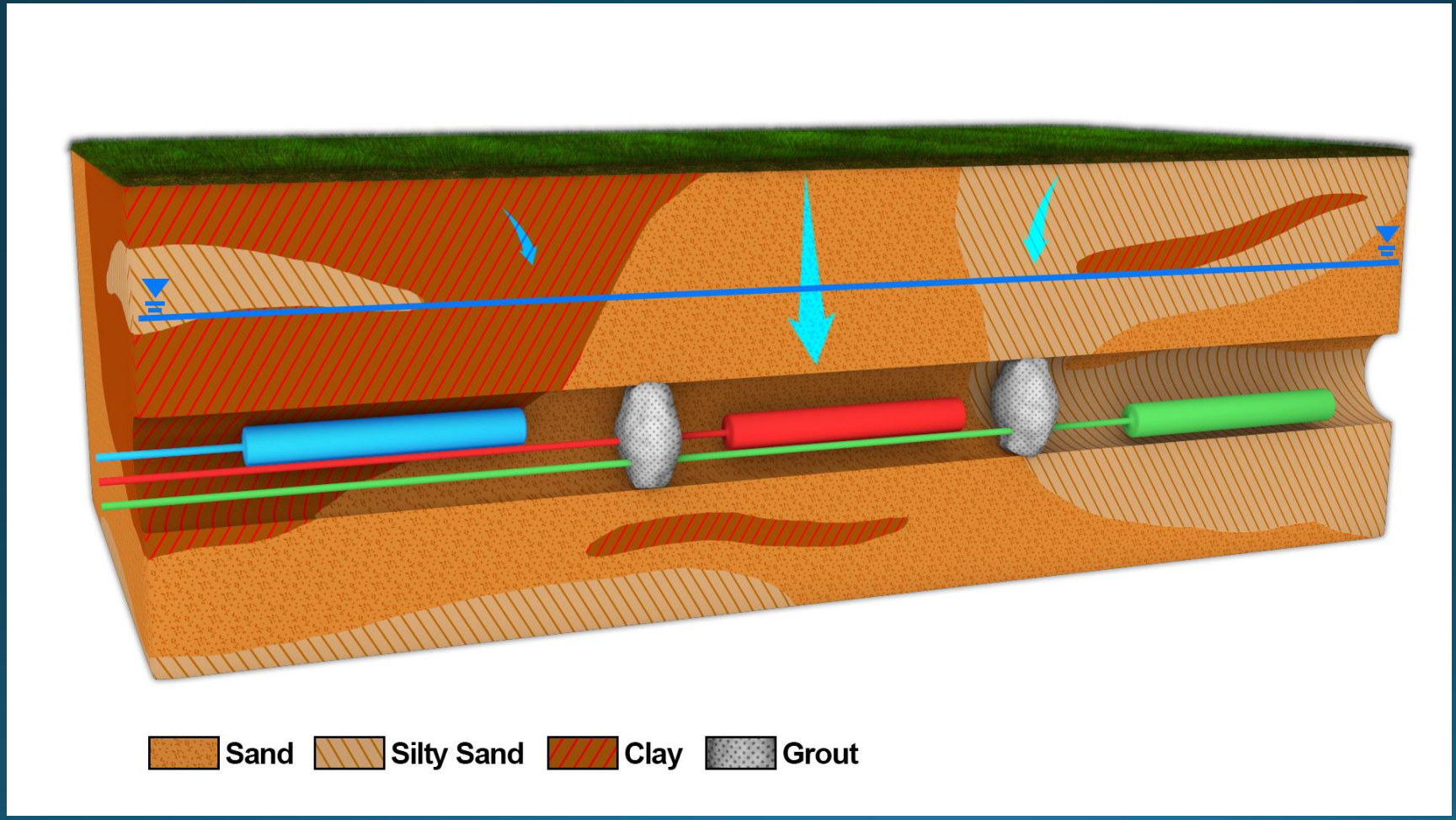
Next Gen Site Investigation & Remediation Technology



Single horizontal units are very susceptible to preferential flow path influences.

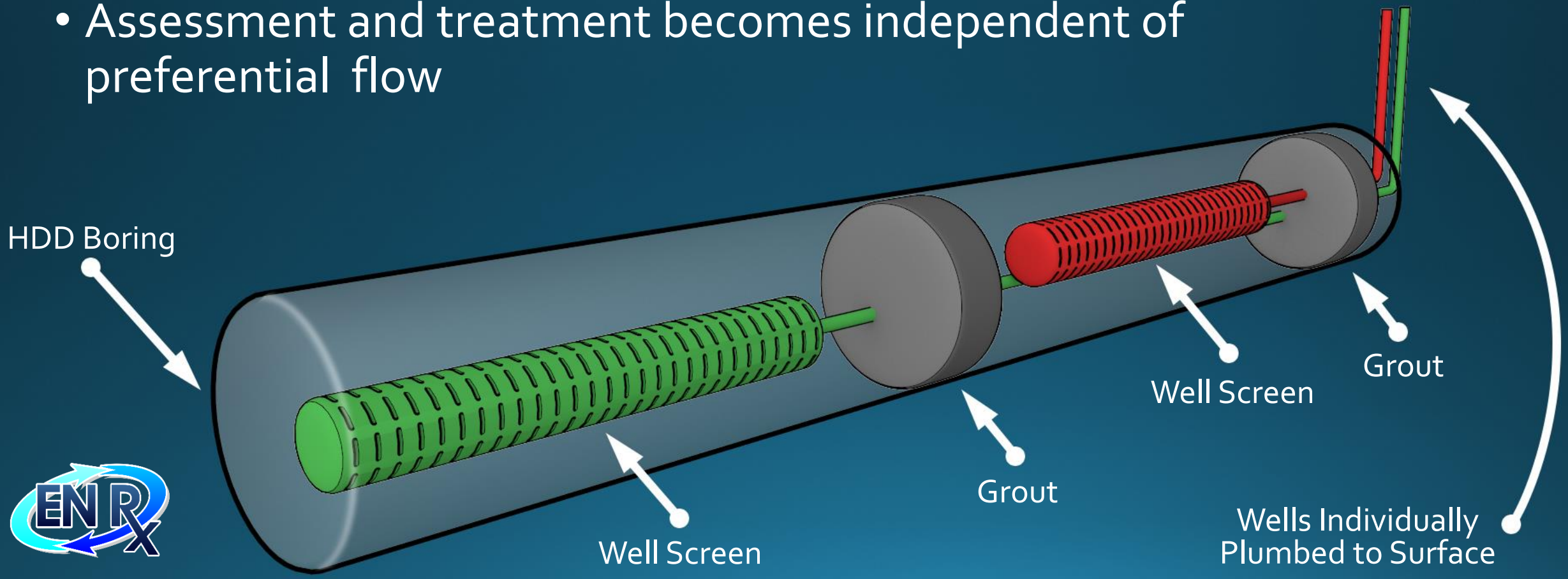


Nested wells avoid these complications.



Vertebrae™ Simplified Subsurface Model

- Nested wells are discrete, using grout-based isolation, but still communicate
- Assessment and treatment becomes independent of preferential flow



Horizontal System Advantages
in Sampling and Remediation

Overhead obstructions or subsurface utility issues

Client concerns over Business disruption or site security

Physical limitations related to the built environment, or natural terrain

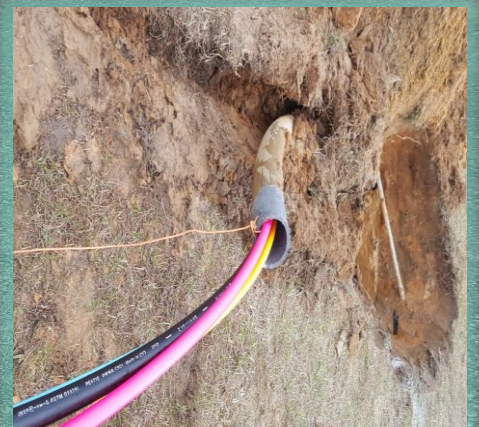
Some Advantages

- Vertebrae™ Horizontal Well Systems have:
  - Reduced investigation costs.
  - Reduced treatment costs.
  - More extensive investigation potential.

Safe, Minimally Invasive Operations

By the Nature of the Operations, a VWS Installation is Inherently Safer.

Individual Access Lines



"Vertebrae™ on a Wheel"

Site Assessment

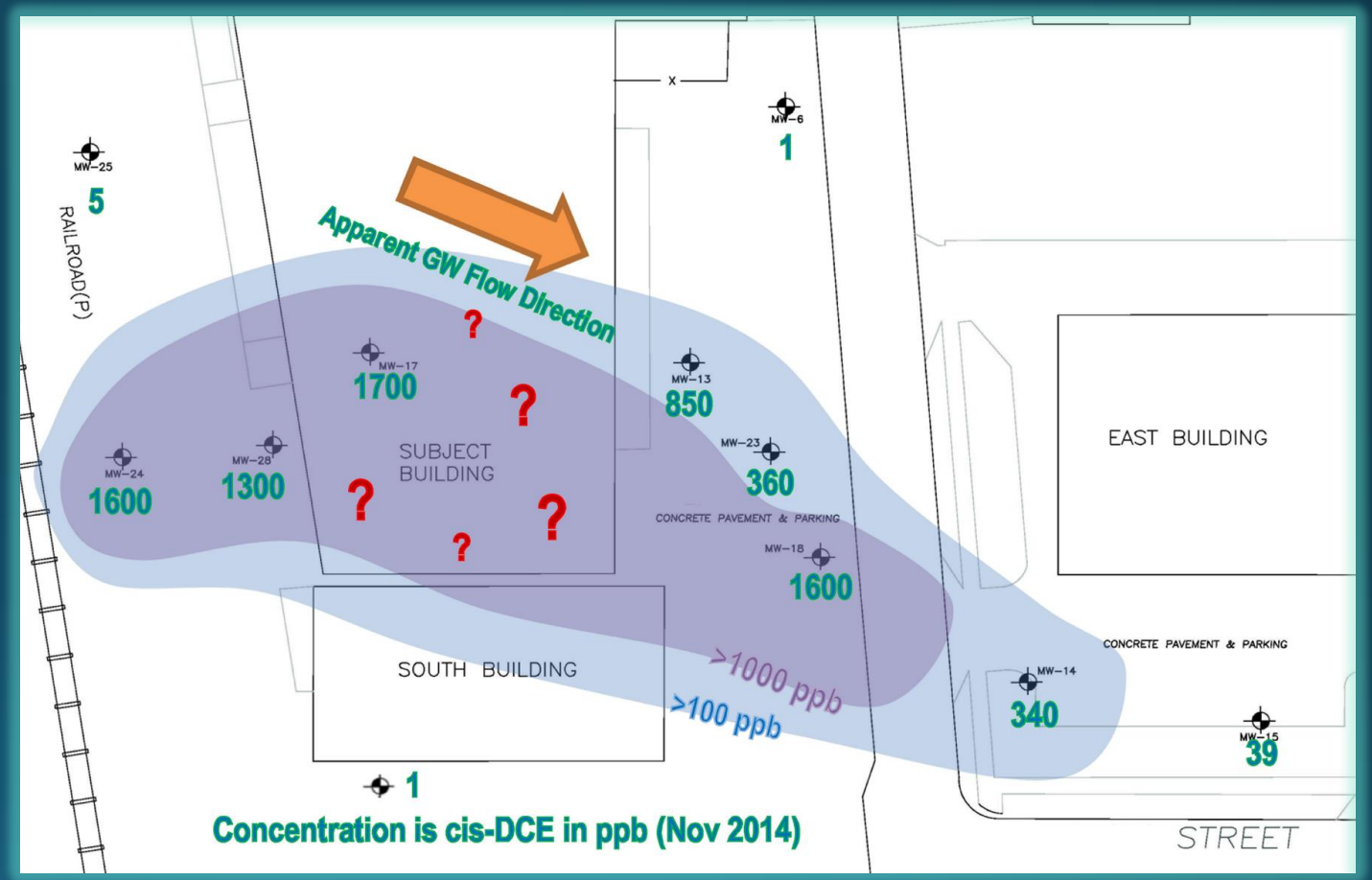
- Vertebrae™ Well Systems address data gaps generated by conventional vertical well assessment.
- The need for accurate assessment cannot be overemphasized, as it is not practical to begin a journey without a proper map.
- The use of segmented horizontal wells allows the creation of new and unique Conceptual Site Models, which is invaluable.
- Best of all, Vertebrae™ Well Systems "hit from both sides of the plate" in that after assessment they can function as a reagent delivery mechanism.

Site Remediation

- Vertebrae™ Well Systems can deliver reagents that drive oxidative and/or reductive contaminant remediation.
- The segmented configuration allows the engineer to maximize efficiency by adapting to plume dynamics.
- The only limitation is the physicality of the reagent such that it can pass through a well screen effectively.
- The Systems can also be used for air sparging or soil vapor extraction (SVE).

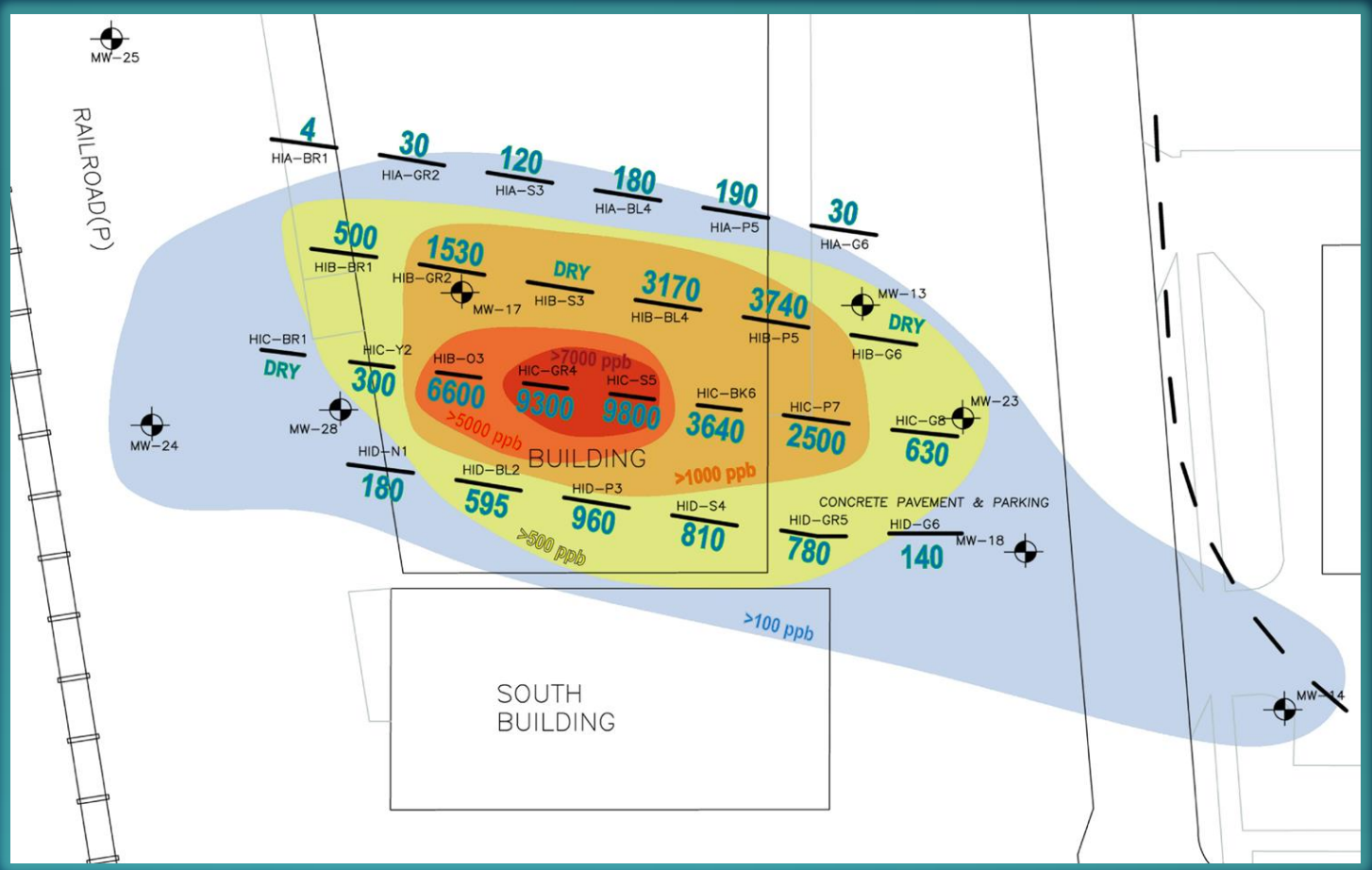
Case Study 1. Assessment of Data Gaps

- Often the data gap is in the area of highest concentration.



Case Study 1. Assessment of Data Gaps

- Sampling nested wells identified 400% more contamination.
- Note how the data supports how the wells are effectively isolated.

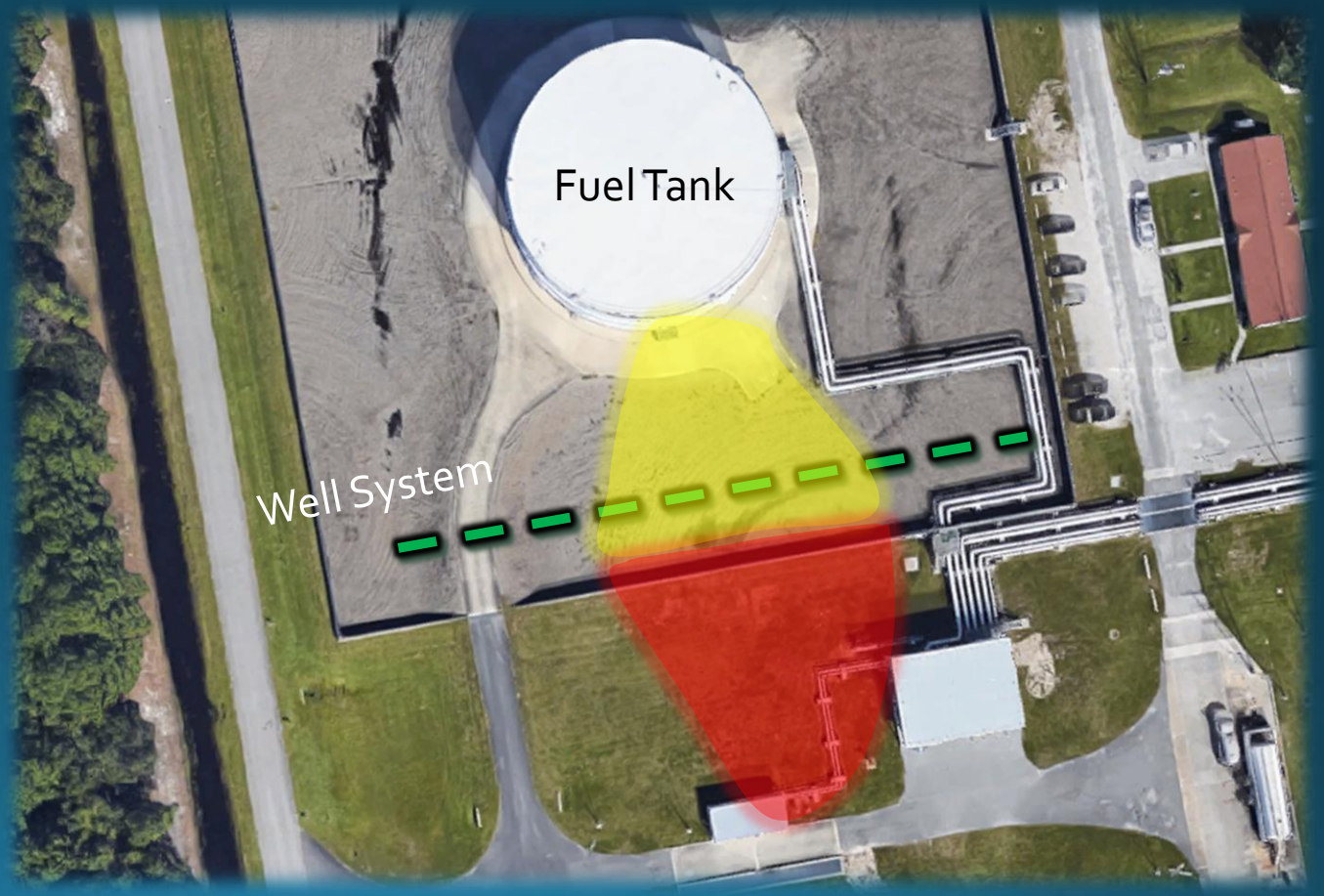


Case Study 2. Data Gaps

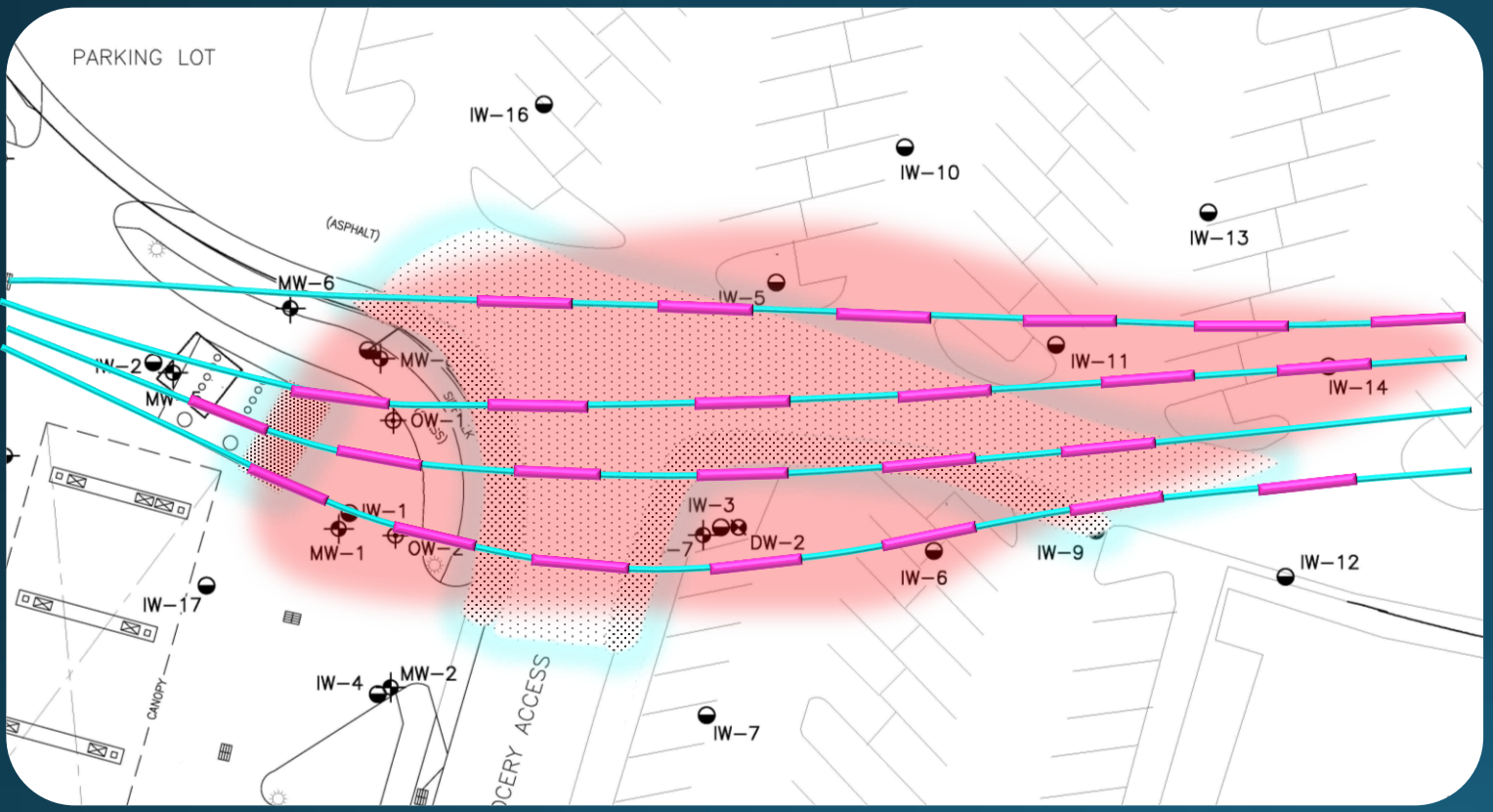
One Vertebrae™ Well System installed in 20’ sections to assess source of a dissolved phase hydrocarbon plume at a naval base.

The assumption that the tank was leaking was refuted. The problem was shown to be related to adjacent piping infrastructure.

The situation was simplified and a huge relief to the operators.



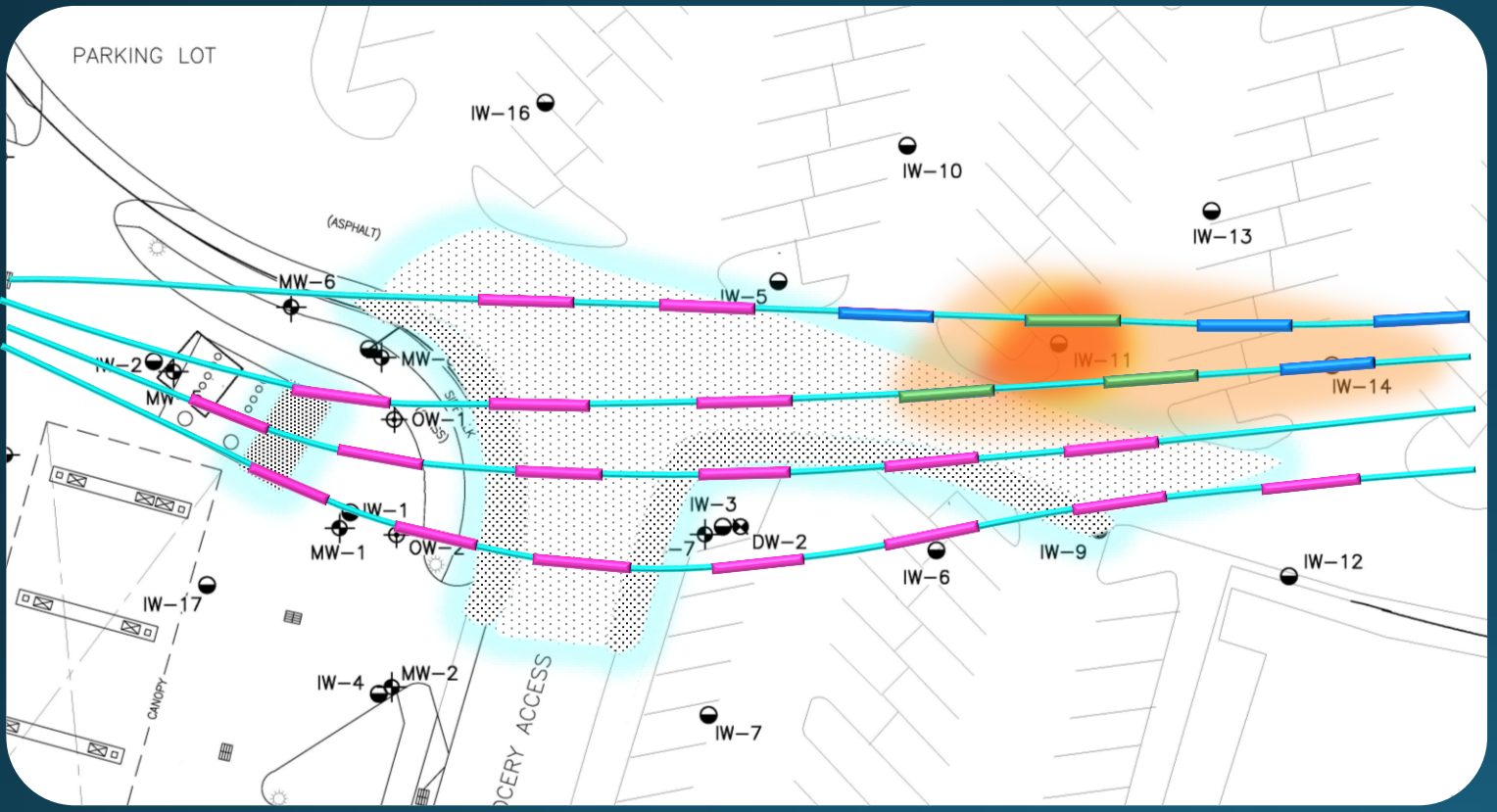
Case Study 3. A Complex Problem



- Impacts under tanks, adjacent roadway and parking lot
- Resistant adjacent property owners
- Four Vertebrae Well Systems™ installed for treatment
- First application made. Shading indicates dosage pattern

- A very important feature of a segmented well system is that it offers unique flexibility not found in conventional horizontal well applications.

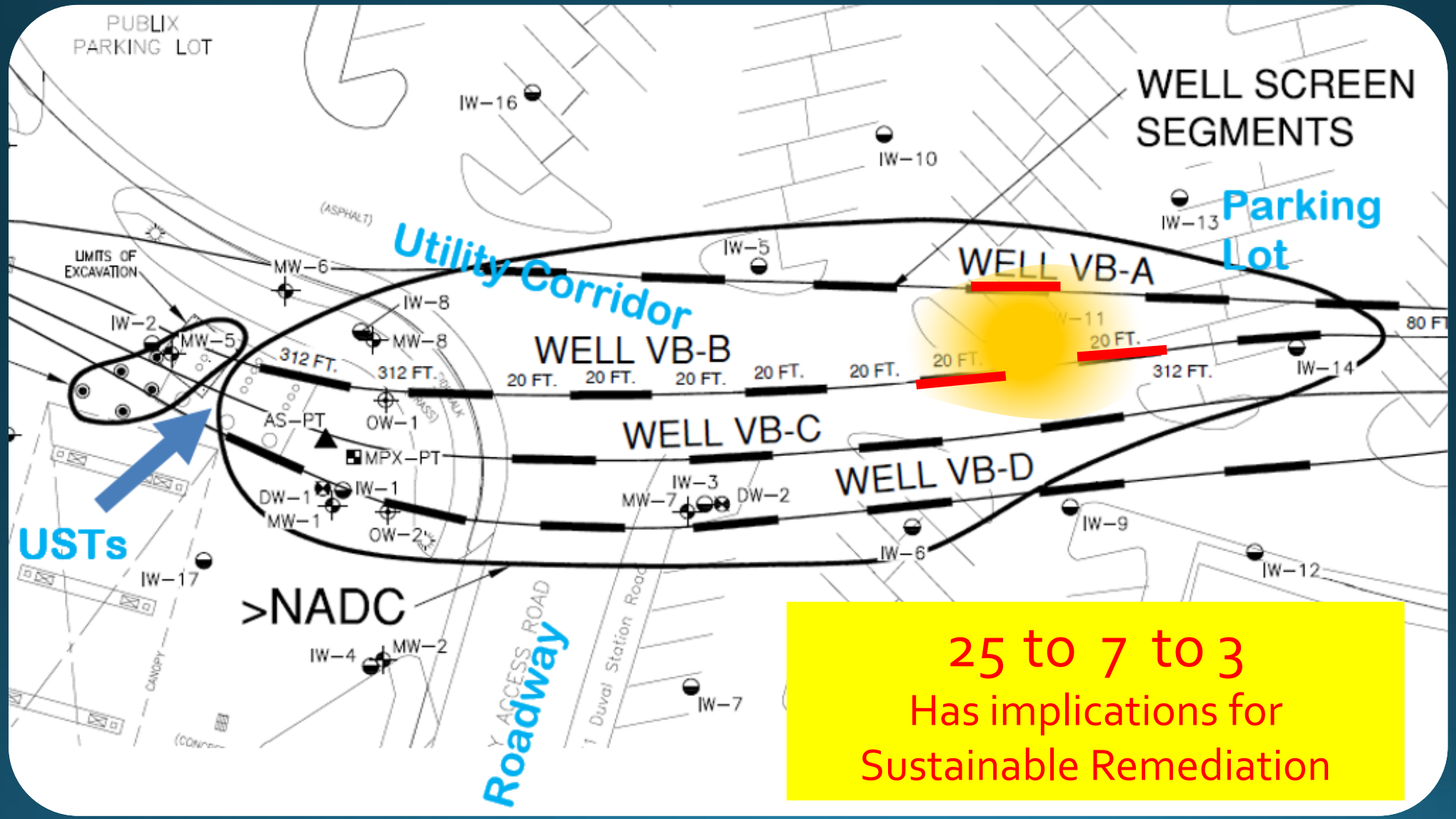
Case Study 3. A Complex Problem



- Subsequent assessment indicated a recalcitrant area toward the rear of the plume, requiring further treatment
- Adjustments were made with simple reproportioning of the treatment scheme to match the plume dynamics.
- Engineer is able to surgically control the treatment in real time.

Adaptive Application made and closure achieved

Recent Data Set

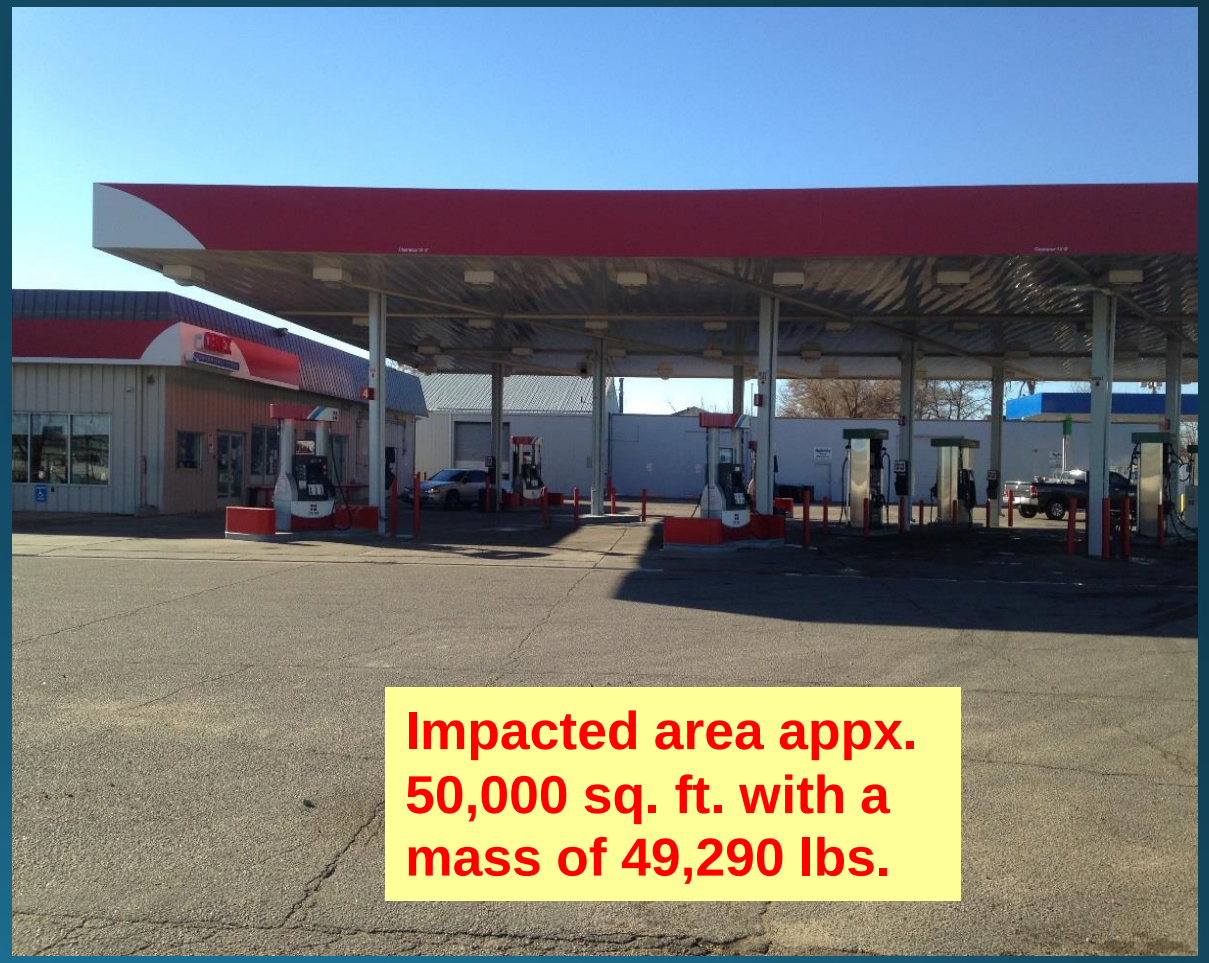


25 to 7 to 3

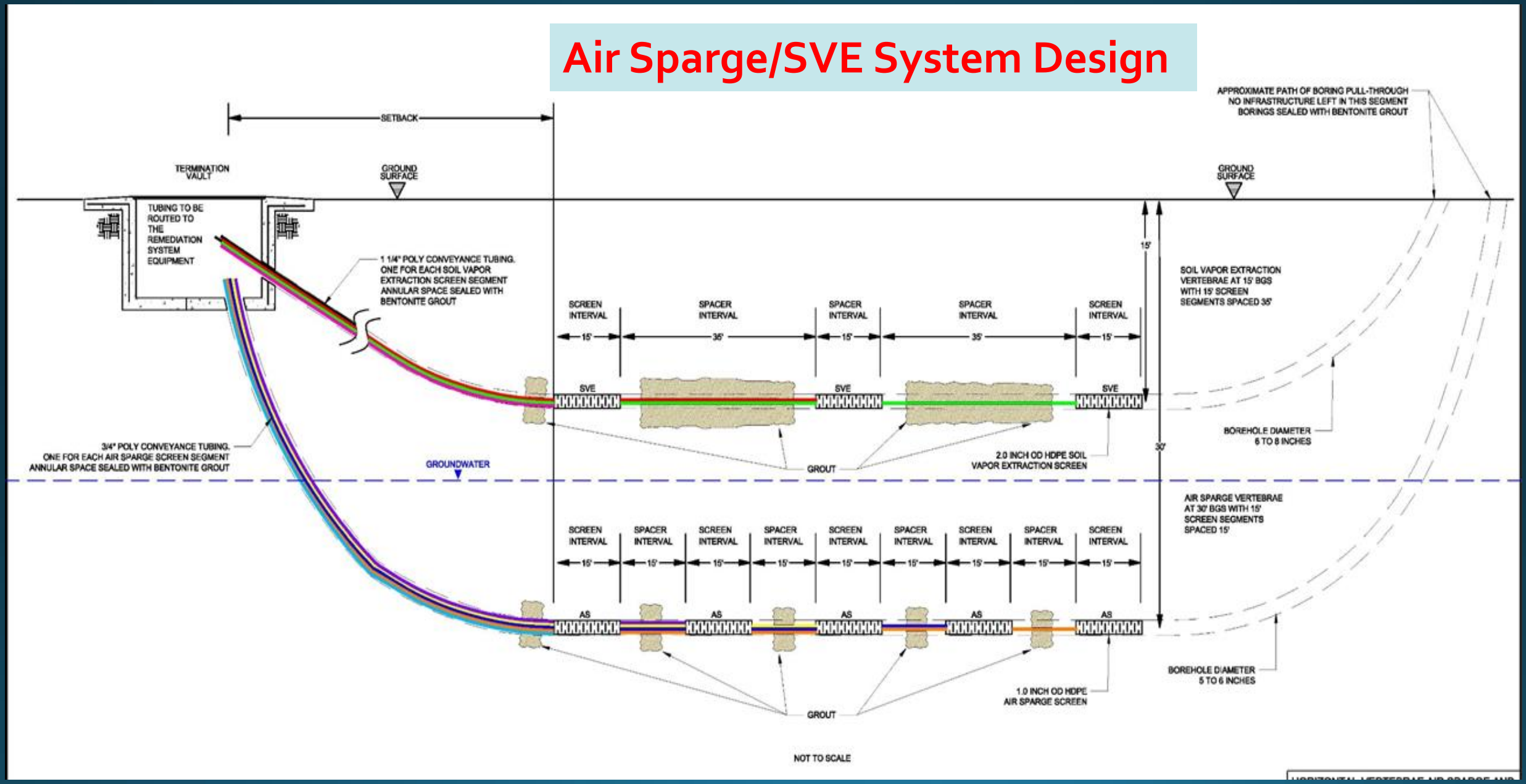
Has implications for Sustainable Remediation

AS/SVE Remediation Case Study

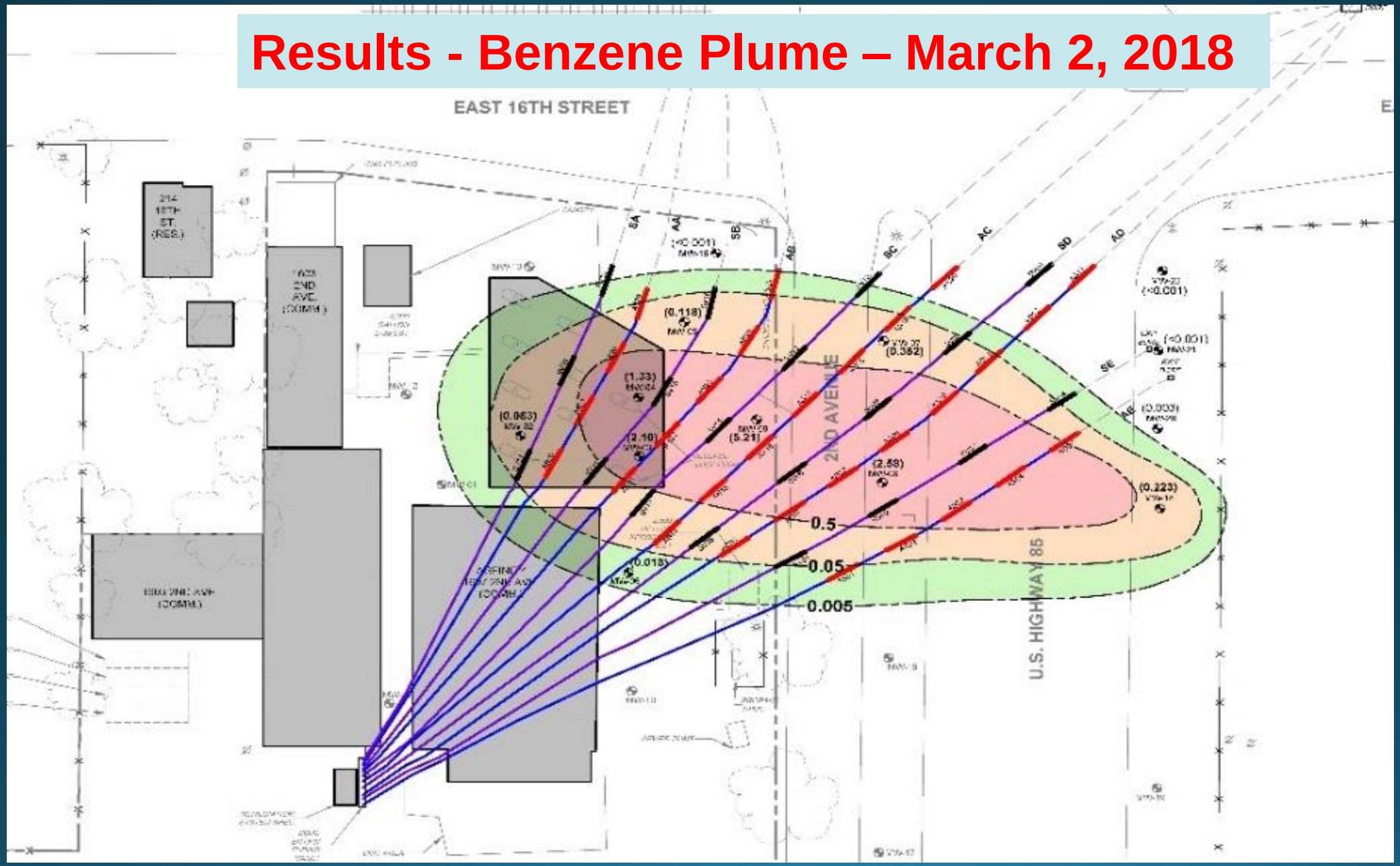
- Active station in Colorado
- Four 12,000 gallon USTs
- Suspected release August, 2016



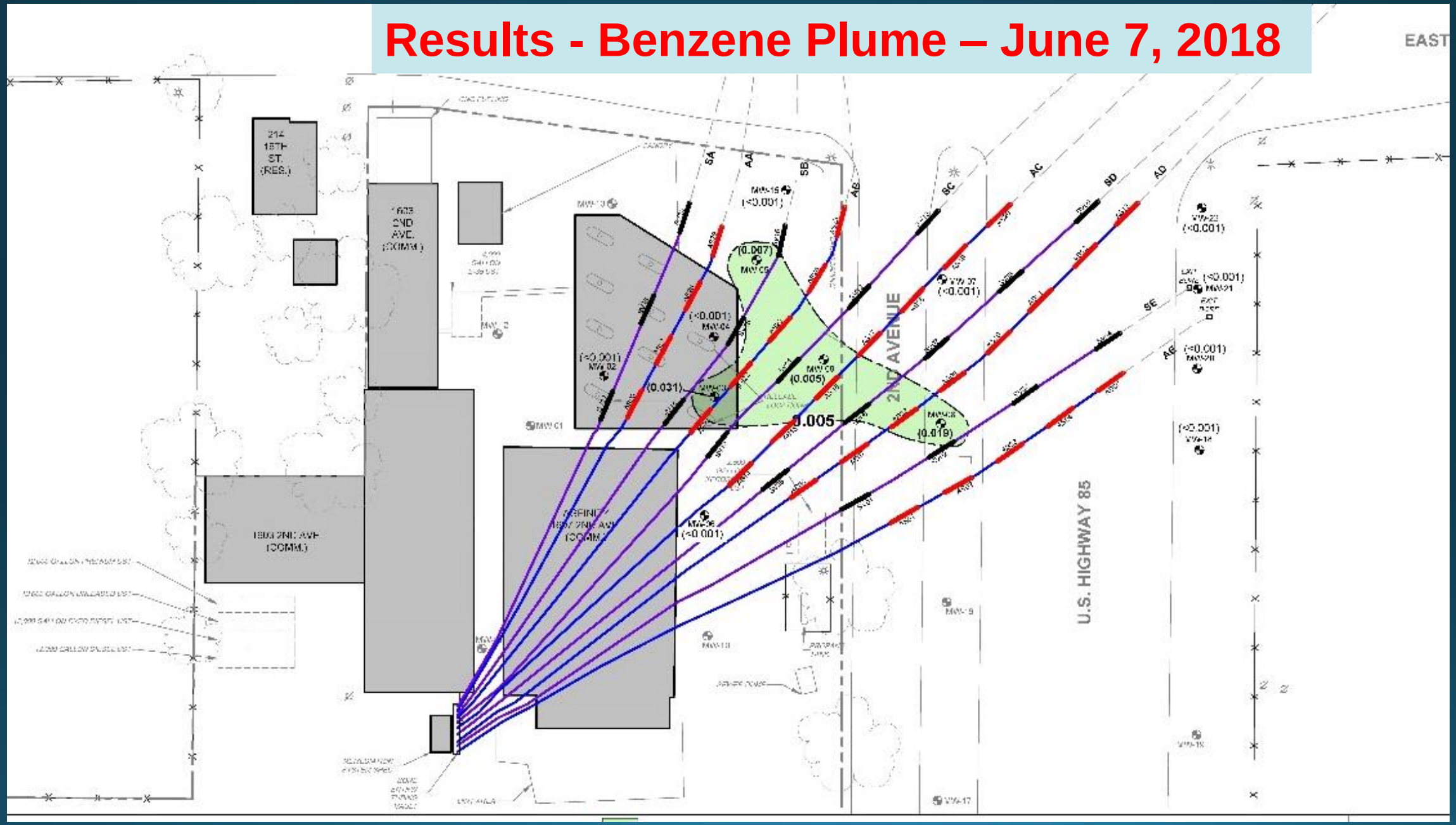
Air Sparge/SVE System Design



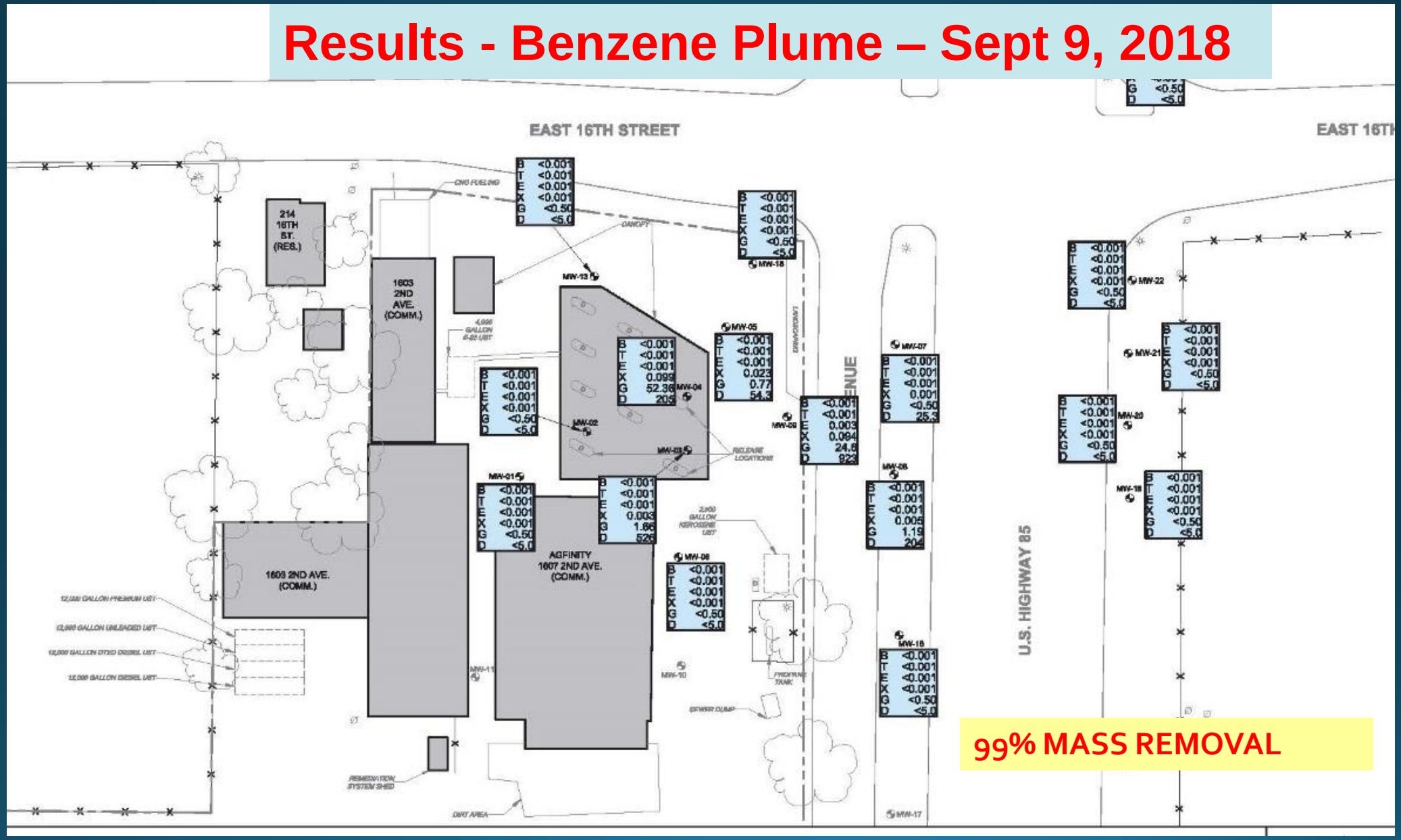
Results - Benzene Plume – March 2, 2018



Results - Benzene Plume – June 7, 2018



Results - Benzene Plume – Sept 9, 2018



Design Considerations

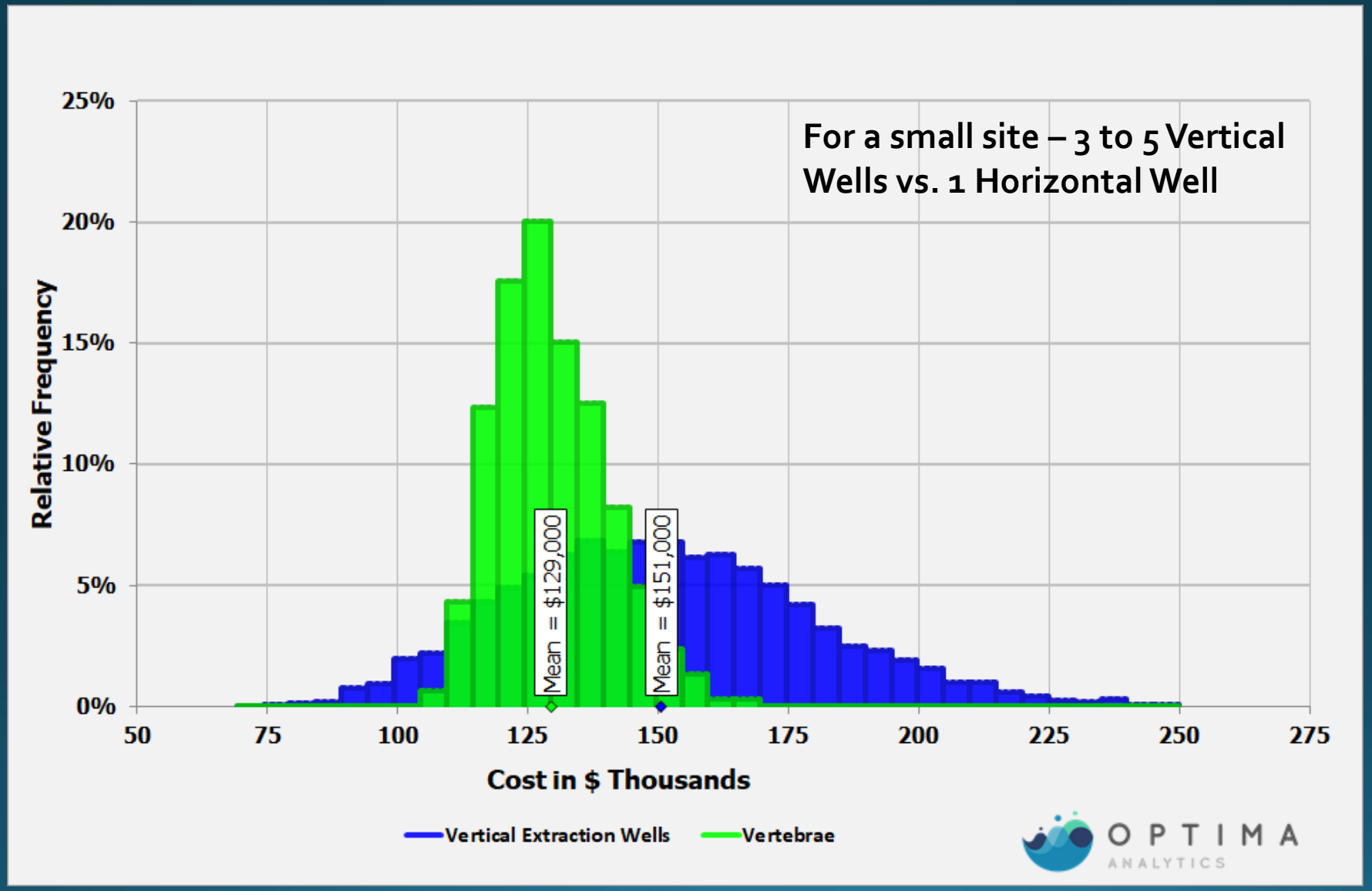
Sizing ► ½ to 1.5 inch OD tubing to surface

HDD Length ► Over ~800 ft. additional cost

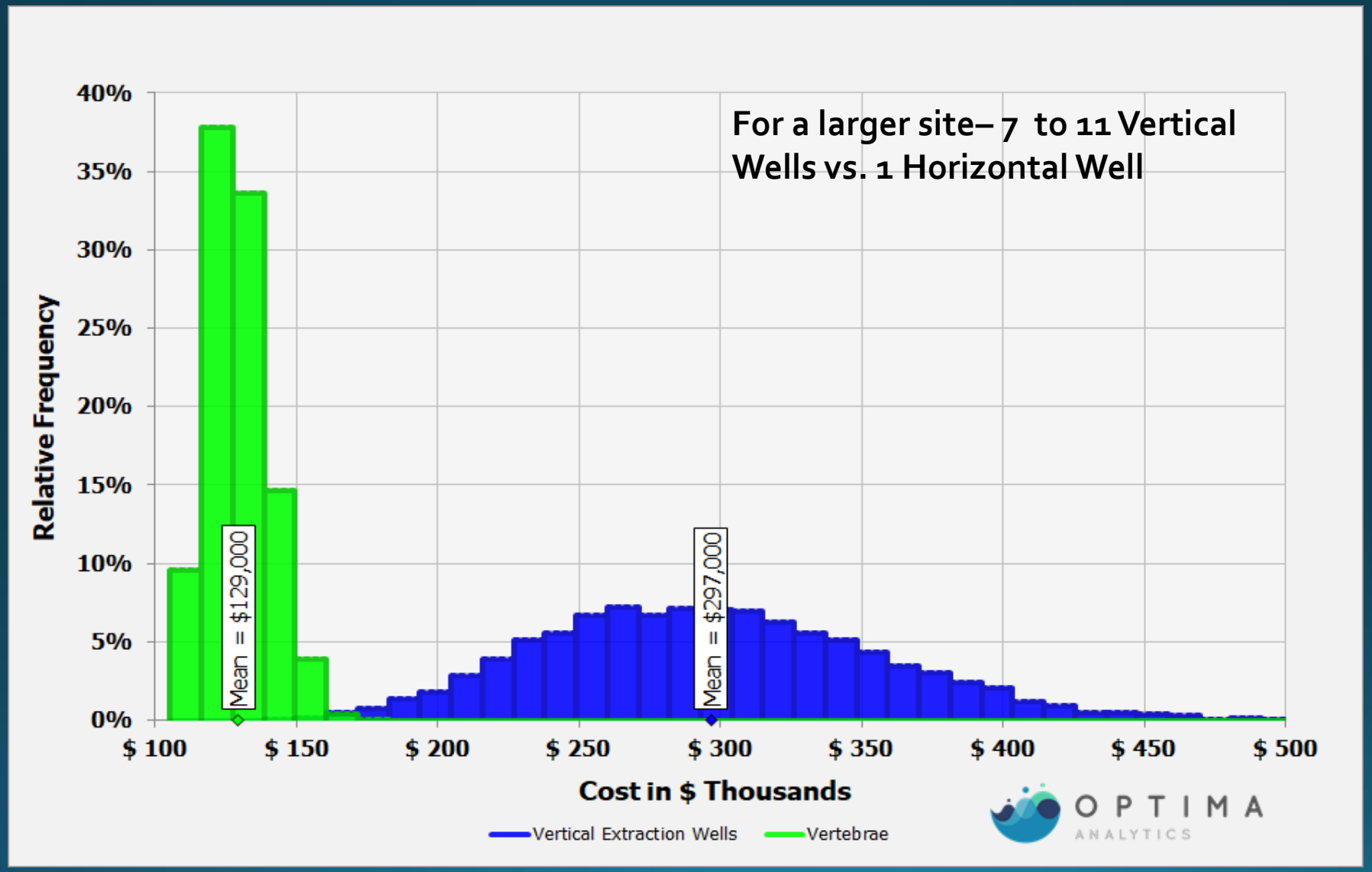
HDD Requires Set-Back ► Rule of thumb 3 to 1

Blind Installations` ► Additional Cost

Comparative Economic Risk Analysis



Comparative Economic Risk Analysis



Technology Comparison

	Vertebrae™	Horizontal Remediation Wells	Vertical Wells Monitoring & Extraction
ADDRESS DIFFICULT ACCESS ISSUES	✓	✓	✗
FOR ASSESSMENT AND REMEDIATION	✓	✗	✓
FILLS IN DATA GAPS	✓	✗	✗
REPEATABLE SAMPLING	✓	✗	✓
SEGMENTATION GIVES FLEXIBILITY AROUND PLUME VARIABILITY	✓	✗	✗
EASY TRANSITION FROM ASSESSMENT TO TREATMENT	✓	✗	✗
WELL SUITED TO LONG, NARROW PLUMES	✓	✓	✗
HIGH VALUE FOR LOW COST	✓	✗	✗

Additional Considerations

- Horizontal wells can avoid some of the risks of vertical wells including reagent daylighting.

- High Resolution Site Characterization (HRSC) produces vertical profiles with varying degrees of "granularity." Vertebrae ™ Well Systems add a dimension to the process. With horizontal assessment we are able, in essence, to create the field of what we are calling High Resolution Contaminant Distribution (HRCD).

- Compliance criteria in parts per trillion, for polyfluoronated alkylsubstances (PFAS), has created serious sampling concerns. Many common materials such as well components, personal care products, food packaging and clothing can have traces of PFAS. We are working towards providing Vertebrae™ Well Systems that are certified free of contaminants.

Additional Considerations

- Vertebrae ™ Well Systems can be factored into permeable reactive barrier (PRB) designs, both to explore the best transect for placement and to provide a safety factor for more treatment should the PRB underperform.

- There is a growing belief that monitoring wells should be restricted to what they are designed to do – monitor. The task of site characterization assessment is better served by HRSC and HRCD operations.

- There are other applications for Vertebrae™ Well Systems, worthy of exploration, including but not limited to:
  - Landfills
  - Sediment Management
  - Vapor Intrusion (as an extraction process)

EN Rx Support Platform (SP)™

- The EN Rx SP is a self-contained, solar-powered, remotely operating and communications-ready device for managing site assessment and/or reagent injection.
- In the assessment mode, the unit has a vacuum module to extract gas or liquid samples from the Vertebrae Wells
- In the injection mode, the unit has a pump module to mix/dilute reagents in a programmed manner.
- Data management accessories are included such as touch screen viewing and remote access and control.

Summary

Vertebrae ™ Well Systems, represent a next generation advancement in site assessment and remediation practices; where needed, site access issues can be overcome.

Nested, discrete horizontal profiling brings great accuracy to assessment and provides more directed treatment operations with a unique flexibility feature to manage dynamic systems.

Site Conceptual Models can be significantly enhanced and, on a case by case basis, there can be significant economic advantages.

Creates a new paradigm: High Resolution Contaminant Distribution.

Contact Information

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