High Resolution Remedial Design Characterization and In-Situ Remediation Technologies Combined to Clean-Up Sites the First Time –

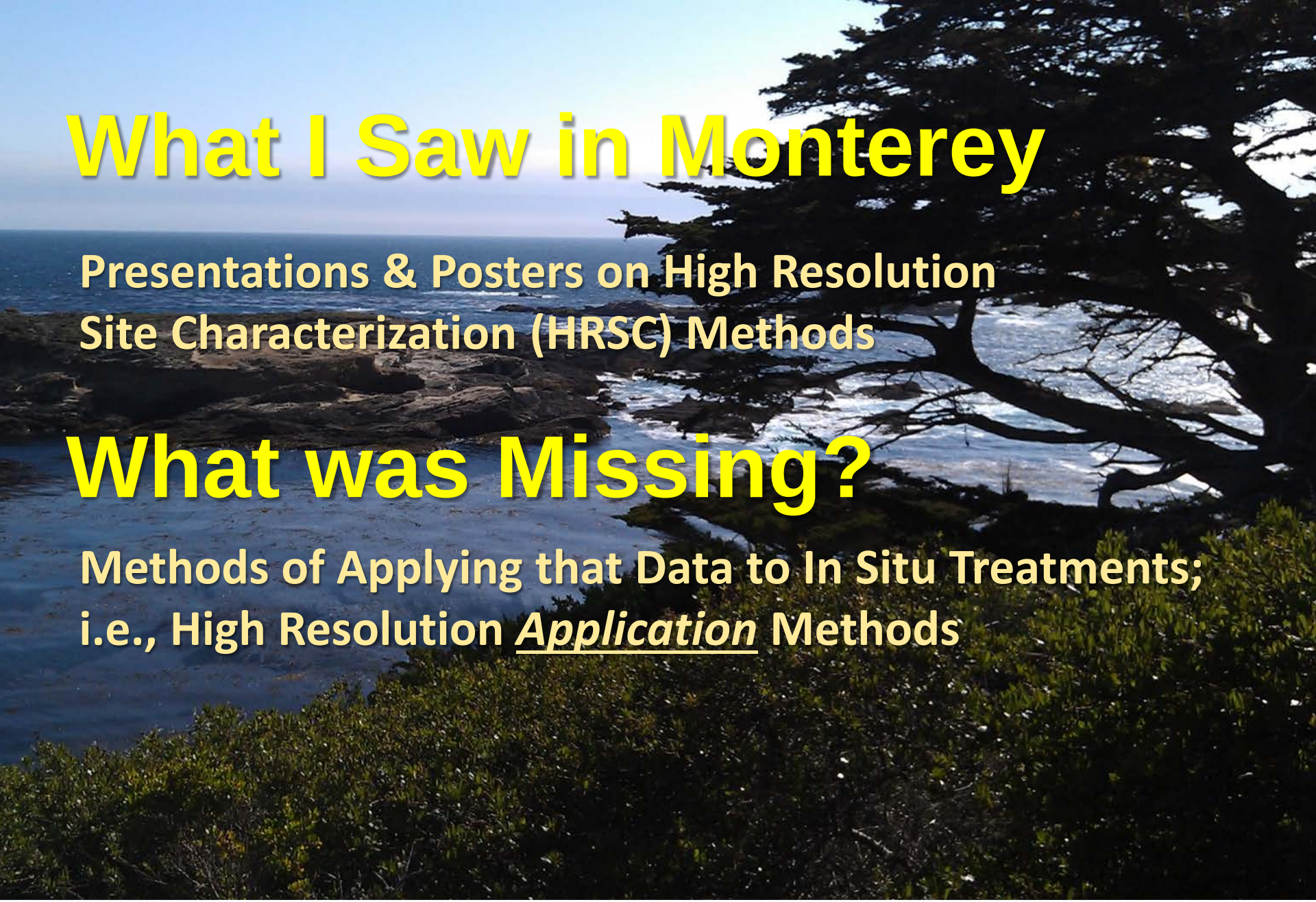
It's a Contact Sport!

John Fontana, PG, President & CEO

THE TEXAS ASSOCIATION OF ENVIRONMENTAL PROFESSIONALS
February 2016, Luncheon Meeting
Brady's Landing, Houston, TX

Vista GeoScience

TAEP



What I Saw in Monterey

Presentations & Posters on High Resolution Site Characterization (HRSC) Methods

What was Missing?

Methods of Applying that Data to In Situ Treatments; i.e., High Resolution ***Application*** Methods

Outline

- In Situ Treatment Technology Review
- The Need & Challenges?
  - Better CSM Development for Remedial Design
  - Followed with Highly Targeted Application Methods
- Remedial Design Characterization (RDC) Phase
  - Collect Adequate 3-D Data
  - Qualitative, Screening and Quantitative Data
- In-Situ Treatment Application Phase
  - Selecting the Right Tools and Methods for a Particular Treatment
  - Applying Higher Resolution Targeted Application Methods
- Recent Examples
- Summary & Conclusion

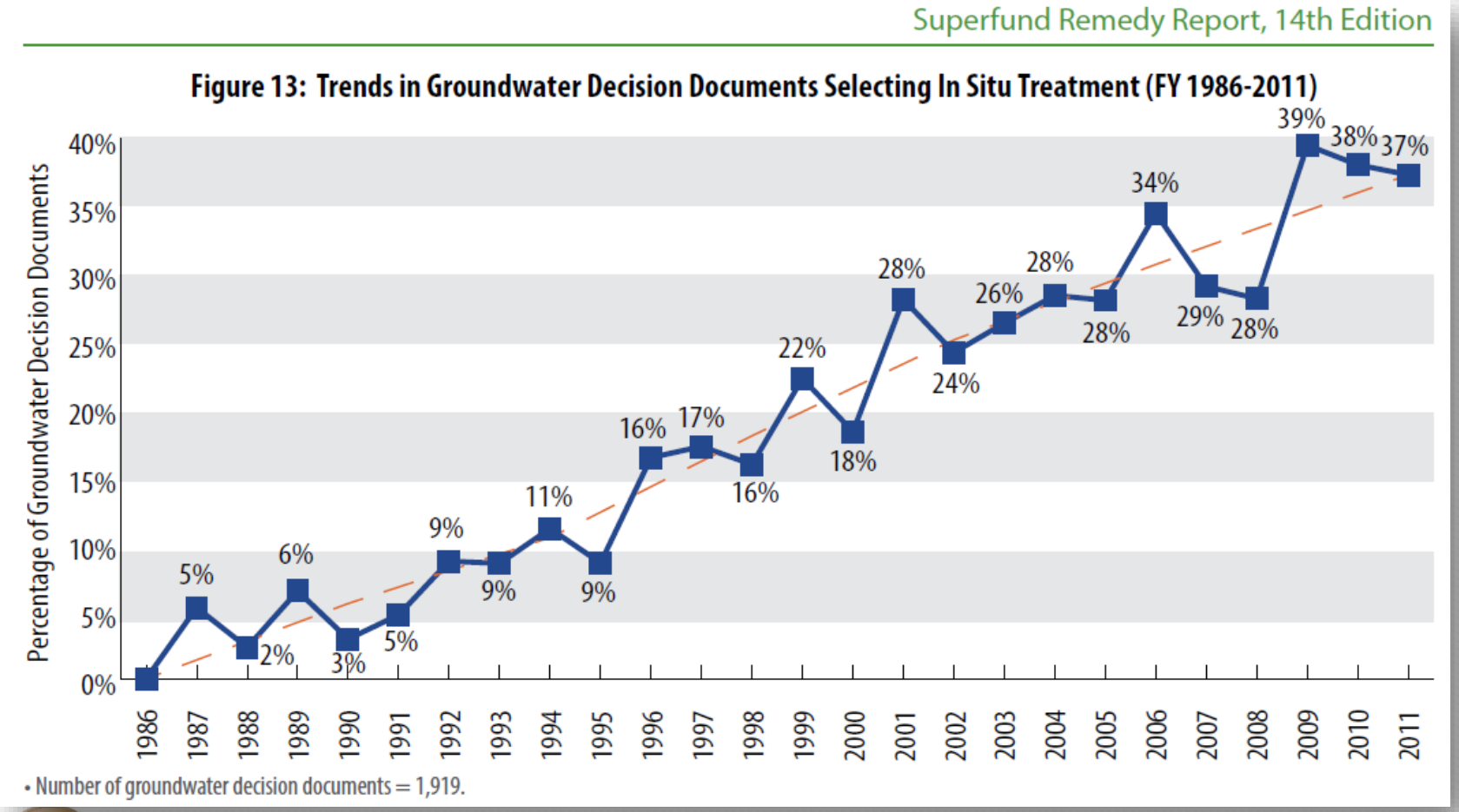
The In-Situ Treatment Revolution!

- **Amendment Injections**
  - **In-Situ Chemical Oxidation (ISCO)**
  - **In-Situ Chemical Reduction (ISCR)**
  - **In-Situ (Enhanced) Bio-Remediation or Bio-Reduction (ISBR)**
- **Environmental Hydraulic Fracturing**
  - **Similar Amendments & Treatments**
  - **Enhanced Permeability**
- ***Too Often are Improperly Applied!***

Sampling of the Many In-Situ Remediation Product Providers

Increased Use of In-Situ Technologies for Groundwater (1985 – 2011, NPL Sites)

EPA-Superfund Remedy Report (SRR) Fourteenth Edition (EPA 542-R-13-016), November 2013



Why In-Situ Injection Installation of Treatments?

- **Limited or No Disposal Issues**
- **In Place Destruction of Contaminants**
- **Less Invasive - Works Around Infrastructure**
- **Many Work with Natural Environment**
- **Direct Push Injection Advancements**
- **Improved Understanding of Hydraulic-Fracturing**
- **Improved Monitoring Methods,**
- **So….. Seen as Faster, Cheaper *and it's……***

Greener & Sustainable Technology!

The Need?

Better Results from In Situ Remediation Projects at Difficult Sites

The How:

1. **Remedial Design Characterization (RDC): Develop & Refine the Conceptual Site Model by Collecting High Resolution Data, both Qualitative and Quantitative.**
2. **Apply In Situ Treatments Using High Resolutions Application Tools and Methods to Better Target Contaminants in Place.**

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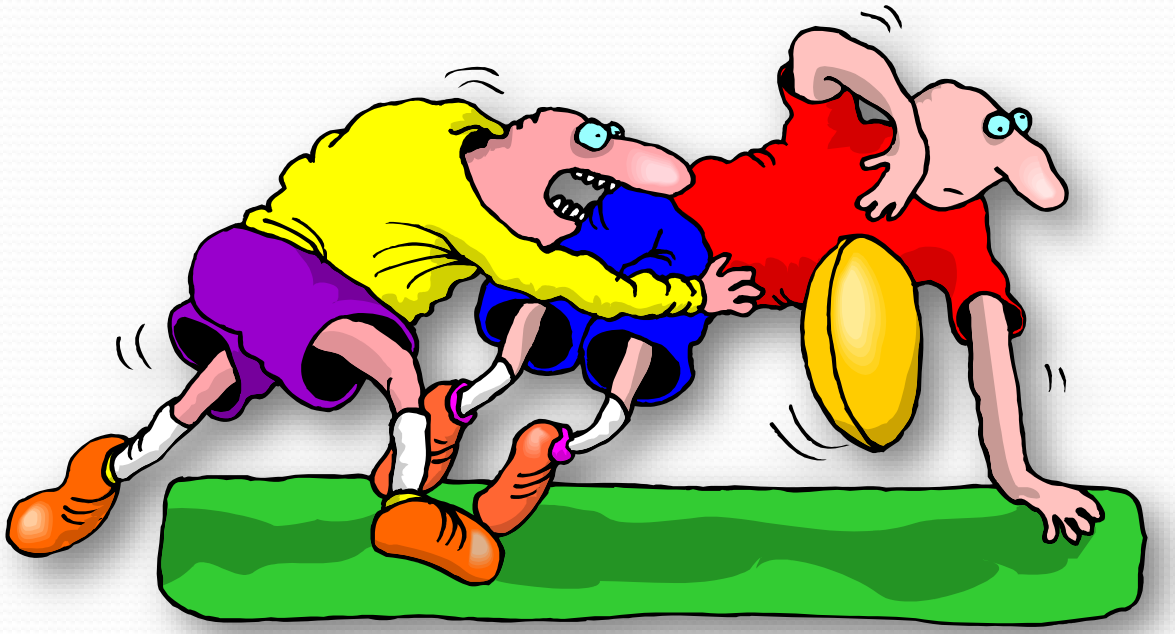
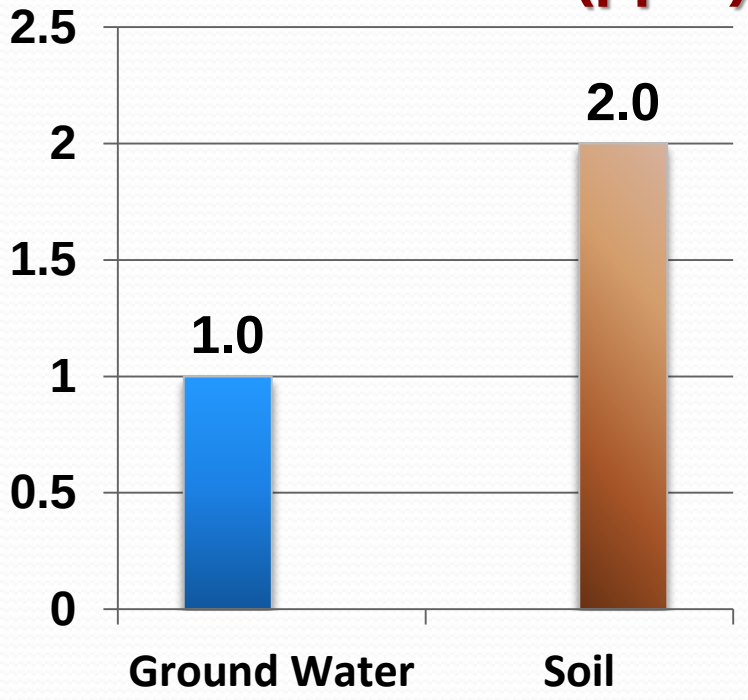
In-Situ Remediation:
It's a Contact Sport!

- **HOME TEAM: Contaminated Soil & Ground Water**
- **VISITING TEAM: Treatment Reagents**

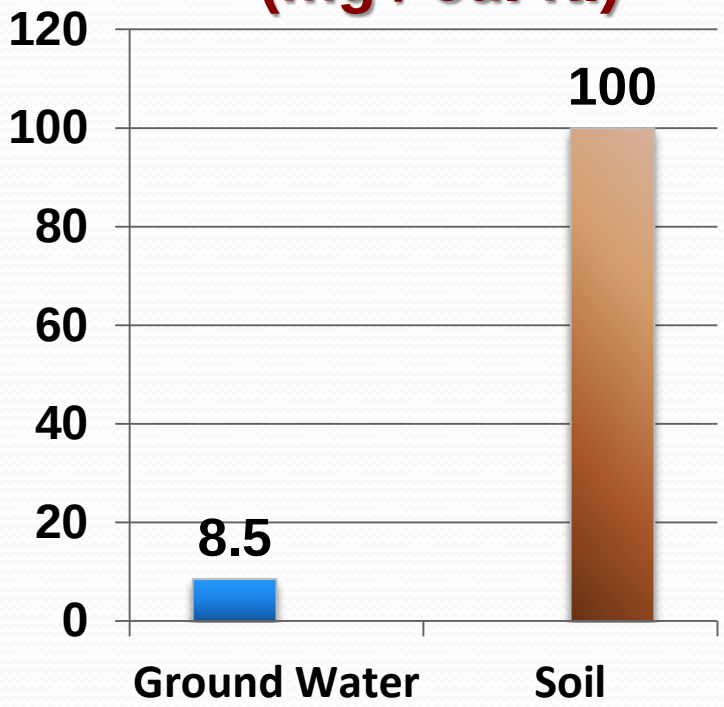


Adsorbed Phase vs. Dissolved Phase Contaminant Loading

Soil and Ground Water Concentration (ppm)



Contaminant Load (mg / cu. ft.)



If you design to only treat the dissolved phase contaminant, you get REBOUND

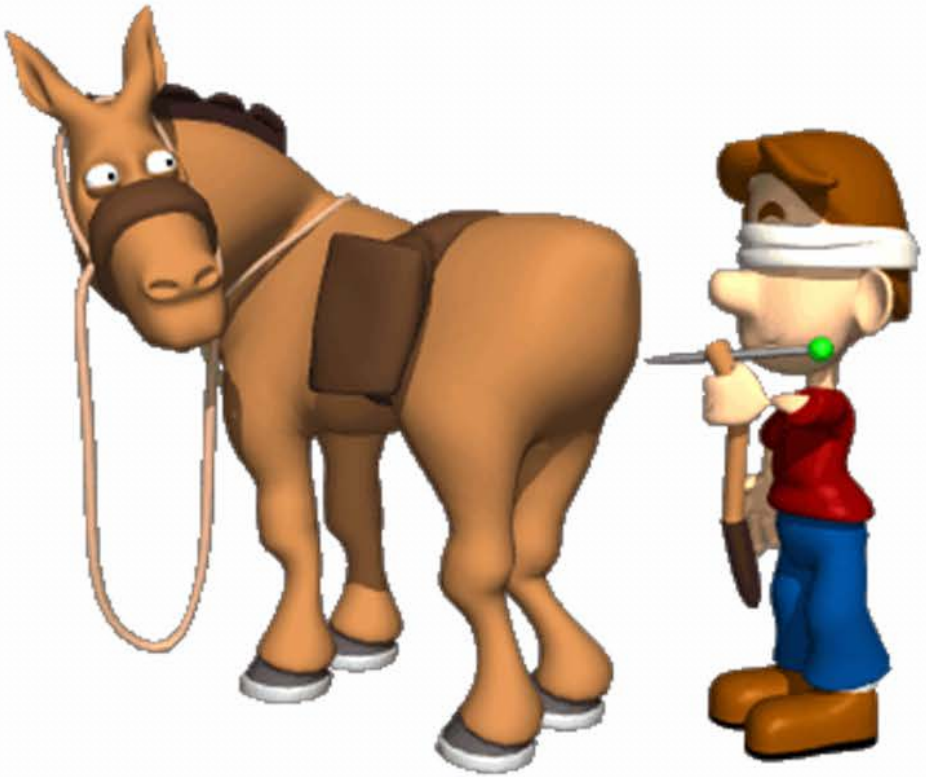
Back Diffusion from Clays = REBOUND
(Consider Mass Flux Discharge in RDC)

Courtesy Tom Sale, PhD, Colorado State University (Go RAMS!)

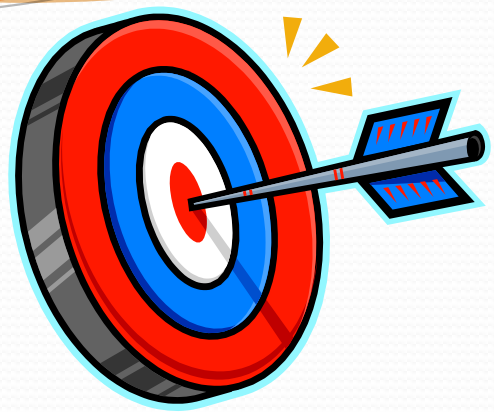
Remedial Design Characterization - Critical for Success

- ***But… My Site is Already Characterized!***
  - Yes, in 2-D, but we need more data for the Remedial Design!
- **Most Important: 3-D Contaminant Distribution *and* Mass**
- **Lithologic & Hydrologic Parameters in greater detail**
- **Chemical Compatibility for certain treatments is unknown**
  - Natural Oxidant or Reductant Demand, e^- Donors & Acceptors
  - Geochemistry/Biochemistry – Bug Populations/Nutrients
- **Errors result in significant under- or over-dosing – or both!**
- ***A vertical and horizontal 3-D image of the site contaminant, geology and geochemistry is required!***

Don’t Be Blindfolded and Miss the Target



The Goals of a RDC



Determine:

- **Where the Contamination is Located**
  - **Vertical and Horizontal Distribution**
- **How Much Mass is There to Treat (Dosing)**
- **Physical, Chemical & Biological Parameters as Needed for Specific Treatments. (SOD, COD, etc.)**
- **If Back Diffusion Affects the Choice of Methods**
- **Delivery Methods Based on Soil/Rock Types & Degree of Heterogeneity**

Use High Resolution Data to Create "Decision Units" for Treatment Dosing

DEPTH

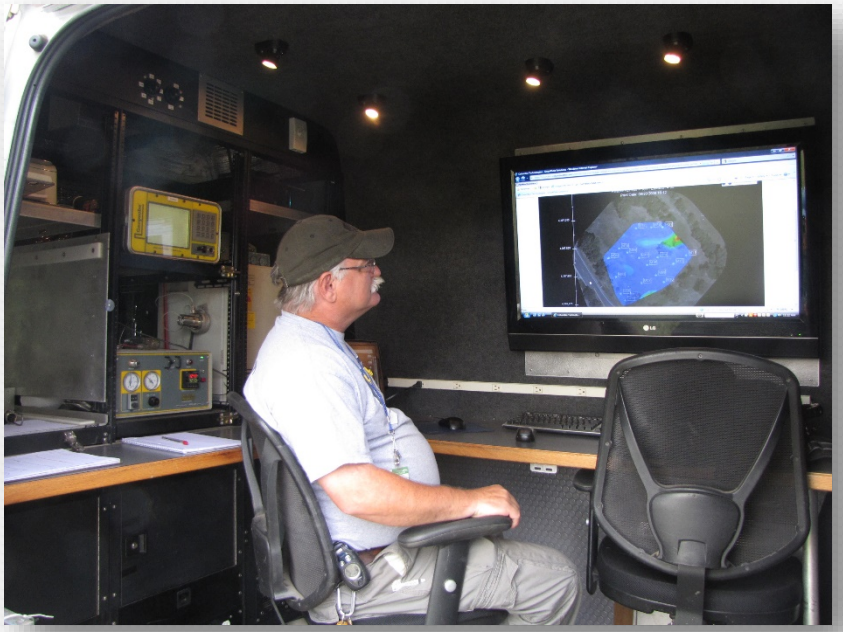
Injection Depth	Area A 500 sq. ft, 5 pts.	Area B 1,500 sq. ft, 15 pts	Area C 4,000 sq. ft. 40 pts.
12'			
14'	10 lbs	25 lbs	10 lbs
16'	40 lbs	40 lbs	25 lbs
18'	25 lbs	25 lbs	25 lbs
20'	10 lbs	10 lbs	10 lbs
22'			10 lbs

High Resolution Site Characterization (HRSC)

Tools for Remedial Design Characterization

- ✓ **Direct Sensing Probing Tools**
- ✓ **High Resolution Sampling Methods**
- ✓ **Screening Level Analyses**
- ✓ **Biologic Investigation Tools**
- ✓ **Treatability Studies**

High Resolution "Direct Sensing" Investigation Tools



Membrane Interface Probe (MIP) at the Denver Federal Center

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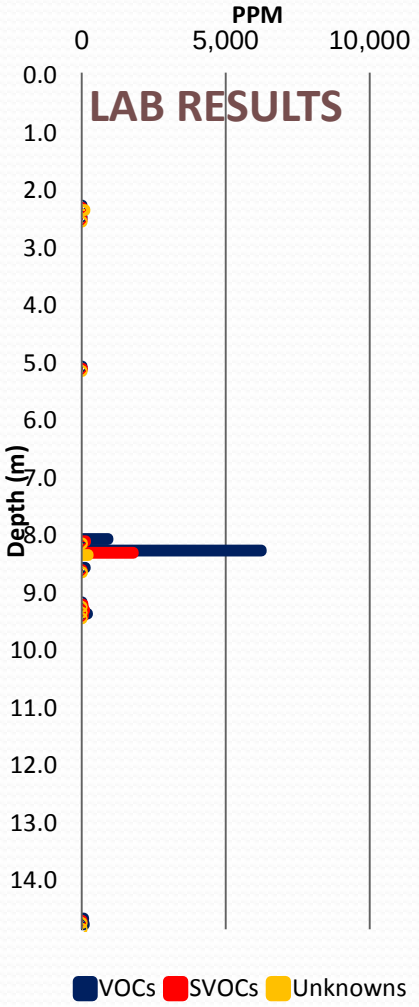
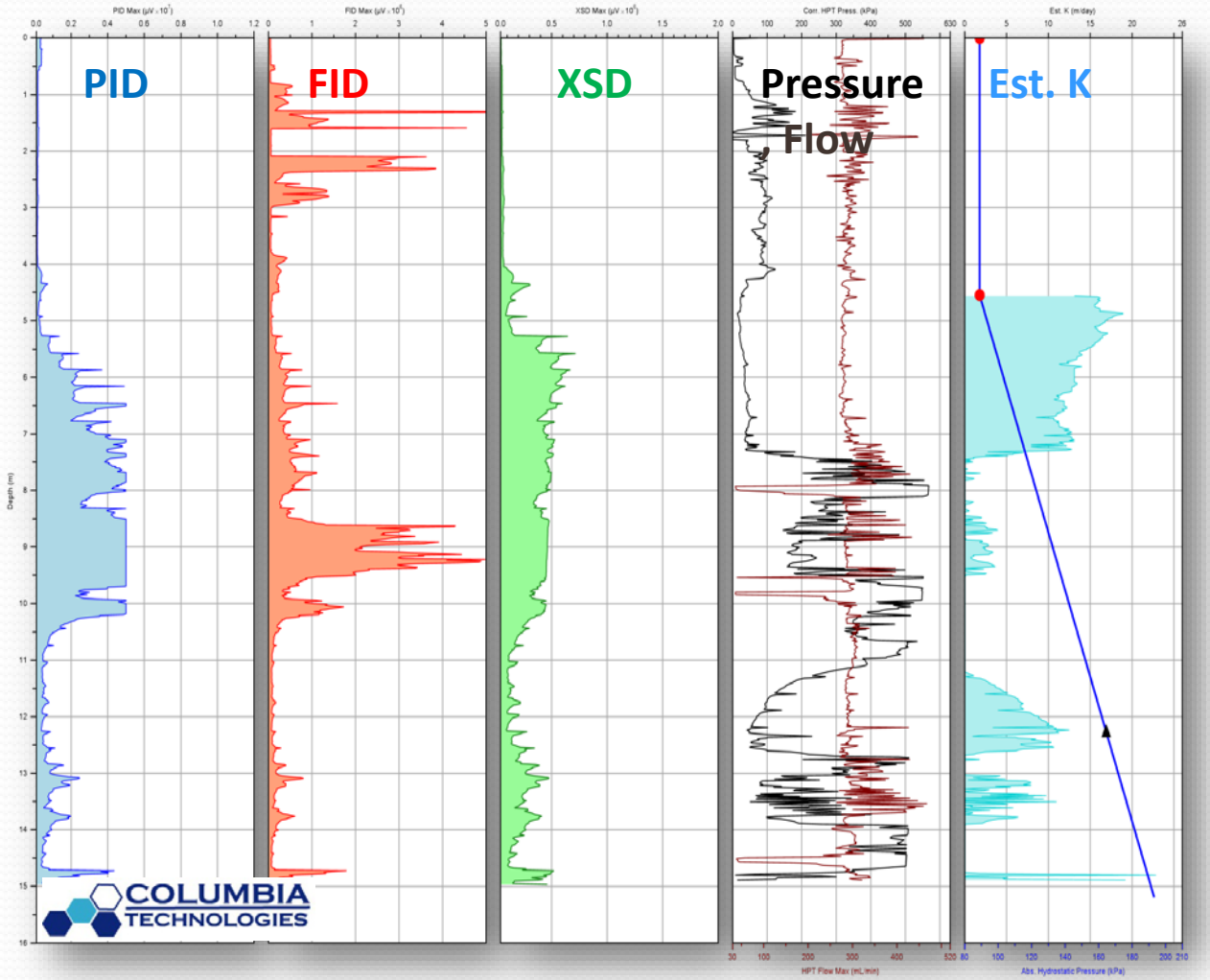
High Resolution Systems

Method	Target Data
MIP (Membrane Interface Probe) **(MIP-EC, MiHPT, MIP-HTL, LL MIP, MIP-XSD)**	**Volatile Organic Compounds (VOCs)** **(Dissolved phase petroleum and/or Solvents)**
LIF (Laser Induced Fluorescence) **(UVOST®, ROST®, TarGOST®, FFD)**	**LNAPL/Residual phase petroleum** **Light petroleum fuels to coal tars**
HPT (Hydraulic Profiling Tool)	**Soil hydraulics (pore pressure, soil permeability)**
PST (Pneumatic Slug Test)	**Soil characteristic - permeability**
EC (Electrical Conductivity)	**Soil characteristic - electrical**
CPT (Cone Penetrometer)	**Soil characteristic, behavior type**
Discrete Groundwater Profiling *Short, discrete screen interval (0.2 – 1.0 meter)*	**VOCs, SVOCs, Metals, Biologics, Gases**
Onsite Laboratory Analyses *Rapid Laboratory grade GC, GCMS, HPLC, other*	**VOCs, SVOCs, Metals, Gases**
Real Time Data Management *Mapping and vertical profile charts*	**Quality Assurance and Decision Making** **Results presented via Internet in real time**

High Resolution = Millions of Data Points

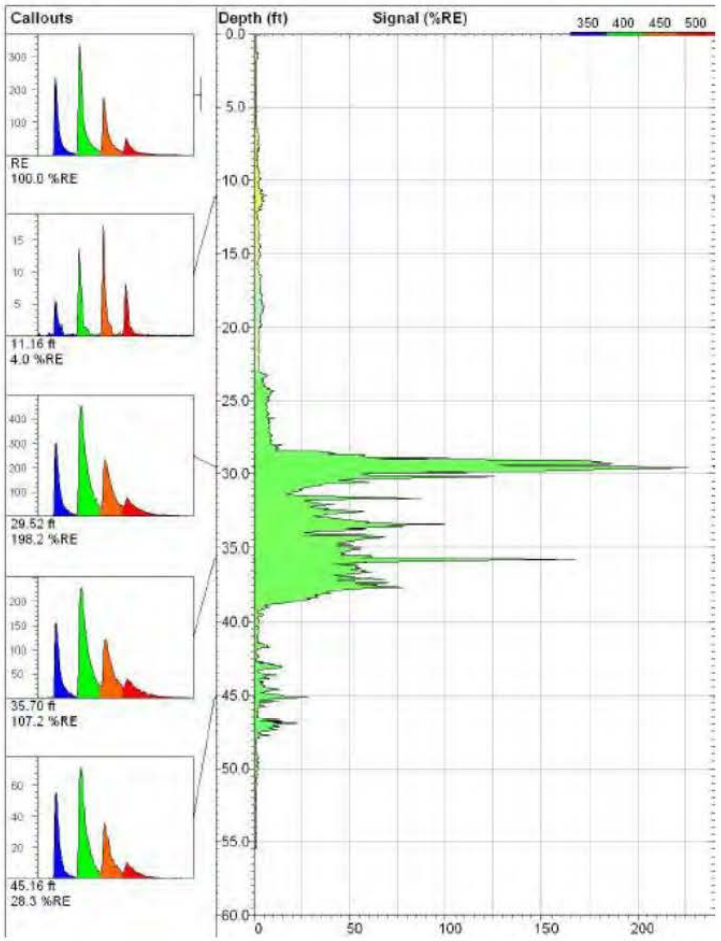
MiHpt Log - Tracking SVOC DNAPL

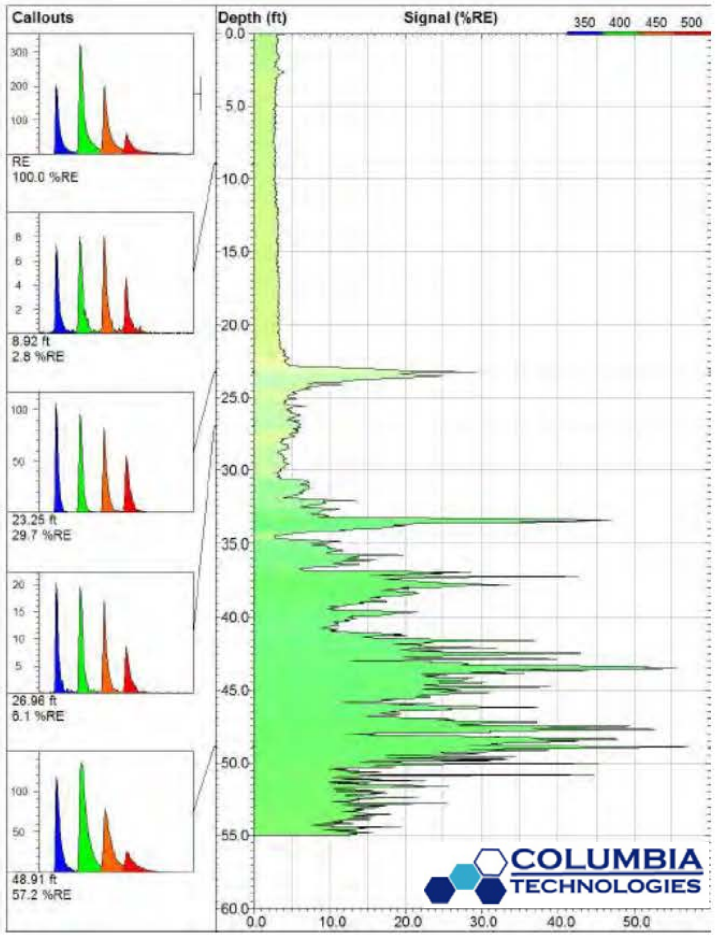




Laser Induced Fluorescence (LIF) Logs
(Ultra Violet Optical Screening Tool – UVOST)

LIF Logs



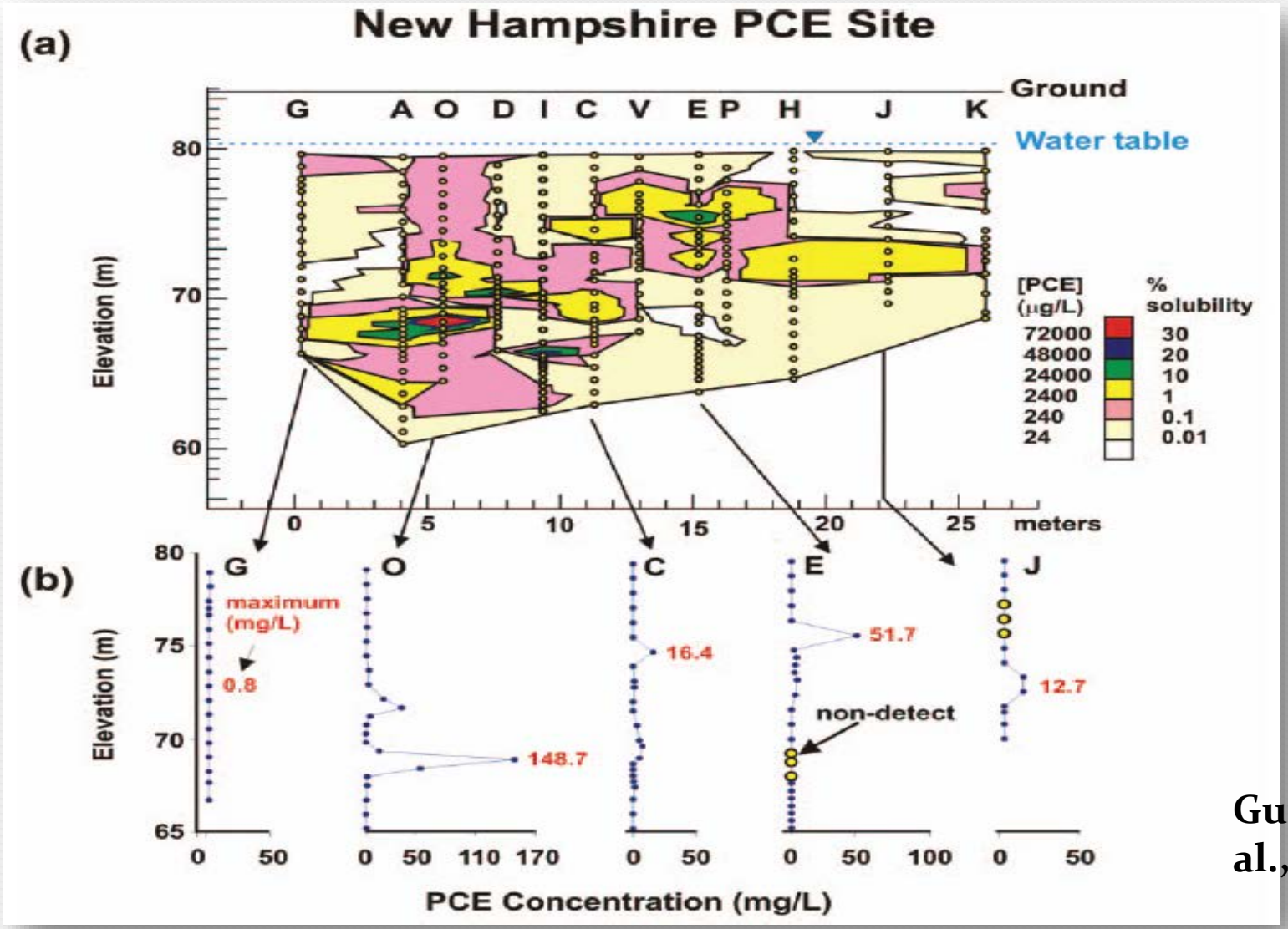


High Resolution Sampling

Low Tech: Required for Quantitative Analysis of Mass Present

- Dosing calculations require quantitative horizontal and vertical mass distribution in soil & ground water
- Measure other parameters that react with the reagents or affect the biologic system.

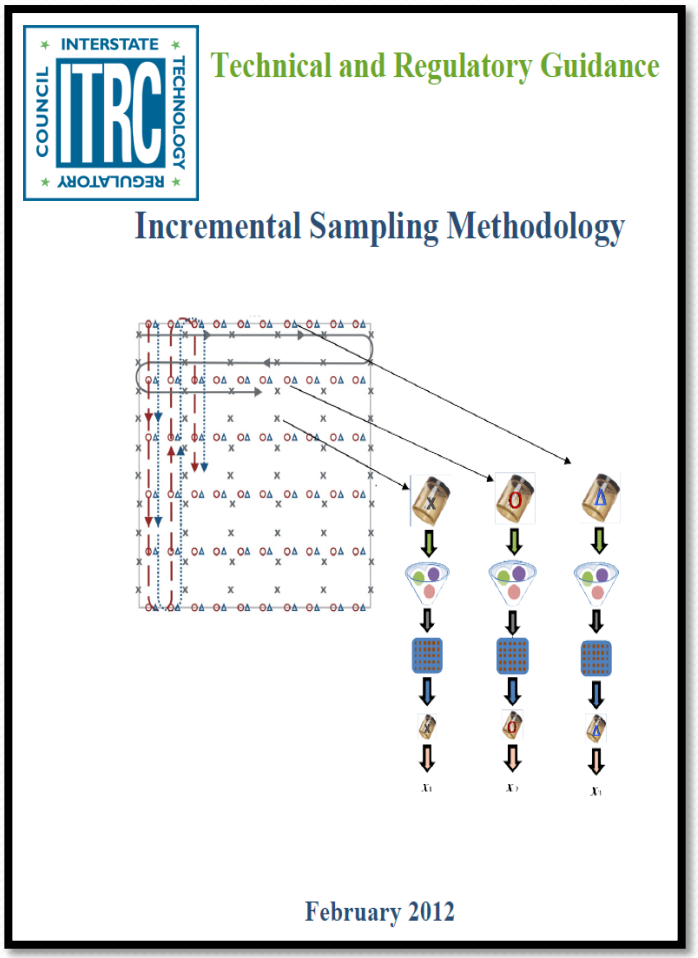
High Resolution Soil Sampling



Guilbeault et al., 2005

Incremental Sampling Method (ISM)

- **New ITRC Guidance**
- **Structured Composite Sampling Protocol**
- **Reduces variability & provides accurate estimates of mean concentrations for a set volume compared to traditional discrete (grab) sampling methods.**
- **Integrates Quantitative Soil Sampling Objectives with Site Conceptual Model**
- **More Accurate for Characterization, Risk and Development of CSM.**
- ***Results in Decision Units That Can Be Used for Remedial Design***



ITRC (Interstate Technology & Regulatory Council). 2012. *Incremental Sampling Methodology. ISM-1. www.itrcweb.org.*

Representative Sampling from Continuous Soil Cores

(Remember: A saturated soil sample includes the pore water, and therefore the combined adsorbed and dissolved phase)

Sub-Sampling Continuous Cores for VOCs Using Plugs

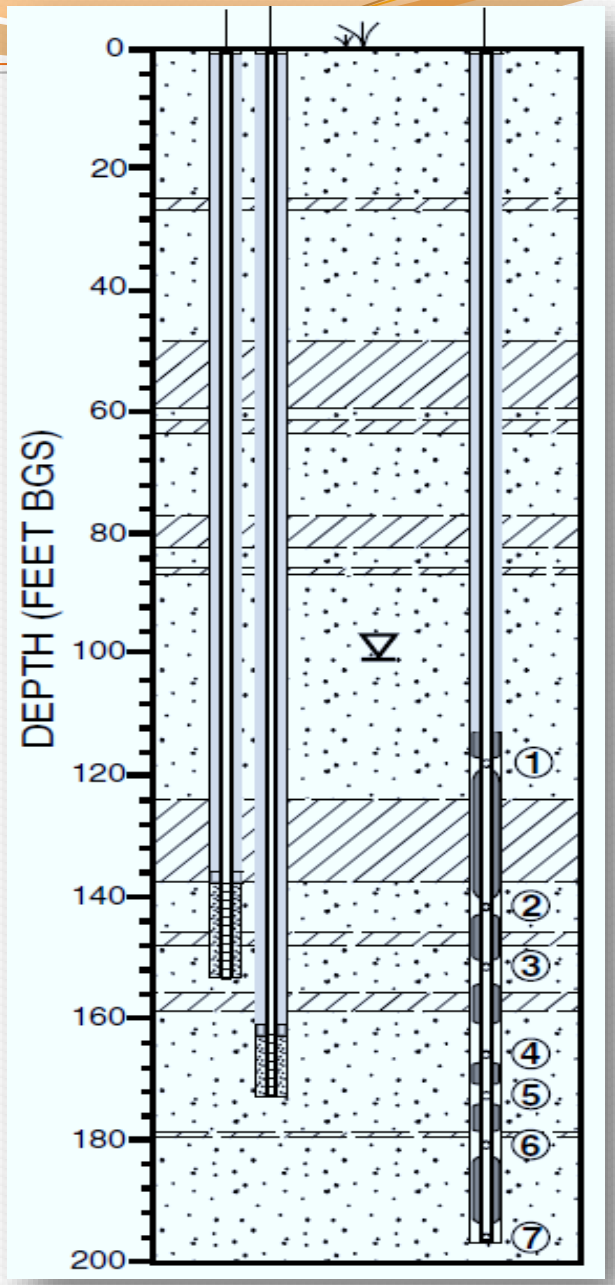
Cutting a Composite "Wedge" from the Continuous Core

ITRC (Interstate Technology & Regulatory Council). 2012. *Incremental Sampling Methodology. ISM-1. www.itrcweb.org.*

Tools for Discrete Ground Water Samples

- Discrete GW Sampling Tools
- Multiple Wells with Discrete Screens
- Single Well with Multi-Level Ports
- ….BUT REMEMBER: 80-90% of the mass resides in the saturated soils.

Geoprobe® Screen-Point Sampler



Practical Handbook of Environmental Site Characterization and Ground-Water Monitoring, Second Edition, Ed. David M. Nielsen – CH 11, Multi-Level Ground Water Monitoring, Murray Einarson

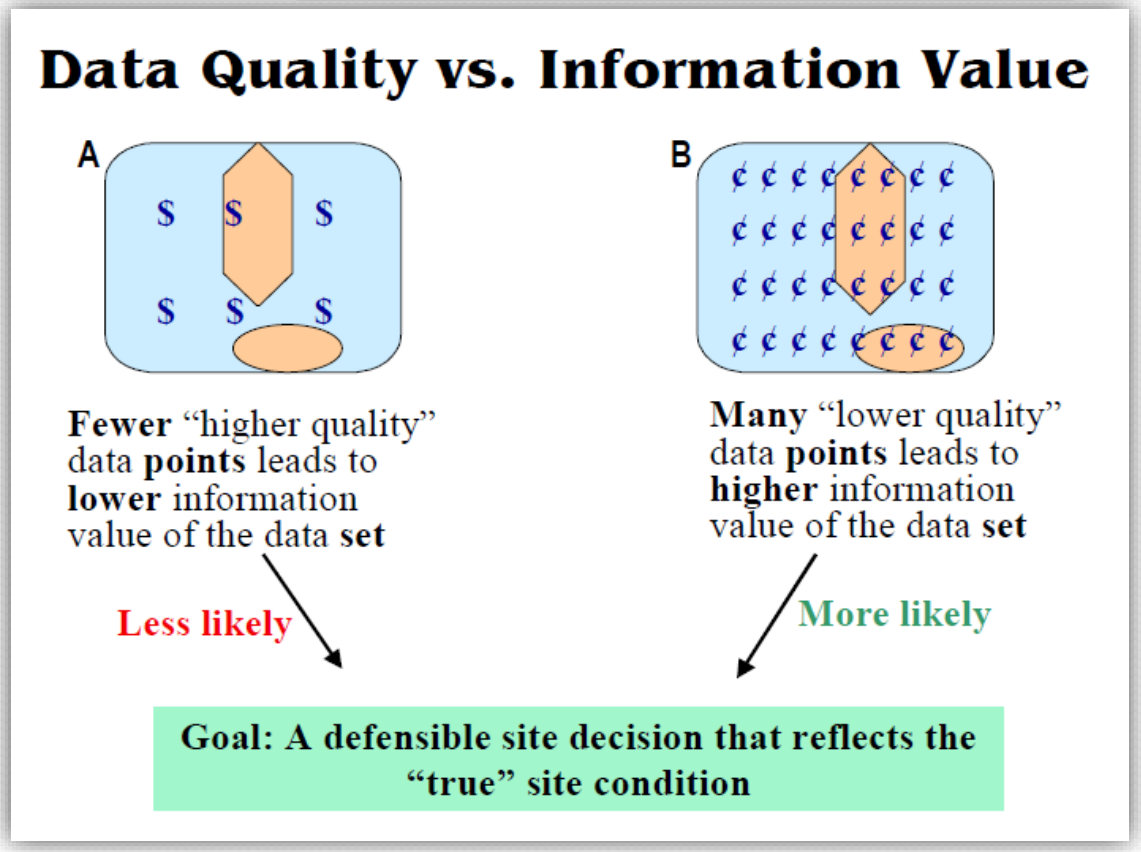
Definitive vs. Screening Level Data

How much will all of that detailed analysis cost!?!?!

- **Do I need Definitive Data, or can I use Screening Level Data?**
- **MYTH: Screening level data cannot be used for decision making.**
- ***Data produced by screening methods can be of known and documented quality; adequate quality control can be used in conjunction with data generated in the field or lab.***
- **Define the quality goals required remediation design, not for regulatory decisions.**

How much will all of that detailed analysis cost!?!?!

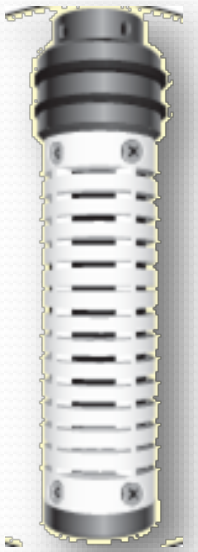
Use Screening Data vs. Definitive Data to Reduce Cost *and* Increase Detail



2001, D. M Crumbling, EPA 542-R-01-013, Current Perspectives in Site Remediation and Monitoring

Bench Testing, Treatability, or Pilot Testing?

- **Bench Testing – Make Sure its Done Right.**
  - Mixing together of soil, ground water and treatment.
  - Generally, it has already has been done by someone!
  - Some "test tube" methods do not simulate real subsurface conditions.
  - We often already know which treatments work on what contaminants.
  - Difficult with anaerobic methods, requires zero-O_2 chambers.
  - **Proper applications requires mimicking field conditions.**
- **Treatability Studies**
  - Soil Oxidant Demand
  - Chemical Compatibility
  - In-Situ Treatability Testing (bio-remediation)
  - Bacteria Type & Health Testing
- **Pilot Testing**
  - **Best to test methods before going full scale.**



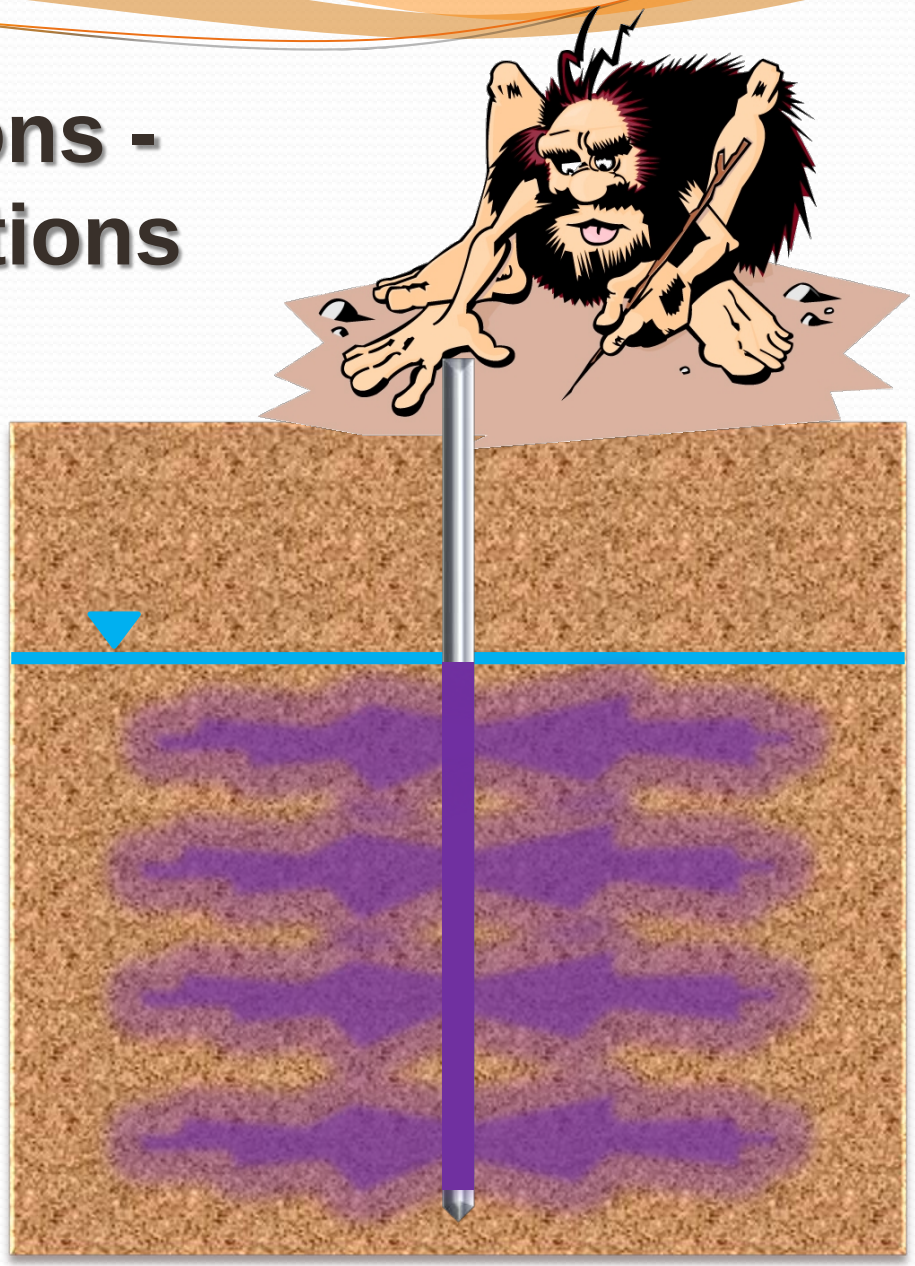
Applying RDC Data to In Situ Remediation Treatments

- Now we know ***where*** the contaminants are and ***how much*** is there, so now we need ***properly targeted & applied treatments***.
- Old vs. New Application Methods
- Conventional Injections vs. Hydraulic Fracturing Methods

“Early” In-Situ Injection Methods

- New Treatments on the Market
- Existing Monitoring Well Network
  - Socks
  - Gravity Feed
  - Injections in it’s Infancy
- Open Auger Bore Holes, Open Pits, Trenching
- Dedicated Injection Wells using HSA
- *We used what we had!*

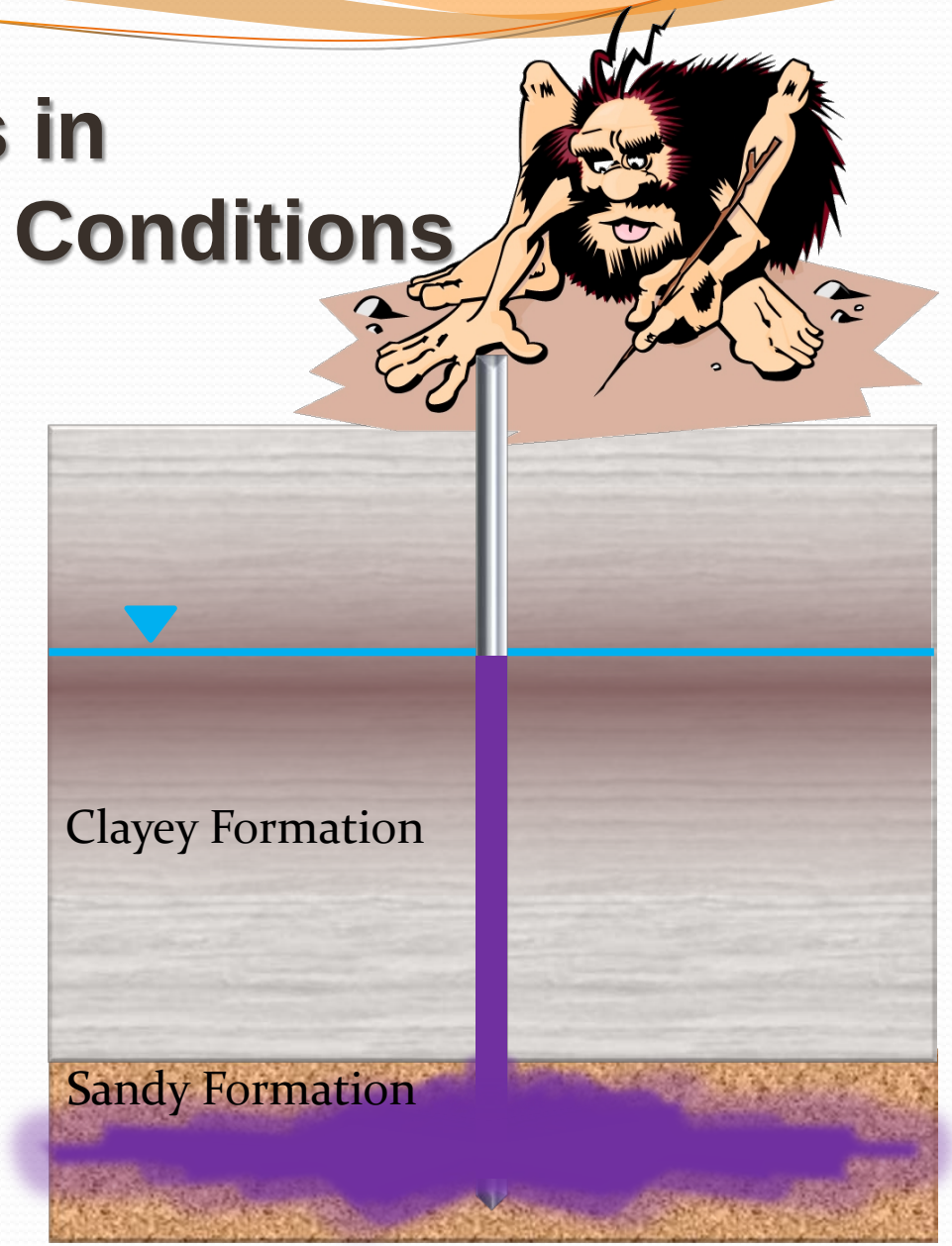
Bottom Up Injections - Under *Ideal* Conditions



- Homogeneous
- Porous/Permeable
- No Preferential Bedding Planes
- Coarsening Upward
- Even Gravity Fed Wells are OK here!

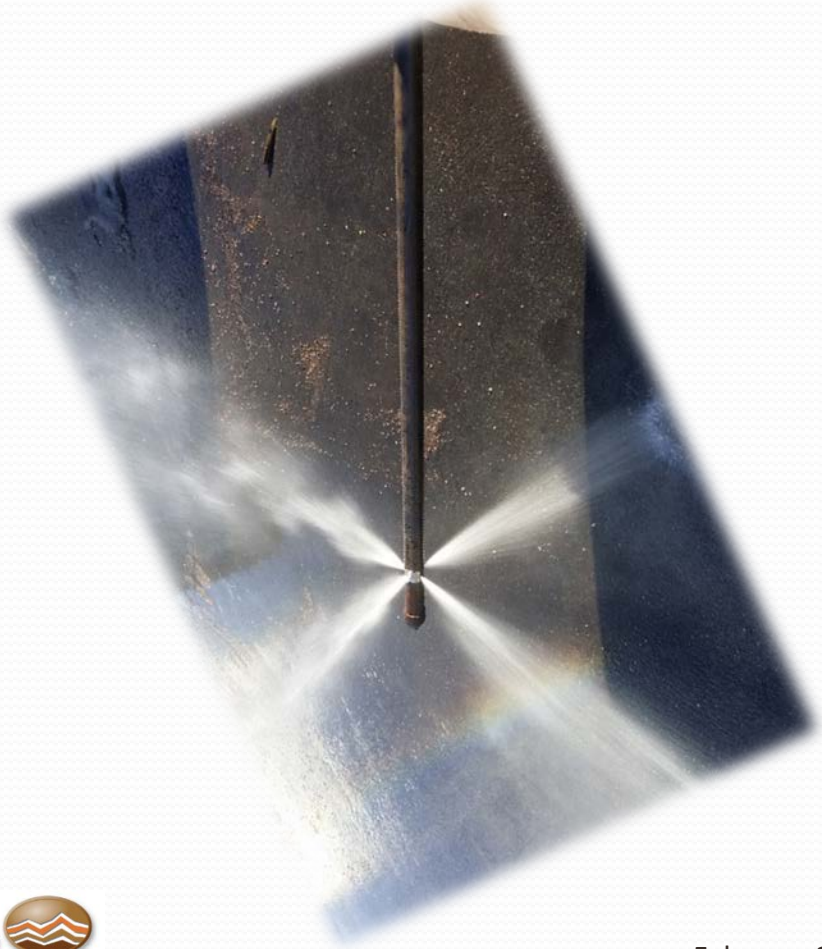
Bottom Up Injections in *Non-Ideal* (Common) Conditions

- Less Porous & Permeable Soils
- Preferential Bedding Planes
- Fracturing May Occur
- Coarsening Downward
- Path of Least Resistance



SOLUTIONS: Surgical Injection Methods

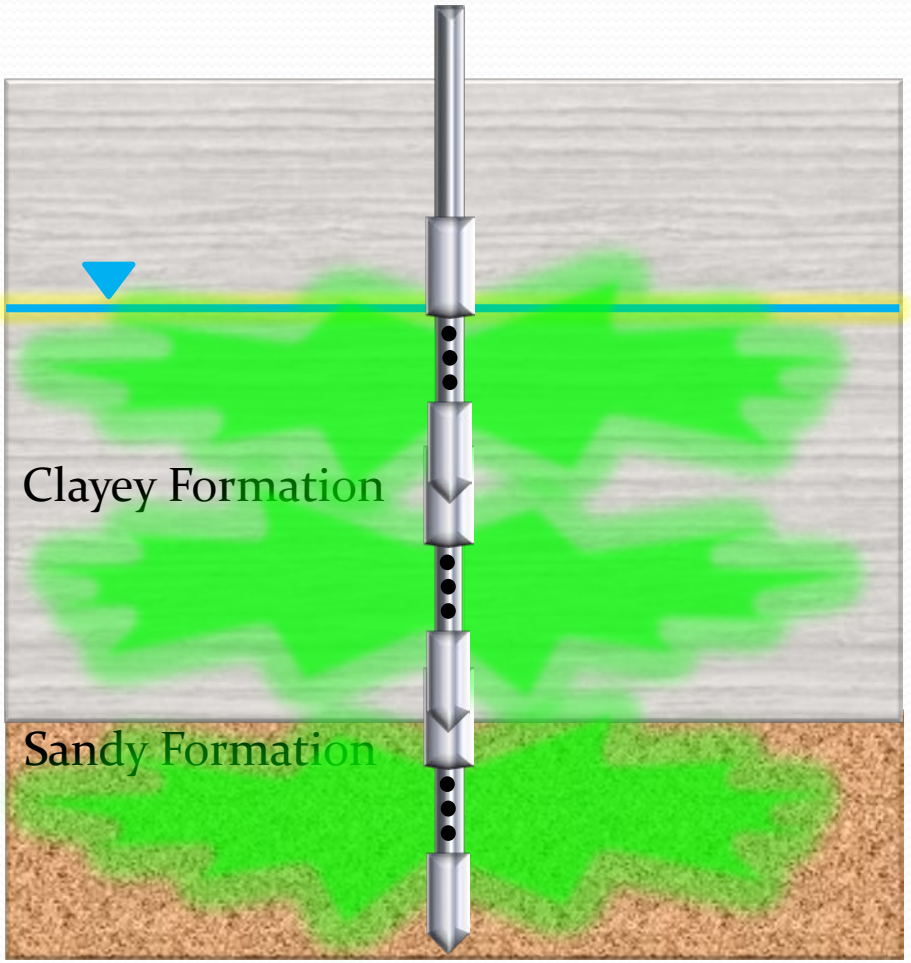
- Top-Down Injections Tools
- High Pressure, High Flow



- Straddle Packers
- Isolated Intervals

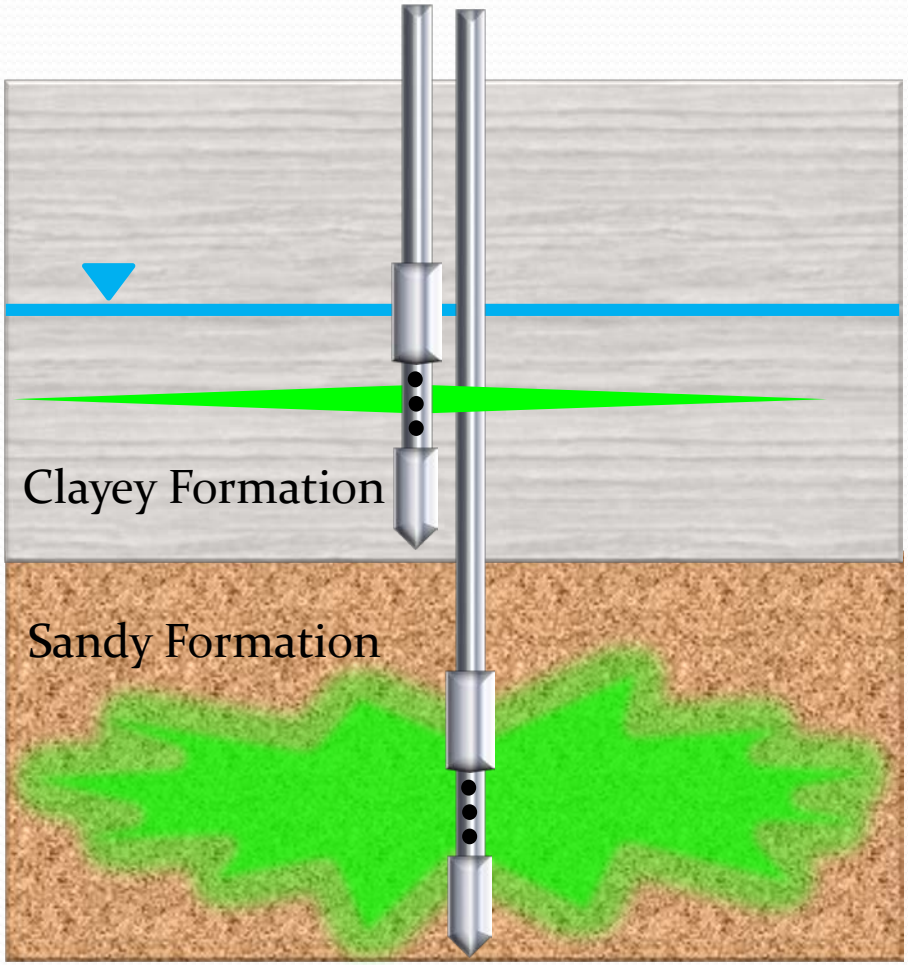
SOLUTIONS: Improved Injection Methods

- Top Down Injection or Discrete Placement Tooling
- Seals Off Intervals
- Precise Placement
- Slower Application
- *= BETTER CONTACT!*

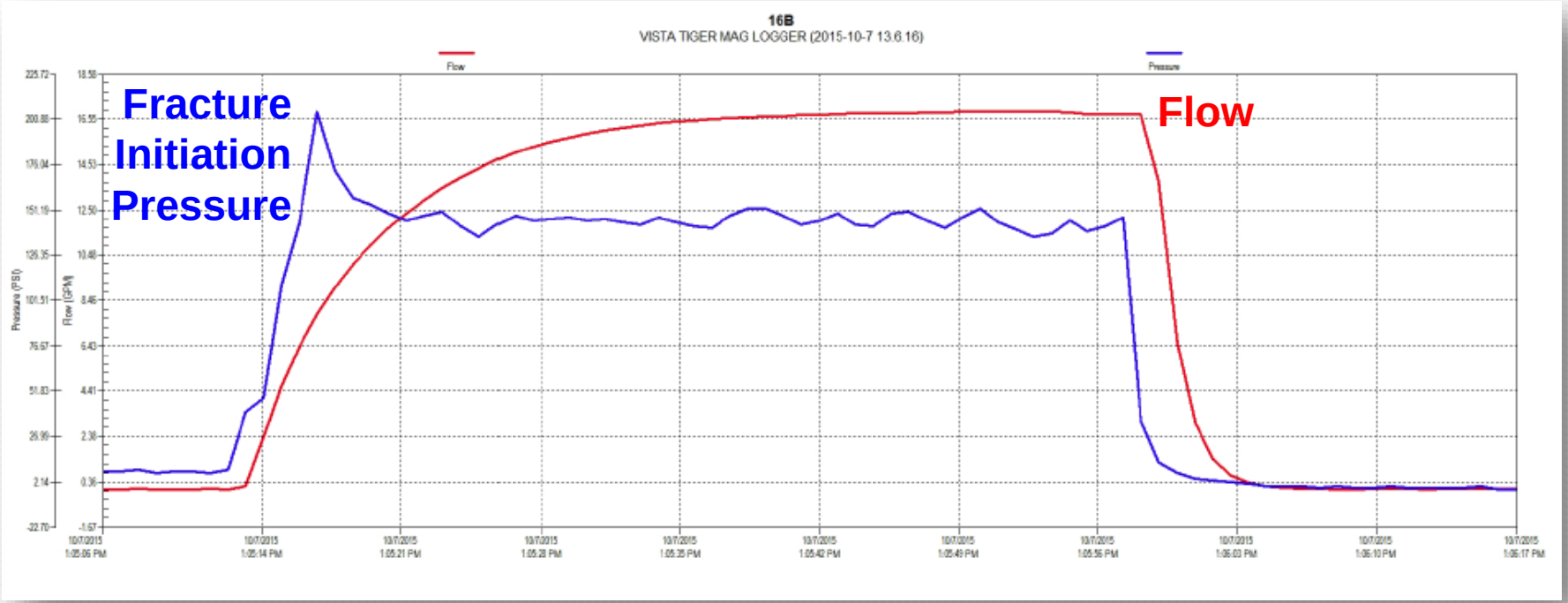


Exceeding Overburden Pressures (Low Perm Formations / Bedrock)

- **Permeable Formation take higher flows at lower pressures**
- **Tight Formations will require higher pressures to gain flows and will more likely create horizontal fractures with a larger ROI.**

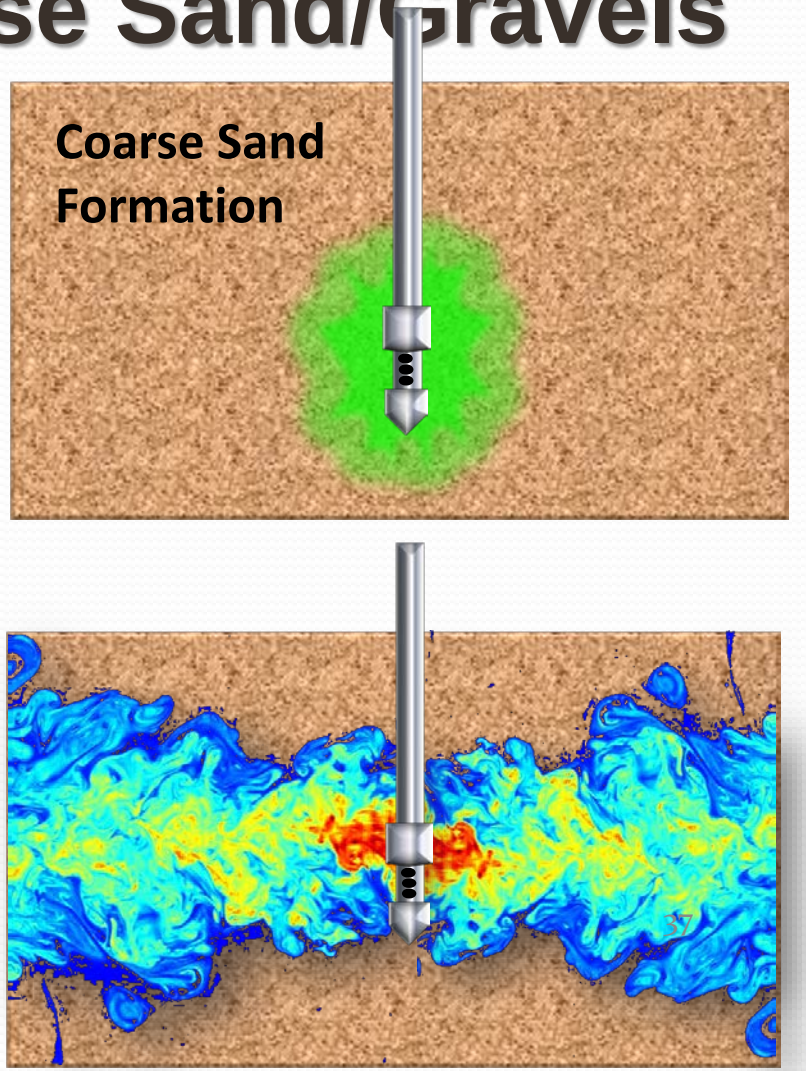


Pressure and Flow Graph from Vista Digital Injection Monitoring System



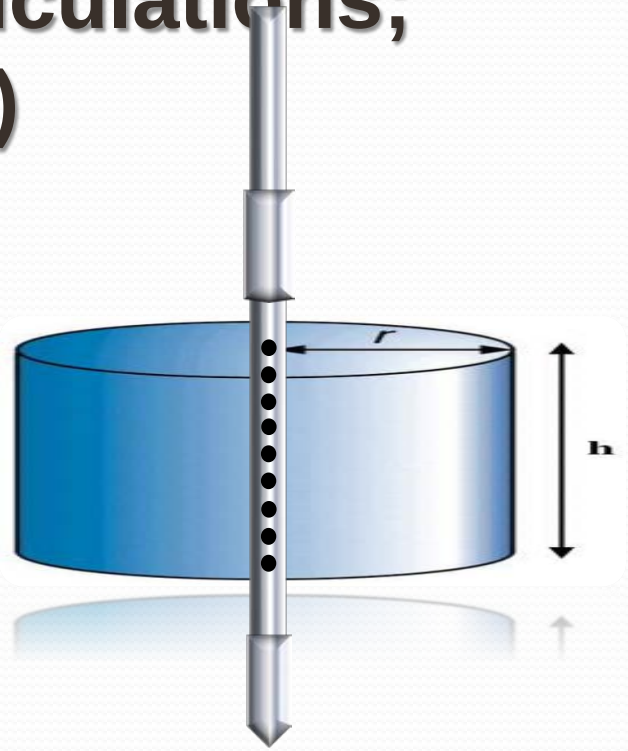
Injection of Slurries (Solids) into Unconsolidated Coarse Sand/Gravels

- Liquids follow granular pore space paths.
- Slurries may filter out or "block off" porosity at low flow, solids drop out.
- High Velocity Injections can create additional mixing and extend ROI



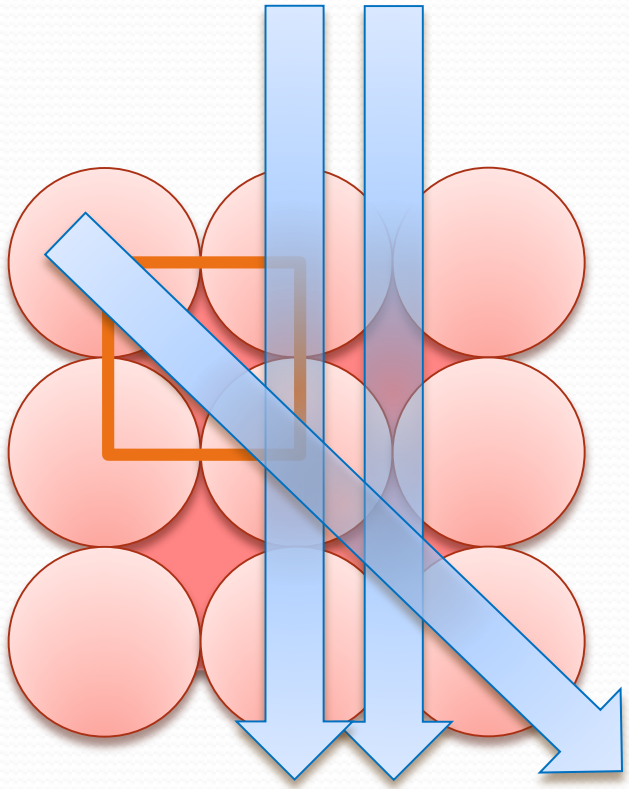
Radius of Influence (ROI) Calculations; (Displacement vs. Pore Flow)

- 10’ Injection Grid:
  - Radius = r = 5’
  - Area = πr^2
  - Vertical Treatment Interval = h = 2’
  - Assuming *Effective* Porosity ≈ 20%
  - Volume conversion: 1 ft^3 = 7.48 gallons
- Therefore:
  - Volume = $\pi(5')^2$ x (2’) x (0.2) = 31.42 ft^3
  - Pore volume = 31.42 x 7.48 = 235 gallons
  - A 50 gallons injection = about 21% of pore volume.
- **HOWEVER: ROI is more a function of what % of the formation fractures during injection (displacement) vs. fluids that move through pore spaces.**

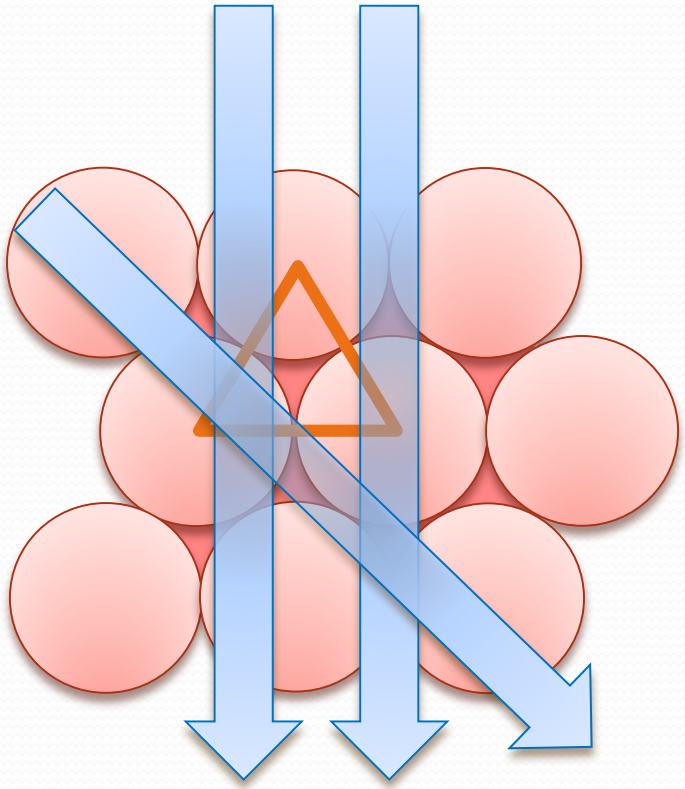


Triangular vs. Square Injection Grids (Surface View)

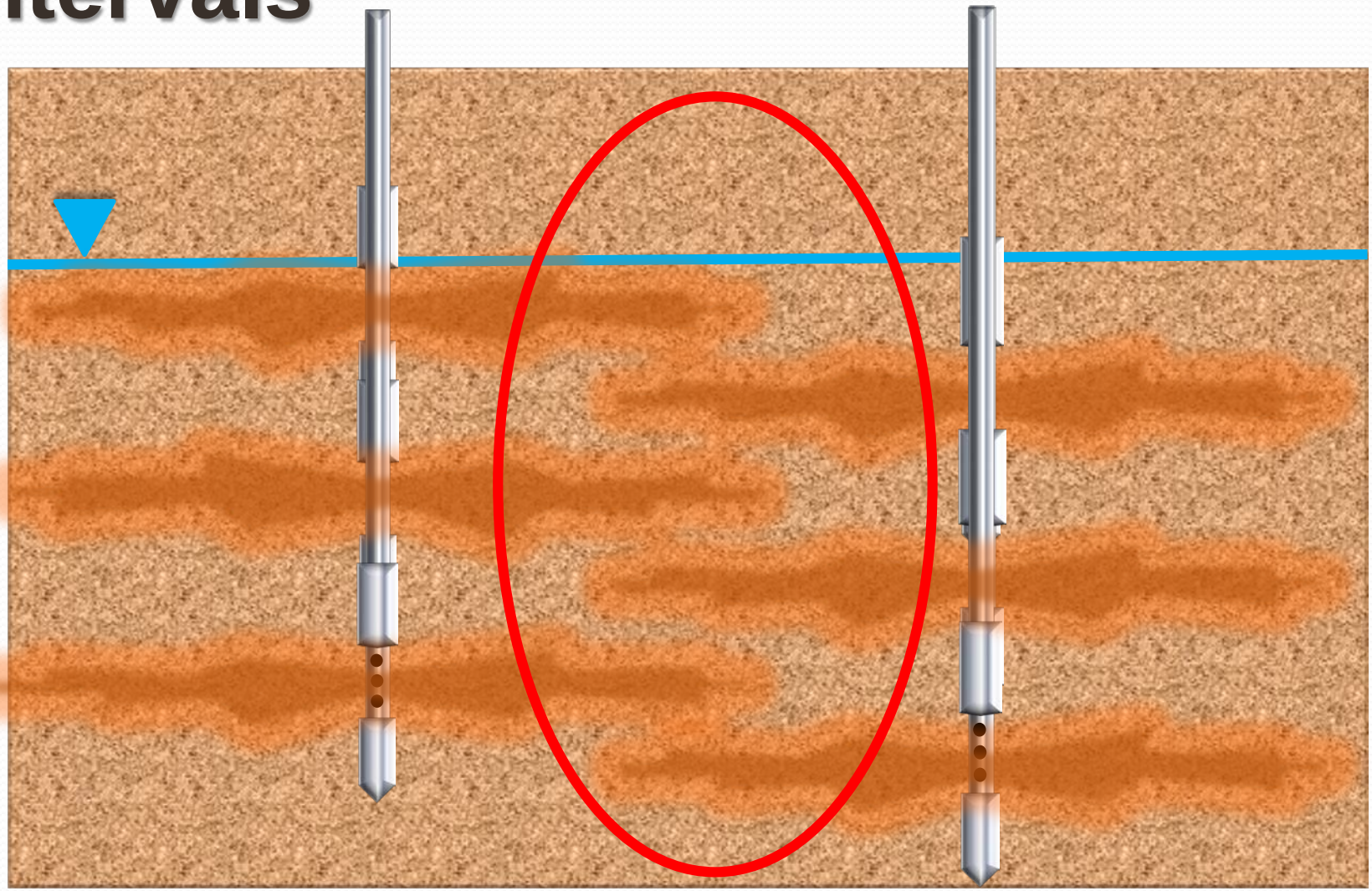
- **Square Grid**



- **Triangular Grid**

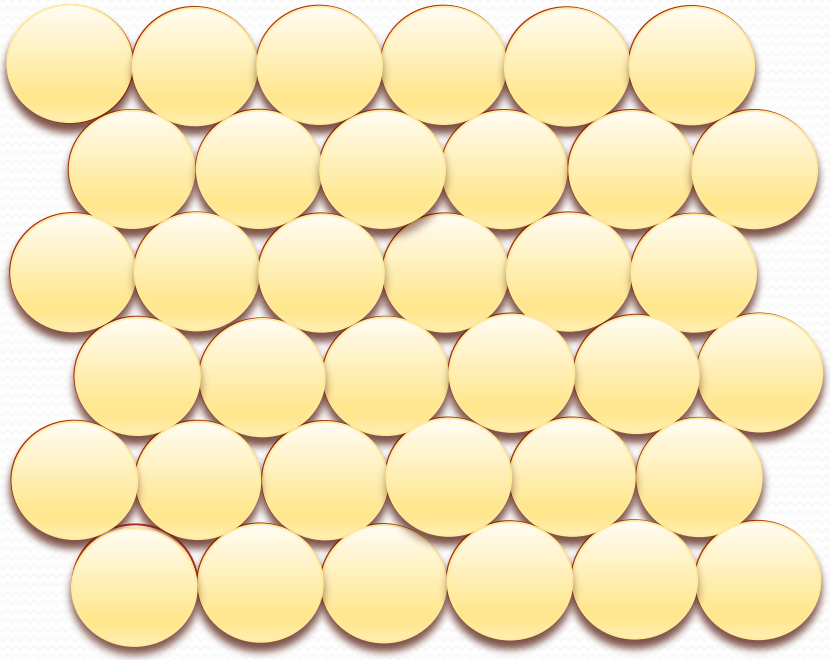


Staggered Top-Down Injection Intervals



Will We Move Contaminants?

- **Yes, but not far from empirical evidence.**
- **Remember: Most of the mass is generally sorbed.**
- **Start injections from outer edge of plumes.**
- **Bounces around injection grids, do not move from one point to the next, or one side to the other.**
- **Possible Exceptions? High volume dilute injectates such as diluted emulsified vegetable oils. NAPL**



Optimized Pumping & Mixing Systems

- ***Use the right system for the right job!***
- **High-Pressure/Low Volume?**
- **High-Volume/Low Pressure?**
- **Liquids vs. Slurries/Solids?**
- **Corrosive Chemicals**
- **In-Line Activator Mixing**
- **Many Pump Types (Progressive Cavity, Piston, Diaphragm, Centrifugal, to name a few)**
- **Experiment with flow rates and pressures to reduce surfacing of product.**
- **Lower flows may INCREASE surfacing.**





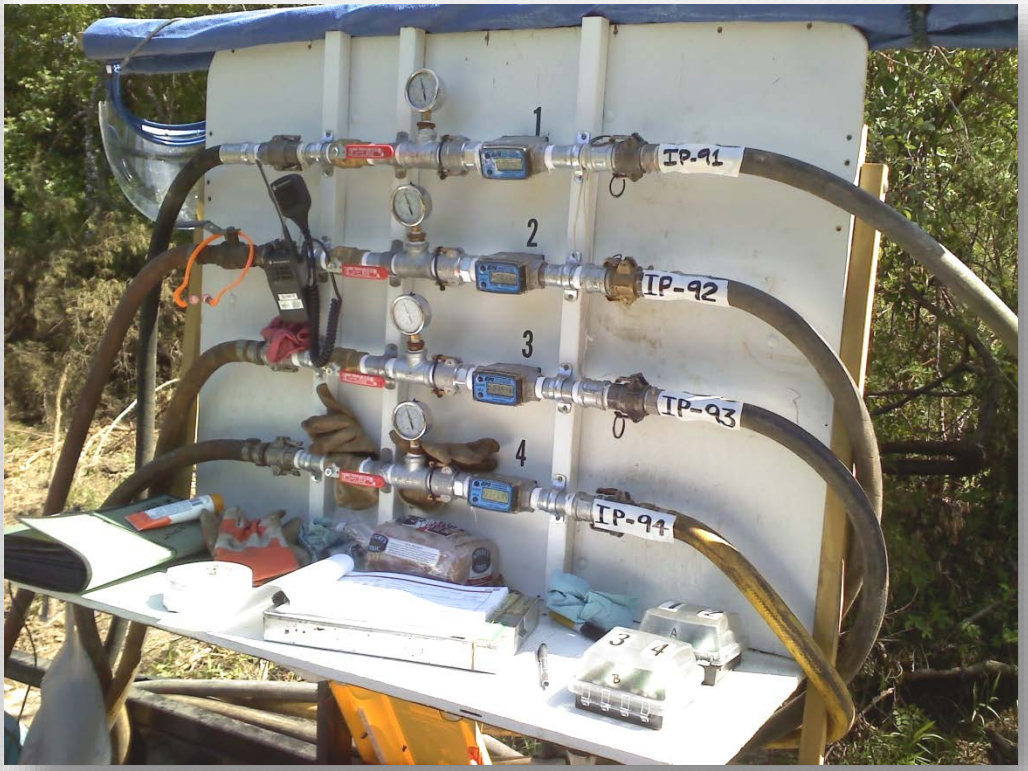
Slurry (Powders & Solids) Mixing & Pumping Systems

Safe Oxidant Mixing Systems

- Caustic/Acid Mixing
- In-Line Blending
- Spill Control Plans / Containment
- Neutralizers on Site

- Additional PPE
- Stainless or PVC Fittings
- Exothermic Reactions - Temperature Monitoring/Control

Simultaneous Injection Points for High Volume Applications



Hydraulic Fracturing Installations

- For Injection of Suspended Solids Treatments in Tighter Formations or Bedrock
- To Increase Permeability or Create Permeable Treatment Zones, Barriers or Cells.

Hydraulic Fracturing Remediation Applications

- Air Sparge (AS) or Soil Vapor Extraction (SVE)
  - Sand or Synthetic Proppant Support
- Bio-Remediation Treatment Flow Cells
  - Sand or High Surface Area Synthetic Proppants
  - Nutrient Additives, Organic Carbon,
  - Activated Carbon + Nutrients
- Chemical Treatment Flow Cells
  - Optional Proppant Fracture Support
  - Solid Chemical Slurry Injections

Vista GeoScience

Direct Push (DPT) or Auger/Rotary Hole + Packers for Hydraulic Fracture Installations

In-Situ Slurry Injection & Fracture Rigs

Proppants

- ***Inert or Reactive***
- **Mixtures of:**
  - **Silica Sand**
  - **Porous Ceramic (Isolite™)**
  - **Activated Carbon +?**
  - **Zero Valent Iron**
  - **Potassium Permanganate**
  - **Chitin (Polysaccharide)**
  - **Bacteria Augmentation**

When Proppants are Used, Cross-Linked Guar-Gum is Used to Suspend the Proppant

Courtesy Foremost Inc.

Performance Monitoring & Combined Methods

- **Another Section, Out of time, but…..**
- **Combined Methods or Phased Approach may be appropriate for some sites.**
- **Performance Monitoring *should* be part of the Game Plan. Can be done *on the fly* – Allowing for adjustments during the treatment phase on larger scale projects.**

Ex. #1: 3400 York Street; Denver, Former Gas Station

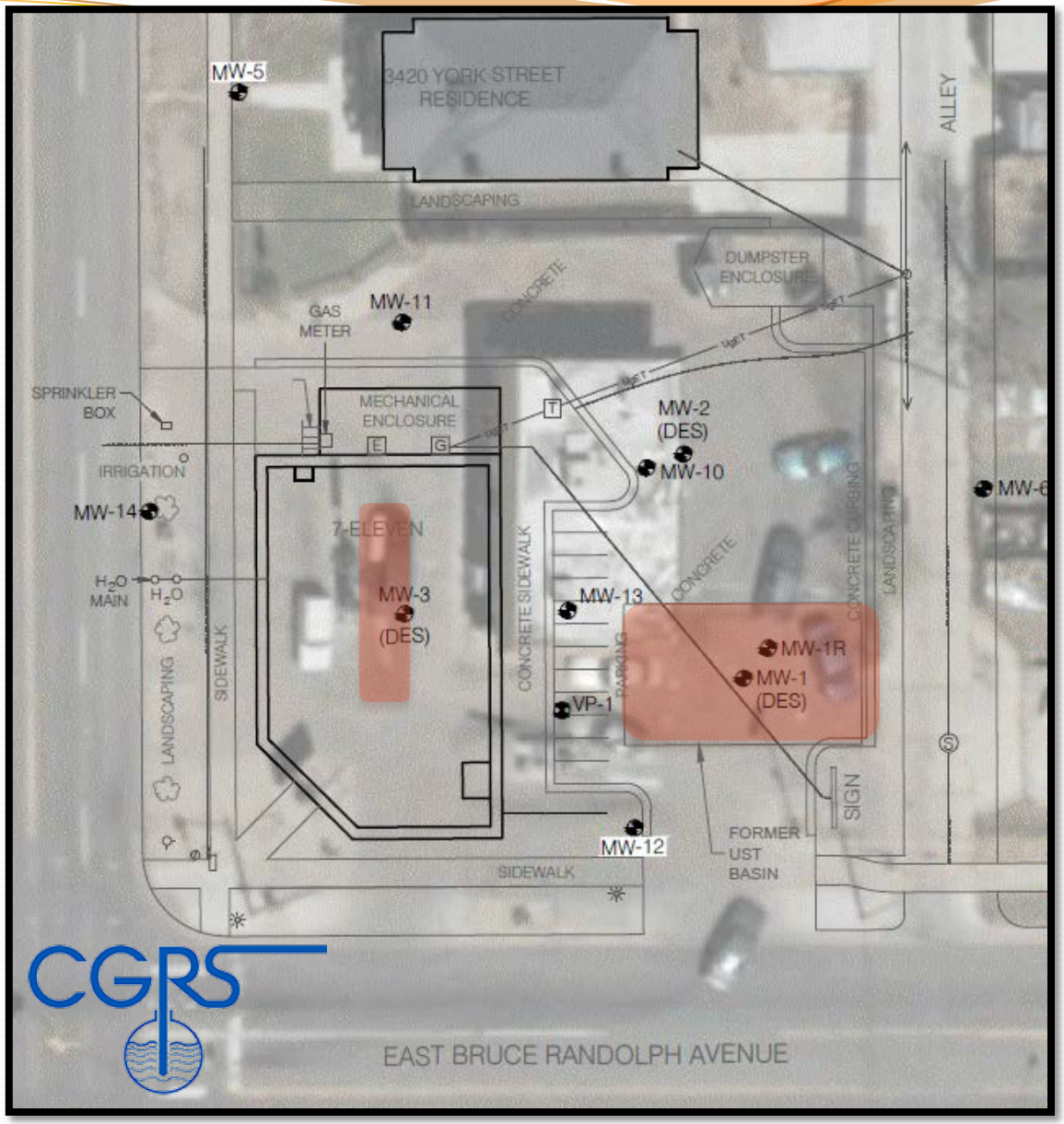
- CDLE-OPS Event No. 11494
- Release Discovered During Tank System Removal, August 2011
- 2nd Tank System Removed July 26, 2012; No Release Detected.
- Co-Mingled with PCE Plume from Upgradient Dry Cleaner Site
- New 7-Eleven Store Built Over Part of Plume Prior to Remediation
- Relatively Deep (Groundwater at ~45')
- Team Partners:

3400 York Street; Phases of Work

- **Site Developer: "NOT WAITING," New Building *Going In***
- **Chosen Remedy: Remediation Products BOS 200®** (Activated Carbon, Nutrients, Bacteria Augmentation)

1. **RDC Sampling & Treatment Design**
2. **Pilot Injection Test Conducted Near MW-1R, Former Tank Pit Area (May 2013)**
3. **Full Scale Site Injection on Balance of Site (Nov. 2013)**
4. **Post Injection Well Cleaning and Redevelopment**
5. **Post Injection Sampling & Monitoring**

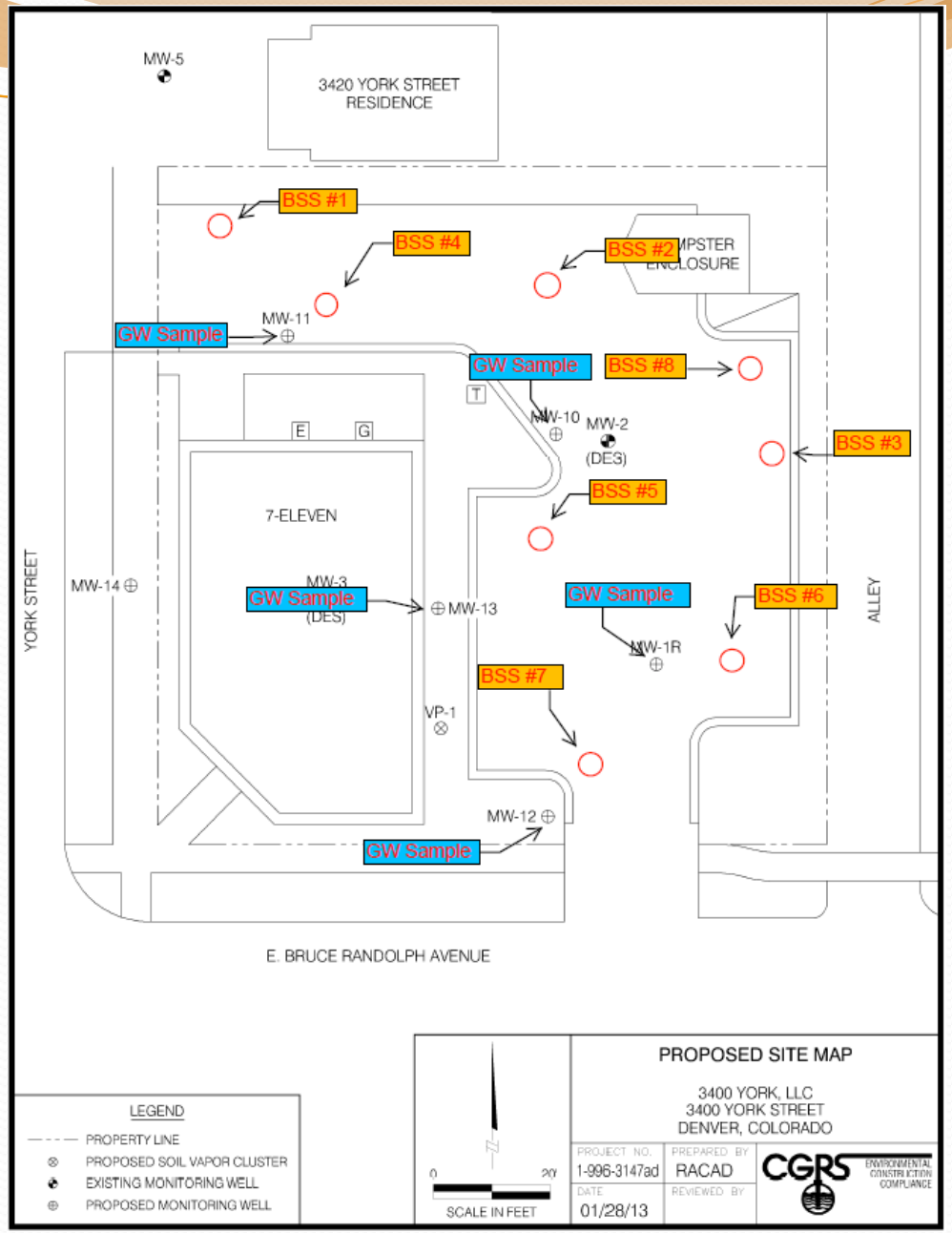
Overlay of New Building Plan on Former Gas Station Site



Courtesy CGRS Inc.

RDC Event

- **8 Continuous Soil Cores 5’ – 50’ in Treatment Area**
  - 56 soil samples collected at 2’ composite intervals.
- **5 Monitor Wells Sampled in Treatment Area.**
- **Analysis of 56 Soil & 5 Ground Water Samples:**
  - 8260 VOCs (BTEX, MTBE, TVPH, PCE & Daughters)
  - Sulfate, Chloride, Nitrate, Nitrite, Acetate (waters only)
- **Identified Shallow Vadose Contamination in Former Tank Pit Area.**



Courtesy CGRS Inc.

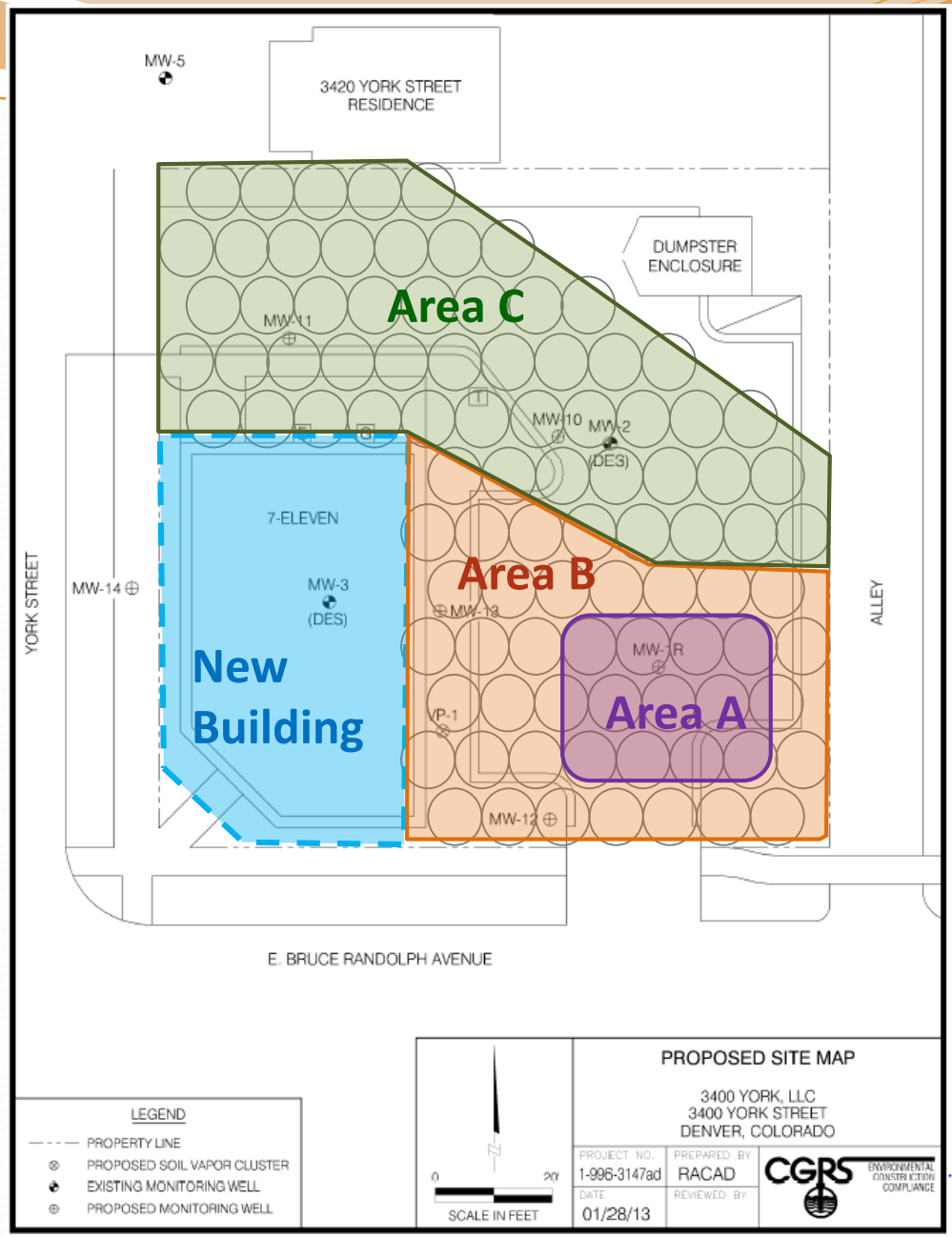
Injection Design

PILOT TEST: (May 2013)

- **Area A:** MW-1R, former tank pit/source area; 12 pts, 15lbs/ft. 40'-50'
- **Total** 1,800 lbs BOS200

FULL SCALE: (Nov 2013)

- **Area B1:** 15pts, 10 lbs/ft, 40'-50'
- **Area B2:** 16 pts, 7.5 lbs/ft, 40-50'
- **Area C**: 42 pts, 5 lbs/ft, 40-50'
- **Total** 4,650 lbs BOS200



Courtesy CGRS Inc.

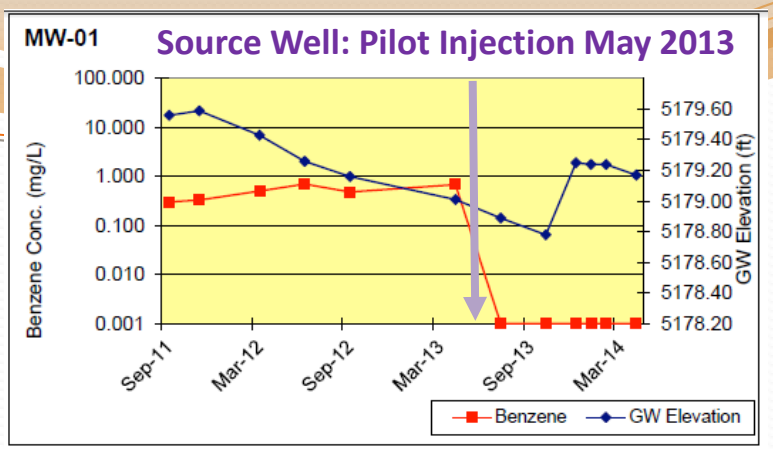
Results (Benzene ppb)

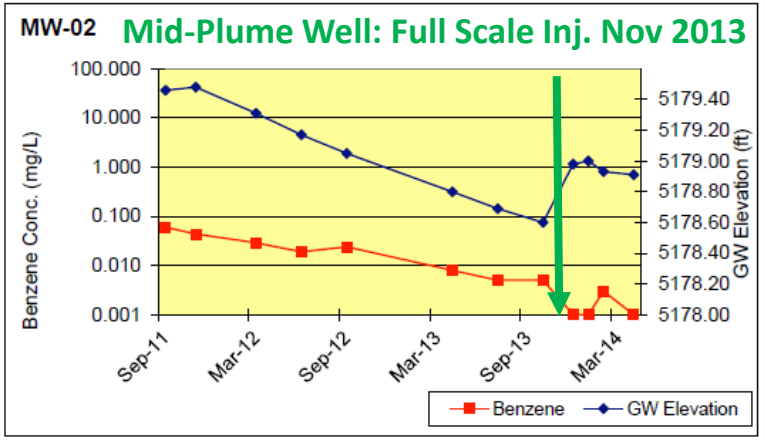
SOURCE

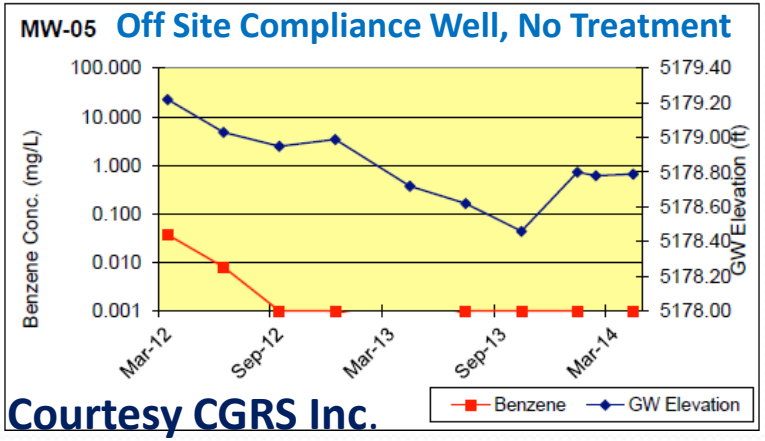
- **MW-1R:** 310-688 ➔ ND
  - (PCE: 3330 ➔ ND)

MIDPLUME

- **MW-10/2:** 8-60 ➔ ND-3
  - (PCE: 6270 ➔1830)
- **MW-11:** 2-3 ➔ ND
  - (PCE: 2710 ➔ 11)
- **MW-12:** 5-12 ➔ ND-3
  - (PCE: 13900 ➔12900)
- **MW-13**: 23-47 ➔ 3-6
  - (PCE: 595 ➔ 1080)
- *Anticipate **NFA** in 2015 after post injection monitoring requirements*







Cost to Our Client (Labor & Materials)

• RDC Sampling	• $5,000
• Pilot Test	• $16,000
• Full Scale	• $57,000
• **TOTAL:**	• **$78,000**

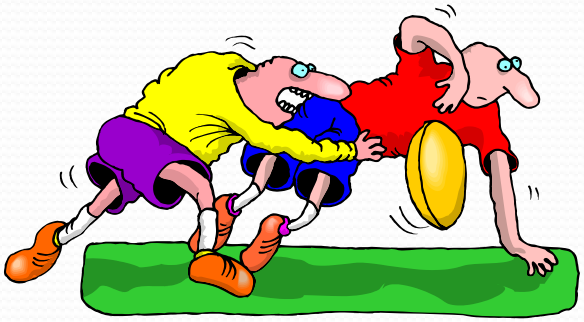
= Cost Effective Cleanup – The First Time!!

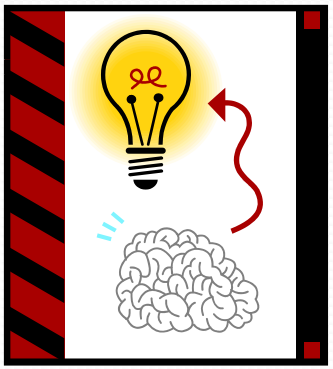
Summary

- **In-Situ Treatment Success Rates are Significantly Improved by Performing a RDC phase to create a 3-D CSM by utilizing:**
  - **3-D Imaging and High Resolution Sampling Tools (Qualitative & Quantitative)**
  - **Advanced Targeting Injection Tools and Methods**
- **Applying Treatments Using Decision Units -Targeted Dosing**
- **Understanding ROI and Hydraulic Fracturing in Tighter Formations**
- **Utilizing Pilot Testing, Performance Monitoring Tools and Methods to Monitor Progress and Make Adjustments**
- **= The Goal of Clean Up – The First Time!**

More Summary

- ***It's a Contact Sport, AND A TEAM SPORT !***





- ***Geology, Hydrology, Chemistry, Biology***
- ***Consultant + Driller + Installer + Supplier***

Questions?

High Resolution Remedial Design Characterization and In-Situ Remediation Technologies Combined to Clean-Up Sites the First Time – *It's a Contact Sport!*

John Fontana, PG

JFontana@VistaGeoScience.com

Contact Information

- **John Fontana -** PG, President/CEO
  - JFontana@VistaGeoScience.com
- **Janet Castle** – VP Business Development
  - JCastle@VistaGeoScience.com
- **Mike Martin –** Field Operations Manager
  - MMartin@VistaGeoScience.com
- **TJ Haley -** Gulf Coast Regional Manager
  - TJHaley@VistaGeoScience.com
- Rocky Mountain Regional Office (303) 277-1694
- Gulf Coast Regional Office (281) 310-5560