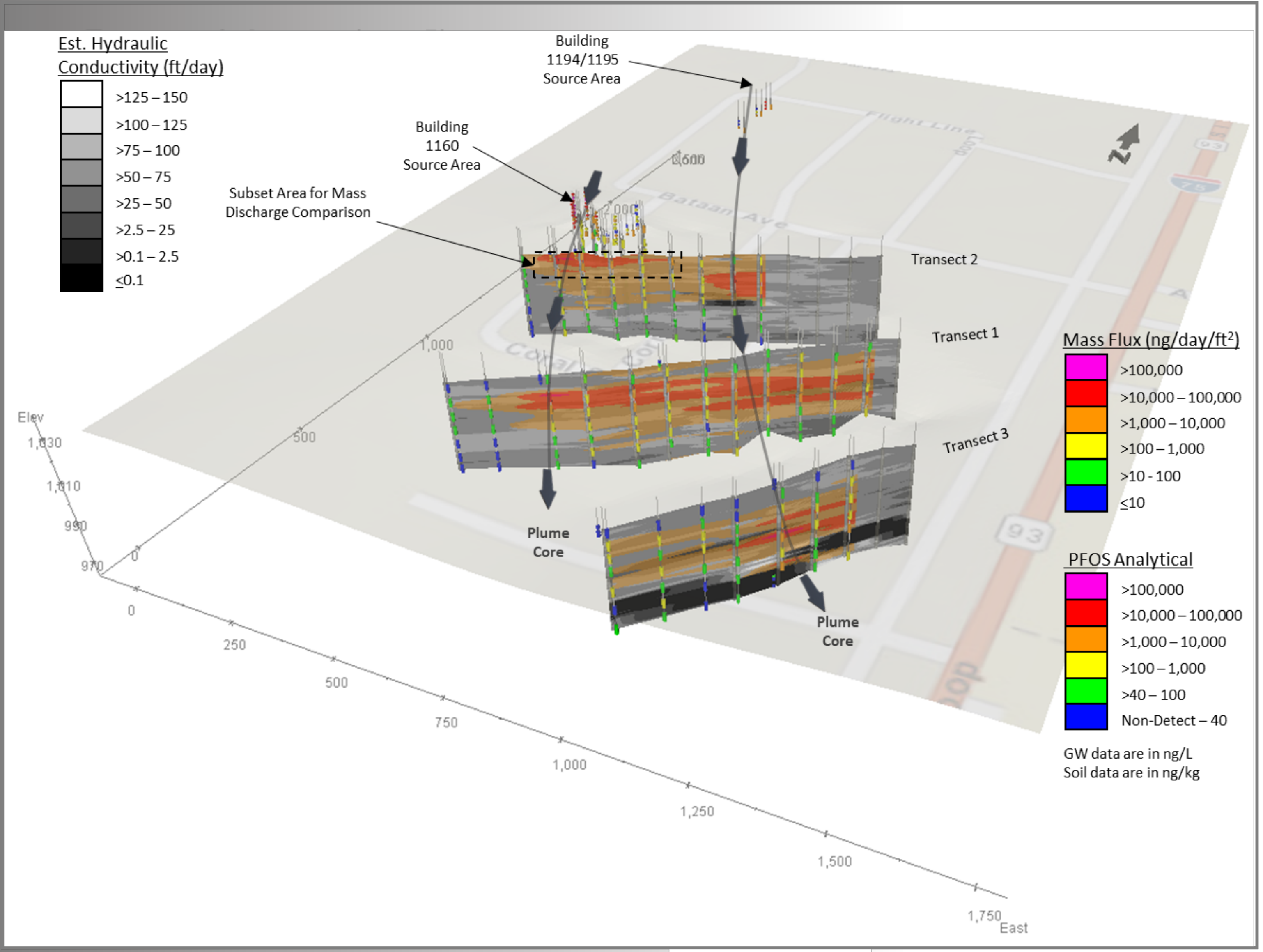
HRSC Technologies and Methods for Mapping PFAS Concentrations and Mass Flux



Federal Remediation Technologies Roundtable

November 7, 2023

Agenda

- Why does Flux matter?
- HRSC for PFAS RIs
- 4 Key Elements
- PFAS Considerations
- Buckley SFB Example
- Flux monitoring

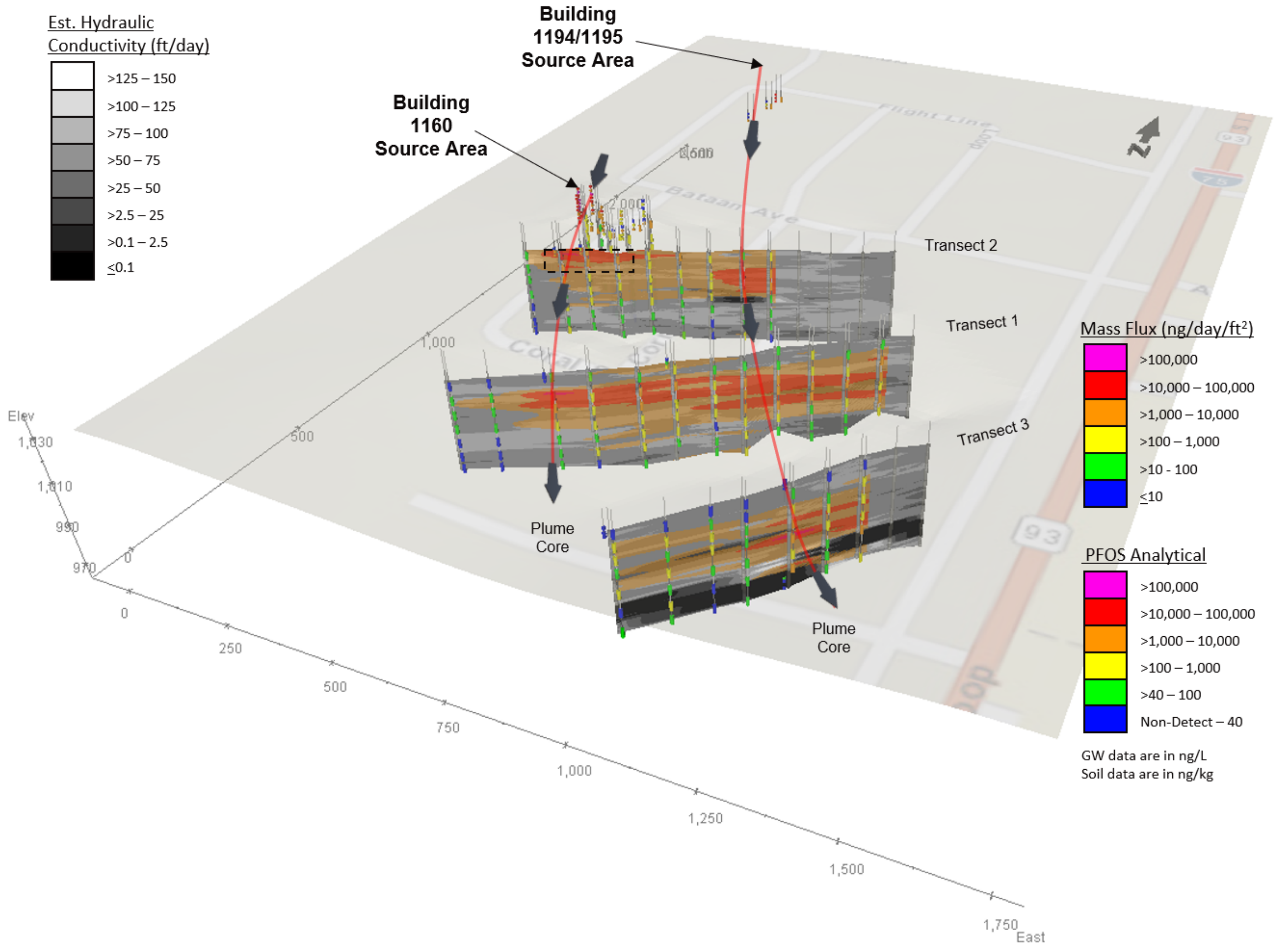
Why Does Flux Matter?

Contaminant maps are only half of the story

- Flux distinguishes mass in high permeability and low permeability zones to better quantify mass transport

Mass Flux describes the concentration of contaminant movement

- Better understanding of risk
- Focus remedies to improve performance and cost efficiency



ESTCP-ER19-5203

Mass Flux and Mass Discharge

<u>Mass Flux:</u>

Mass flow across a unit area

$\mathbf{J = K\ i\ C}$ (mass/time/area)

K = Hydraulic Conductivity

i = Hydraulic Gradient

C = Concentration

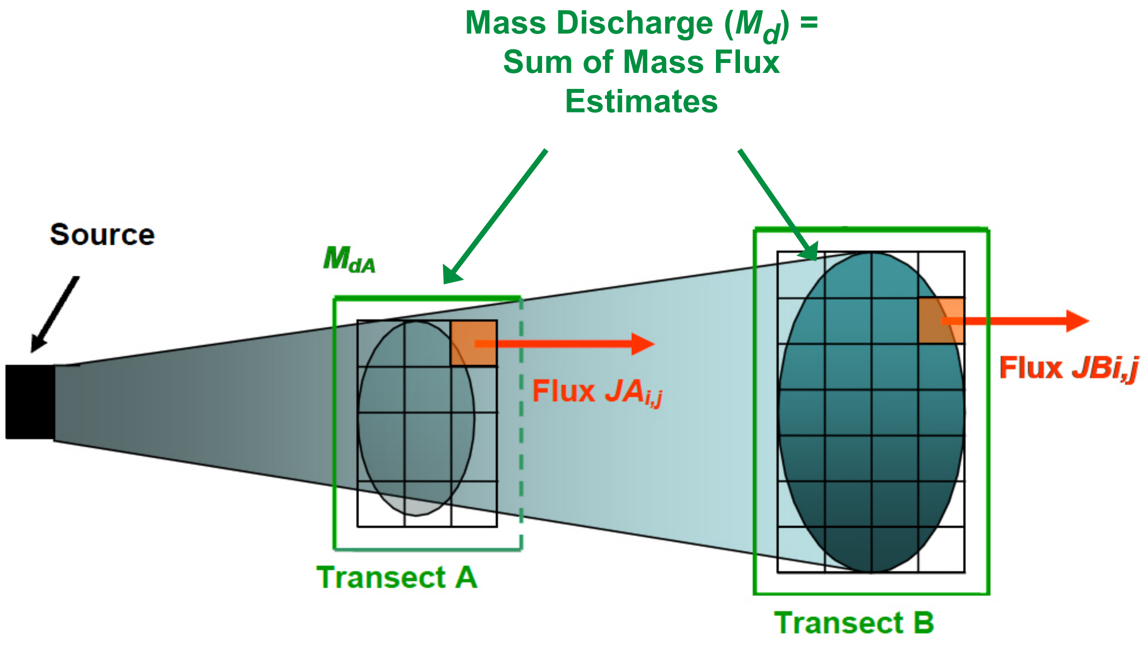
<u>Mass Discharge:</u>

Integrated mass flux

$\mathbf{M_d = \int_A J\ dA}$ (mass/time)

J = Mass Flux

A = Total area



Adapted from ITRC, 2010

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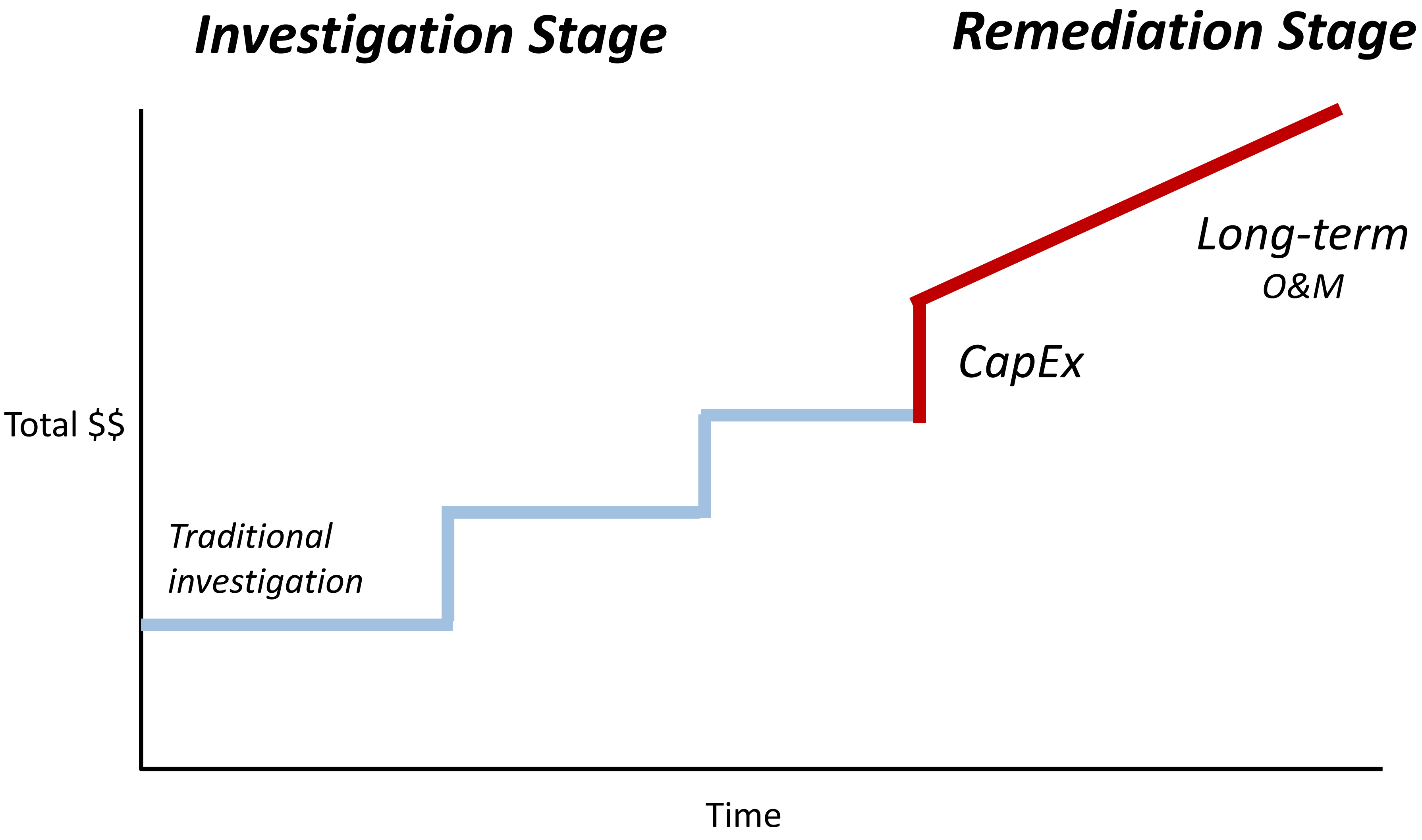

Doesn’t high resolution mean high-cost characterization?

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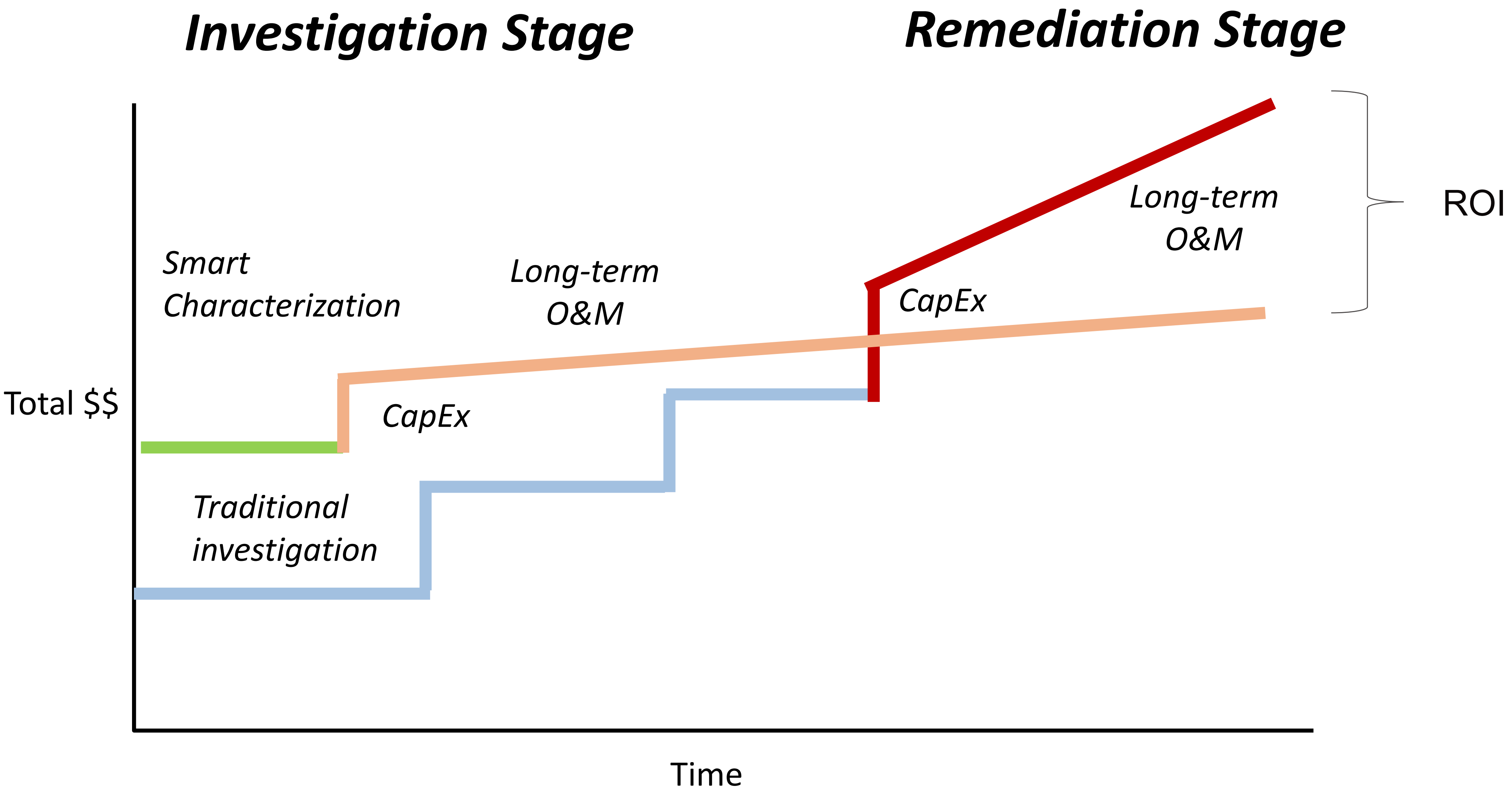
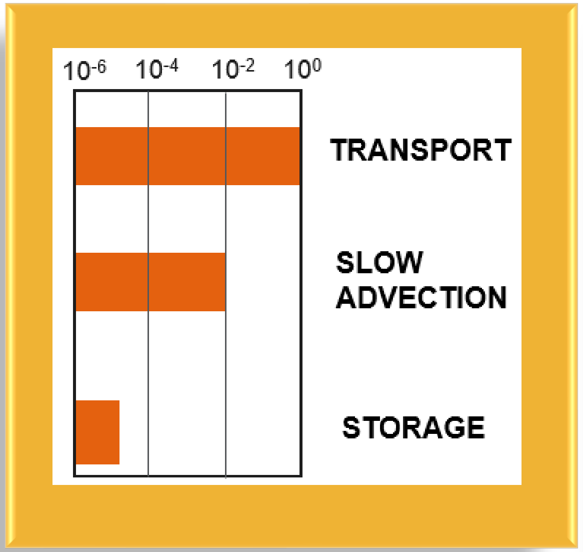


The return on investigation – life-cycle cost and performance optimization

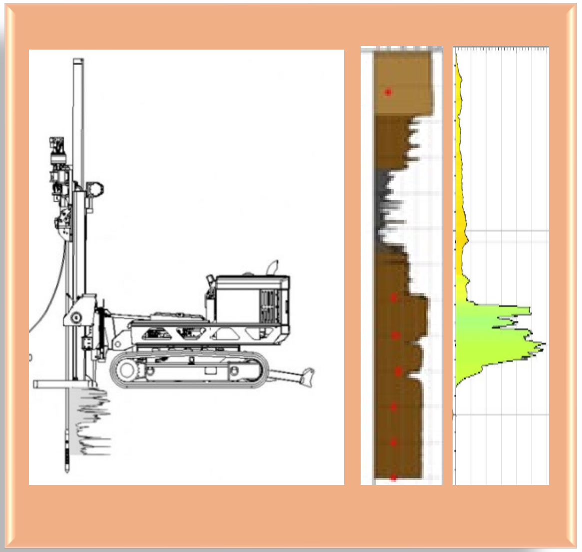
Smart Characterization® : *Find the Flux*

Flux-Based CSM



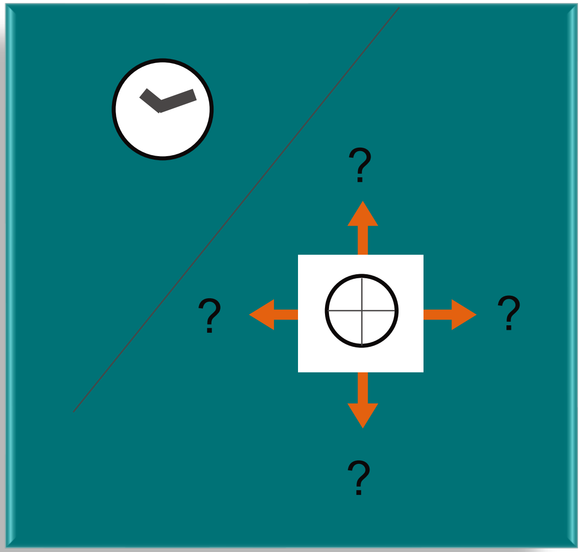
- *Majority of flux in permeable zones*

Right tools to map flux



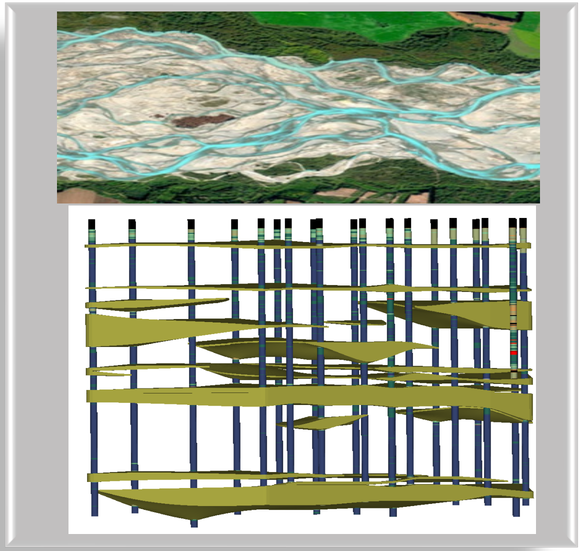
- *Quantitative*
- *High-resolution*

Real-time & adaptive



- *Lower investigation costs*

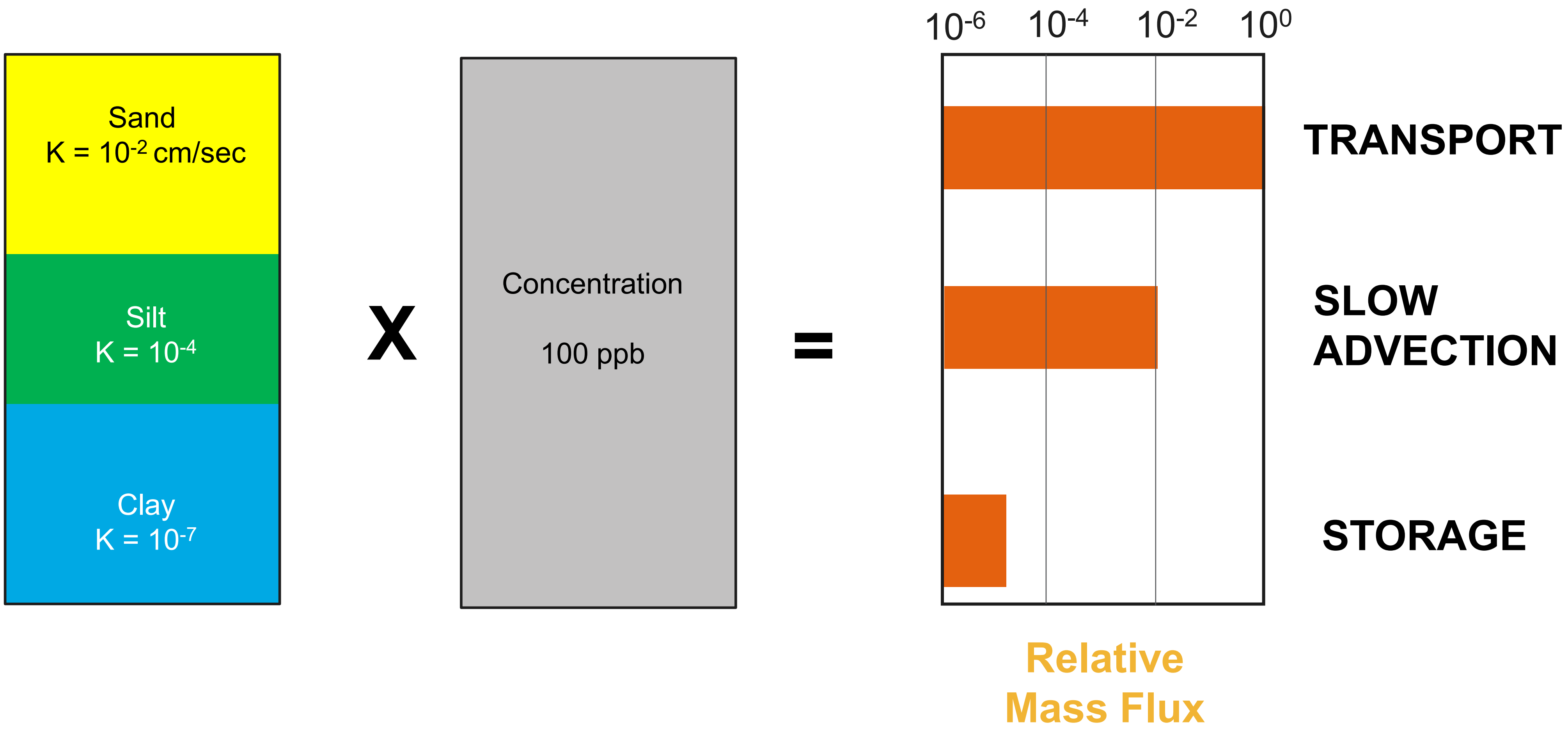
Interpretation



- *3D analysis*
- *Classical geologic approach*

Stratigraphic Flux Framework for Transport

Evaluating mass flux based on the soil types and permeability structure of the aquifer



HRSC for PFAS?

Data Quality Objectives:

PFAS Compounds - Concentration

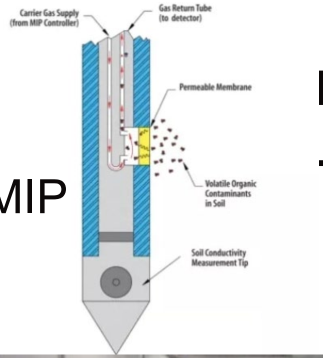
- Selectivity to accurately measure specific PFAS compounds
- Sensitivity to resolve specific compounds relative to USEPA risk-based screening levels
- Near real-time results to facilitate adaptive characterization

Stratigraphy and Hydraulic Conductivity (K)

- Continuous logging – essential to see facies trends
- Provide consistent and reliable estimates of K

Current PFAS Analytical Options

No field screening options



MIP

No PFAS Direct Sensing Technologies Exist

No PFAS Mobile Labs Available

ASD memo requires USEPA Draft Method 1633

Compliant with QSM 5.4 Table B24

- Slow method/surging demand
- Significant Delays
- Up to 6 months for validated data
- High Costs, approx. $375/sample

Solution

Use workflow planning and HRSC sampling methods

- Vertical aquifer profile sampling, hand augers, passive flux meters, etc
- Screening methods with rapid turn-around

Current PFAS Analytical Options - Screening Levels Methods

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Two Categories of Screening Level PFAS Techniques

Non-targeted screening methods – Examples are AOF by EPA 1621 and PIGE

- Total fluorine results, limited value
- RLs in ppb range – too high
- Not field deployable
- Relatively slow and expensive

RL too high and not selective

Targeted Screening Methods – ASTM D8421

- Target compound list – up to 40 compounds
- Easier method, rapid TAT = ~ 3 to 5 days
- Cost ~ $250/sample
- Can meet most characterization DQO requirements

Not as efficient as the analytical tools used for fuels and solvents
BUT*…*
Much faster and cheaper than using only 1633

PFAS Analytical Screening Options

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ASTM D8421 - Additional Information and Recommendations

- Rigorous multi-lab validation study using 11 environmental waters >>>
- DoD Acceptance: ASD Memo Dated 8/7/23 states "*Other methods for analysis may be considered for screening samples to determine the presence or magnitude of PFAS concentration*" Requires approval.
- Approval process - DMA with ARNG underway
- Used in conjunction with 1633 (USEPA Triad's collaborative data collection)
- Capacity is strong – Pace, SGS, Elle and several other smaller labs providing this type of service.

Matrices Tested

- Landfill Leachate
- Metal Finisher
- POTW Effluent 1
- Hospital
- POTW Influent
- Bus Washing Station
- Powerplant
- Pulp and Paper
- POTW Effluent 2
- Ground Water
- Surface Water

Implementing Screening

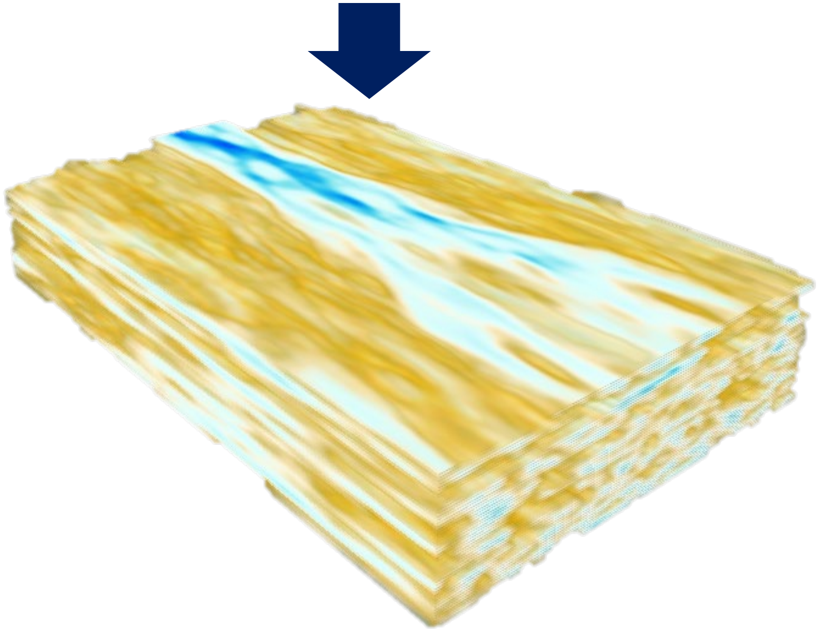
- **Planning Phase**
  - Define DQOs
    - Regulatory requirements
    - Interim data vs final data
    - Pace of work, phased vs. near real-time
    - Quantity and type of samples

    } Does adaptive/screening work make sense?
  - Setup comparison studies
    - Split frequencies
    - Statistics – standard correlations and reliability evaluations
    - Evaluation of comparison data sets, look at reliability
- **Field Work Phase**
  - Digital CSM to aid with data management and presentations
  - Decision logic used for managing adaptive workflow

Geological Soil Description

Aquifers are Created by Complex Depositional Environments:

- Not homogenous
- Highly variable vertically and horizontally
- Features are directionally dependent
- Permeability will vary by several orders of magnitude within short distances

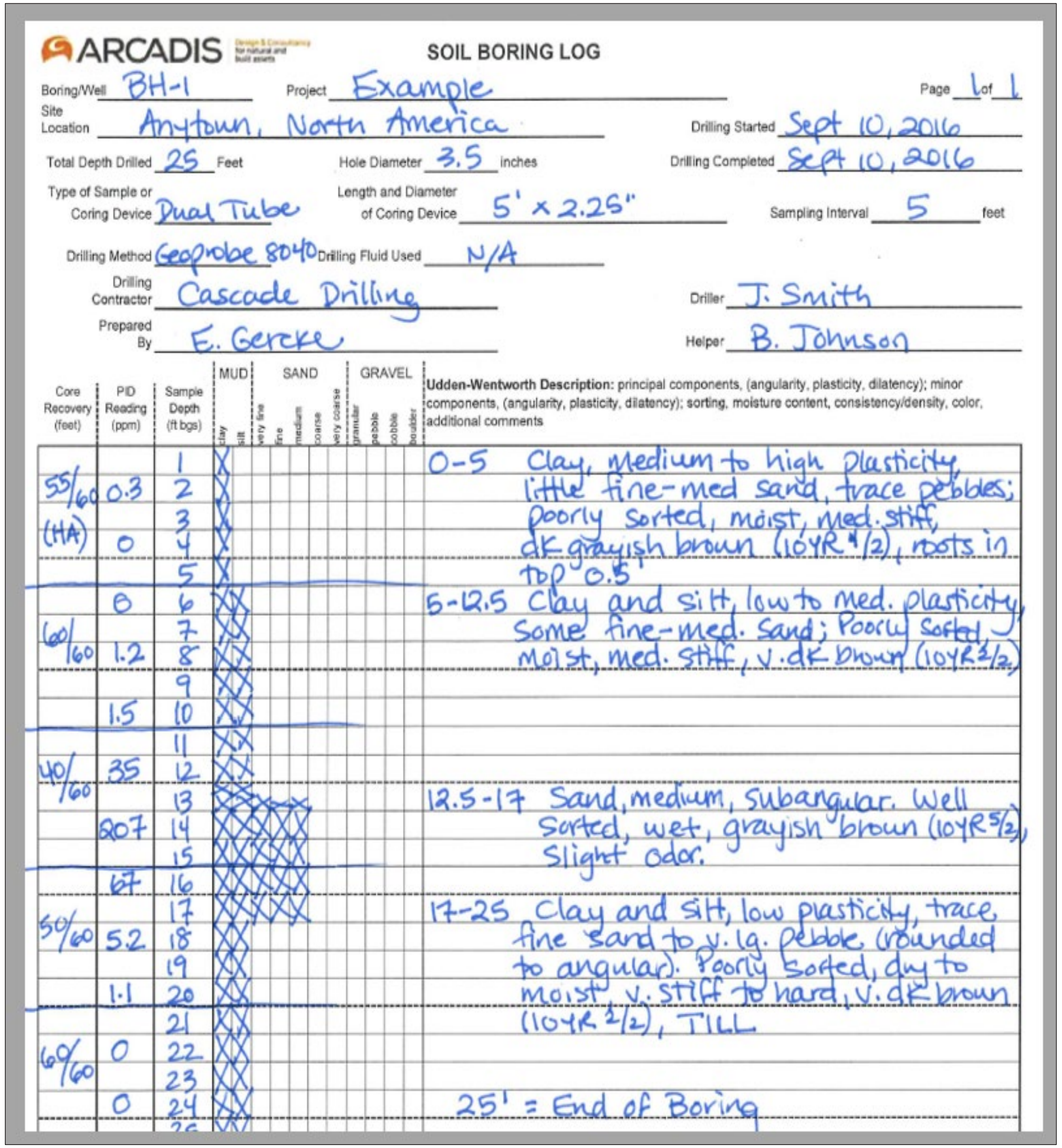


Characterizing aquifer variability key to stratigraphic flux-based CSM

Stratigraphic Logging

Interpret geology based on transport potential:

- Recommend Udden-Wentworth based soil descriptions
  - **Principal and minor grainsize**
  - **Sorting**
  - Density
  - Plasticity vs dilatency to distinguish silt from clay
- Graphical logs provide good first approximation to transport potential
- Reclassify existing logs using hydrofacies analysis


ARCADIS — SOIL BORING LOG

Boring/Well: BH-1 | Project: Example | Page 1 of 1

Site Location: Anytown, North America | Drilling Started: Sept 10, 2016

Total Depth Drilled: 25 Feet | Hole Diameter: 3.5 inches | Drilling Completed: Sept 10, 2016

Type of Sample or Coring Device: Dual Tube | Length and Diameter of Coring Device: 5' x 2.25" | Sampling Interval: 5 feet

Drilling Method: Geoprobe 8040 | Drilling Fluid Used: N/A

Drilling Contractor: Cascade Drilling | Driller: J. Smith

Prepared By: E. Gercke | Helper: B. Johnson

Core Recovery (feet)	PID Reading (ppm)	Sample Depth (ft bgs)	Udden-Wentworth Description: principal components, (angularity, plasticity, dilatency); minor components, (angularity, plasticity, dilatency); sorting, moisture content, consistency/density, color, additional comments
55/60 (HA)	0.3, 0	1–5	0-5 Clay, medium to high plasticity, little fine-med sand, trace pebbles; poorly sorted, moist, med. stiff, dk grayish brown (10YR 4/2), roots in top 0.5'
60/60	0, 1.2, 1.5	6–10	5-12.5 Clay and silt, low to med. plasticity, some fine-med. sand; poorly sorted, moist, med. stiff, v. dk brown (10YR 2/2)
40/60	35, 207, 67	11–15	12.5-17 Sand, medium, subangular. Well sorted, wet, grayish brown (10YR 5/2), slight odor.
50/60	5.2, 1.1	16–20	17-25 Clay and silt, low plasticity, trace fine sand to v. lg. pebble (rounded to angular). Poorly sorted, dry to moist, v. stiff to hard, v. dk brown (10YR 2/2), TILL
60/60	0, 0	21–25	25' = End of Boring

Sieve Analysis & K estimates

Grainsize and Sorting are the Primary Properties Determining Permeability

- Validate soil descriptions
- Use sieve analysis to verify soil descriptions and estimate hydraulic conductivity
- Best for evaluating coarser-grained sand and gravels
- Limitations with clay rich soils due to flocculation (<20%)

Standard ASTM Sieve Set	Udden-Wentworth Based Sieve Set
3"	1½"
2"	1"
1½"	3/4"
1"	3/8"
¾"	#4
3/8"	#10
#4	#12
#10	#14
#20	#35
#40	#40
#60	#60
#100	#100
#140	#140
#200	#200
Hydrometer	#230
	Hydrometer

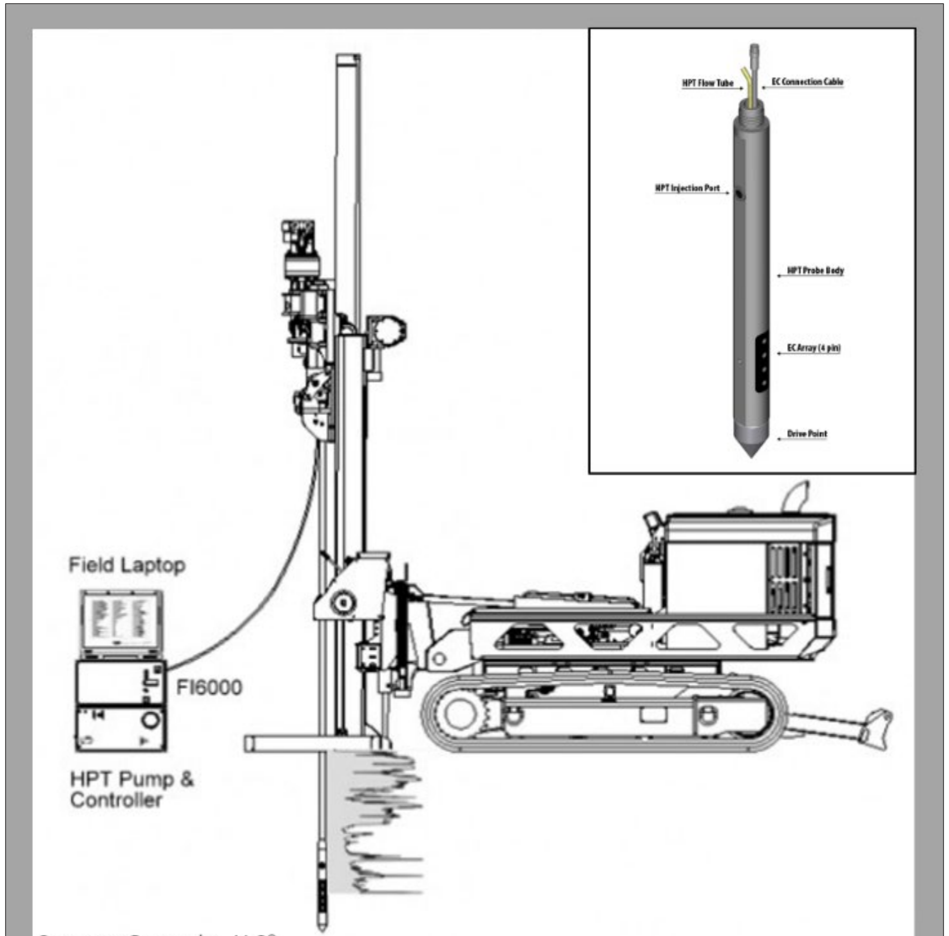
Direct Push Injection Logging Methods

For Shallow Systems (<100 ft bgs), Direct Push Drilling Methods can be used to Advance a Variety of Direct Sensing Equipment

- HPT – Hydraulic Profiling Tool
- APS - Waterloo Advanced Profiling System
- CPT – Cone Penetrometer Testing

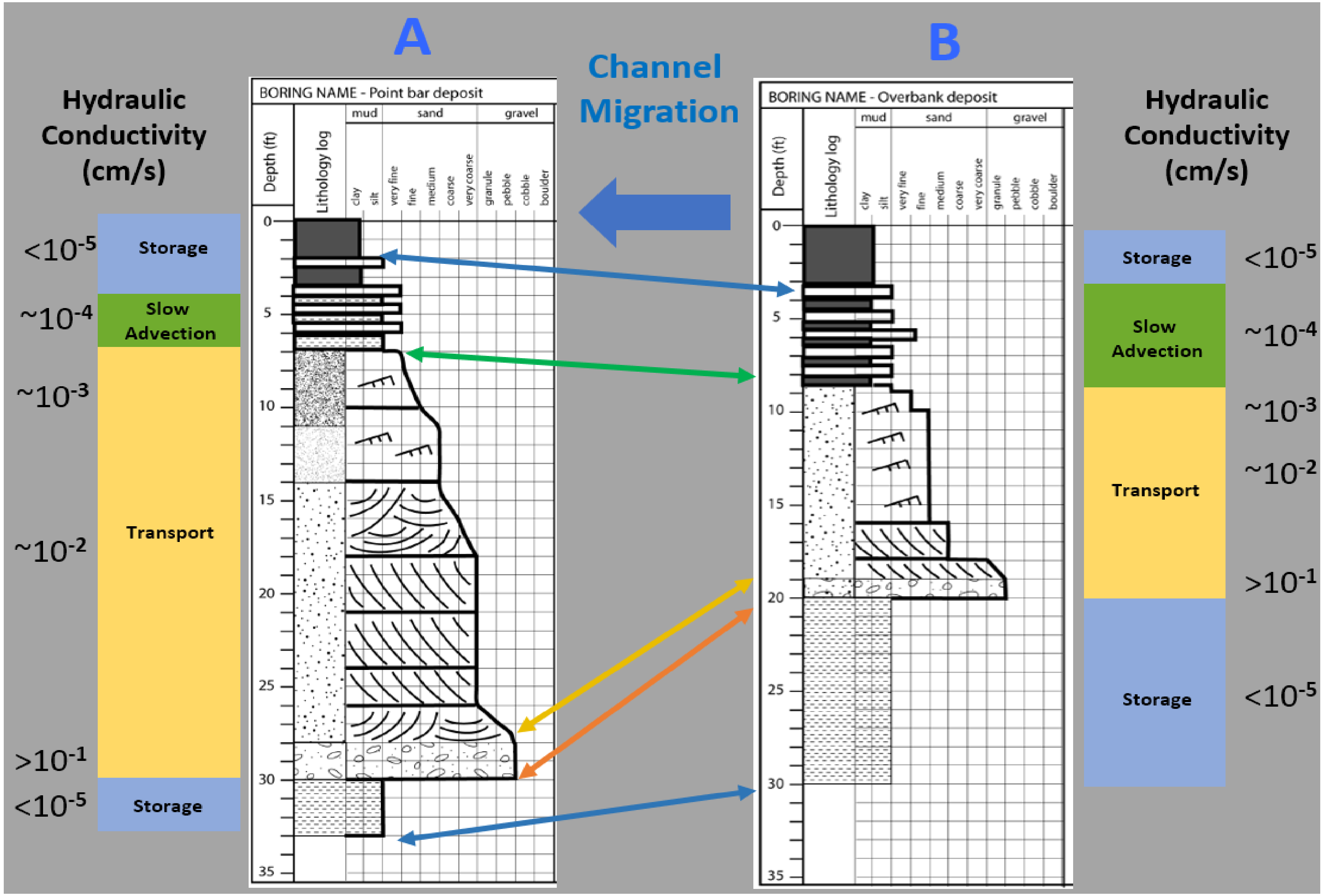
Combination Drilling can Extend Depth of Direct Push Tools

- HPT or APS / Sonic
- Downhole Hammer



Courtesy Geoprobe, LLC®

Sequence Stratigraphy and Hydrofacies Classification



Mass Flux Transects

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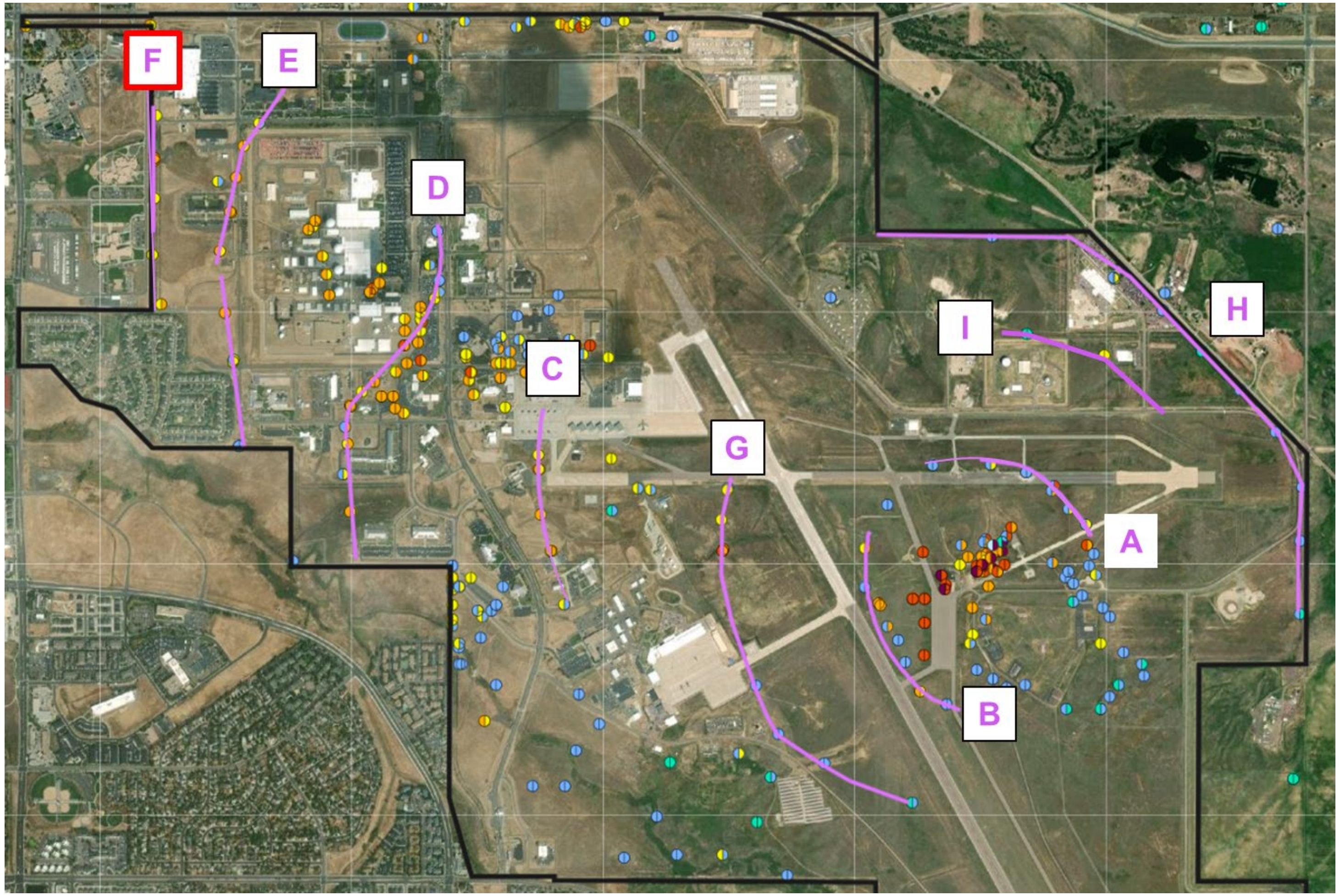
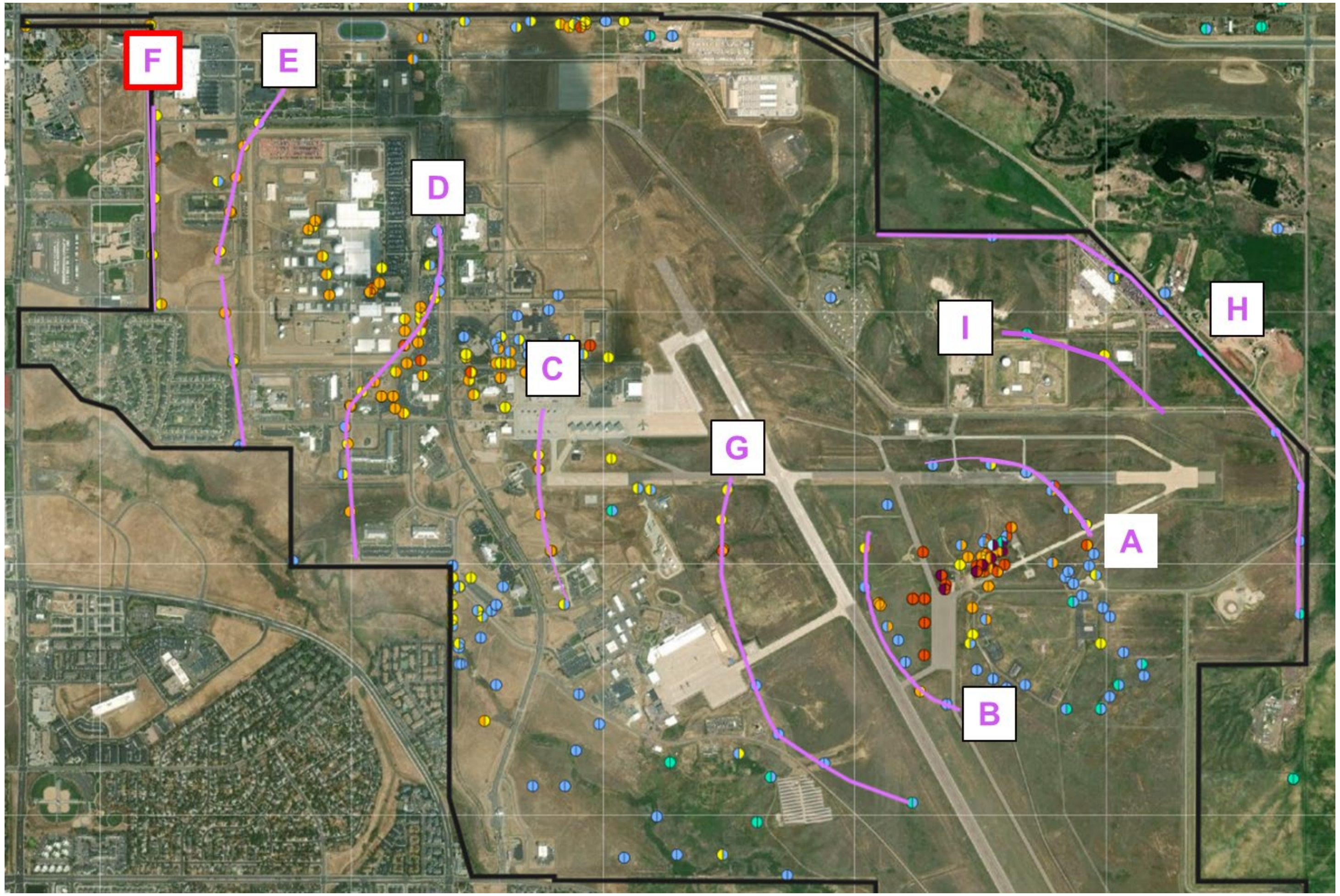
- Sampling strategy on transects
  - Resolve variability in lithology and concentration distribution
  - Refine resolution to zoom in on hotspot or step-out for delineation
- Applied downgradient of source(s) or at installation boundary to support early decision making
  - Spatial trends between transects along flow can guide extrapolation to RBSLs for delineation during RI
  - Mass discharge provides measure of source strength for ranking and prioritization
  - Mass flux provides target for interim measures
- Sampling strategy on transects
  - Resolve variability in lithology and concentration



Stratigraphic Flux Model Development: Buckley Space Force Base

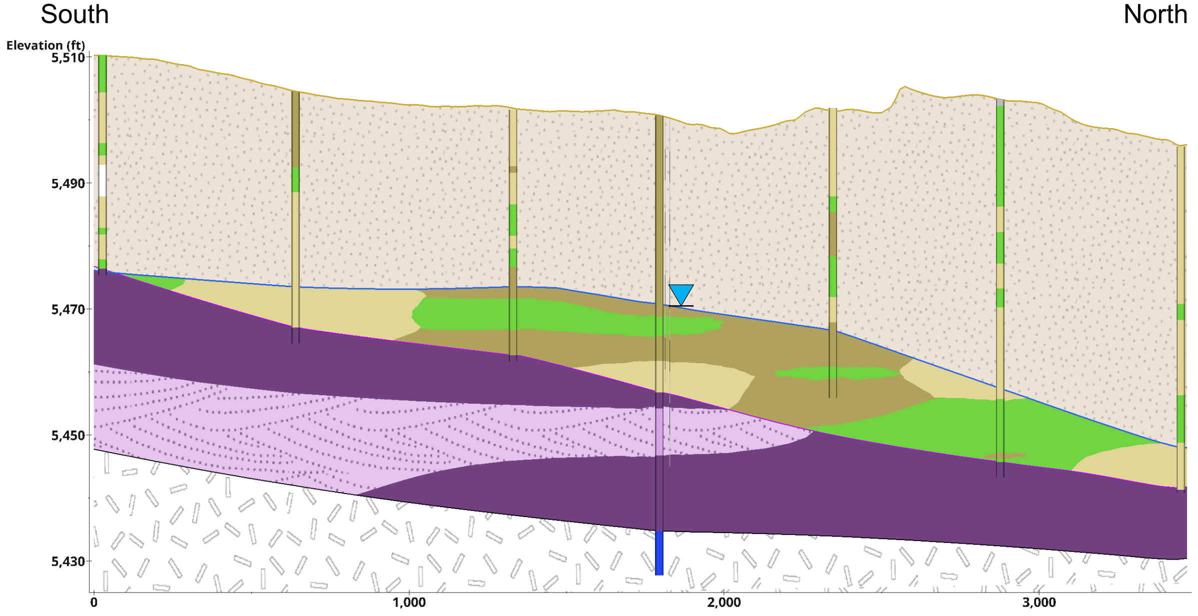
Mass Flux Transects

- Lithology: Geo classification and grain size data from borings
- Hydraulic Conductivity (K): slug tests, low flow drawdown tests, and grain size analysis
- Concentration (C): Groundwater samples from vertical aquifer profile(VAP) borings and monitoring wells
- Interpret/Interpolate hydrofacies unit across transect using 3D modeling
- Correlate average K with lithologic units
- Interpolate groundwater concentrations across transect
- Multiply interpolated distributions of hydraulic conductivity and concentration

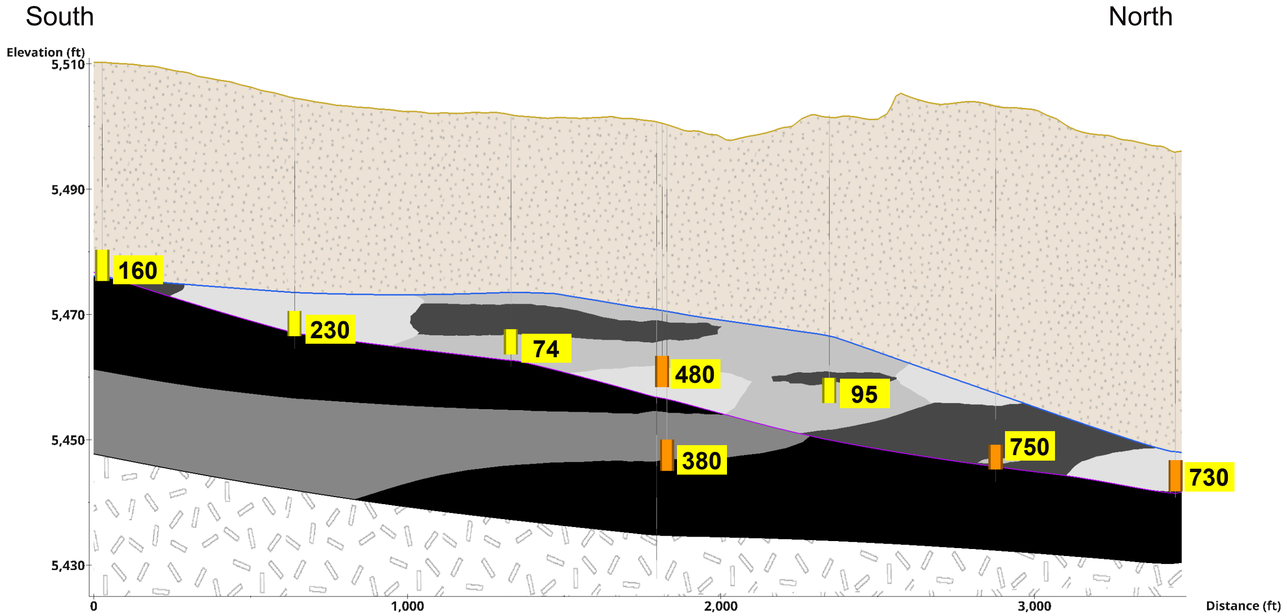


Transect F – PFOS Flux

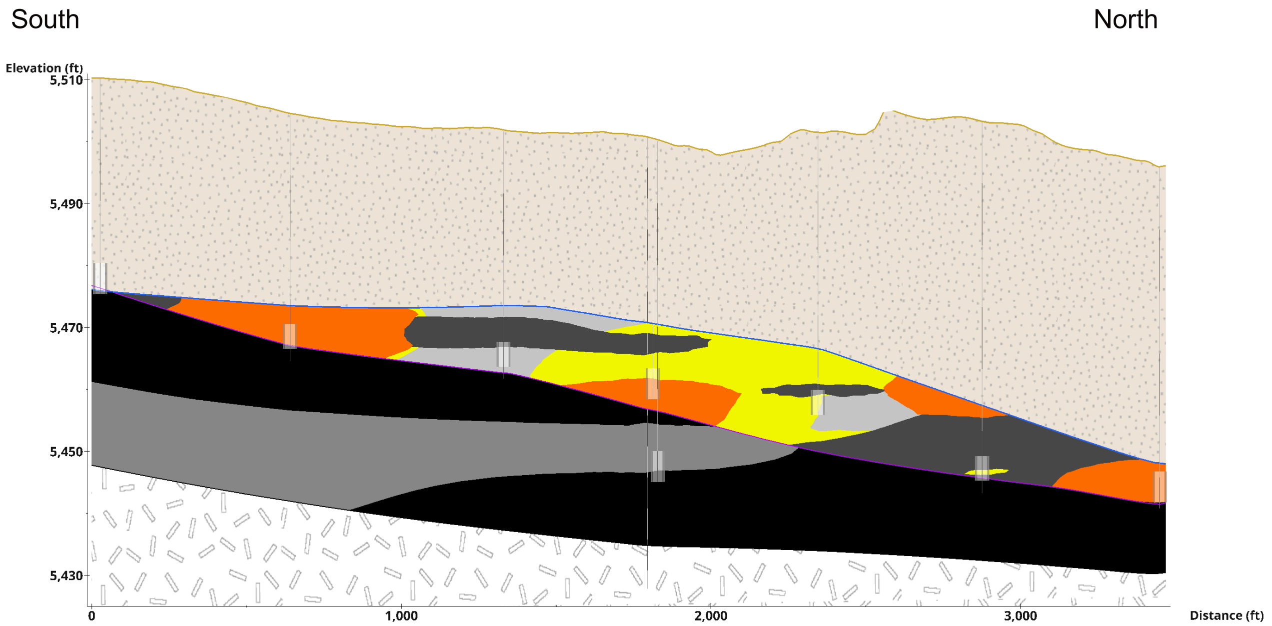
Geology

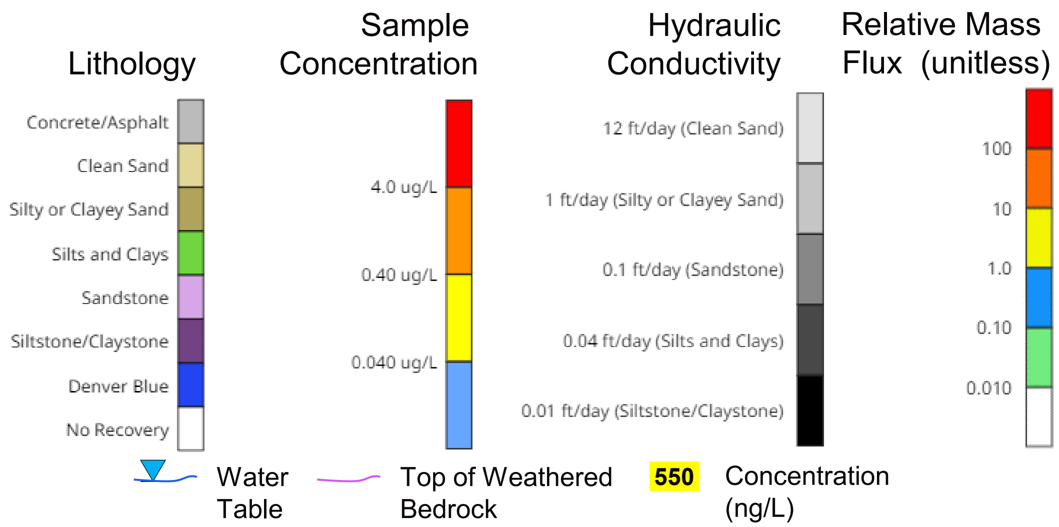


Hydraulic Conductivity and Sample Concentration

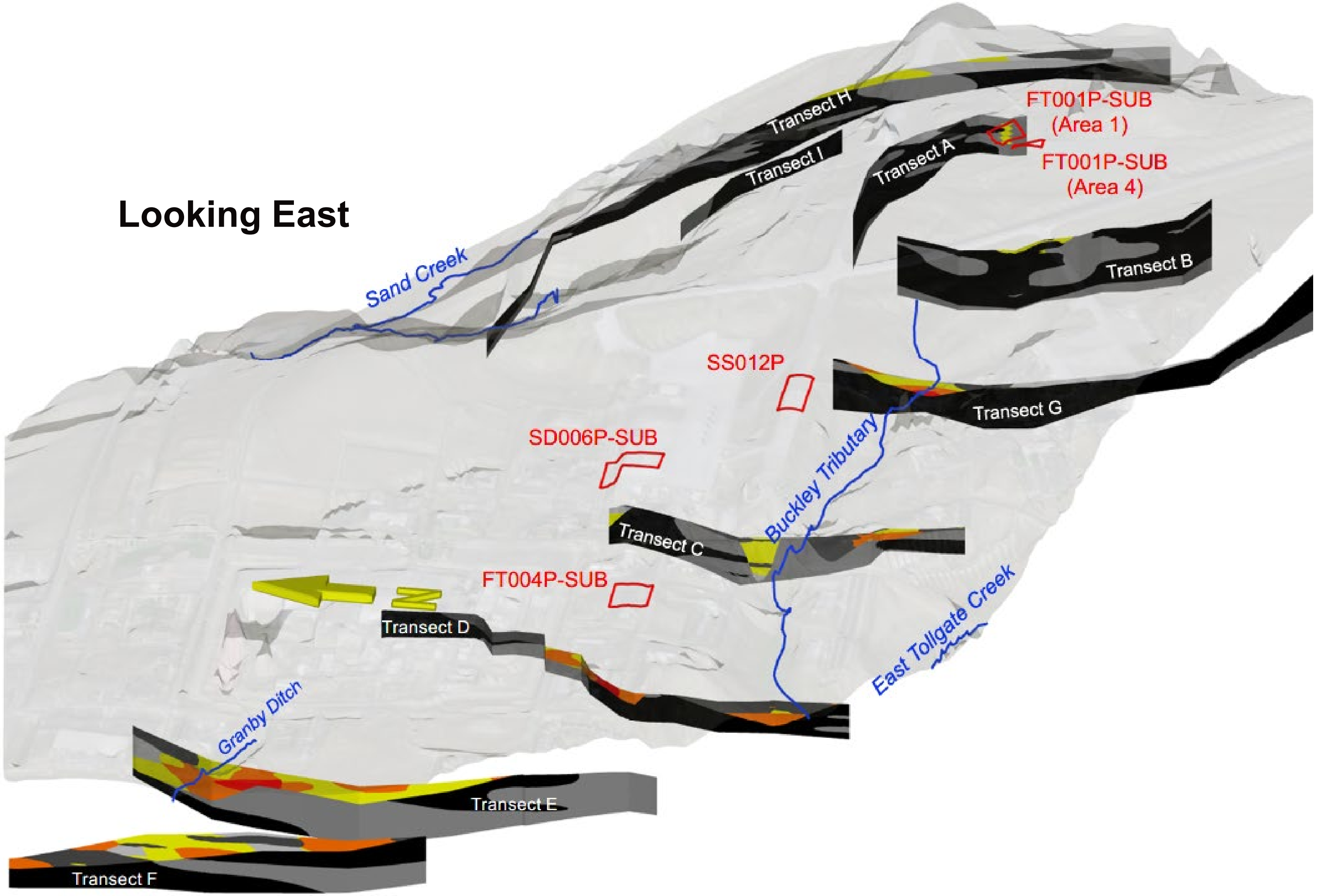


Relative Mass Flux





Stratigraphic Flux – Buckley SFB



Legend

Relative Mass Flux

- > 100
- 10-100
- 1-10

Hydraulic Conductivity (ft/day)

- 12 (Clean Sand)
- 0.8 (Silty/Clayey Sand)
- 0.1 (Sandstone)
- 0.04 (Silts/Clays)
- 0.01 (Siltstone/Claystone)

AFFF Area

Stream

Source Evaluation

Site-Specific Leaching Behavior

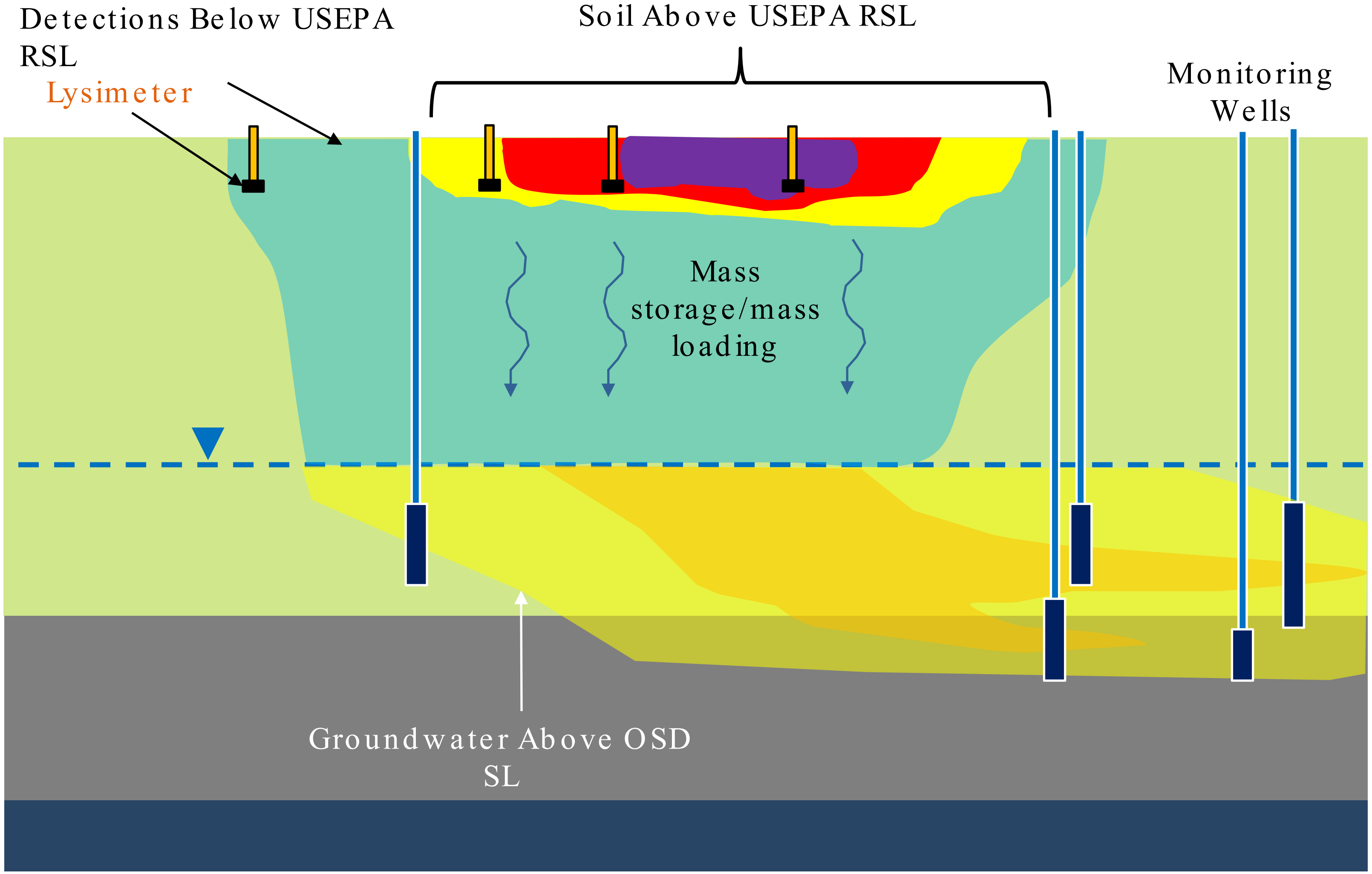
Understanding source strength is key to evaluate if PFAS in soil poses a risk to groundwater

Several methods:

- Ratio of soil concentration to groundwater concentration
- Synthetic Precipitation Leaching Procedure (SPLP)
- Lysimetry and pore water sampling

Estimate bulk partitioning through regression analyses

- Calculated mass loading at source compared to downgradient mass discharge = bulk attenuation factor
  - Empirical basis for site-specific soil-to-groundwater standard

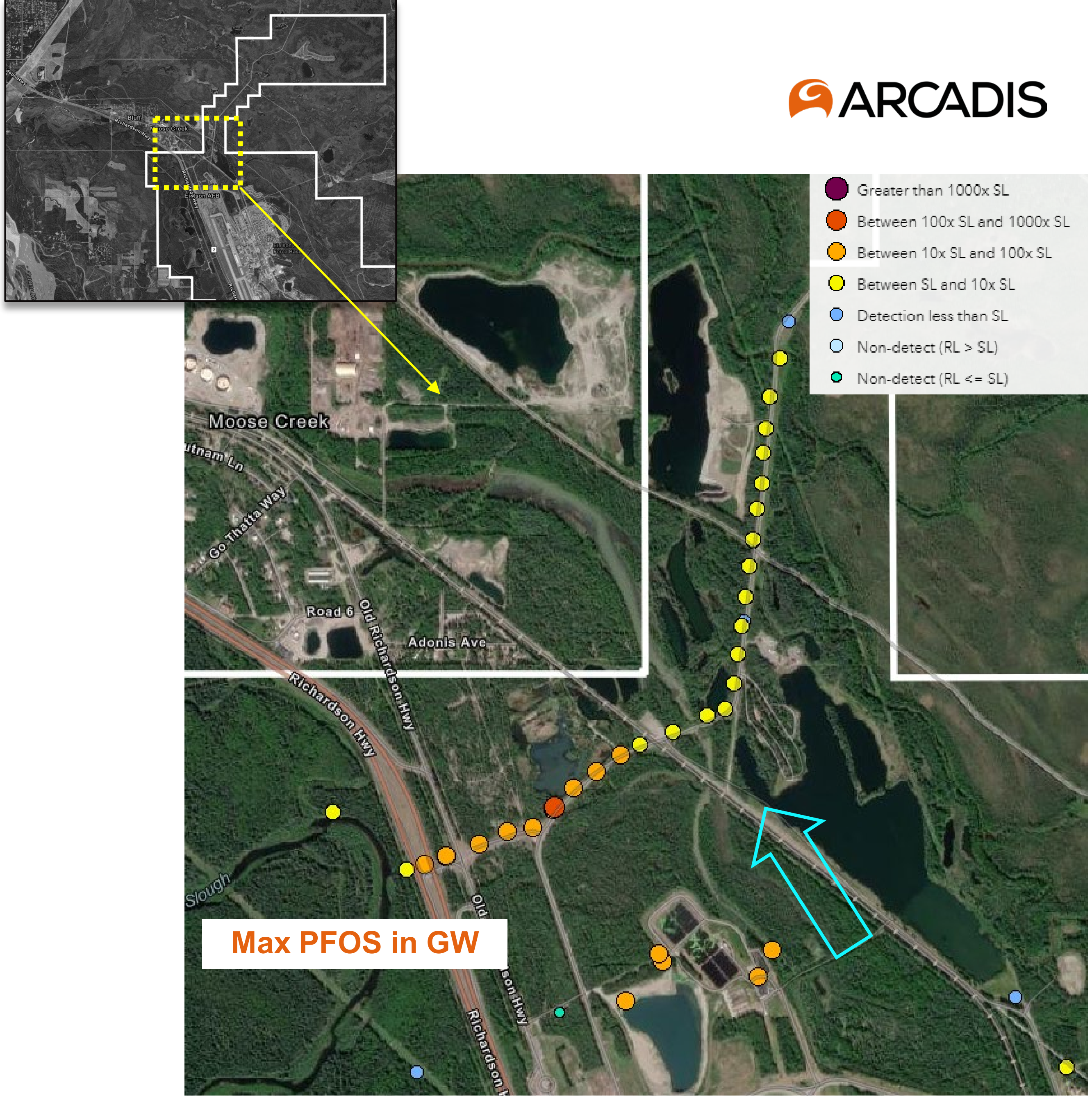


Flux Monitoring

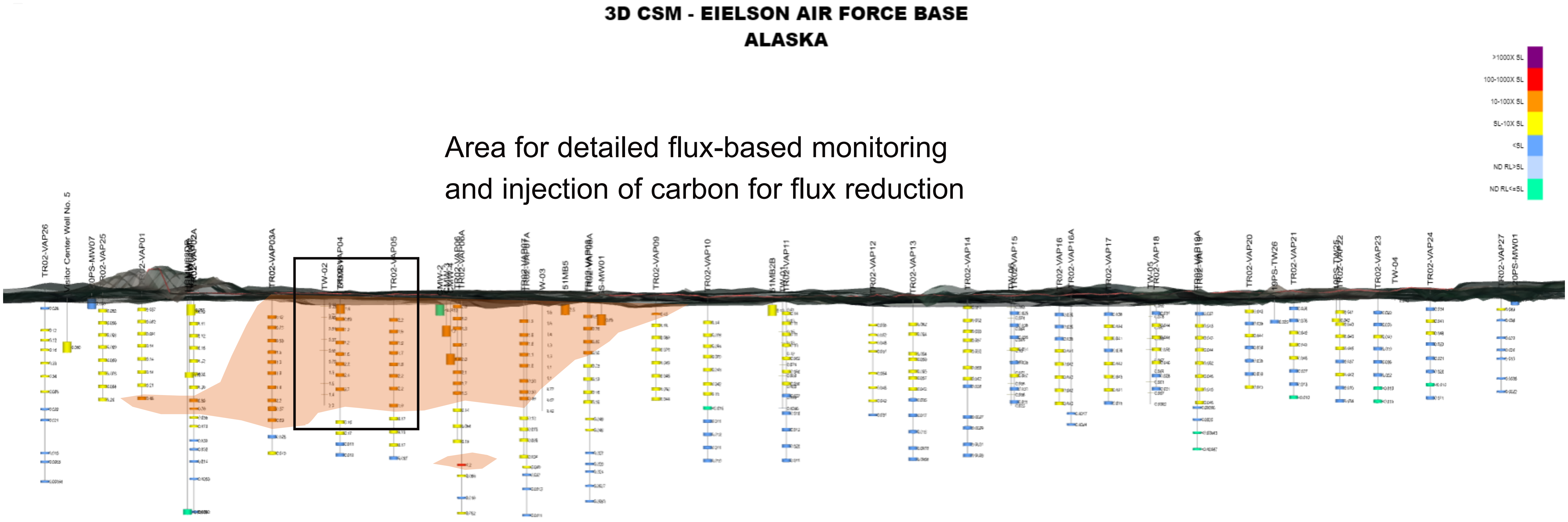
Property Boundary Transects

Property boundary transects – provide useful information and early warning of potential off-site migration

- Vertical aquifer profile (VAP) or monitoring wells are installed during initial phase of RI, when:
  - Plume suspected or confirmed at site perimeter
  - Groundwater flow and transport indicate potential for off-site migration
  - Off-site receptors are less than 1 mile from base perimeter
- Use perimeter results to rank and prioritize EECA/interim actions



Eielson AFB - Transect 2: PFOS in Groundwater



Scope

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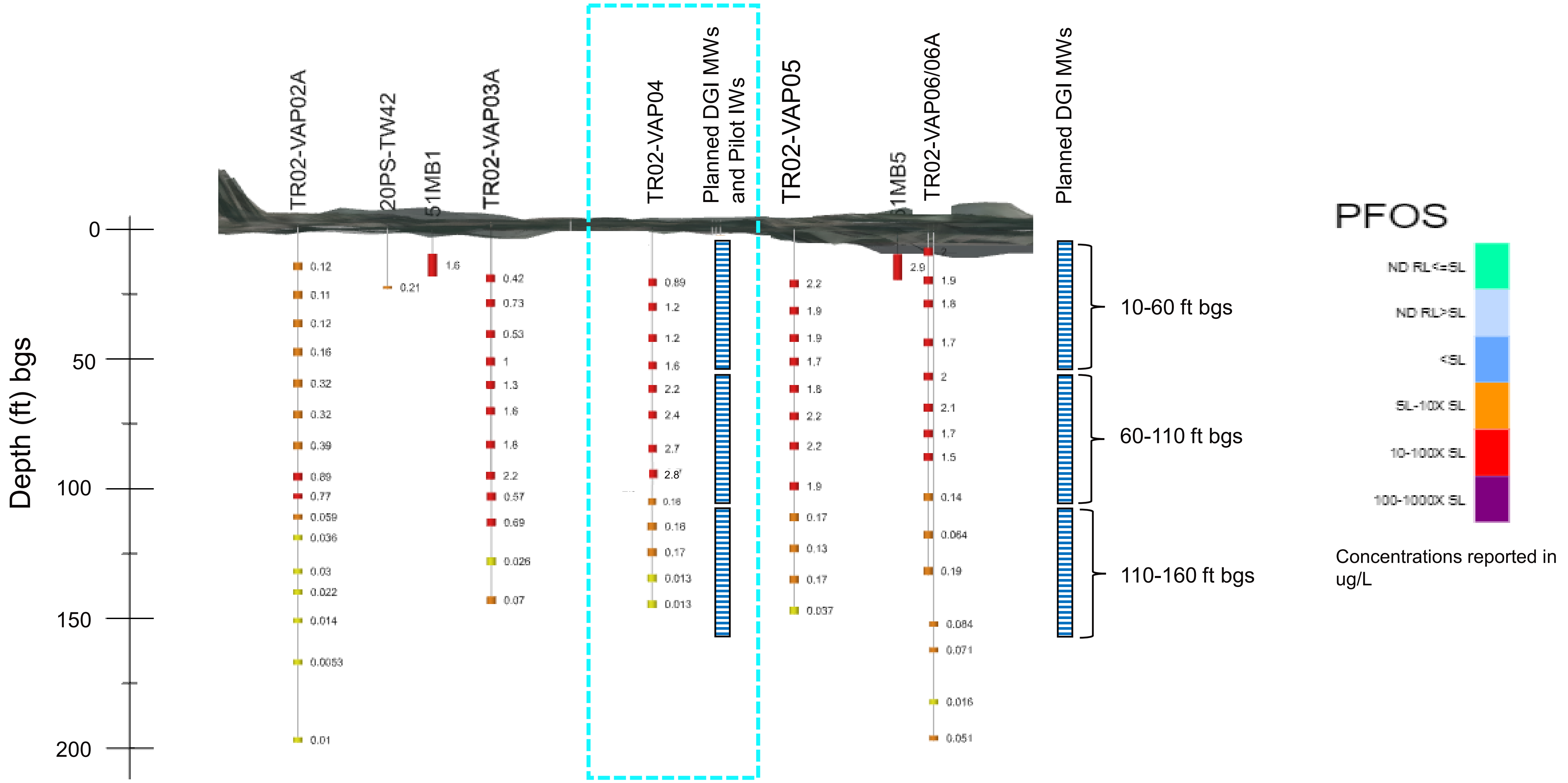
- Planned Data Gap Investigation Scope (2024)
  - Install 8 monitoring well clusters with 3 wells per cluster (24 total) - 10-60 ft, 60-110 ft, 110-160 ft
  - Conduct low flow sampling at each well (24 samples)
  - Perform slug testing at each well (24 total)
  - Deploy 9 passive flux meters (PFMs) per well (216 total)

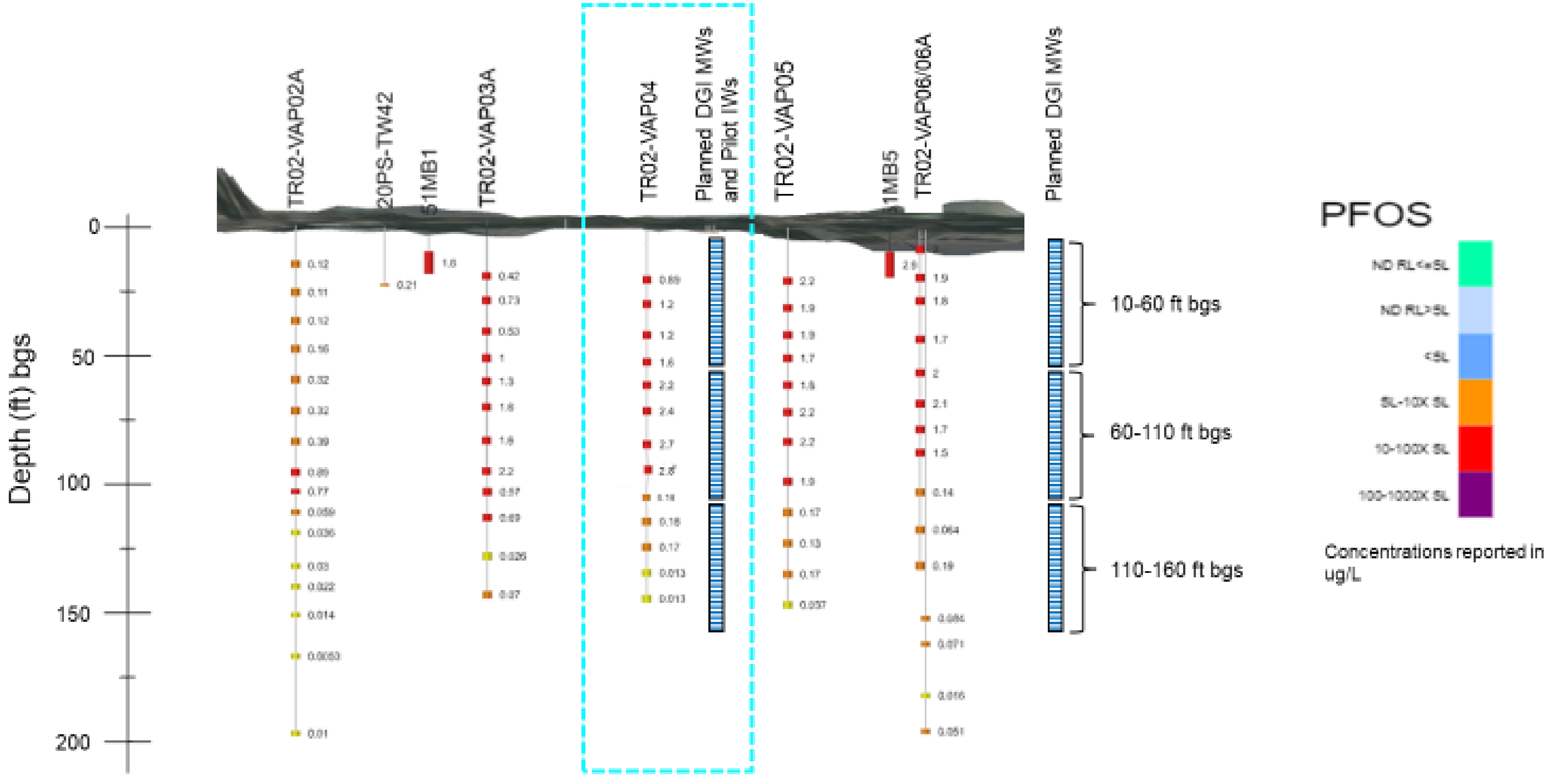
- Planned Pilot Study Construction scope (2024)
  - Install 25 clusters of 3 injection wells per cluster (75 total) - 10-60 ft, 60-110 ft, 110-160 ft
- Review results and refine injection strategy as needed for 2025
  - Revisit PFM results to evaluate mass flux/discharge reduction



Depth (ft) bgs
0
50
100
150
200
TR02-VAP02A
20PS-TW42
51MB1
TR02-VAP03A
TR02-VAP04
Planned DGI MWs and Pilot IWs
TR02-VAP05
51MB5
TR02-VAP06/06A
Planned DGI MWs
0.12
0.11
0.12
0.16
0.32
0.32
0.39
0.89
0.77
0.059
0.036
0.03
0.022
0.014
0.0053
0.01
0.21
1.6
0.42
0.73
0.53
1
1.3
1.6
1.6
2.2
0.57
0.69
0.026
0.07
0.89
1.2
1.2
1.6
2.2
2.4
2.7
2.8
0.16
0.16
0.17
0.013
0.013
2.2
1.9
1.9
1.7
1.8
2.2
2.2
1.9
0.17
0.13
0.17
0.037
2.9
2
1.9
1.8
1.7
2
2.1
1.7
1.5
0.14
0.064
0.19
0.084
0.071
0.016
0.051
10-60 ft bgs
60-110 ft bgs
110-160 ft bgs
PFOS
ND RL<=SL
ND RL>SL
<SL
SL-10X SL
10-100X SL
100-1000X SL
Concentrations reported in ug/L

➢ DGI Scope (2024)

- Install 8 monitoring well clusters (24 wells)
- Low flow sampling at each well
- Slug testing at each well
- Deploy 9 passive flux meters (PFMs) per well (216 total)



500 ft wide transect targeting VAP04

- Compare and apply flux results to refine design of carbon injection program
- Monitor mass flux/discharge reduction following carbon injection

ARCADIS

Q&A

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References

Joseph Quinnan, Michael Rossi, Patrick Curry, Mark Lupo, Margaret Miller, Helmer Korb, Cameron Orth, Kristen Hasbrouck, 2021. Validation of streamlined mobile lab-based real-time PFAS analytical methods. ESTCP ER19-5203 final report. https://serdp-estcp-storage.s3.us-gov-west-1.amazonaws.com/s3fs-public/project_documents/ER19-5203_Final_Report.pdf

Joseph Quinnan, Michael Rossi, Patrick Curry, Mark Lupo, Margaret Miller, Helmer Korb, Cameron Orth, Kristen Hasbrouck, 2021. Application of PFAS-mobile lab to support adaptive characterization and flux-based conceptual site models at AFFF releases. Remediation Vol 31, No. 3, pp 7-26. https://doi.org/10.1002/rem.21680.

Patrick J. Curry, Nicklaus R.H. Welty, Alison J Yanites, Catharine Varley, and Joseph Quinnan, 2020. Stratigraphic flux- a method for determining preferential pathways for complex sites. Remediation Vol 30, No. 2. https://doi.org/10.1002/rem.21644

Joseph Quinnan, Patrick Curry, 2017. Stratigraphic Flux – A Method for determining preferential pathways for complex sites, Air Force Plant 4 – Chrome Pit 3, BAA 967. Air Force Civil Engineering Center.

Patrick Curry, Nicklaus Welty, Jess Wright, Dave Favero, Joseph Quinnan, 2016. Smart Characaterization – An integrated Approach for Evaluating a Complex 1,4-Dioxane Site. Remediation Vol 27, No 1, pp-29-45. https://doi.org/10.1002/rem.21495

Extra Slides

Site Investigation – Adaptive and Flux Based

Adaptive, flux-based investigations are scalable with a la carte components and include:

- Background sampling
- “Prescriptive / adaptive” source area delineation
- “Source strength” characterization
- Perimeter mass flux evaluation
- Storm-water and sediment sampling
- Groundwater-Surface Water Interface (GSI) evaluation
- Surface water and sediment sampling
- Flux-based groundwater monitoring