ARCADIS Design & Consultancy for natural and built assets

STRATIGRAPHIC FLUX™

Applying Sequence Stratigraphy and High-Resolution Site Characterization to Find Contaminant Flux

Session C5 – High Resolution Site Characterization

BATTELLE BIOREMEDIATION SYMPOSIUM

6/12/2017

Acknowledgments

Contributors

Joseph A Quinnan (joseph.quinnan@arcadis.com) (Arcadis, Inc, Novi, MI USA)

Patrick Curry (Arcadis, Inc, Novi, MI, USA)

Eric Killenbeck (Arcadis, Inc, Newton, PA, USA)

Linden Peters (Arcadis, Inc, Lenexa, KS, USA)

Catharine Varley (AFCEC, San Antonio, TX, USA)

Kent Glover (AFCEC, San Antonio, TX, USA)

Mark Rodriguez (AFCEC, San Antonio, TX, USA)

Air Force Civil Engineer Center

Funding through BAA 967

Guidance manual available Q3 2017

Outline

- *Smart* characterization™ and Return on *Investigation*™
- Stratigraphic Flux™
- Air Force Plant 4 TCE

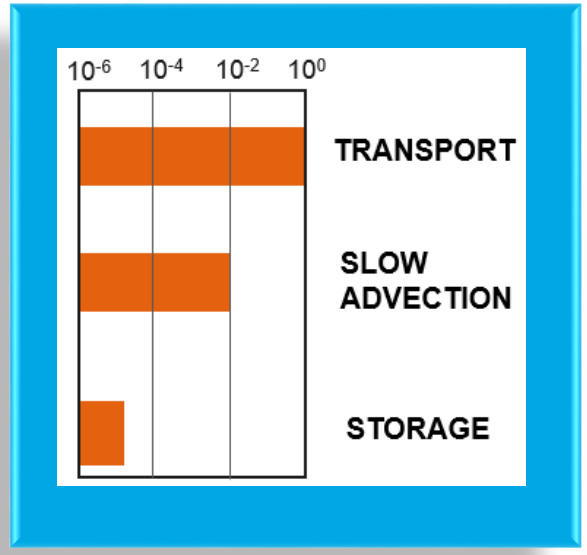
ARCADIS Design & Consultancy for natural and built assets

ROI framework streamlines process, maximizes value of information

ARCADIS Design & Consultancy for natural and built assets

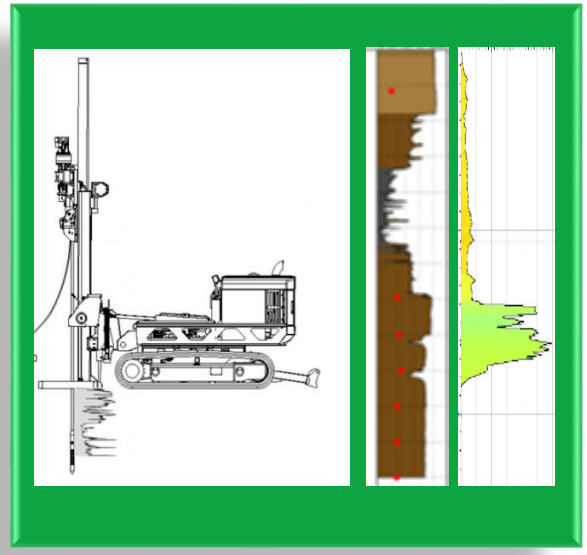
Smart Characterization™: *Find the Flux*

Flux-Based CSM



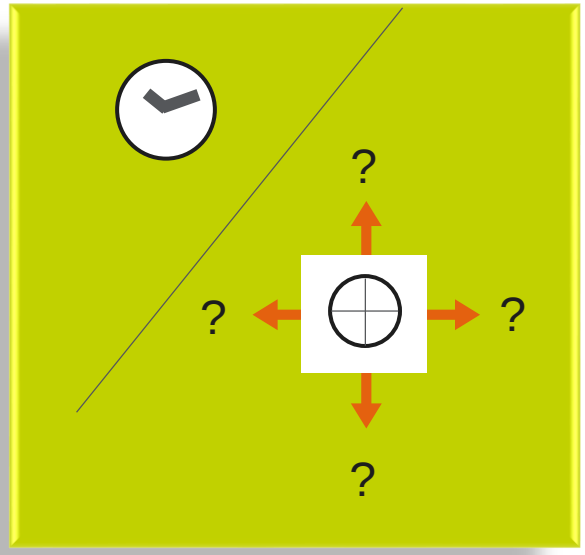
- *Majority of flux in permeable zones*

Right tools to map flux



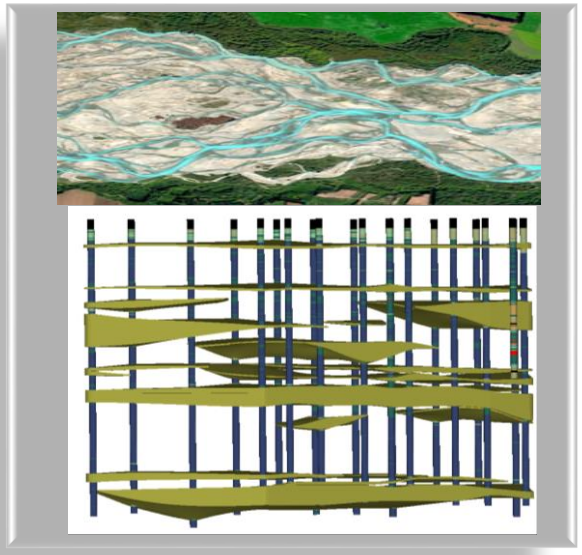
- *Quantitative*
- *High-resolution*

Real-time & adaptive

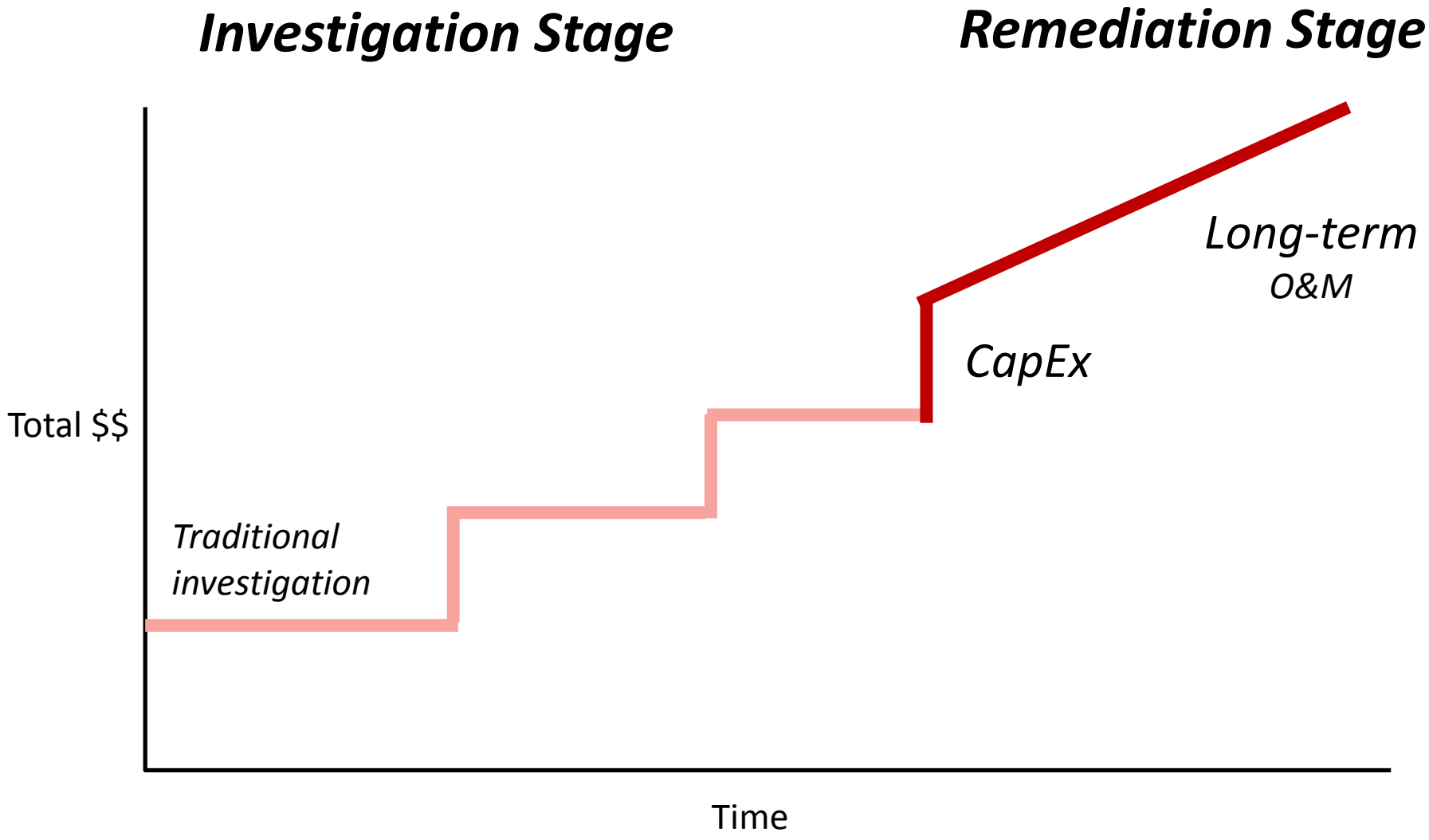


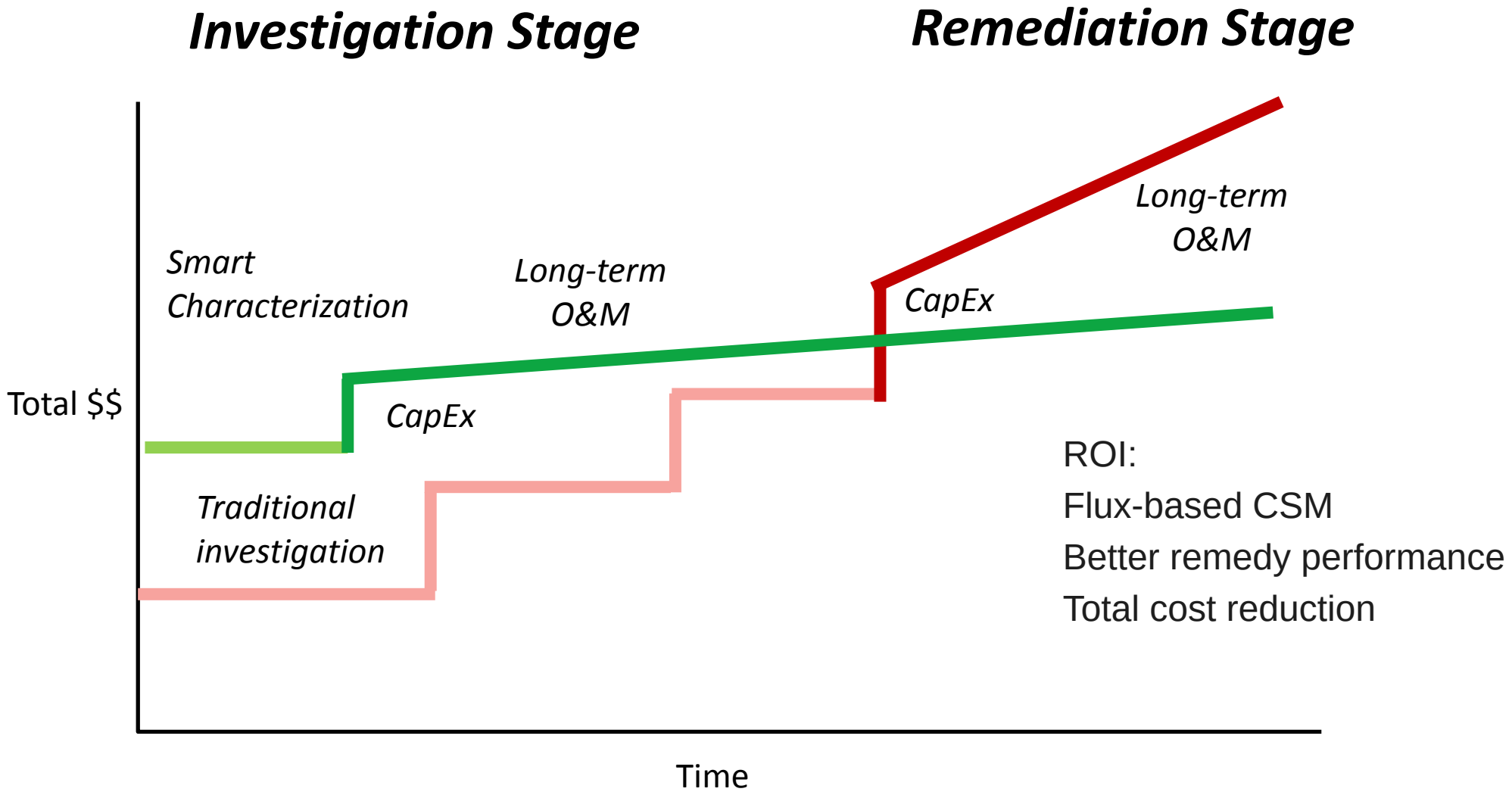
- *Lower investigation costs*

Interpretation



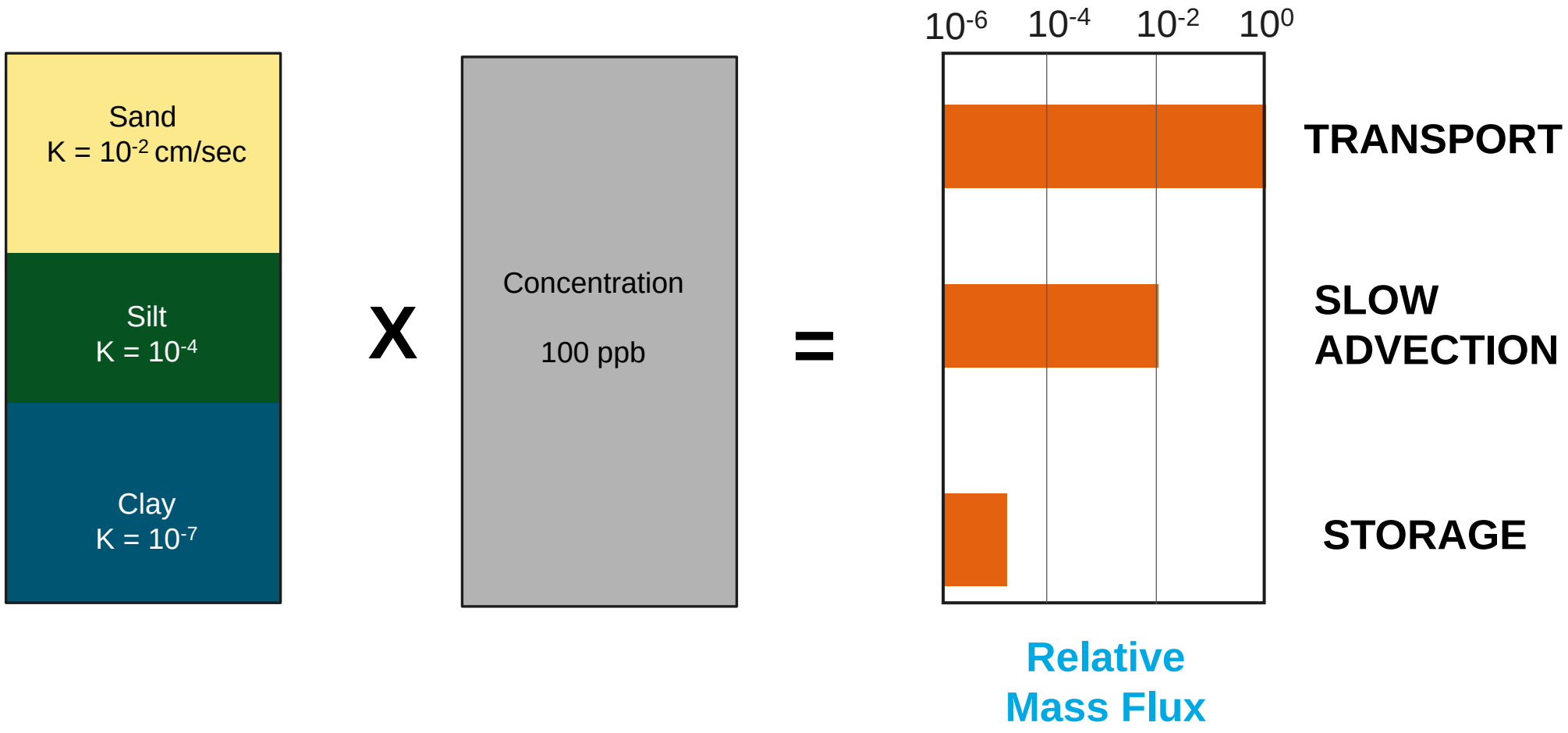
- *3D analysis*
- *Classical geologic approach*



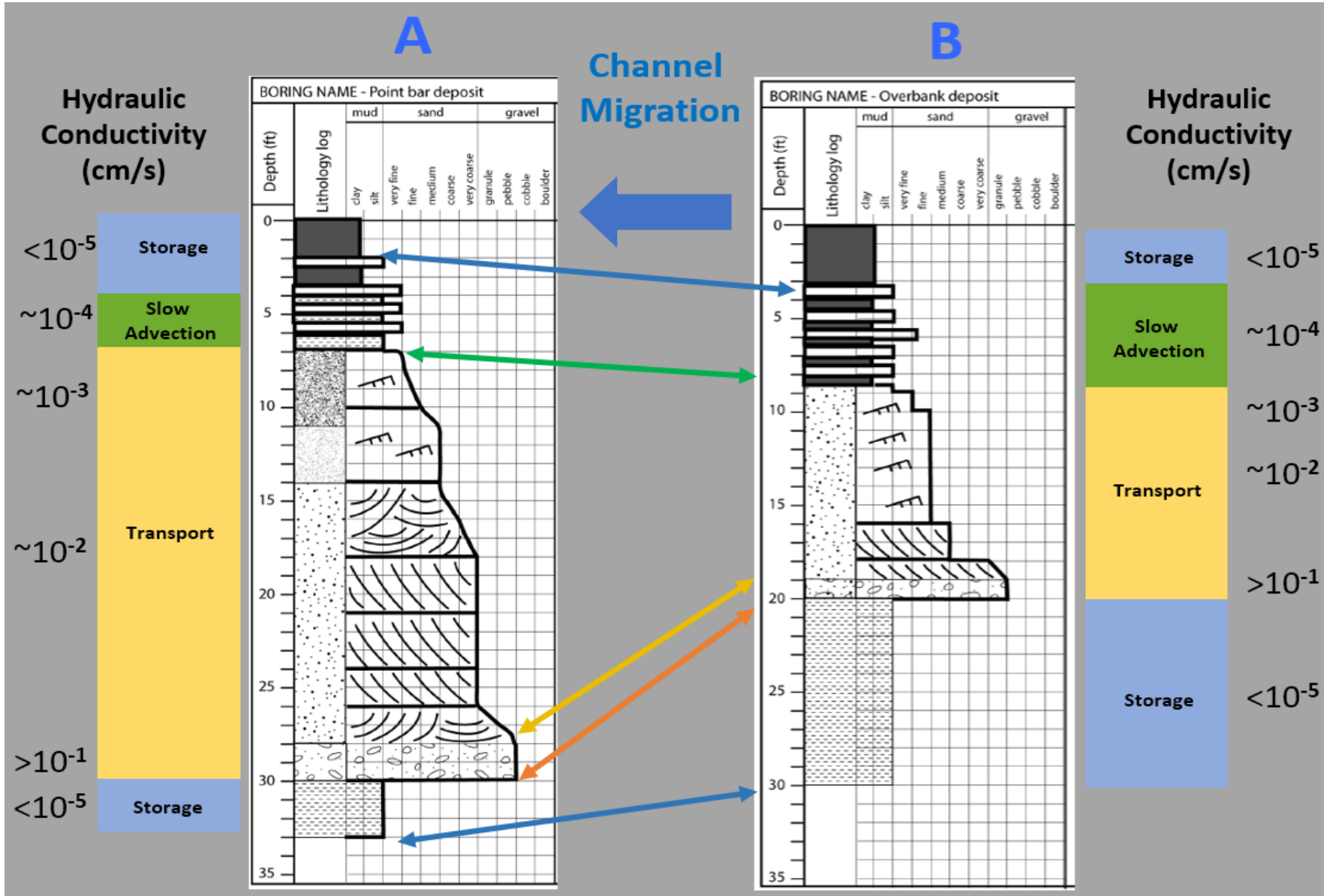


Relative Flux Framework for Transport

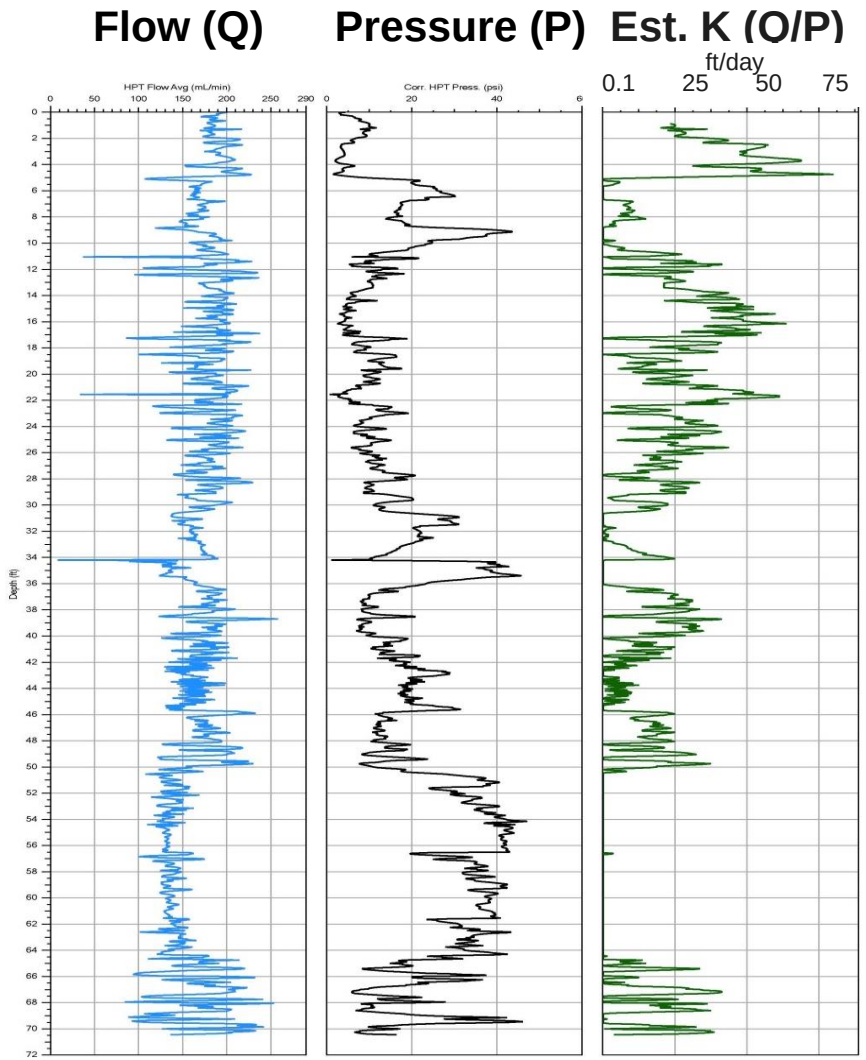
Evaluating mass flux based on the soil types and permeability structure of the aquifer



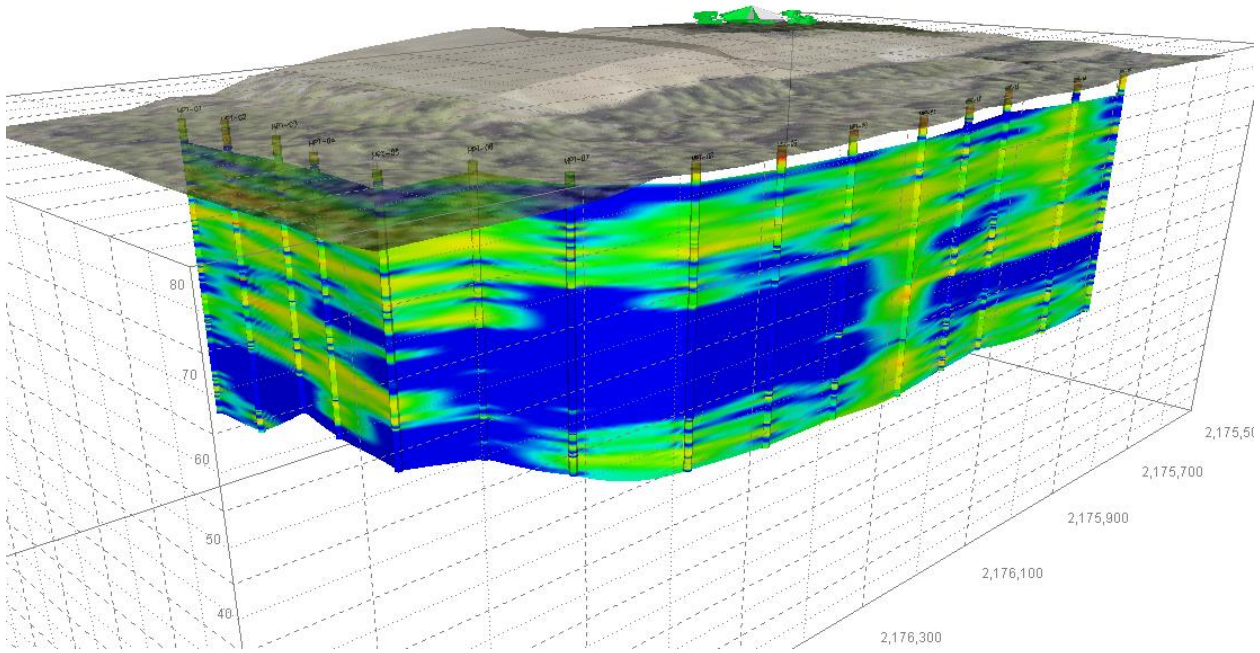
Hydrofacies Classification



Stratigraphic Flux™ Case Study



Permeability fence diagram

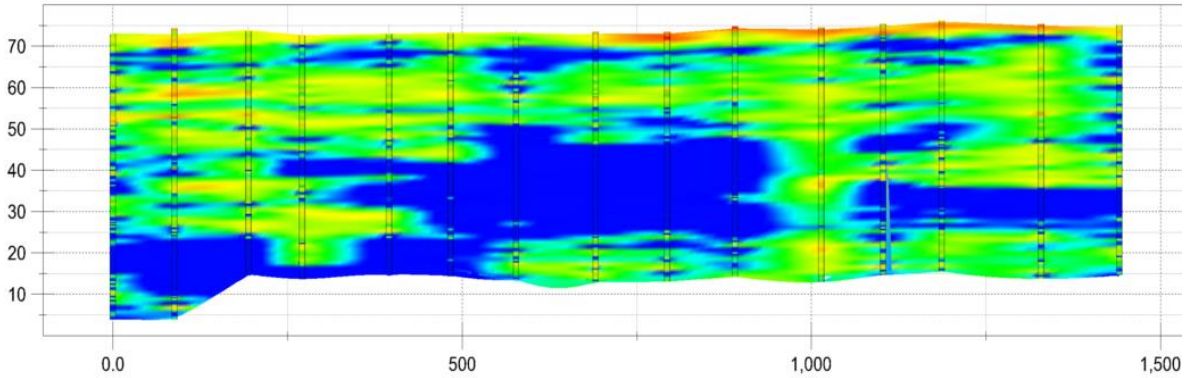


Objective:

- Optimize capture of existing P&T system
- HPT for relative K; vertical aquifer profiling for concentration

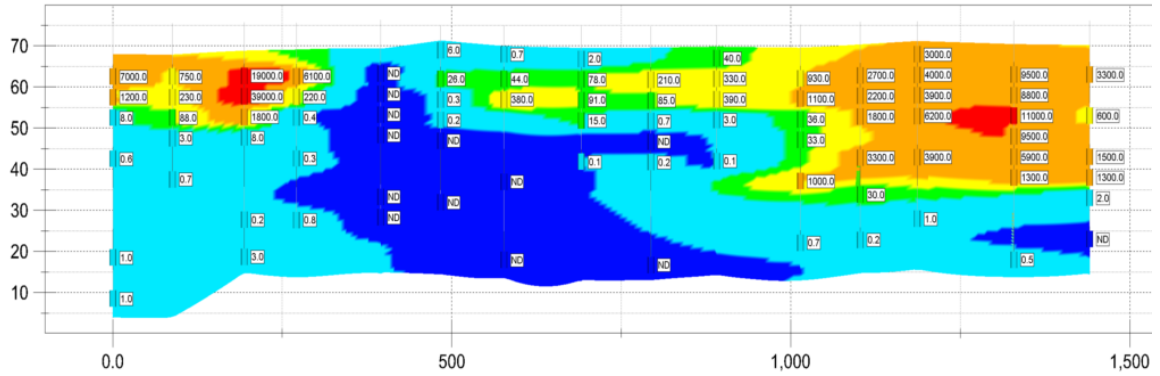
Stratigraphic Flux™

Hydraulic Conductivity (K)



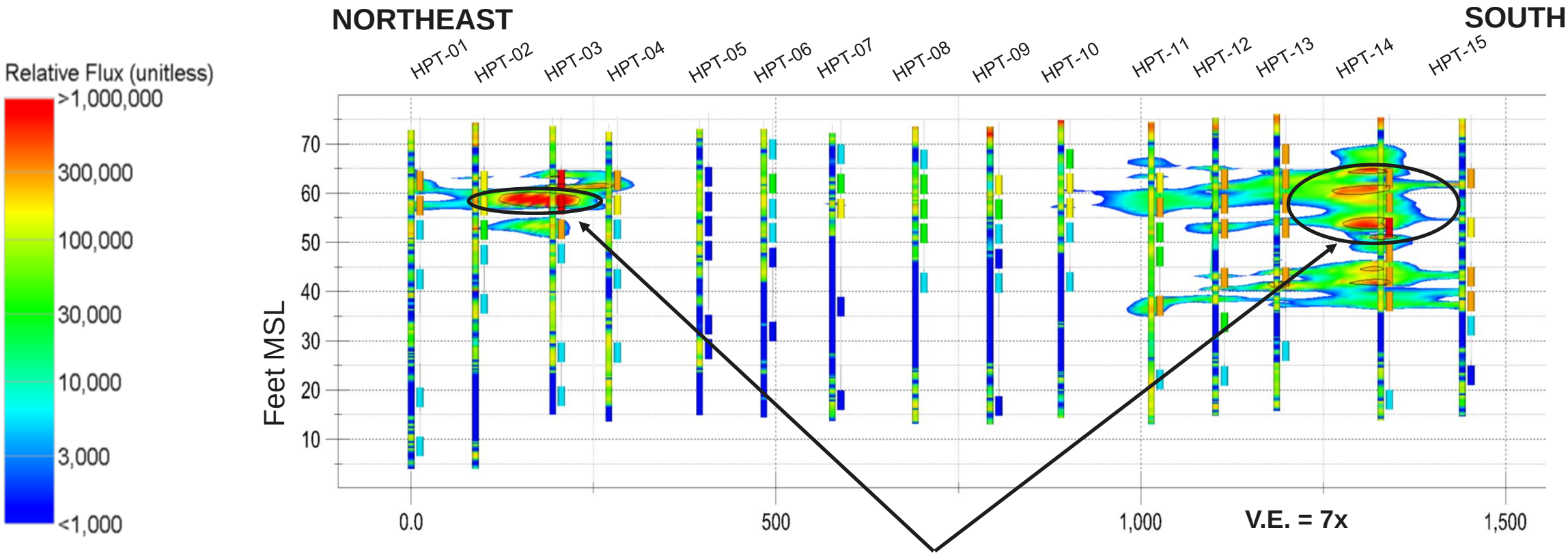
X

Concentration (C)



=

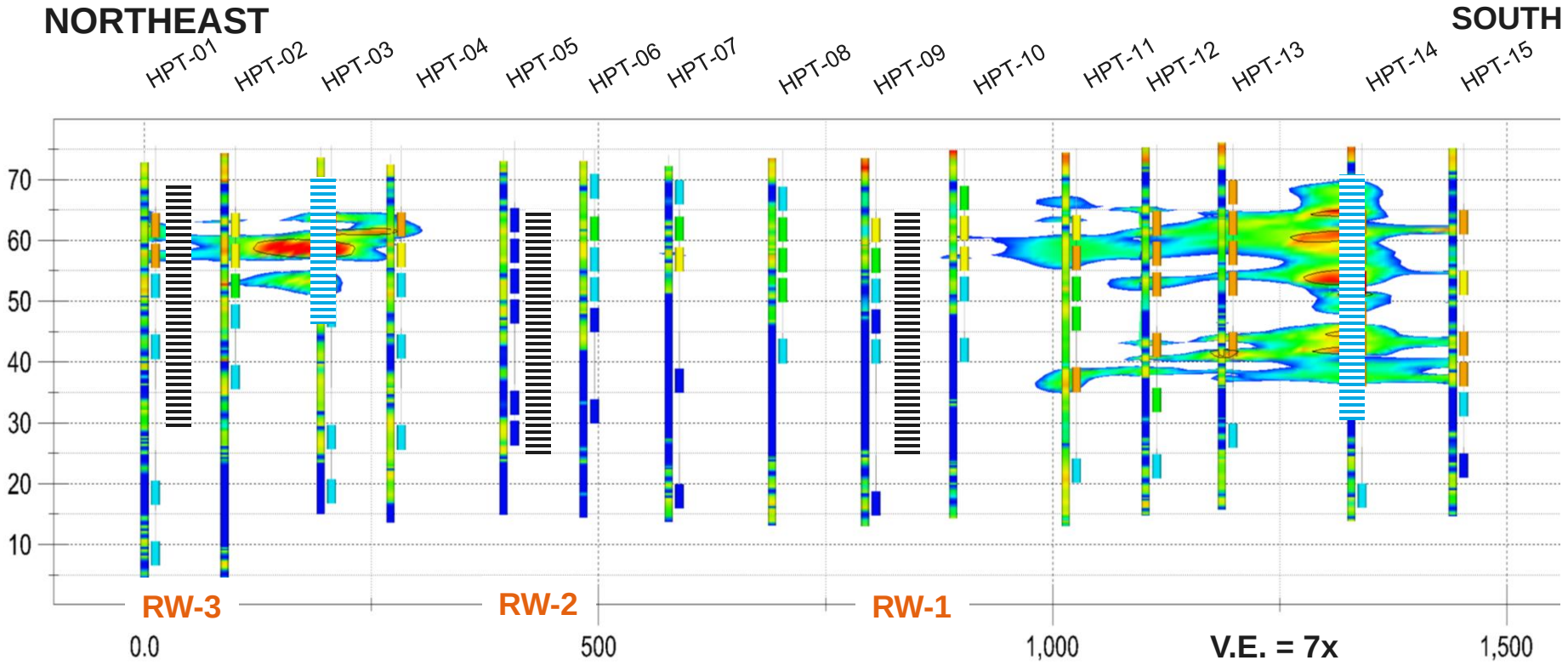
Stratigraphic Flux™



>90% of flux occurs in <10% of cross-section

Stratigraphic Flux™ - ROI

- Existing recovery wells not co-located with flux
- Focused flux enables simple, cost-effective optimization – move recovery wells



Return on Investigation: avoided perimeter slurry wall & optimized pumping wells

ARCADIS Design & Consultancy for natural and built assets

Stratigraphic Flux

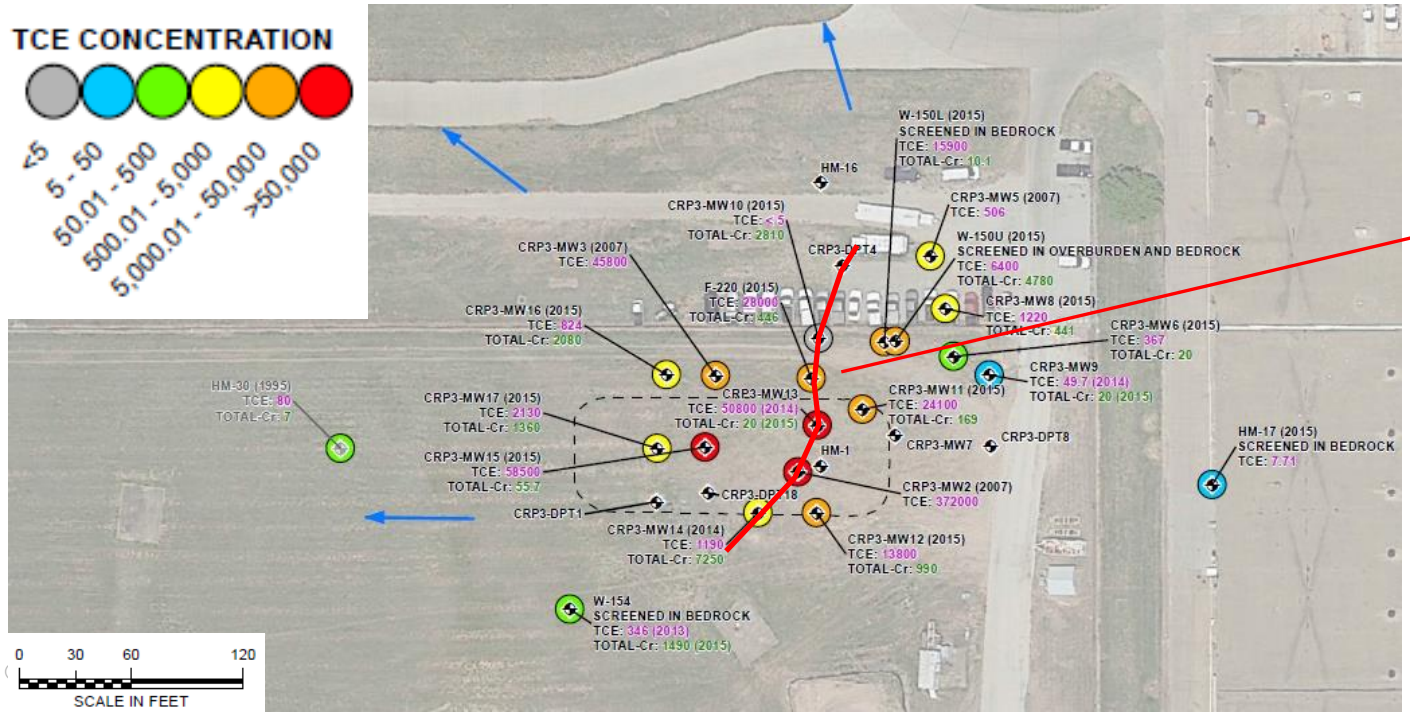
Air Force Plant 4, Chrome Pit 3

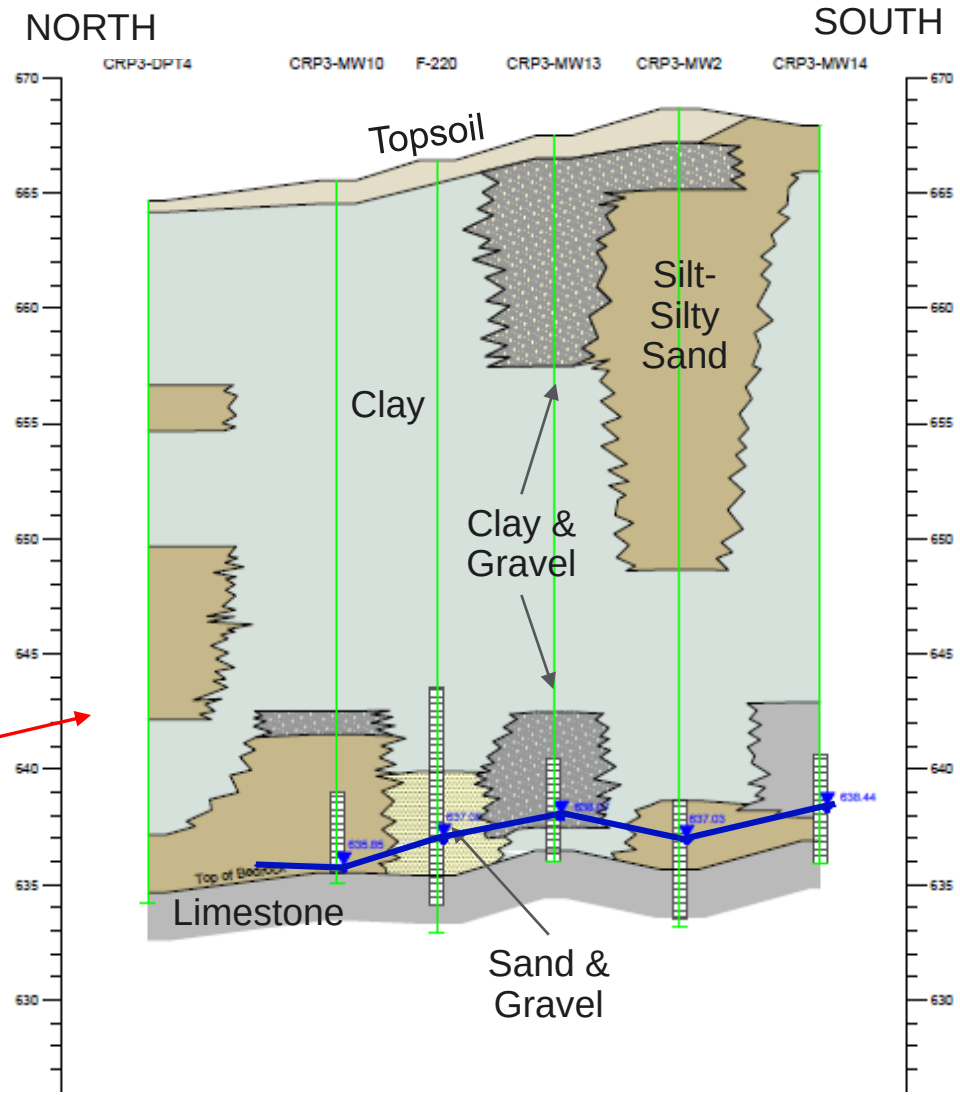
Fort Worth, Texas

- Barium chromate sludge disposal
- High concentrations of TCE and chromium
- Previous source remediation
  - Excavation - mass removed from vadose zone
  - ISCO and in-situ bio applied for saturated zone treatment

Challenging Conditions….

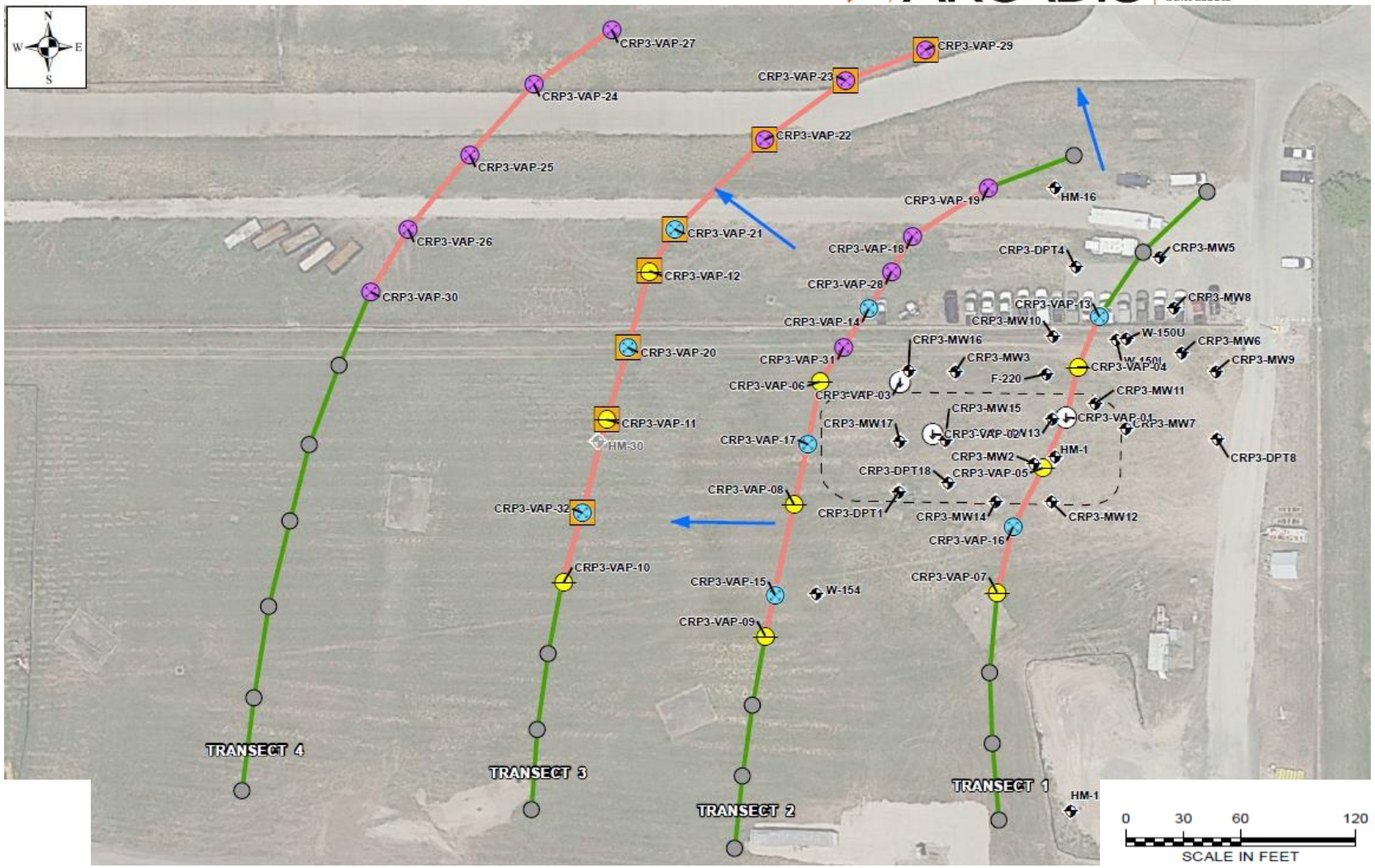
- High concentrations of TCE in dense low permeability clays/silts
- Limited saturated thickness
- Shallow, weathered bedrock with saturated rubble zone





Approach

- Adaptive transects in overburden - real-time analysis
- Detailed soil descriptions with sieve analysis
- Whole Core Soil Sampling:
  - Soil results for vadose zone
  - Equivalent groundwater results for saturated zone



LEGEND

- ABANDONED MONITORING WELL
- CRP3 MONITORING WELL
- CALIBRATION BORING (3)
- PRIMARY BORING (9)
- ADAPTIVE BORING (8)
- PROVISIONAL BORING (12)
- NOT COMPLETED (18)
- HPT LOCATION (8)
- CRP3 COMPLETED TRANSECT
- CRP3 PROPOSED TRANSECT
- FORMER CHROME PIT 3 FOOTPRINT
- GROUNDWATER GRADIENT

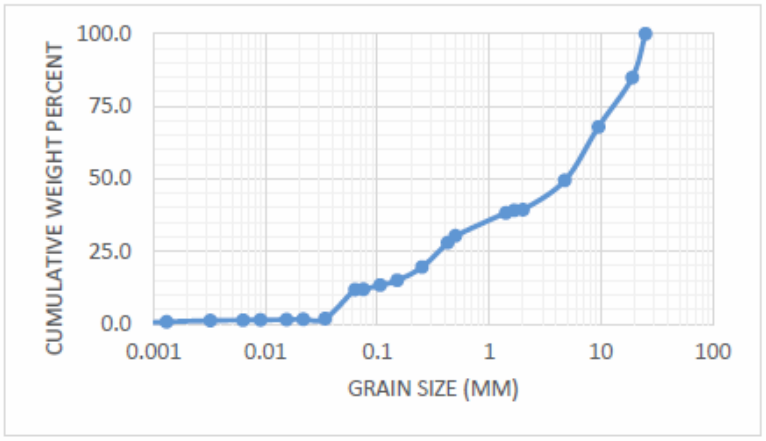
Hydrostratigraphic Analysis

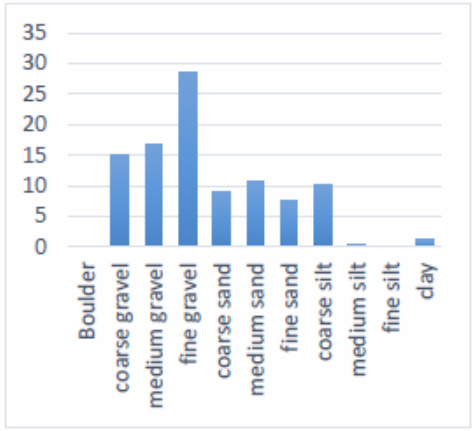
Geologic soil descriptions and sieve analysis to characterize hydrofacies in terms of permeability

1. Storage – low permeability, diffusion dominates
2. Slow advection – moderate permeability, 10% of flow
3. Transport – highest permeability, 90% of flow

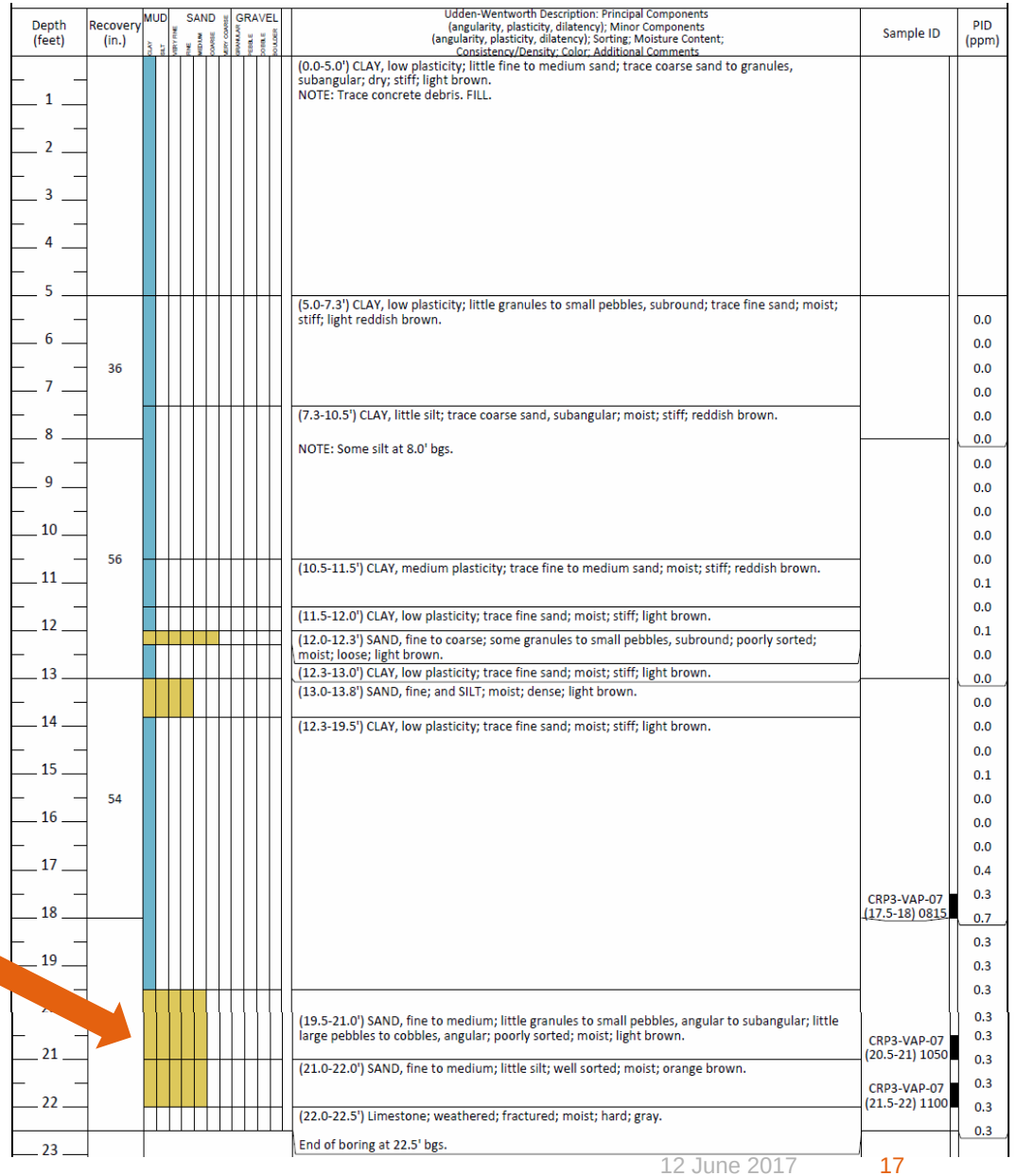
Sieve results used to estimate average K to each hydrofacies unit:

Poorly sorted sandy gravel low in fines





CRP3-VAP-07

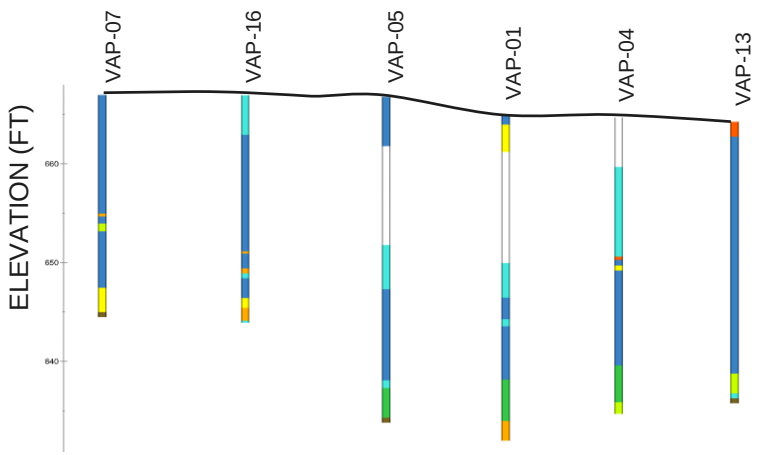


Hydrostratgraphic Model Development

ARCADIS Design & Consultancy for natural and built assets

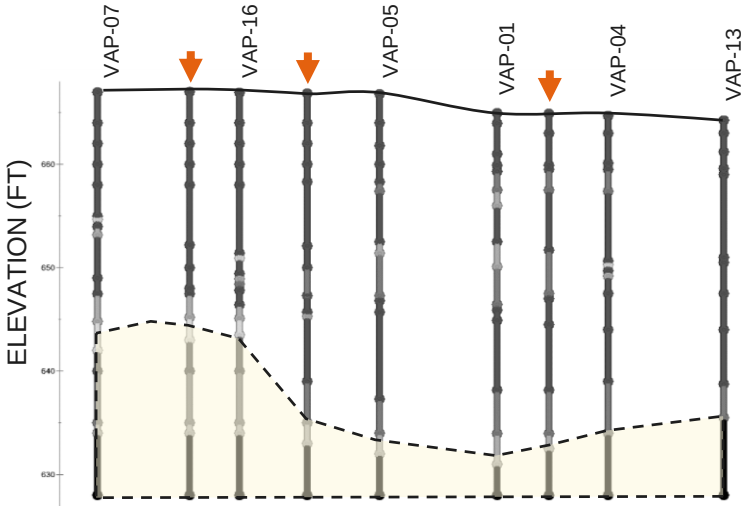
Recorded Boring Lithology

- CLAY
- SAND/SILT AND CLAY
- SILT
- SILT SAND
- SAND
- SAND AND GRAVEL
- GRAVEL
- LIMESTONE
- NO RECOVERY



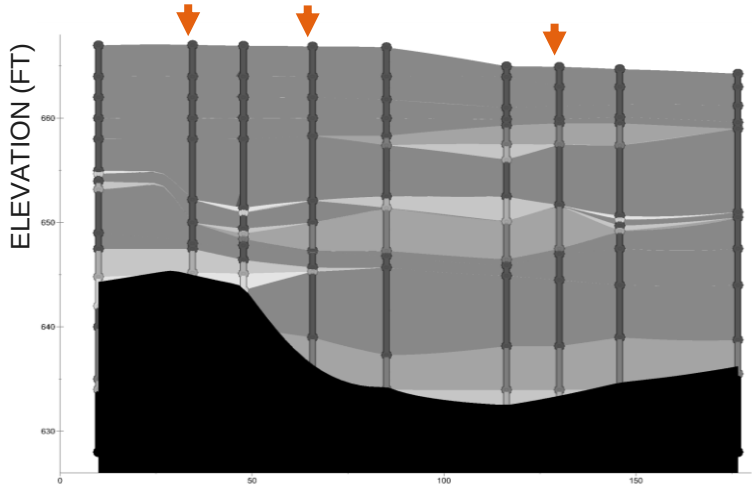
Categorize stratigraphy into hydrofacies

Add calibration (▼) points as necessary



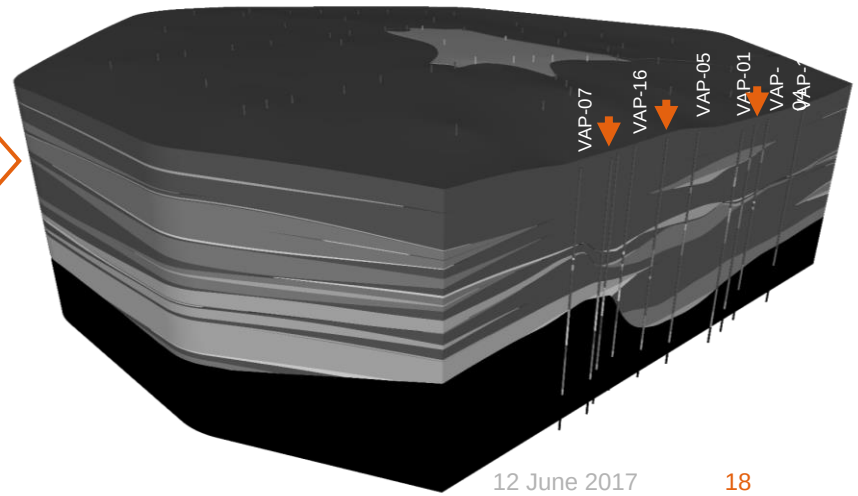
3D Interpolation of Hydraulic Conductivity (cm/s)

- (2.x10^{-2} cm/s)
- **TRANSPORT**
- (3 x 10^{-3} cm/s)
- **SLOW ADVECTION** (4 x 10^{-4} cm/s)
- **STORAGE** (4 x 10^{-6} cm/s)
- **BEDROCK**

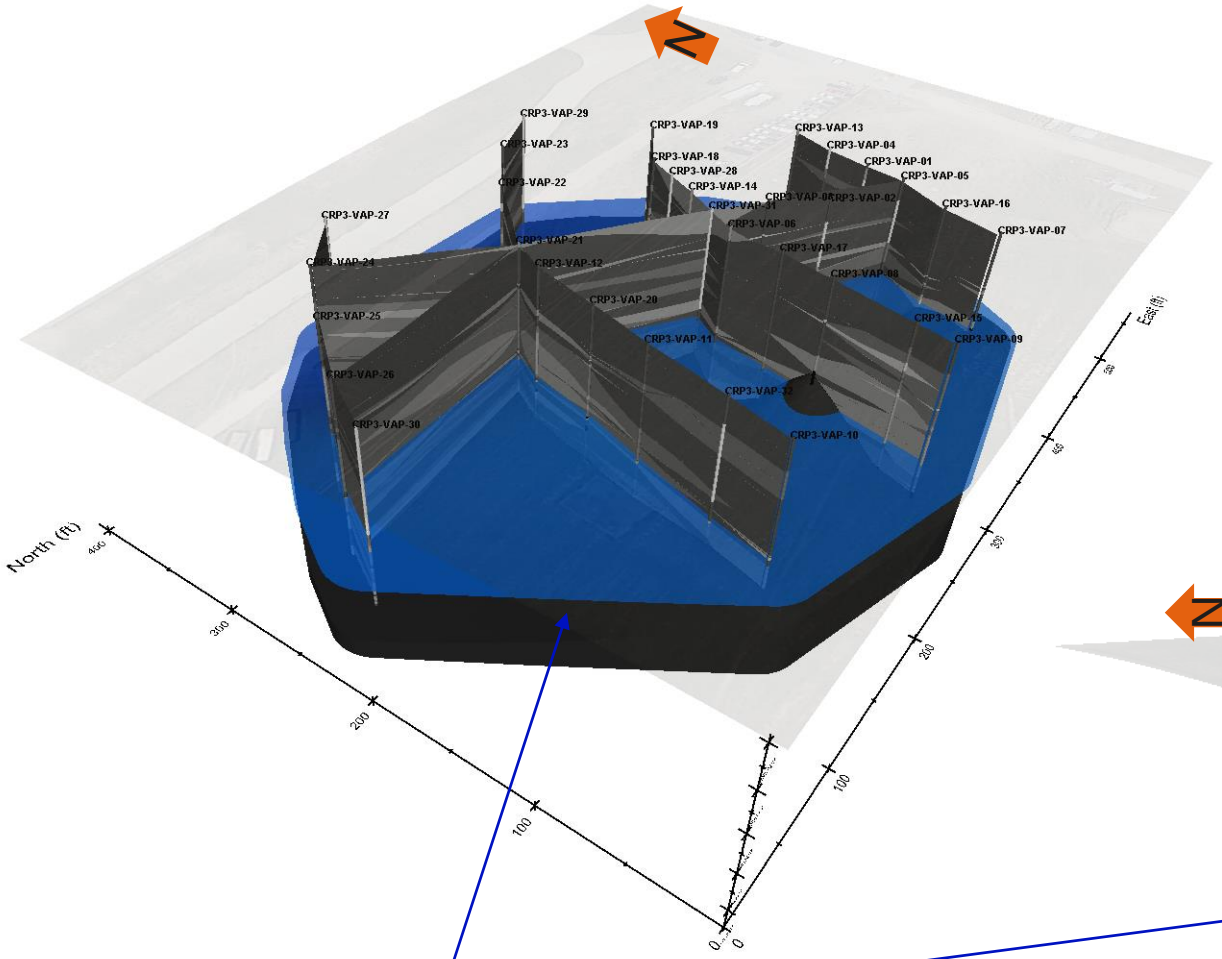


Develop hydrofacies correlation through iteration,

Expand to 3D model of entire site



Hydrostratigraphic Model



Transport Potential

3D Interpolation of Hydraulic Conductivity (cm/s)

(2 x 10^{-2} cm/s)

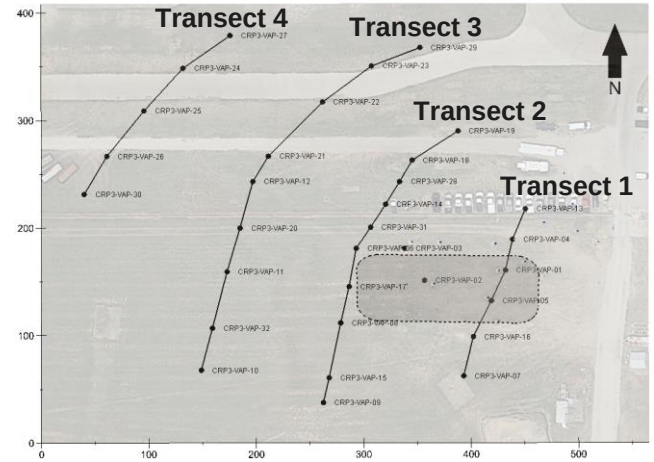
TRANSPORT

(3 x 10^{-3} cm/s)

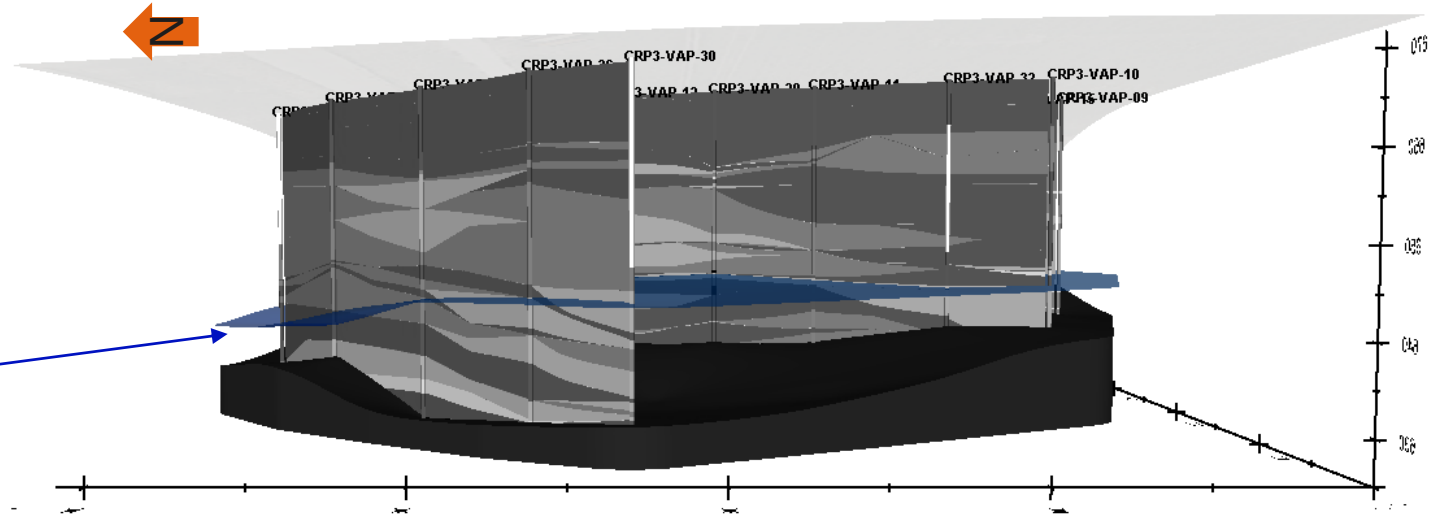
SLOW ADVECTION (4 x 10^{-4} cm/s)

STORAGE (4 x 10^{-6} cm/s)

BEDROCK



WATER TABLE



Whole Core Soil Sampling

High-resolution soil sampling in lieu of groundwater sampling to map concentration in vadose and saturated zones.

TCE concentration (ug/L)

- >50,000 ug/L
- 5,000-50,000 ug/L
- 500-5,000 ug/L
- 50-500 ug/L
- MDL-50 ug/L
- <MDL

TCE in Groundwater

Plume >30 ug/L

TCE concentration (ug/kg)

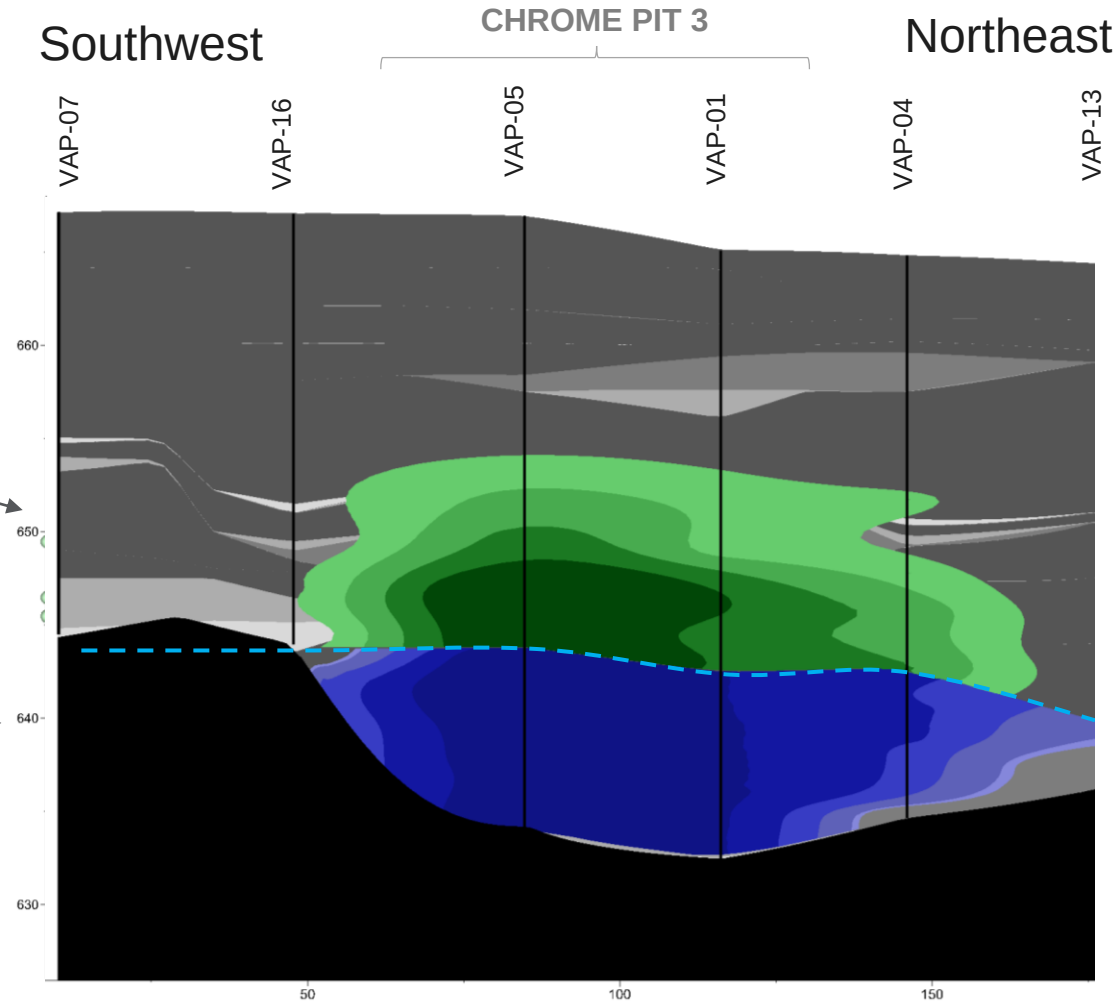
- >18,000 ug/kg
- 1,800-18,000 ug/kg
- 180-1,800 ug/kg
- MDL-180 ug/kg
- <MDL

TCE in Soil

Plume >18 ug/kg

Vadose soil concentrations (µg/kg)

Equivalent groundwater concentrations (µg/L)



ARCADIS Design & Consultancy for natural and built assets

- **Comparison of equivalent groundwater to monitoring well concentrations**

- Reliable agreement

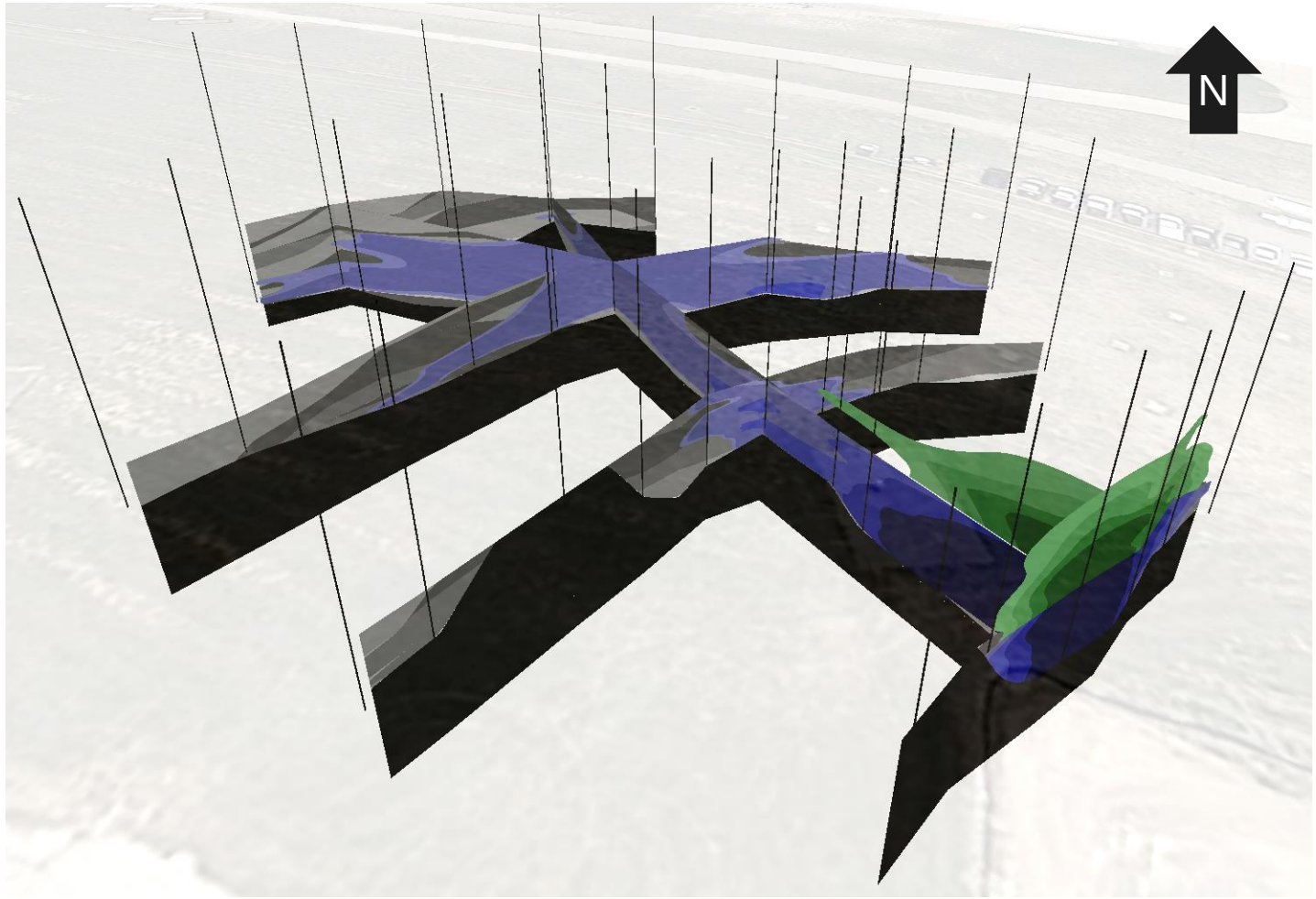
- Distinguish source from low concentrations

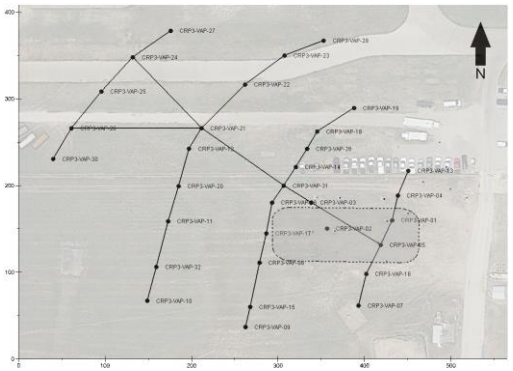
	Comparison Type	Hydrofacies	Location of Comparison GW / Soil	Average TCE in Soil* (µg/kg)	Calculated Saturated Soil to GW Conversion Ratio**	Calculated Equivalent Groundwater Concentration (µg/L)	TCE in Co-located Groundwater (µg/L)	Relative Percent Difference Eq GW : GW
1	Monitoring Well	Slow advection and transport	CRP3-MW13 / CRP3-VAP-01 27-31 ft bgs	10,800	6.1	66,000	50,800	23%
2	Monitoring Well	Slow advection and storage	CRP3-MW15 / CRP3-VAP-02 30-35 ft bgs	8,600	5.1	44,000	58,500	25%
3	Monitoring Well	Slow advection	CRP3-MW16 / CRP3-VAP-03 27-32 ft bgs	114.8	6.1	700	824	15%
4	VAP	Slow advection	CRP3-VAP-23 / CRP3-VAP-23 29-33 ft bgs	30.1 J	5.8	180 J	167	7%
5	VAP	Transport	CRP3-VAP-25 (35-37) / CRP3-VAP-25 35-37 ft bgs	<5.2	6.8	<35	14	NA
6	VAP	Slow advection and storage	CRP3-VAP-27 (0-30) / CRP3-VAP-27 25-30 ft bgs	<5.4	4.7	<25	13	NA
7	VAP	Transport	CRP3-VAP-30 / CRP3-VAP-30 40-40.5 ft bgs	16.2 J	6.1	98 J	93.3	6%

ARCADIS Design & Consultancy for natural and built assets

TCE Concentration

Hydrostratigraphic model below water table for clarity:





3D Interpolation of Hydraulic Conductivity (cm/s)

(2.26 E-2 cm/s)
TRANSPORT
(3.09 E-3 cm/s)
SLOW ADVECTION (4.15 E-4 cm/s)
STORAGE (4.49 E-6 cm/s)
BEDROCK

TCE concentration (ug/L)

>50,000 ug/L
5,000-50,000 ug/L
500-5,000 ug/L
50-500 ug/L
MDL-50 ug/L
<MDL

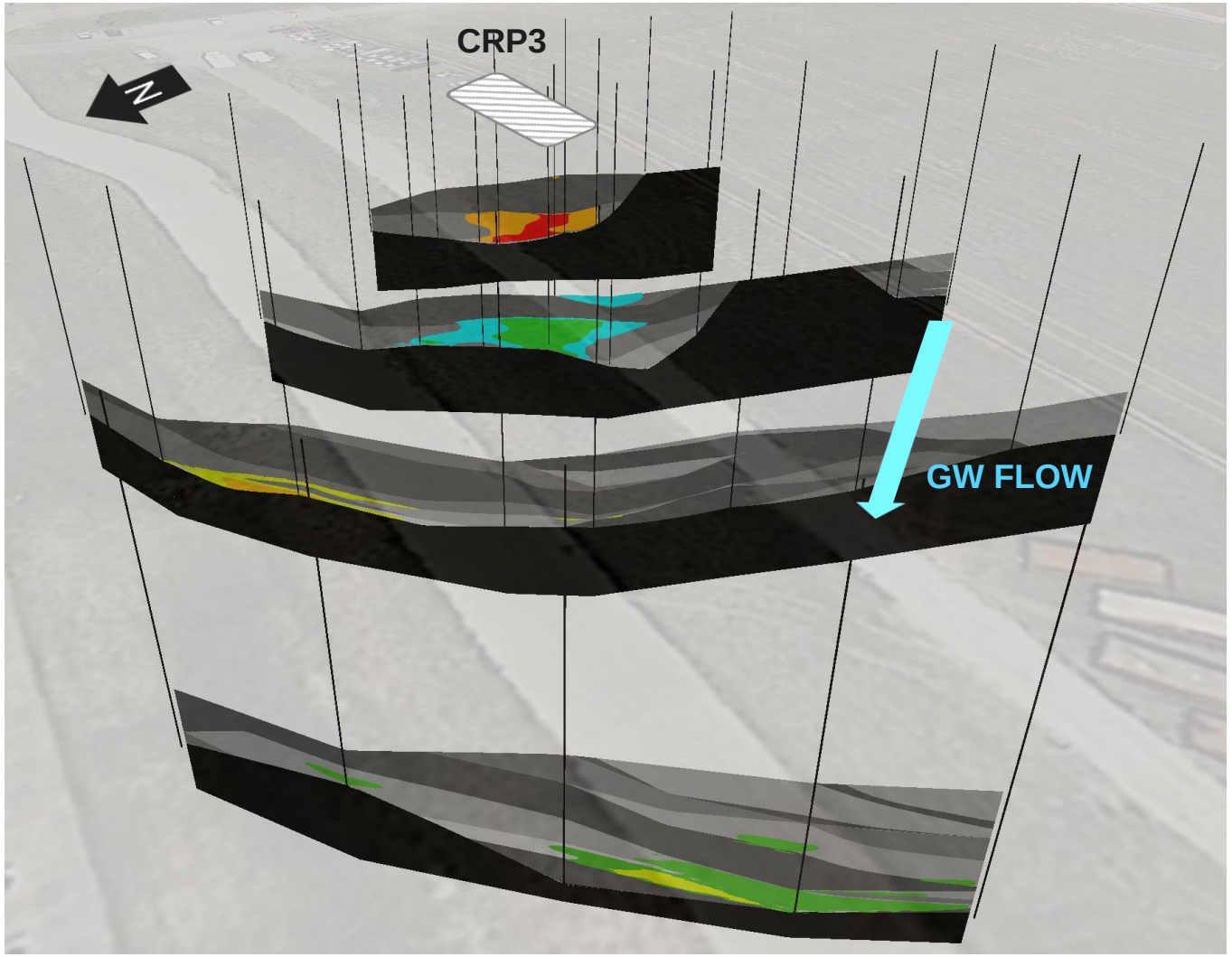
TCE in Groundwater
Plume >30 ug/L

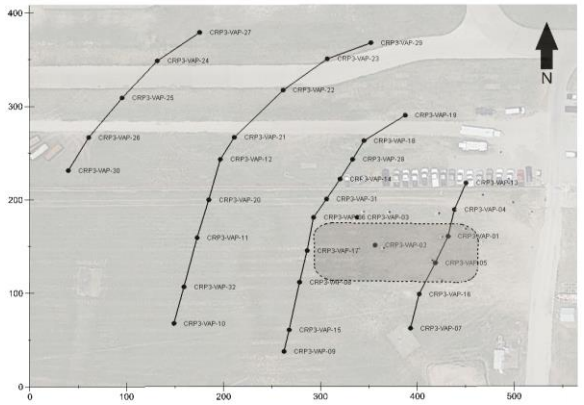
TCE concentration (ug/kg)

>18,000 ug/kg
1,800-18,000 ug/kg
180-1,800 ug/kg
MDL-180 ug/kg
<MDL

TCE in Soil
Plume >18 ug/kg

3D Stratigraphic Flux





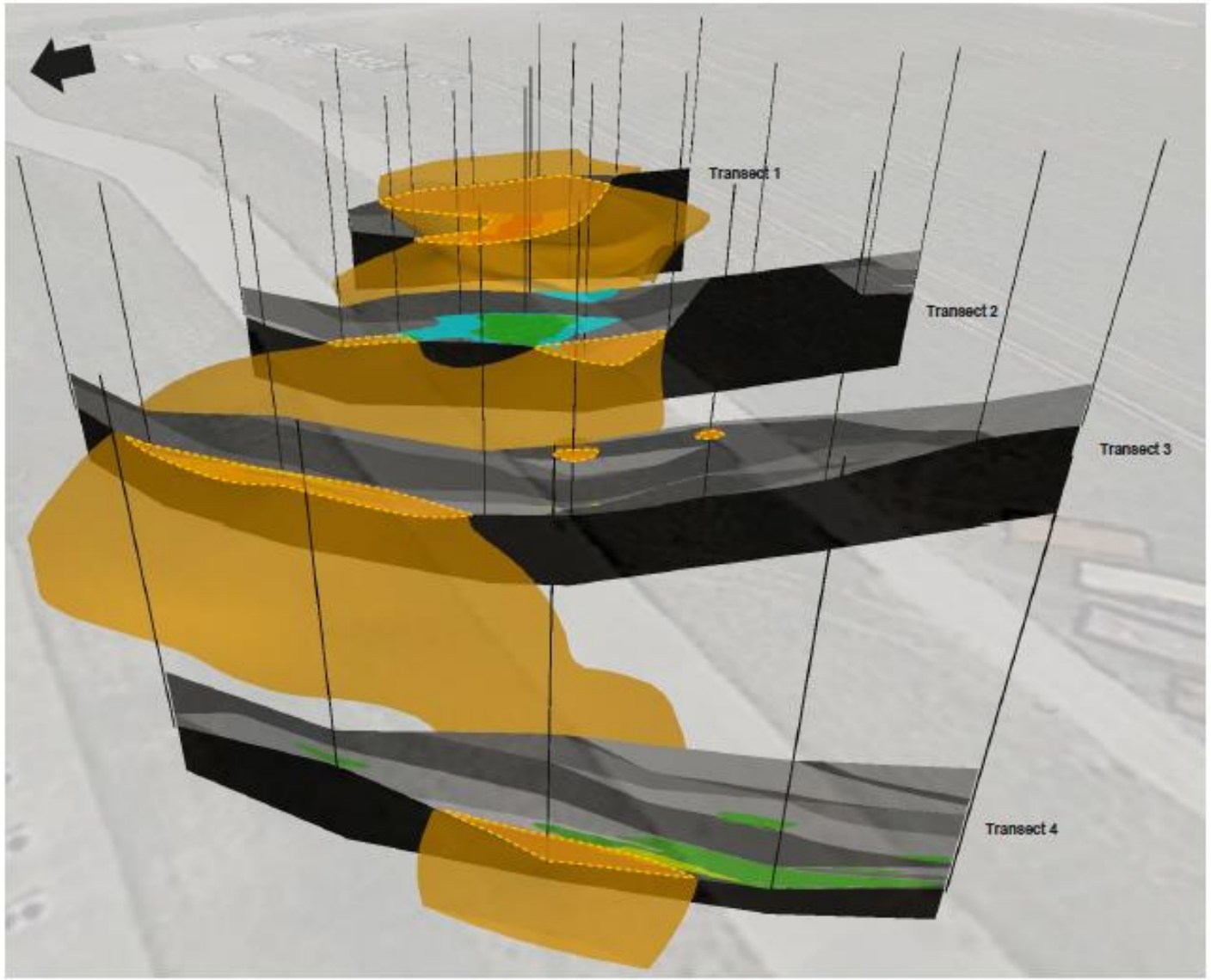
3D Interpolation of Hydraulic Conductivity (cm/s)

(2.26 E-2 cm/s)
TRANSPORT
(3.09 E-3 cm/s)
SLOW ADVECTION (4.15 E-4 cm/s)
STORAGE (4.49 E-6 cm/s)
BEDROCK

Relative Flux (unitless)

100 - 1,000
10 – 100
1 – 10
0.1 – 1
0.01 - 0.1

Chrome Results



Chrome distribution provides another line of evidence for transport pathway

Chromium in soil > 10 mg/kg

Chromium in soil > 10 mg/kg along each transect

Results

- Results being used to refine strategy
  - Bound plume with wells
  - MNA assessment
  - Determine TI waiver potential

What's next?

- Stratigraphic Flux™ Guide and training for Air Force Civil Engineer Center (AFCEC)
  - Publicly available June 2017
  - AFCEC Training August 2017
  - Technology transfer and publication 2018
  - For more info:

http://www.afcec.af.mil/Home/Environment/Technical-Support-Division/Environmental-Restoration-Technical-Support-Branch/BAA/

Questions?

JOSEPH QUINNAN
Global Director of Site Investigations and North American Director of Emerging Contaminants

o +1 248 789 4951

e joseph.quinnan@arcadis.com