Injection System Operation and Optimization

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Lexington, KY

20 years with Arcadis

Arcadis TechEx Antwerp, April 2024

An *in situ* report card

FINAL REPORT

Development of an Expanded,
High-Reliability Cost and Performance Database for In-Situ
Remediation Technologies

ESTCP Project ER-201120

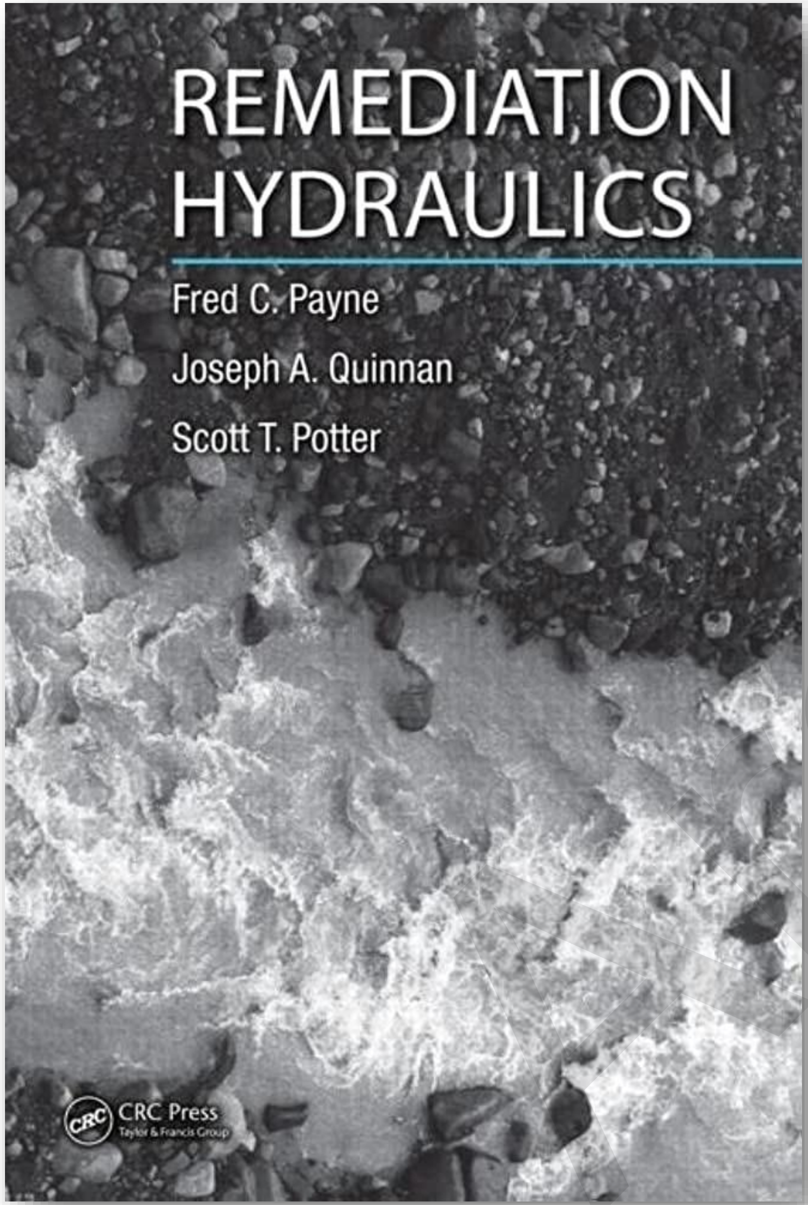
MARCH 2016

The big data from 235 remediation sites indicates:

- The 50th percentile achieve a 0.8 order of magnitude (OOM) reduction in source concentration
  - 75th percentile achieves 1.4 OOM
- Only 21% of 710 monitoring wells achieved drinking water criteria
- 7% of sites (17 out of 235) achieved drinking water criteria at all wells
  - 10 of 17 had a single monitoring well!
- For sites where “treatment train” remedies were deployed, median reduction was 2.3 OOM

ARCADIS

Re-Thinking Our Framework



Groundwater Monitoring&Remediation Advances in Remediation Solutions

Advancing Contaminant Mass Flux Analysis to Focus Remediation: The Three-Compartment Model

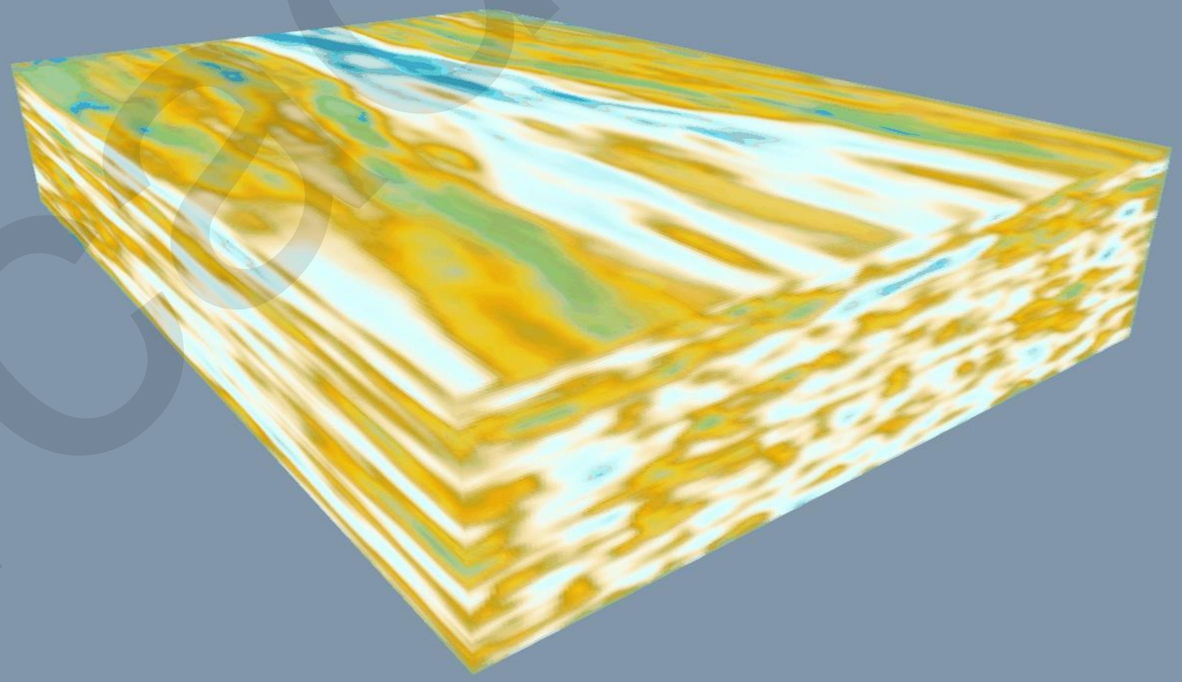
by John Horst, Scott Potter, Matthew Schnobrich, Nicklaus Welty, Ankit Gupta, Joseph Quinnan

Groundwater Monitoring & Remediation 37, no. 4/ Fall 2017, 15-22

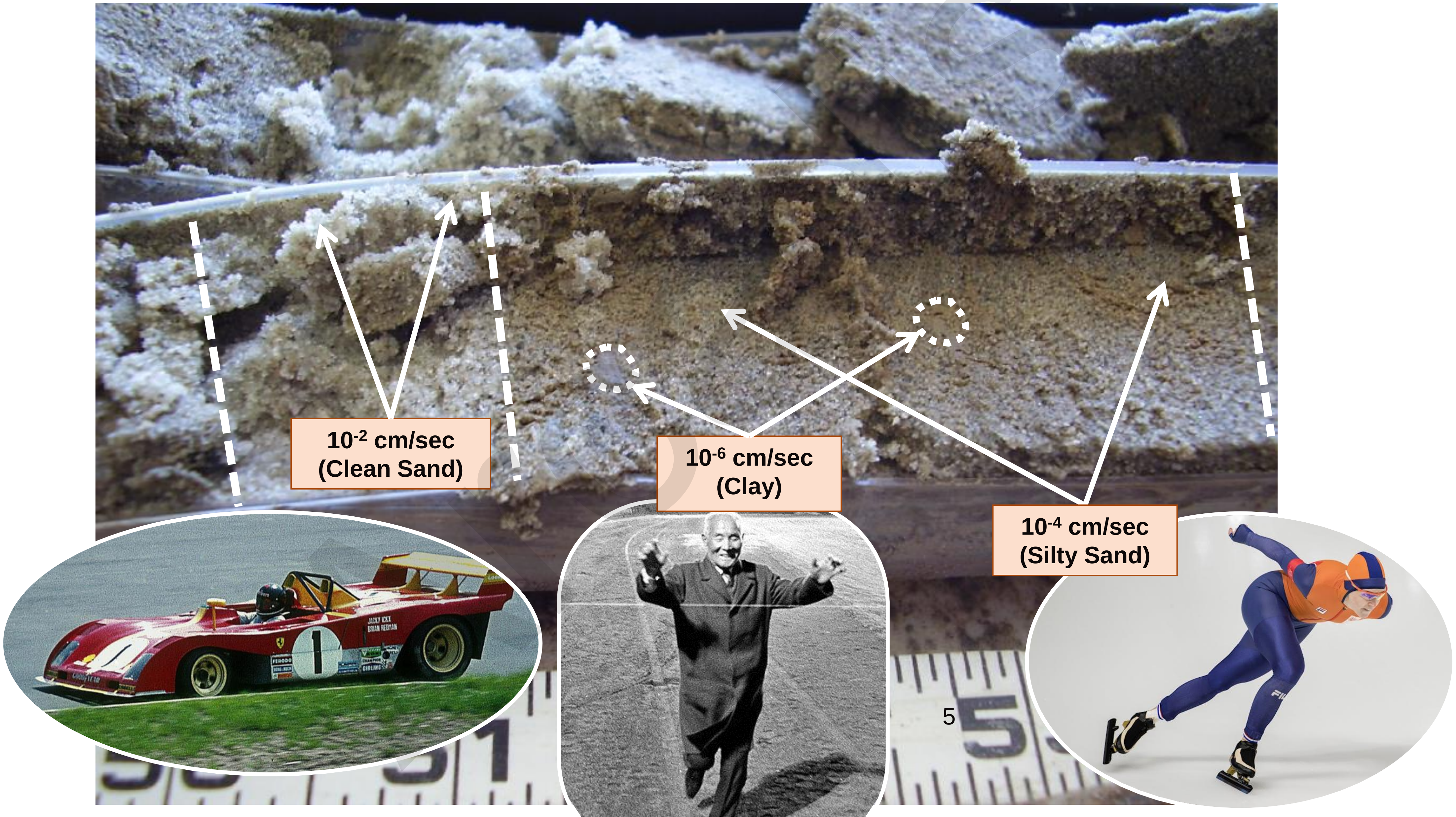
Re-Thinking Our Framework

We reassessed our data and started building aquifers to fill in missing parts

Hydraulic conductivity in a 3-D aquifer



Contrasts in Permeability

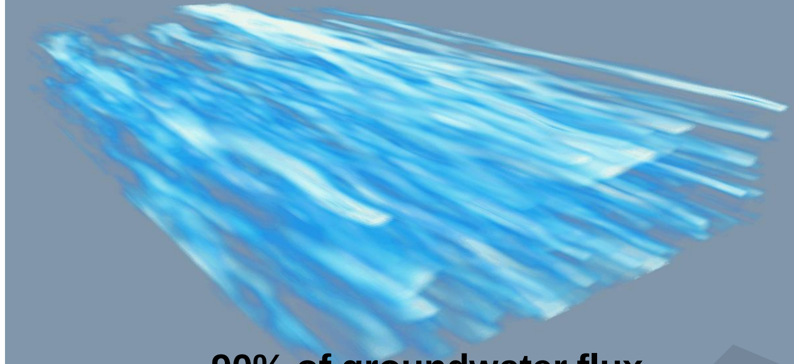


Re-Thinking Our Framework – 3-Compartment Model

Groundwater flow in an aquifer is divided based on *order of magnitude contrasts in groundwater flux*

Compartment 1 (C1 or Q_{90})

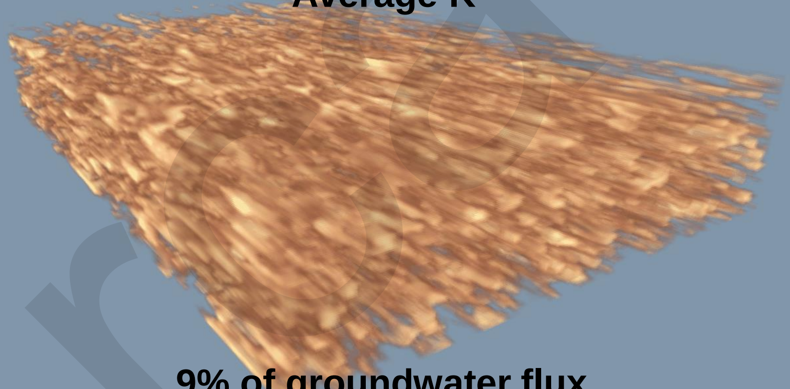
10x Average K



90% of groundwater flux
(advection/transport zone)

Compartment 2 (C2 or Q_{9})

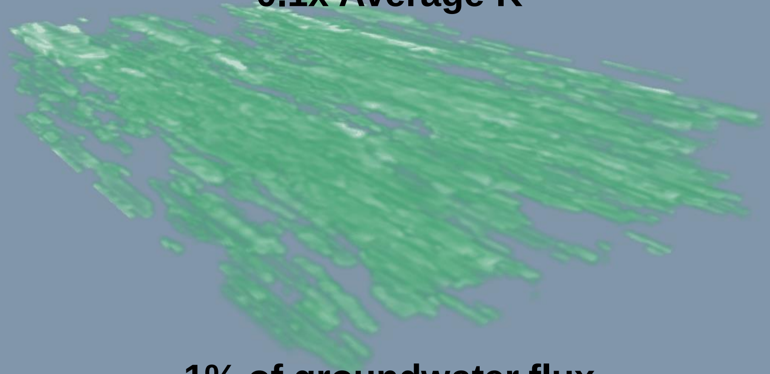
Average K



9% of groundwater flux
(slow advection/storage zone)

Compartment 3 (C3 or Q_{1})

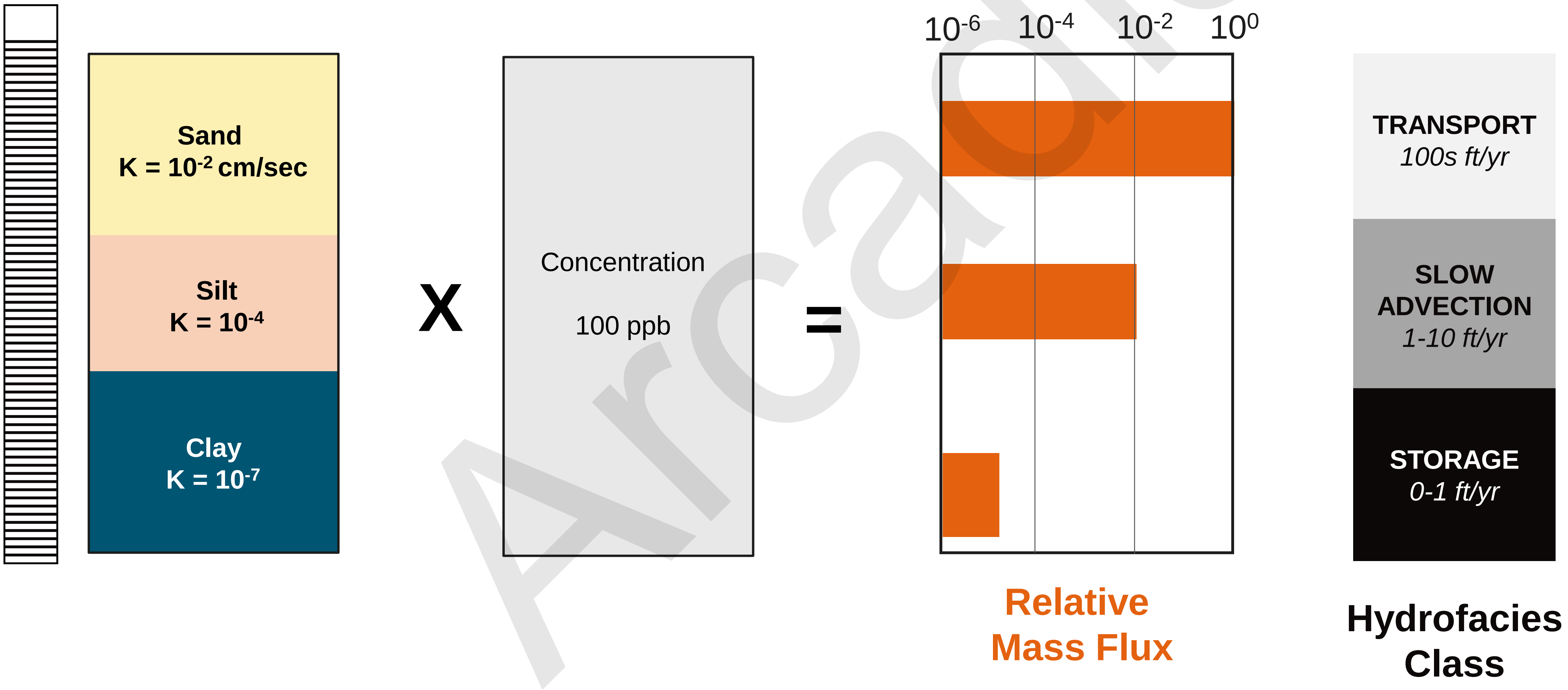
0.1x Average K



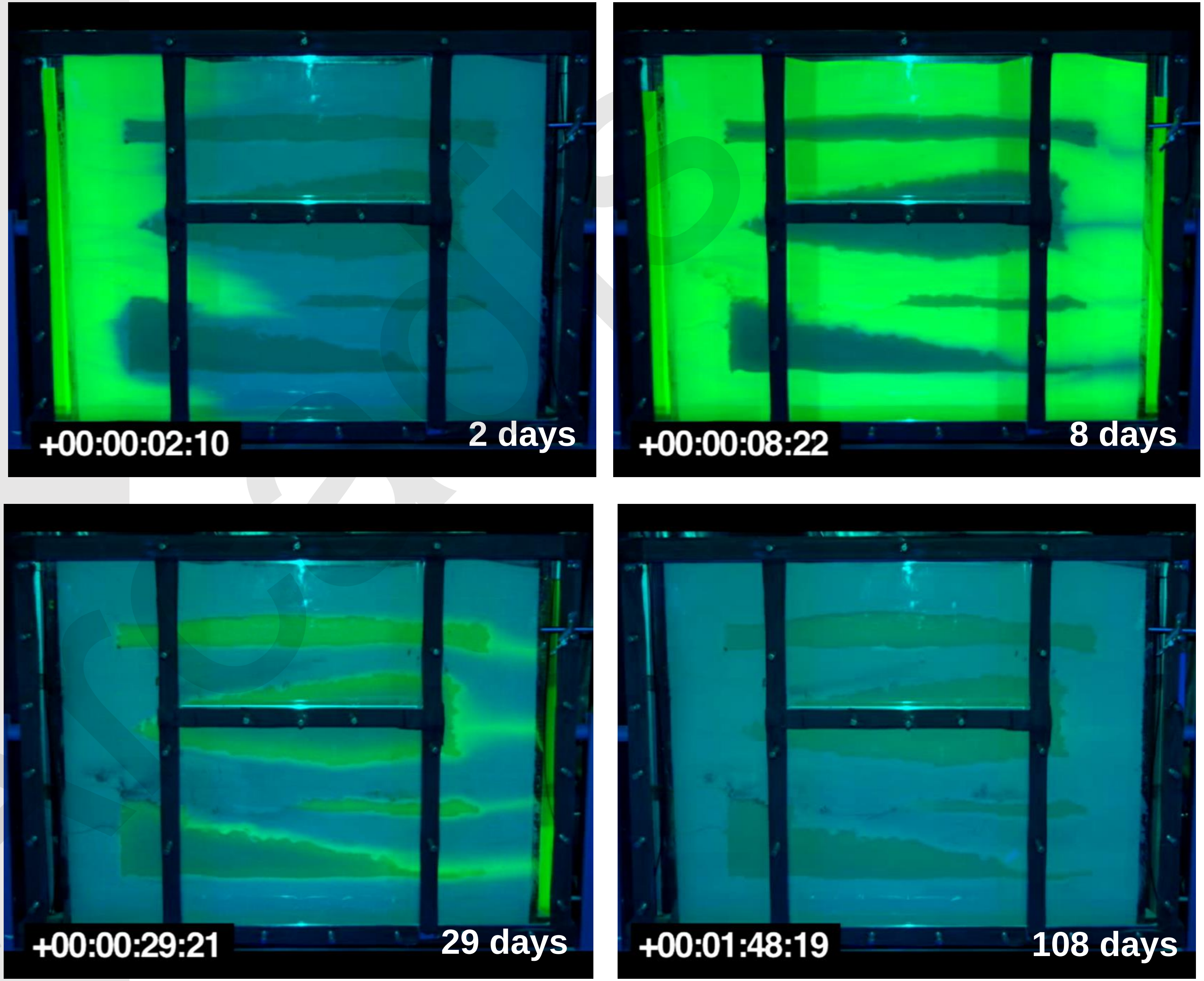
1% of groundwater flux
(storage zone)

Permeability dictates contaminant transport …

Mass Flux (J) = K i C



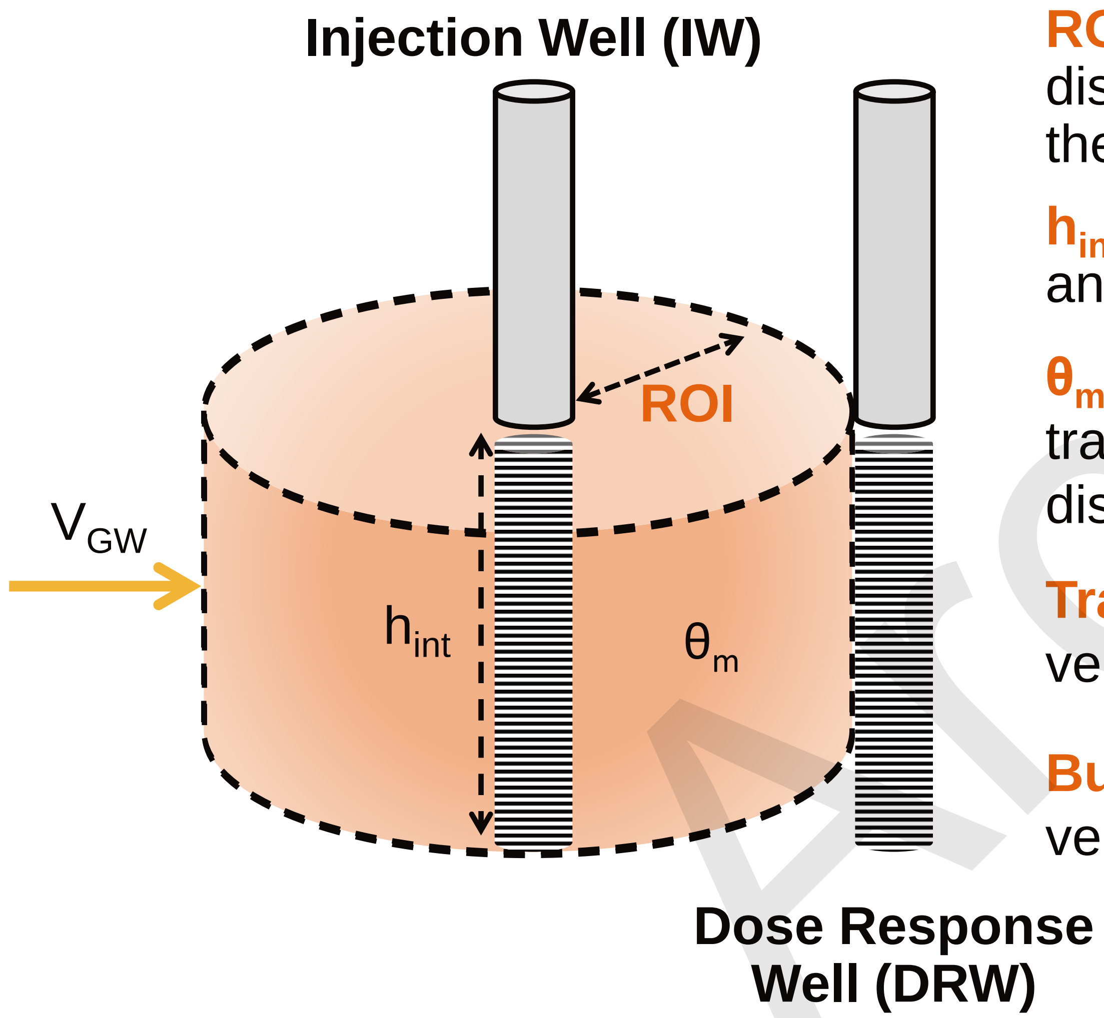
… and the distribution of injection reagents



Tom Sale, Colorado State

- Dark layers are bentonite clay
- Light layers are quartz sand
- Source loading: Days 1 – 23
- Source flushing: Days 23 – 132

Porosity-Based Injection – Tracer Testing



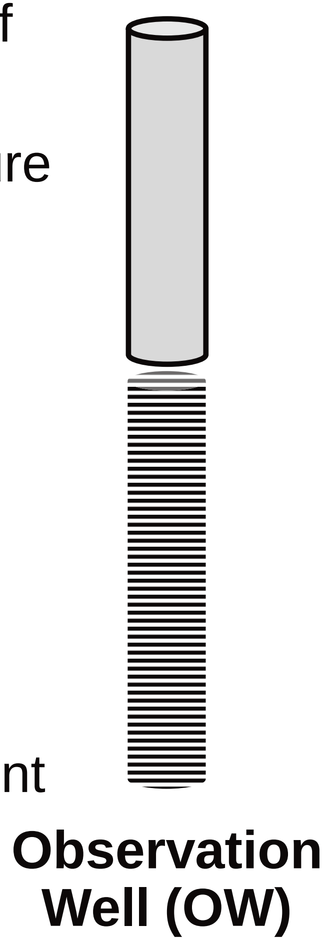
ROI = Radius of influence; targeted radial distance to achieve normalized response of the injected reagent/tracer

h_{int} = Injection interval; dictated by the nature and extent of impacts

θ_m = Mobile fraction (of θ_{total}); primary transport pathway, assumes uniform radial distribution (~5% to ~15%)

Transport Velocity = Groundwater flow velocity; time to achieve 50% of the C_{peak}

Bulk Velocity = Average groundwater flow velocity; time for M_{half} to pass through a point



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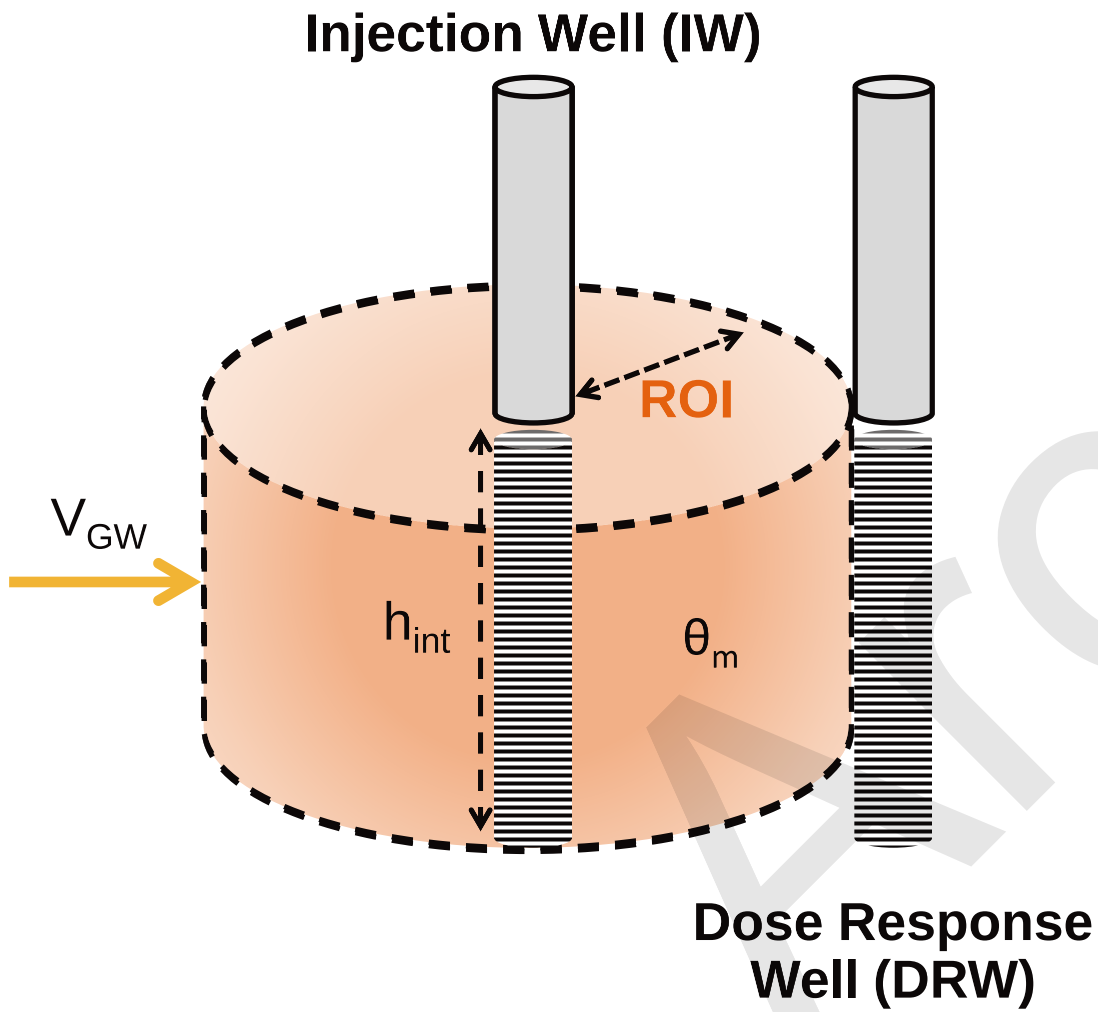
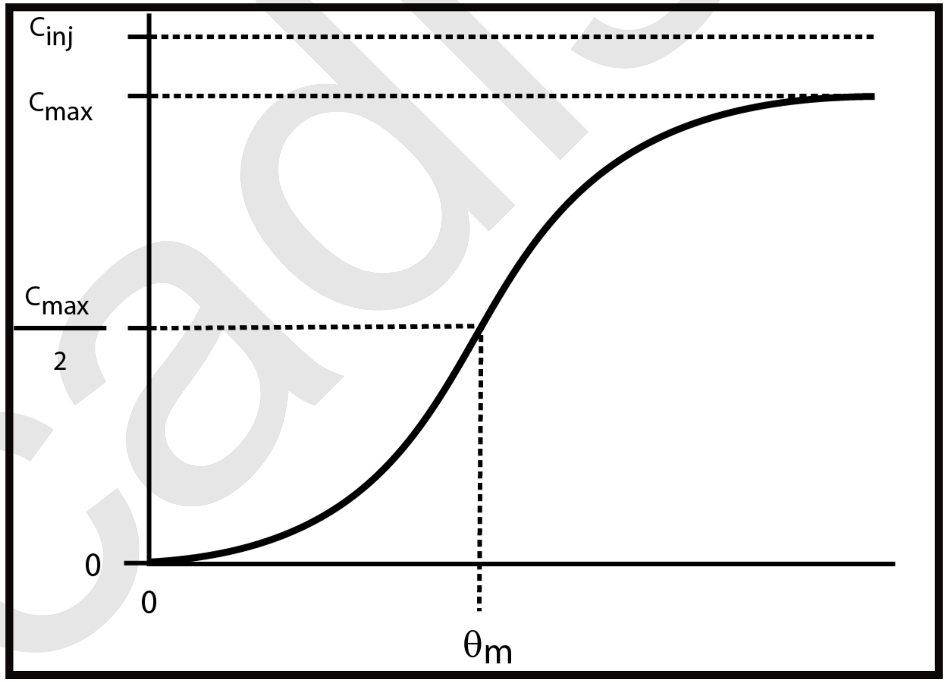
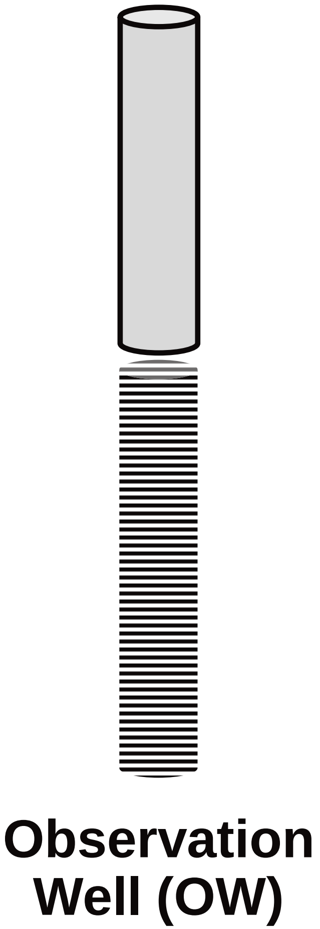




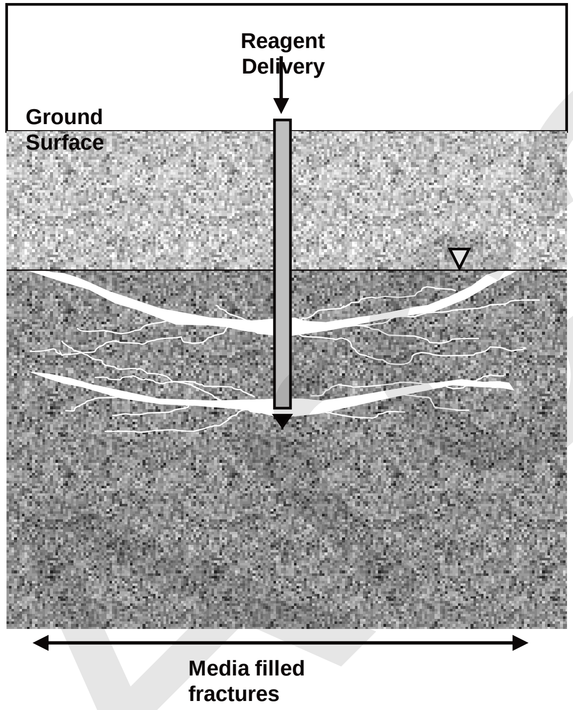
Breakthrough Curve (BTC) = Tracer response versus cumulative volume (during injection) or time (post-injection) at dose response or observation wells, respectively



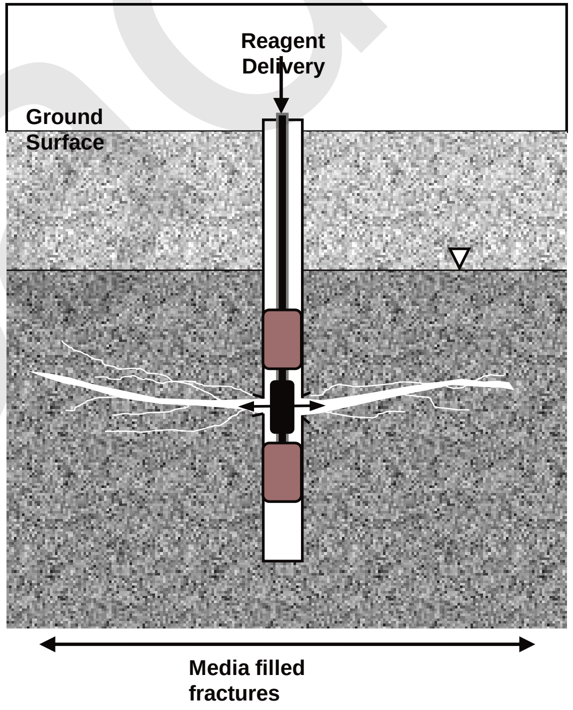
Alternative Delivery Methods – Fracturing

- Subsurface fracture deformation under high pressure injection
- Low permeability settings
- Solid/slurried reagents
- Limited delivery control
- Targets qualitative concentration goals (i.e., not MCLs)

Direct Push Technology

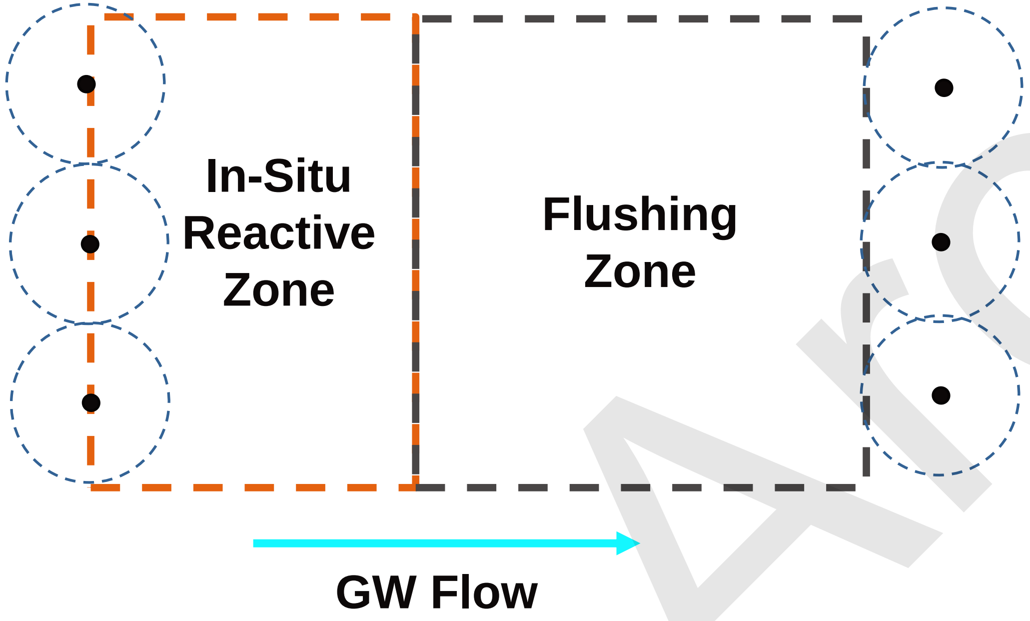


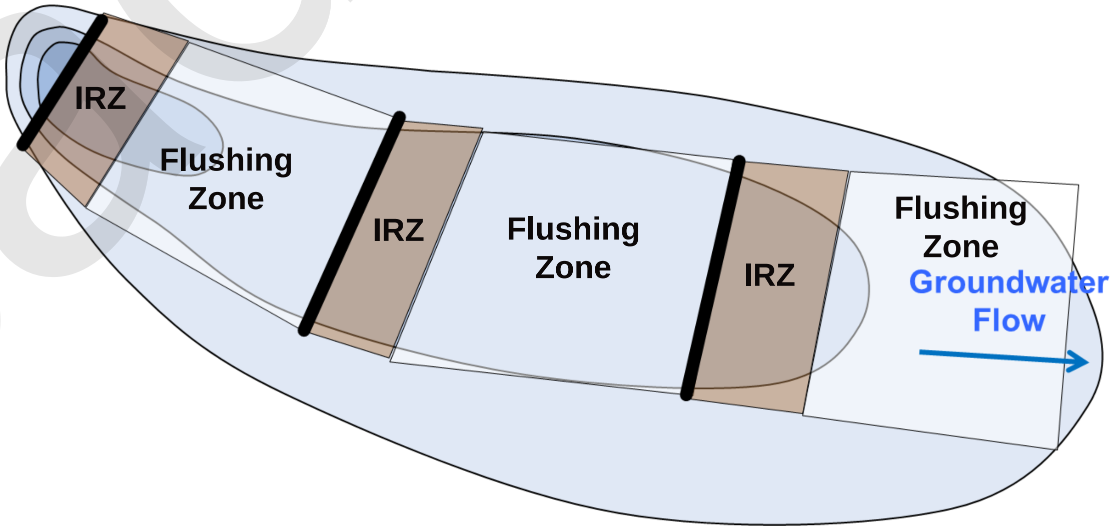
Hydraulic & Pneumatic



Injection Design Concepts

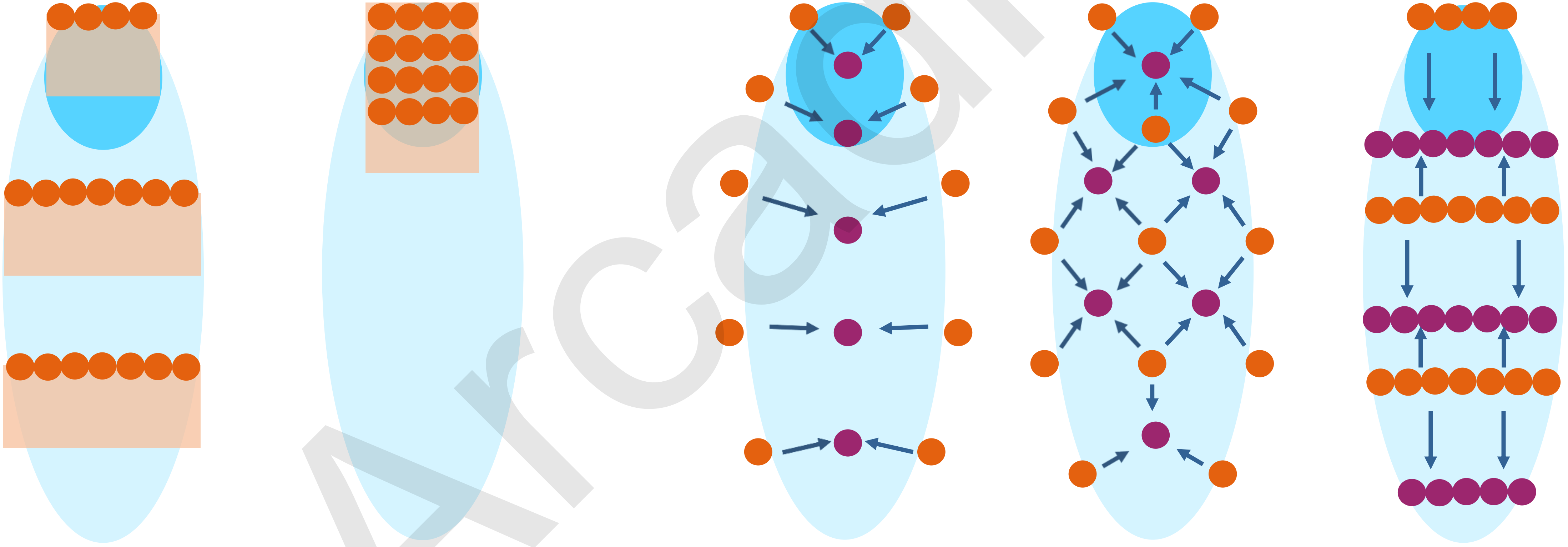
Injection Transect Design





Dynamic Groundwater Recirculation

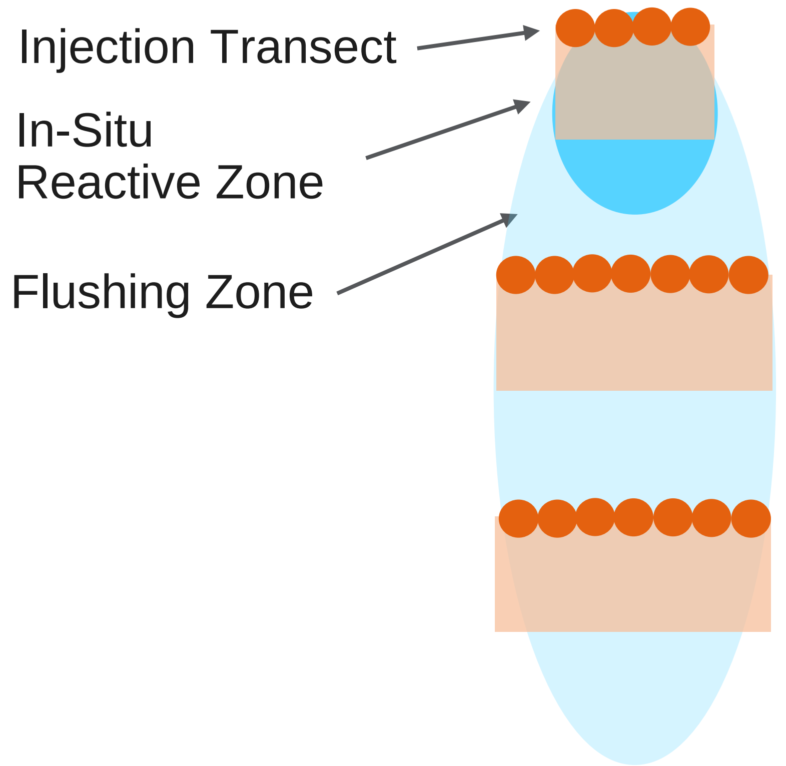
Injection/Extraction Well Layouts



Transects Source Coverage Recirculation

Inject-and-Drift

Conceptual Injection Design



	Pre-Set Spacing (soluble)
Trans. Spacing	***200 feet***
Time	9.1 years
# of Injections	23
Cost	€1.26M

- Injection designs can vary based on multiple drivers …
  - Site access restrictions
  - Target cleanup periods
  - Substrate transport behavior (soluble vs solid)
  - Varied CSM conditions:
    - Groundwater velocity
    - Feasible injection rates
    - Depth to groundwater, etc.
- All of these impact cost.

Costing includes implementation, injections, and monitoring for the target time period. Cost are presented in Euros (millions).

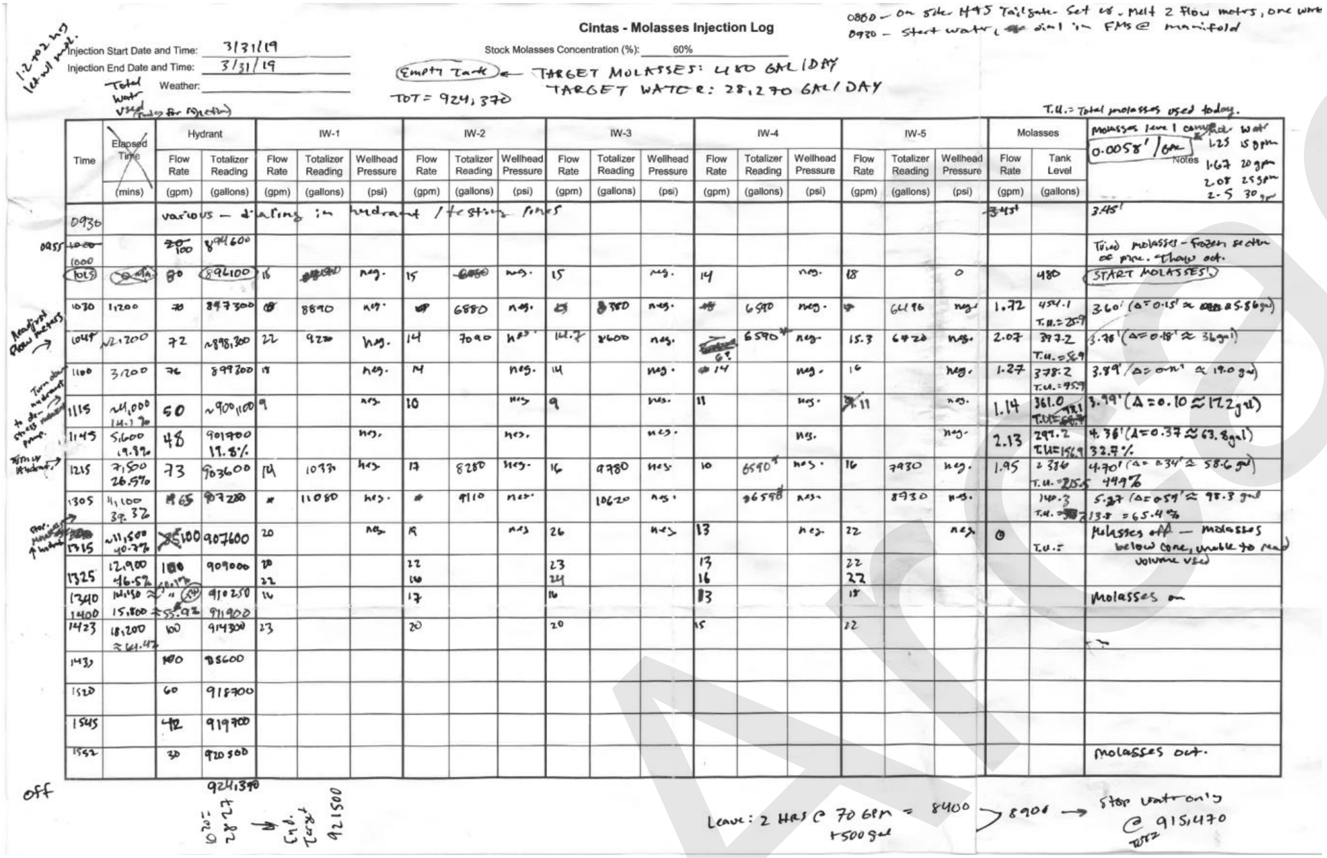
Operation and Optimization

Injection Systems

- Low cost of construction, high cost of operation
- Highly adaptable
- No permanent above ground footprint
- Best for inject-and-drift sites with limited number of planned injections

- High cost of construction, low cost of operation
- Highly adaptable
- Permanent above ground footprint
- Best for recirculation sites or sites with long-term injections or remote location

The Old vs the New …



Cintas - Molasses Injection Log

Injection Start Date and Time: 3/31/19

Injection End Date and Time: 3/31/19

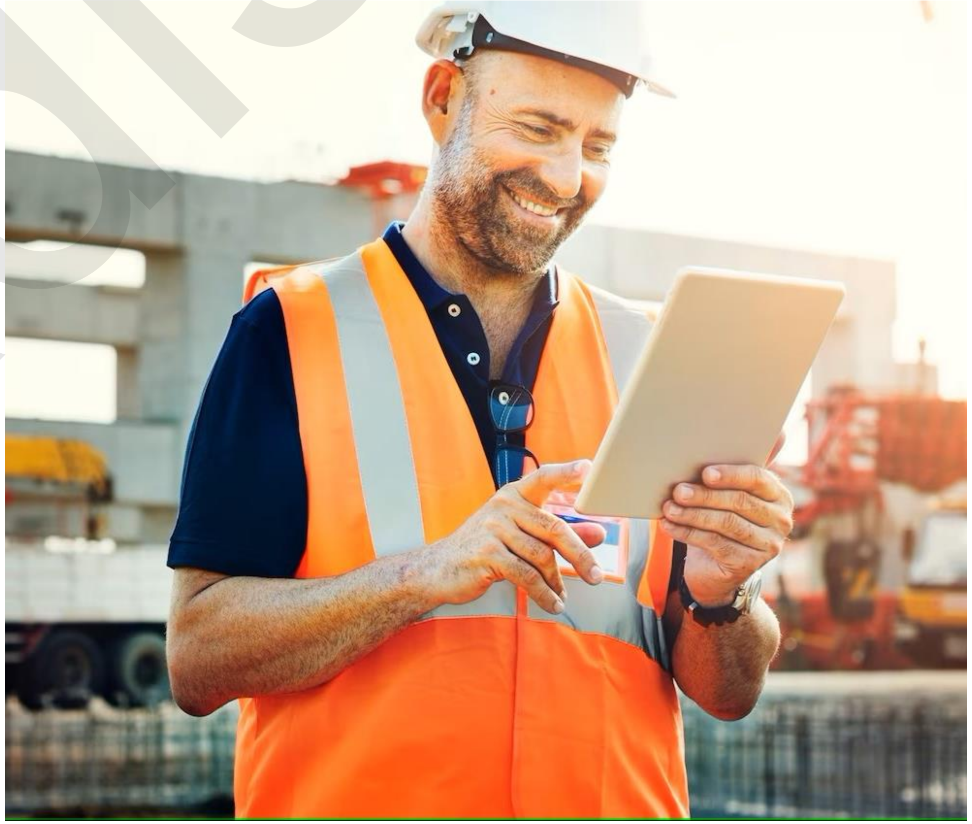
Weather:

Stock Molasses Concentration (%): 60%

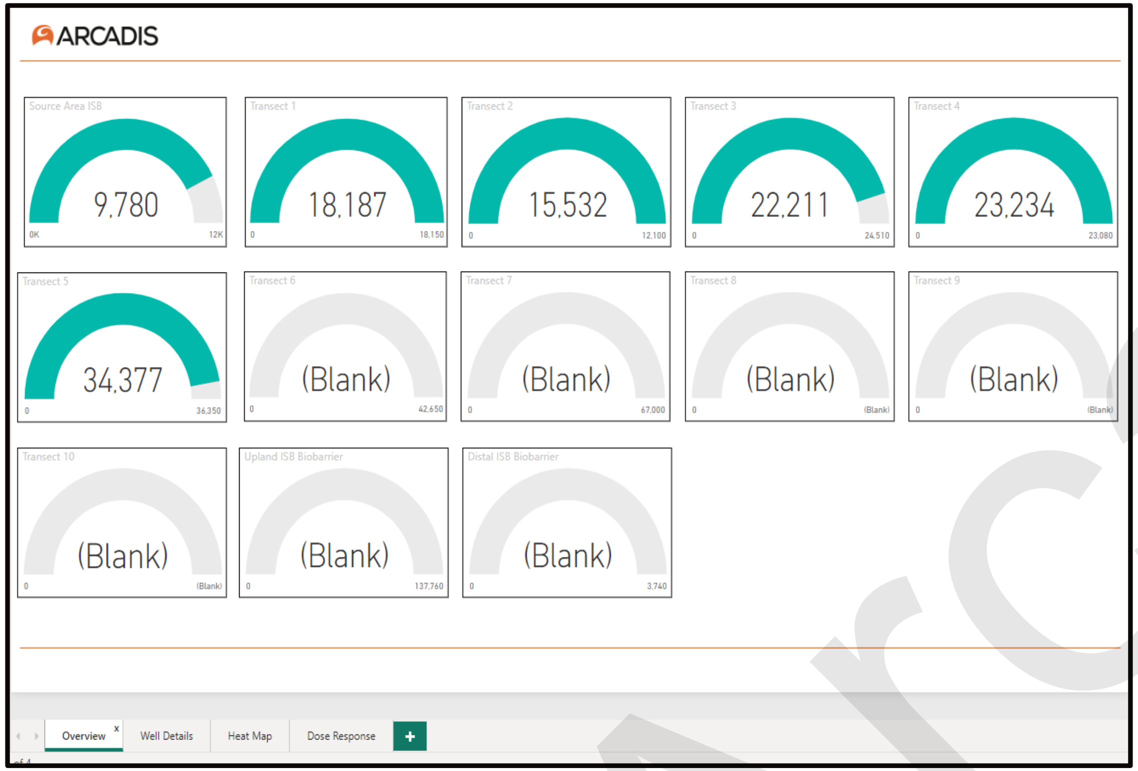
TARGET MOLASSES: 480 GAL/DAY

TARGET WATER: 28,270 GAL/DAY

Time	Elapsed Time (mins)	Hydrant Flow Rate (gpm)	Hydrant Totalizer Reading (gallons)	IW-1 Flow Rate (gpm)	IW-1 Totalizer Reading (gallons)	IW-1 Wellhead Pressure (psi)	IW-2 Flow Rate (gpm)	IW-2 Totalizer Reading (gallons)	IW-2 Wellhead Pressure (psi)	IW-3 Flow Rate (gpm)	IW-3 Totalizer Reading (gallons)	IW-3 Wellhead Pressure (psi)	IW-4 Flow Rate (gpm)	IW-4 Totalizer Reading (gallons)	IW-4 Wellhead Pressure (psi)	IW-5 Flow Rate (gpm)	IW-5 Totalizer Reading (gallons)	IW-5 Wellhead Pressure (psi)	Molasses Flow Rate (gpm)	Molasses Tank Level (gallons)	Notes

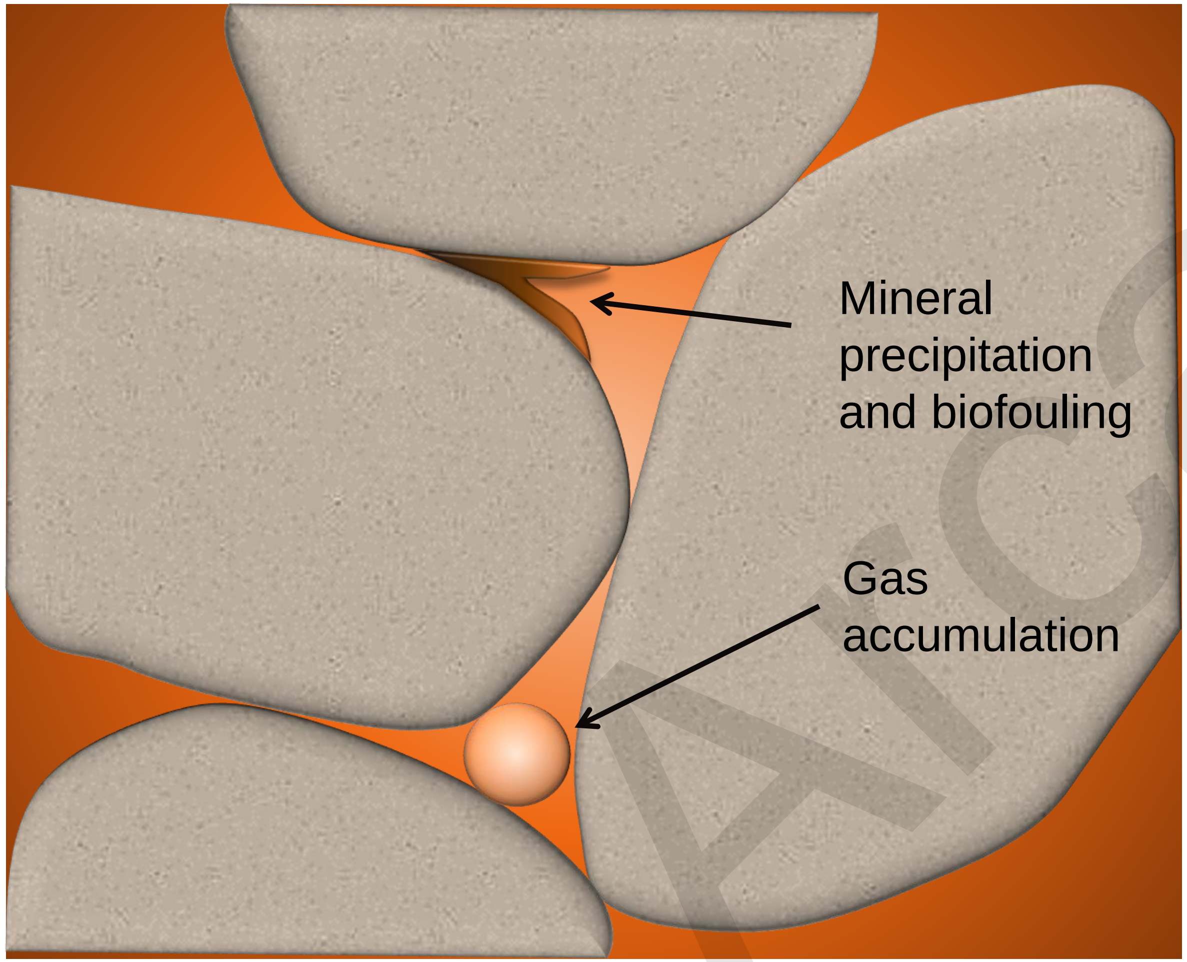


Field Data Collection and Power BI



- Injection optimization occurs in ***real*** time and ***over*** time…
- Requires attentive staff and direct connection between office and field crews

Porosity Reduction



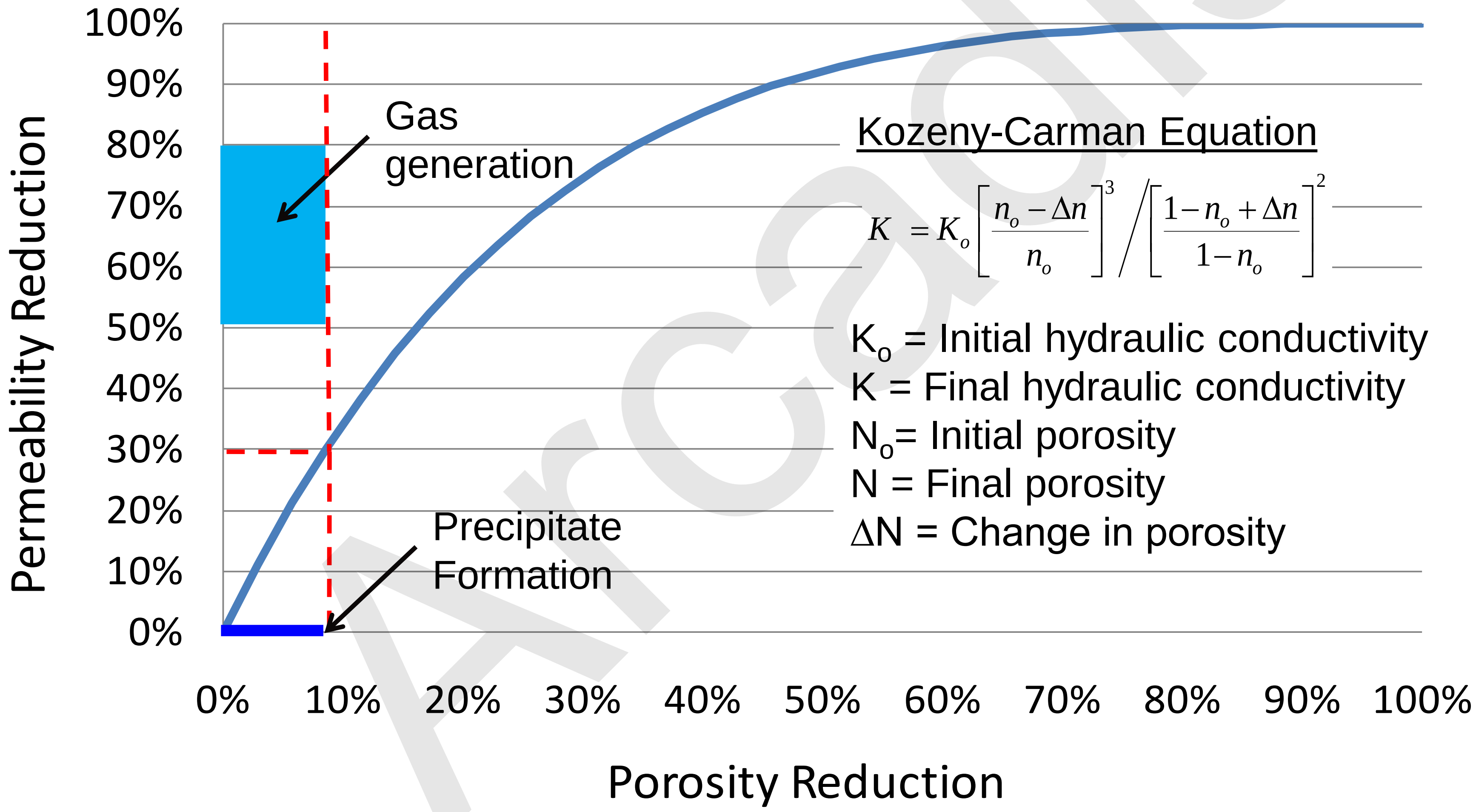
Mineral precipitation and biofouing

- Slow formation
- Persistent
- Minor reduction in injection capacity, but increasing over time

Gas accumulation

- Rapid formation
- Transient
- Large reduction in injection capacity

Porosity Reduction

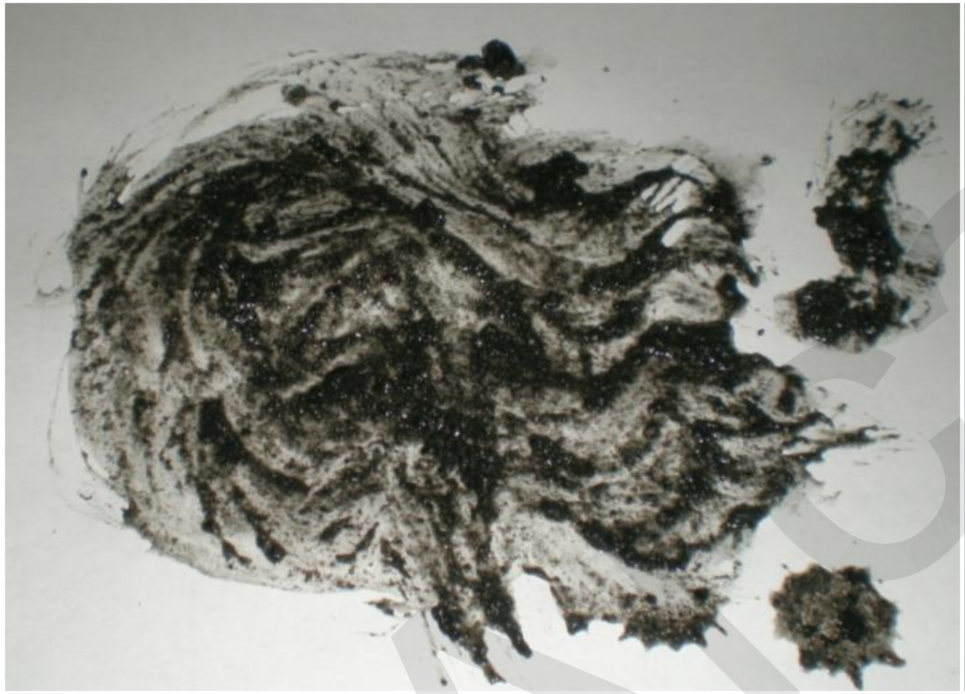


<u>Kozeny-Carman Equation</u>

$$K = K_o \left[\frac{n_o - \Delta n}{n_o}\right]^3 \Big/ \left[\frac{1 - n_o + \Delta n}{1 - n_o}\right]^2$$

K_o = Initial hydraulic conductivity
K = Final hydraulic conductivity
N_o= Initial porosity
N = Final porosity
ΔN = Change in porosity

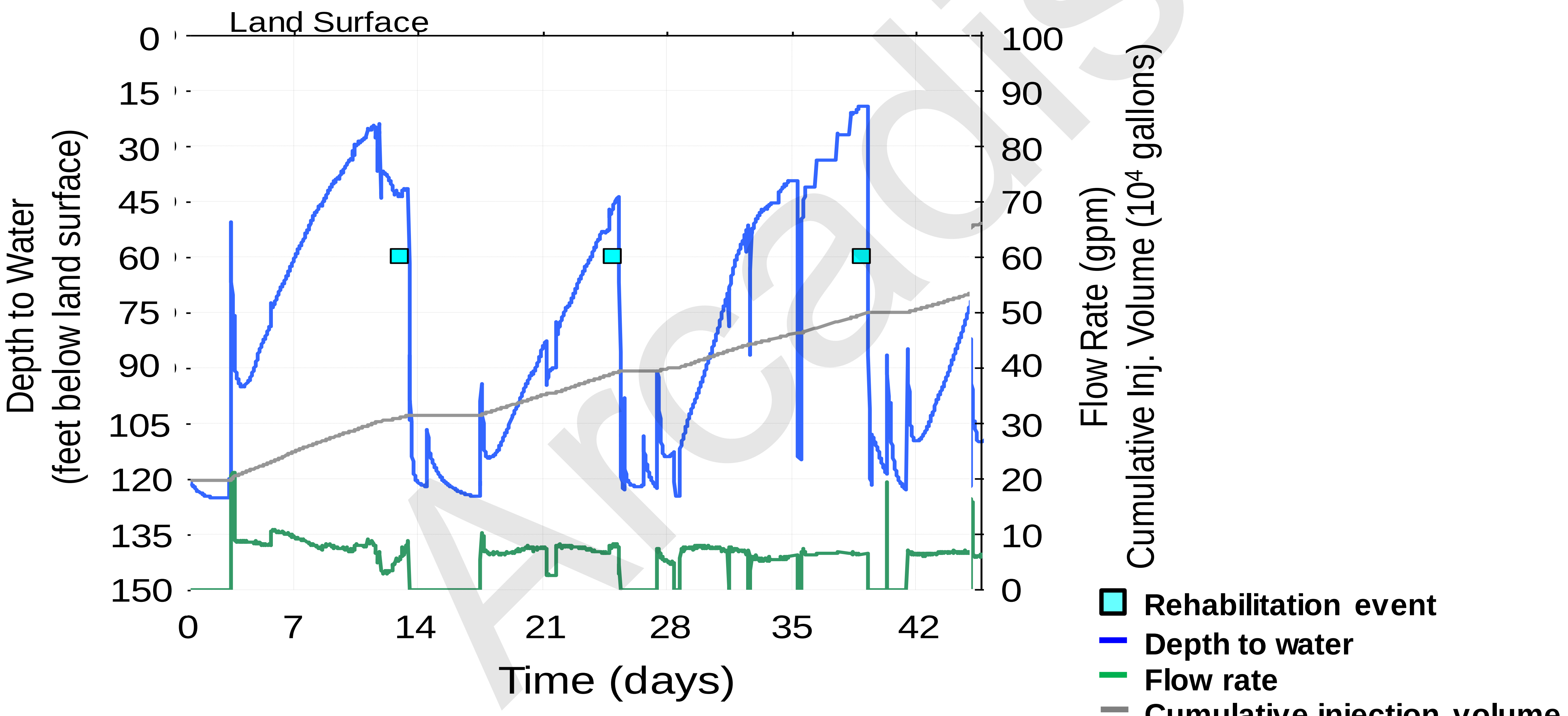
Well Fouling



Mineral Precipitation: Granular texture, low visible extra cellular polymer (ECP)

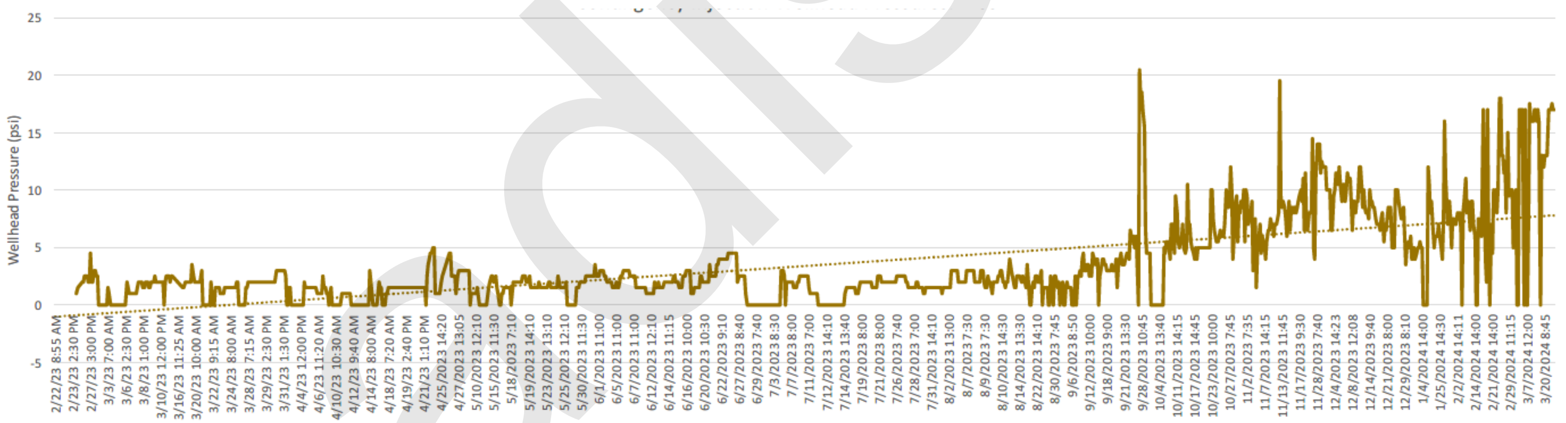
Biomass: Gelatinous texture, large quantities of ECP

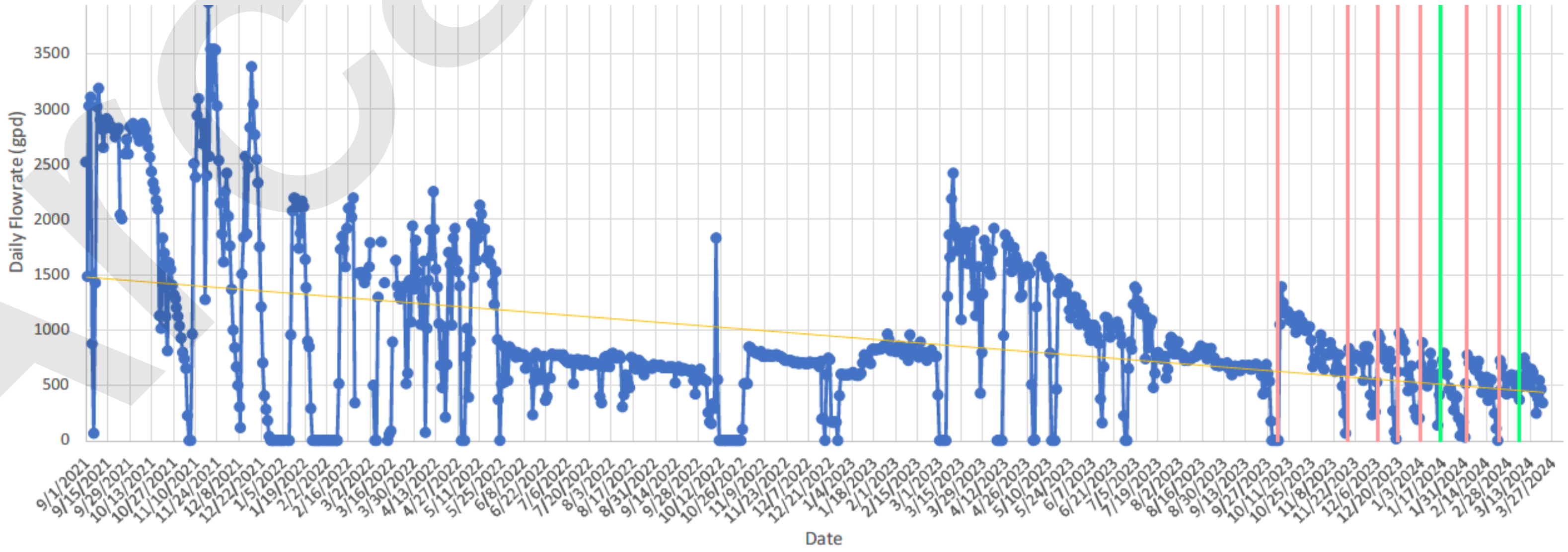
Biomass Removal: Hydraulic Response



Injection and Extraction Recirculation

- 380 total dual-purpose injection / extraction wells
- > 140 million liters extracted
- > 133 million liters injected
    - Molasses
    - Emulsified vegetable oil
    - Calcium polysulfide
- 5 years sustained operation





Well Redevelopment

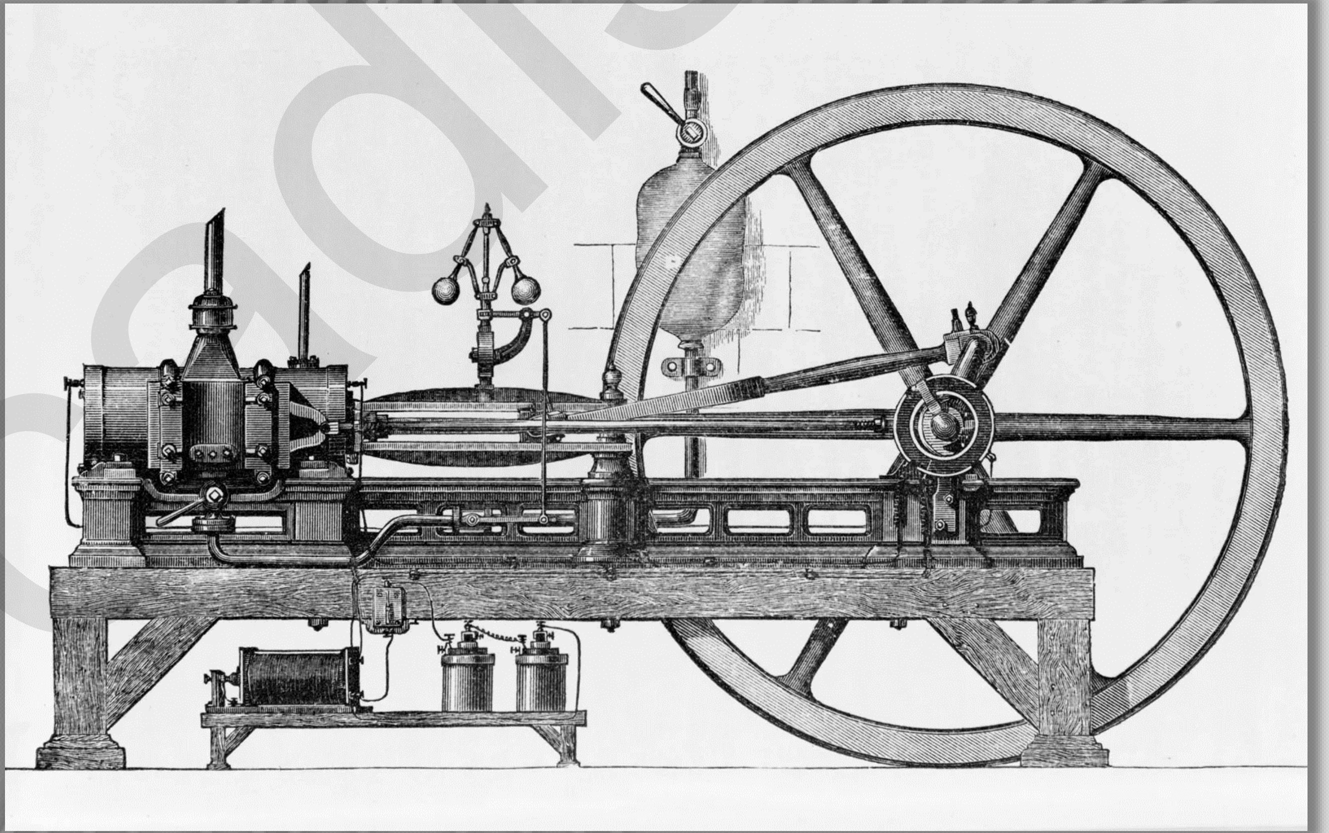
	Well Installation	Well Maintenance
Physical	Surge block Air Lifting	Brushing Surging Jetting
Chemical	Mud Dispersants	Acids Antibacterial Agents

- Requires some information about the source of fouling
- Screen intersects clays
- Dosage calculator is available

Our Best Innovation: YOU

Adaptive operations include:

- Injection volumes
- Substrate dosing and type
- Bioaugmentation
- pH adjustment
- Injection sequencing
- TISR



Thank You