In-situ Amendment and Delivery Methods: Design and Construction Considerations

Moderated Panel

Today's Panel

Mark Strong
Jacobs Engineering

Panelist

Glenn Iosue, PE
REGENESIS

Panelist

Chapman Ross, PE
FRx, Inc

Panelist

Jason Ruf
S2C2, Inc.

Panelist

Rick Cramer, PG
Burns & McDonnell

Panelist

Rich Evans, PE
Groundwater & Environmental Services, Inc.

Moderator

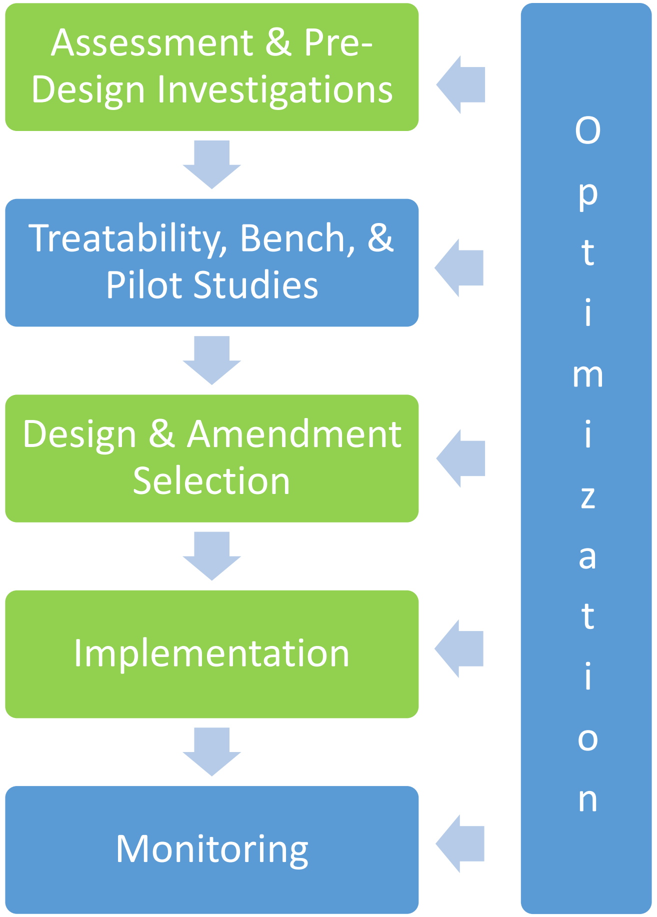
Audience Demographics Poll Questions

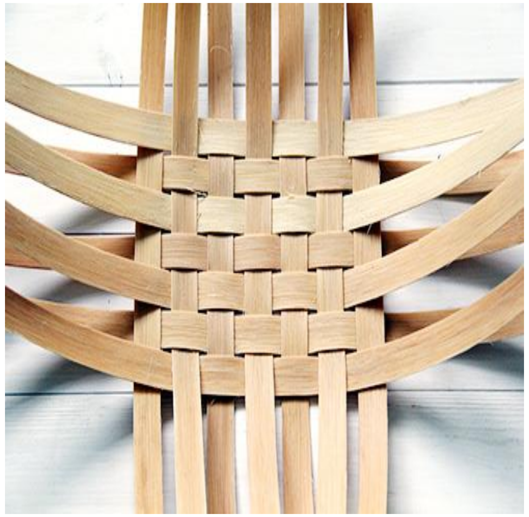
1. Have you achieved a no further action/site closure using an in-situ injection technology?
   a. Yes, as the primary remedy
   b. Yes, as a secondary or polish remedy

2. How do you measure success of an in-situ remediation project?
   a. No further action attainment/site closure
   b. Mass reduction
   c. Removing pathways to sensitive receptors
   d. Improving site conditions for beneficial re-use
   e. Other


Why in-situ remedies fail…
…and how to make them succeed.

In-situ Project Stages and Panel Discussion

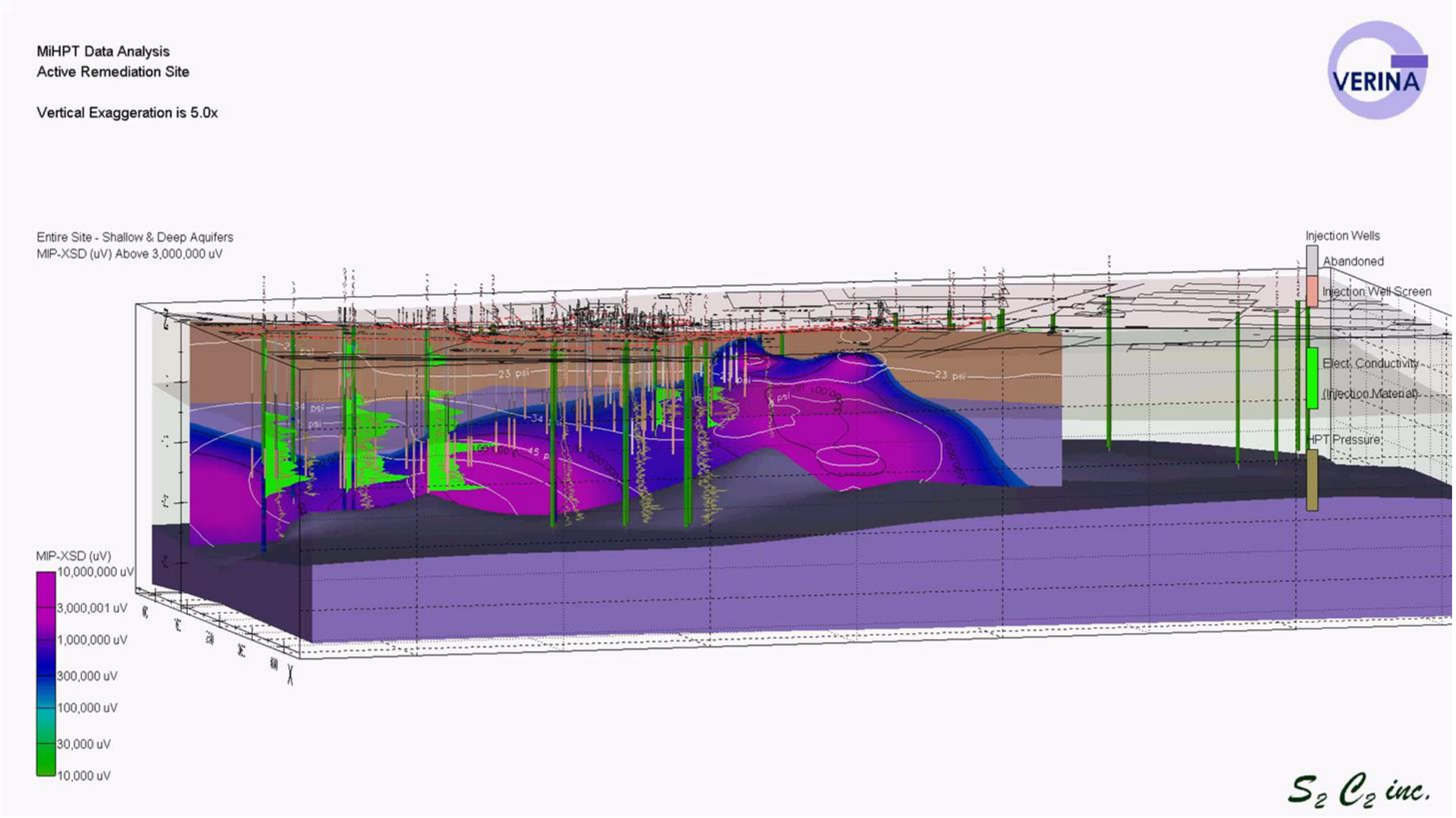




- Best management practices
- Common pitfalls
- Setting expectations
- Costs
- Sustainability

Assessment & Pre-Design Investigations

Case Study – 3D Visualization and HRSC a tool for Optimization of In-Situ Remediation

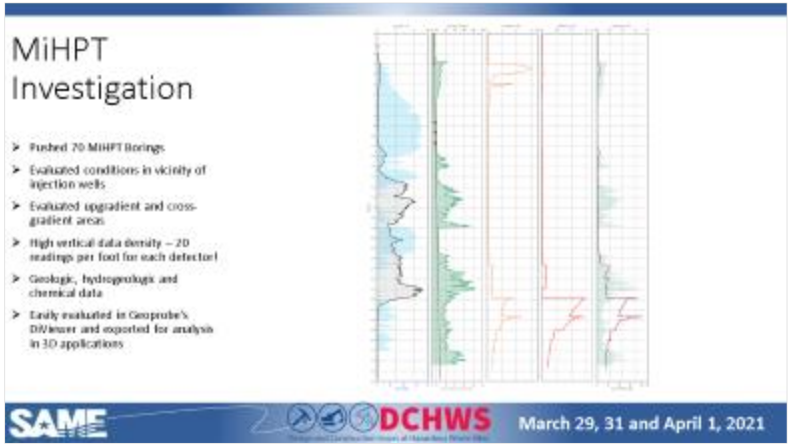


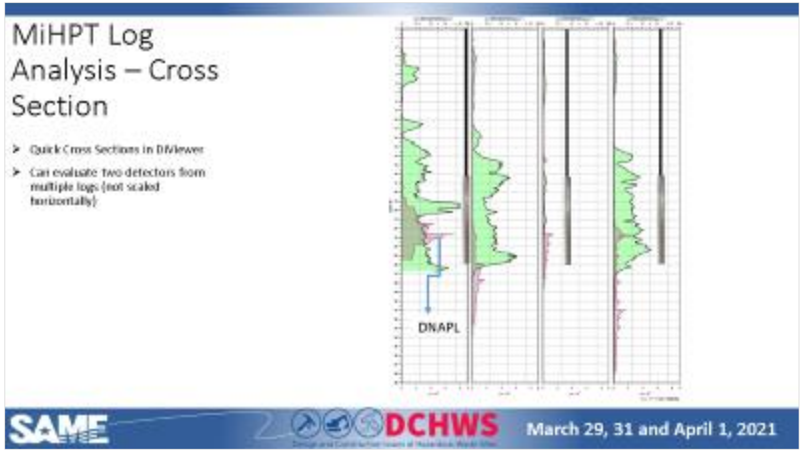
Poll Questions

3. Have you completed a direct-sensing (High Resolution Site Characterization) prior to implementing an injection program?
    a. No
    b. Yes - if so, which tools were used
        i. MIP
        ii. MiHPT
        iii. HPT
        iv. Waterloo Profiler
        v. CPT
        vi. LIF/UVOST/OIP
        vii. TarGOST
        viii. Geophysics
        ix. Other
4. Have you completed a direct-sensing program as part of a post remedy evaluation?
    a. Yes
    b. No

The Problem: How do we optimize Site Remediation and achieve Site Closure?

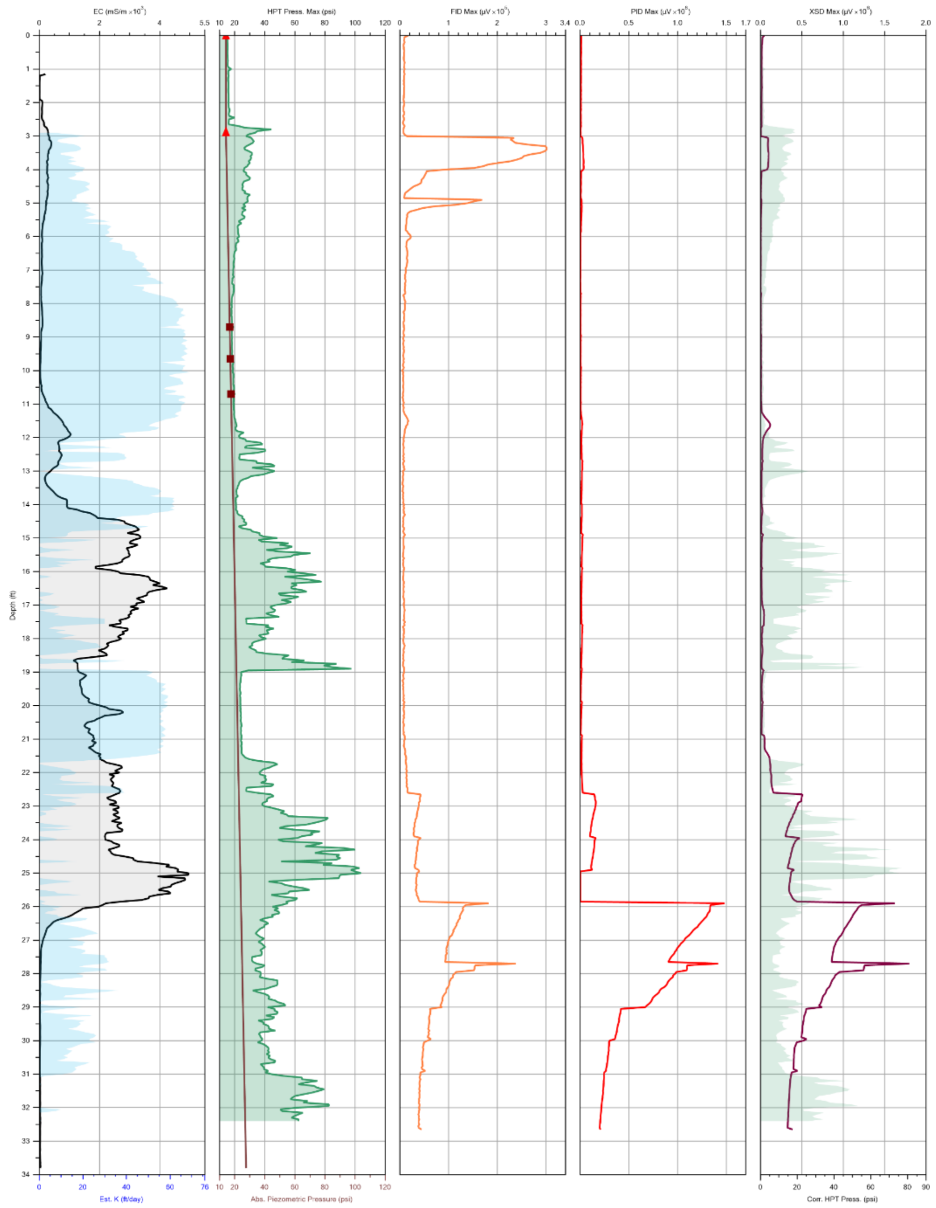
- Client wanted to evaluate current conditions – post remediation
- Recommended HRSC using MiHPT and development of 3D CSM :
  - Use MiHPT to identify untreated mass
  - Use MiHPT to evaluate mass vs geology
  - Use MiHPT to evaluate past injection effectiveness
  - Develop 3D CSM to evaluate chemical trends/mass and to visualize monitoring well data vs HRSC data
- Closure Strategy – Focused source treatment, institutional controls and MNA





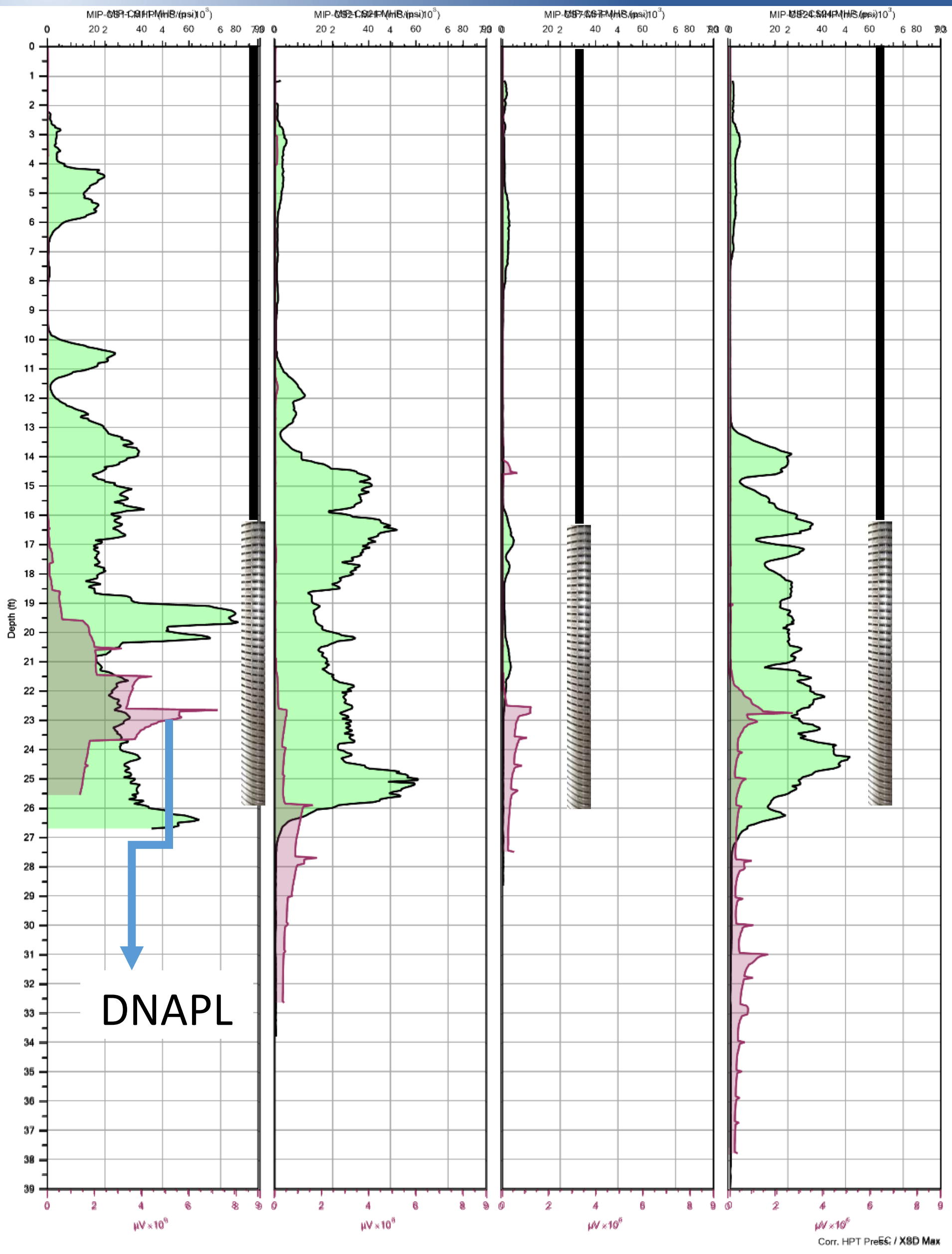
MiHPT Investigation

- Pushed 70 MiHPT Borings
- Evaluated conditions in vicinity of injection wells
- Evaluated upgradient and cross-gradient areas
- High vertical data density – 20 readings per foot for each detector!
- Geologic, hydrogeologic and chemical data
- Easily evaluated in Geoprobe's DiViewer and exported for analysis in 3D applications



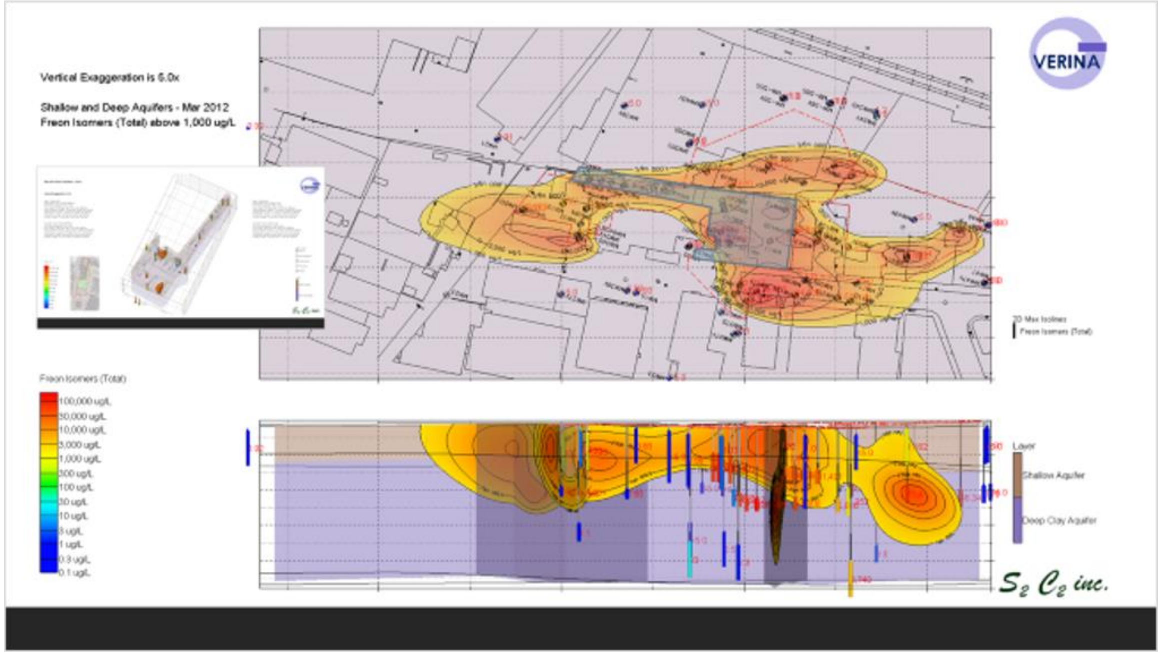
MiHPT Log Analysis – Cross Section

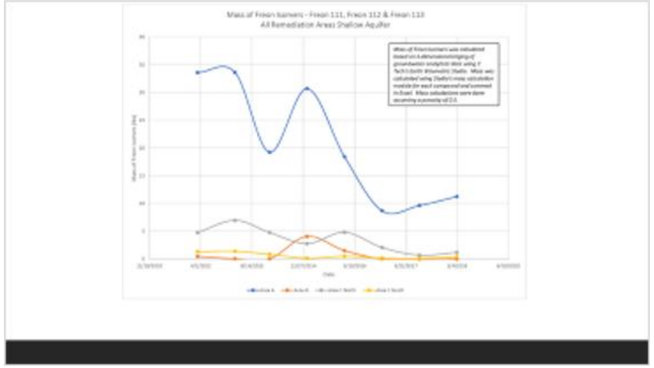
- Quick Cross Sections in DiViewer
- Can evaluate two detectors from multiple logs (not scaled horizontally)

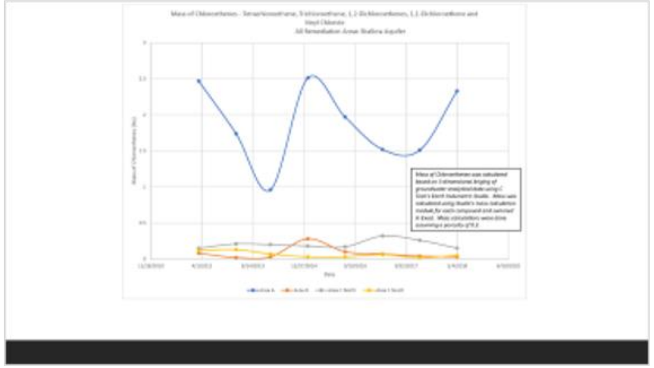


3-Dimensional Conceptual Site Models & Data Analysis

- Analyze spatial relationships as well as temporal relationships of analytical groundwater monitoring data
- For this site we calculated mass for 5 injection areas, 16 analytes (4 groups of analytes), two geologic units, & 8 sampling events (2012-2019).
- **That's 1,280 calculations! (We can do this today in minutes using python)**

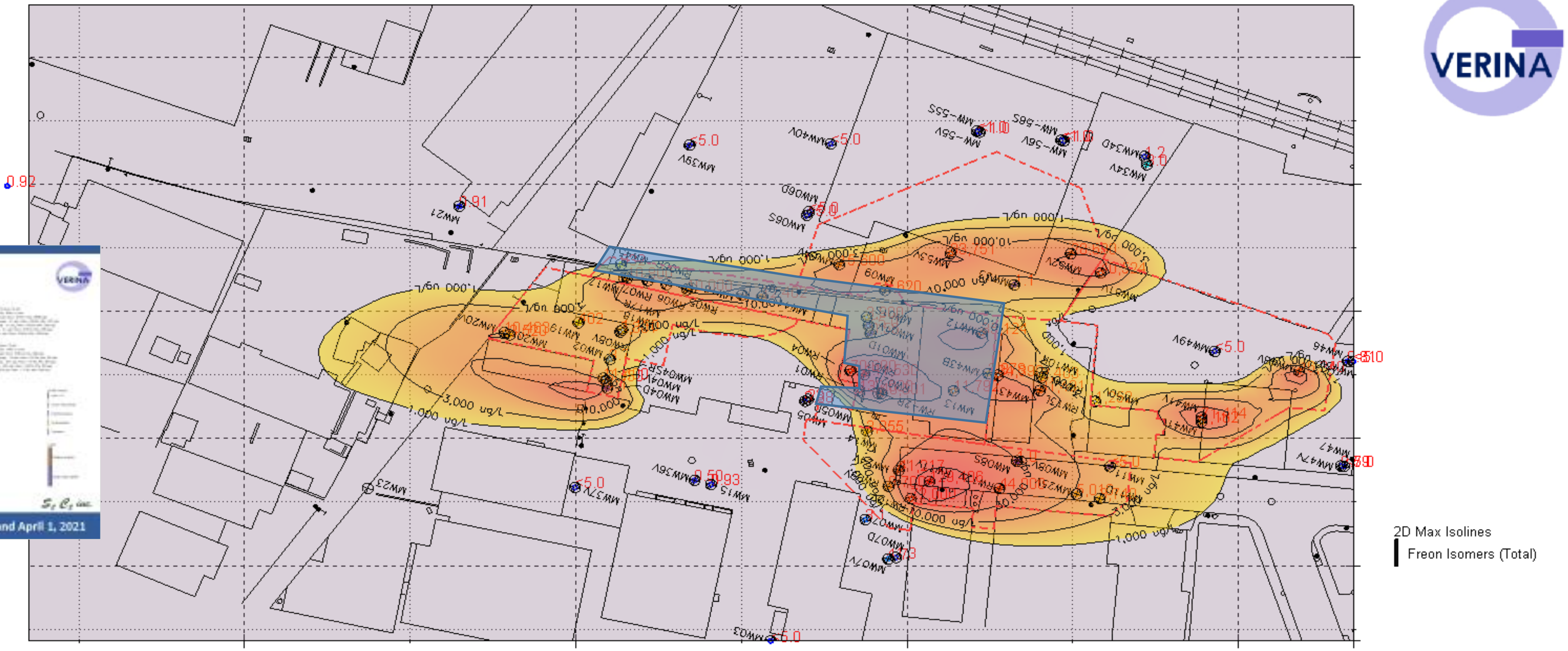


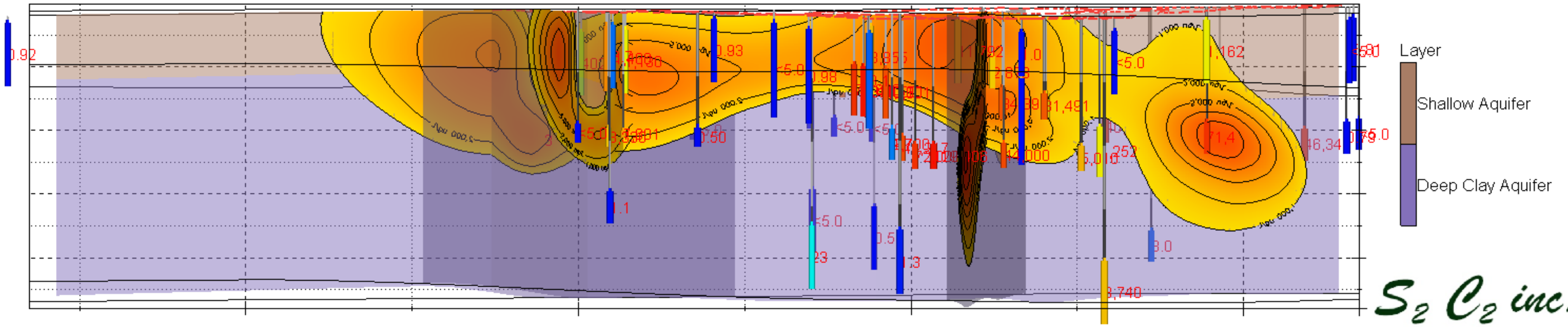




Vertical Exaggeration is 5.0x

Shallow and Deep Aquifers - Mar 2012
Freon Isomers (Total) above 1,000 ug/L





Freon Isomers (Total)

100,000 ug/L
30,000 ug/L
10,000 ug/L
3,000 ug/L
1,000 ug/L
300 ug/L
100 ug/L
30 ug/L
10 ug/L
3 ug/L
1 ug/L
0.3 ug/L
0.1 ug/L

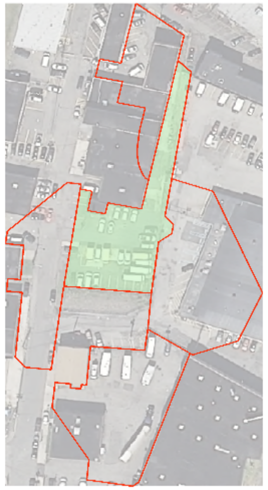
Mass and Volume Calculations - Area A

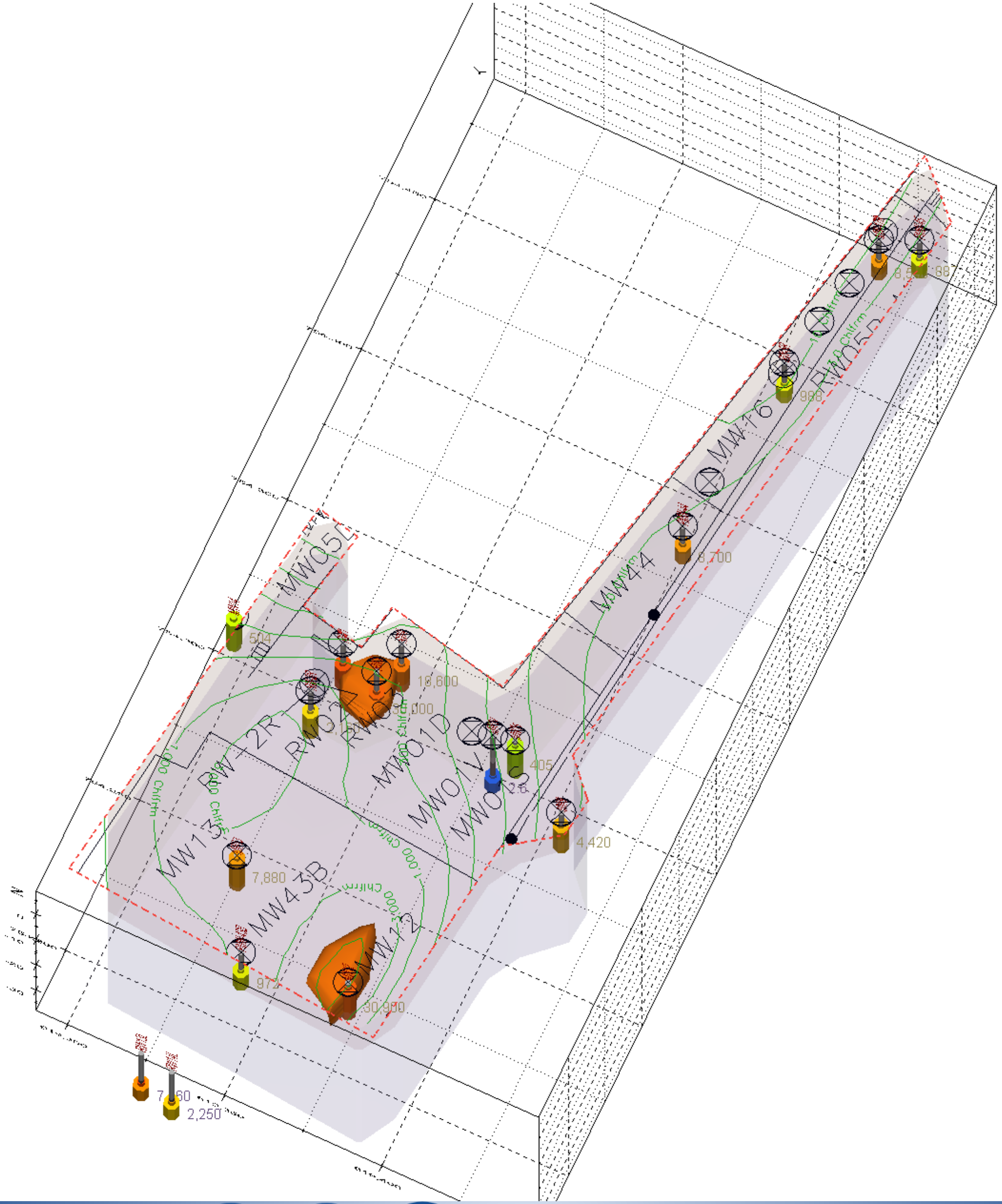
Vertical Exaggeration is 2.5x

Area A - February 2019
Shallow Aquifer - Freon 113 Above 20,000 ug/l
Total Volume (Including Soil): 91 cu. yards
Freon - Average: 25145.6 ug/L; Mass: 0.97 lbs; Max: 39800 ug/L
Carbon Tetrachloride - Average: 0.0 ug/L; Mass: 0.00 lbs; Max: 1970 ug/L
Tetrachloroethene - Average: 0.0 ug/L; Mass: 0.00 lbs; Max: 2590 ug/L
Trichloroethene - Average: 0.0 ug/L; Mass: 0.00 lbs; Max: 1690 ug/L
Chloroform - Average: 0.0 ug/L; Mass: 0.00 lbs; Max: 15200 ug/L

Clay Aquifer - Freon 113 Above 20,000 ug/l
Total Volume (Including Soil): 20 cu. yards
Freon - Average: 24881.4 ug/L; Mass: 0.21 lbs; Max: 7860 ug/L
Carbon Tetrachloride - Average: 123.3 ug/L; Mass: 0.00 lbs; Max: 403 ug/L
Tetrachloroethene - Average: 1387.3 ug/L; Mass: 0.01 lbs; Max: 969 ug/L
Trichloroethene - Average: 395.2 ug/L; Mass: 0.00 lbs; Max: 999 ug/L
Chloroform - Average: 4121.4 ug/L; Mass: 0.03 lbs; Max: 2540 ug/L

Freon 113
100,000 ug/L
30,000 ug/L
10,000 ug/L
3,000 ug/L
1,000 ug/L
300 ug/L
100 ug/L
30 ug/L
10 ug/L
3 ug/L
1 ug/L





Area A - February 2019
Shallow Aquifer - Freon 113 Above 1.0 ug/l
Total Volume (Including Soil): 5594 cu. yards
Freon - Average: 3710.0 ug/L; Mass: 8.75 lbs; Max: 39800 ug/L
Carbon Tetrachloride - Average: 0.1 ug/L; Mass: 0.00 lbs; Max: 1970 ug/L
Tetrachloroethene - Average: 0.1 ug/L; Mass: 0.00 lbs; Max: 2590 ug/L
Trichloroethene - Average: 0.1 ug/L; Mass: 0.00 lbs; Max: 1690 ug/L
Chloroform - Average: 0.1 ug/L; Mass: 0.00 lbs; Max: 15200 ug/L

Clay Aquifer - Freon 113 Above 1.0 ug/l
Total Volume (Including Soil): 17492 cu. yards
Freon - Average: 686.4 ug/L; Mass: 5.06 lbs; Max: 7860 ug/L
Carbon Tetrachloride - Average: 1.9 ug/L; Mass: 0.01 lbs; Max: 403 ug/L
Tetrachloroethene - Average: 55.7 ug/L; Mass: 0.41 lbs; Max: 969 ug/L
Trichloroethene - Average: 59.9 ug/L; Mass: 0.44 lbs; Max: 999 ug/L
Chloroform - Average: 159.0 ug/L; Mass: 1.17 lbs; Max: 2540 ug/L

2D Max Isolines
- Freon 113
- Carbon Tetrachloride
- Tetrachloroethene
- Trichloroethene
- Chloroform

Layer
- Shallow Aquifer
- Deep Clay Aquifer

Treatability, Bench, & Pilot Studies

Treatability, Bench, & Pilot Studies

1996 EPA Environmental Response Training

Glenn Nicholas Iosue in Level A Suit (right)

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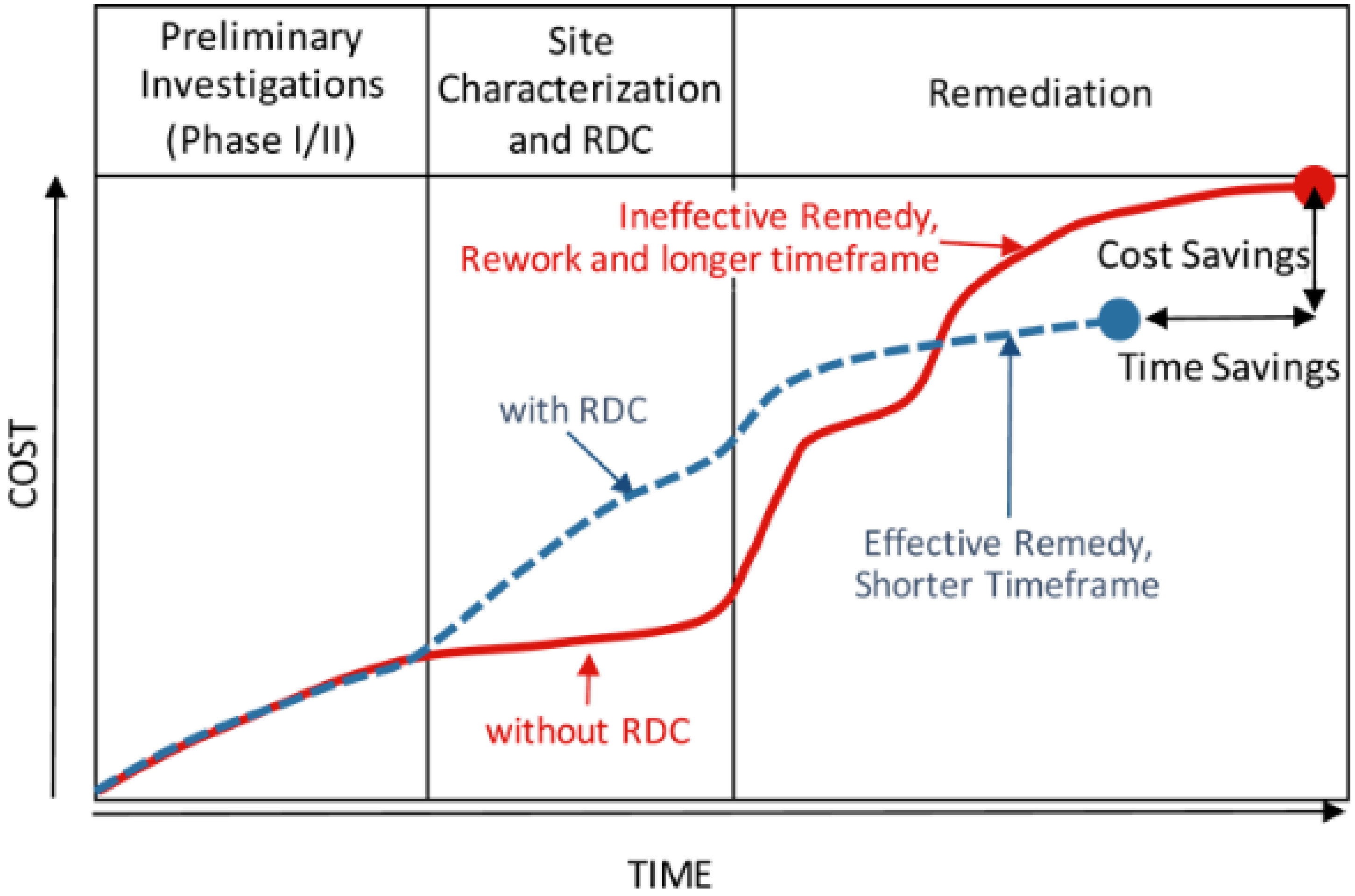
Technology-Based Solutions for the Environment

Poll Questions

6. What are your primary concerns when choosing/implementing an in-situ remediation (excluding cost)?
   a. Technology selection
   b. Feasibility of implementation (contact)
   c. Managing expectations
   d. Confidence in the conceptual site model

7. Have you had a site where rebound has occurred following implementation of an in-site technology?
   a. Yes
   b. No

Common Pitfalls and BMPs



Conceptual lifecycle costs with and without RDC / DVT

- **Remedial Design Characterization (RDC), or Design Verification Test (DVT)**
- **Geology**
- **Mass Flux**
- **High Resolution Characterization, cost ramifications**
- **Role of modeling in developing CSM and remedy**

Source: Modified from ITRC 2015

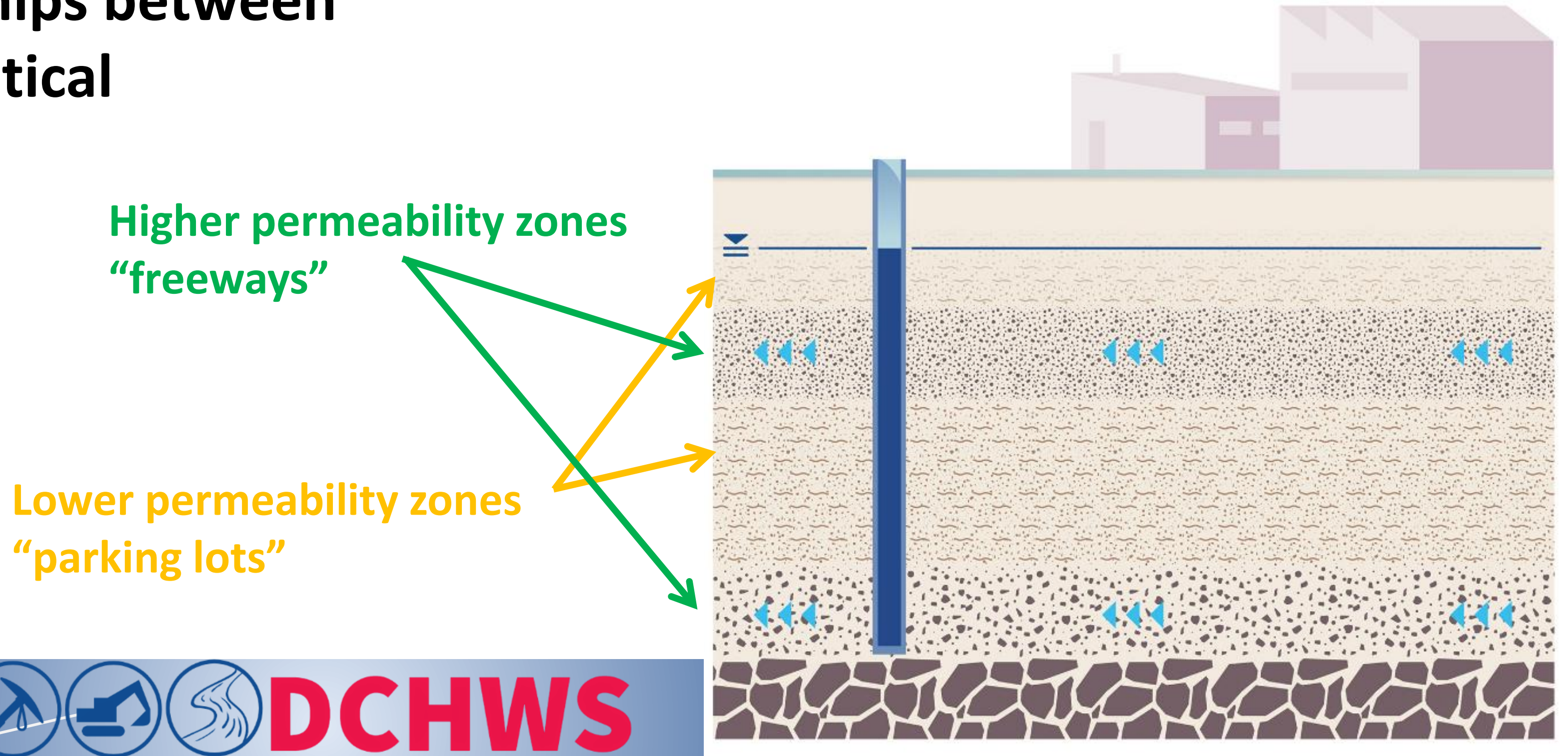
Fundamentals of Contaminant Distribution

Mass Storage

- Relationship of fine and coarse grained units play large role in plume shape

Contaminant distribution is controlled by soil type positional relationships

- Vertical and lateral relationships between low and high Kh zones are critical
- Remediation is site-specific
  - ➢ based on site's specific aquifer characteristics
  - ➢ often unique to the site



Design Verification Process – Why?

Site Assessments have different objectives than Design Verification, such as

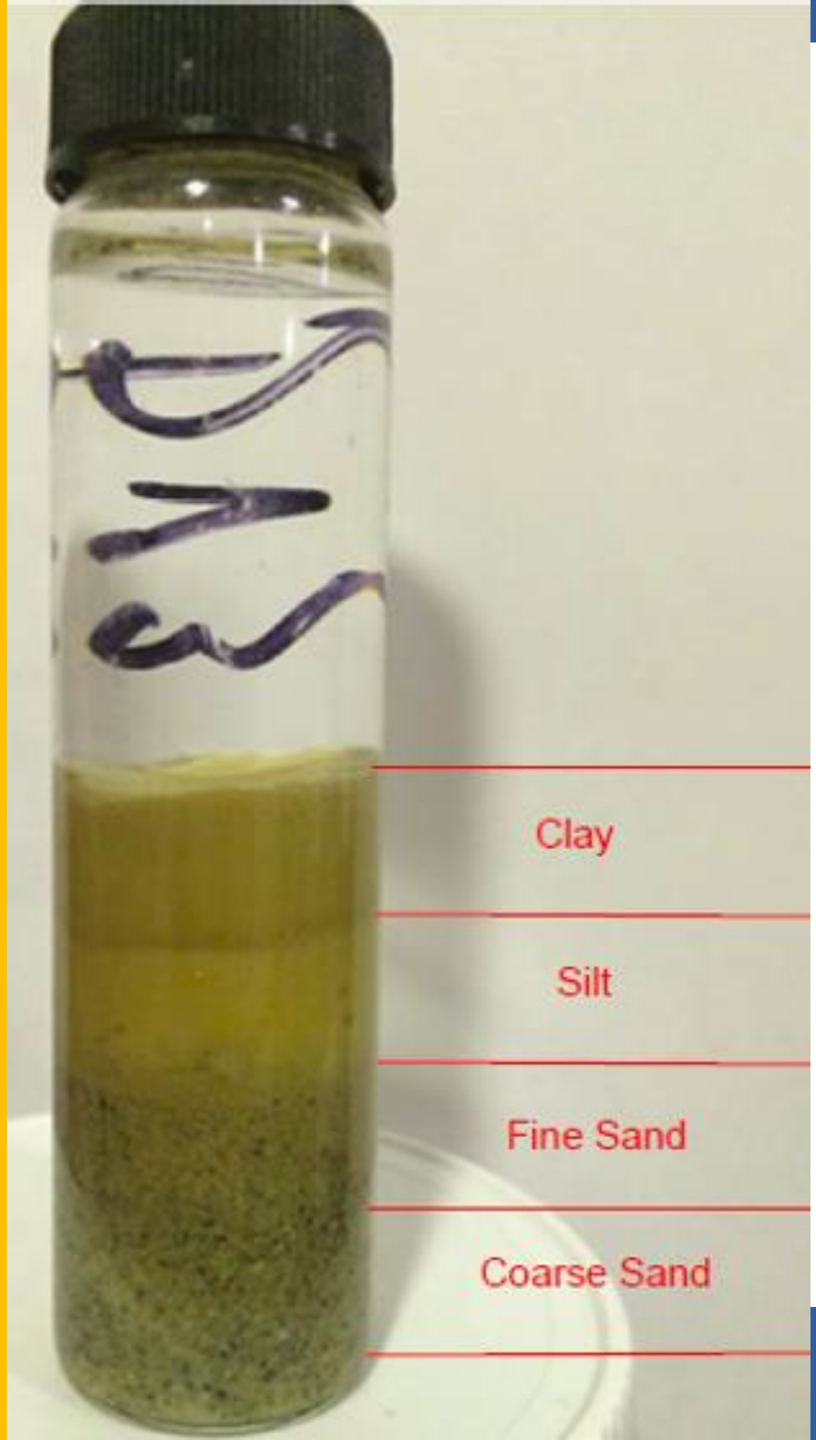
- Nature and Extent, Plume Boundaries
- Liability and Risk, Sensitive Receptors

DVT improves remedial outcome by increasing site resolution

- Focusing on identifying position of contaminant mass and high flux zones
- Emphasis on identification of principal impacted units
- Provides greater reagent-contaminant contact for improved performance

Design Verification Tools

- **Continuous Soil Core Logging**
  continuous soil coring into saturated zone used to look at bigger remedial picture and start to map and target horizontal flow pathways
- **Soil Contaminant Analysis**
- **Settling Tubes**
- **Clear Water Injection**
- **Passive Flux Meters**



Design Verification Test: Clear Water Injection

Documents acceptance rates and volumes

- Vertical Target Treatment Zone (TTZ) intervals

Assists in application decisions

- Direct Push Injection
  - Top-down vs Bottom-up
- Injection wells
  - Screened Intervals

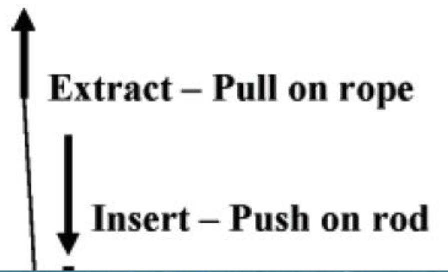
Data collected often differs greatly from estimated Kh based volume

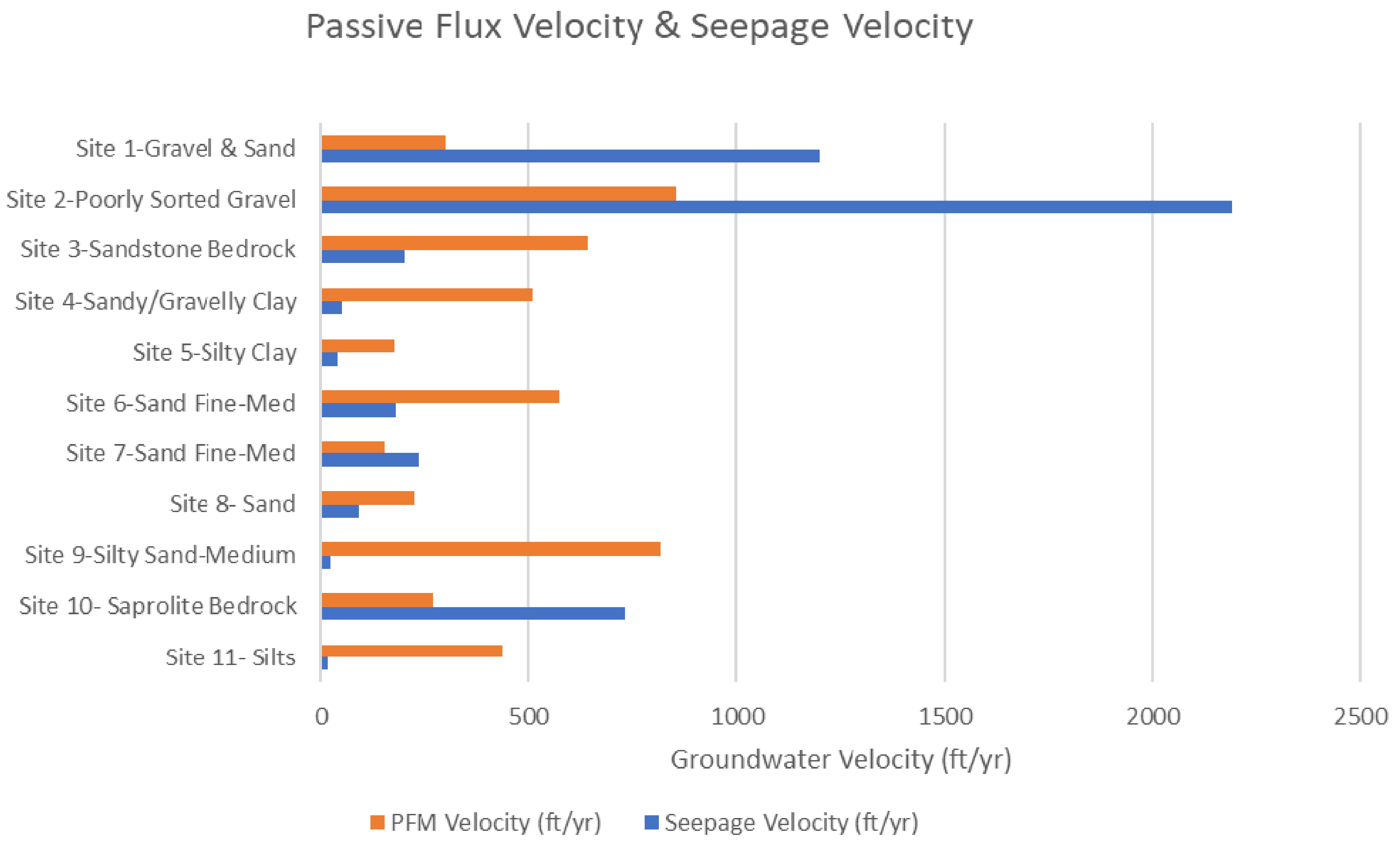
REGENESIS Land Science a division of REGENESIS

Design Verification Test: Unknown Velocity?

Passive Flux M

- Self Contained
  designed for 2
- Filled with Per
  - Accumulat
    based on fl
- Carbon pre-loa
  known sorpti
  - Loses trace
    and flux co




Passive Flux Velocity & Seepage Velocity
Site 1-Gravel & Sand
Site 2-Poorly Sorted Gravel
Site 3-Sandstone Bedrock
Site 4-Sandy/Gravelly Clay
Site 5-Silty Clay
Site 6-Sand Fine-Med
Site 7-Sand Fine-Med
Site 8- Sand
Site 9-Silty Sand-Medium
Site 10- Saprolite Bedrock
Site 11- Silts
0
500
1000
1500
2000
2500
Groundwater Velocity (ft/yr)
PFM Velocity (ft/yr)
Seepage Velocity (ft/yr)

Design Verification Analysis

Project Population

- 43 Sites

Project Design Approach

- 33% source areas
- 67% mid- to distal- plume

Contaminant Type

- 35% Petroleum
- 61% CVOCs
- 4% Comingled

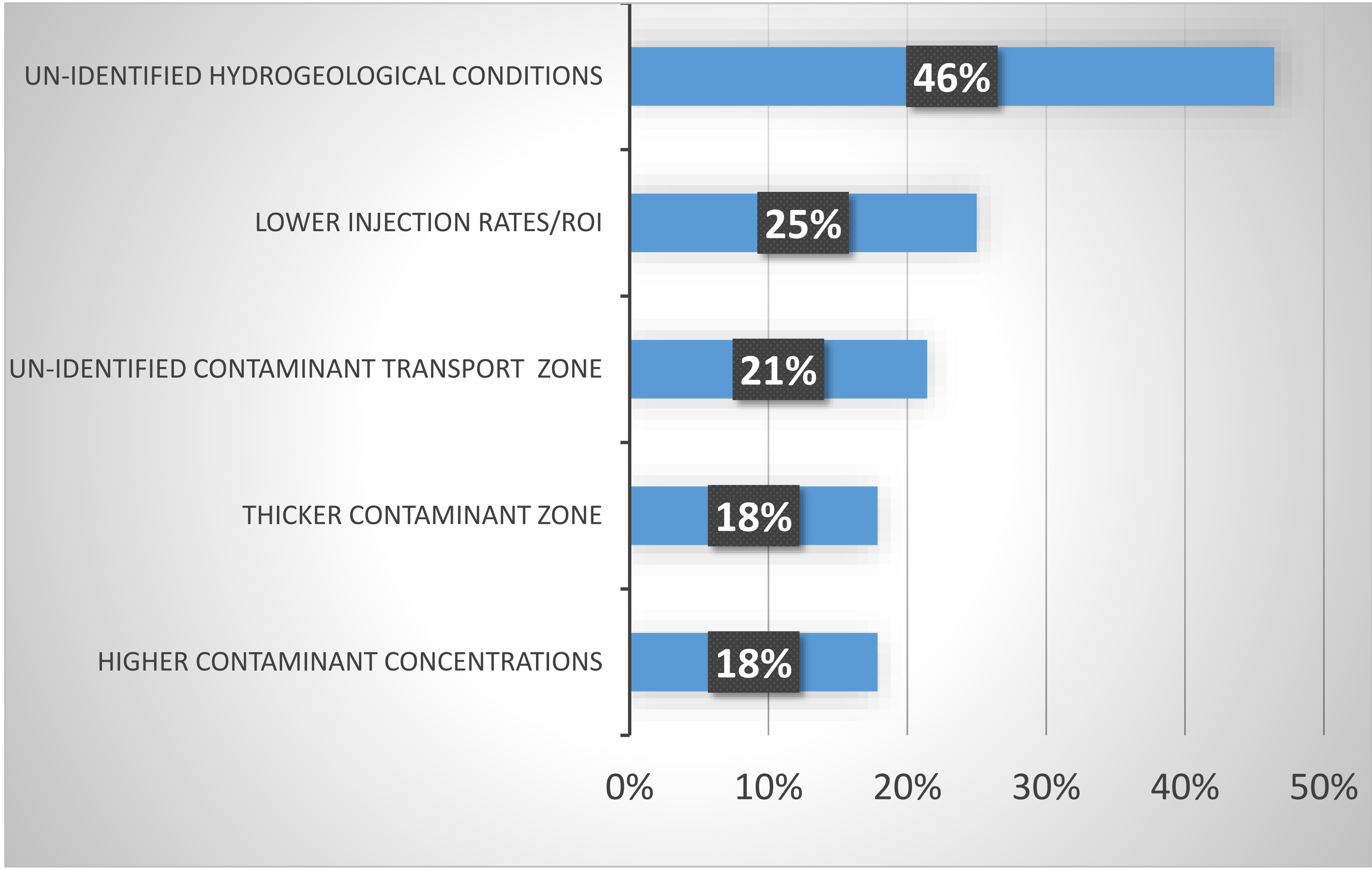
General Soil Type

- 50% Fine grained (Clays and Silts)
- 50% Coarse grained (Sand and Gravel)

Analysis of Technical Blind Spots

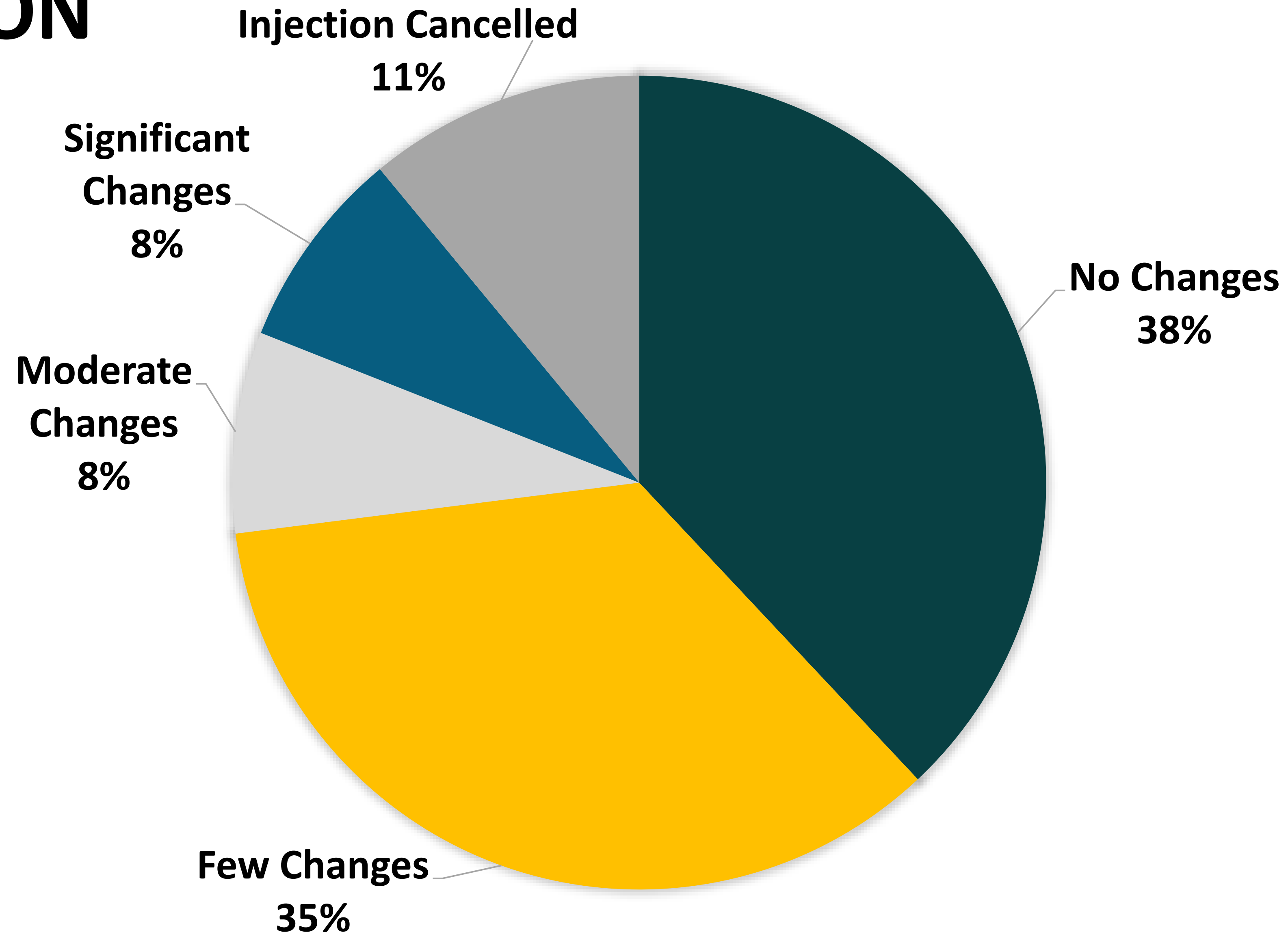
What's the outcome?

- **~80% of tests to date found unanticipated results (technical blind spots)**
- **62% of preliminary designs were modified / refined**
- **Most design changes were cost-neutral**



DESIGN VERIFICATION

Design Changes



DVT Analysis of 43 Sites

Lessons Learned: Design Verification Test

- Depositional Processes significantly control contaminant distribution
  - Depositional processes are predictable and non-random
  - Design Verification data provides additional remedial insight
- Design Verification Test improves
  - Predictability
  - Implementation time and efficiency
  - Early identification of "Technical Blind Spots" and problems
  - Enhances final design and application program outcomes

Panel Session A

Implementation

Hydraulic Fracturing to Deliver Amendments in Low-Permeability Formations and Weathered Bedrock

Chapman Ross (cross@frx-inc.com)

Poll Question

8. What types of injection delivery methods have you used on your remediation projects (select all that apply)?
    a. Traditional injection wells
    b. Horizontal injection wells
    c. Direct-push injection
    d. Hydraulic fracturing
    e. Pneumatic fracturing
    f. Soil mixing
    g. Slurry wall

ITRC Injection Optimization Guidance Document

https://ois-isrp-1.itrcweb.org/

ITRC Guidance Document – Delivery Techniques

Delivery Technique / Hydrogeologic Characteristics Unified Soil Classification System	Direct Push Injection (DPI) [D1]	Injection Through Wells & Boreholes [D2]	Electrokinetics This is injection through wells. [D3]	Solid Injection [D4]: Hydraulic Delivery Through Wells & Boreholes [D5]	Solid Injection [D4]: Pneumatic Delivery Through Open Boreholes [D6]	Permeable Reactive Barriers (PRBs) [D7]
Gravels	• (Sonic)	•	NA	NA	NA	•
Cobbles	• (Sonic)	•	NA	NA	NA	•
Sandy Soils (Sm, Sc, Sp, Sw)	•	•	NA	▣	▣	•
Silty Soils (Ml, Mh)	•	▣	•	•	•	•
Clayey Soils (Cl, Ch, Oh)	•	▣	•	•	•	•
Weathered Bedrock	•	•	▣	•	•	▣
Competent/Fractured Bedrock	NA	•	NA	▣	▣	▣
K ≤ 10^{-3} to 10^{-4} (Low Perm Soils)	•	▣	•	•	•	•
K ≥ 10^{-3} (High Perm Soils)	•	•	▣	▣	▣	•
Depth > Direct Push Capabilities	NA	•	▣	▣	▣	▣

"Widely used = •", "Site-specific = ▣", and "Not applicable = NA"

Match delivery method with geology

Table 3-4

https://ois-isrp-1.itrcweb.org/

Hydraulic Fracturing of Solid Amendment

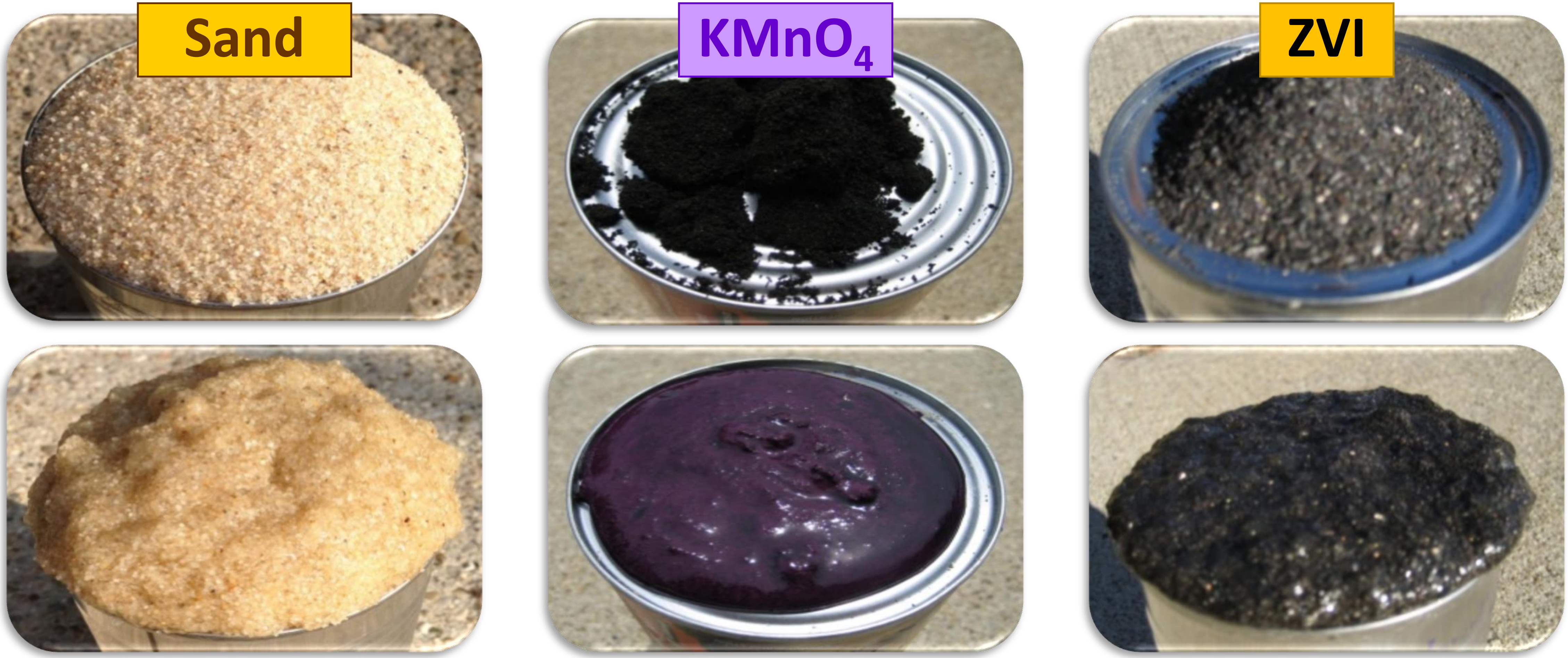
ITRC Guidance Document - Amendments

Treatment Type	Description/Summary	Target COCs	Typical Injection/Emplacement Technologies Methods
Common Biotic Amendments (A.1)			
Anaerobic (A1.3) biological reduction	Contaminants are degraded via a reductive process by certain types of microbes under anaerobic conditions. Fermentable organic substrates are injected or placed into the subsurface to enhance the production of hydrogen, which is in turn used by the microbes in the reductive reactions.	• Chlorinated solvents • Many pesticides and munitions • Certain inorganic compounds • Petroleum hydrocarbons (typically by introduction of electron acceptors such as nitrate and/or sulfate)	• Direct push injection • Permanent injection wells • PRBs
Abiotic Amendments (A2)			
Chemical oxidants (A2.1)	Oxidants delivered to the subsurface degrade or transform contaminants via oxidation and reduction reactions in the vadose and saturated zones. Oxidants can be used for source area remediation in conjunction with other compatible remedial alternatives to address downgradient areas with dissolved-phase or lower concentrations. Reaction rates depend on temperature, pH, reactant concentrations, activators or stabilizers, reaction byproducts, natural organic materials, and oxidant scavengers. Activators, stabilizers, and chelating agents may be used to enhance the subsurface oxidation reactions.	• BTEX • MTBE • TPH • Chlorinated solvents • SVOCS • Energetics • 1,4-dioxane	• Trenching/soil mixing • Direct push injection • Permanent injection wells • Soil mixing • Permeability enhancement (i.e., environmental fracturing) • Recirculation • Slow-release oxidant cylinder (Evans 2018) • Ozone sparging
Chemical reducing compounds for degradation enhancement (A2.2)	In general, reducing agents degrade or chemically transform contaminants into potentially less toxic and less mobile forms. The reductive processes depend on the contaminant, the type of reduction, and natural processes in the subsurface.	• Metals and metalloids • Chlorinated solvents • Energetics	• Trenching/soil mixing • Direct push injection • Permanent injection wells for very fine zero-valent iron (ZVI) products and calcium polysulfide • Hydraulic and pneumatic emplacement

Match amendments with contaminants AND delivery method

Table 3-2
https://ois-isrp-1.itrcweb.org/

Solid Amendment Options



Mass Loading and Cost

- Costs for treatment using hydraulic fracturing
  - $50-150/CY for ZVI treatment of chlorinated solvents (costs for range of treatment from diffuse plume to DNAPL source zone)
- Hydraulic fracturing is capable of delivering much higher mass loading than traditional injection methods.
  - ZVI mass loading of >3% (by dry weight soil) is readily achievable

Horizontal Remediation Wells, Challenges and Benefits

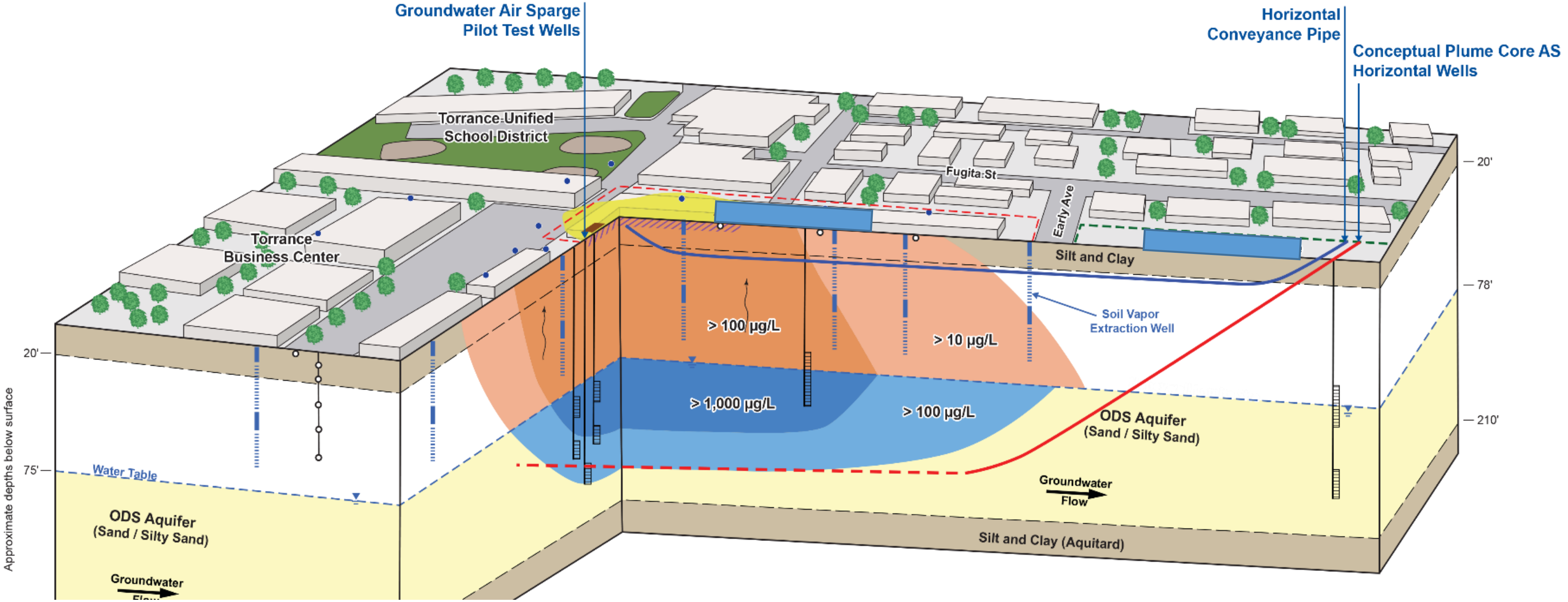
MARK STRONG, JACOBS ENGINEERING

Remediation Industry Experience with HDD

- First environmental wells installed in late 80s (DOE - Savannah River), continued development in 90s, several technical challenges.
- Mid to late 2000s, improved installation methods and more successful installations.
- Current and Historical Applications:
  - Air Sparging (AS) and Soil Vapor Extraction (AS/SVE)
  - Groundwater/NAPL pumping
  - PRBs, slope stabilization, landfill drains, etc
  - Liquid injection
  - Horizontal Heaters/ERH
- Developing Sustainable Remediation Options:
  - Passive/limited infrastructure treatment cells such as Arcadis HRX or coaxial treatment wells

Why Directional Drilling

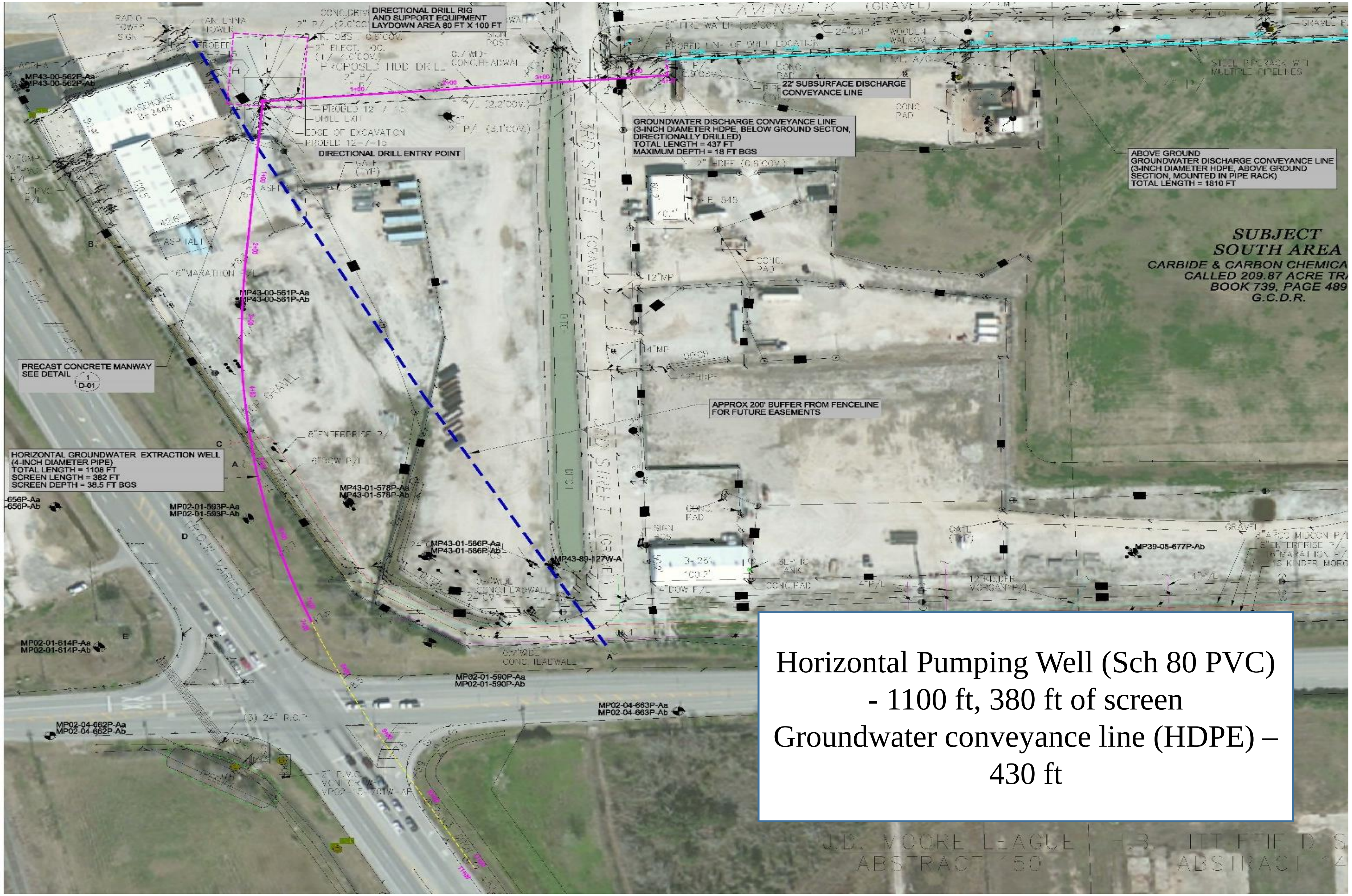
- Plume Access
- Contact Efficiency
- Decreased Site Impact
- Cost (for large plumes, less infrastructure, I&C, conveyance lines, etc – simpler O&M)



Recent Developments

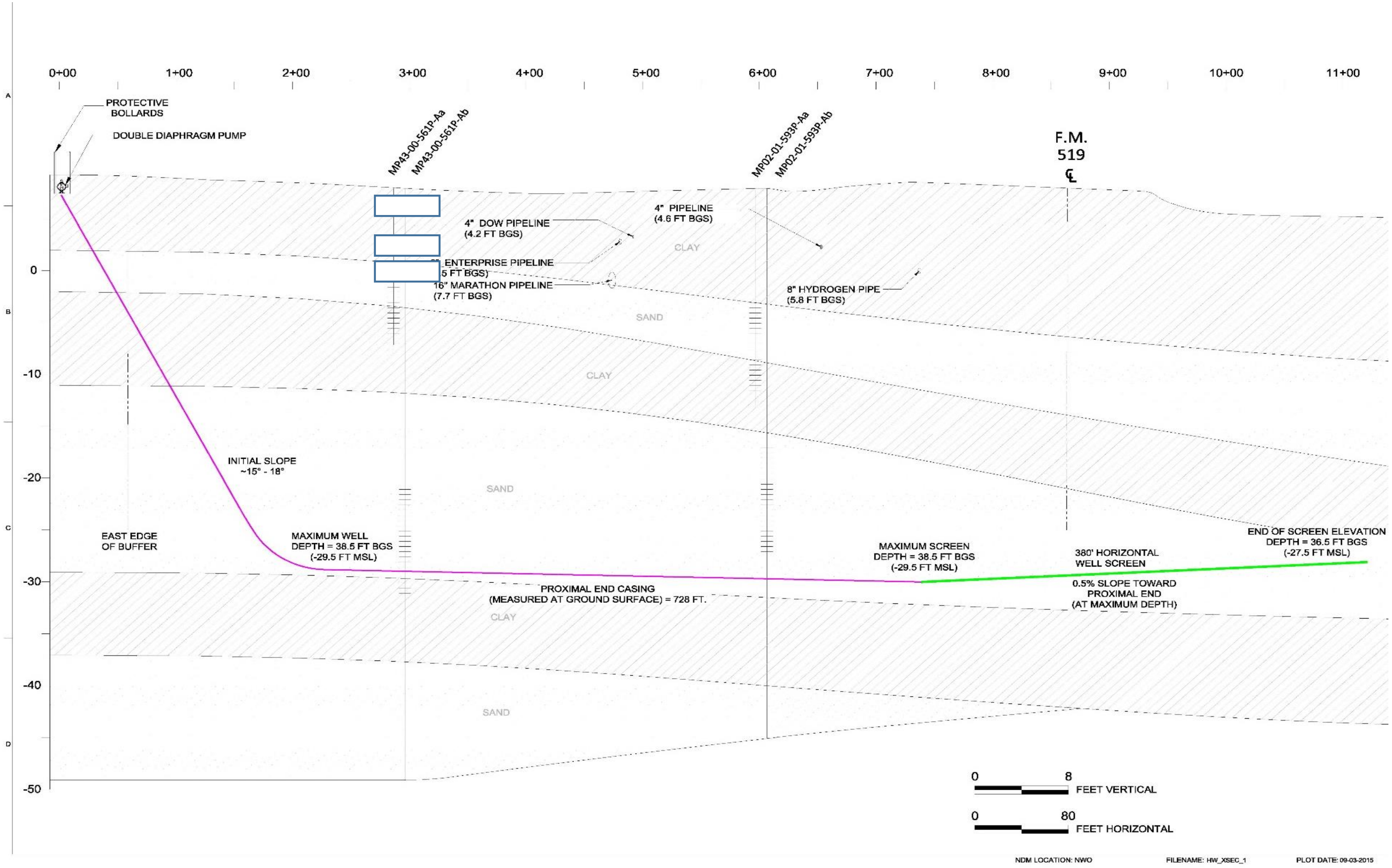
- Blind end drilling in sands
- Gyro steering tools that do not require surface access
- Cased well installation techniques facilitate use of lower cost well materials
- Improved accuracy of navigation at depths exceeding 100 ft bgs

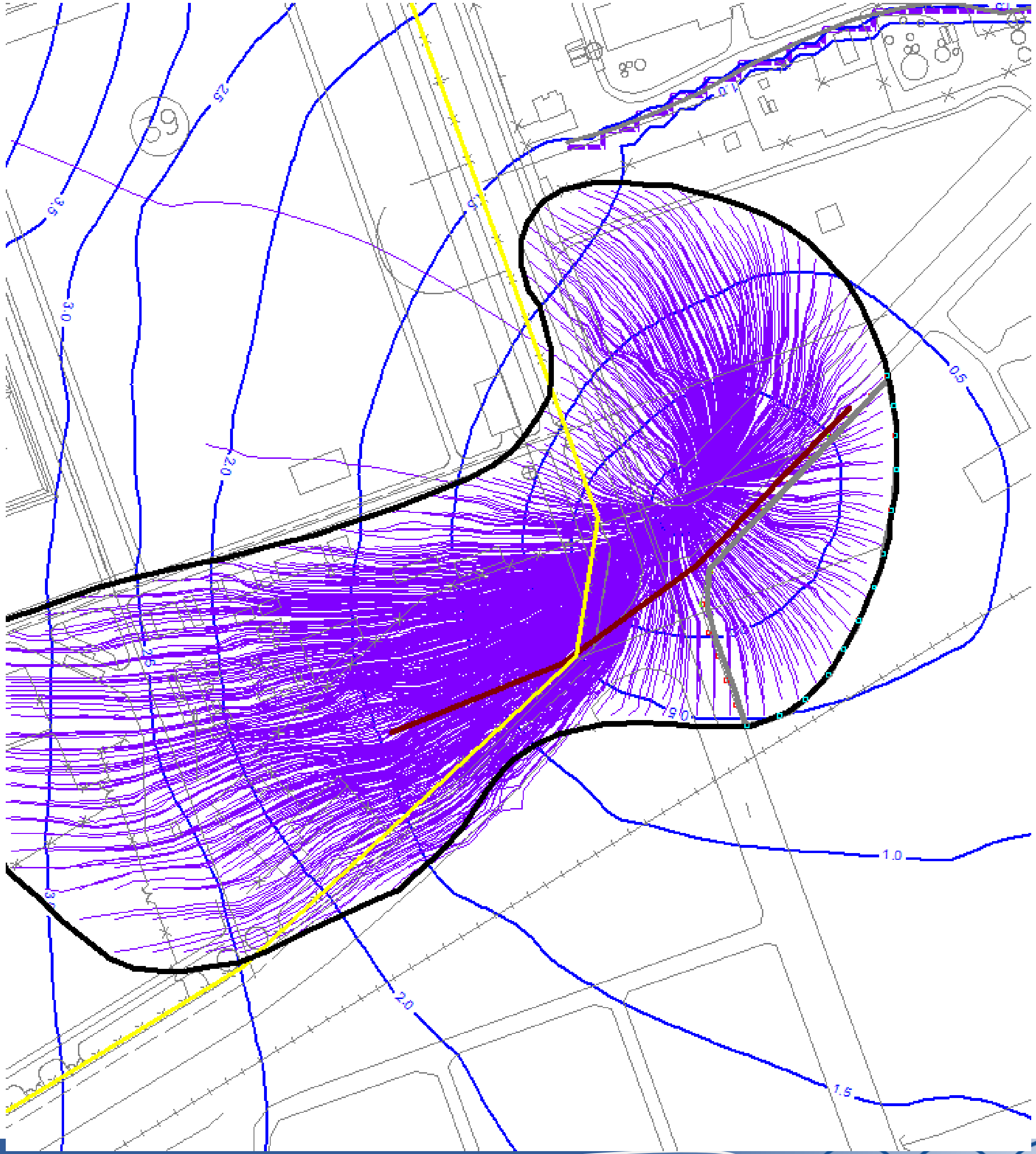
Case Study – Groundwater Plume Containment, Industrial Client, South Texas



Horizontal Pumping Well (Sch 80 PVC) - 1100 ft, 380 ft of screen
Groundwater conveyance line (HDPE) – 430 ft

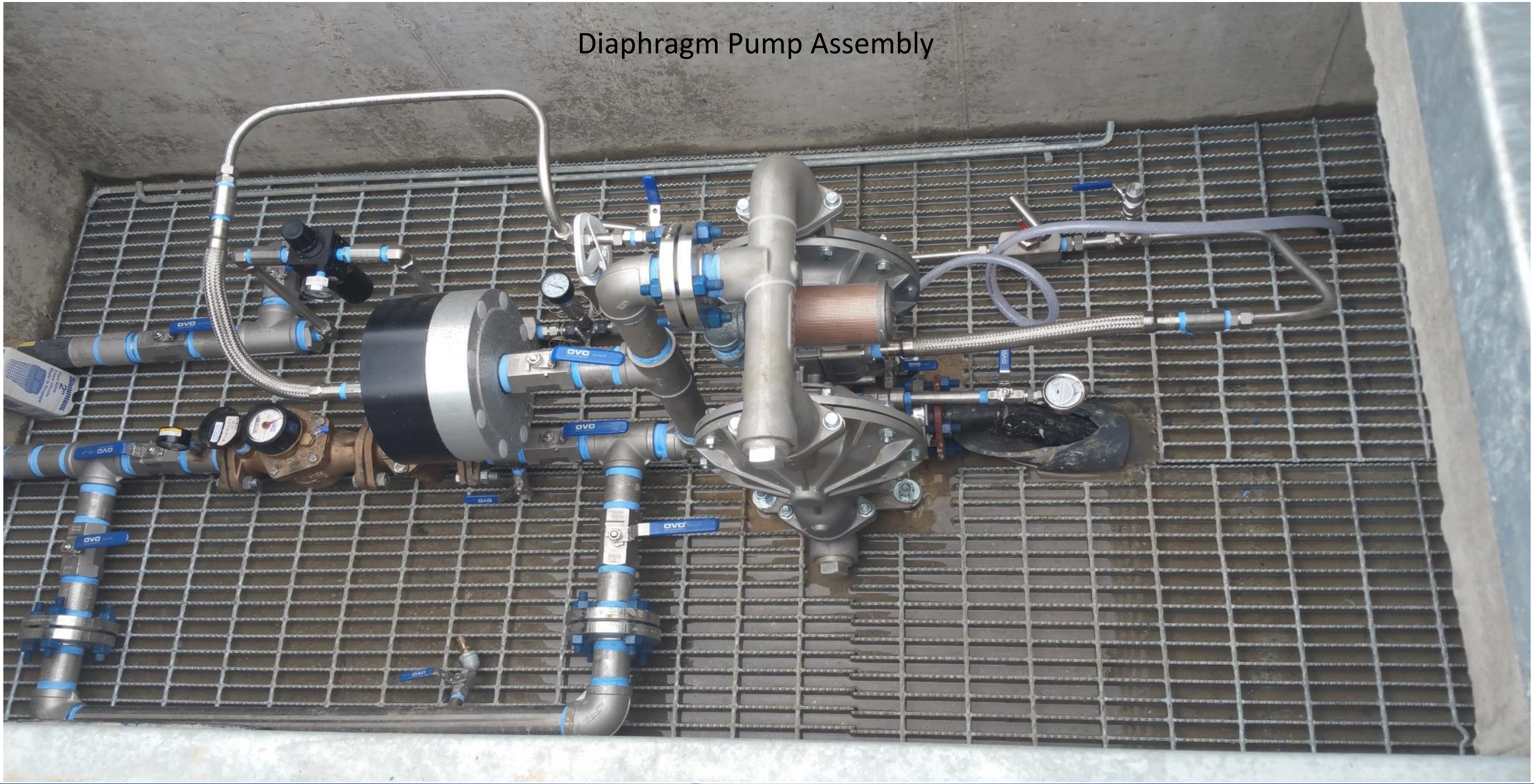
Cross Section





- Model output 380 ft screen at 30-40 ft bgs, 12 gpm
- Particle tracks and water level contours
- Field data indicated capture zone stabilization in ~3 weeks

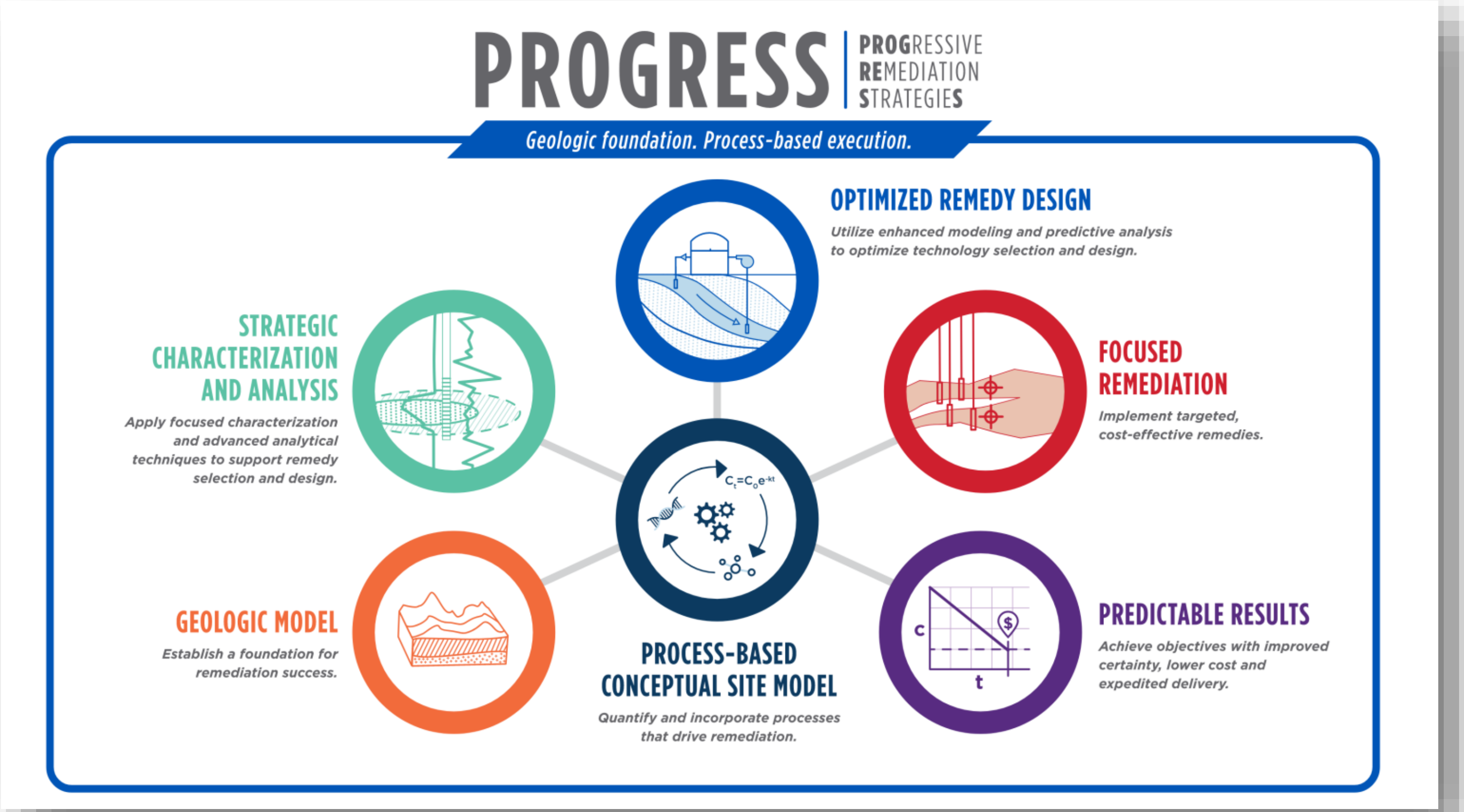
Pre-Cast Vault


Diaphragm Pump Assembly

Panel Session B

Optimization

Geology-Focused Approach to Optimize In-Situ Groundwater Remediation



Rick Cramer, PG Burns & McDonnell

Poll Questions

8. Have you completed an Environmental Sequence Stratigraphy (ESS) or depositional based evaluation of geologic conditions as part of an in-situ design?
   a. Yes
   b. No

Geologic Model

Establishes a foundation for remediation success

- Use “better science” to map contaminant transport, transition and storage zones
- “Untangle” heterogeneity and establish accurate geologic framework with clearly defined Hydrostratigraphic Units (HSUs)
- Develop a *framework and structure* that brings focus and efficiency to site investigation and remediation
  - Conceptual Structure AND Data Structure (Digital CSM)

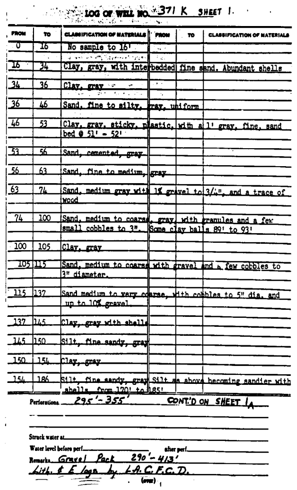
Groundwater lives in and is controlled by the Geology
Dr. J.H. Birman GSi/water, 1996

Geologic Model

Direct relationship to subsurface processes

- **Hydraulic processes (primarily advection, but also dilution and dispersion)**
  - **Geologic Model** provides the permeability architecture to evaluate hydrogeologic properties.
- **Matrix diffusion processes**
  - Permeability architecture (transport/storage zones) and distribution of organic carbon defined in the **Geologic Model.**
- **Adsorption/desorption**
  - Organic carbon distribution is defined by the **Geologic Model** and hydrogeologic setting and conditions.
- **Biological degradation**
  - **Geologic Model** and aquifer hydraulics can inform geochemical conditions that affect prevalence (or viability) of requisite organisms, functional genes, electron donors/acceptors, nutrients etc.
- **Abiotic degradation**
  - **Geologic Model** and aquifer hydraulics can inform geochemical conditions that affect prevalence (or viability) of requisite reactants, redox conditions, processes, etc.
- **Environmental forensics**
  - **Geologic Model** defines the contaminant migration pathway, essential to all forensic analyses.

The Environmental Sequence Stratigraphy (ESS) Process


LOG OF WELL NO. 371 K SHEET 1.

FROM	TO	CLASSIFICATION OF MATERIALS
0	16	No sample to 16'
16	34	Clay, gray, with interbedded fine sand. Abundant shells
34	36	Clay, gray
36	46	Sand, fine to silty, gray, uniform
46	53	Clay, gray, sticky, plastic, with a 1' gray, fine, sand bed @ 51' - 52'
53	56	Sand, cemented, gray
56	63	Sand, fine to medium, gray
63	74	Sand, medium gray with 1% gravel to 3/4", and a trace of wood
74	100	Sand, medium to coarse, gray, with granules and a few small cobbles to 3". Some clay balls 89' to 93'
100	105	Clay, gray
105	115	Sand, medium to coarse with gravel and a few cobbles to 3" diameter.
115	137	Sand medium to very coarse, with cobbles to 5" dia. and up to 10% gravel.
137	145	Clay, gray with shells
145	150	Silt, fine sandy, gray
150	154	Clay, gray
154	186	Silt, fine sandy, gray Silt as above becoming sandier with shells, from 170' to 185'

Perforations 295'-355' CONT'D ON SHEET 1A

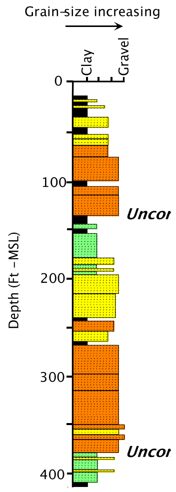
Struck water at

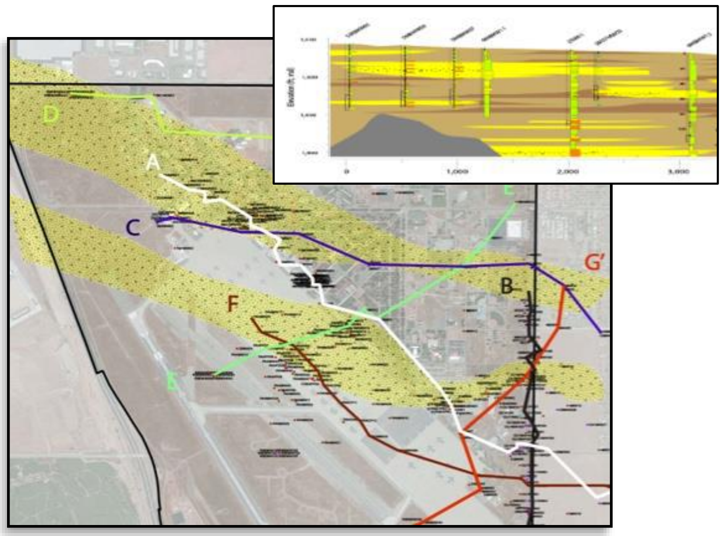
Water level before perf. after perf.

Remarks Gravel Pack 290'-413'

Lith. & E logs by L.A.C.F.C.D.

(over)



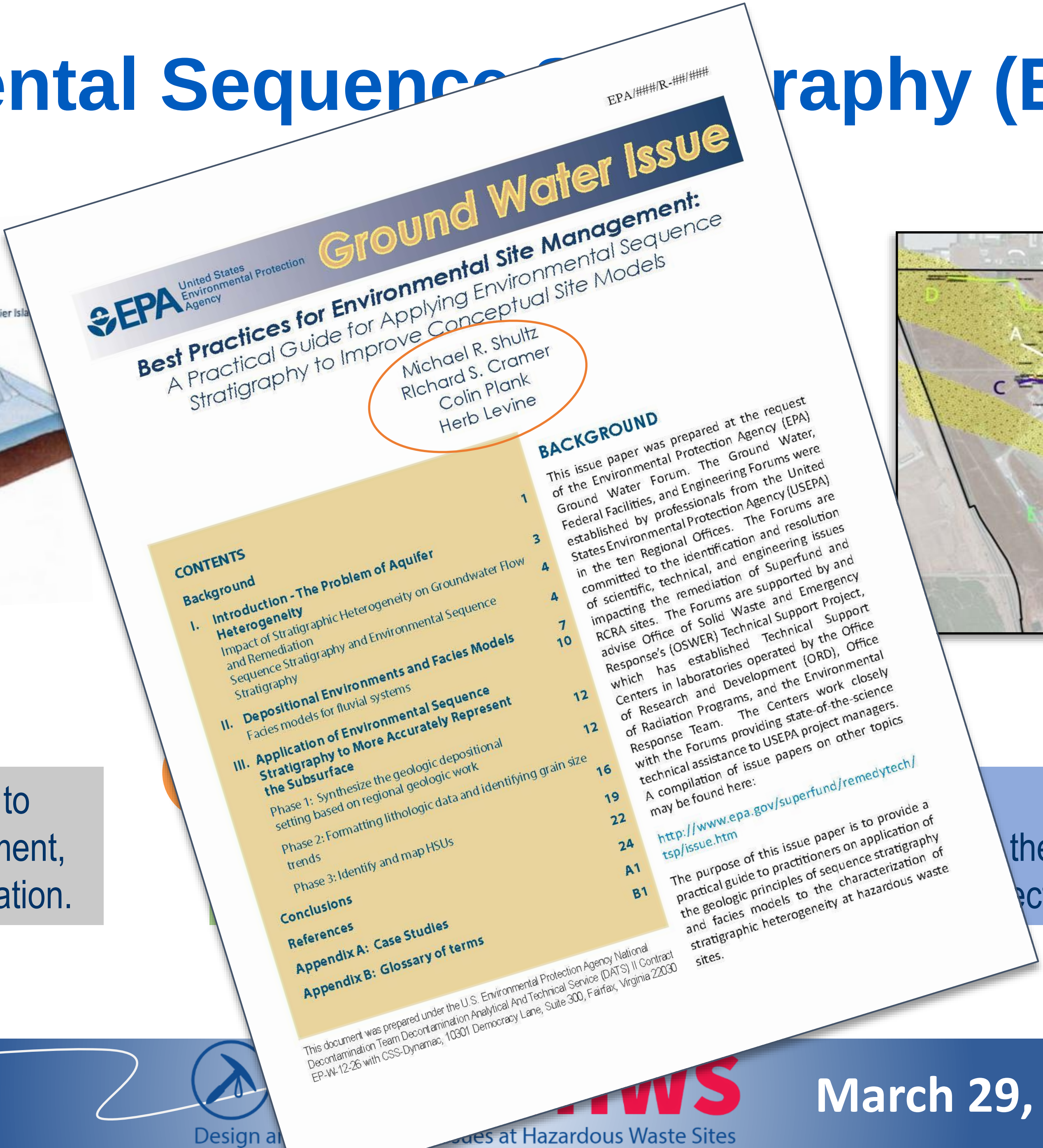


1 Research regional geology to determine depositional environment, the foundation of the ESS evaluation.

2 Leverage existing lithology data: vertical grain size patterns indicative of genetic relationships.

3 Map and predict the subsurface permeability architecture away from the data points.

The Environmental Sequence … raphy (ESS) Process



EPA/###/R-###/####

EPA United States Environmental Protection Agency

Ground Water Issue

Best Practices for Environmental Site Management:
A Practical Guide for Applying Environmental Sequence Stratigraphy to Improve Conceptual Site Models

Michael R. Shultz
Richard S. Cramer
Colin Plank
Herb Levine

CONTENTS

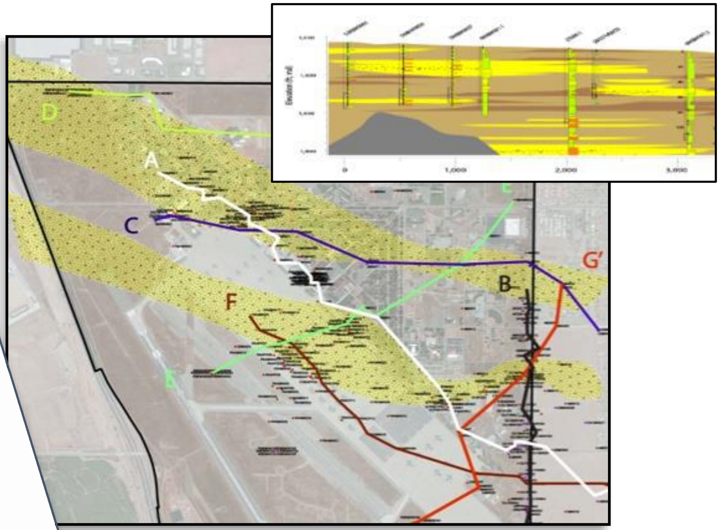
BACKGROUND

This issue paper was prepared at the request of the Environmental Protection Agency (EPA) Ground Water Forum. The Ground Water, Federal Facilities, and Engineering Forums were established by professionals from the United States Environmental Protection Agency (USEPA) in the ten Regional Offices. The Forums are committed to the identification and resolution of scientific, technical, and engineering issues impacting the remediation of Superfund and RCRA sites. The Forums are supported by and advise Office of Solid Waste and Emergency Response's (OSWER) Technical Support Project, which has established Technical Support Centers in laboratories operated by the Office of Research and Development (ORD), Office of Radiation Programs, and the Environmental Response Team. The Centers work closely with the Forums providing state-of-the-science technical assistance to USEPA project managers. A compilation of issue papers on other topics may be found here:

http://www.epa.gov/superfund/remedytech/tsp/issue.htm

The purpose of this issue paper is to provide a practical guide to practitioners on application of the geologic principles of sequence stratigraphy and facies models to the characterization of stratigraphic heterogeneity at hazardous waste sites.

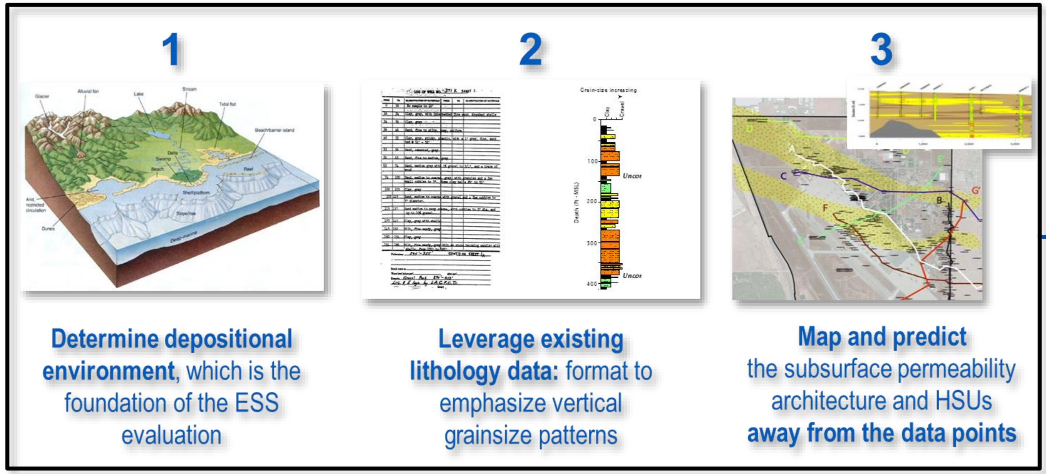
This document was prepared under the U.S. Environmental Protection Agency National Decontamination Team Decontamination Analytical And Technical Service (DATS) II Contract EP-W-12-26 with CSS-Dynamac, 10301 Democracy Lane, Suite 300, Fairfax, Virginia 22030

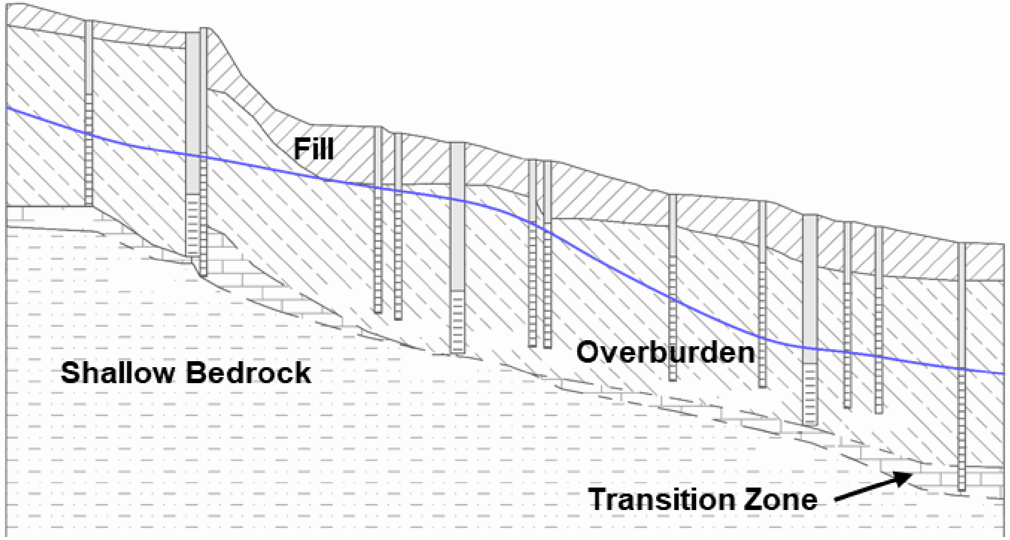


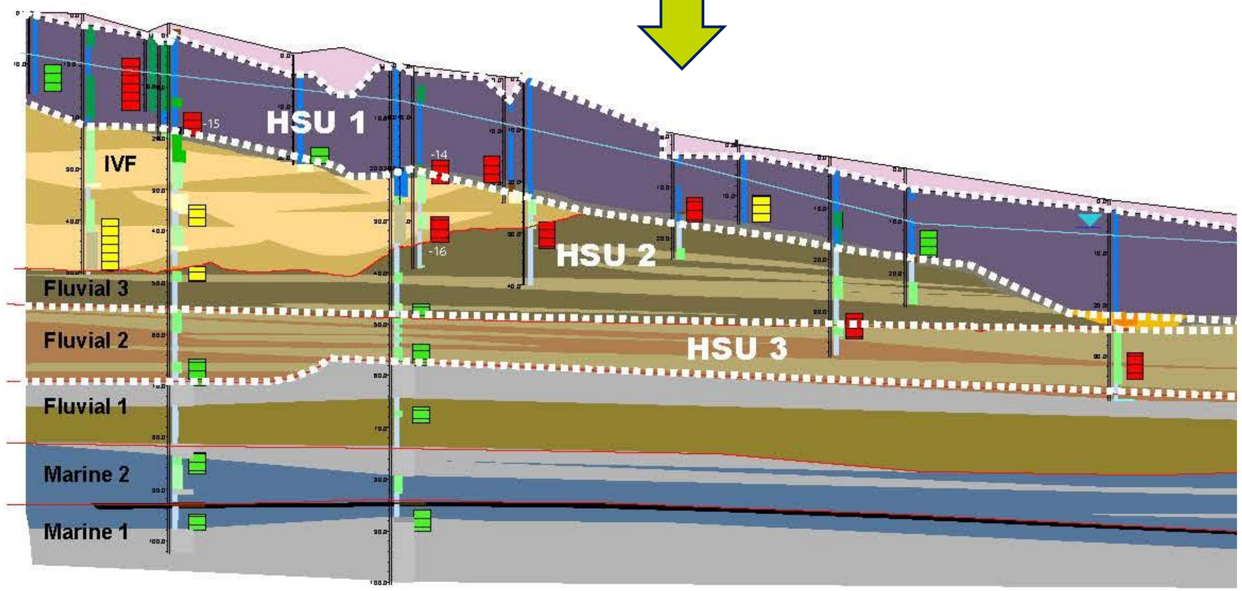
1 **Research regional geology** to determine depositional environment, the foundation of the ESS evaluation.

Map and predict the subsurface permeability … ecture away from the data points.

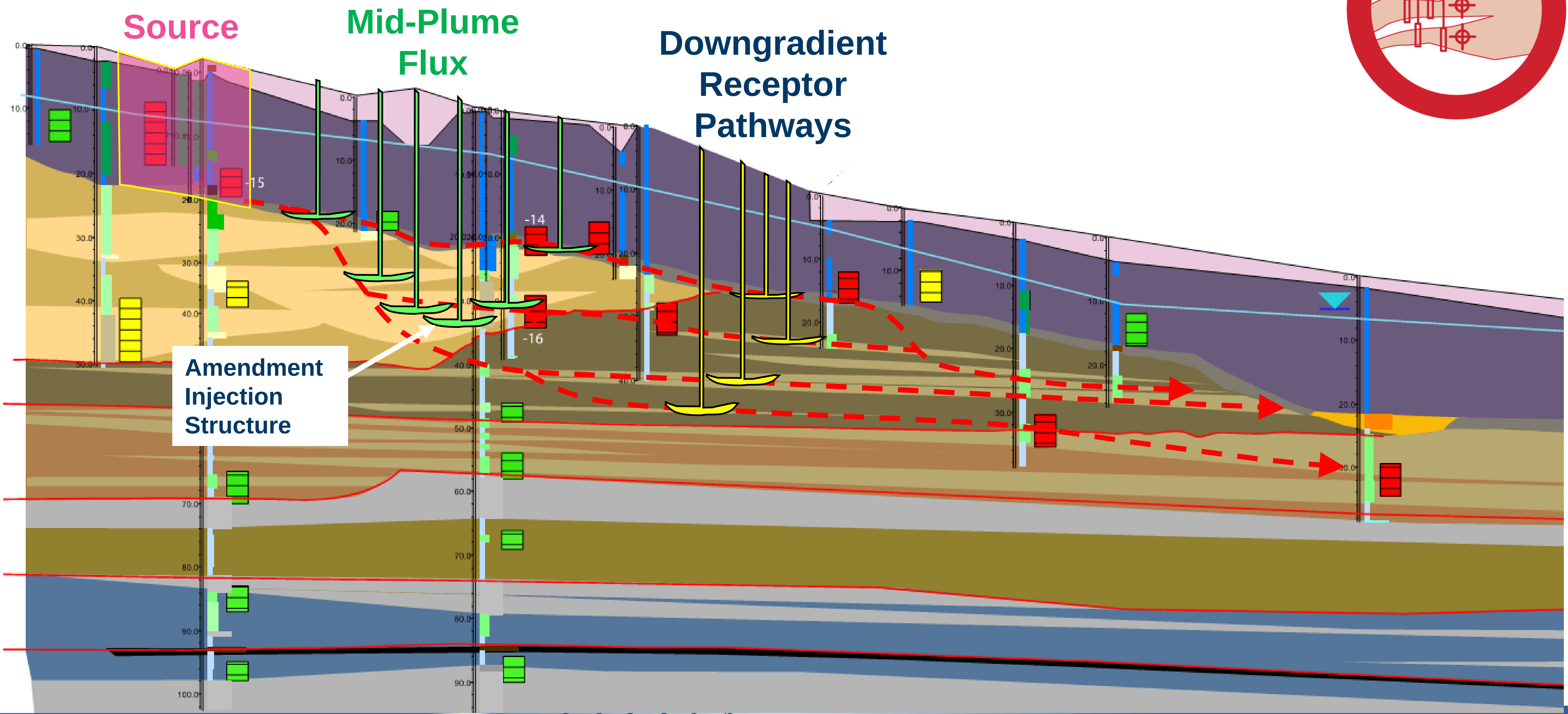
The Geologic Model







Focused Remediation



Panel Session C