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Slower than Expected Aquifer Cleanup – Back Diffusion or Something Else?

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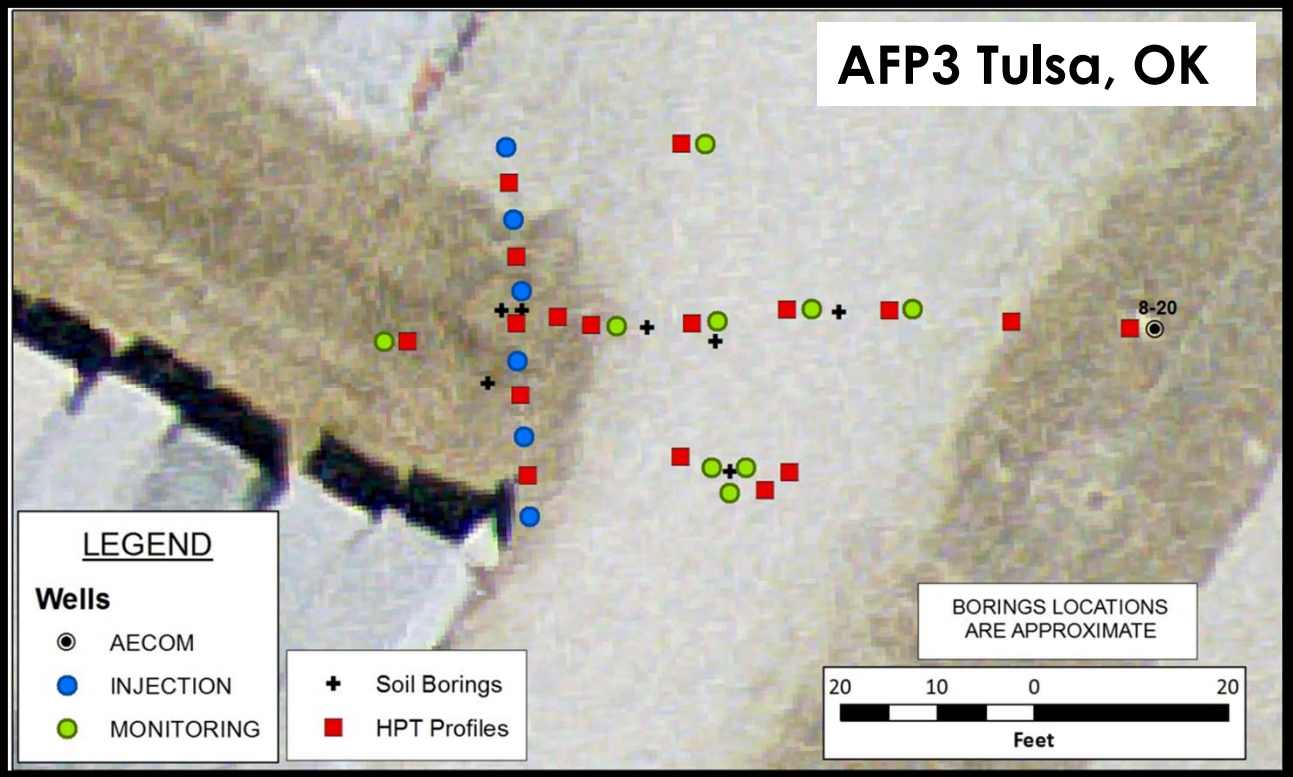
EVO PRB Pilot Test

AFP3

- Geology
  - 80% silty clay
  - 1-2 ft sand layers
- Contaminants
  - TCE
  - 14D
- EVO PRB
- Br tracer test during injection



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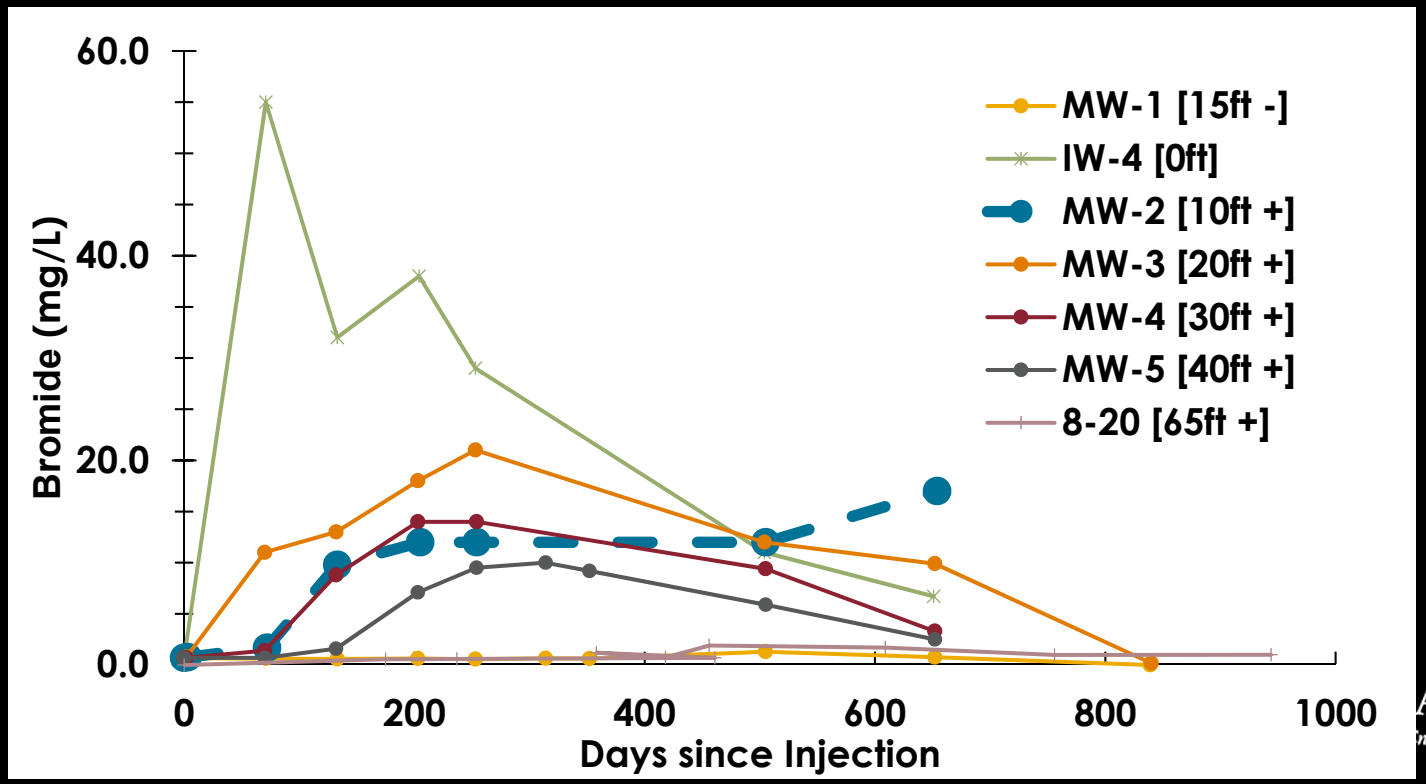
Br^- Tracer Test

- **Br^- pulse migrates past down-gradient Monitoring Wells**
  - Rapid increase → slower decline
  - Average K: 5 ~ 15 [ft/day]
  - Slower movement around MW-2



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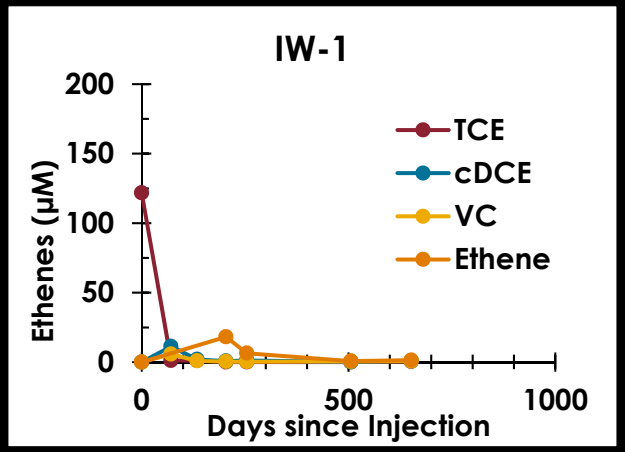
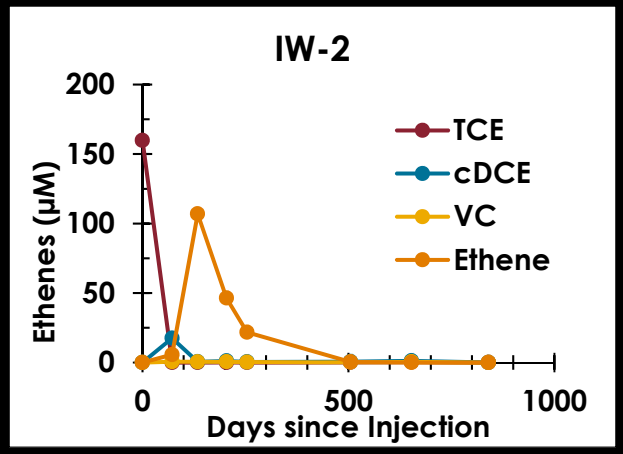
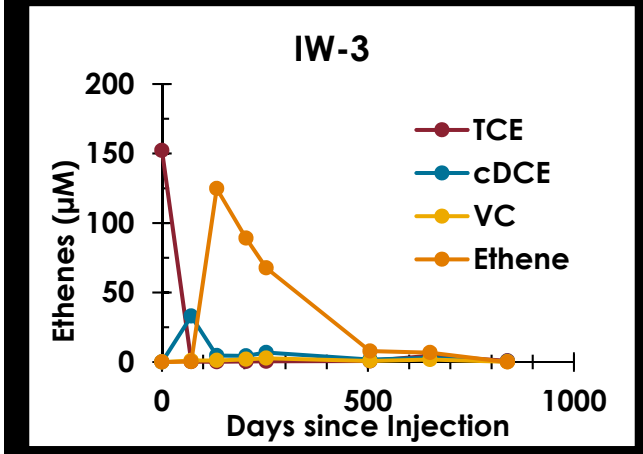
Injection Wells

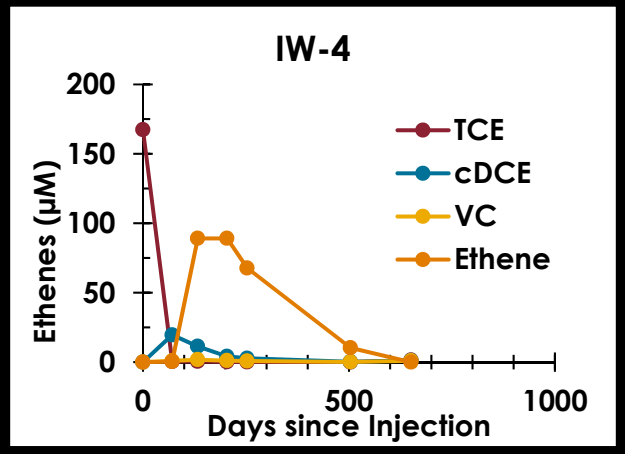
'Perfect' conversion of TCE → Ethene

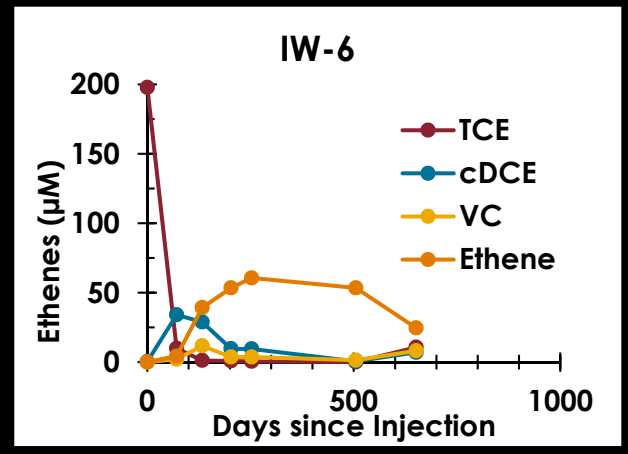
- TCE: >99.9% removal
- Lots of ethane produced
- Ethene gradually declines











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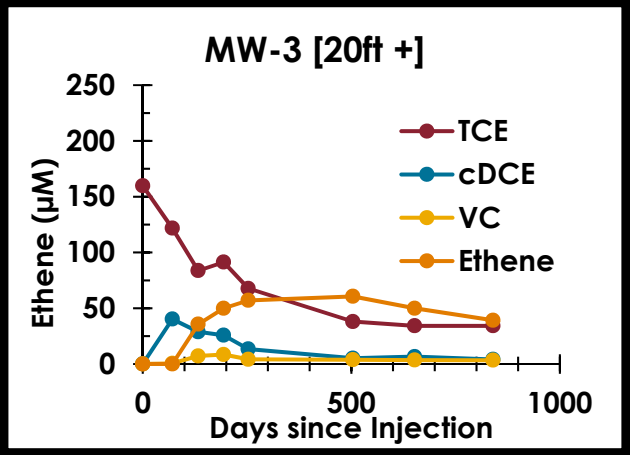
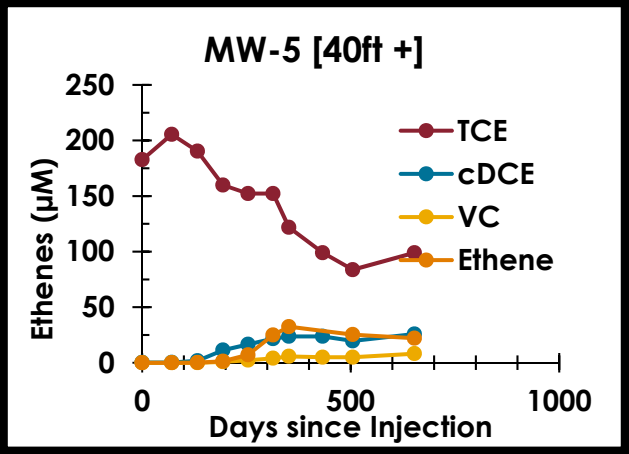
Down-gradient Monitor Wells

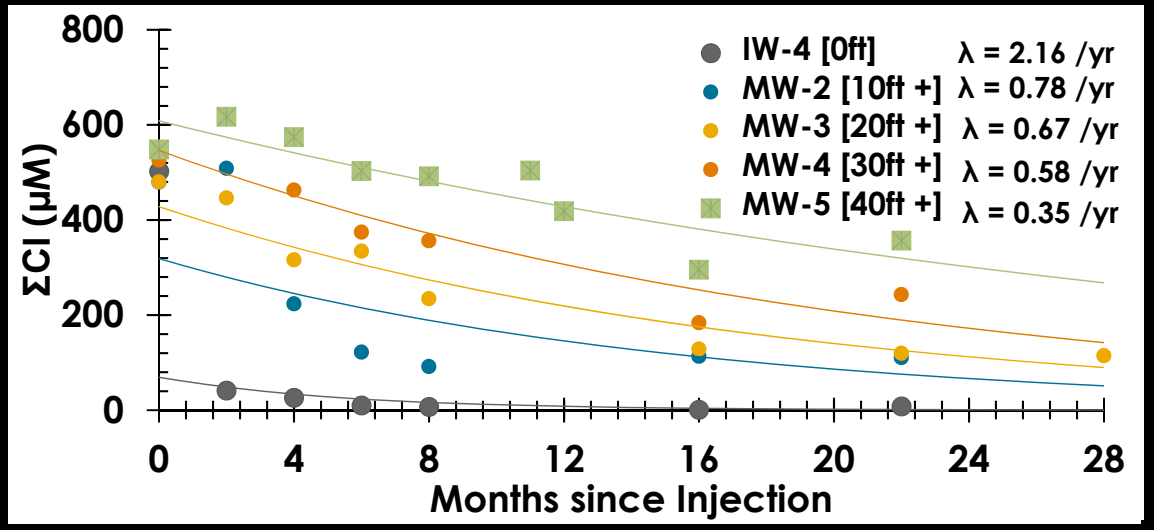
- High levels of Ethene
- Slow TCE decline





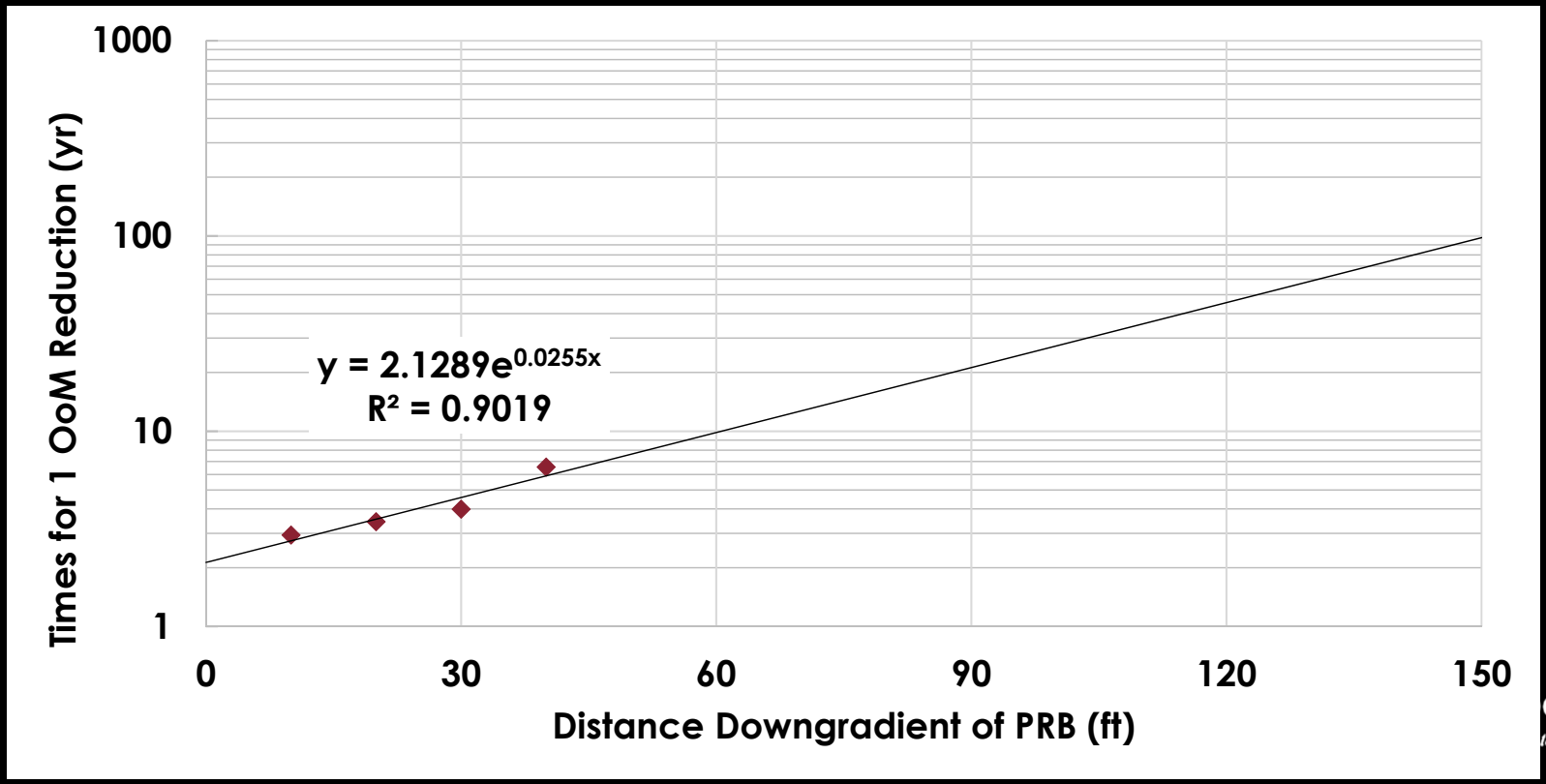
- $\sum Cl = 4 \cdot [PCE] + 3 \cdot [TCE] + 2 \cdot [DCE] + 1 \cdot [VC]$

- Fit ∑Cl to exponential function
- Decay rates (λ) decrease with distance down-gradient



Why is clean-up so slow?

- Estimate time for 1 OoM decline in ∑Cl from **λ**
- Cleanup time increases with distance
- At 100 ft down-gradient 30 years for 1 OoM reduction
- Projected to take centuries to cleanup at 150 ft down-gradient



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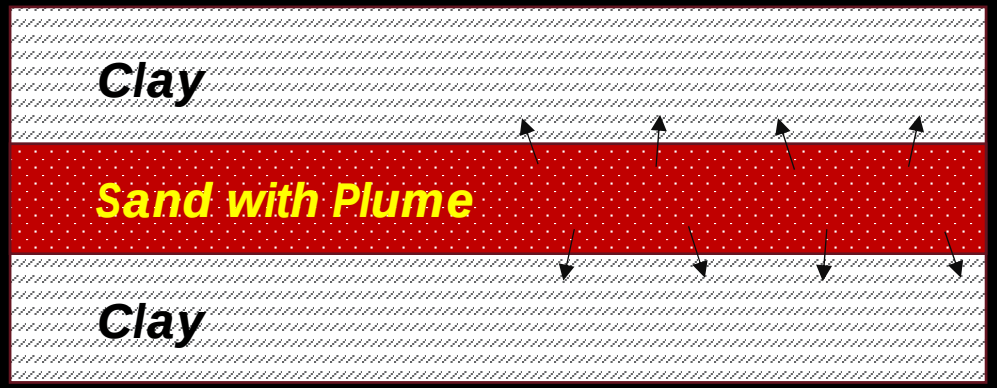
Hypothesis #1 - Matrix Diffusion

- **Matrix Diffusion Models**
  - Advection through 'sand'
  - Diffusion only through silt (no advection)

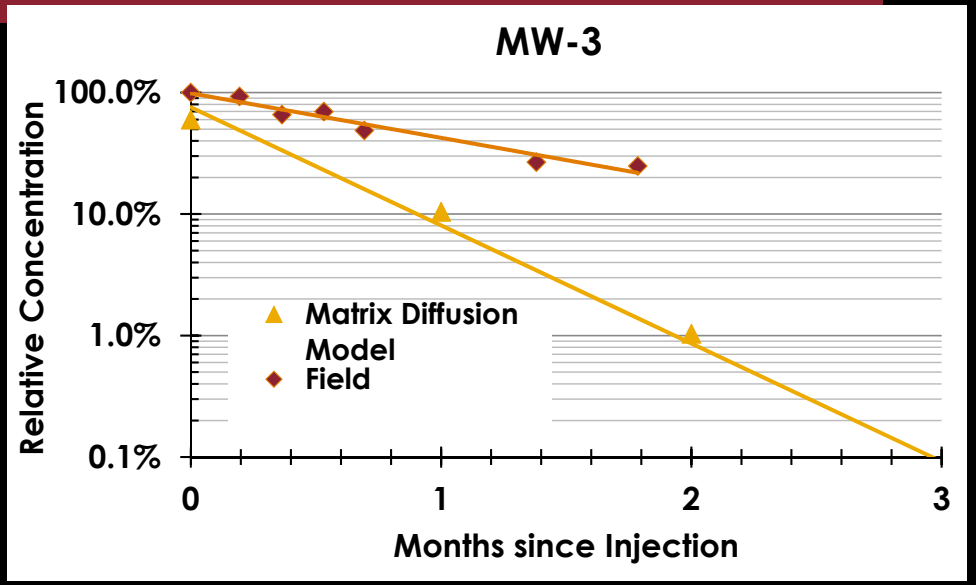


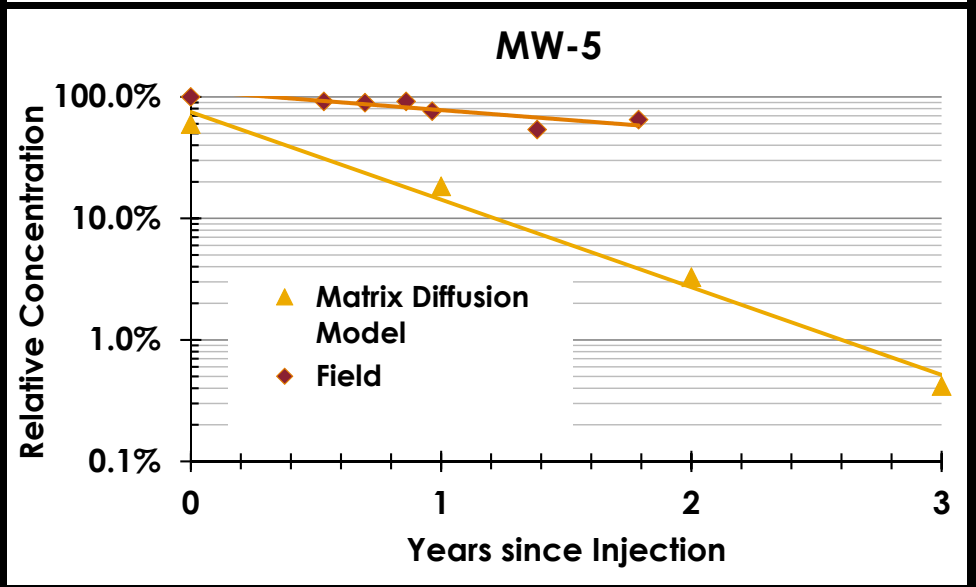
- **Model Parameters**
  - Volume Fraction
    - Approx. 80% clayey-silt / 20% sand - HPT Logs
  - Diffusion Length
    - 4 ft.
  - Interfacial Area
    - Estimated from volume fraction and diffusion length relationship
  - 50 Year loading period (1962 – 2012)
  - GW Velocity from Bromide Test

Field vs. Matrix Diffusion Model

- **At MW-3 (20 ft. down-gradient)**
  - ❖ Field data: 80% reduction/2 yr
  - ❖ Matrix Model: 99% reduction/2 yr
- **At MW-5 (40 ft. down-gradient)**
  - ❖ Field data: 40% reduction/2 yr
  - ❖ Matrix Model: 97% reduction/2 yr

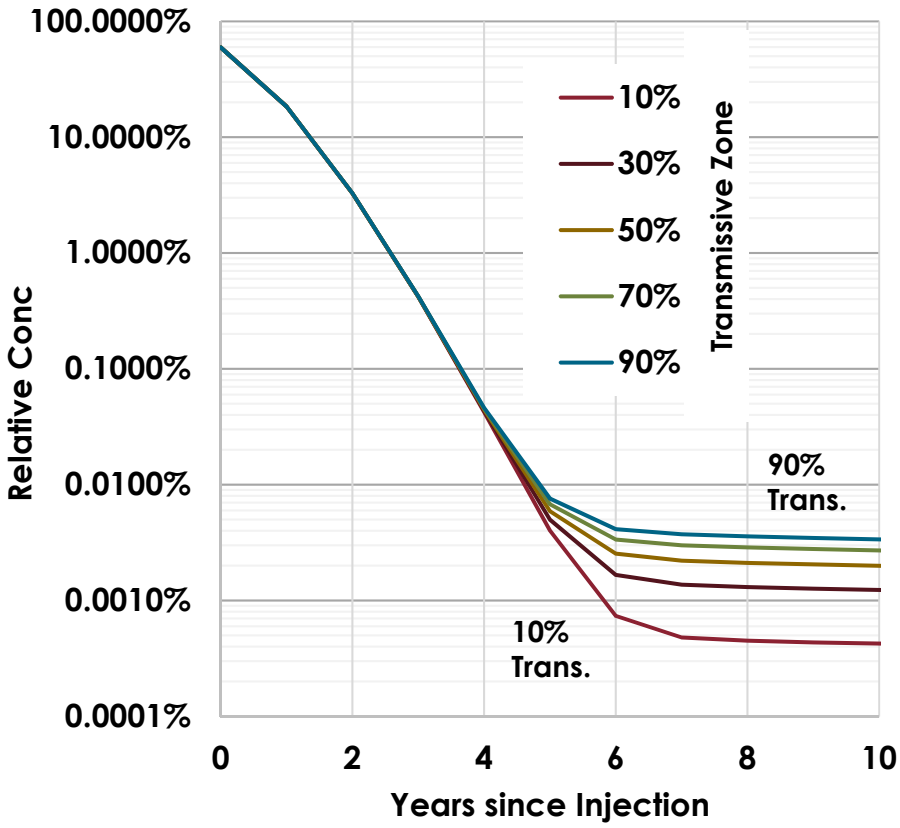
Matrix Diffusion Model estimates FAST reduction compare to the field observation





Matrix Diffusion Model Sensitivity - Volume Fraction

- **Determine if poor fit to field data is due to parameter selection**
- **Volume Fraction (VF)**
  - ❖ Same gw velocity for high K zone for all VF tested
  - ❖ Transmissive zone (10 to 90%)
- **Results**
  - ❖ Volume Fraction cause 1 OoM variation at plateau stage
  - ❖ Less than 6 yr for over 4 OoM reduction



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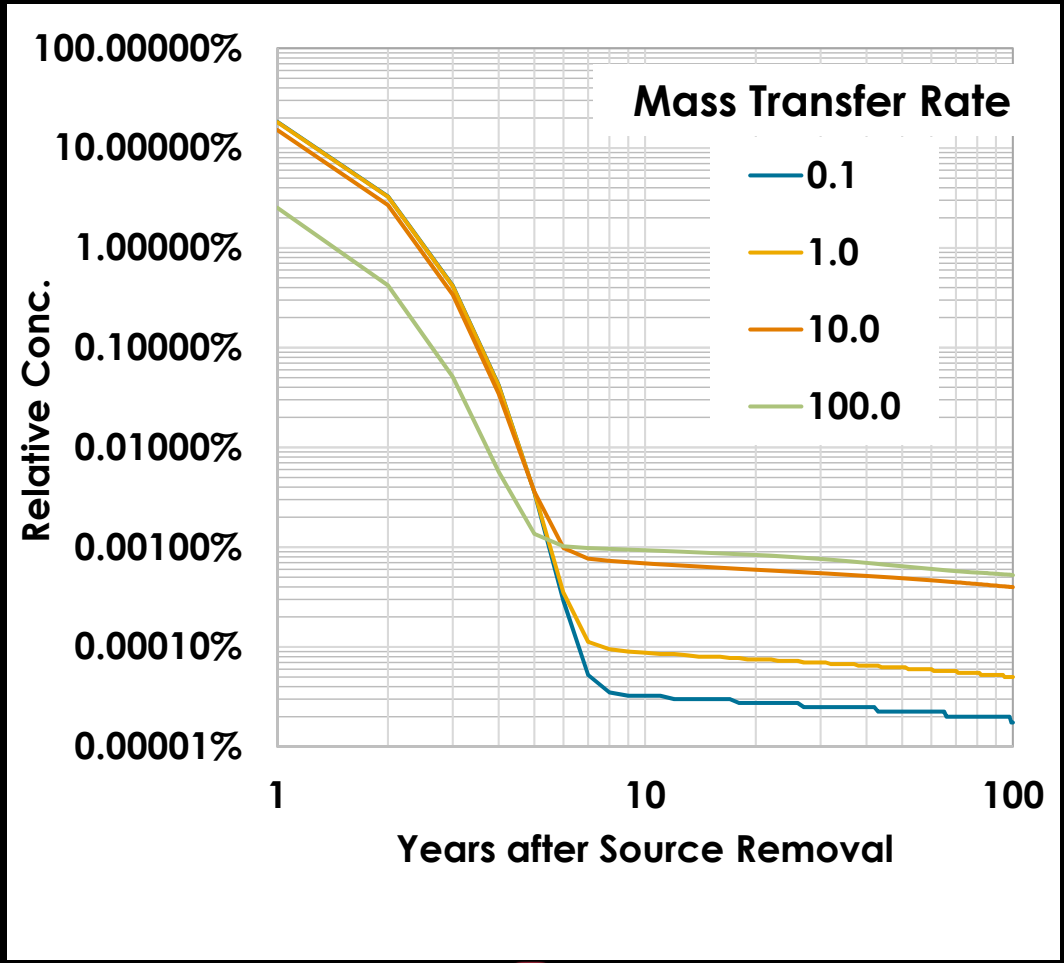
Matrix Diffusion Model Sensitivity - Mass Transfer Rate

- **Mass Transfer Rate**
  - 4 Orders Magnitude Compared
- **Result**
  - Higher mass transfer rate reaches to threshold quicker but longer to complete cleanup
  - All mass transfer rate: 3 OoMs reduction within 5 yrs

Matrix Diffusion Model estimates FAST reduction compare to the field observation



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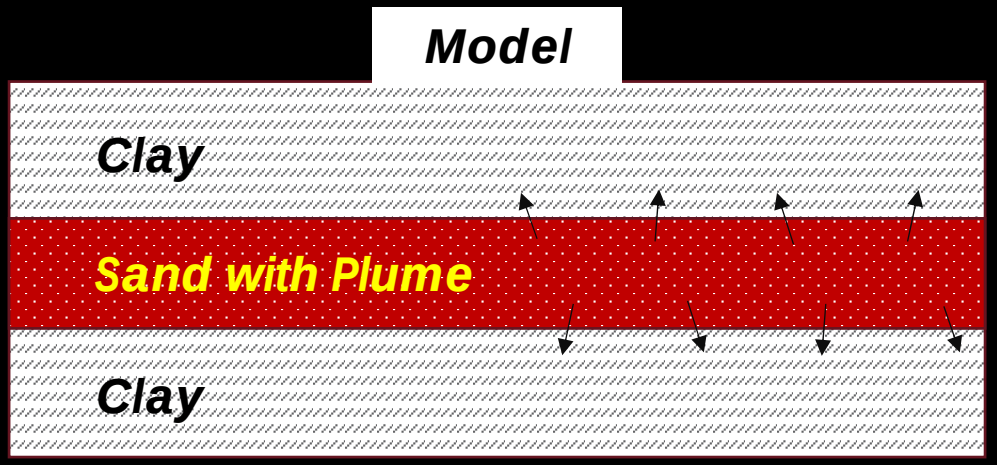
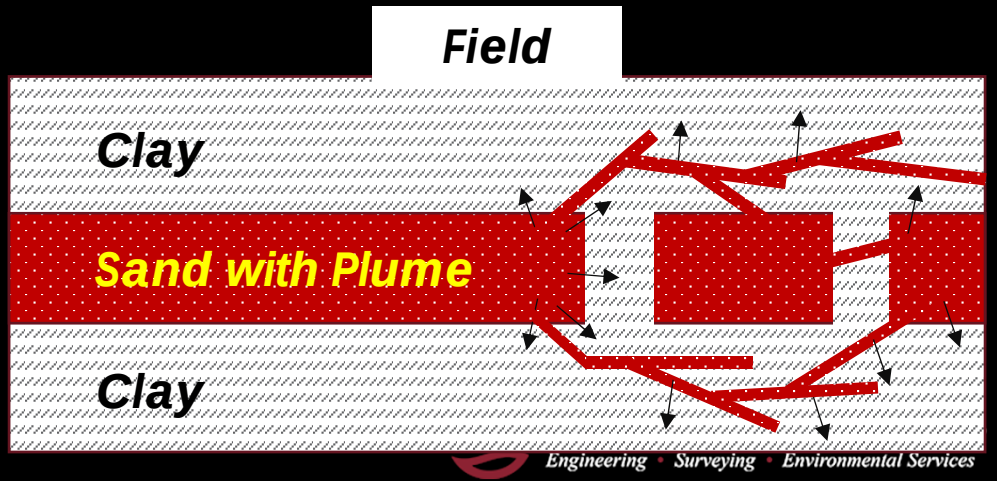
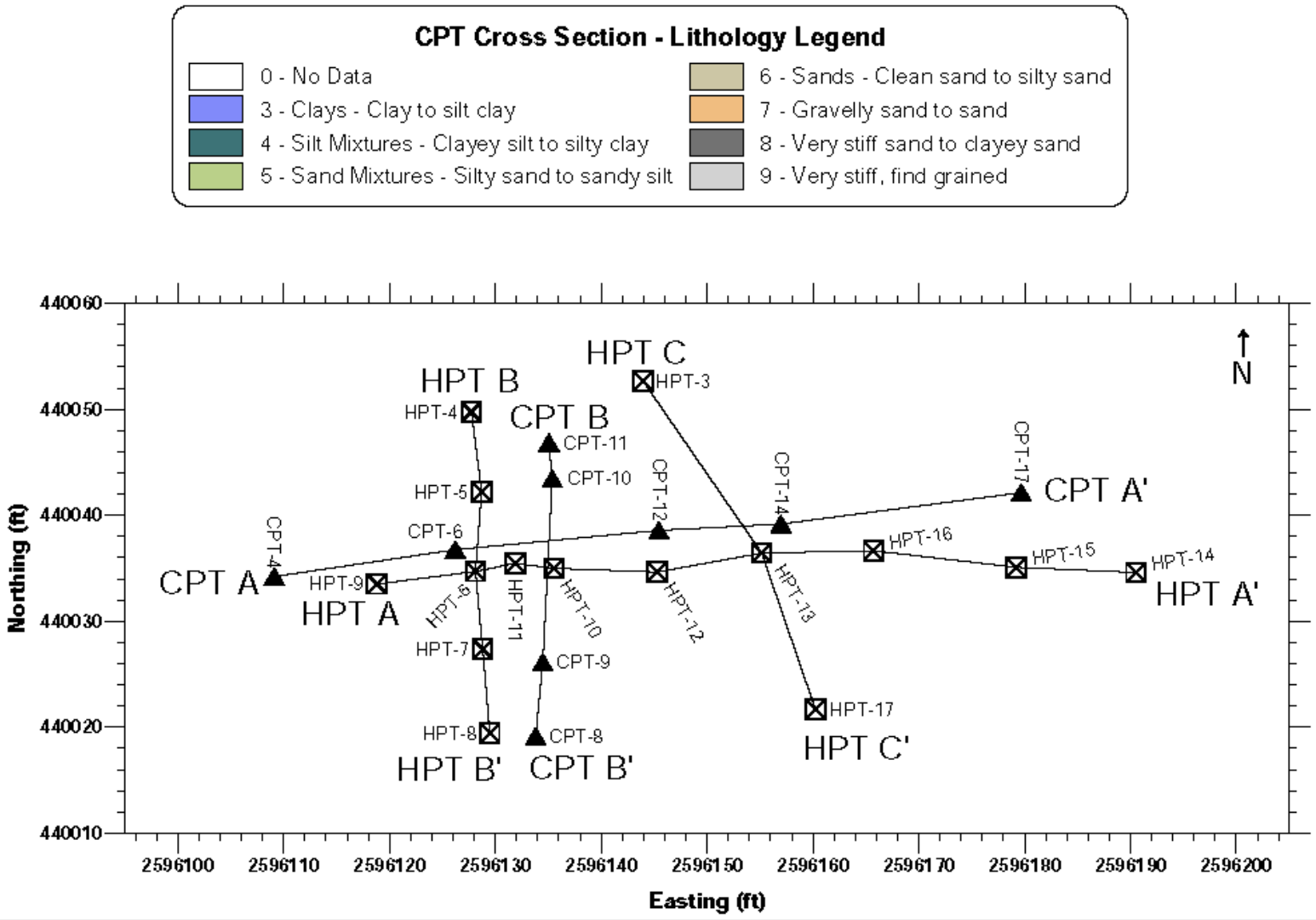
Hypothesis #2 - Connectivity

- **Matrix Diffusion Model assumes continuous flow**
  - ❖ No advection flow in Low K
- **Field Condition**
  - ❖ Approx. 80% clayey-silt / 20% sand
  - ❖ Sand in <u>discontinuous</u> bodies
  - ❖ Forces some flow through low K units
  - ❖ Greatly increases mass transfer from high to low K zone



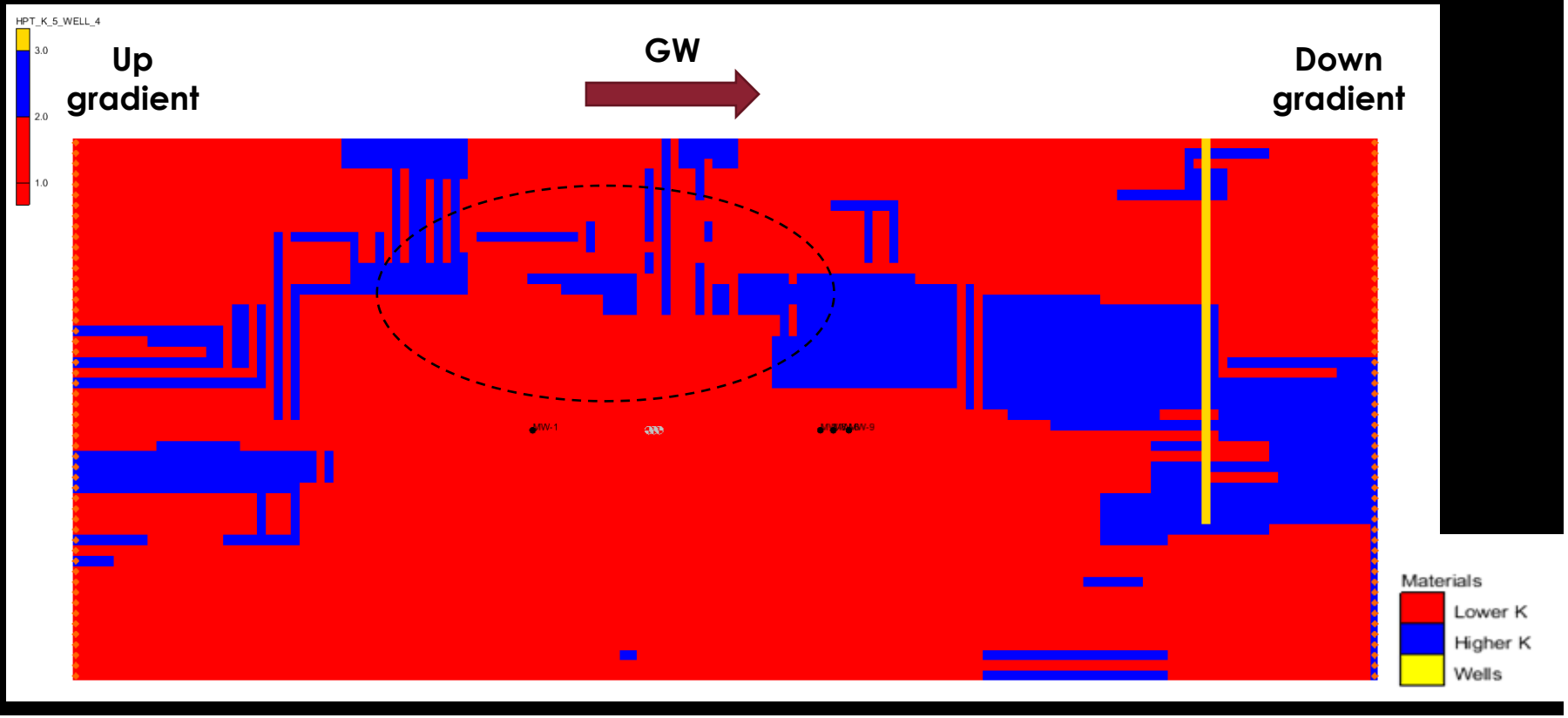


Field Observation



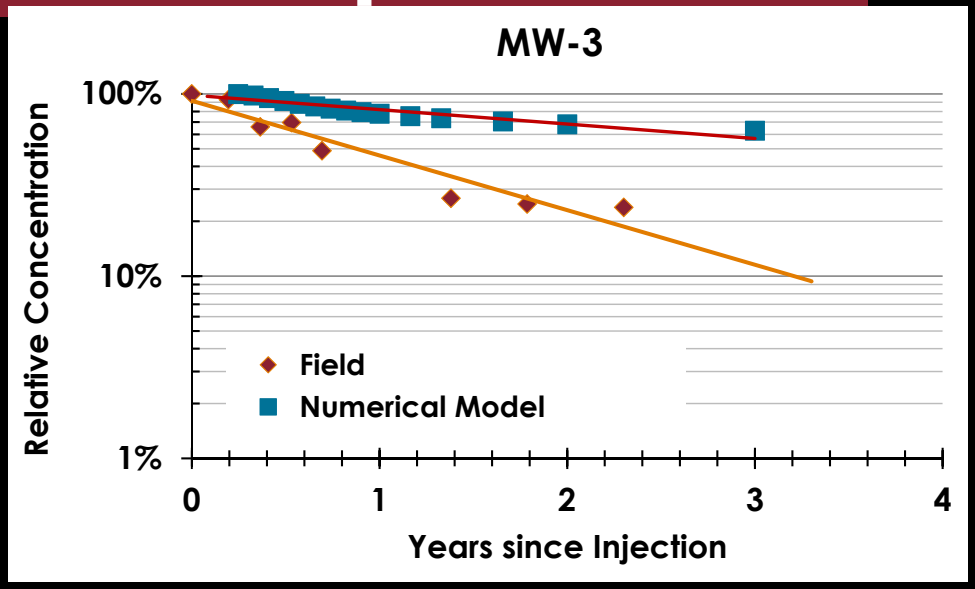
T-PROGs/K Field

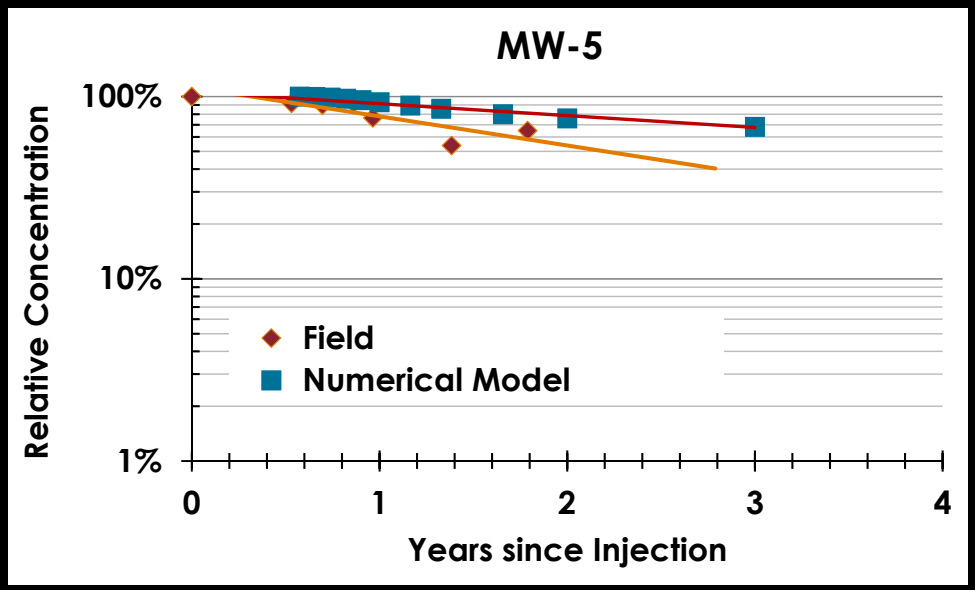
- T-PROGs: Transitional PRObability Geostatistics
- Create *K* field from HPT with two zones: High K & Low K
- Disconnected flow channel from T-PROG



Impact of Disconnected Aquifer

- **Numerical Model confirms**
  - ❖ Disconnected Aquifer result **SLOWER** remediation at all monitoring wells
- **Not significantly different between MW-3 and MW-5**
  - ❖ 30~45% in 2 yrs
- **Numerical model estimates similar to field data at MW-5**





Summary

- ✓ ***Lesson Learned***
  - Disconnected aquifer can increase the cleanup time
  - Current semi-analytical/analytical models assume no disconnection of flow channel

    ➔ ***Underestimate*** *the cleanup time*
  - Should have better understanding of ***Connectivity of Transmissive zone***
- ✓ ***Future Work***
  - How to measure connectivity? Parameter?
    - Direct Push Tools (CPT, HPT, etc.)
    - Geospatial analysis

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QUESTIONS ?

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