BEGINNING WITH THE END IN MIND:

Financially Responsible Approach To Site Characterization To Improve Remedial Outcomes

Aestus

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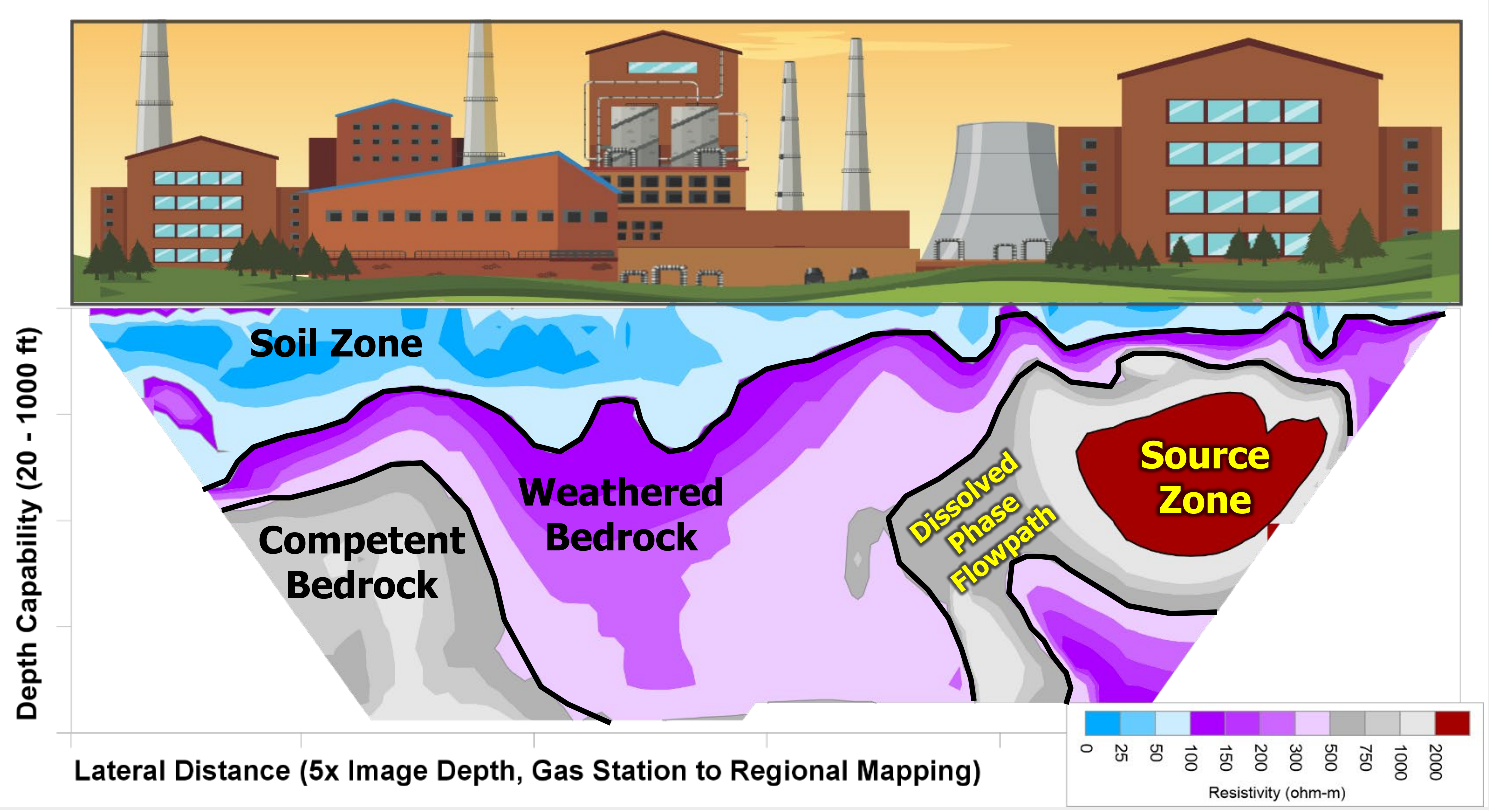
Today's Topics

1. Is Your MW Helping or Hurting Your CSM?
2. Drilling vs Scanning
3. Electrical Hydrogeology™ Principles & Applications
4. The GeoTrax Survey™ Difference
5. Closing Remarks
6. Q&A



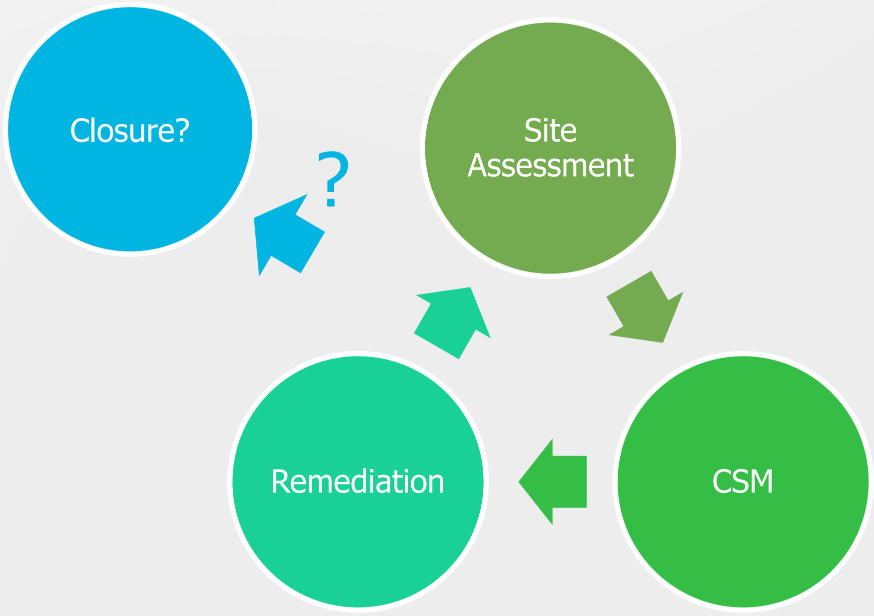
Ultra-HRSC – Continuous vertical images of subsurface

What is the Environmental Industry's Goal?

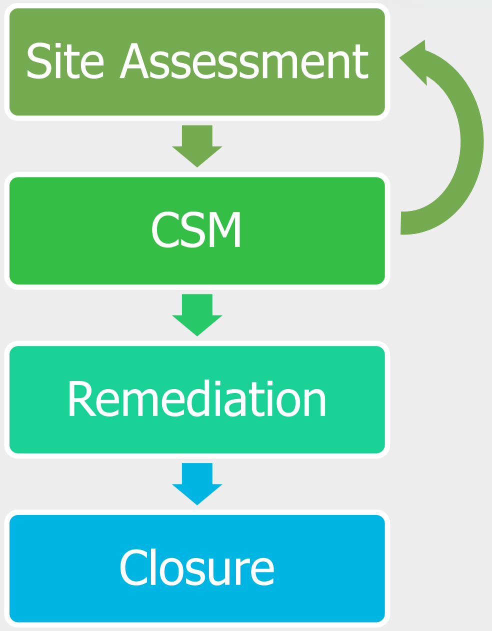
EPA's mission: protect human health and the environment

Our mission: clean up sites <u>effectively</u> & <u>efficiently</u>

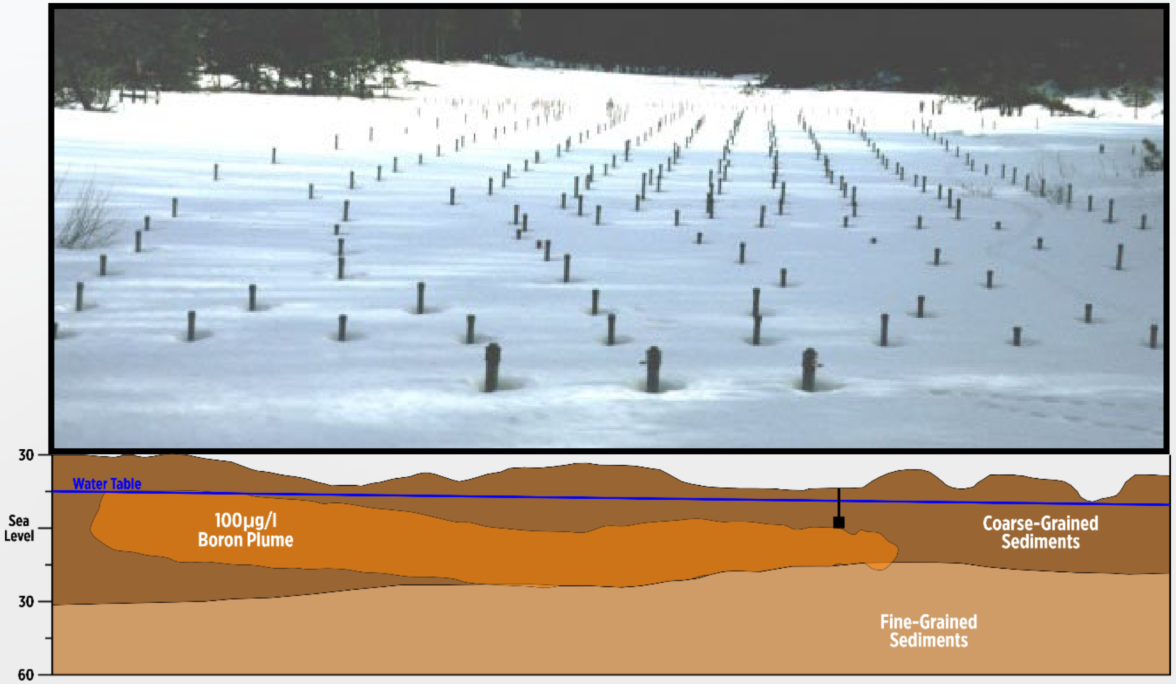
How it often goes…



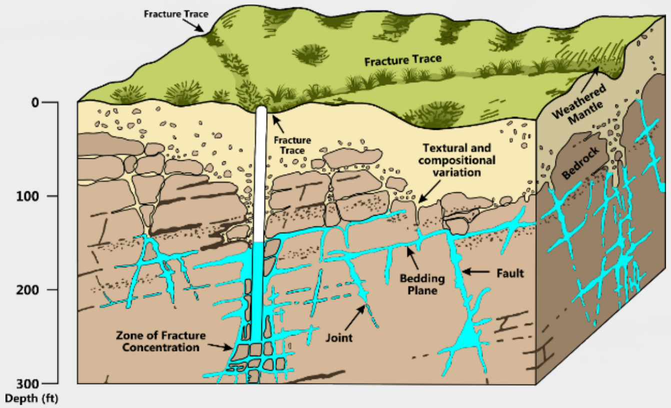
How we want it to go…

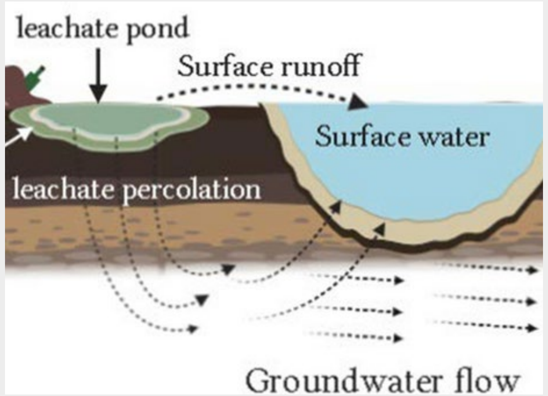


Can Wells Tell Us Enough?



Images after Cape Cod (LeBlanc et al. 1991); Borden (Sudicky et al. 1983)

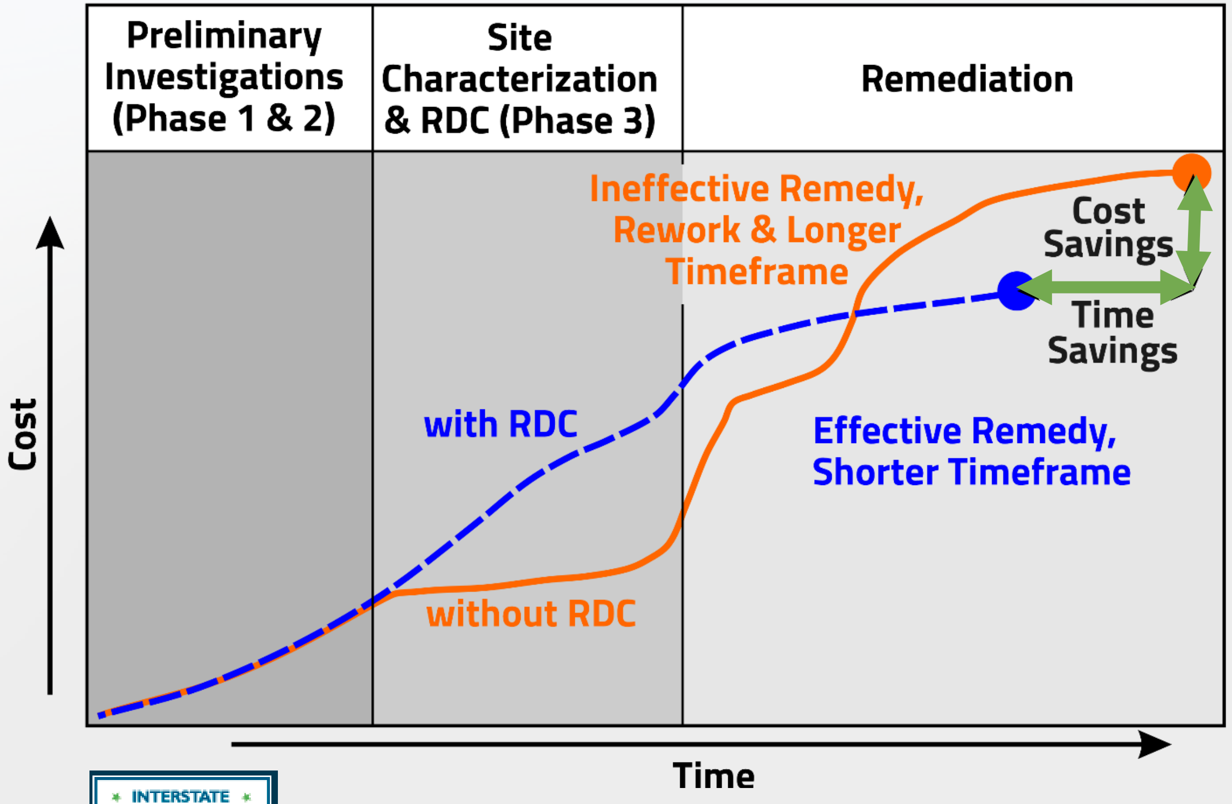




~Need 10,000 wells to "see" this!

How many wells to "see" this?!

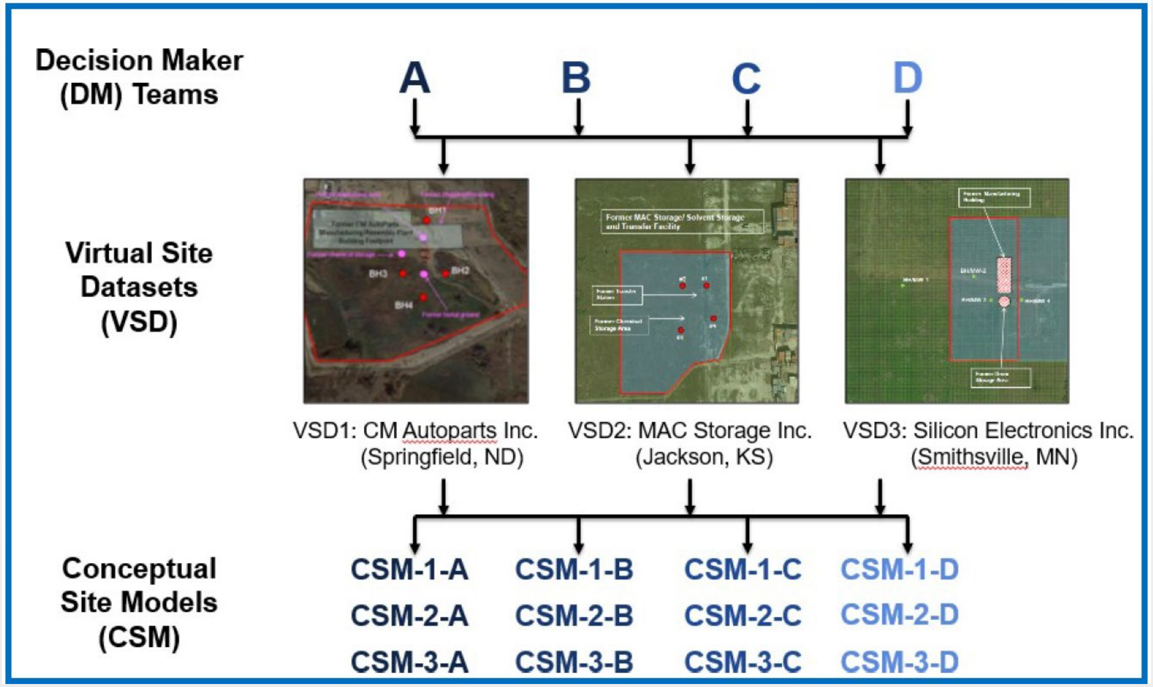
ITRC Research Says…



After Interstate Technology & Regulatory Council. 2020.

Investing in remedial design characterization (RDC) will save significant ***<u>time and money</u>*** on an overall project basis

DoD Research Says...



Study completed by the Department of Defense (DoD) Strategic Environmental Research and Development Program (SERDP).

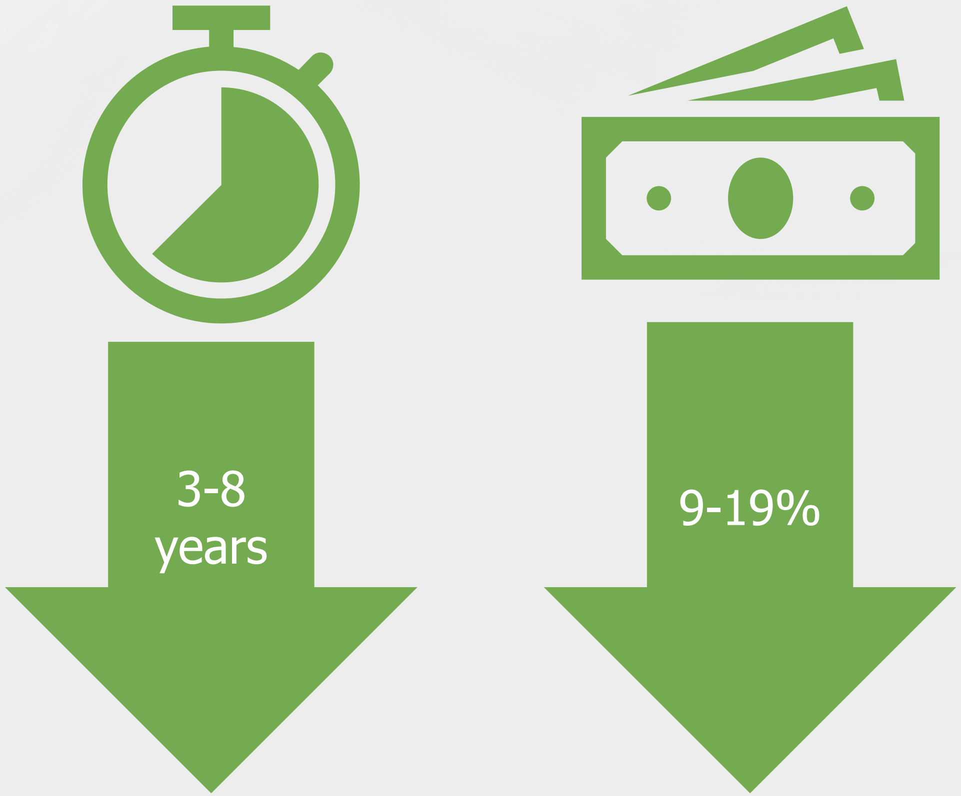
- When only utilizing vertical tools (e.g., monitoring wells and/or MIP/HPT) to investigate a DNAPL site:
  - 0% achieved success at reasonable cost
  - 75% didn't achieve success
  - 0% had high accuracy for all CSM metrics
- The most common pitfalls of accurate CSM development are:
  - Underestimating subsurface heterogeneity
  - Insufficient density of subsurface data
  - Poor interpretation of the data

SERDP, 2022

EPA Research Says….

Deploying HRSC on UST release sites could result in as much as **50% cost savings** and **10 years reduction** in overall project timeline

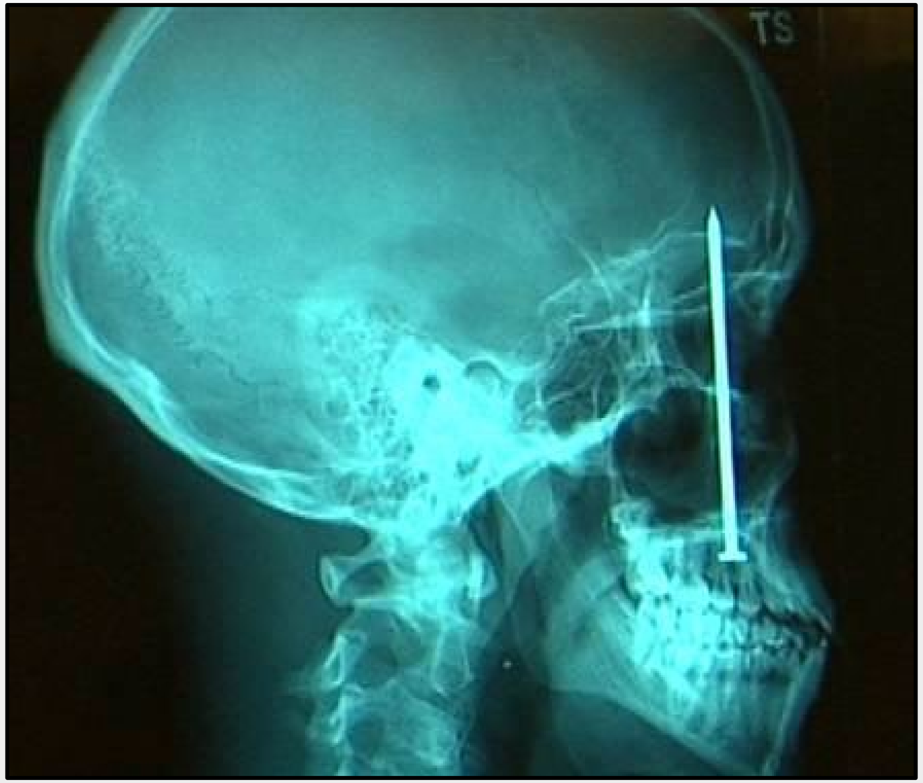
Estimated average savings on overall project



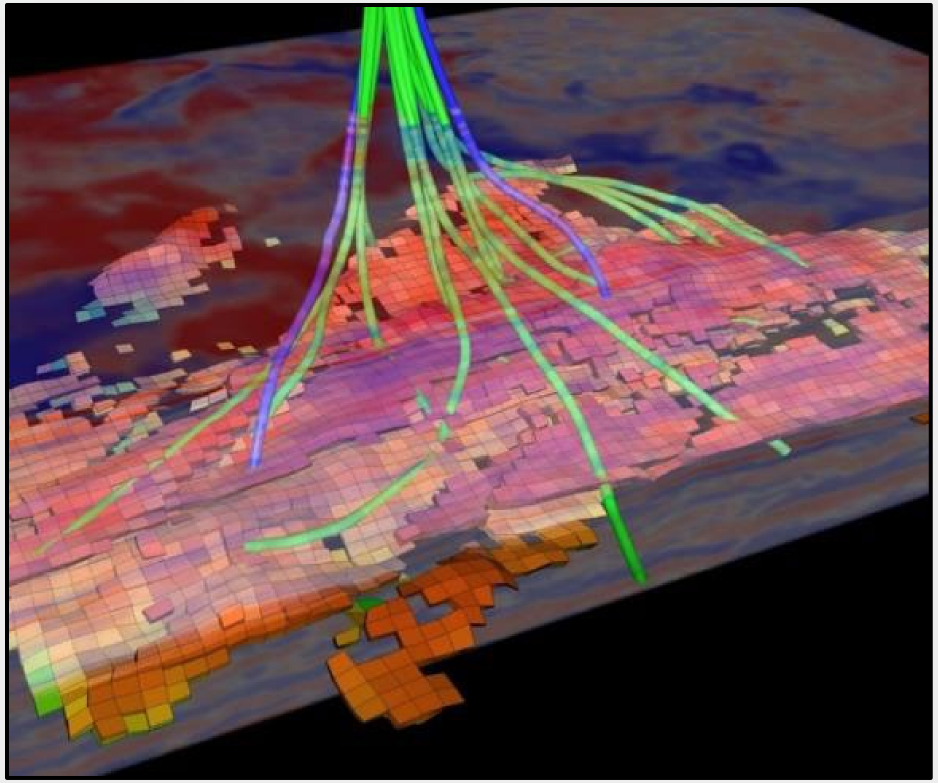
For three common types of petroleum UST release scenarios (a "typical" release, catastrophic release, stalled in corrective action), the expert panel concluded HRSC could save these amounts, on average, of the total project costs. – EPA, 2023, "High Resolution Site Characterization at Petroleum Underground Storage Release Sites – Applicability, Benefits, and Costs," https://www.epa.gov/system/files/documents/2023-04/High%20Resolution%20Site%20Characterization%20Study%20Report.pdf

Scan then Target Approach: Aligning with Other Industries

Other industries requiring data "below the surface" evolve to scan first then go invasive



X-ray of Skull
nydailynews.com

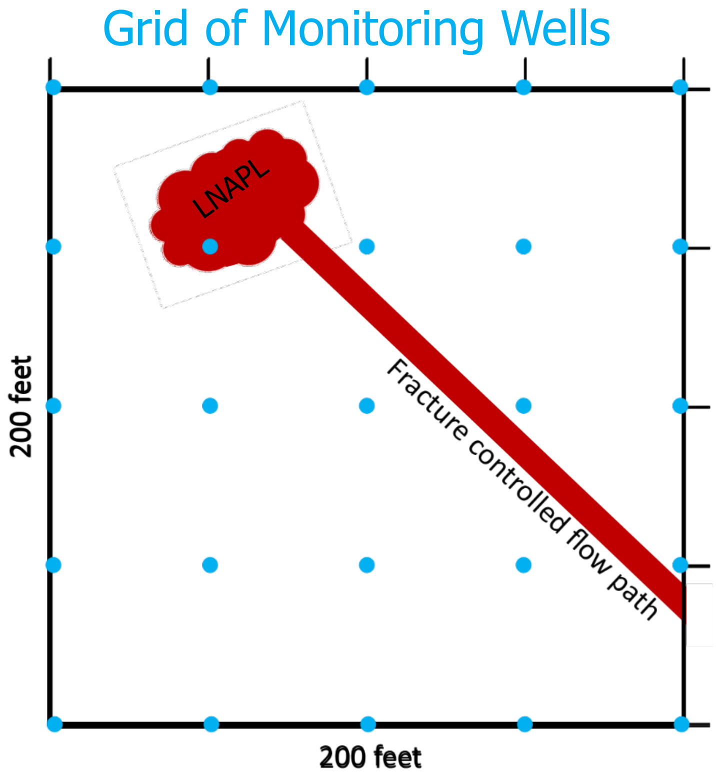


3-D Seismic North Sea
dgi.com

Scanning in the Environmental Industry

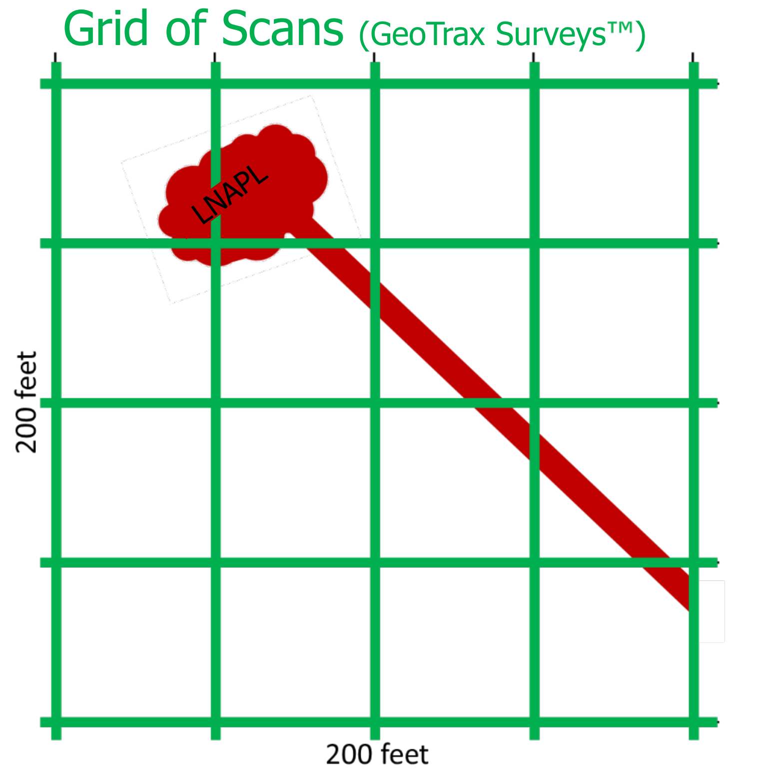
Video found at https://www.youtube.com/watch?v=FqGjHWf08Io

Scanning Increases Characterization Certainty



	MWs	Scans
Number of Wells/Surveys	25	10
Impacted Zones Detected	1	8
Impact Extents Understood?	No	Yes
3D Model Included?	No	Yes
Targeted Areas for Additional Investigation?	No	Yes

Sampling interval of 50 ft for both MWs & ERI Scans
Values calculated assuming 30 ft drilling depth, 2" PVC

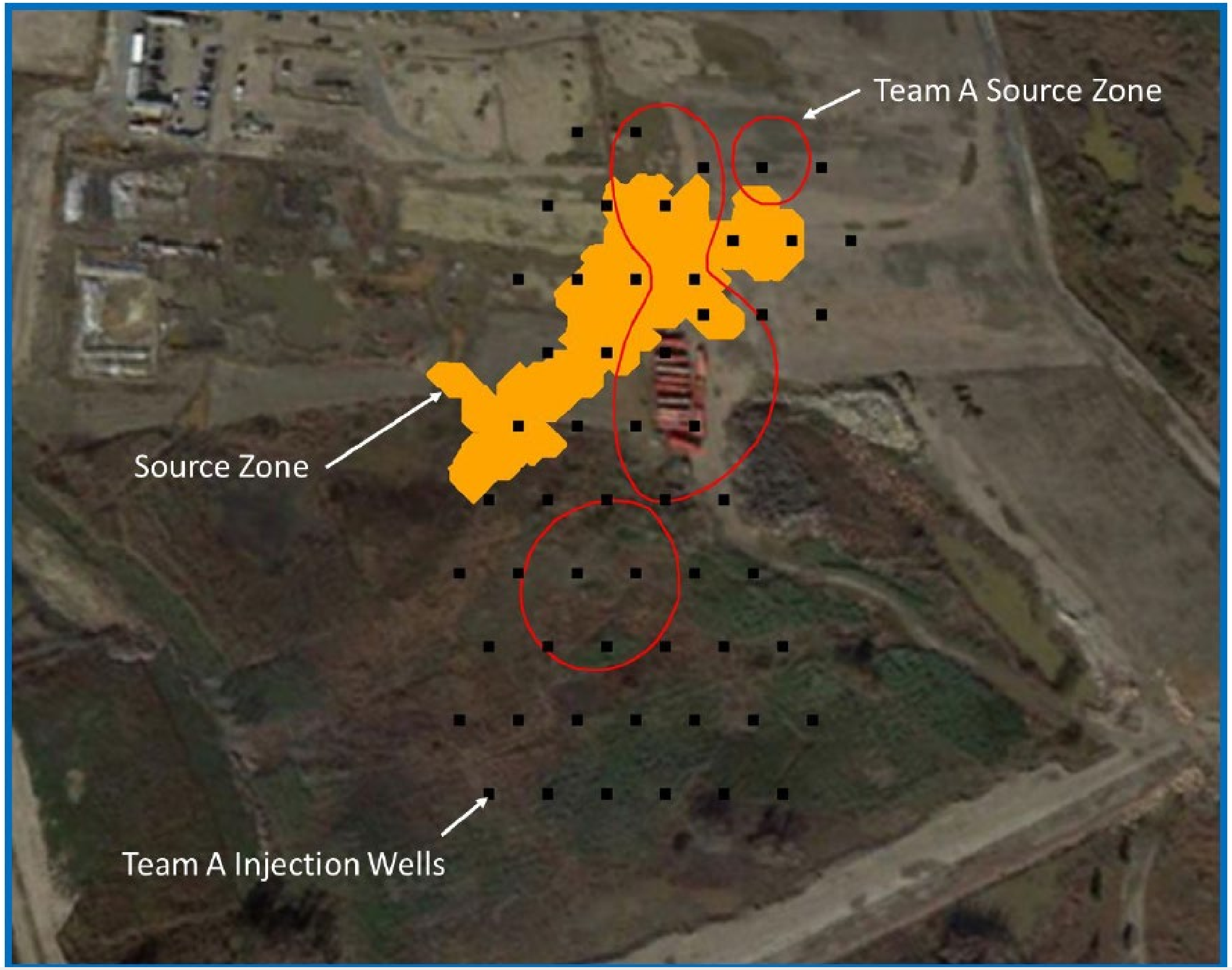


Most sites aren't this simple!

Scanning first provides clear next steps

Why Does Characterization Certainty Matter?

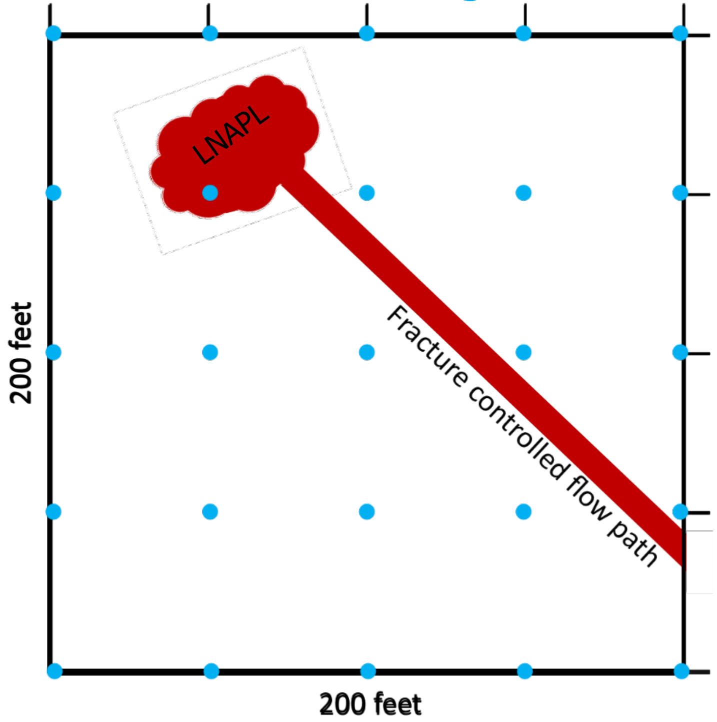
- Poor estimates of DNAPL mass and source zone footprint were directly linked to failure to meet project objectives following remediation
- In 40% of cases, even a factor of safety >30 could not overcome CSM limitations



SERDP, 2022

Scanning is More Cost Efficient

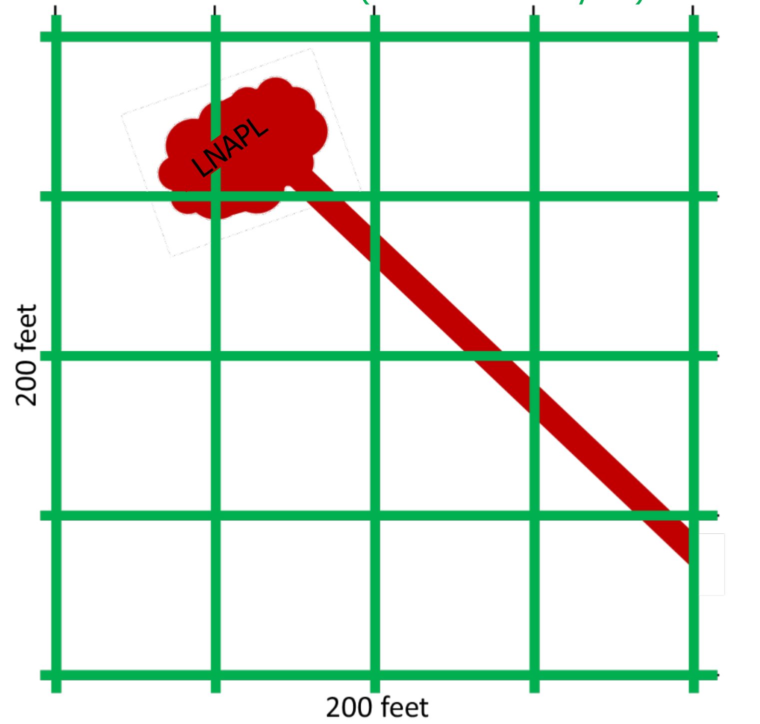
Grid of Monitoring Wells



	MWs	Scans
Number of Wells/Surveys	25	10
Impacted Zones Detected	1	8
Impact Extents Understood?	No	Yes
3D Model Included?	No	Yes
Targeted Areas for Additional Investigation?	No	Yes
Total Approx. Cost	$114k	$200k
Approx. Cost / ft²	**$230**	**$20**

Sampling interval of 50 ft for both MWs & ERI Scans
Values calculated assuming 30 ft drilling depth, 2" PVC

Grid of Scans (GeoTrax Surveys™)



Scanning first is more cost effective and provides clear next steps

How Much Does a MW Actually Cost?

Assumptions:

- 2 inch well diameter
- 5 feet well screen
- Construction includes installation, rehabilitation, and removal[1]
- Sampling includes reporting costs[2]

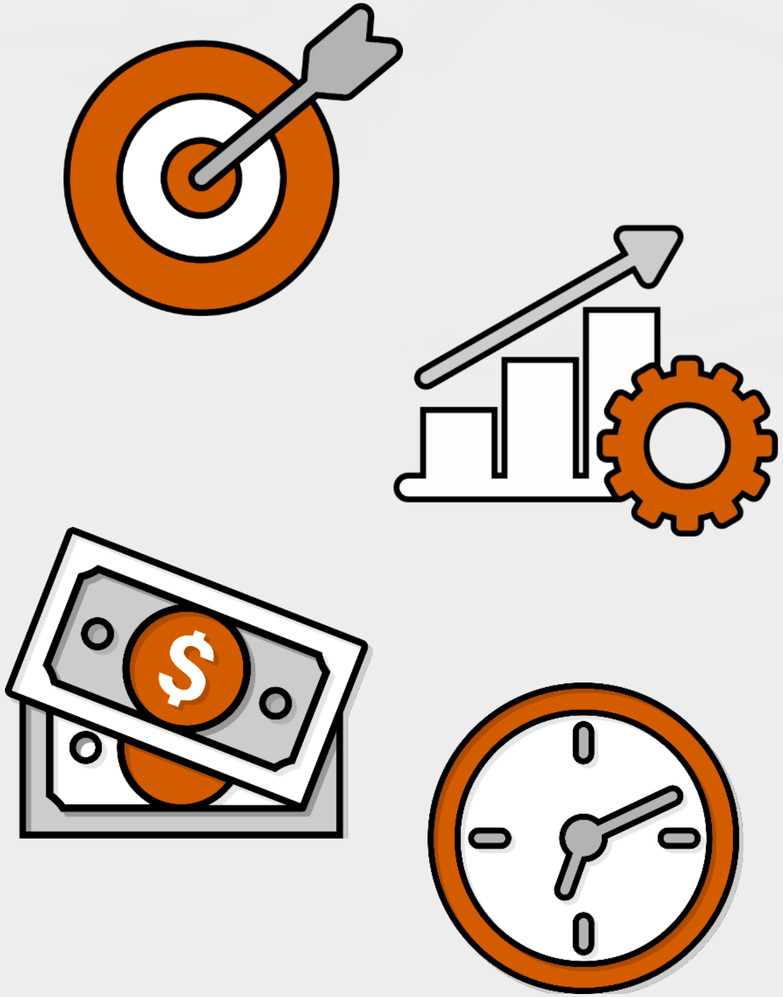
Total Costs*			
	Well Total Depth		
Sampling Duration	20 ft	50 ft	75 ft
5 years	**$53,100**	$66,400	$84,400
10 years	$89,100	$102,400	$120,400
20 years	$163,100	$176,400	**$194,000**

*Without inflation

[1]ESTCP, 2008
[2]CA Water Board, 2023; one annual monitoring report and a conditions report every 5 years

Benefits of a Scan-First Approach

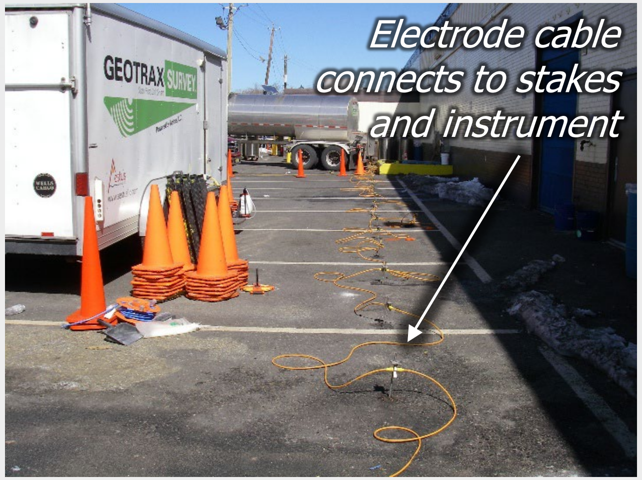
- Increased CSM accuracy/certainty
- Probability of investigation/remedial success is higher
- Cost and time efficient:
  - Short term – get equivalent data coverage at < 1/10th the cost of a well
  - Long term – scan an entire site for the lifetime costs of 1 well; targeted remediation could reduce remediation costs by 20%+

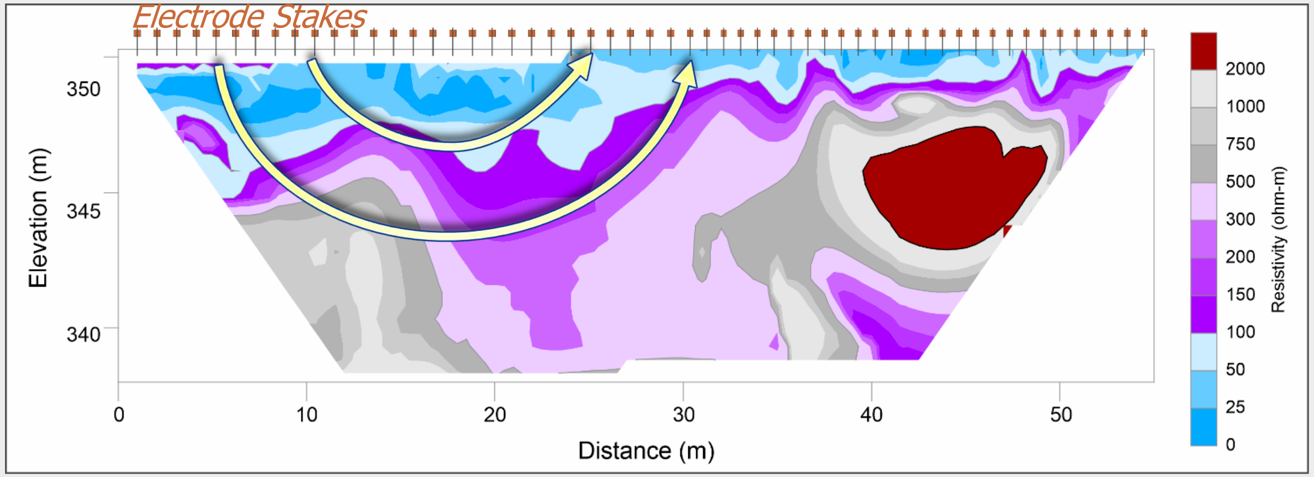


Field Deployment - Static Imaging

(single site characterization event, temporary installation)

- Must be in a straight line
- Line length=5x imaging depth
- In place for ~3 to 5 hours



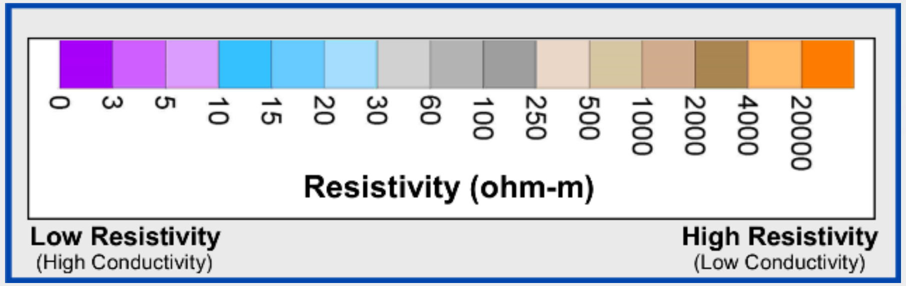


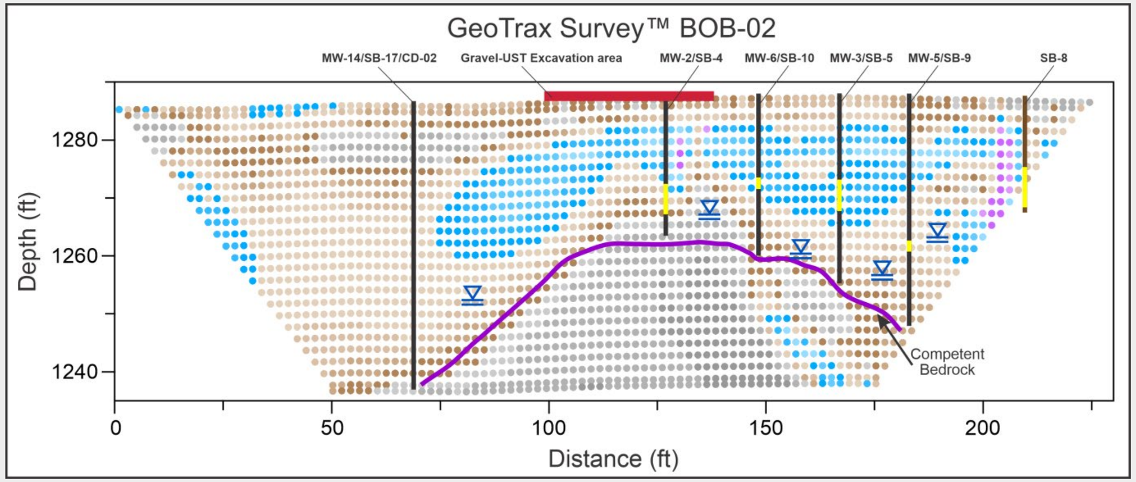
Electrical current flows between electrode pairs
Results in a vertical 2D continuous electrical image of the subsurface

What Do Electrical Images See?

Each data point (pixel) equals the sum of:

1. Biological activity
2. Contamination/ Injectates/etc.
3. Groundwater/Fluids
4. Soil and rocks





Electrical Hydrogeology:
Leveraging Integrated Data Sets

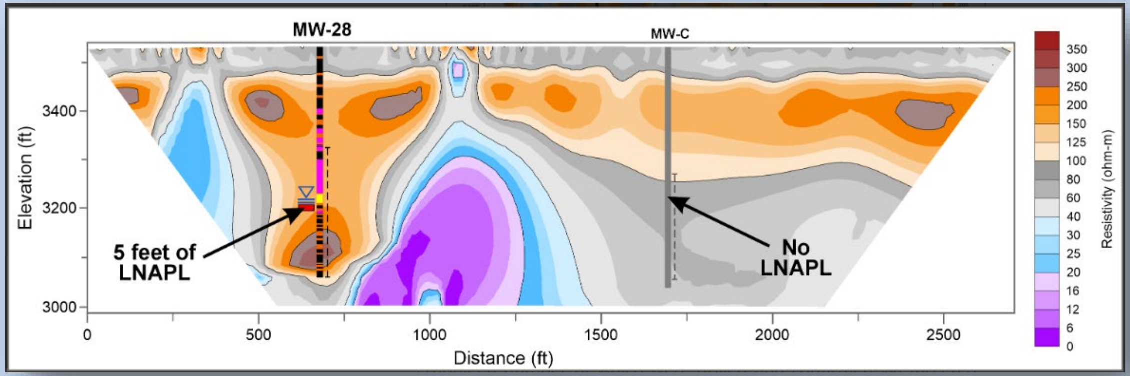
Traditional Hydrogeology

- Potentiometric surface maps
- Lithology logs
- Stiff Diagrams
- Pipe Diagrams
- GW Chemistry
- GW Flow Models
- Geology Maps
- Aquifer Maps
- HPT/MIP Results
- Etc.

Electrical Hydrogeology =

\+

Electrical Imagery/Targeted Drilling



Applications:

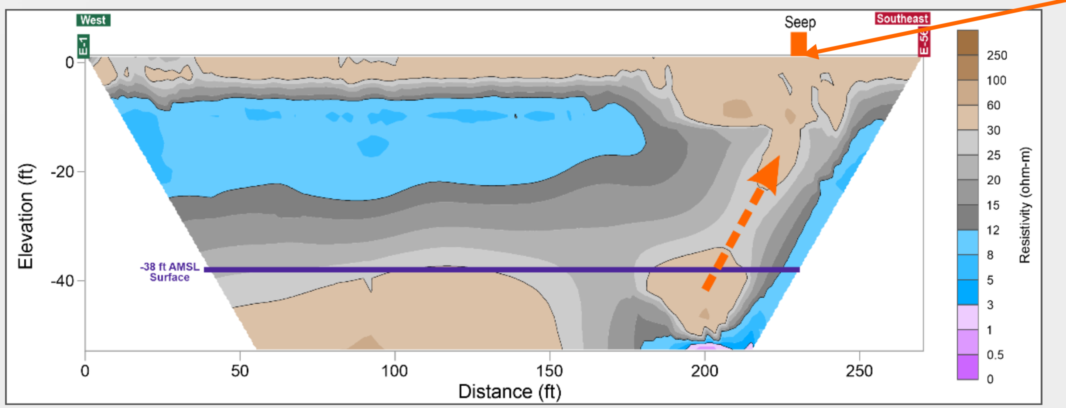
1. ***Site Characterization (Static Imaging)***
2. ***Site Monitoring (Temporal Imaging)***

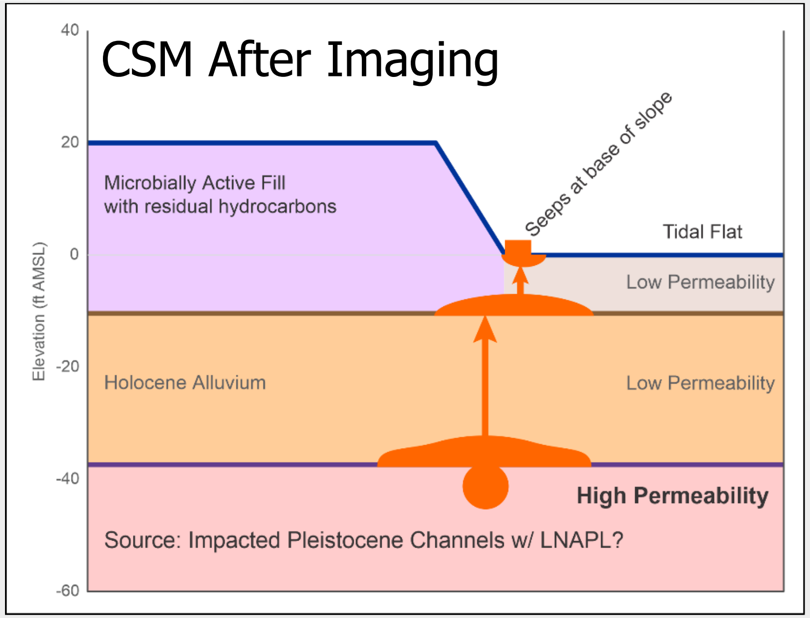
Proven Process
Remedial Design Characterization Process

1	2	3	4	5
Visualize Existing Site Data in 3D	**Ultra-High Resolution Electrical Scan**	**Interim Report (w/Hypotheses)**	**Confirmation Drilling (by Client)**	**Final CSM+ Report**
- Client sends existing site data to Aestus - Must occur prior to field work (Step 2)	- Field Acquisition: *GeoTrax Survey™* 2D Imagery - Use dynamic work strategy with QA/QC	- Integrate/QC data sets in 2D&3D (*GeoTrax Viz™*) - Select confirmation drilling (biopsy) locations with client	- Targeted drilling & sampling; test CSM hypotheses - Client sends final confirmation drilling data to Aestus	- Integrate confirmation data (*GeoTrax Viz™*) - Finalize GeoTrax CSM+™

LNAPL Seeps in Sediments
CSM Redefined

- Seeps occurring outside of retaining wall
- Seep source was uncertain



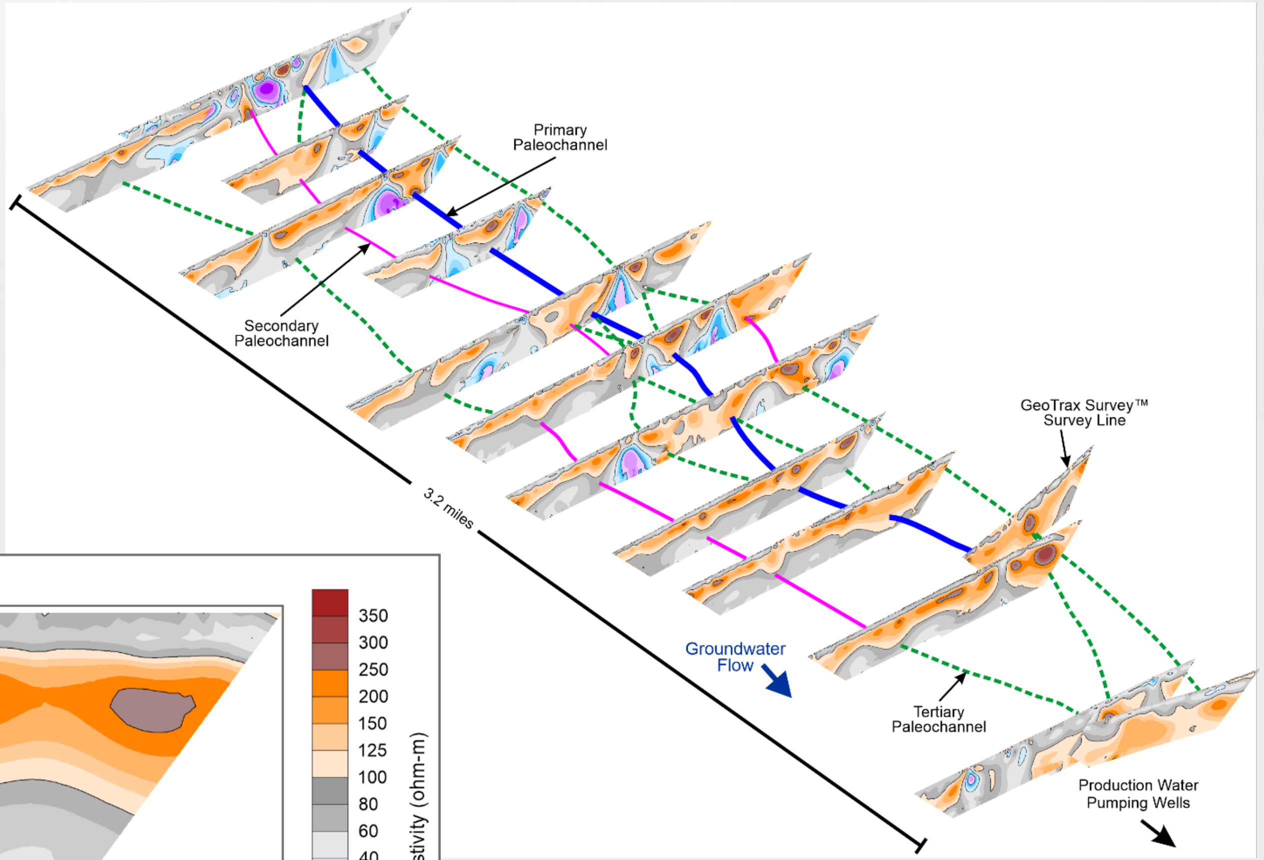


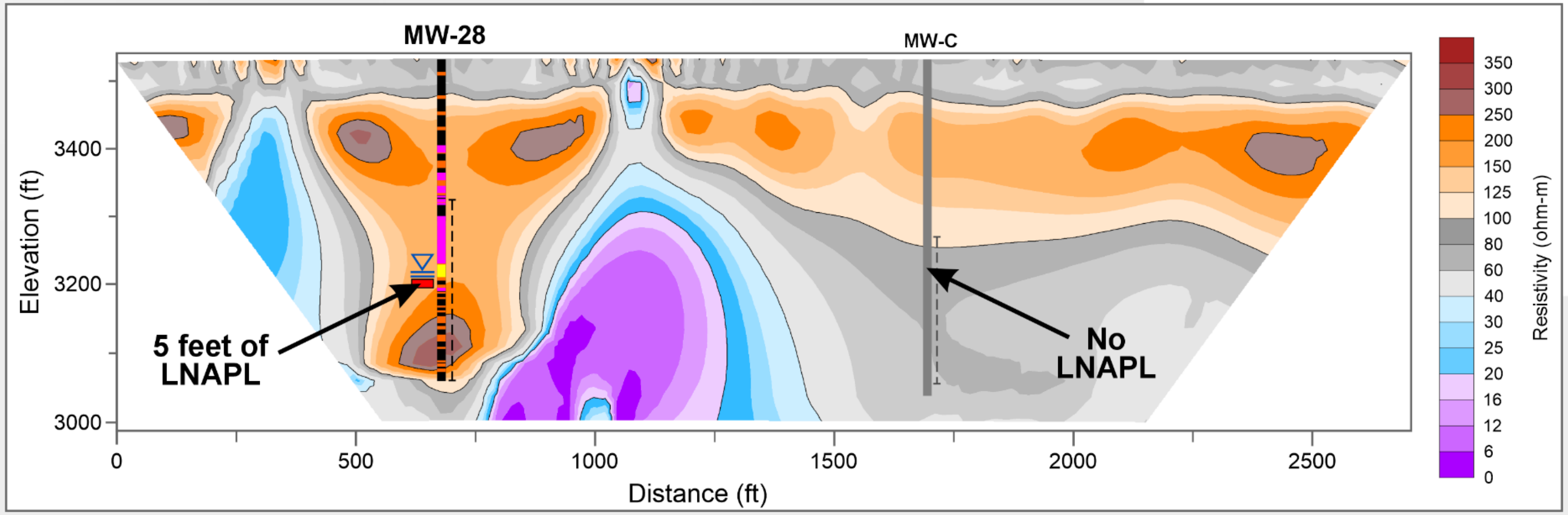
CSM Before: Seeps from fill getting under retaining wall

CSM After: Seep source is much deeper and further upgradient – impacted Pleistocene channels

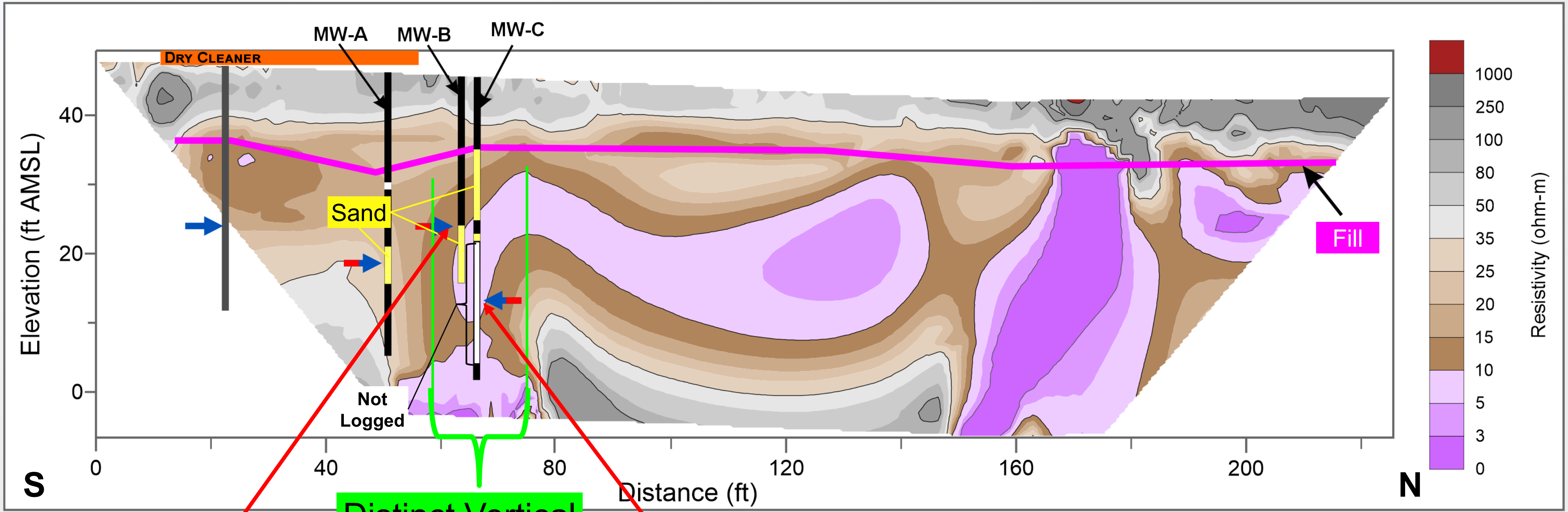
Mapping Impacted Paleochannels
Est. $20M Saved in Characterization

- Impacts found 1+ miles from the refinery at depths of 350 feet BGS
- Wells cost ~$180k each
- Images found impacts & paleochannels; used to inform groundwater models





Flow Paths Found
Est. $3.7M Saved on Remediation



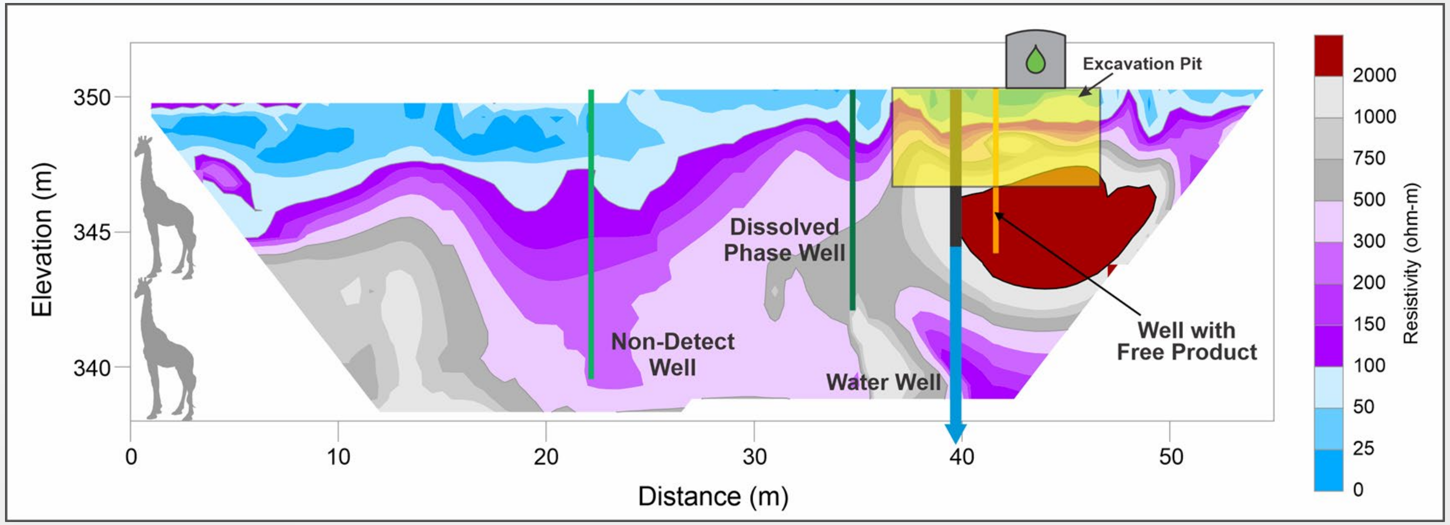
PCE – 120,000 µg/L
TCE – 22,000 µg/L
DCE – 15,000 µg/L
VC – 1,300 µg/L

PCE – 25,000 µg/L
TCE – 3,200 µg/L
DCE – 15,000 µg/L
VC – ND

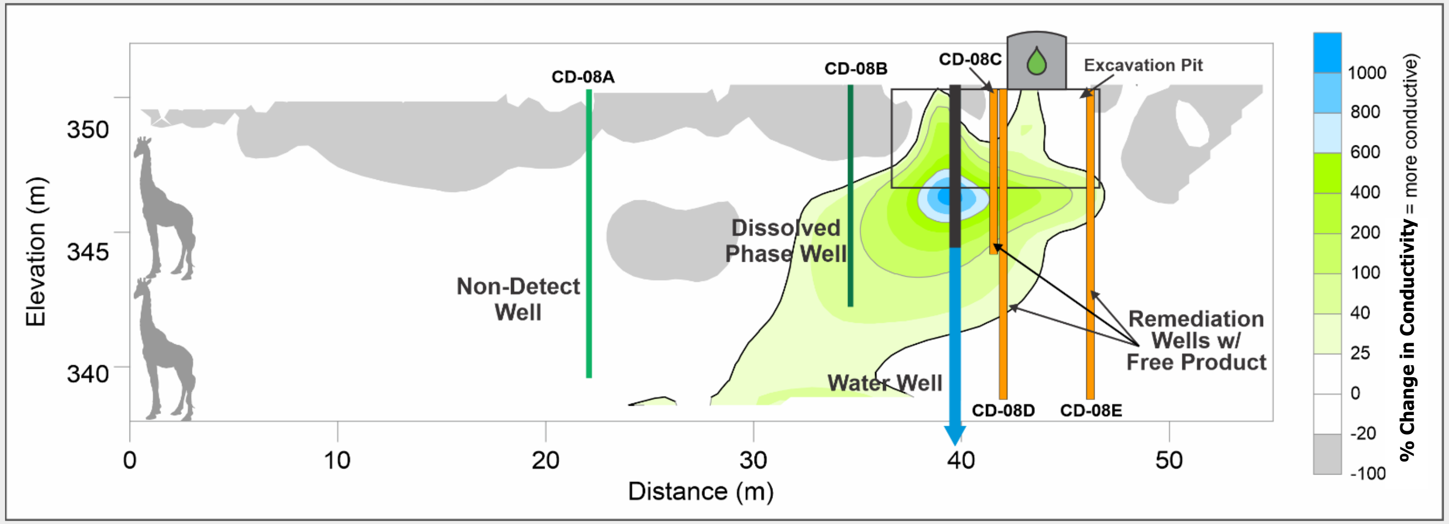
Discrete vertical migration pathway imaged & targeted on PCE site in heterogeneous glacial till

LNAPL in Karst
Spill to Closure in < 2 years

GeoTrax Survey™ Static Image (Res)

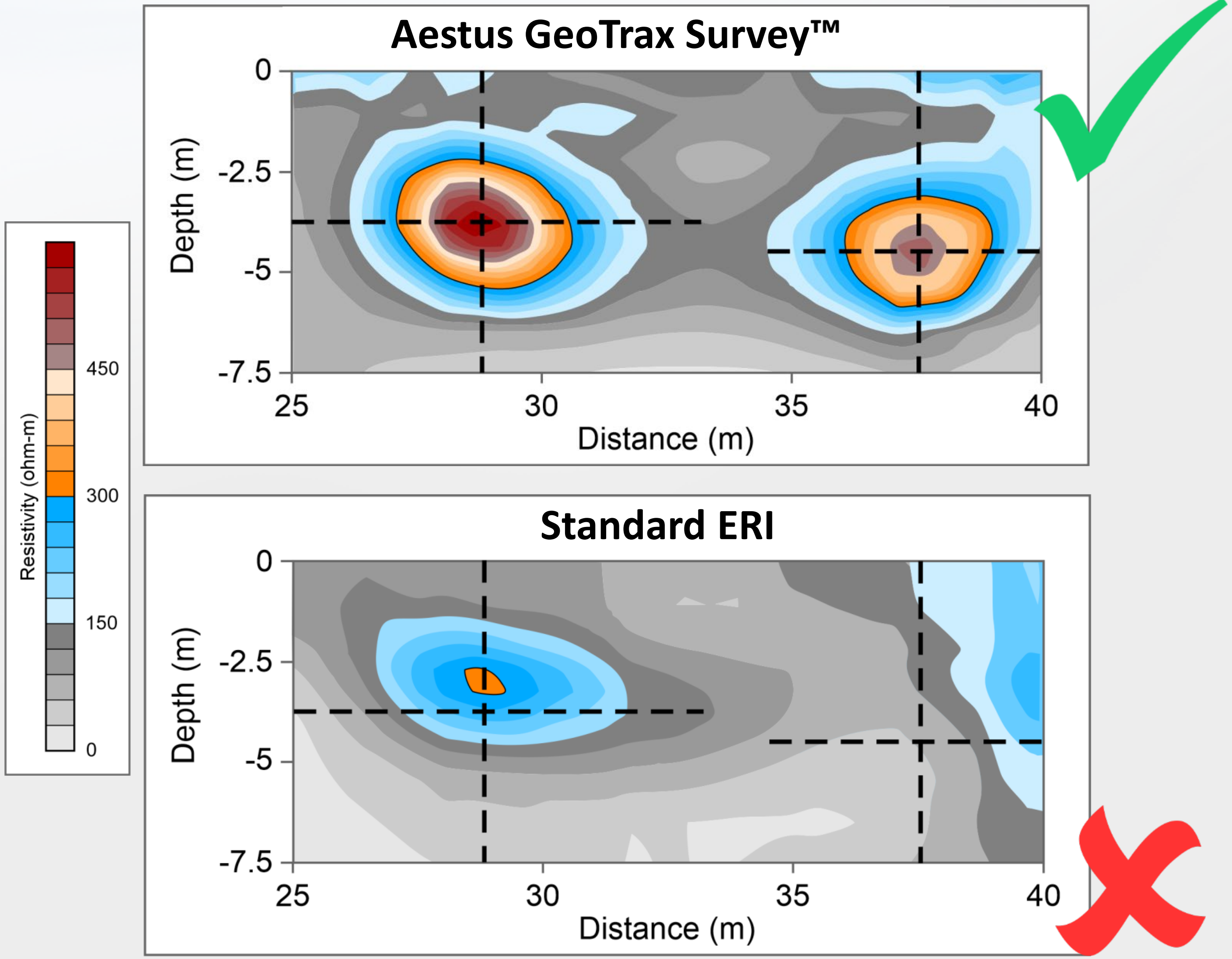


GeoTrax Monitoring™ Temporal Image (ΔRes)



- 2,000 gallon diesel spill in karst
- Initial images guided remediation wells
- Additional imaging supported well data – site was clean and could be closed

Better Data
GeoTrax Survey™ vs Standard ERI



Drillable Image

- ✓ *Designed for Environmental Contaminants*
- ✓ *Higher Sensitivity*
- ✓ *Better Quality Image*
- ✓ *Strong QA/QC Protocols*
- ✓ *Confirmed by EPA Ada Lab*

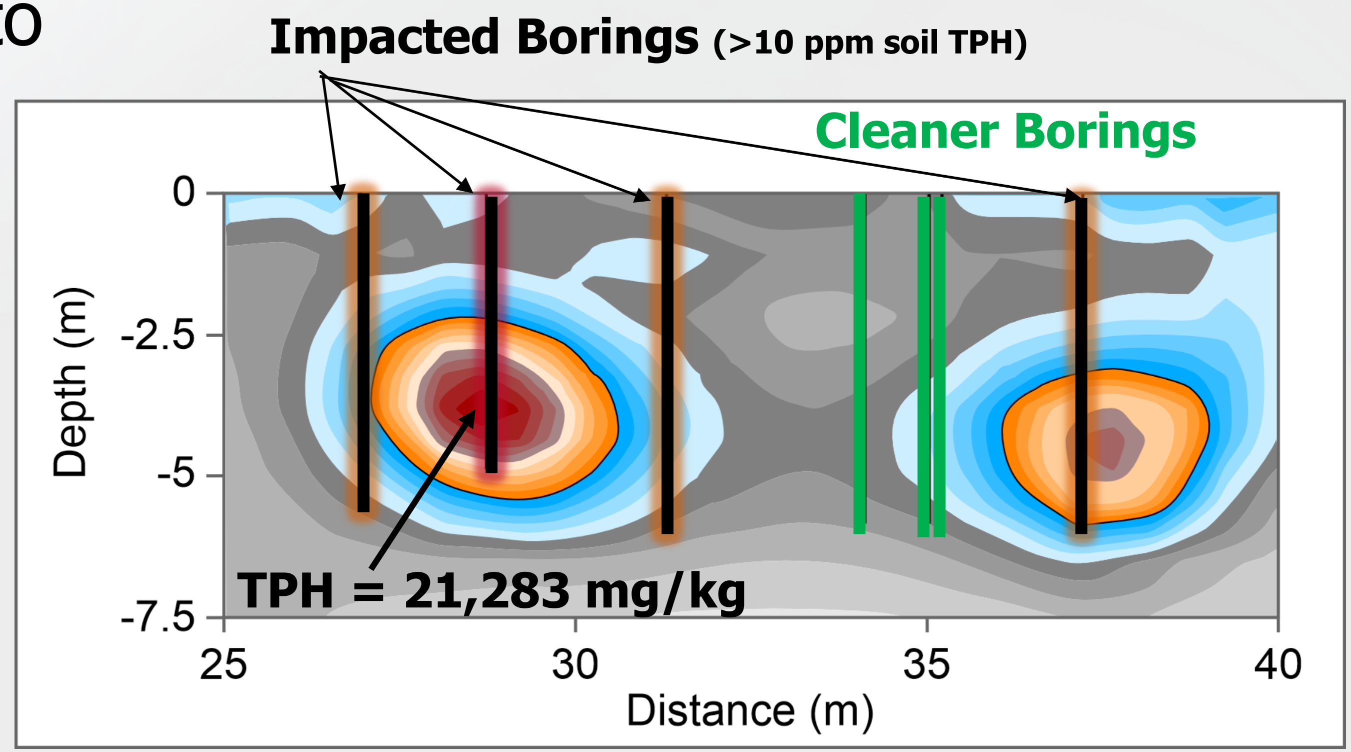
from Halihan et al, 2005

Same equipment

Same transect line

Better Data
GeoTrax Survey™ vs Standard ERI

- GeoTrax Survey™ designed to accurately see contaminants via higher sensitivity image
- "Drillable" datasets (discrete targets for drilling)



Post-remediation evaluation of a LNAPL site using electrical resistivity imaging

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First published as an Advance Article on the web 24th February 2005

Cost vs Benefit?

Can we afford to scan prior to remediation?

Cost vs Benefit?

~~Can we afford to scan prior to remediation?~~

Can we afford NOT to scan prior to remediation?

Why Isn't Scanning Common Practice in the Environmental Industry?

"…a certain degree of "**momentum of practice**" is occurring, whereby practitioners continue to do what they were trained to do or what has worked for them in the past.

The concept of what has worked in the past is somewhat uncertain in the environmental field as the ultimate goal post, **no further action (NFA), is rarely achieved at groundwater contaminated sites** (NRC, 2013; Clayton, 2017) and many sites continue through multiple investigation phases and five-year reviews of the remedy."

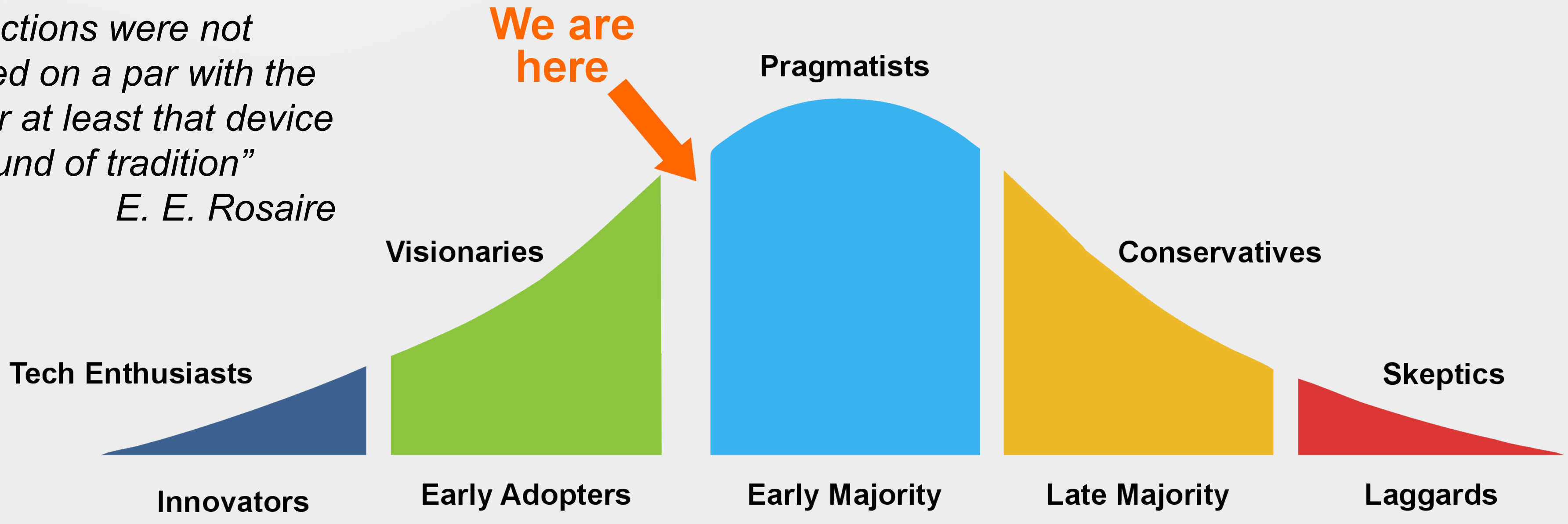
– SERDP, 2022

Next Era of Site Characterization and Monitoring: It Can Start Now

Opportunity now for "pragmatist" environmental professionals:

- Consultants: gain technology competitive advantage; add **value**
- Regulators: have better answers at a **lower total cost** for taxpayers
- Water managers: have better data and **minimize liabilities**

"(seismic) reflections were not even considered on a par with the divining rod, for at least that device had a background of tradition"
E. E. Rosaire



Best Practices for Modern Characterization

- Monitoring Wells ≠ Characterization Wells
- Vertical tools alone are not sufficient for good CSM development
- Remedial efficacy is only as good as the underlying CSM
- Scanning first is accepted best-practice in other industries
- Electrical hydrogeology results in:
  - Targeted drilling locations
  - Robust CSM
  - Time and cost savings for characterization AND remediation with minimized trailing liabilities

Acknowledgements & References

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Washington State Department of Ecology

Environmental Protection Agency

Aquaterra

California Waterboard

City of Ada, Oklahoma

Greystone Environmental

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Better Data, Better Decisions

QUESTIONS?

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