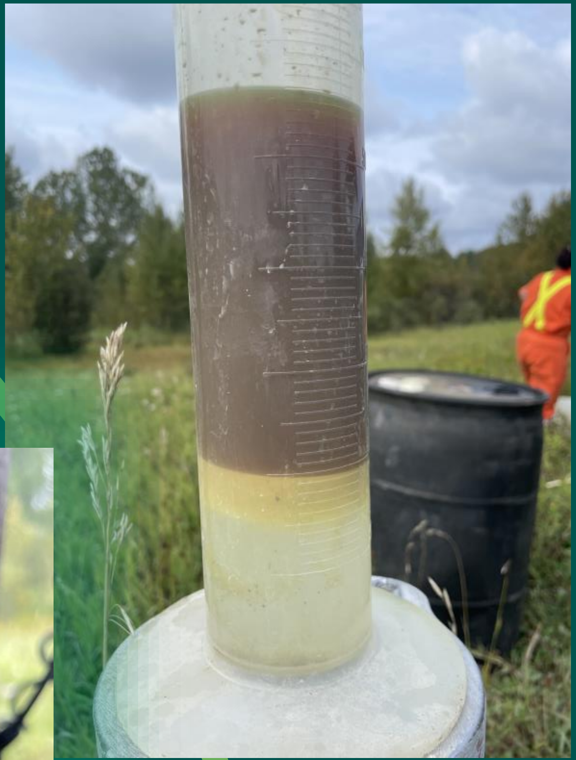
LNAPL Conceptual Site Model Refinement at a Condensate Blowout Site



October 16, 2024

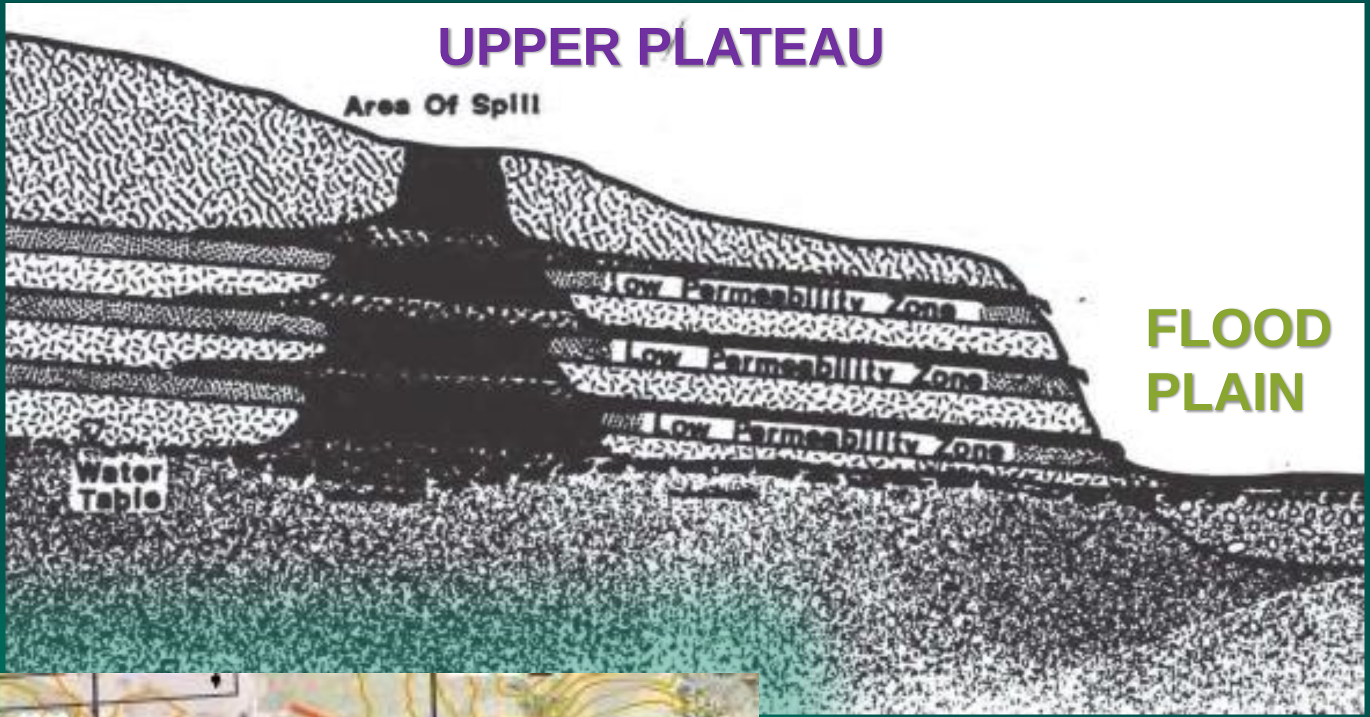
Giulio Scarzella

Outline

- Site Description
- Site Studies – Overview
- Natural Source Zone Depletion Study
- LNAPL Transmissivity
- LNAPL Transmissivity Testing
- Long term LNAPL and water level monitoring
    - Buoyed Pressure Transducer
- Site Data Story
- Next Steps
- Study and Subject Matter Expert Contacts

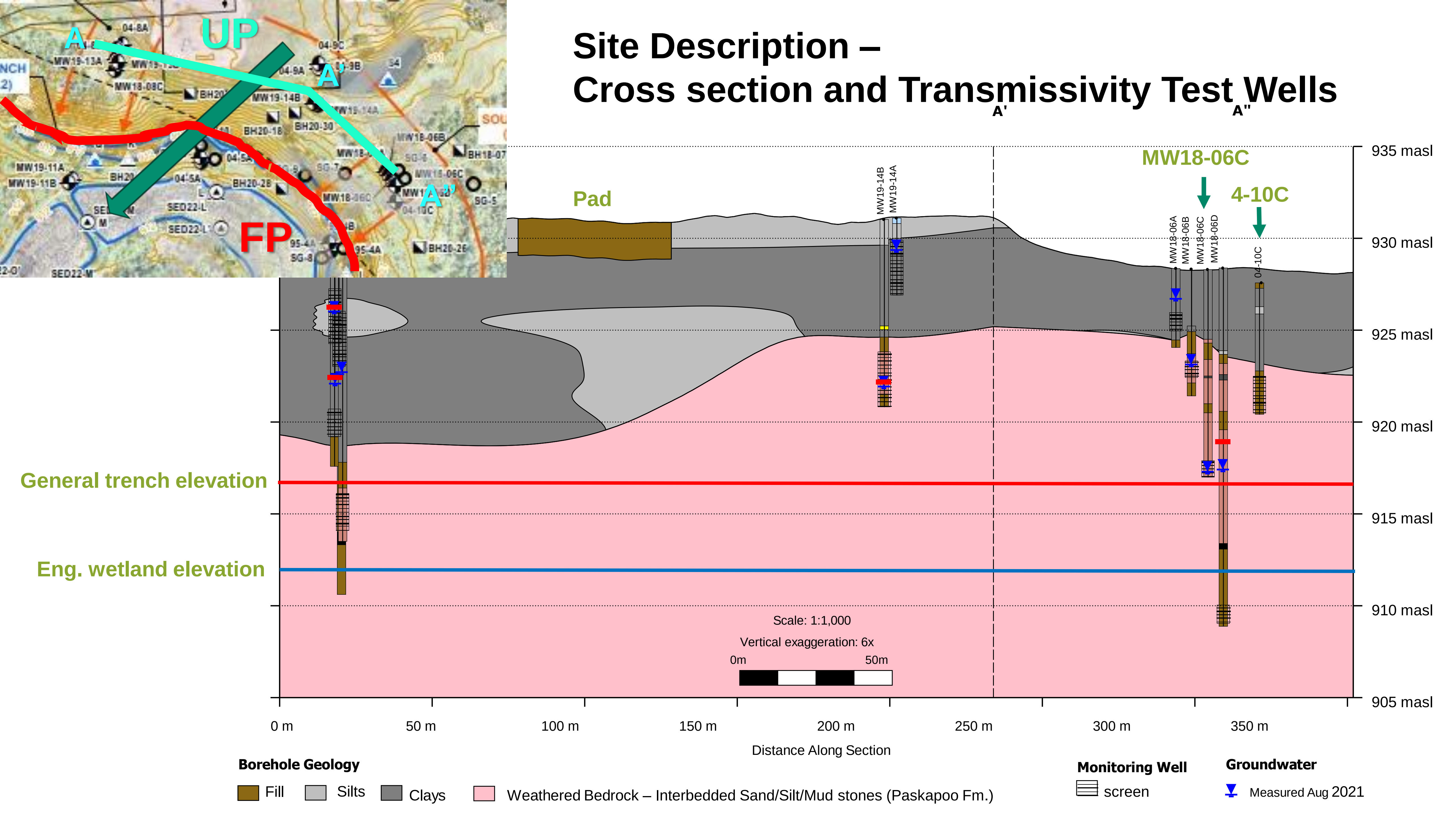
Site History - Early Migration Effects

- Soil impacts, low loading OK.
- Soil impacts, mod to heavy require “more reclamation efforts”
- Clear cut areas with heavy condensate loading
- Condensate migrating laterally + low permeable zones
- NW and SE Legs
- Initial temporary restrictions



Western Reclamation Services, 1983

Site Description – Cross section and Transmissivity Test Wells

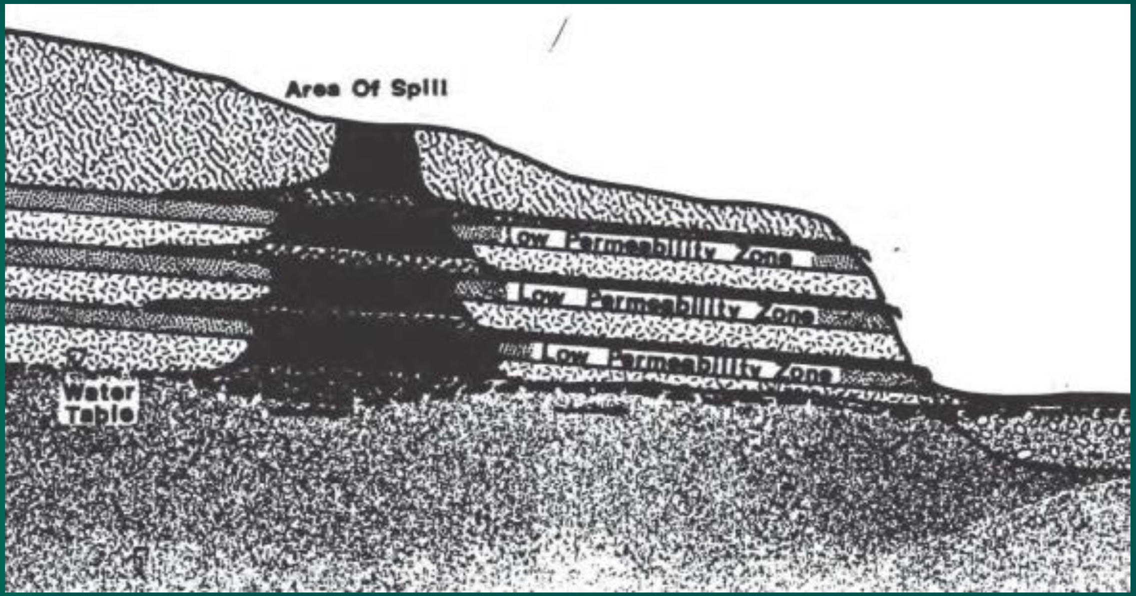


Site Description – Hydrostratigraphy, APECS, COCs

- APECs, Upper Plateau:
  - 1.1 Wellsite and West Source
  - 1.2 SE Leg
  - 1.3 NW Leg
  - 1.4 Relief Wellsite
- APECs, Lower Floodplain:
  - 2.1 Engineered Wetland
  - 2.2 East and West Trenches
  - 2.3 NW Trench

- Till over Paskapoo Fm.
  - Paskapoo –interbedded sand, silt ,and claystone
  - Highly heterogeneous regionally
- COCs
  - PHCs F1-F4, BEX
  - SAR, EC, TDS sulphide
  - Select Metals

Location	Screened Lithology	Range Screen Depths (mbgs)	Range Depth to Water (mbgs)	Range Groundwater Elevation (masl)	Hydraulic Conductivity (m/s)
Upper Plateau	Till	0.2 – 10.2	0.52 – 7.08	922.32 – 946.17	1.3×10^{-6} - 3.4×10^{-9}
	Predominantly unconsolidated bedrock	4.7 – 10.9	3.07 – 10.04	914.15 – 927.71	9.9×10^{-7}
	Shallow consolidated bedrock	6.9 – 17.9	4.05 – 14.97	916.88 – 932.25	1.6×10^{-6} - 2.0×10^{-8}
	Deep consolidated bedrock	15 – 24.4	5.15 – 10.75	917.65 – 922.89	-
Flood Plain	Till and fluviolacustrine sediments	0.2 – 3.9	0.02 – 3.54	907.51 – 912.87	1.1×10^{-6} - 2.6×10^{-8}
	Poorly consolidated bedrock	4.5 – 7.55	-0.12 – 4.71	906.98 – 912.29	7.4×10^{-5} - 5.3×10^{-7}



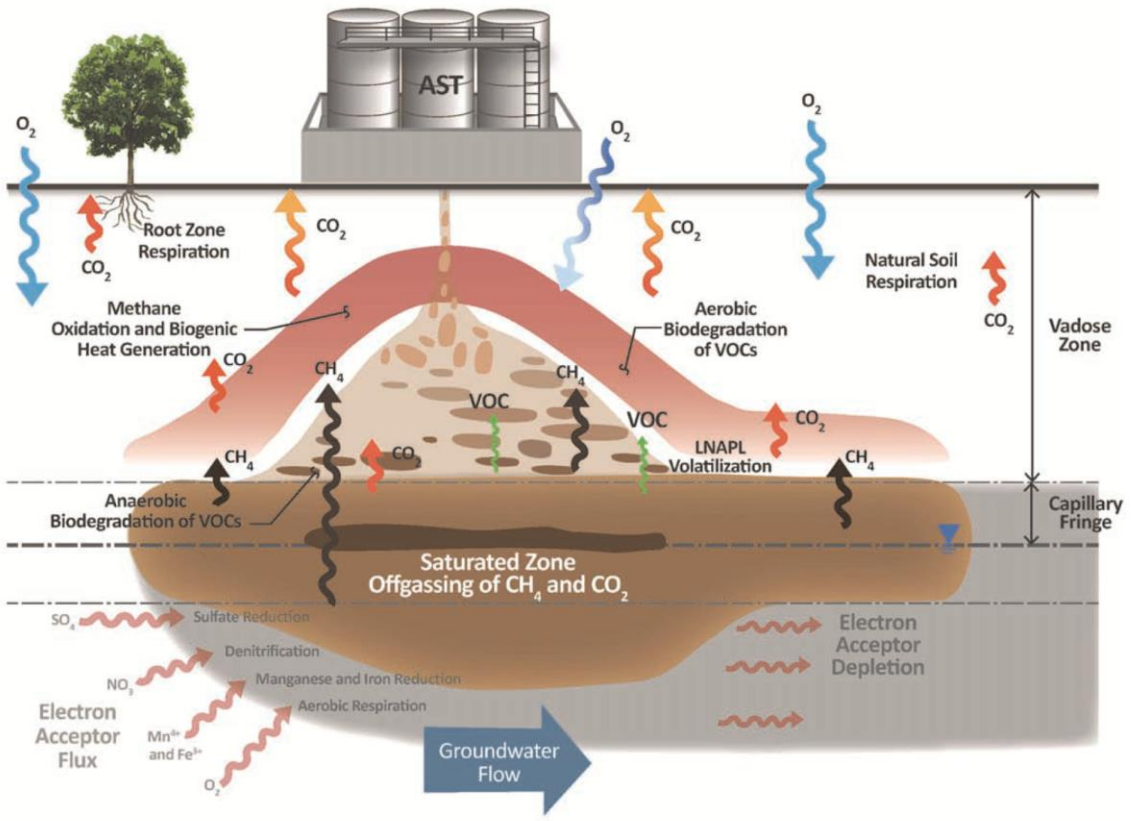
Western Reclamation Services, 1983

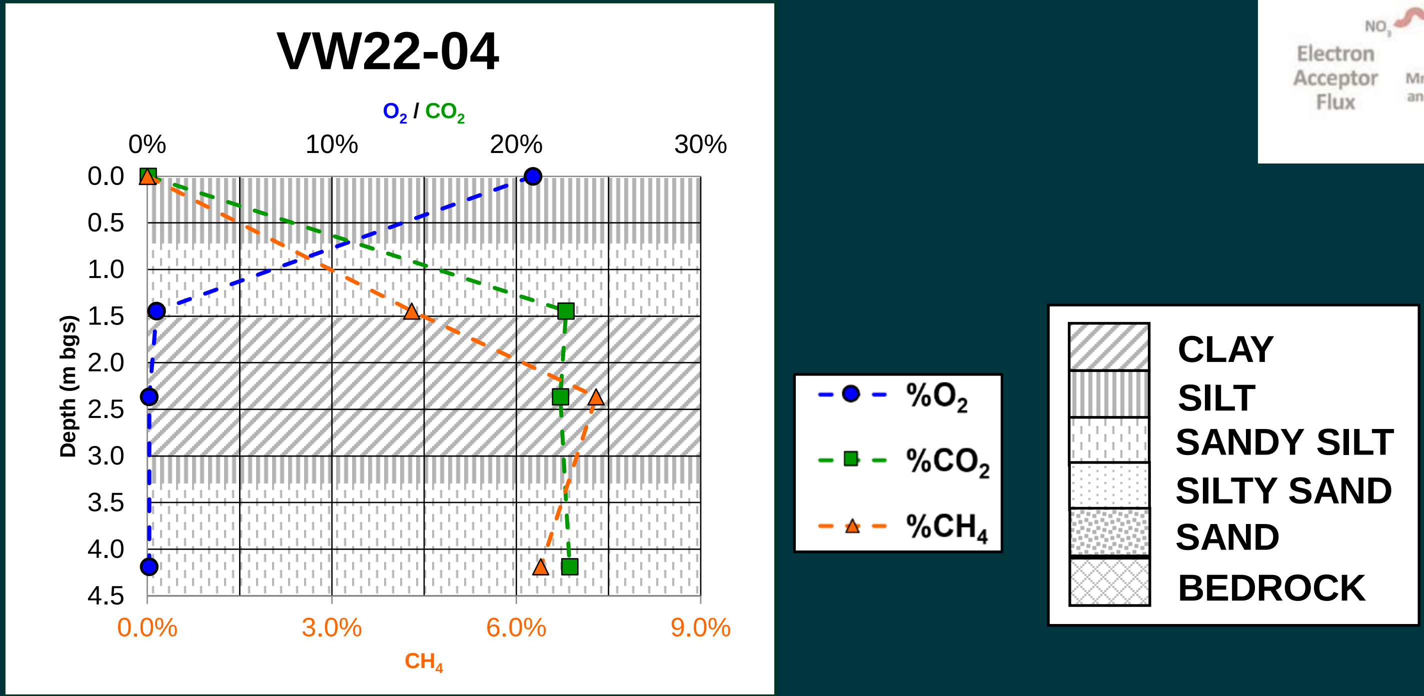
Site Studies – Refine the CSM

- Site Specific Risk Assessment
  - 2023 Problem Formulation
- Natural Source Zone Depletion Evaluation
  - Statistical trends
  - Geochemical degradation (bio, etc.)
  - Soil Gas
- LNAPL Transmissivity Testing
  - Remedial efficacy
  - LNAPL behavior with different conditions
- Natural Attenuation Monitoring
- More studies to come!

Natural Source Zone Depletion

- Many methods to evaluate:
  - Mass loss, bulk mass and/or energy balance electron flux,
  - PHC degradation product flux such as CO_2 or heat
- Currently at Site:
  - Screening level - NSZD processes - LNAPL mass reduction
  - Soil gas composition profiling in MWs vadose zone
  - Mann Kendal Analysis - trends
  - Geochemical biodegradation indicators – association
  - Corroborating data – empirical evidence





Atmospheric control (vol%):

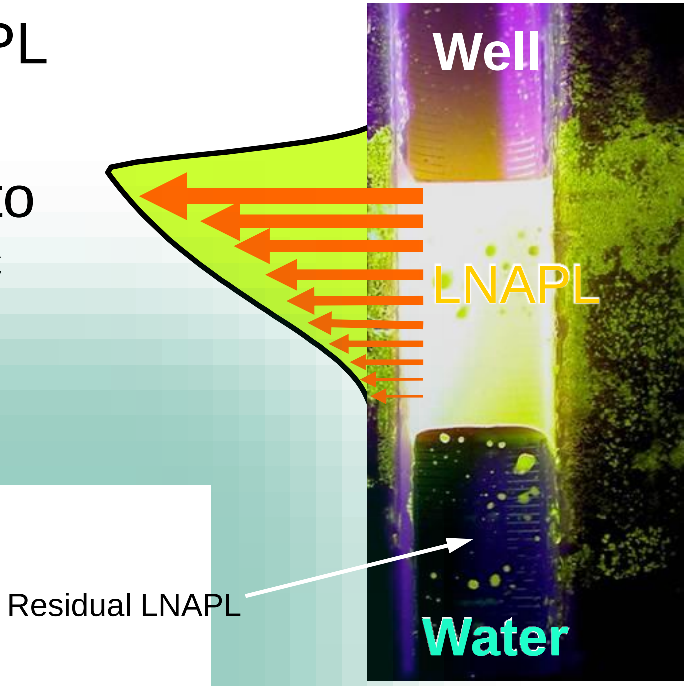
O_2 = 20.9

CO_2 = 0.04

CH_4 = 0.0

- Ideal Metric for Evaluating Recovery Potential
  - As LNAPL Saturation Approaches Residual, T_n Approaches Zero
  - Tn ≤ 0.1 to 0.8 ft^2/day indicates that remaining LNAPL is dominated by residual
- Best Practices for Testing and Data Analysis Established within Last Decade

- **Simple definition:** Rate at which LNAPL can be pumped from a well
- LNAPL recoverability is not just related to LNAPL thickness in a well, but hydraulic recovery proportional to T



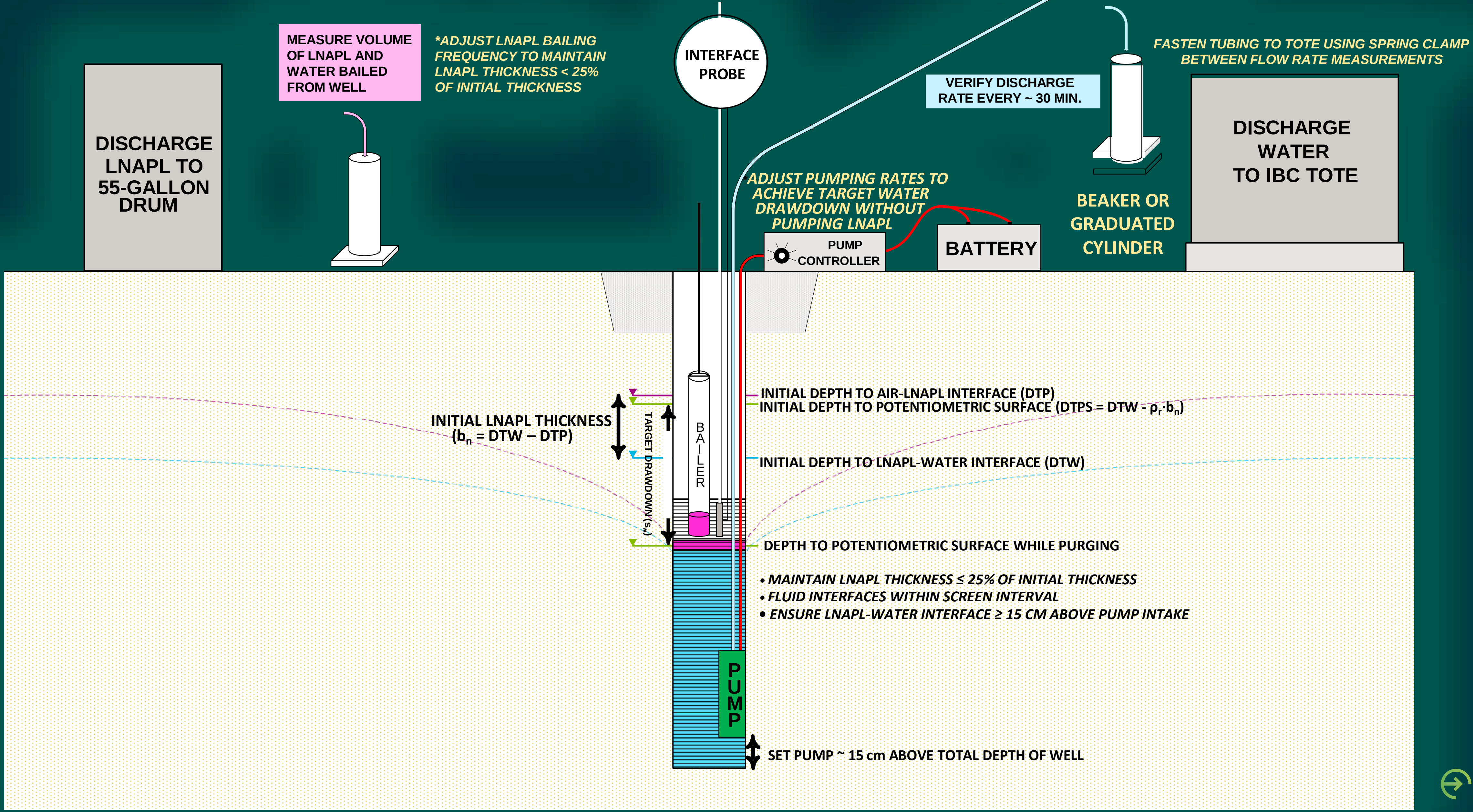
Courtesy of Andrew Kirkman

$$T_n = \frac{Q_n \cdot T_w}{Q_w \cdot \left({}^{1}/_{\rho_r} + {}^{s_{skim}}/_{s_w} \right)}$$

Where,

T_n	= LNAPL Transmissivity (m^2/day)
T_w	= Groundwater Transmissivity (m^2/day)
ρ_r	= LNAPL/Groundwater Density Ratio, or Specific Gravity (unitless)
Q_n	= LNAPL Recovery Rate (L/day)
Q_w	= Groundwater Recovery Rate (L/day)
S_{skim}	= Available LNAPL Skimming Drawdown (m)
S_w	= Groundwater Drawdown (m)

LNAPL Transmissivity Testing – Established Methodology



Transmissivity Testing – In the Field @ 4-10C

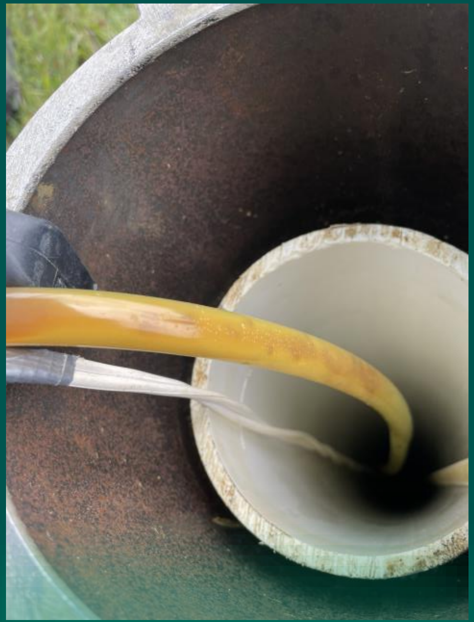
2023

2024

Transmissivity Testing – In the Field @ MW18-06C

2023

MW18-06C



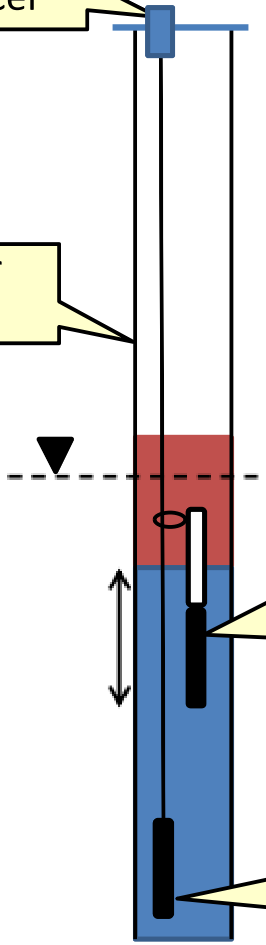
2024

Transmissivity Testing Methodology
Buoyed Pressure Transducer – How's it Work?

LNAPL monitoring configuration shown. Minimal LNAPL thickness required for fluid interface transducer to maintain proper buoyancy

Well cap suspends deep transducer with guide wire for fluid interface transducer

2-inch diameter well or larger



Depth of fluid interface transducer remains constant relative to LNAPL/water interface; transducer measures changes in LNAPL head above transducer

Deep transducer data installed beneath LNAPL-water interface to measure changes in potentiometric surface

Measured Parameters

- **LNAPL Head**
- **LNAPL Density**
- **Potentiometric Surface**

Calculated Parameters

- **LNAPL Thickness**
- **Air-LNAPL & LNAPL-water Interfaces**

Buoyed Pressure Transducer – Benefits and Limitations

Benefits

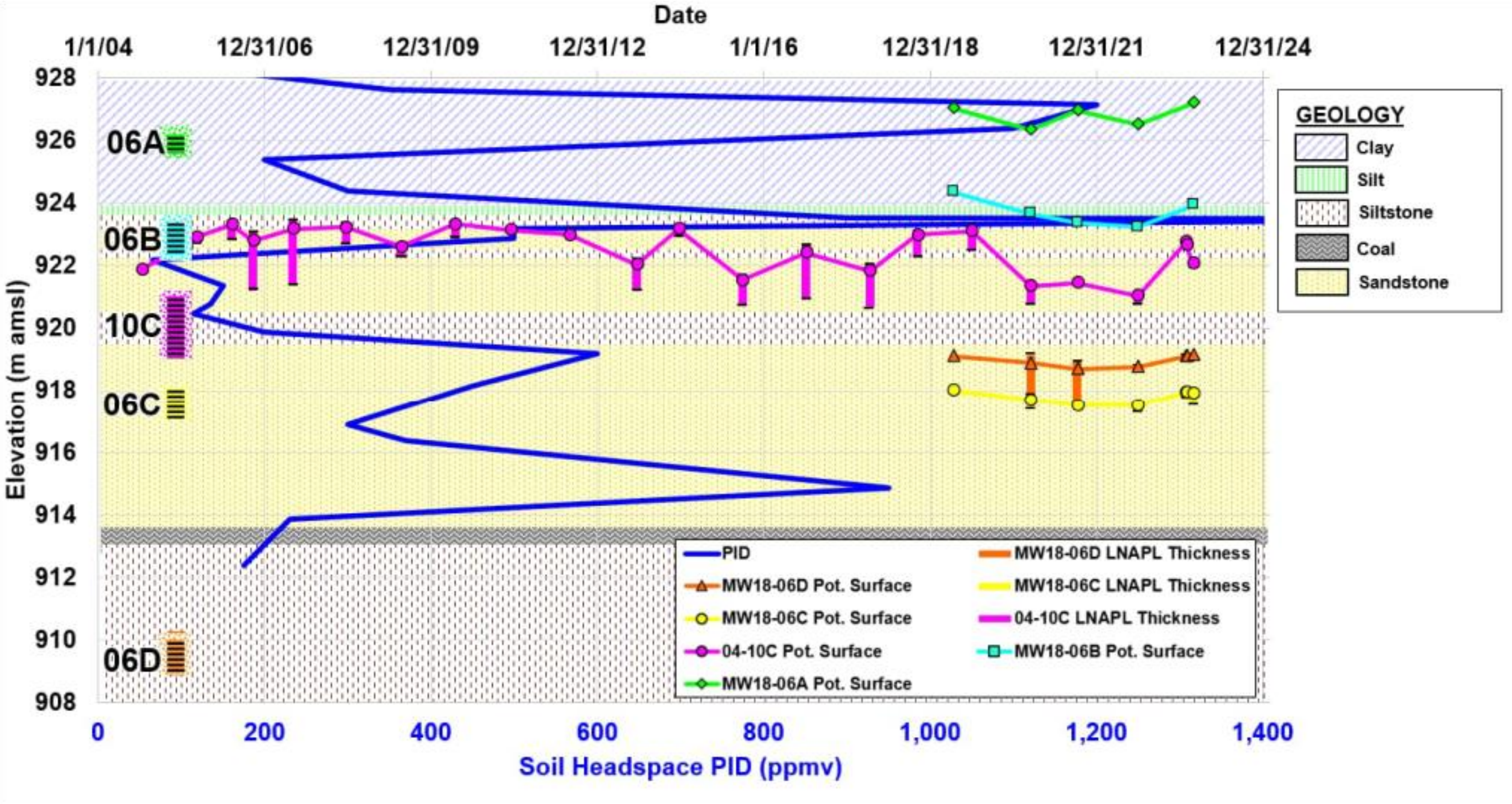
- High resolution data collection for transmissivity testing
- Long term fluid level monitoring
  - Remote locations
  - Tidal studies
- Reduced time for personnel in field
  - Reduced costs
  - Reduced H&S concerns

Limitations

- Requires a minimal thickness in well before readings are linear
  - Minimal thickness depends on specific gravity of NAPL and tool configuration

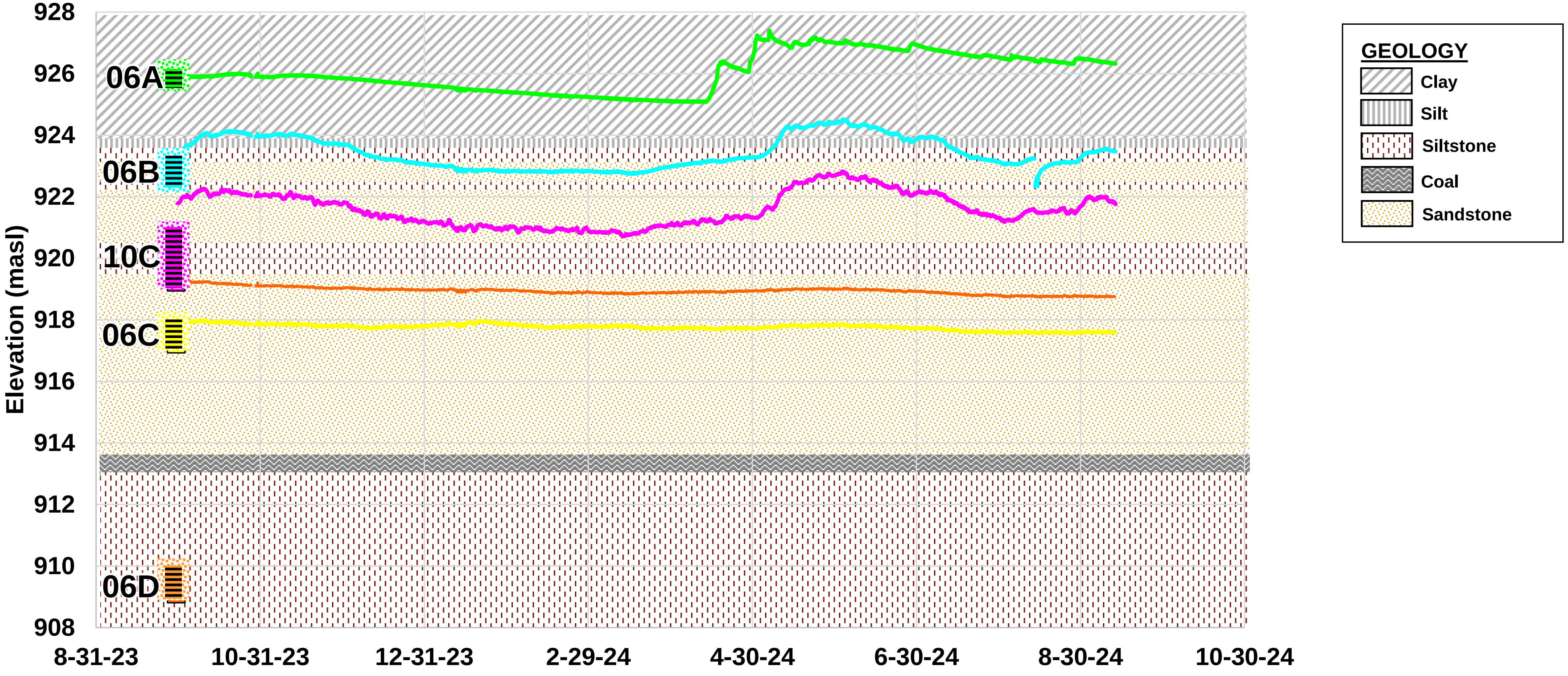
Site CSM Story – 4-10C and MW18-06C LNAPL Equilibrium

- 4-10C historically not at equilibrium with well screen – poor recovery no remedial efficacy – close to residual saturation
- BUT – MW18-06C also not in equilibrium (smaller data set)
- Multiple variables influencing behavior

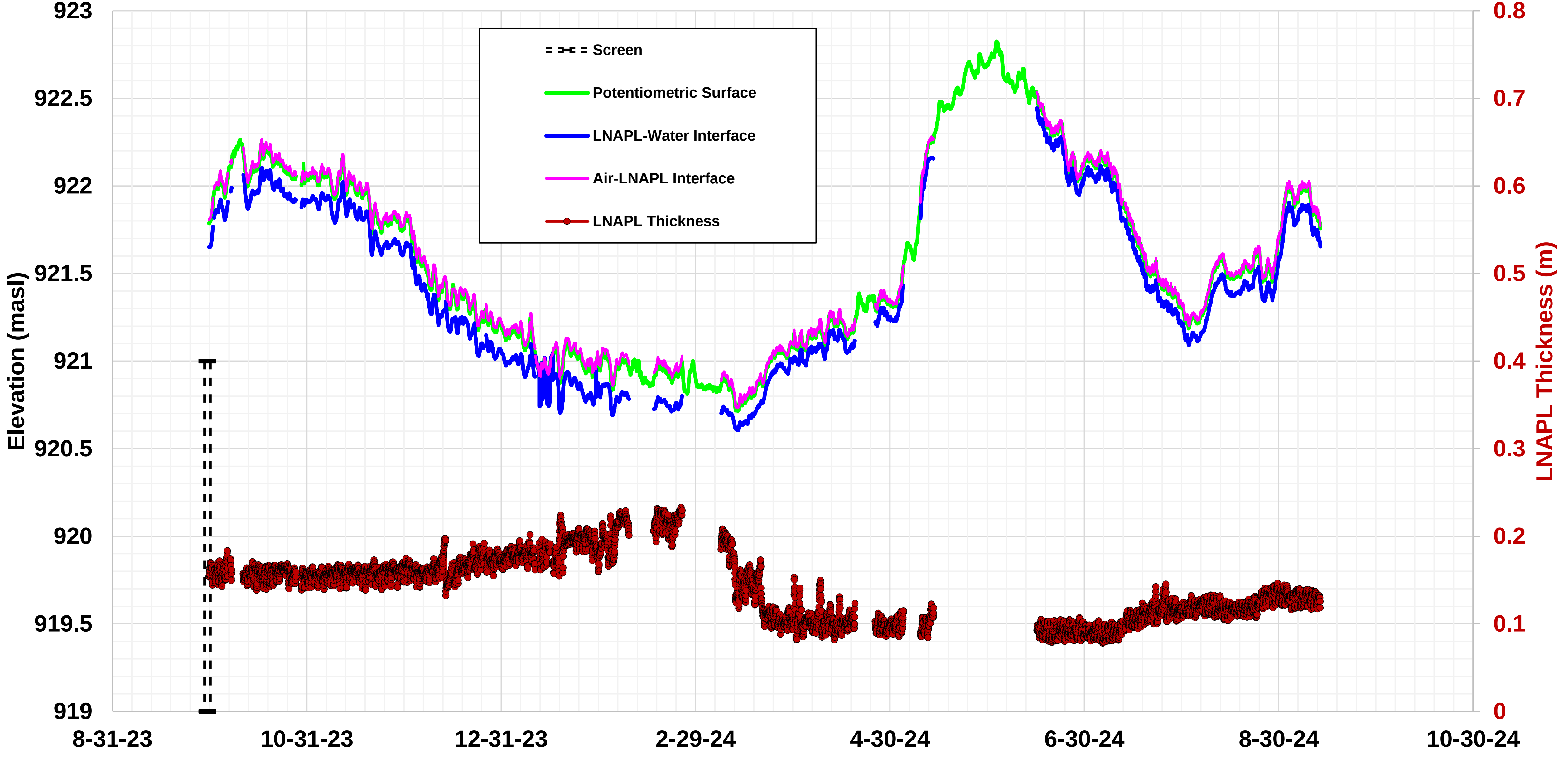


Time-Series Hydrograph of Co-located wells

Transducer Data – Water Levels



Buoy Data: 04-10C



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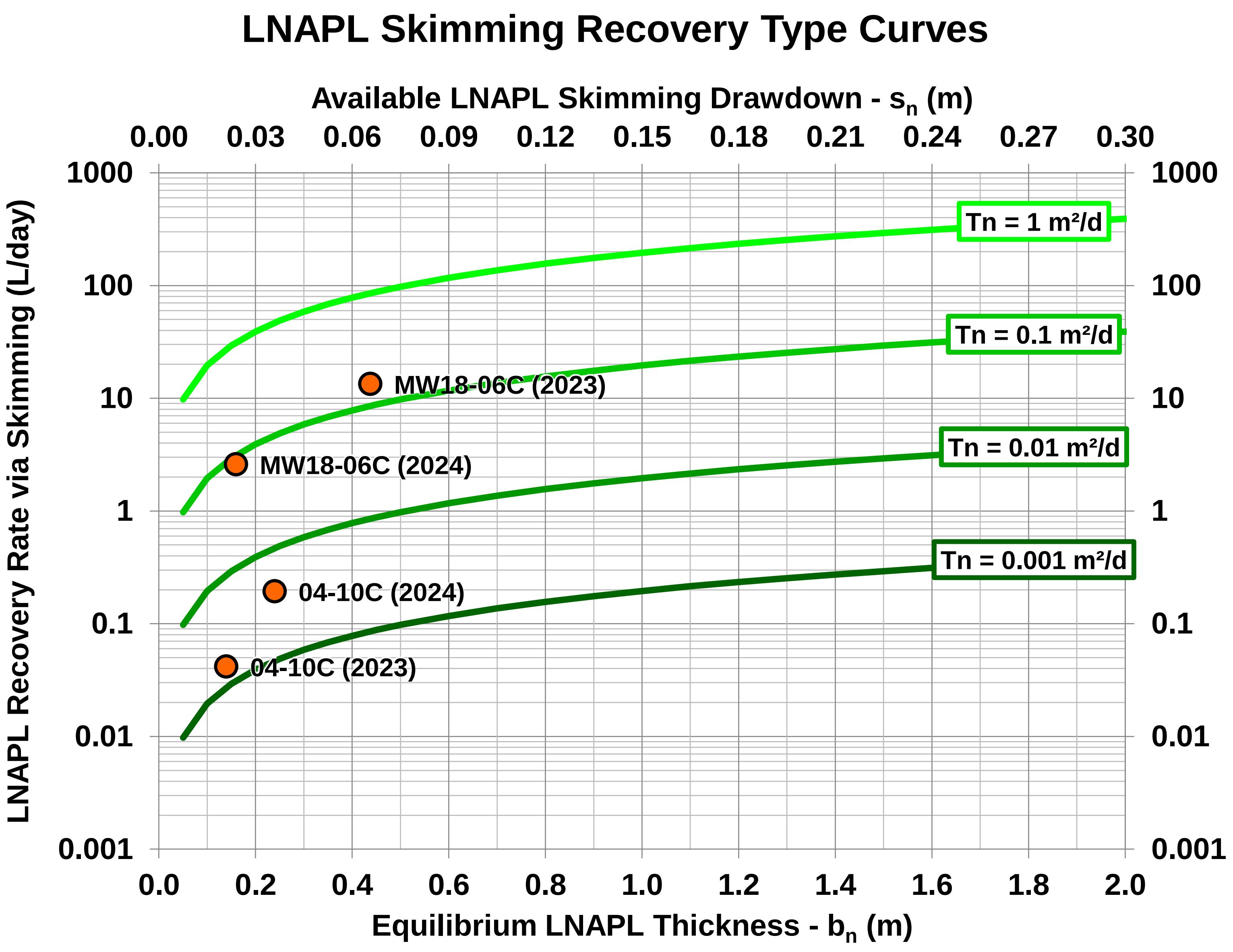
Site CSM Story – LNAPL Transmissivity Results

- Why different results? Diff of factor of 2 is acceptable, even good or great
- **Equipment** - accuracy and precision
- **Water Level** - saturated thickness
- **Natural Controls**
  - Hydraulic gradient – vert and horiz
  - Number, size and orientation of fractures
  - Bedrock contacts and macropore networks
  - Fluid dynamics and LNAPL-water interface in equilibrium with screen interval



Next Steps

- Continued long term water and NAPL level monitoring
  - Ongoing evaluation of hydrostratigraphic interconnectivity and gradient influences
  - Assess evolving LNAPL behavior
  - Continued NSZD monitoring and assessment
- Install and run small pilot total fluids system at MW18-06C in Spring 2025
  - Exponential drop in LNAPL recovery is expected
- Tracer Test – what types?
- Other geophysical methods? Seismic? CPT?

Contacts!

- Local Schlub
  - Giulio Scarzella, Senior Hydrogeologist, AECOM Canada Ltd
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- Smart People
  - Jonathon Smith, NAPL Technical Specialist, AECOM US West Environment
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  - Steven Gaito, Technical Leader - Remediation, AECOM US West Environment
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Thank you.

Questions I can answer, please!