

Geology Revolution Continued...

“Know What the Well Will Tell You Before You Drill”

Battelle 2024 Chlorinated Conference Panel Discussion
Wednesday June 5, 9:15 – 10:55 am

Rick Wice, PG – Battelle

Rick Cramer, PG - Burns & McDonnell

Todd Halihan, PhD – Oklahoma State University

Ian Bowen, RG - USEPA

Fonda Apostolopoulos, PE – Colorado DPHE

Paolo Ciampi, PhD – Sapienza University of Rome

Robert Borden 1956-2023

- Passed Away November 2, 2023
- Rock Star and Innovator in Our Industry
- NC State Professor 27 years
 - Primary advisor 51 MS and 14 PhD students
- Active Participant Battelle and Other Conferences
- Multiple Awards and Publications
- Always a Fond Hello and Smile
- A friend to many, he will be missed.



Rick Wice

Introduction and Statement of Problem

Panelists

- **Rick Wice, PG, F. SAME, Senior Geologist, Battelle-** Rick's work focuses on site characterization and remediation, mainly chlorinated solvents and PFAS. He likes cycling, hiking, kayaking (with a fishing rod at times) and sipping good bourbons. He has a BS in Geology from University of Oregon and an M.S. Geology Western Washington University.
- **Rick Cramer, PG, Geologist and Senior PM, Burns and MacDonald –** Rick's career has focused on the application of advanced geologic methods to solve groundwater problems. He developed and introduced the practice of Environmental Sequence Stratigraphy (ESS) to the Environmental Industry in 1994. He has a B.S. in Geology from University of the Pacific and an M.S. in Geology from University of California, Davis.
- **Todd Halihan, PhD, Interim Department Head and the Sun Chair in Hydrogeology Oklahoma State University, and Chief Technical Officer for Aestus, LLC.** Todd's professional interests center in subsurface characterization using electrical hydrogeology and sustainable water supply. Todd enjoys traveling with his family and sampling unique beverages. He has a bachelor's in physics from Monmouth College, and a M.S. and Ph.D. in Geological Sciences from the University of Missouri and the University of Texas, respectively.
- **Ian Bowen, Lead Hydrogeologist, USEPA.** Ian provides technical and policy support to a variety of projects including comprehensive site planning, conceptual site model development, characterization approach, remedy selection, and performance monitoring. Out of the office, Ian enjoys spending time with his family, disc golf, classic cocktails, and elk hunting. He has a B.S. in Chemistry and M.S. in Geology from the University of Kansas.

Panelists

- **Fonda Apostolopoulos, PE, CDPHE** - 31 years with DPHE. Fonda has a background in Civil/Environmental Engineering, and Molecular Biology. He has been working in the Hazardous Materials and Waste Management Division as an On-Scene Coordinator and Project Manager at various Superfund Sites in Colorado and is the Voluntary Cleanup Coordinator. His life revolves around his work and taking care of his 4 dogs and 3 cats.
- **Paolo Ciampi, PhD, Sapienza University of Rome** - Paolo graduated in Applied Geology from the University of Rome "La Sapienza" in 2015 and completed his Ph.D. in Earth Sciences in 2020. His research specialized in 2D and 3D hydrogeophysical modeling within a GIS environment and in developing multi-source conceptual models to support sustainable remediation of contaminated sites using innovative technologies.

The Problem

- Do we put wells in as nice looking spatially placed dots on a map?
- Do we really know the regional, local and site-specific conditions and geologic setting?
- Do you know the depositional environments, stratigraphy, secondary impacts/ porosity?
- Do you have a dynamic CSM?
- Are we using the best available tools?
- Are you communicating with the regulatory stakeholders?

Agenda

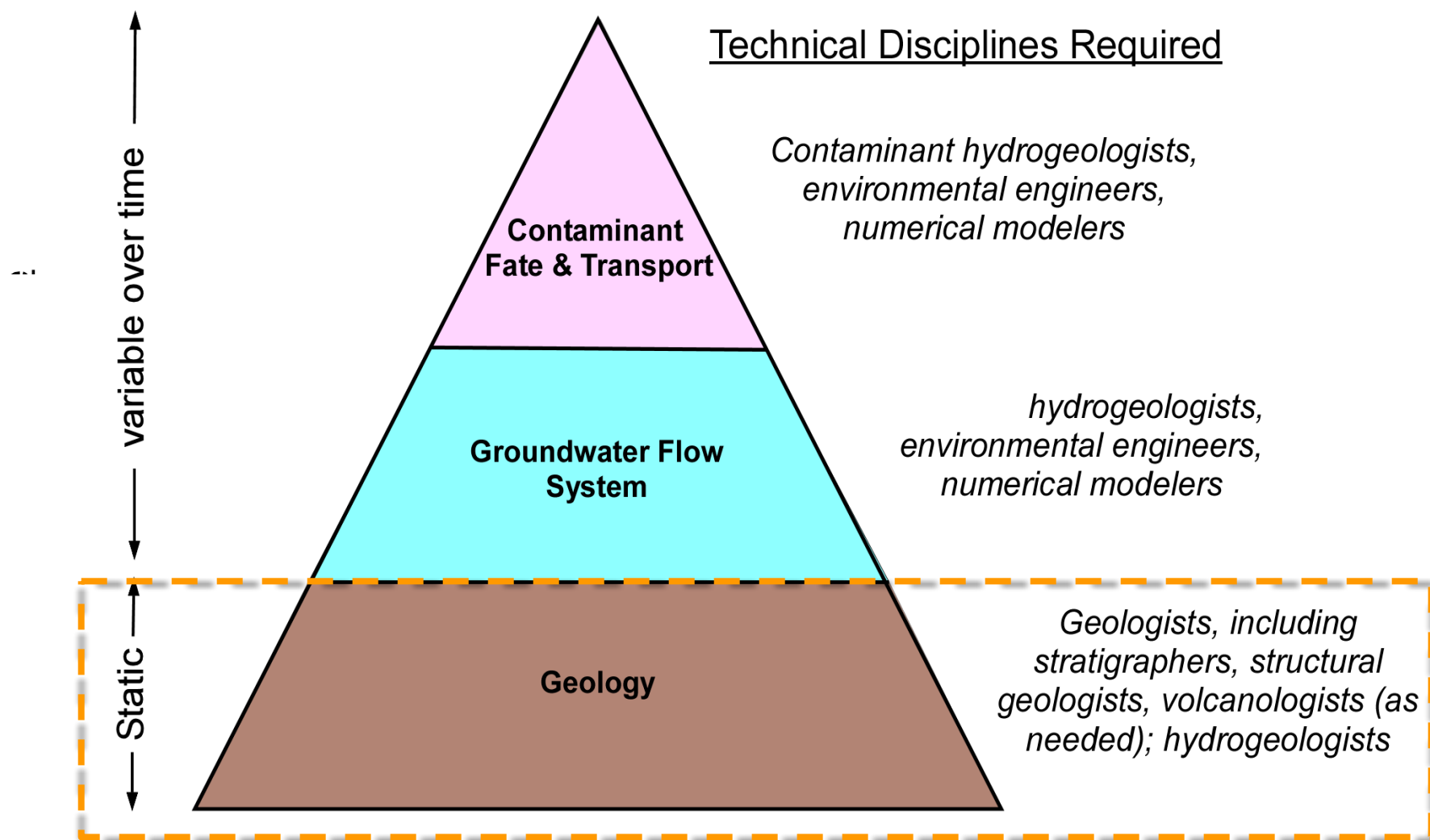
- Introduction and Statement of Problem – R. Wice
- CSMs and Geologic Importance – R. Cramer
- Geophysical Tools – T. Halihan
- EPA Research and Perspective – I. Bowen
- Stakeholders – F. Apostolopoulos
- Case Study – P. Ciampi

- QA and Open Forum with Attendees

Rick Cramer

CSMs and Geology

Components of a Conceptual Site Model (CSM) for a Groundwater Contaminated Site



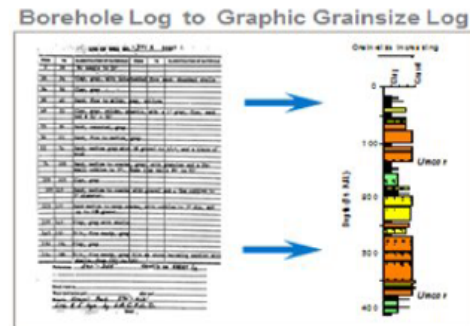
Environmental Sequence Stratigraphy (ESS) and Remediation Geology

“Science can amuse and fascinate us all,



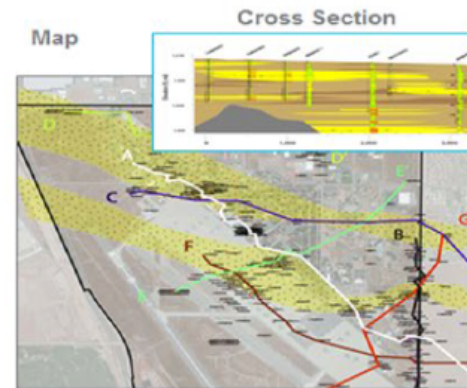
1

Determine depositional environment which is the foundation to the ESS evaluation



2

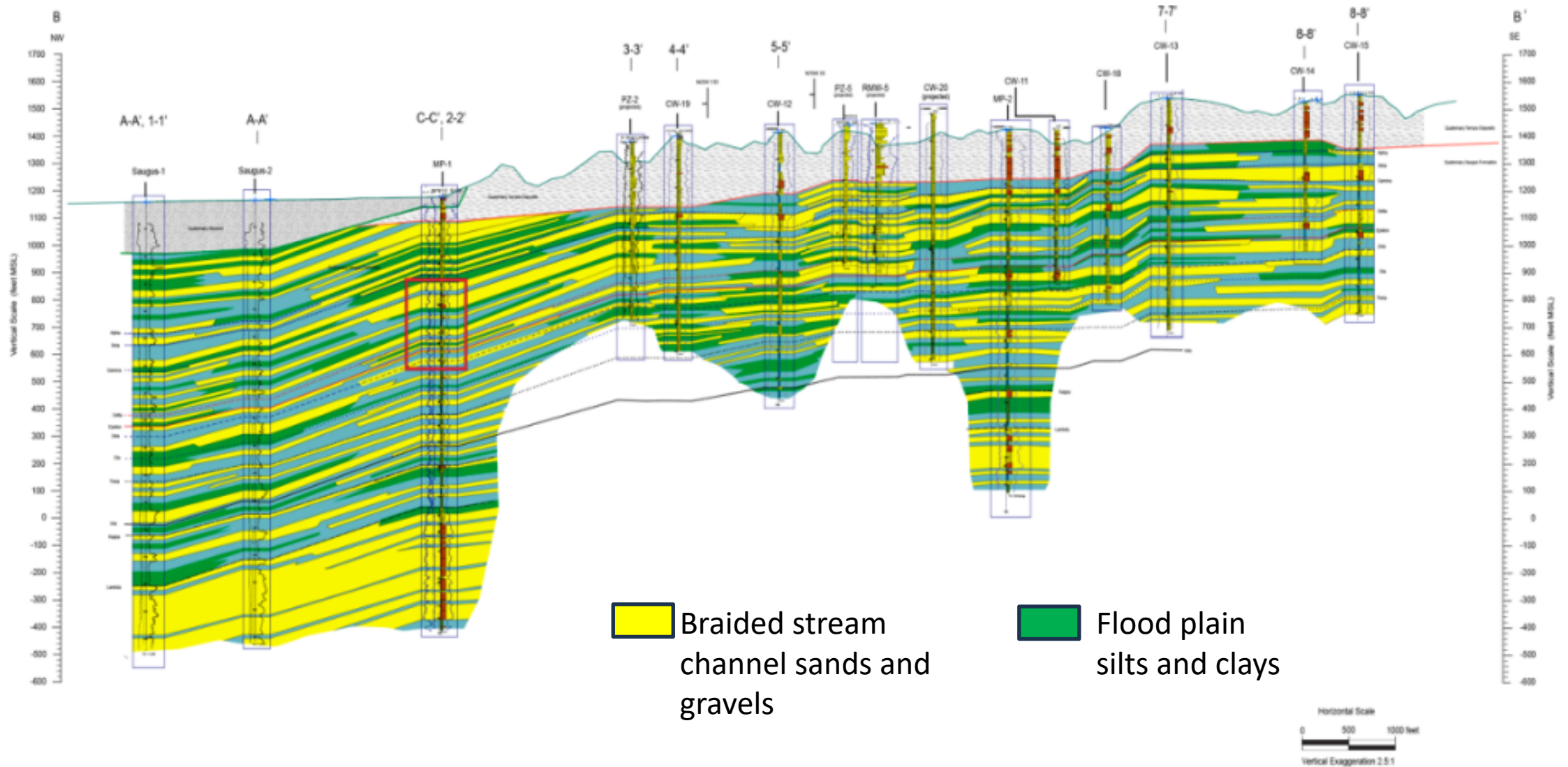
Leverage existing lithology data to identify vertical grain size trends and correlate between boreholes



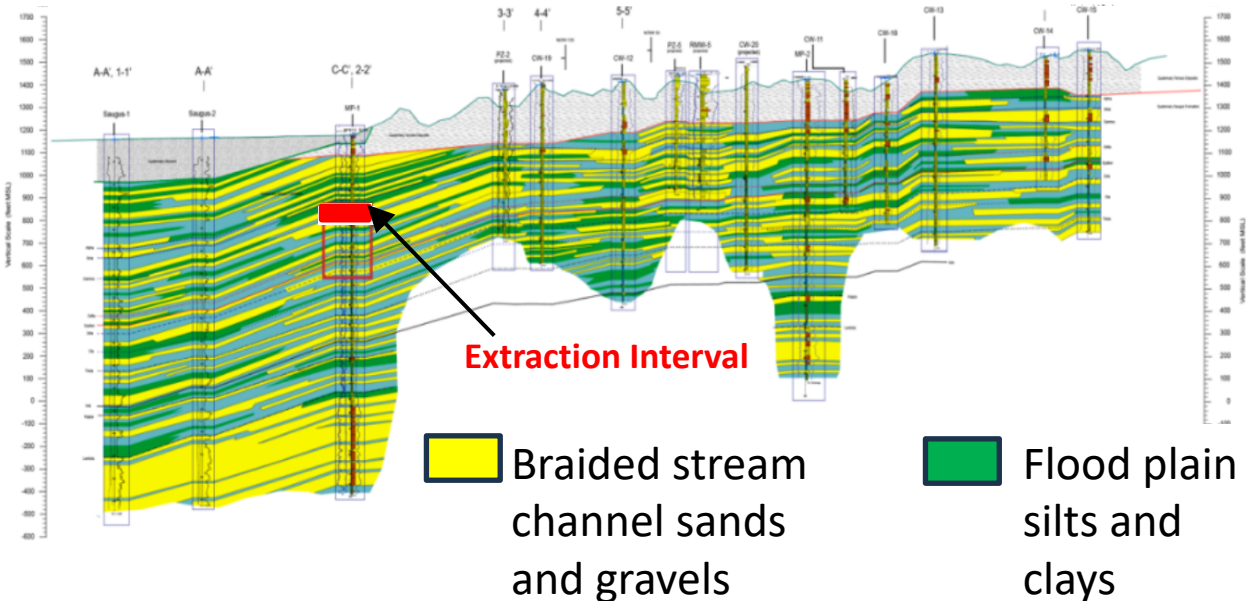
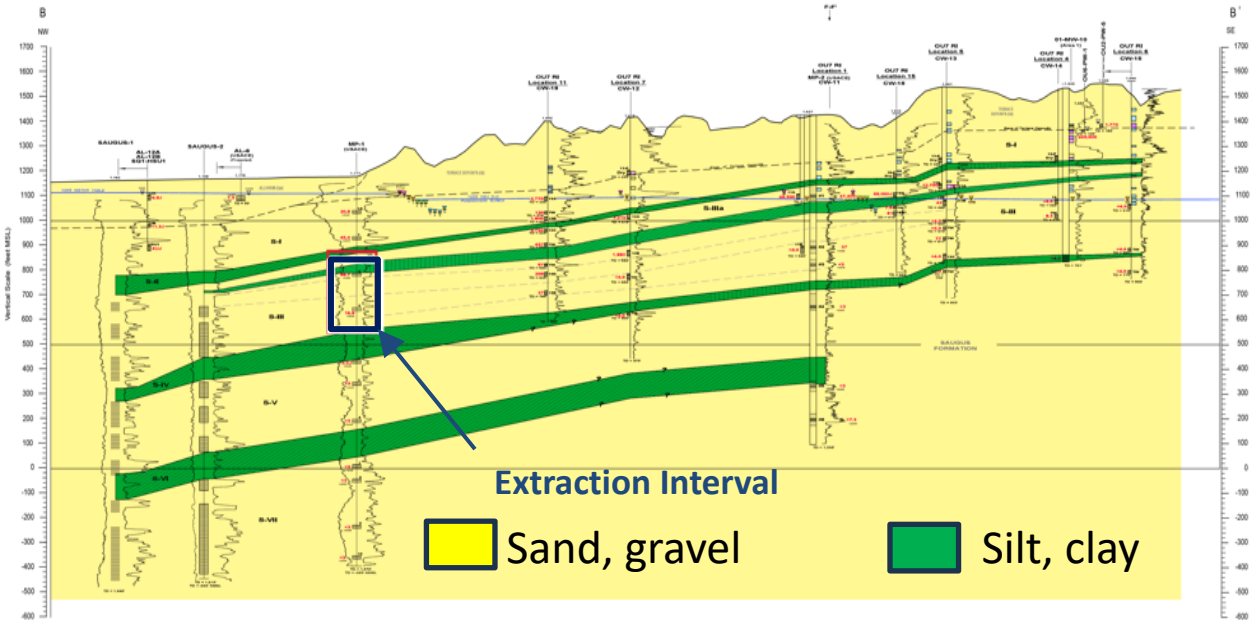
3

Map the permeability architecture to predict contaminant migration

Best Practice: ESS Facies-Based Correlations



The Right Practitioner is Worth \$50MM



- Reduced cost of remediation by >\$50 million
- Reduced quantity of extracted groundwater by >70%

Todd Halihan

Geophysical Tools



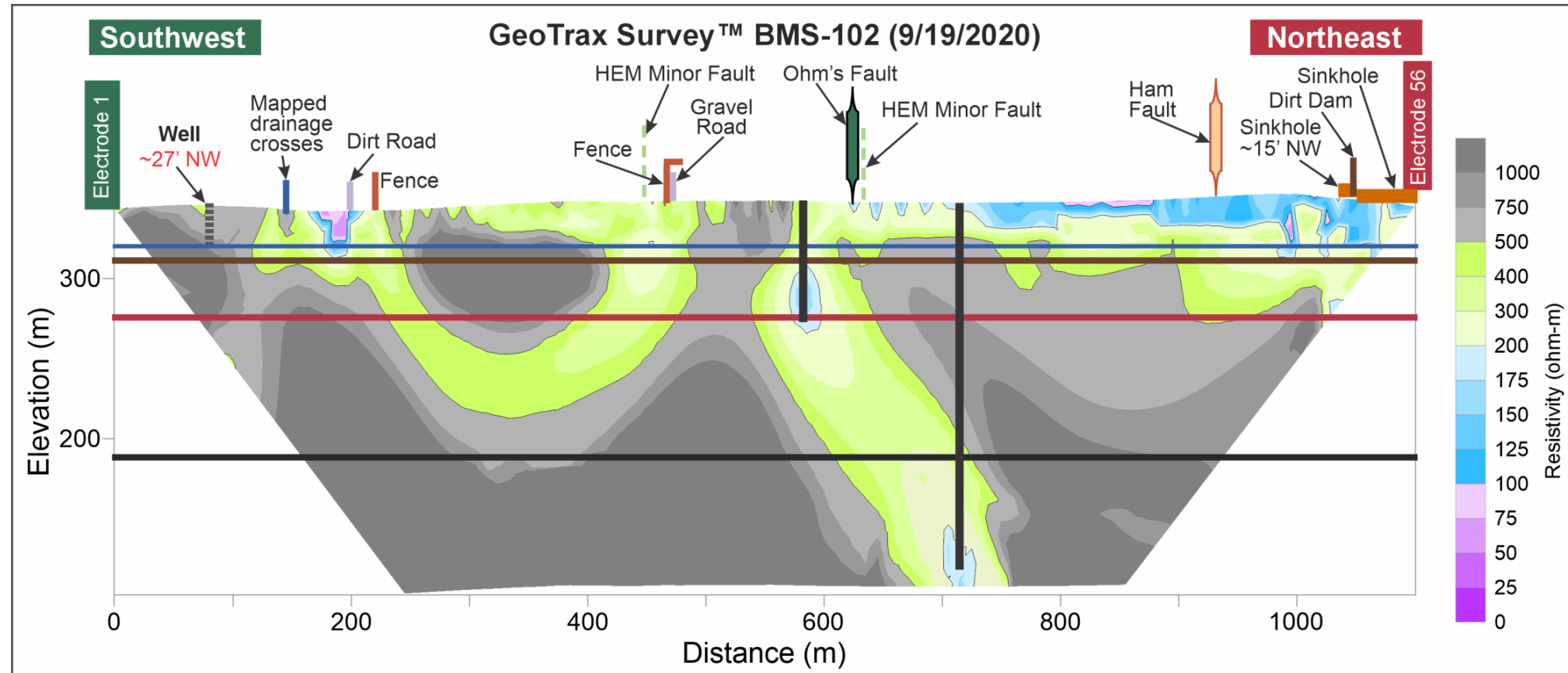
3 Lessons from 30 Years

Todd Halihan
Oklahoma State University
Aestus, LLC

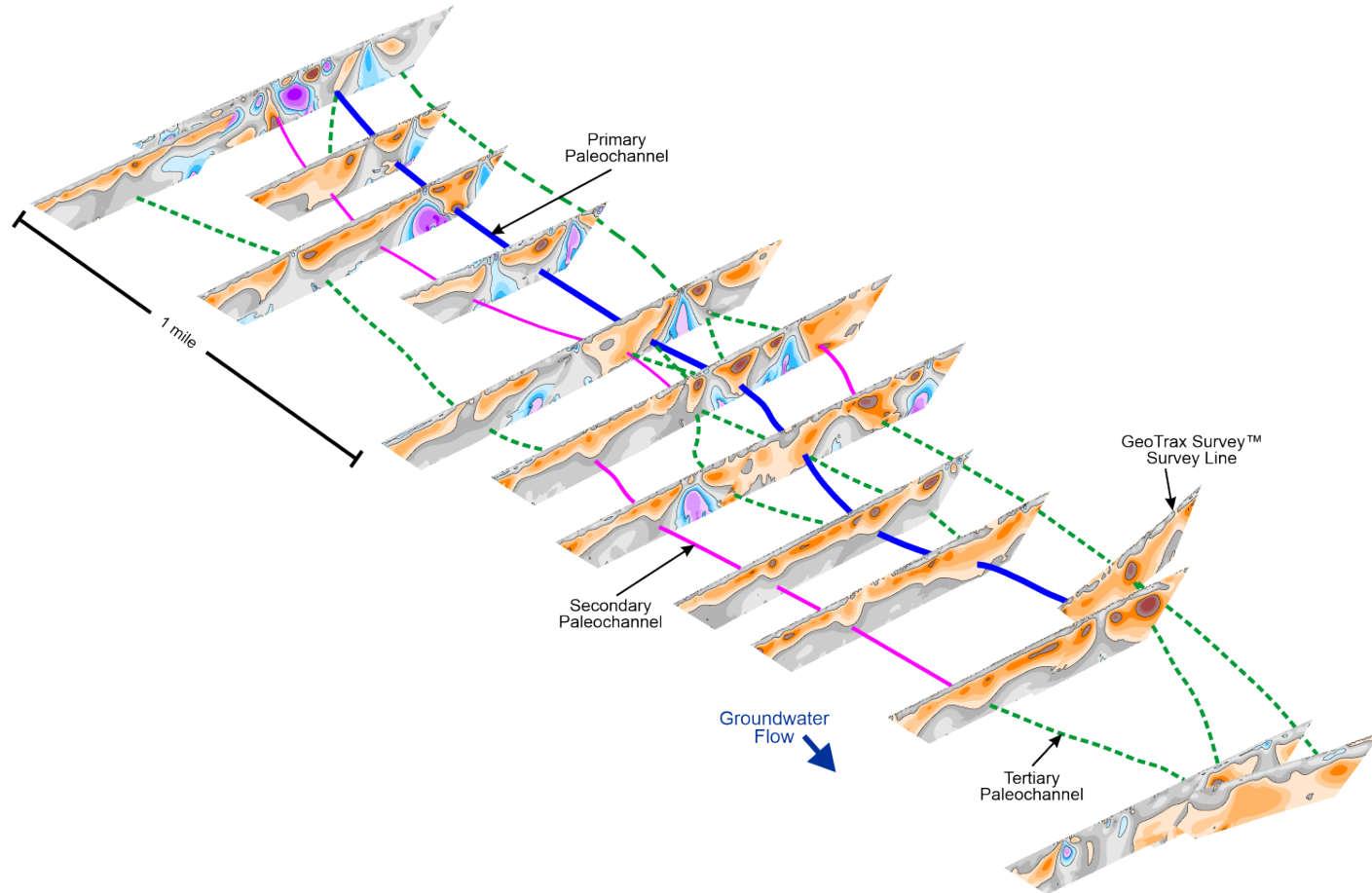


1. Monitoring Wells $\neq$ Characterization Wells

Two-inch PVC will not Elucidate Heterogeneity

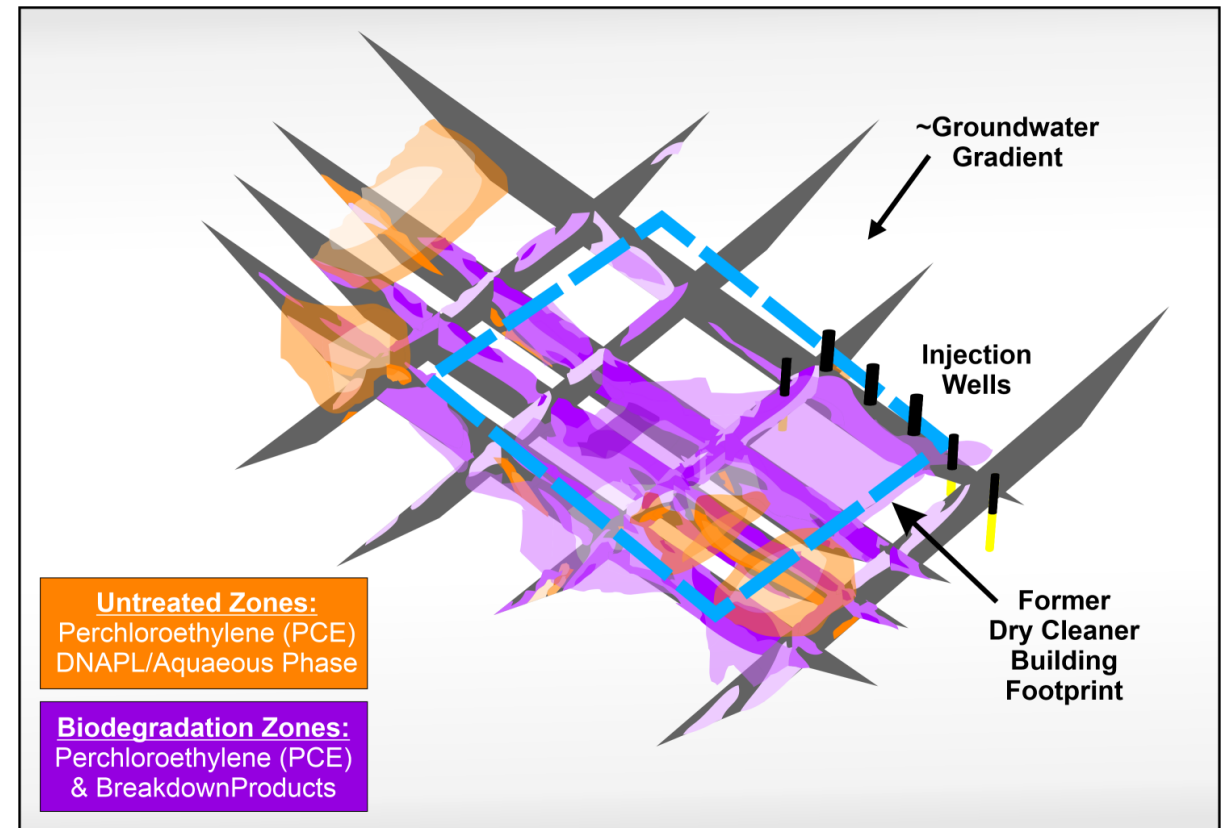


2. Finding Sources is Psychologically Difficult So is Demonstrating No Impacts...



3. Characterization is Most Powerful when Integrating Technologies, Not Relying on One

- Characterization is iterative
- You will learn things which change the direction
- Writing a plan that says what will happen next with certainty is sadly entertaining



Ian Bowen



Ian Bowen

Hydrogeologist
US EPA Region 8

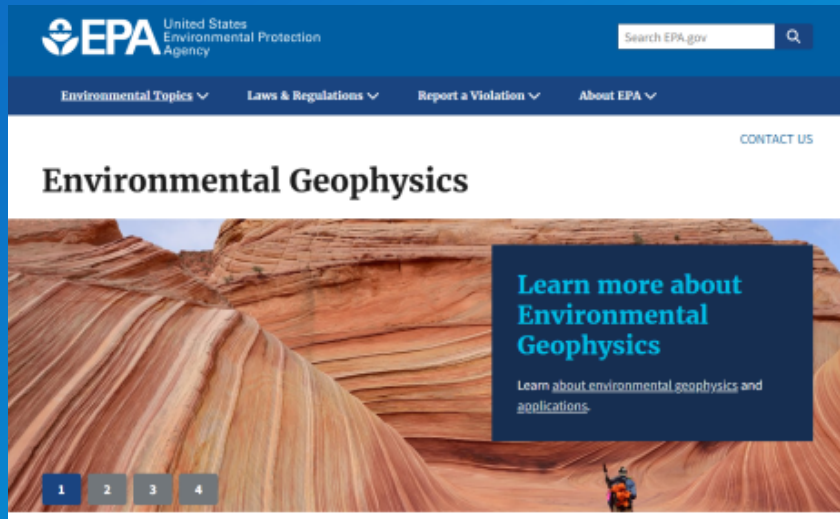
Disclaimer:

- Information in this presentation represents the views of the presenter and has not received formal U.S. EPA peer review.
- This information does not necessarily reflect the views of U.S. EPA, and no official endorsement should be inferred.
- The information is not intended, nor can it be relied upon, to create any rights enforceable by any party in litigation with the United States or any other party.
- Use or mention of trade names does not constitute an endorsement or recommendation for use

Infusion of Funding

- Infrastructure funding added significant resources for the Superfund Program
- Funding previously shelved projects
- Hiring
 - Training many new RPMs
 - Increased characterization related trainings





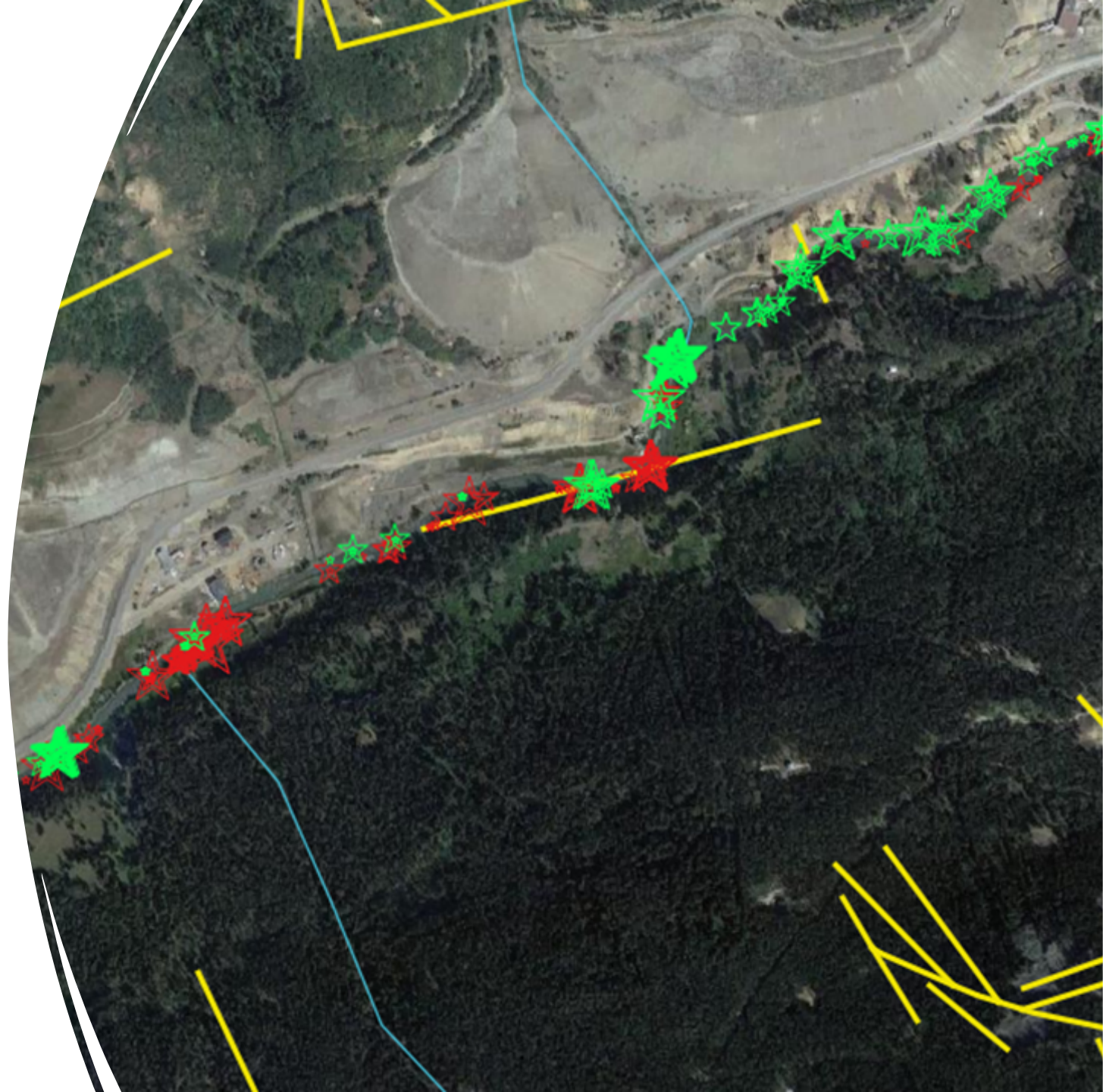
New Emphasis on Geology and CSMs

- Environmental Sequence Stratigraphy Issue Paper
- Geology Best Practices Issue Paper
- Groundwater Forum
 - National Resource for Hydrogeologists
- epa.gov/environmental-geophysics
- New Technical Guides
 - Data Management
 - Strategic Sampling
 - Smart Scoping



Research

- Geophysical characterization methods
 - GW/SW interactions using temperature-based methods
 - Improving resolution and interpretation of geophysical data
- Geochemical Techniques
 - Rare Earth Elements as tracers
 - Isotopes to better understand sources and water/rock interactions
- PFAS Characterization
 - Predicting GW vulnerability



Fonda Apostolopoulos



COLORADO

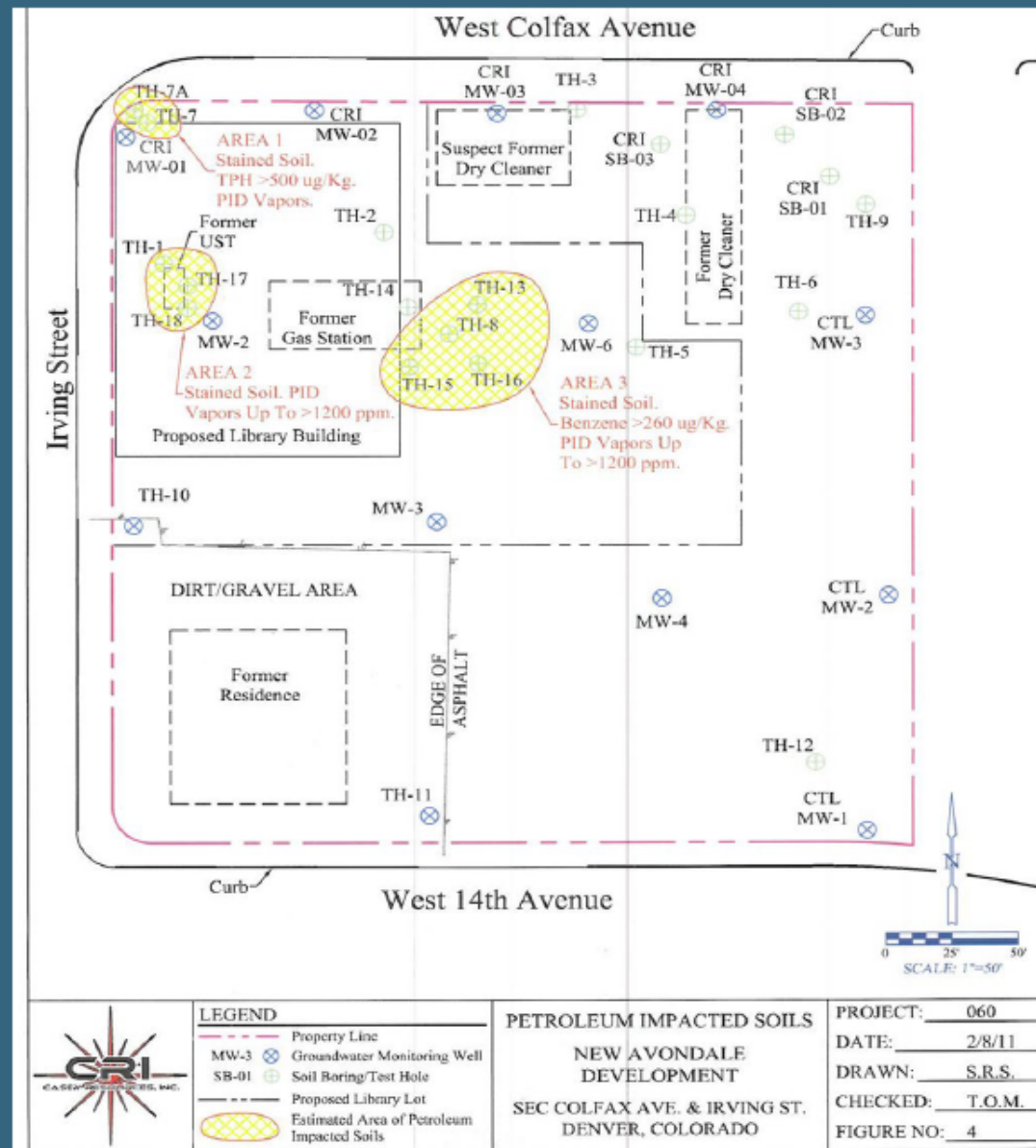
**Hazardous Materials
& Waste Management Division**

Department of Public Health & Environment

Know What The Well Will Tell You Before You Drill

*Mr. Fonda Apostolopoulos, P.E. – CDPHE
Superfund and Brownfields Program*





Central I-70 Project



COLORADO
Hazardous Materials
& Waste Management Division
Department of Public Health & Environment

Environmental Soil testing

- more than 2,100 sample
- more than 1,100 bores





COLORADO

**Hazardous Materials
& Waste Management Division**

Department of Public Health & Environment



RESOURCE GEOSCIENCE, INC.
Consulting Environmental Engineers and Earth Scientists
719-635-0229

• Stock Piles



COLORADO
**Hazardous Materials
& Waste Management Division**
Department of Public Health & Environment



RESOURCE GEOSCIENCE, INC.
Consulting Environmental Engineers and Earth Scientists
719 635 0229



Actual Debris removed





- Mr. Fonda Apostolopoulos
- Colorado Department of Public Health and Environment
- Fonda.Apostolopoulos@state.co.us

Geology Revolution Continued ... Know What the Well Will Tell You Before You Drill

Paolo Ciampi

paolo.ciampi@uniroma1.it



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2024 Chlorinated Conference

June 2-6, 2024 | Denver, Colorado

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Geological boreholes

**Geophysical Investigations
(ERT, LIF, MIP)**



GW level measurements

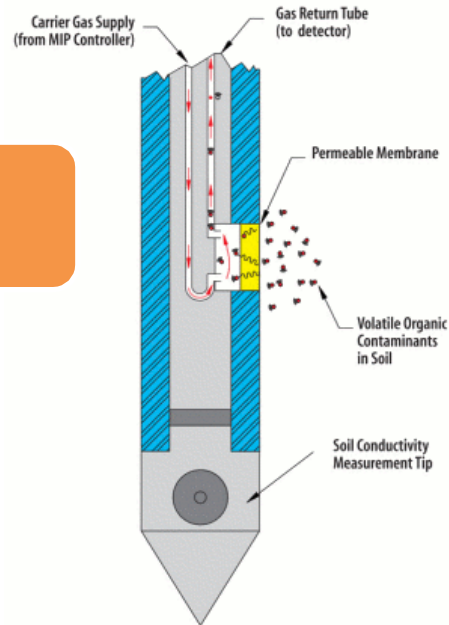
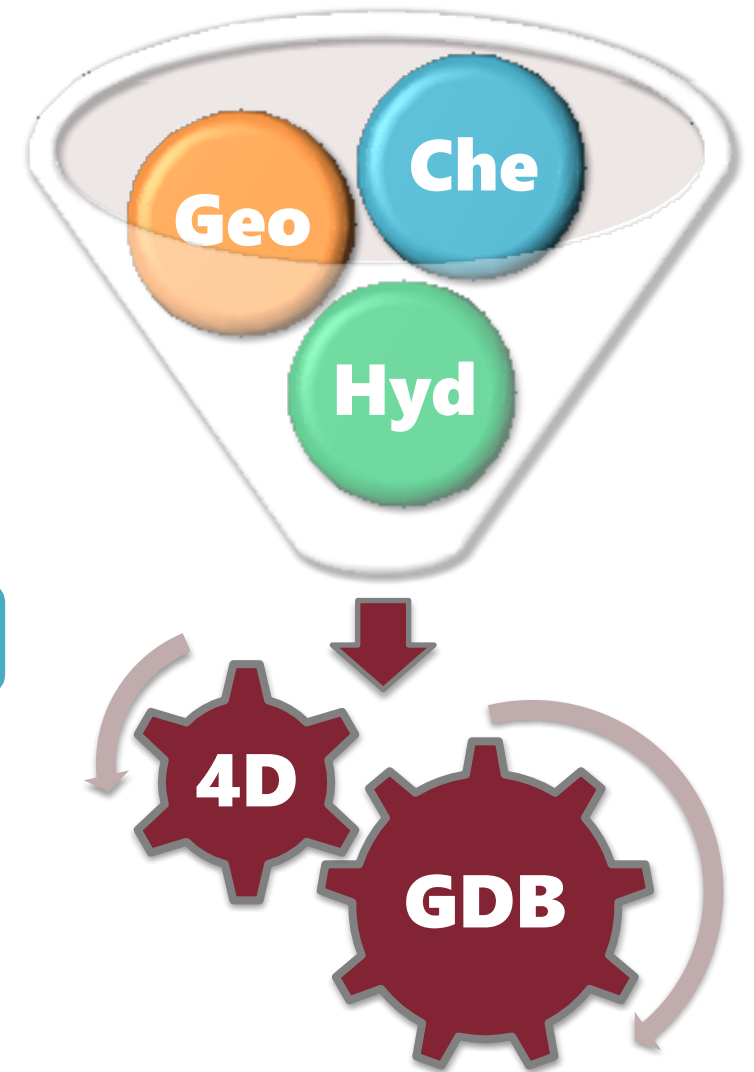
Tabella 01 - Andamento della pianificazione

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Descrizione di attività	2020/01/01	2020/02/01	2020/03/01	2020/04/01	2020/05/01	2020/06/01	2020/07/01	2020/08/01	2020/09/01	2020/10/01	2020/11/01	2020/12/01	2021/01/01	2021/02/01	2021/03/01	2021/04/01	2021/05/01	2021/06/01	2021/07/01	2021/08/01	2021/09/01	2021/10/01	2021/11/01	2021/12/01
2020/01/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2020/02/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2020/03/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2020/04/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2020/05/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2020/06/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2020/07/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2020/08/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2020/09/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2020/10/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2020/11/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2020/12/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2021/01/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2021/02/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2021/03/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2021/04/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2021/05/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2021/06/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2021/07/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2021/08/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2021/09/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2021/10/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2021/11/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2021/12/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2022/01/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2022/02/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2022/03/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2022/04/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2022/05/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2022/06/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2022/07/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2022/08/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2022/09/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54
2022/10/01	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,54	1,					

Lithos
Journal of Mineralogical and Petrological Research

Chemical analyses

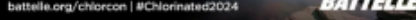
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Multi Criteria Decision Analysis Tool

*Geology Revolution Continued ... Know
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2024 Chlorinated Conference
 June 2-6, 2024 | Denver, Colorado
battelle.org/chlorcon | [#Chlorinated2024](https://twitter.com/Chlorinated2024)

BATTELLE

June 2-6, 2024 | Denver, Colorado

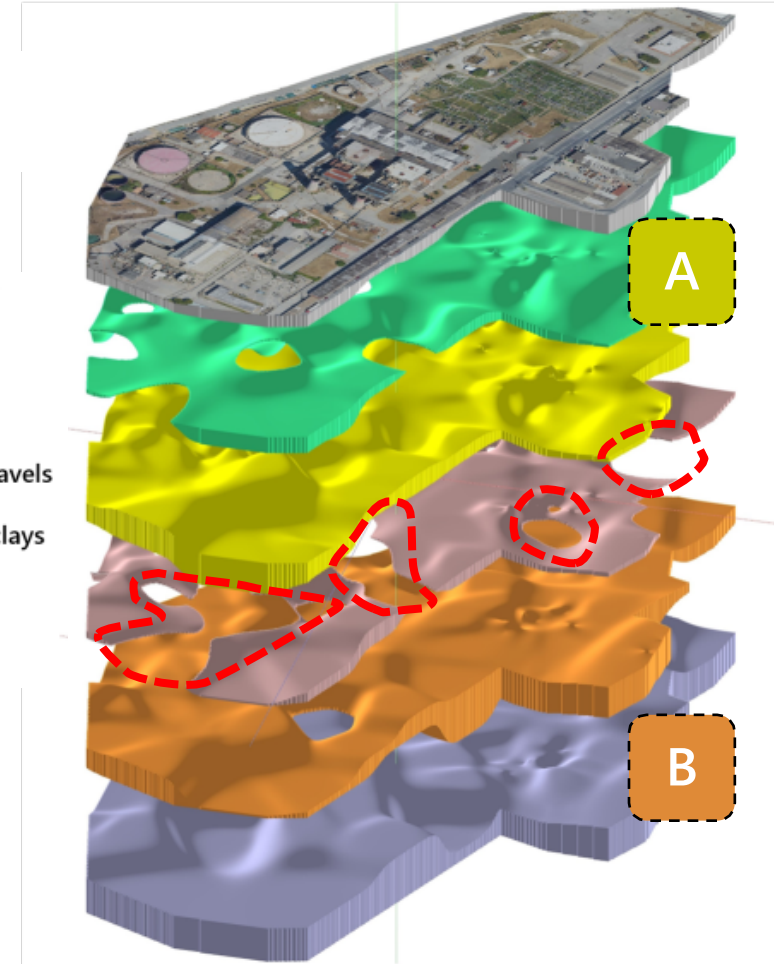
[battelle.org/chlorcon](https://www.battelle.org/chlorcon) | #Chlorinated2024

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Case 1 - DNAPL contaminated site

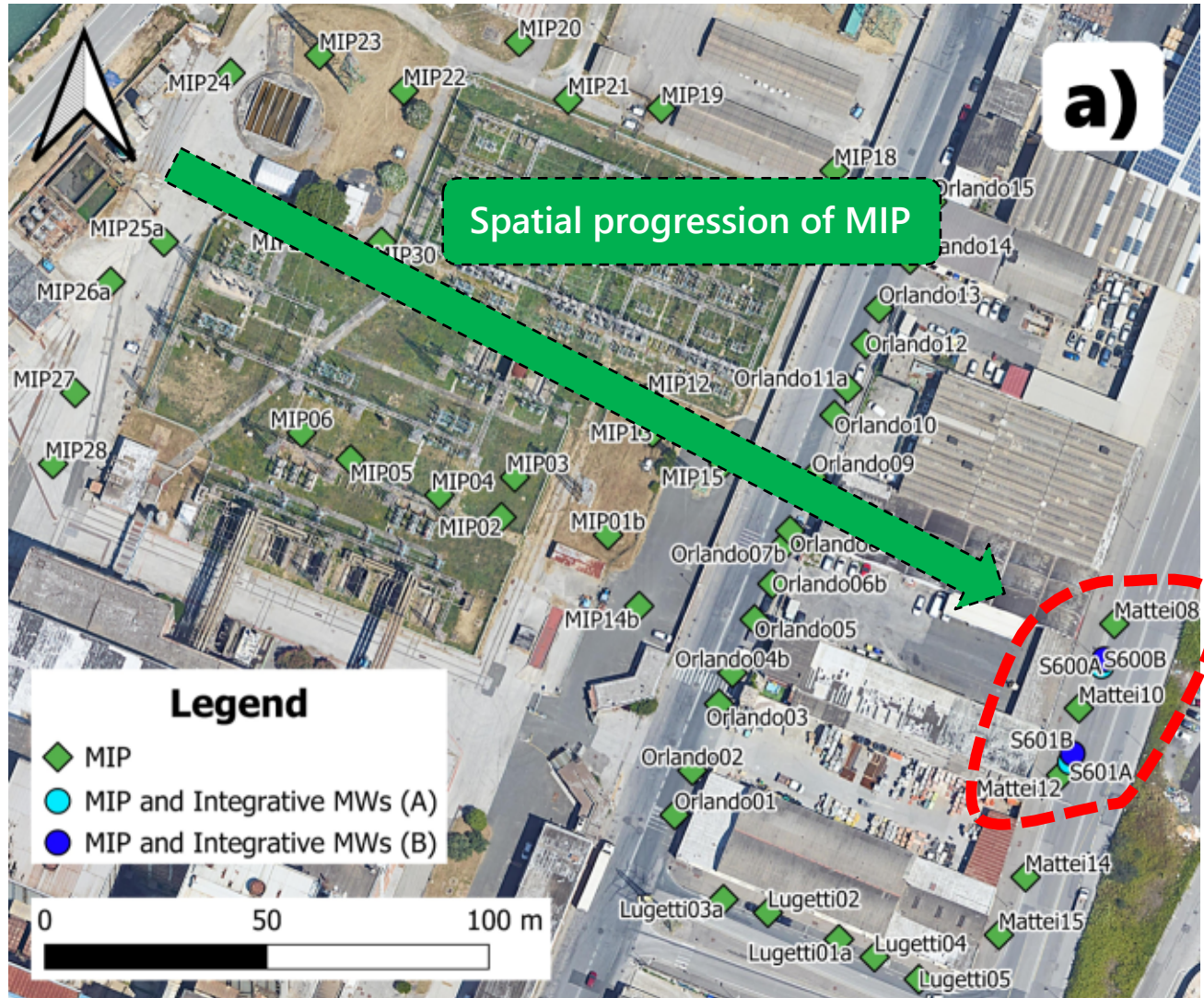


TCE contamination plume with concentrations up to about 10 mg/L (P&S)

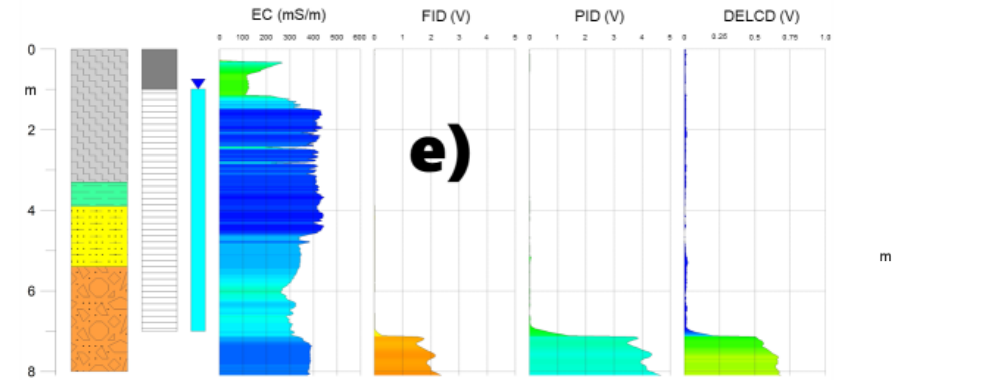


Ciampi et al. 2024

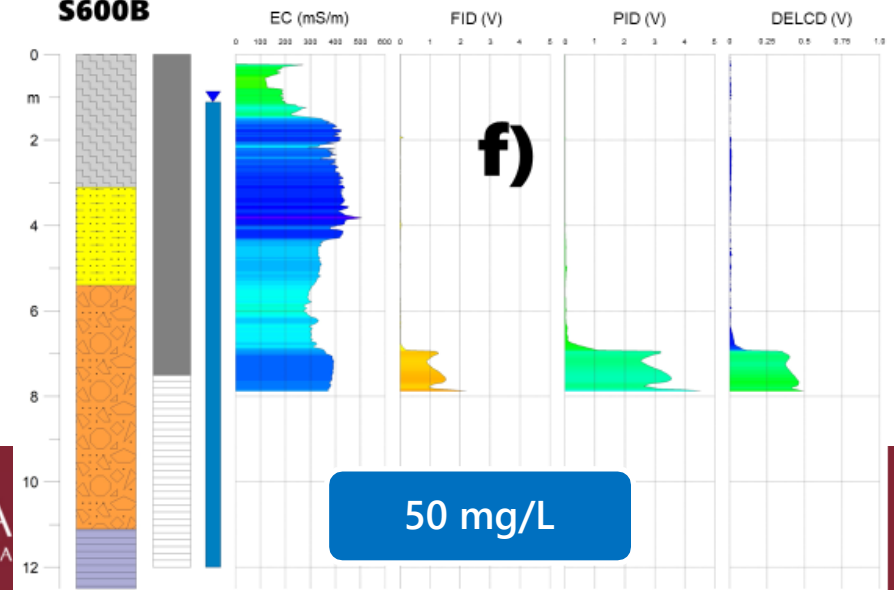
Source Identification



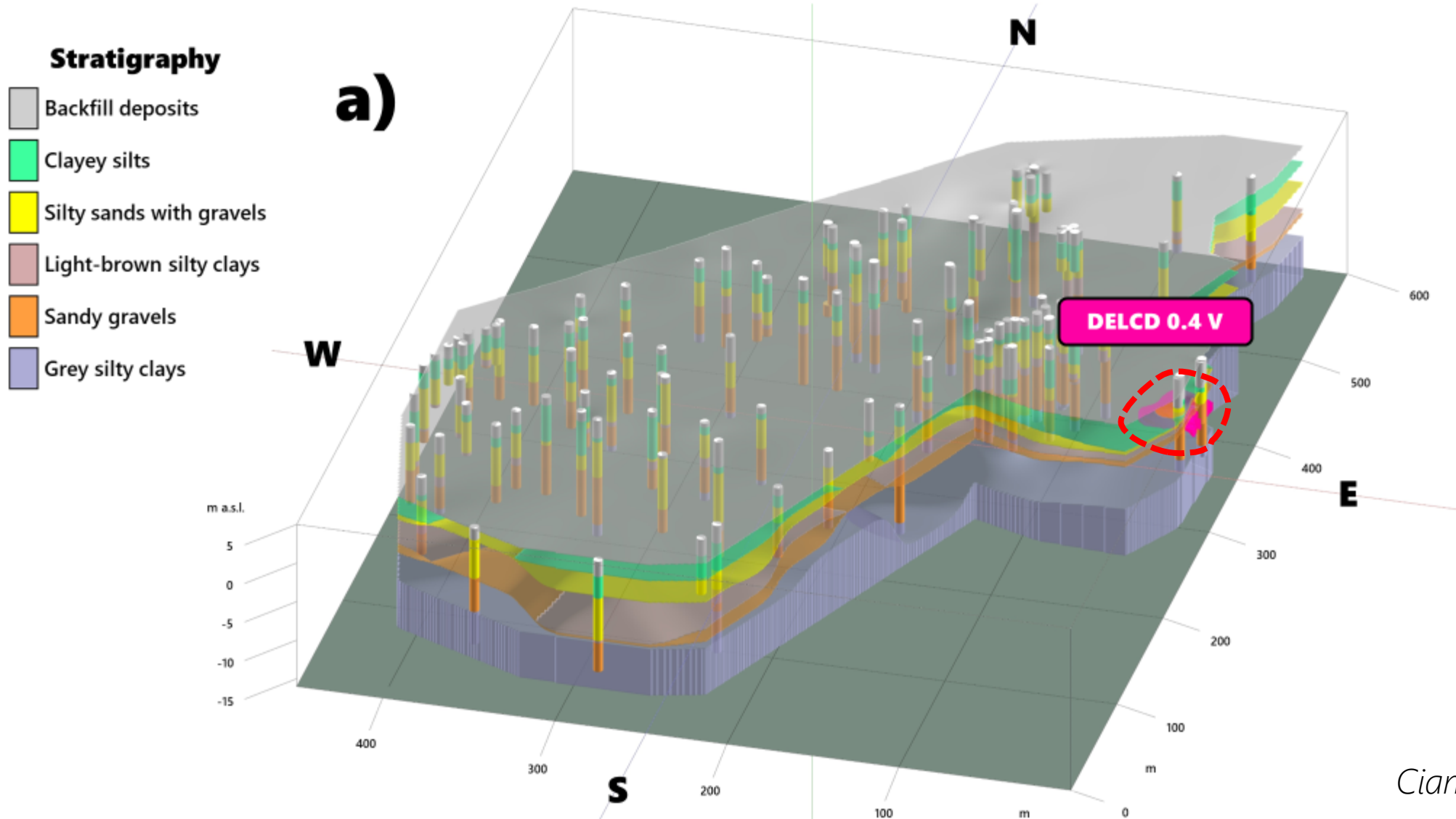
S600A



S600B

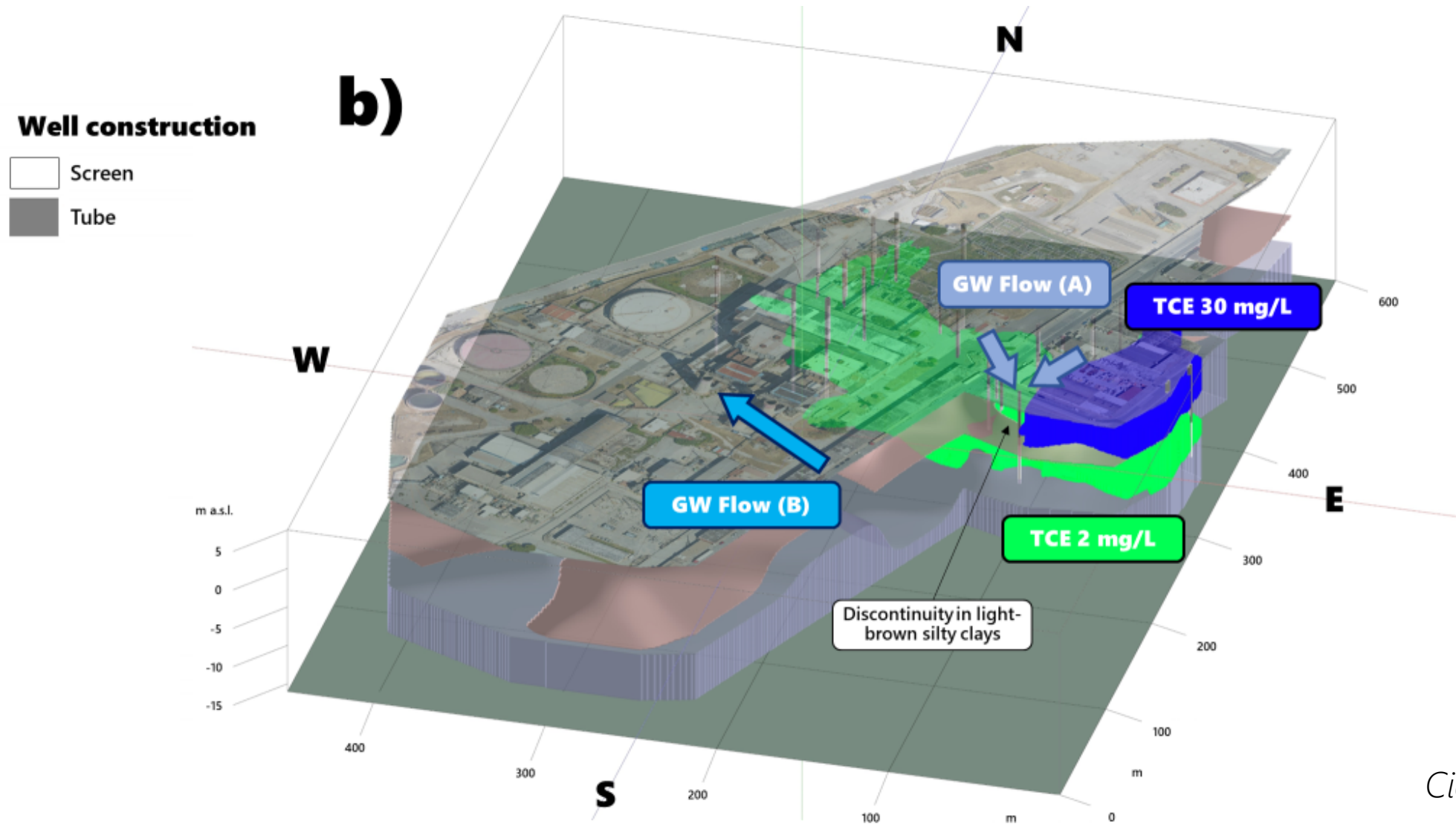


Delimitation of the secondary contamination source



Ciampi et al. 2024

Reconstruction of CSM and "geo-driven" contamination dynamics



Ciampi et al. 2024

Q&A and Open Forum with Attendees

The Problem

- Do we put wells in as nice looking spatially placed dots on a map?
- Do we really know the regional, local and site-specific conditions and geologic setting?
- Do you know the depositional environments, stratigraphy, secondary impacts/ porosity?
- Do you have a dynamic CSM?
- Are we using the best available tools?
- Are you communicating with the regulatory stakeholders?

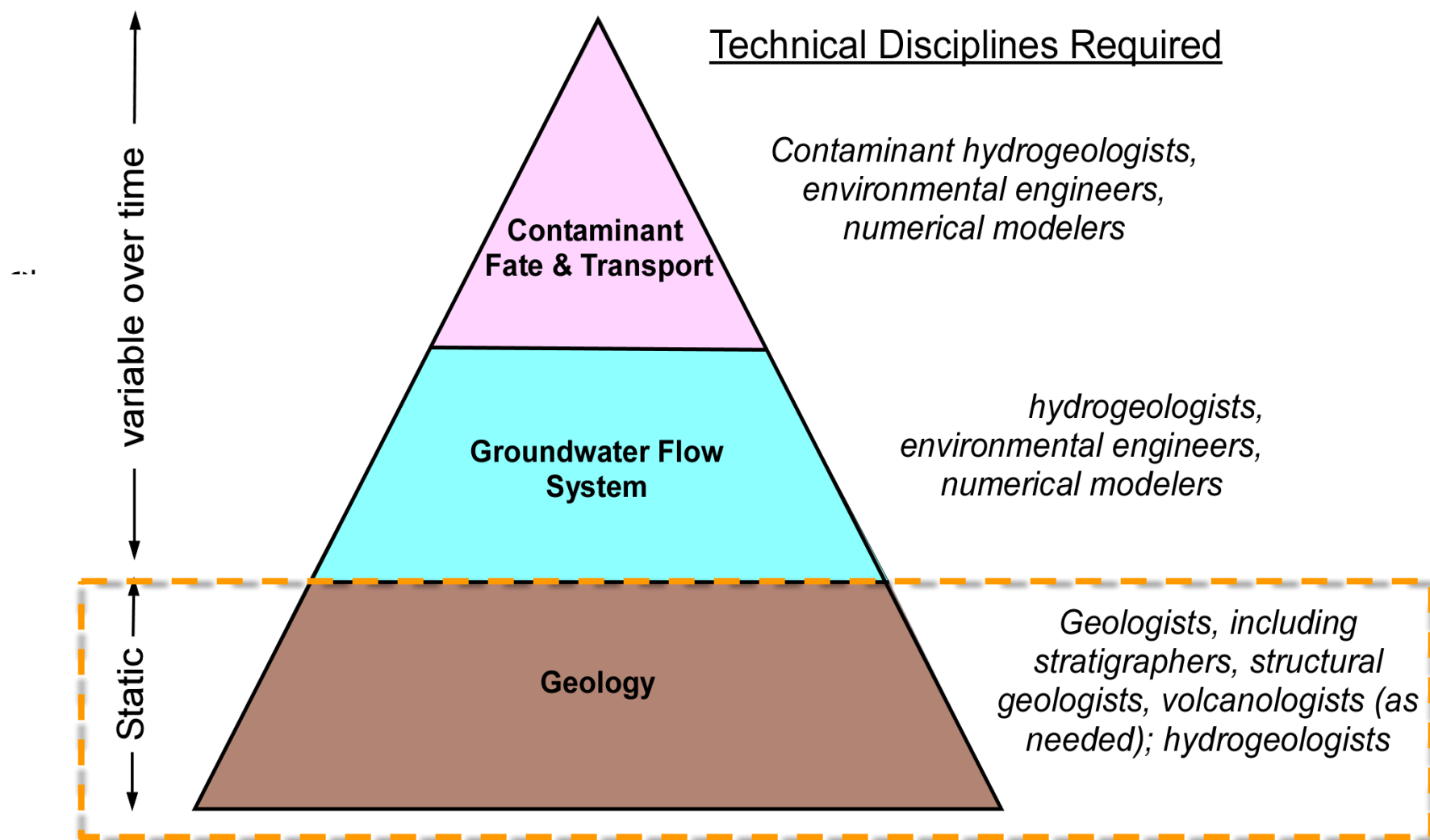
Extra Slides (Rwice)

Extra Slides (RCramer)

Primary Finding was Improved CSM = Remediation Optimization

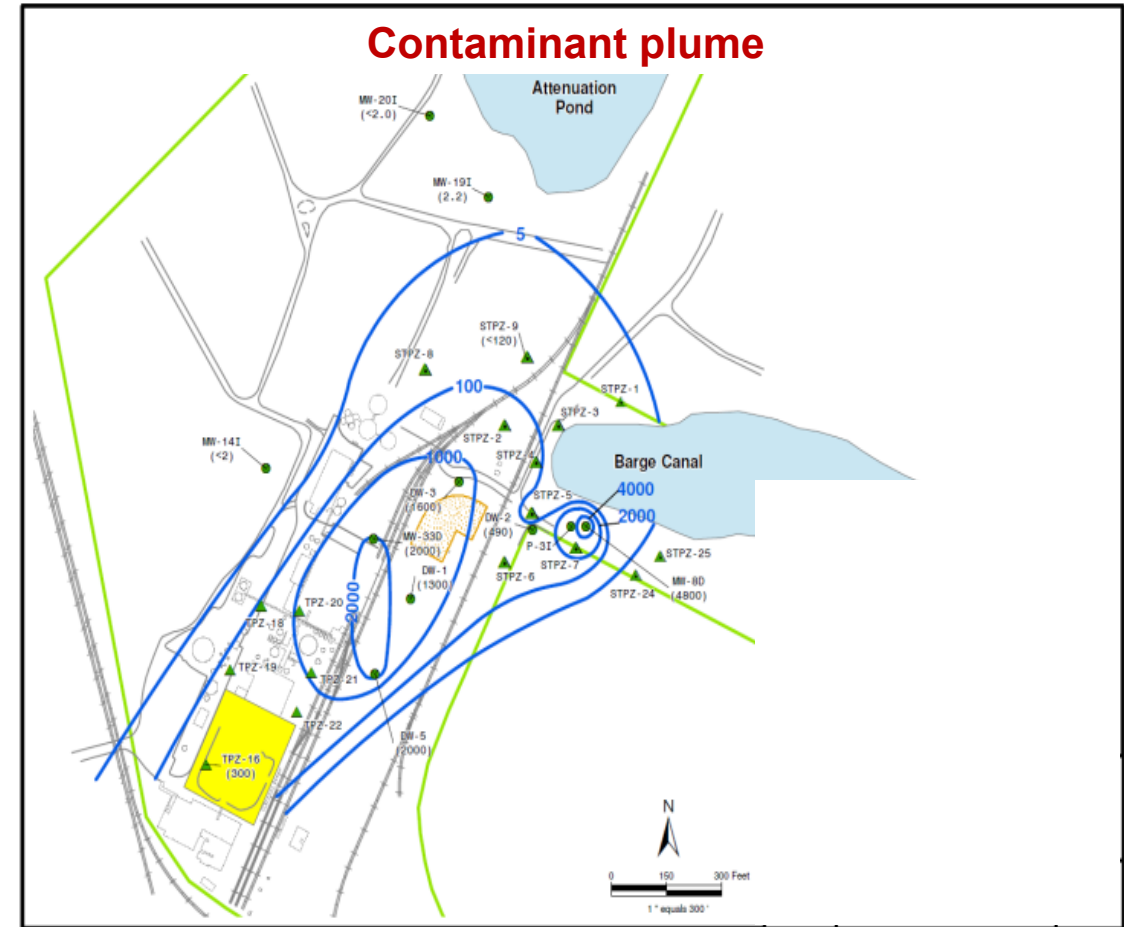
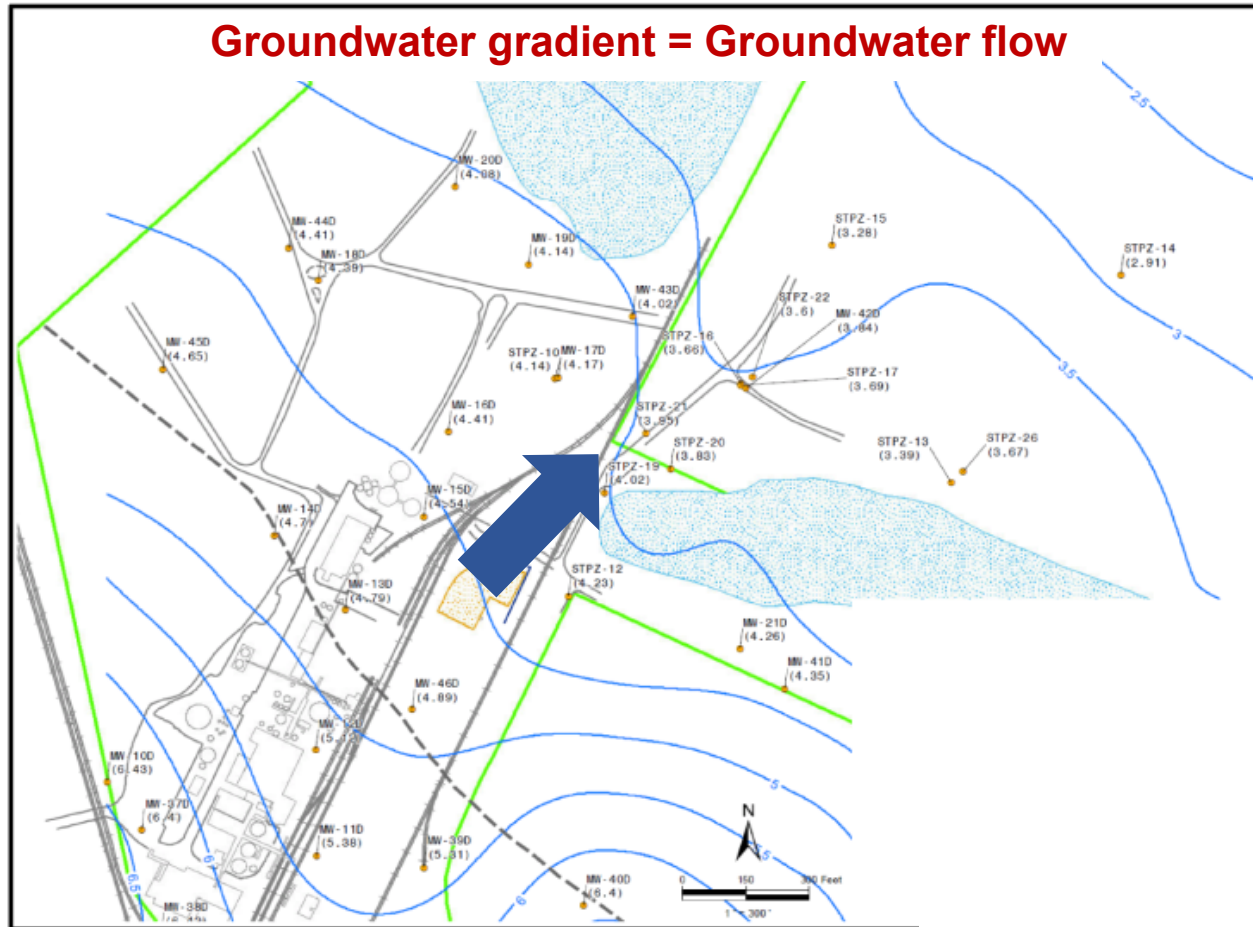


Components of a Conceptual Site Model (CSM) for a Groundwater Contaminated Site



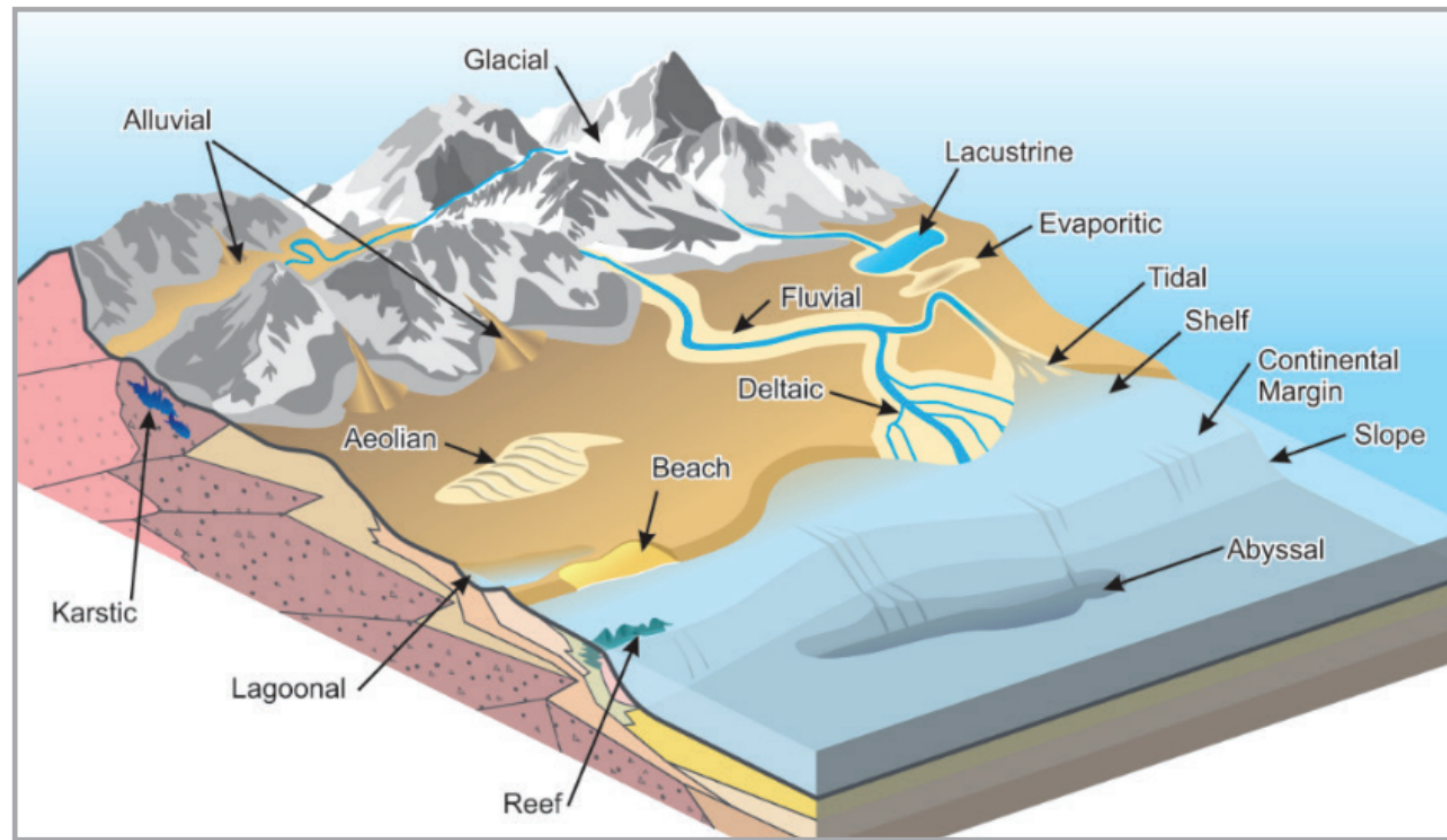
Traditional “Hydrology-Focused” Approach

...assume homogeneous and isotropic conditions, oversimplified representation of the subsurface



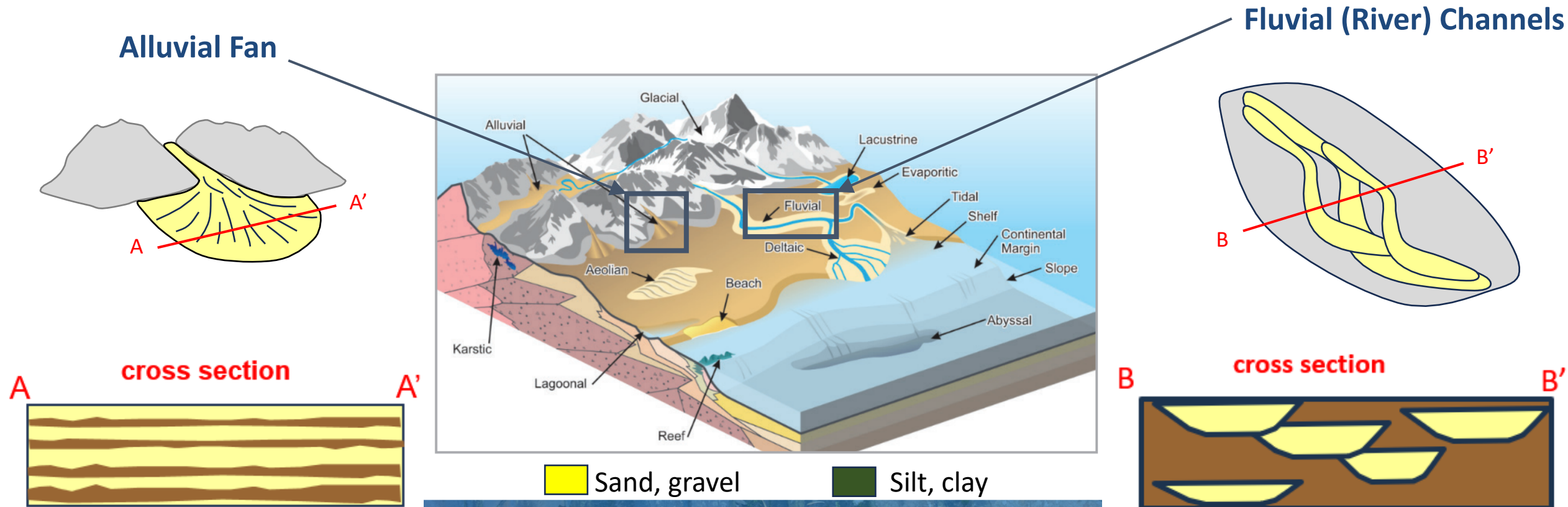
Tying Geology-Focused CSM to Remediation

Hydrostratigraphic Units (HSUs) identified through ESS will inform monitoring well target/design



Tying Geology-Focused CSM to Remediation

Hydrostratigraphic Units (HSUs) identified through ESS will inform monitoring well target/design

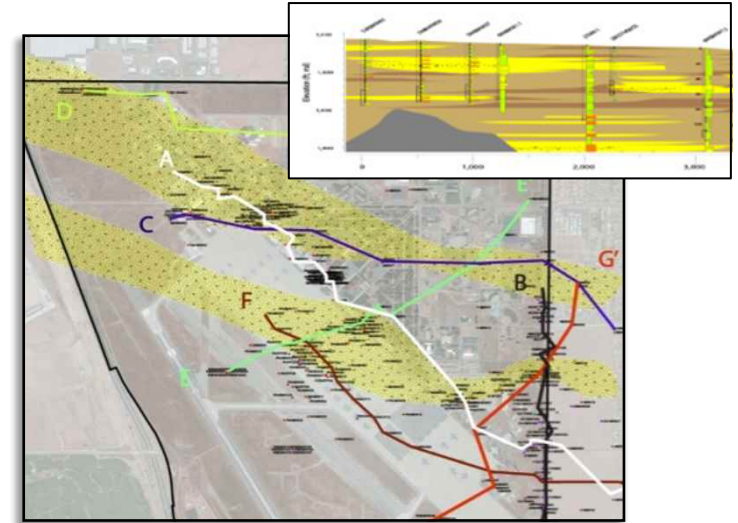
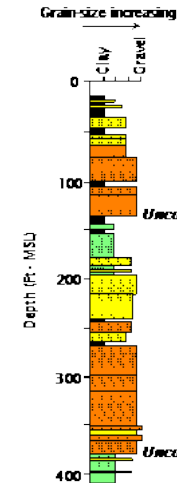


The Environmental Sequence Stratigraphy (ESS) Process



LOG OF W. 1/4 - 371 R. page 1.

Page	To	DESCRIPTION OF SURFACE	Page	To	DESCRIPTION OF SURFACE
10	25	No sample to 30'			
26	35	clay, gray, with interbedded fine med. abundant shells			
36	38	clay, gray			
39	40	clay, fine to silty, gray, uniform			
41	52	clay, gray, silty, with silty, with a 1' gray, fine sand and 1/2" to 1/4"			
53	56	sand, somewhat, gray			
56	63	sand, fine to medium, gray			
63	75	sand, medium gray silty (all gravel to 3/4", and a trace of wood)			
75	300	sand, medium to coarse, gray, with granules and a few small cobbles to 3/4". Some clay balls 1/2" to 1"			
300	305	clay, gray			
307	315	sand, medium to coarse with gravel and a few cobbles to 1" diameter			
315	320	sand medium to deep coarse, with cobbles to 1" dia. and up to 1/2" gravel			
321	345	clay, gray with shells			
345	350	silt, fine sandy, gray			
351	354	clay, gray			
354	386	silt, fine sandy, gray silt, to about becoming sandier with shells from 1/2" to 1"			
Particulars 245' - 355' CENTER ON SECT 1A.					
Drawn by: _____					
Verified by: _____					
Scale: <u>Graph. Scale 8 1/2" = 40'</u>					
Log. & E. Log. by <u>L. G. GARDNER</u>					



1

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

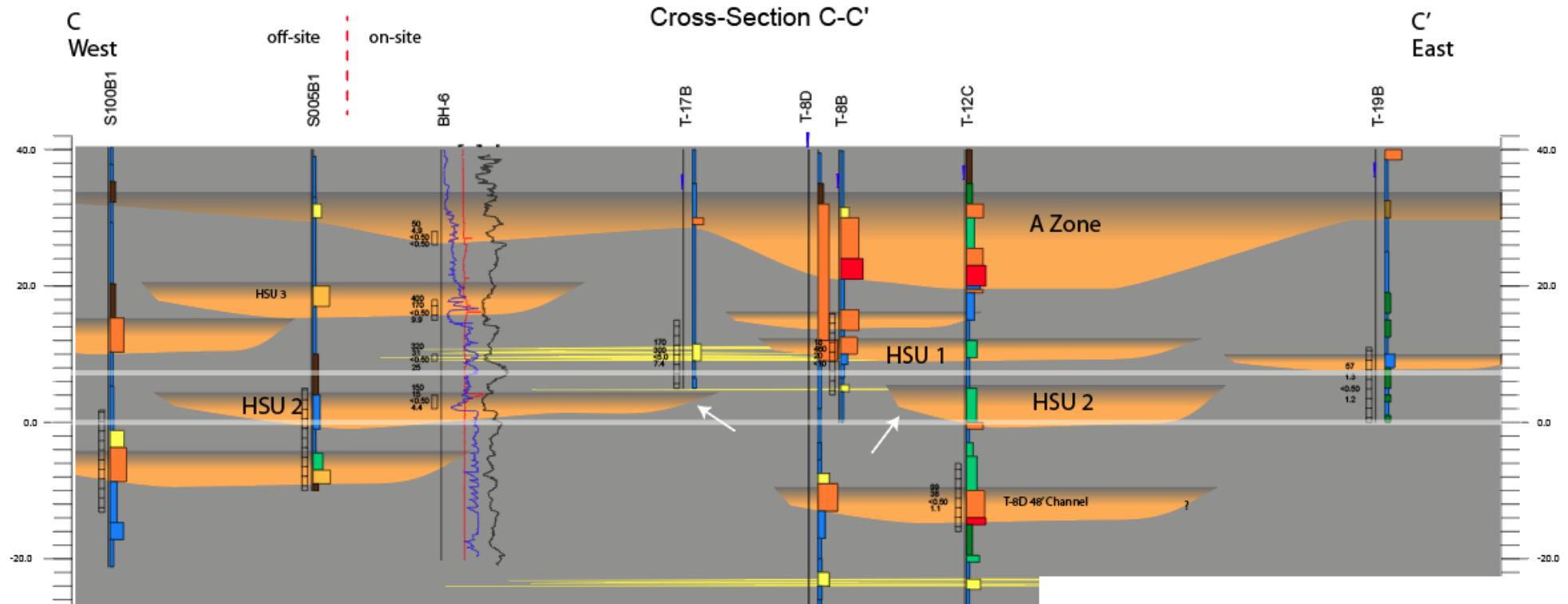
2

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

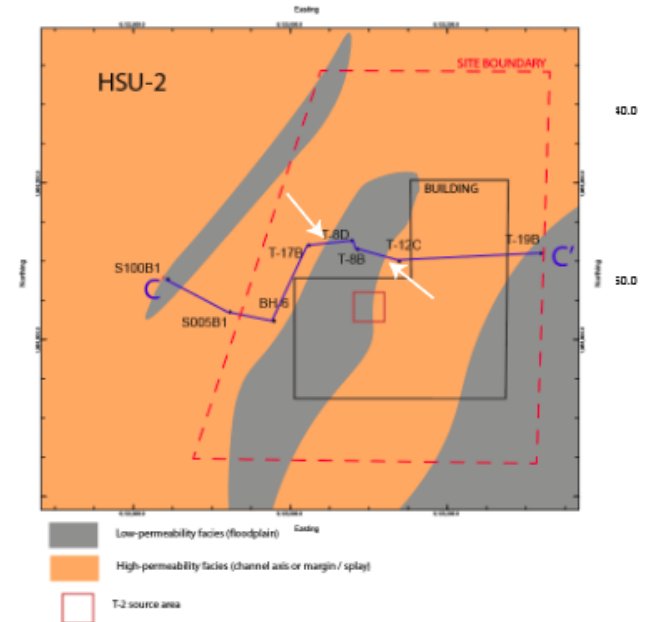
3

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

ESS Cross Section

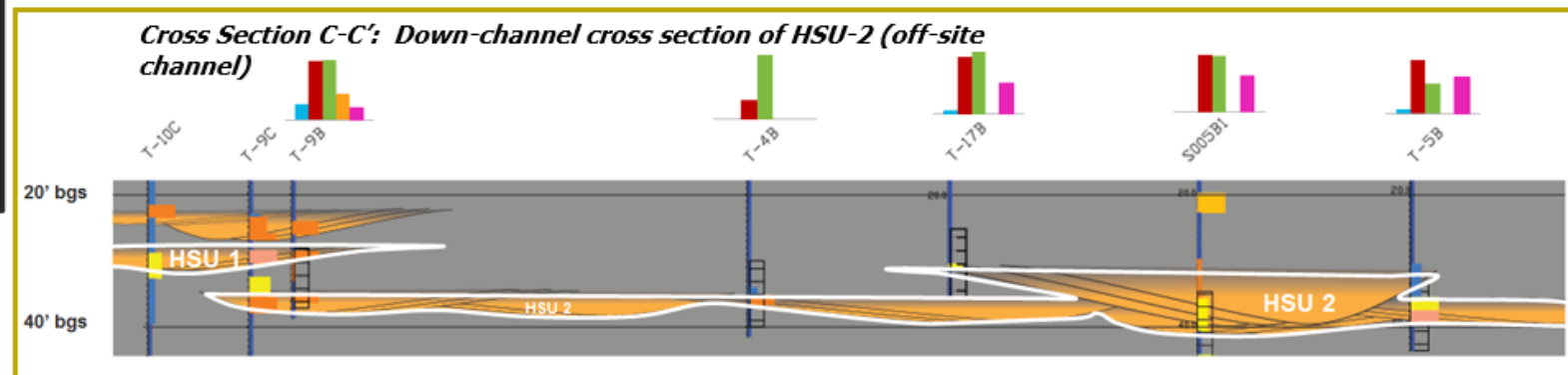
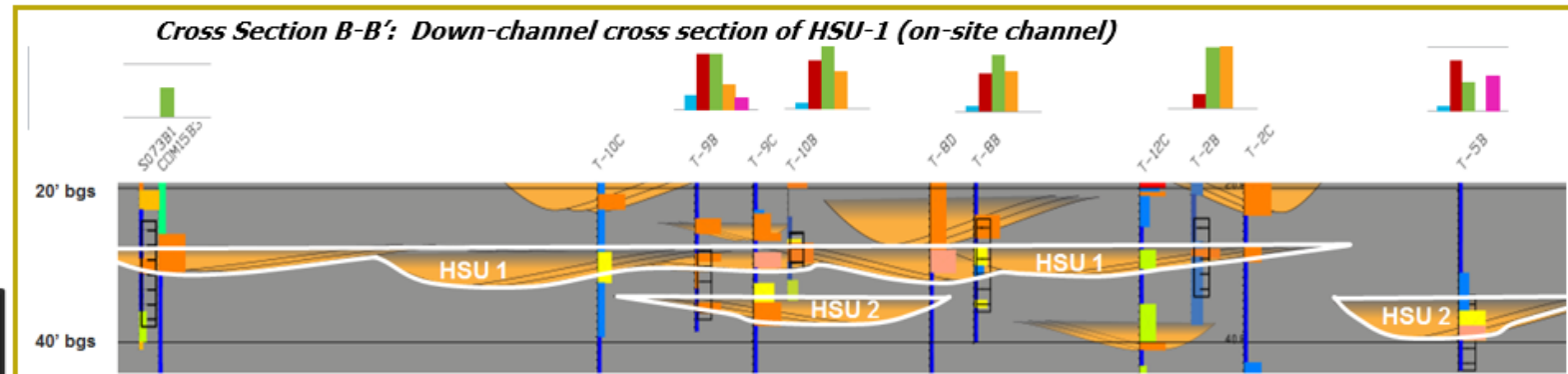
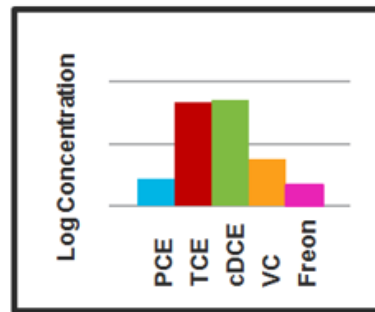
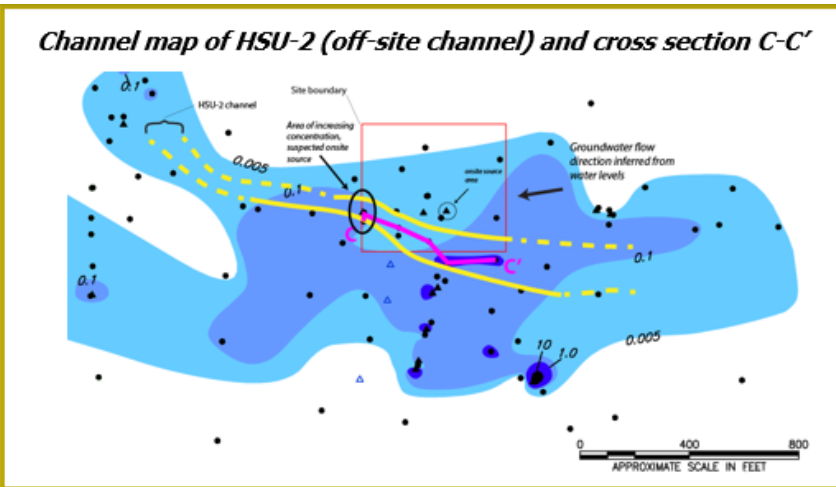
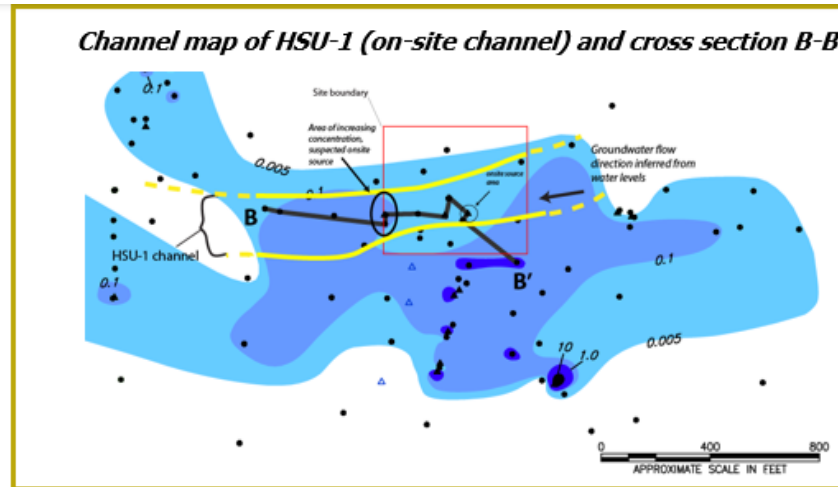


- Detailed mapping of hydrostratigraphic units in three dimensions with maps and cross sections
- Constrained by existing well data, interpreted in context of depositional environment, facies models



ESS-Based CSM

- ▶ Result: detailed understanding of source-to-monitoring well hydraulic connection
- ▶ Confirmed by contaminant fingerprinting
- ▶ Resolved need for additional source area remediation

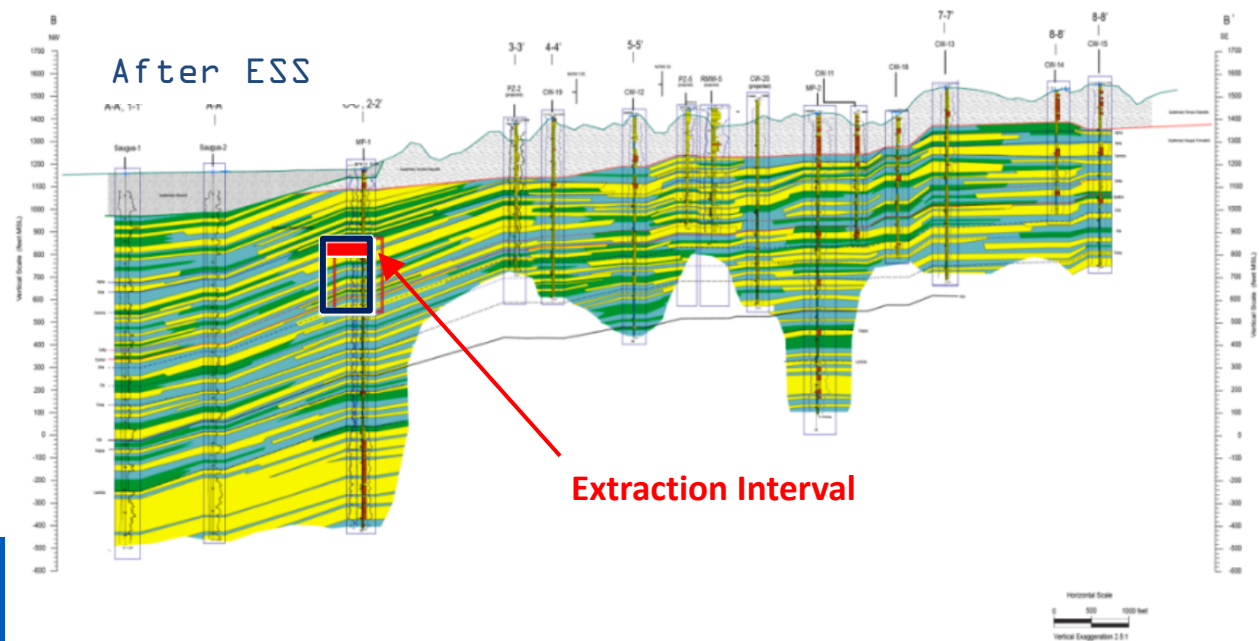
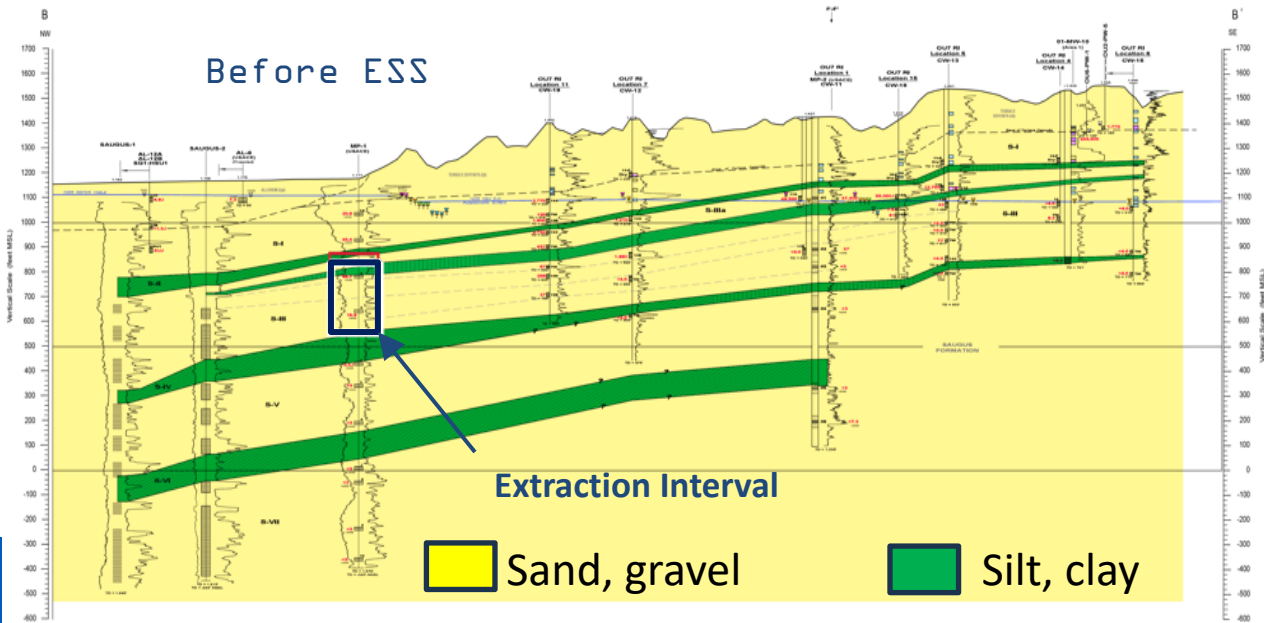


Conceptual Site Model (CSM)

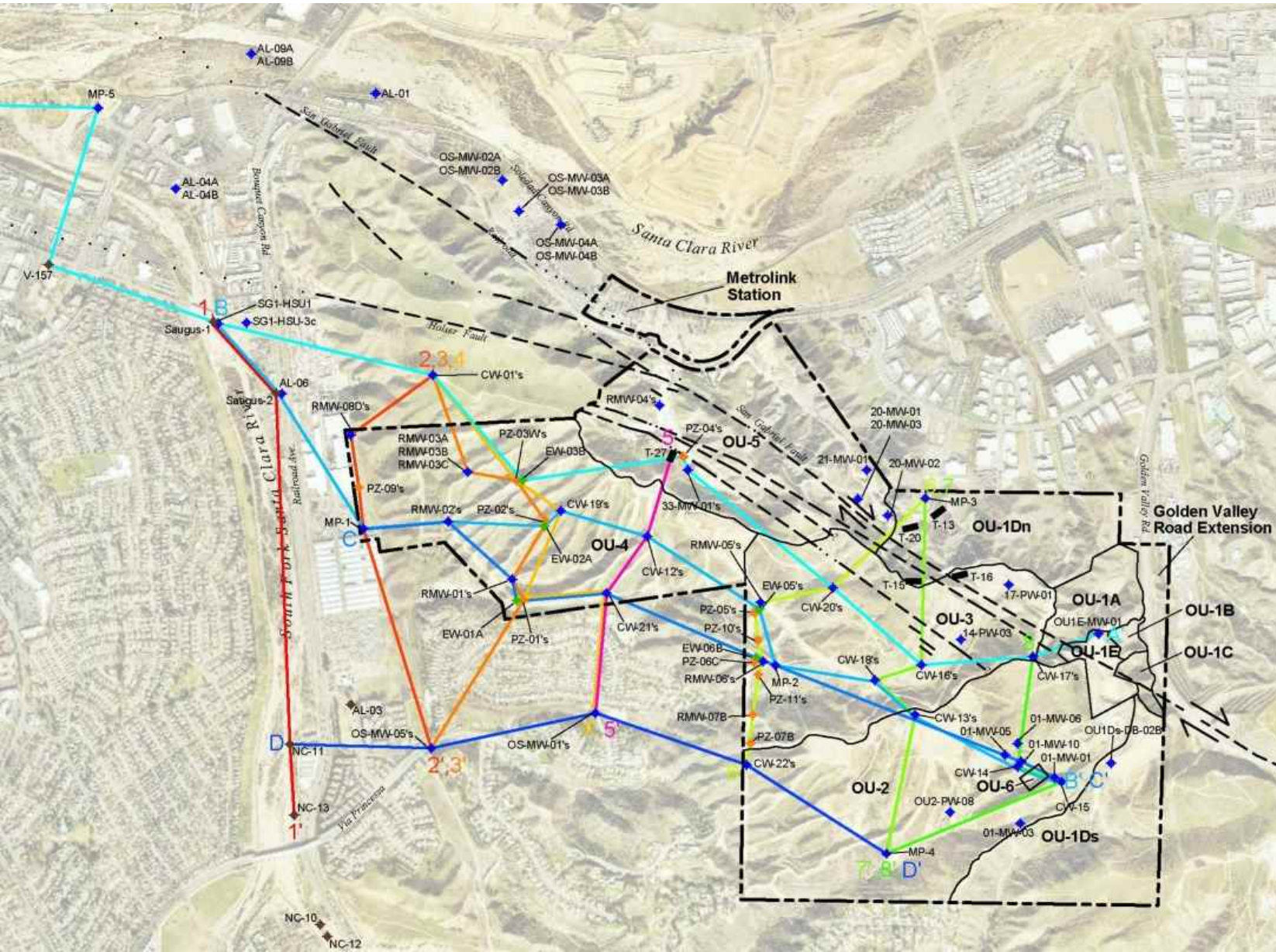
Example:

Applying ESS to a contaminated site in Southern California

- ▶ Original CSM interpreted a layer-cake system of only five units
- ▶ ESS recognized more detailed, complex subsurface conditions

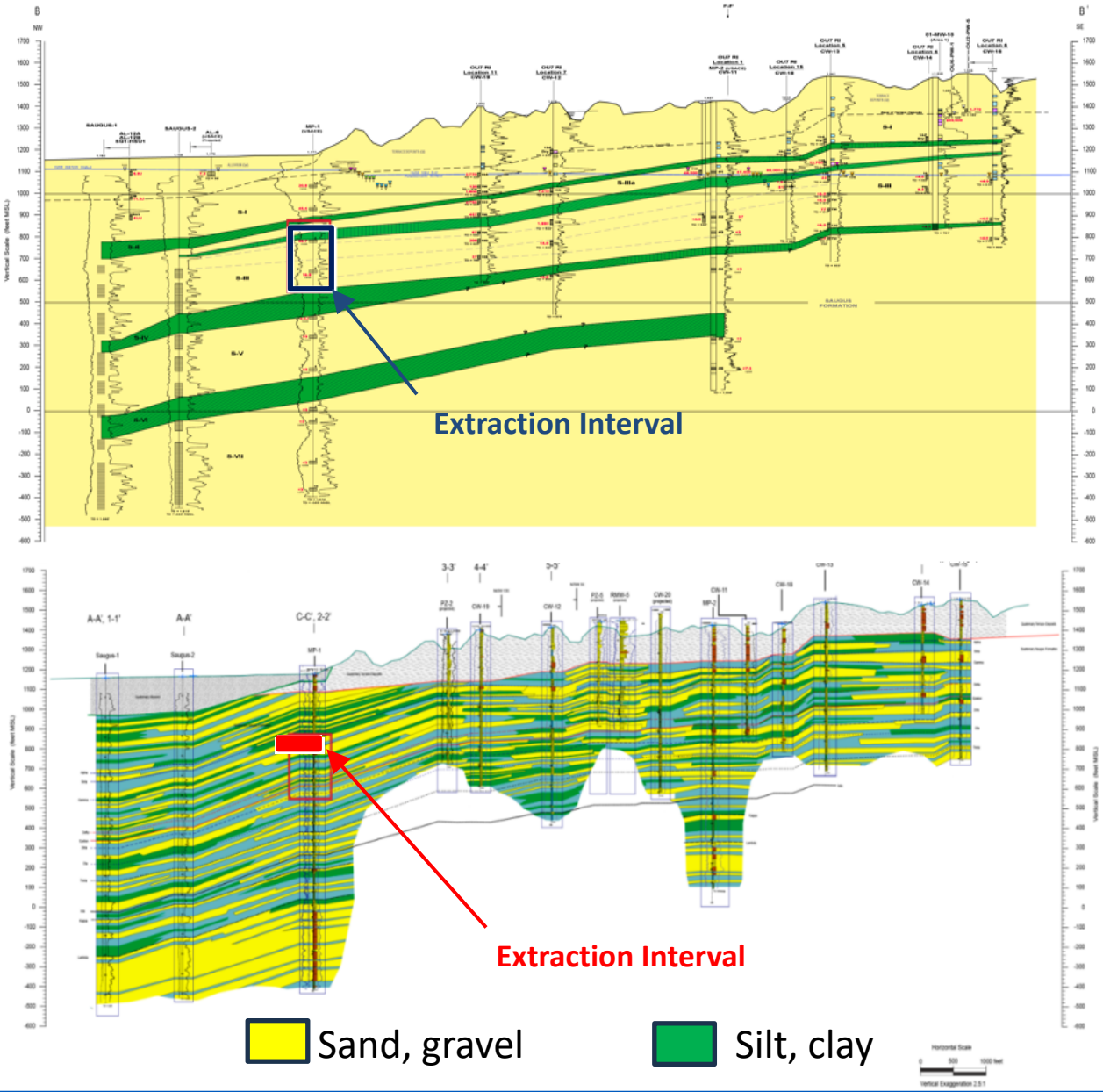


S. CA Site: Shutdown of Production Well (perchlorate)



~\$100,000 ESS
evaluation using
existing data to
create a network of
cross sections
representing a 3D
definition of the
subsurface.

S. CA Site: Shutdown of Production Well (perchlorate)



- Reduced cost of remediation by >\$50 million
- Reduced quantity of extracted groundwater by >70%

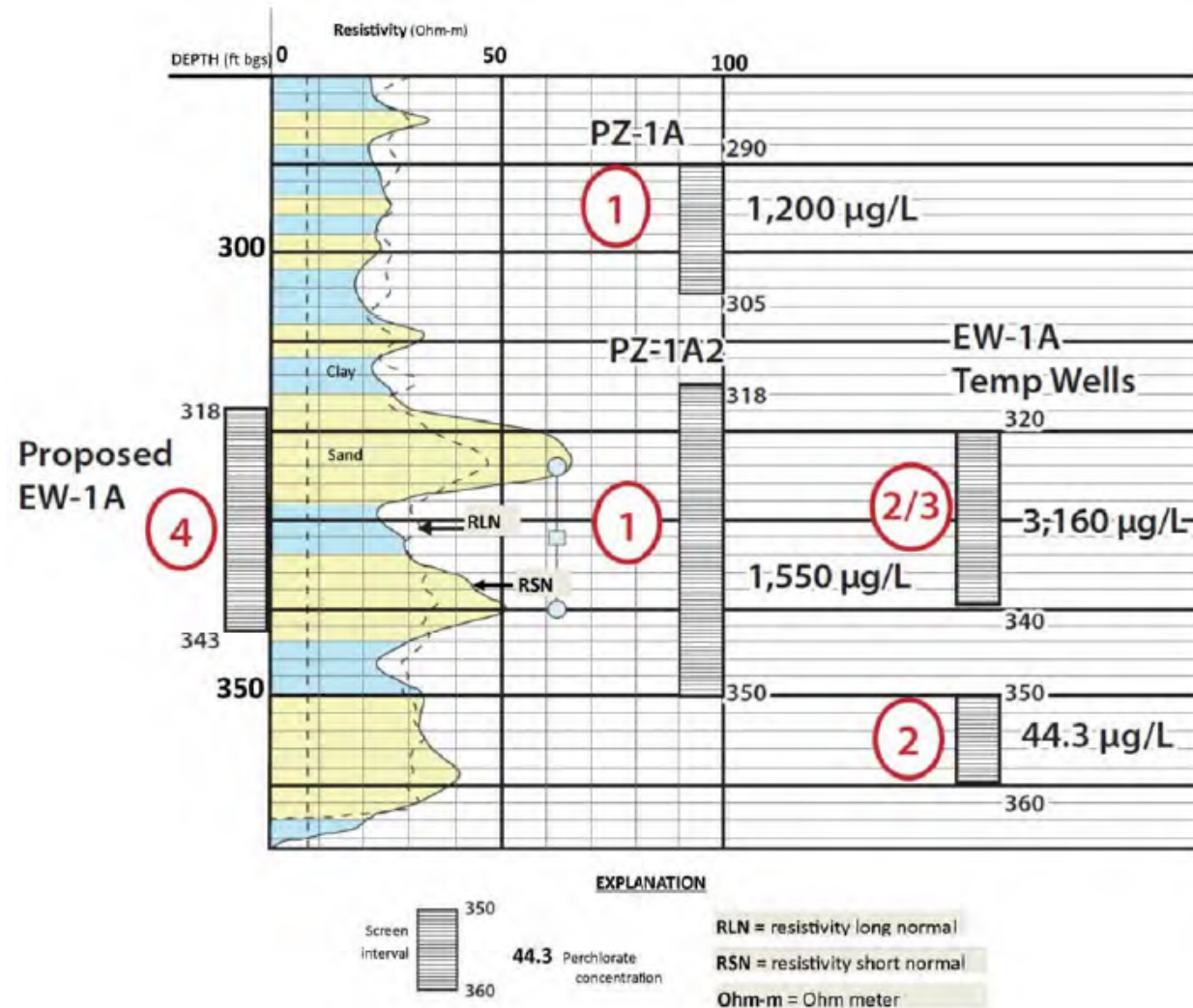


Figure A27. Extraction Well Design – Strategic and Systematic. Based on the ESS CSM, HSU designations of specific well screen intervals were evaluated based on strategic, sequential aquifer tests and groundwater chemistry data to validate the stratigraphic framework and optimize the groundwater extraction well design. Screens 1 are initial pilot hole/piezometers for lithology and monitoring. Screen 2 represents temporary wells to collect depth-discrete groundwater chemistry. Screen 3 represents monitoring wells, and screen 4 is the final extraction well interval.

Extra Slides (THalihan)

Extra Slides (IBowen)

Extra Slides (FondaA)

Extra Slides (PCiampi)

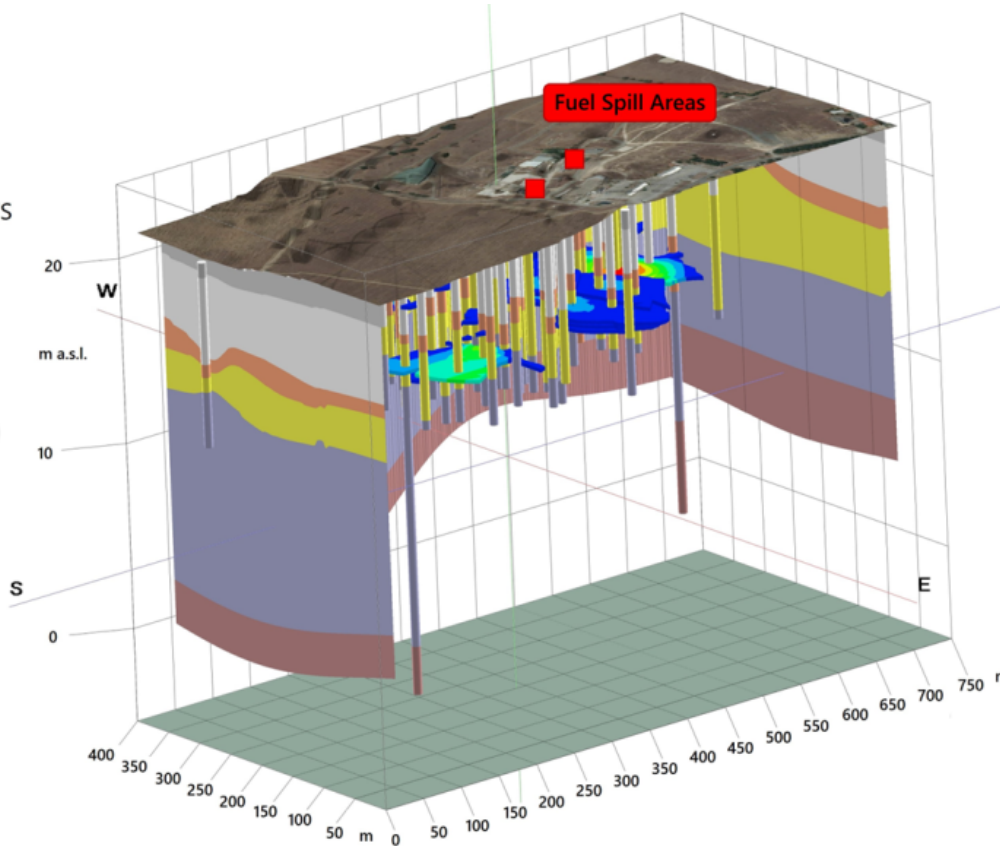
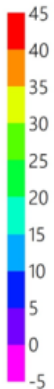
Case 2- LNAPL contaminated site

Ciampi et al. 2022

Stratigraphy

- Backfill
- Recent Alluvia
- Intermediate Clays
- Ancient Alluvia
- Base Clays
- Base Gravels

Fluorescence (%)

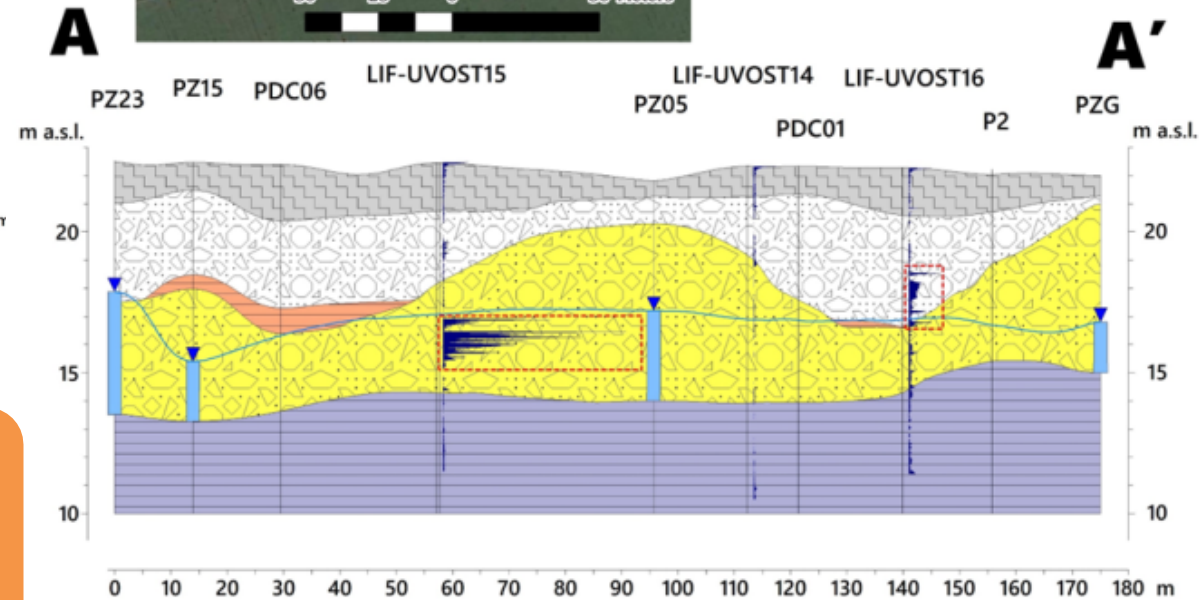


Stratigraphy

- Backfill
- Recent Alluvia
- Intermediate Clays
- Ancient Alluvia
- Base Clays

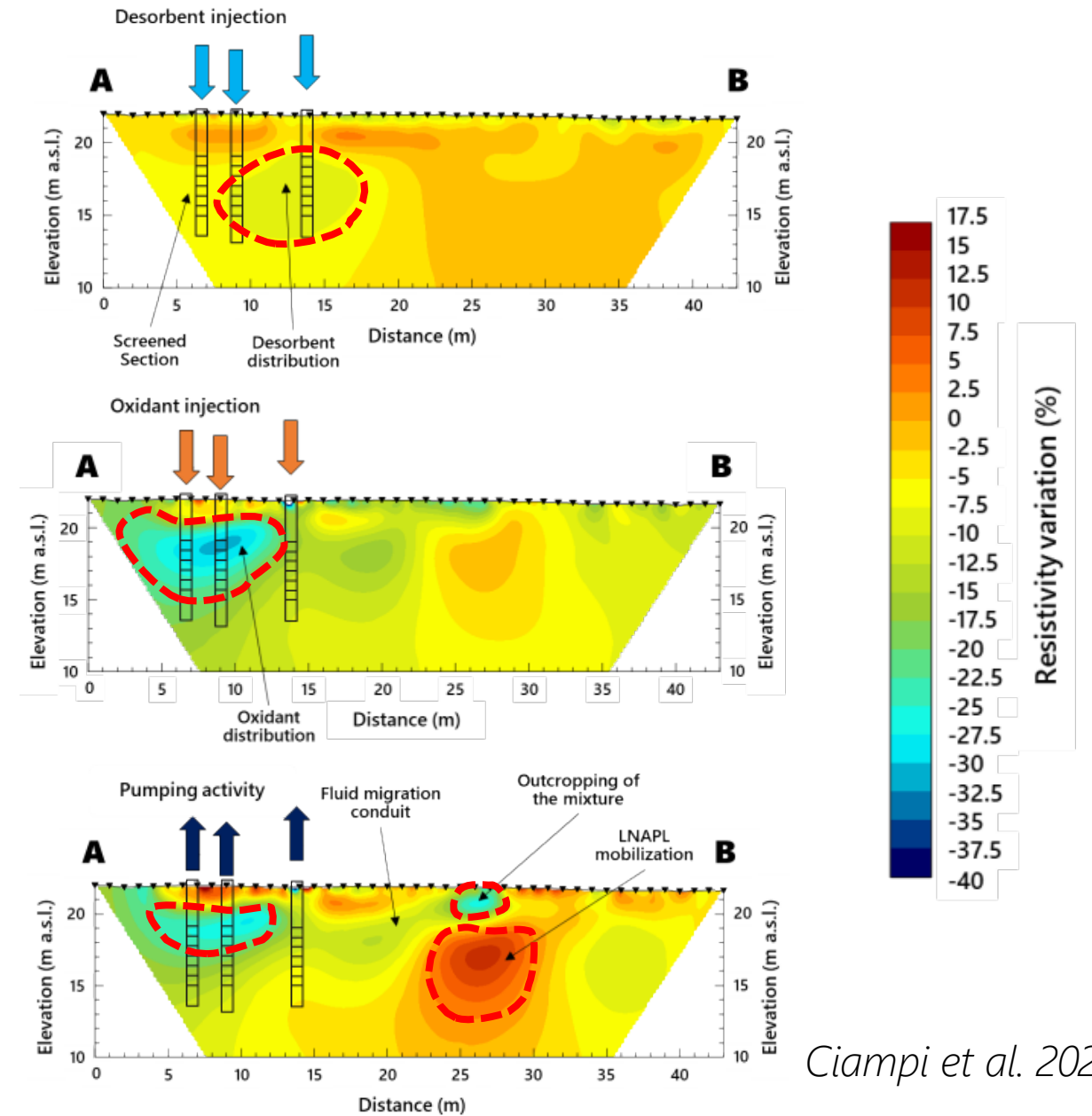
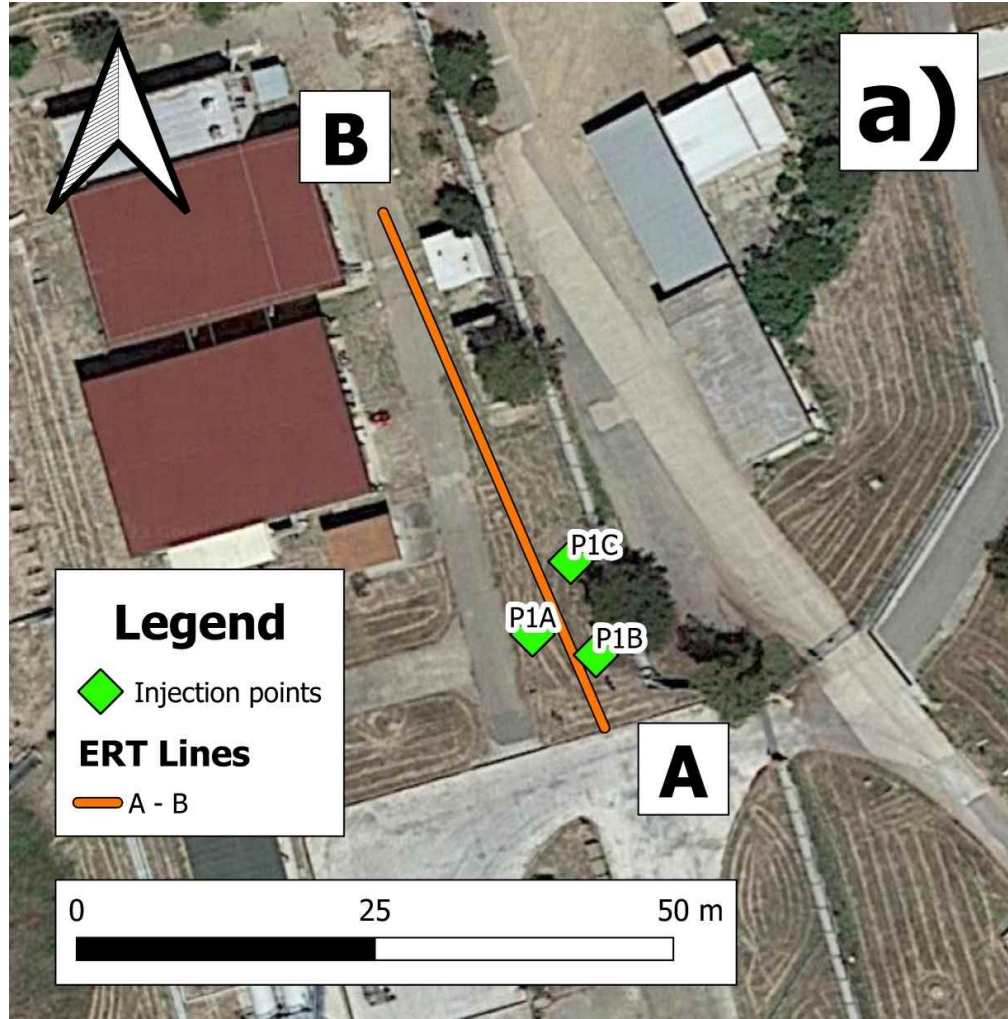
Aquifer

- Shallow aquifer
- Groundwater level



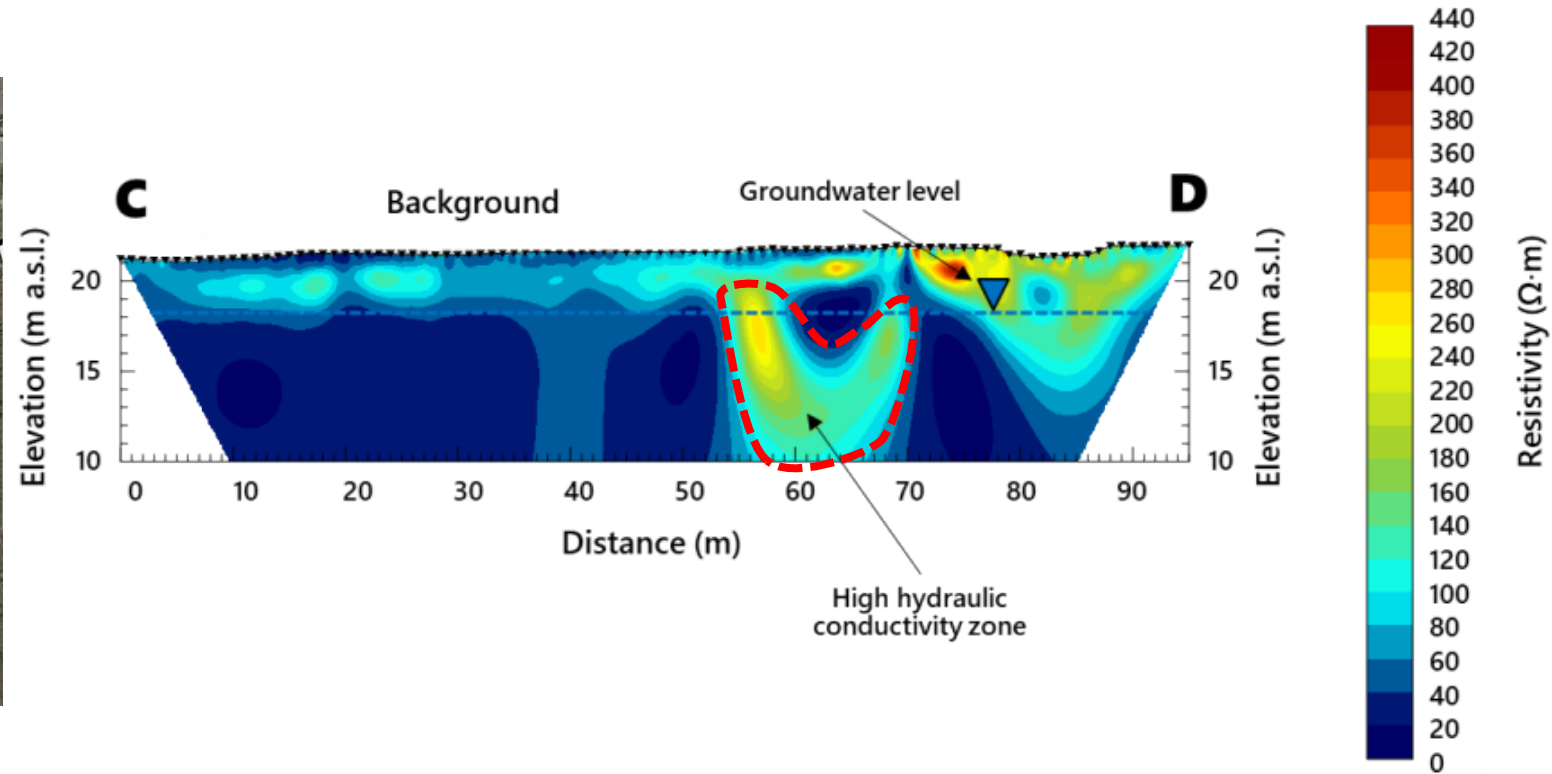
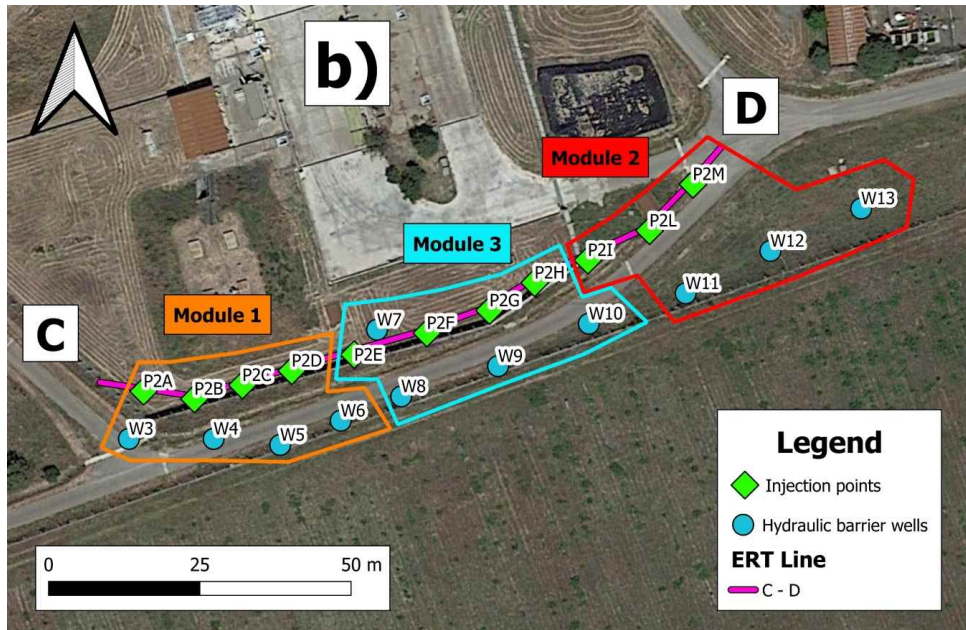
1. A data-driven CSM identifies with high vertical resolution the presence of free-phase or adsorbed contaminants on the solid matrix
2. It unveils the presence of residual free-phase/adsorbed hydrocarbons on the smear zone

4D Full-Scale (ERT line AB)



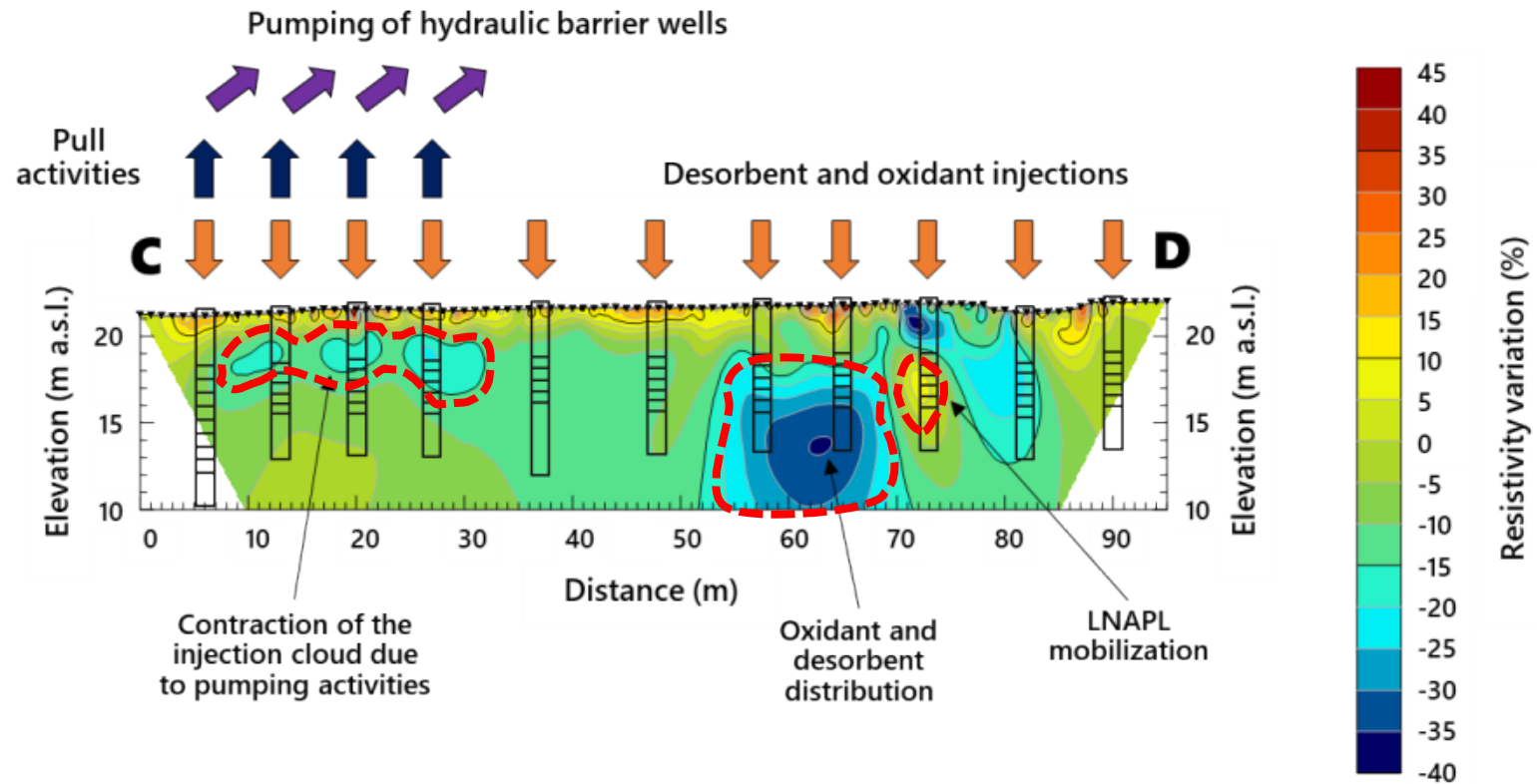
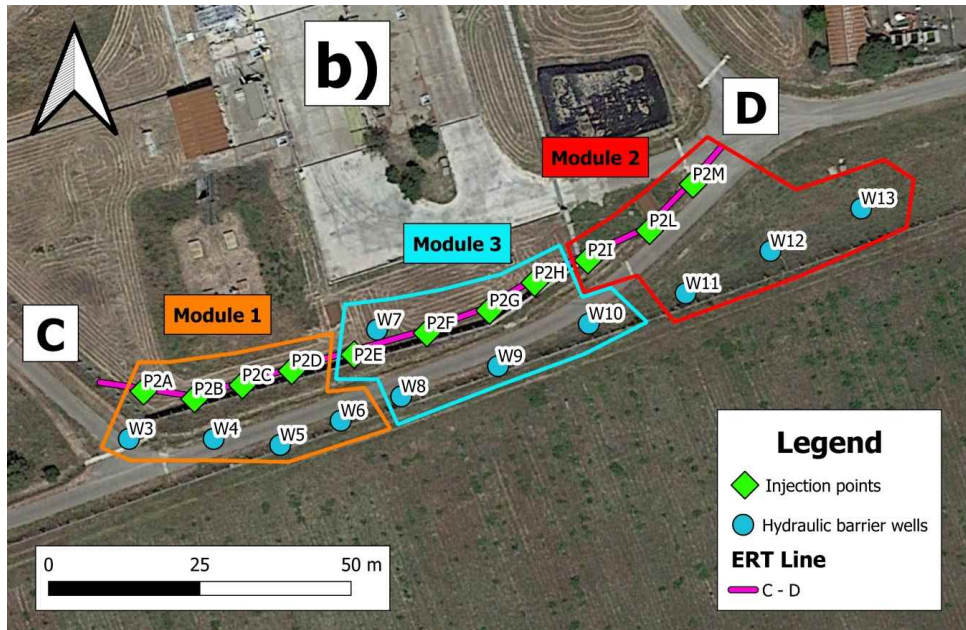
Ciampi et al. 2024

4D Full-Scale (ERT Line CD)



Ciampi et al. 2024

4D Full-Scale (ERT Line CD)



Ciampi et al. 2024