



Injection System Operation and Optimization

Arcadis TechEx Antwerp, April 2024



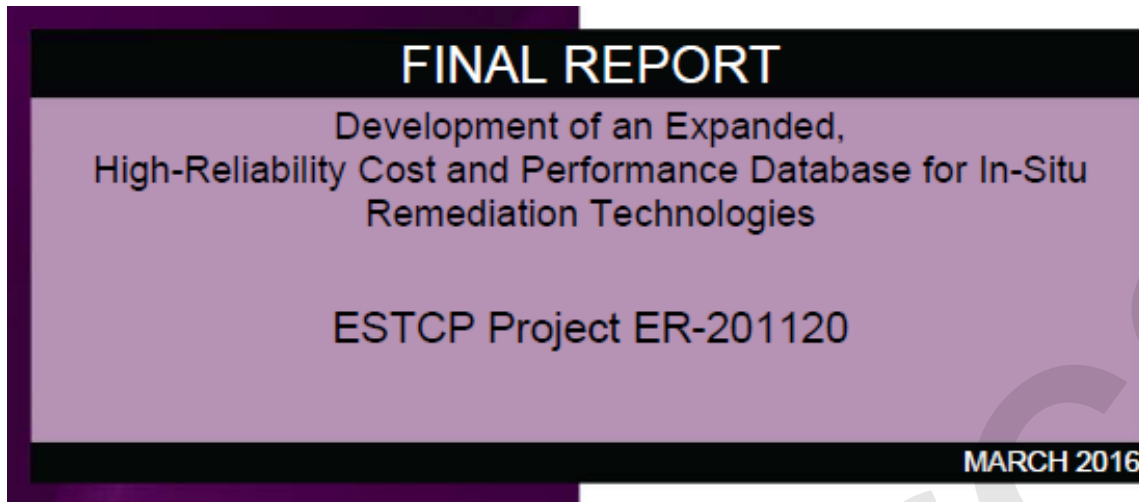
Matt Schnobrich, PE

Technical Expert / Engineer
Leader – Global Remediation
Community of Practice

Lexington, KY

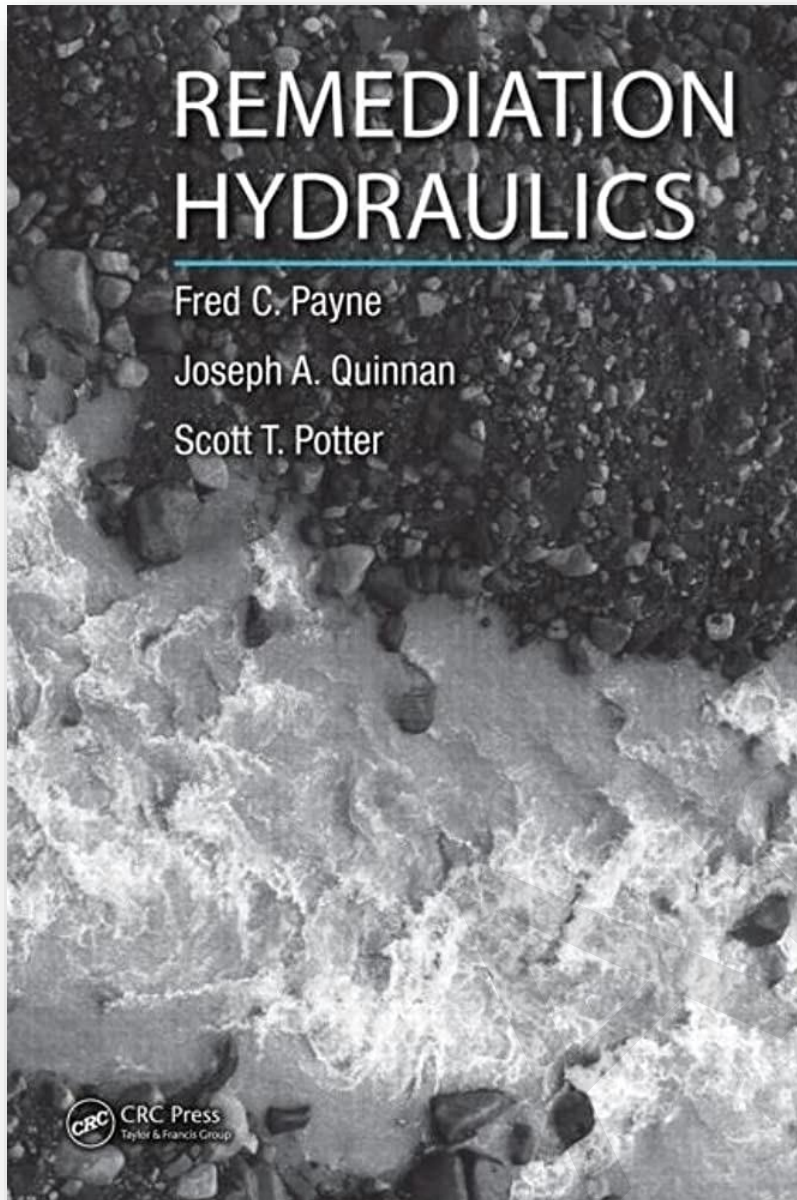
20 years with Arcadis

An *in situ* report card



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



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

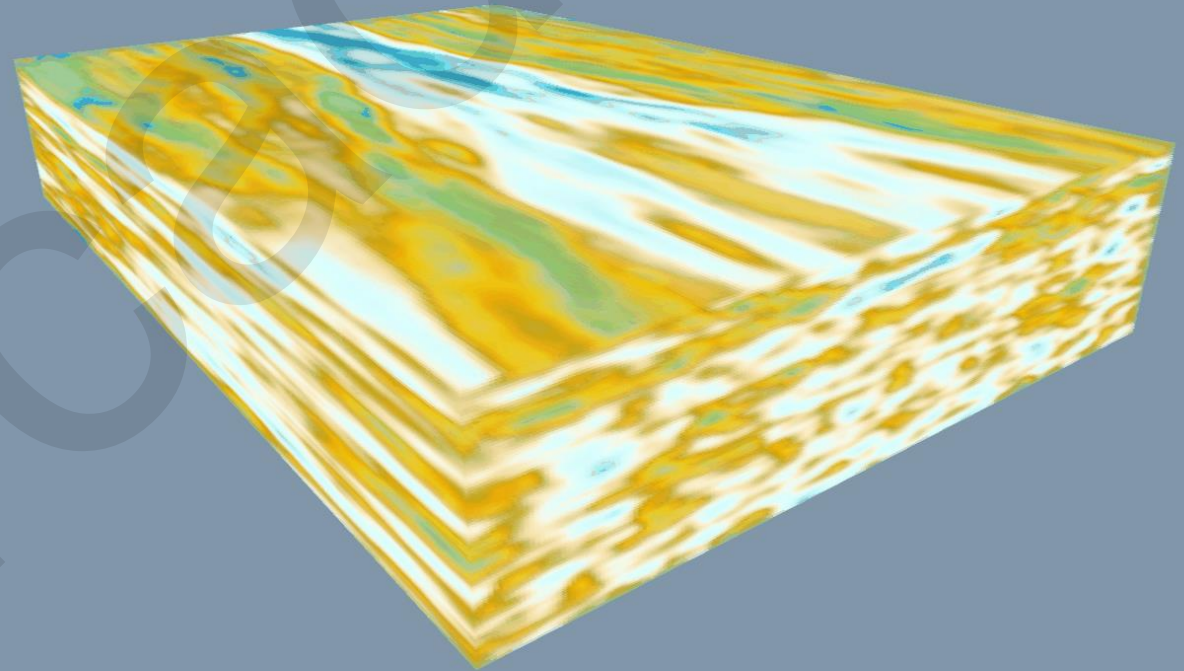
Groundwater Monitoring & Remediation 37, no. 4/ Fall 2017, 15-22

Re-Thinking Our Framework

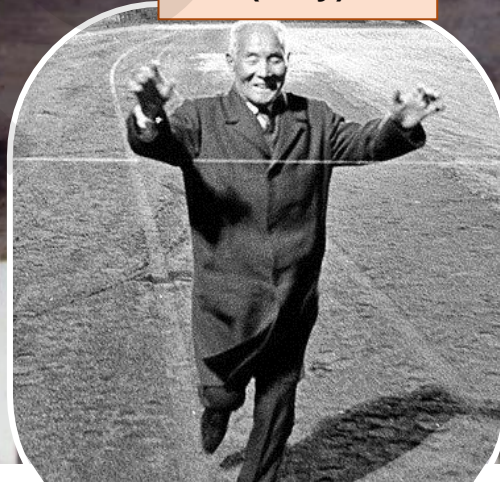
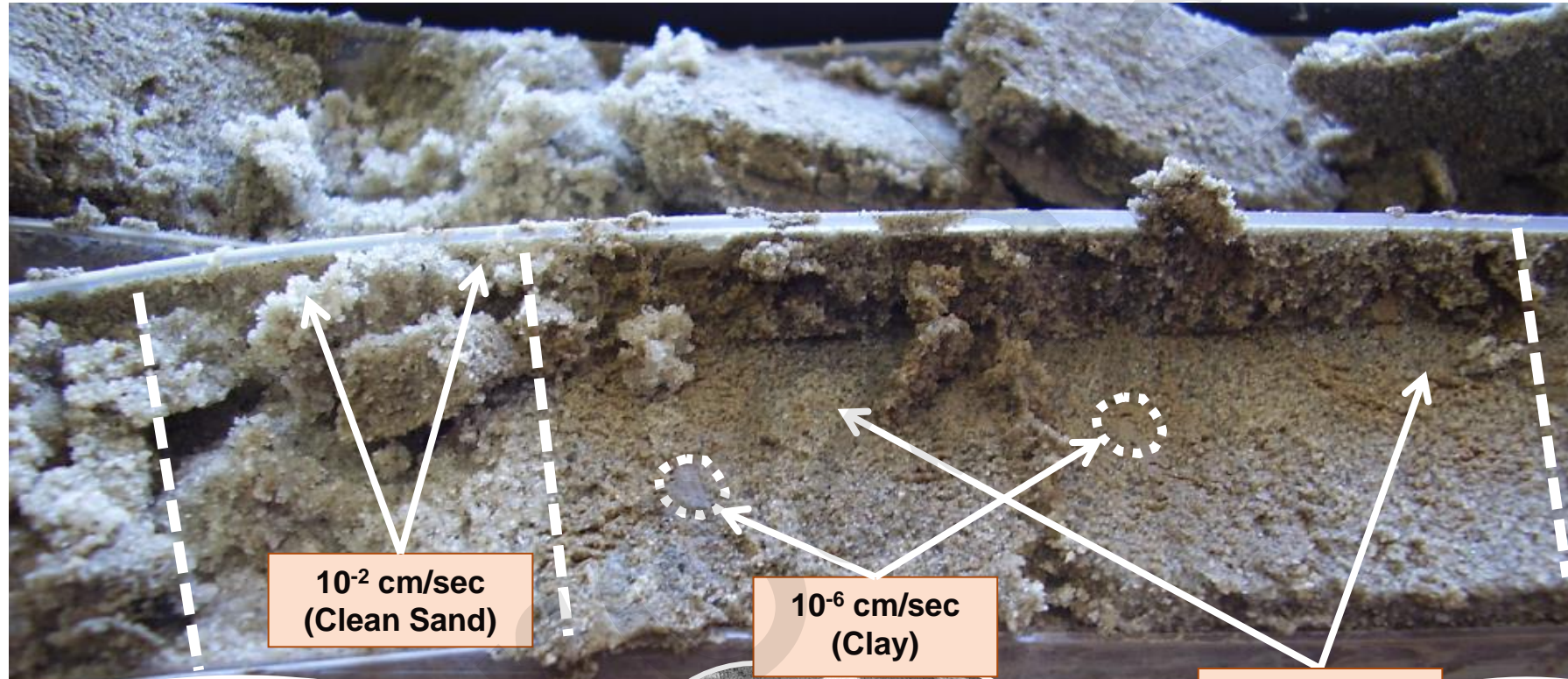
We reassessed our data and started building aquifers to fill in missing parts



Hydraulic conductivity in a 3-D aquifer



Contrasts in Permeability



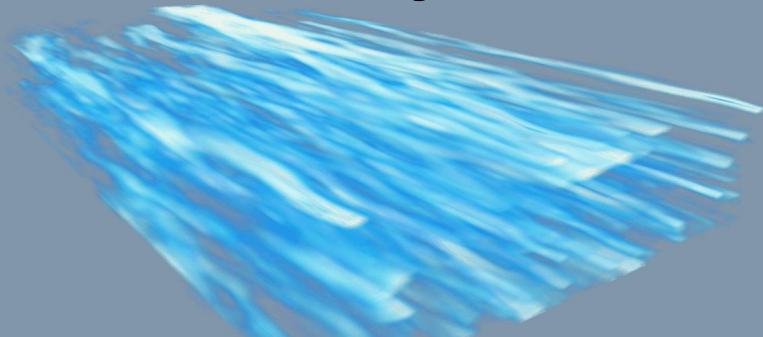
5

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})

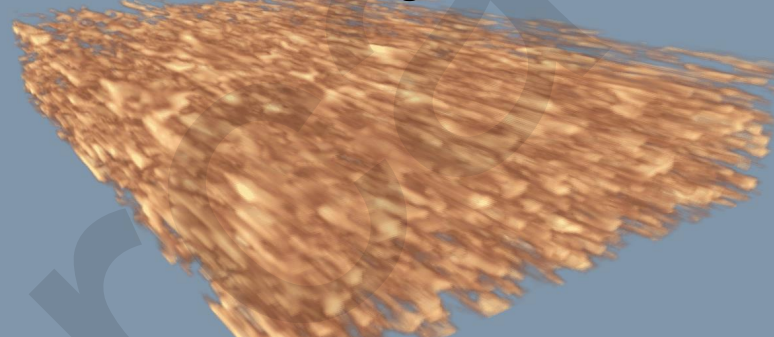
10x Average K



90% of groundwater flux
(advection/transport zone)

Compartment 2 (C2 or Q_9)

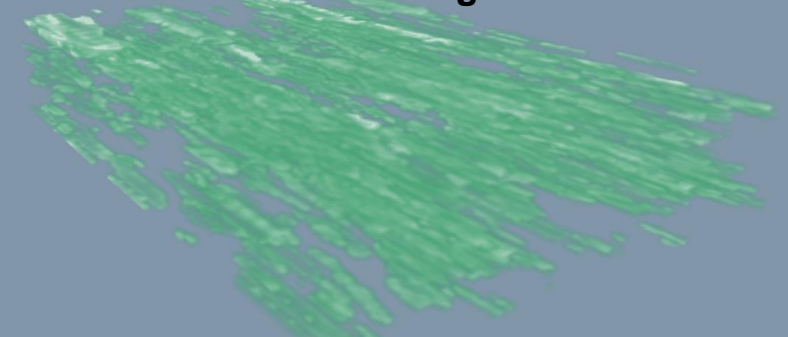
Average K



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

Compartment 3 (C3 or Q_1)

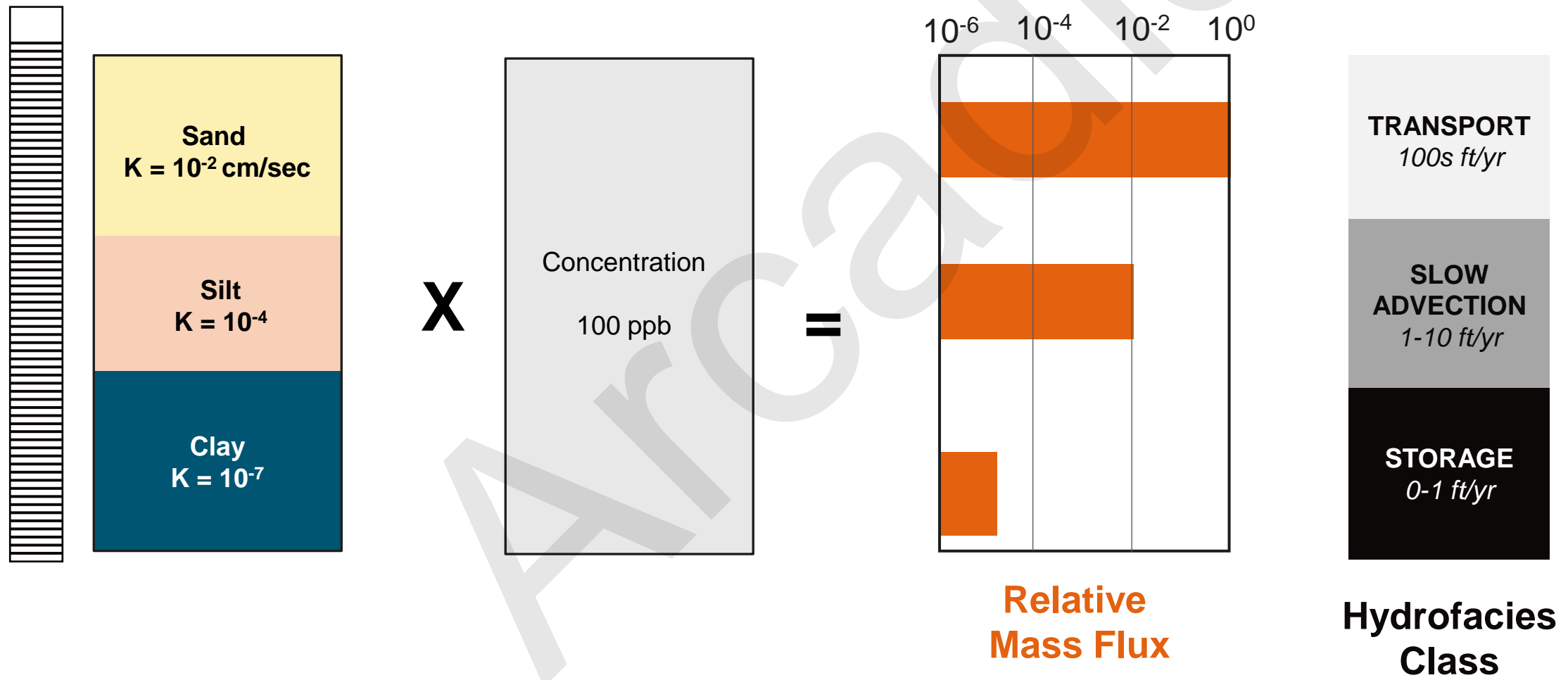
0.1x Average K



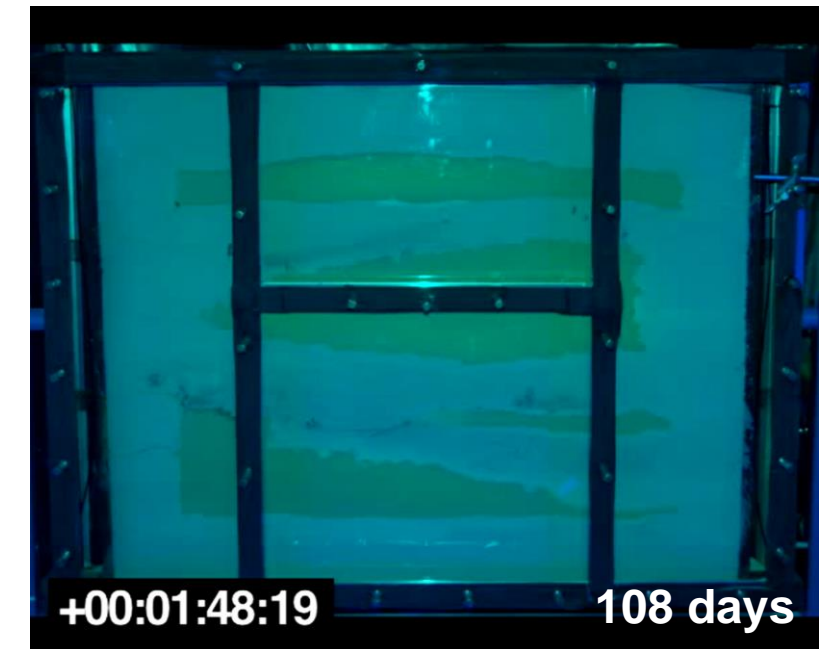
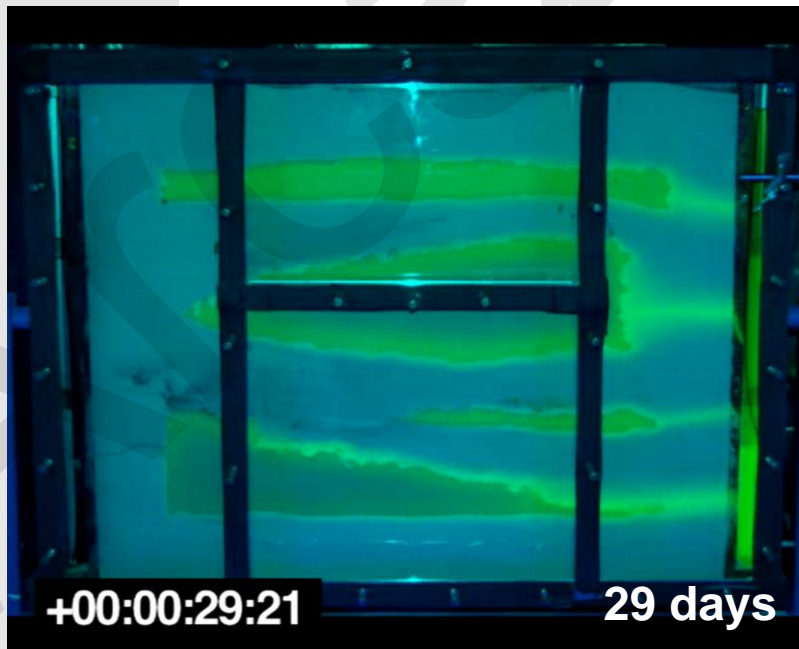
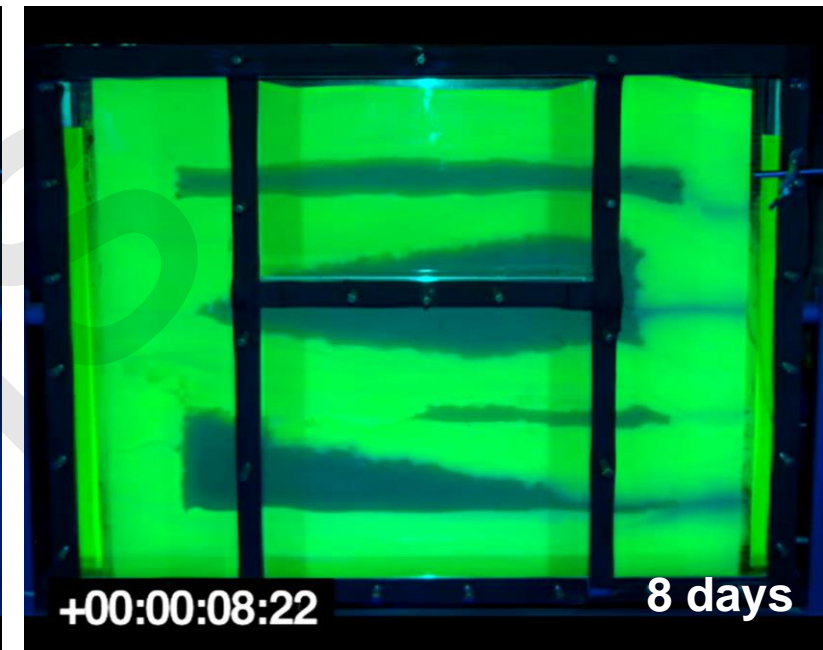
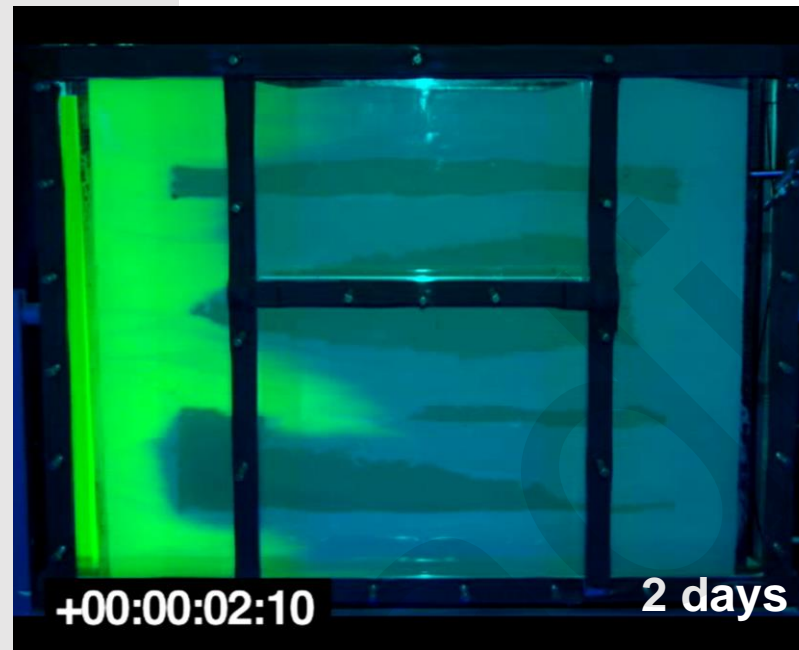
1% of groundwater flux
(storage zone)

Permeability dictates contaminant transport ...

$$\text{Mass Flux (J)} = K i C$$



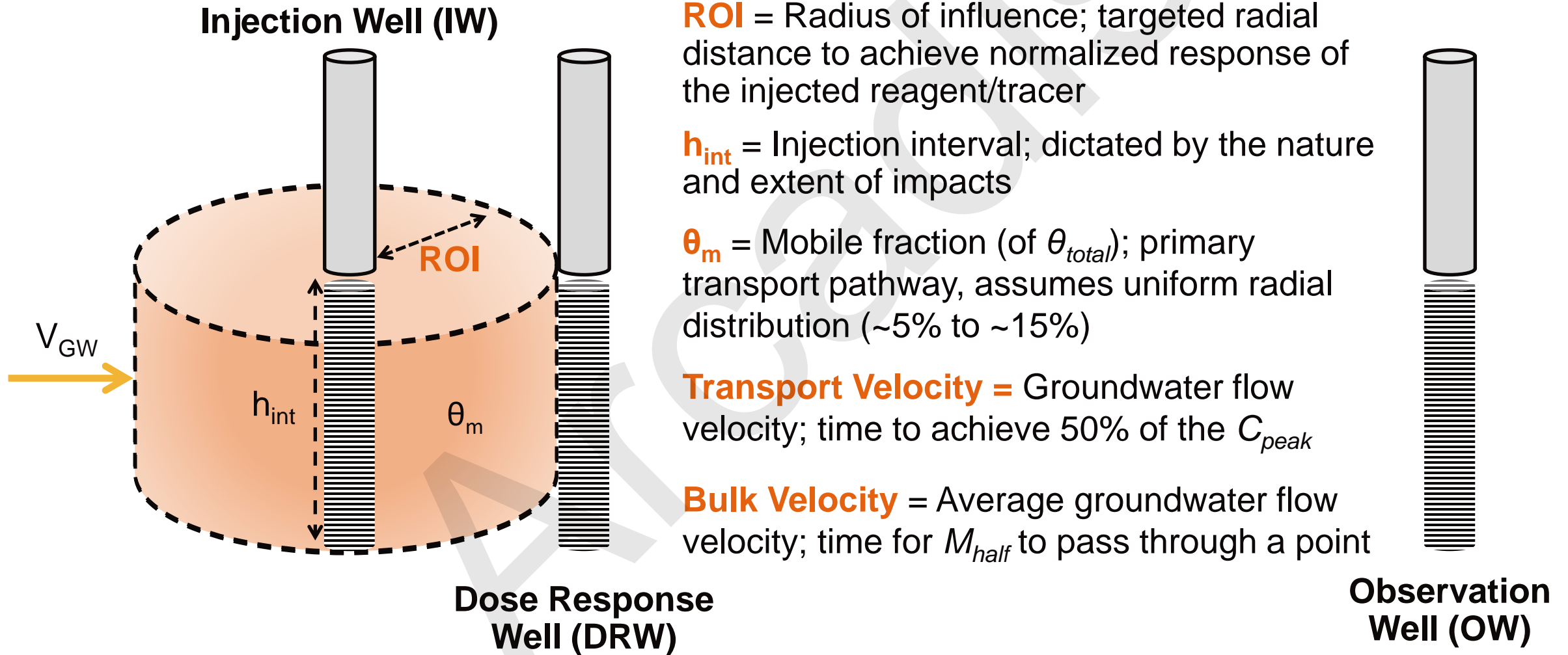
... and the distribution of injection reagents



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

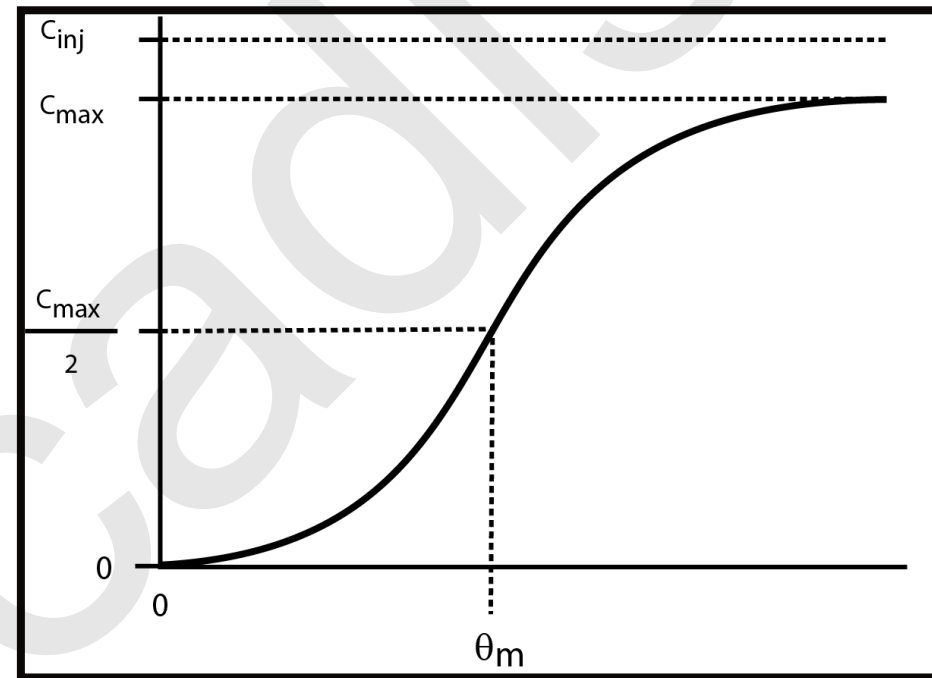
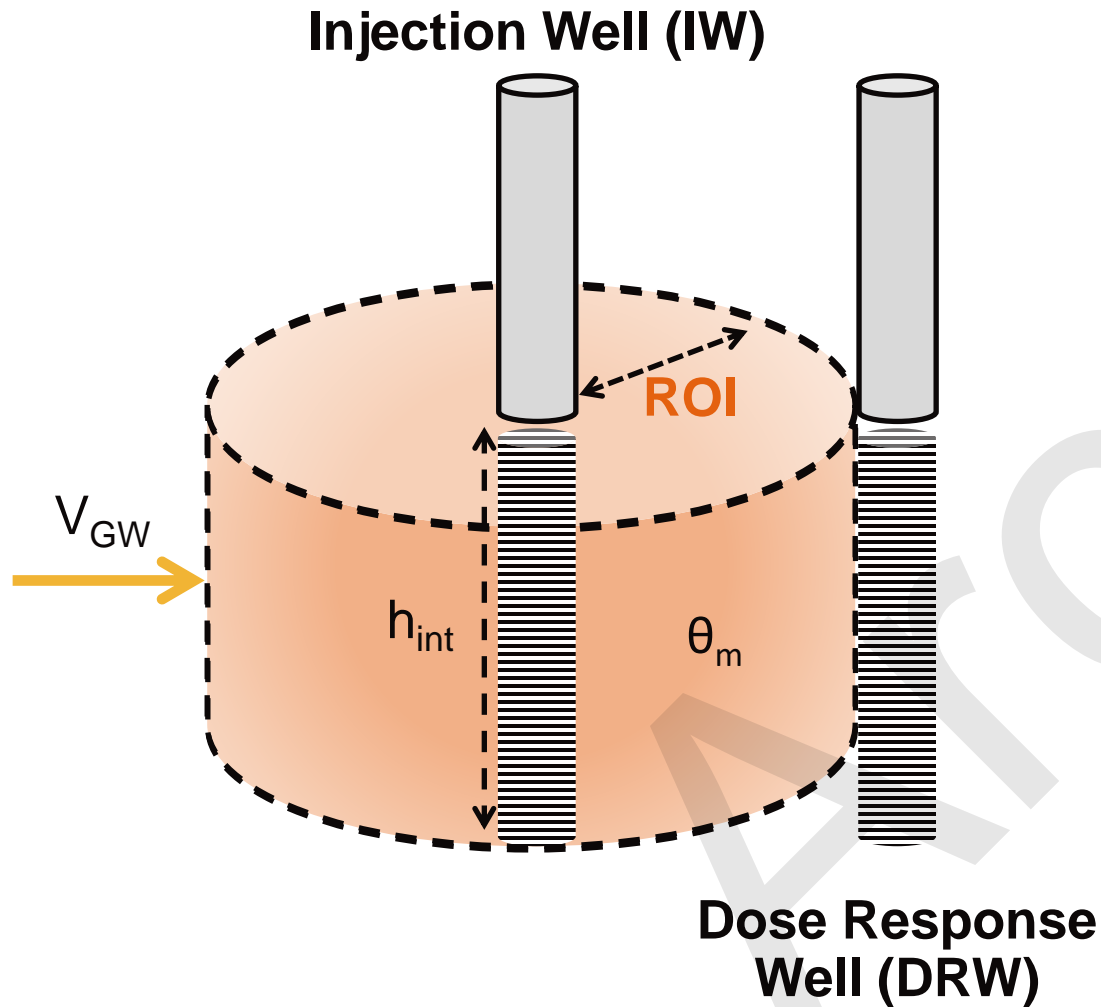
h_{int} = Injection interval; dictated by the nature and extent of impacts

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

Porosity-Based Injection – Tracer Testing



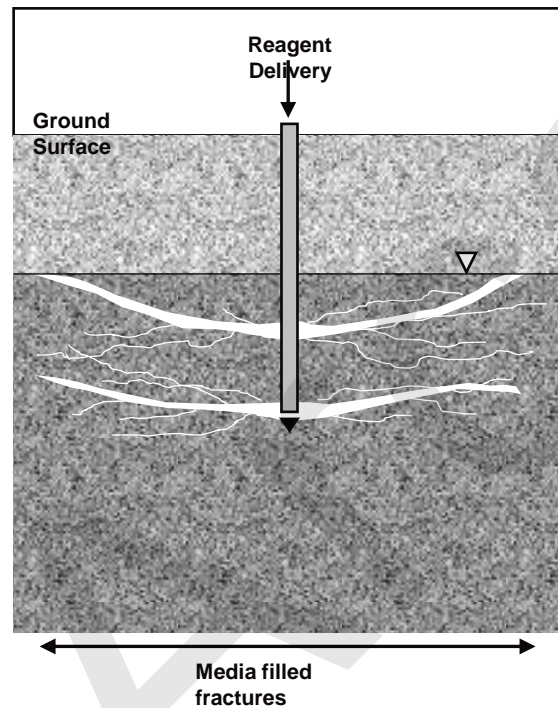
Breakthrough Curve (BTC) = Tracer response versus cumulative volume (during injection) or time (post-injection) at dose response or observation wells, respectively



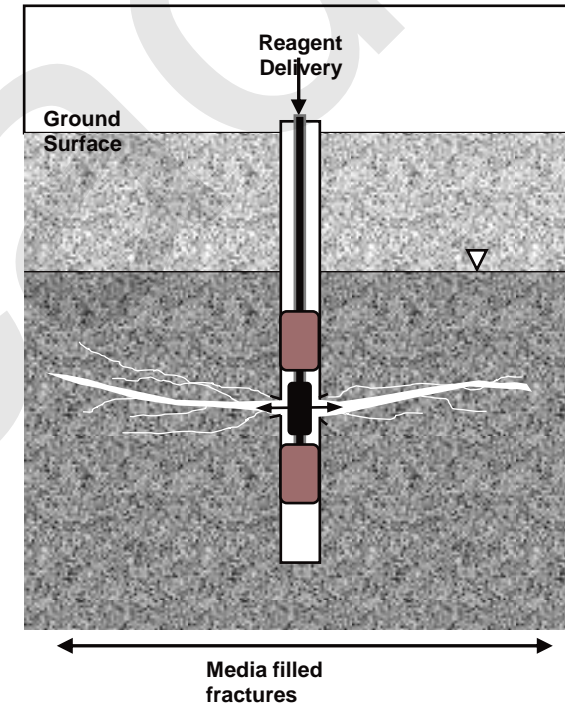
Observation Well (OW)

Alternative Delivery Methods – Fracturing

Direct Push Technology



Hydraulic & Pneumatic



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

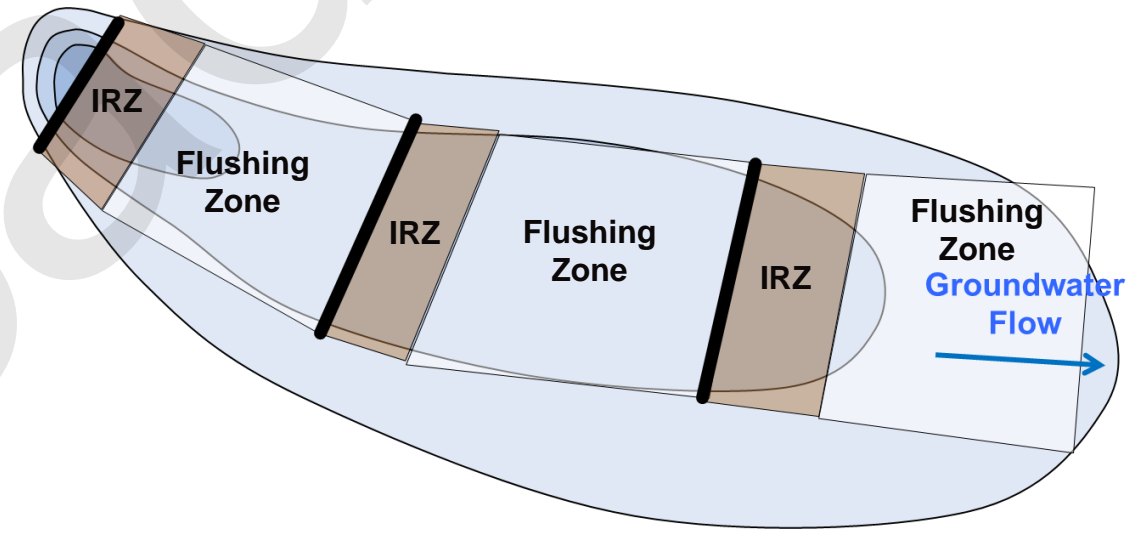
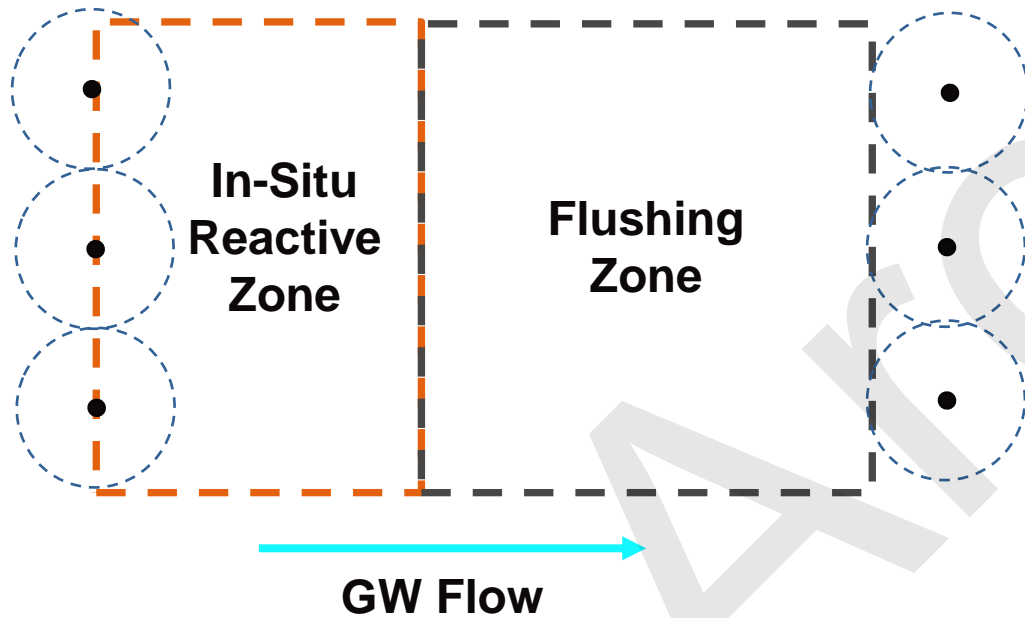


Injection Design Concepts

The background of the slide is a solid black color. Overlaid on this background are numerous thin, white, wavy lines that create a topographic or contour-like pattern. These lines flow from the bottom left towards the top right, with some lines forming closed, irregular loops. The overall effect is a sense of depth and movement, reminiscent of a stylized landscape or a complex data visualization.

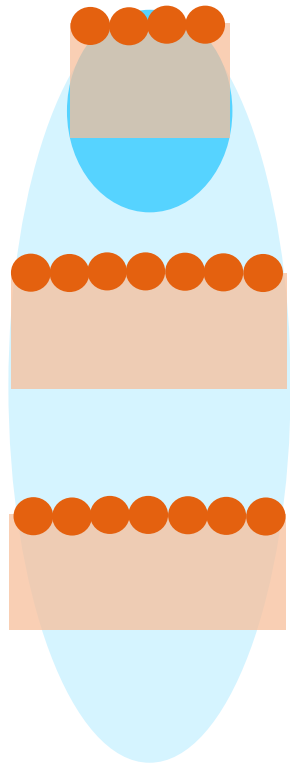
Injection Transect Design

Enhanced
Reductive
Dechlorination

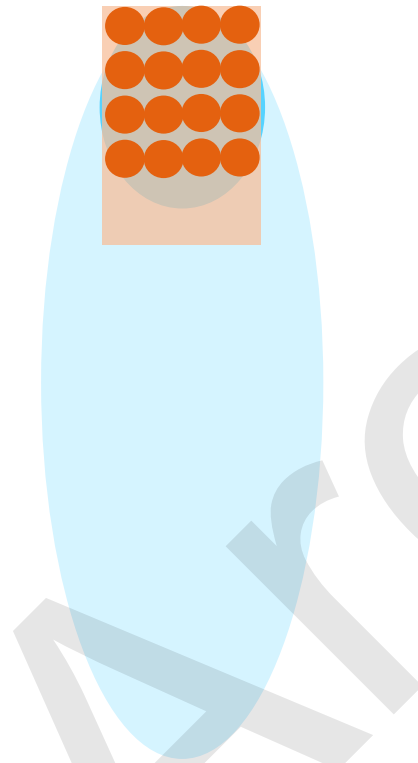


Injection/Extraction Well Layouts

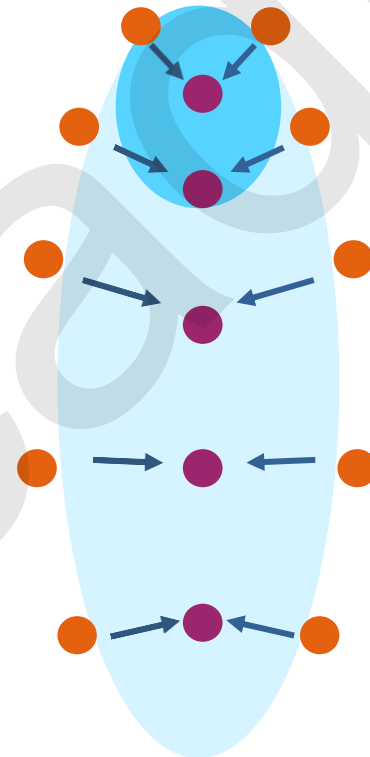
Dynamic
Groundwater
Recirculation



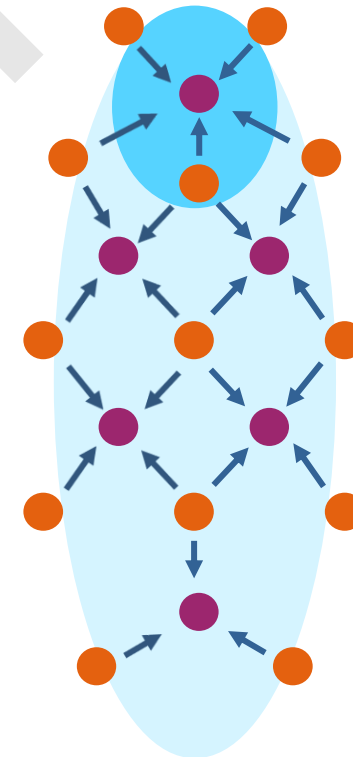
Transects



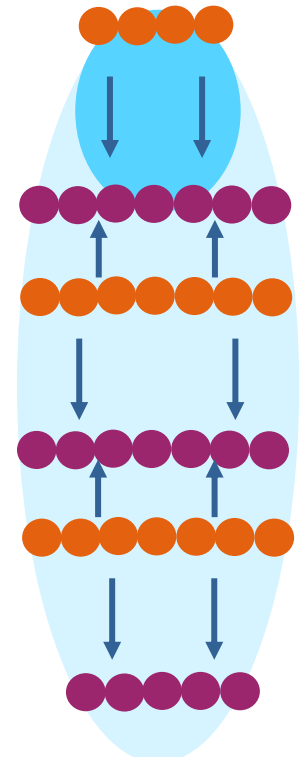
Source Coverage



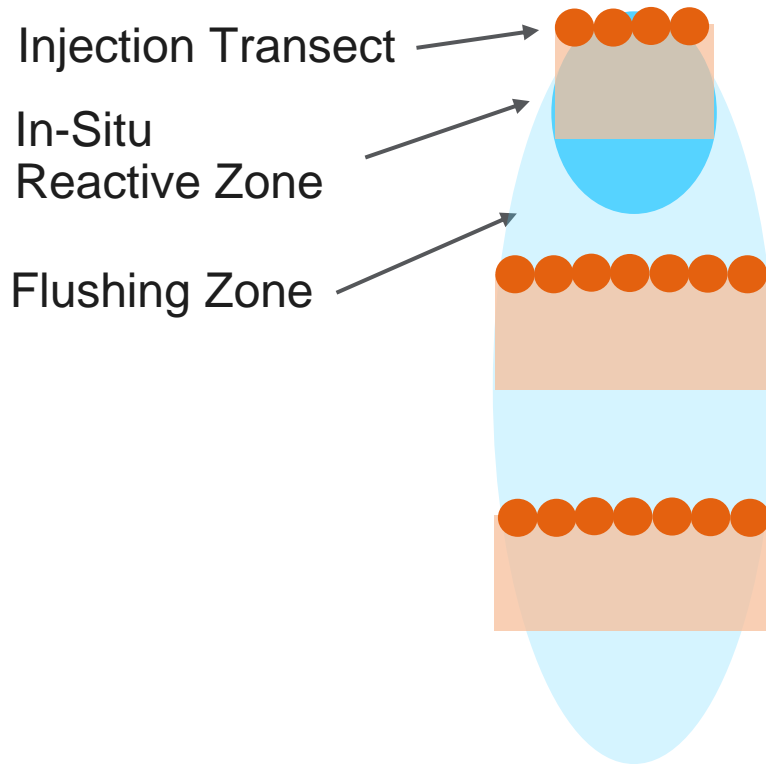
Inject-and-Drift



Recirculation



Conceptual Injection Design



- 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.

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

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

Operation and Optimization

The background of the slide is a solid black color. Overlaid on this background are numerous thin, white, wavy lines that form a pattern resembling topographic contour lines or a complex, organic shape. These lines are most prominent on the right side of the slide, where they curve and loop, and extend towards the bottom left corner.

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 ...

*12:00-2:00
Noval pump:*

*0800 - on site H45 Tank. Set up with 2 flow meters, one with
0900 - start water @ 2 in 1 in FMS @ manifold*

Cintas - Molasses Injection Log

Injection Start Date and Time: 3/31/19
 Injection End Date and Time: 3/31/19
 Stock Molasses Concentration (%): 80%
 Weather: *Empty Tank* TARGET MOLASSES: 480 GAL/DAY
 TDT = 924,320 TARGET WATER: 28,270 GAL/DAY

T.U. = Total molasses used today.

Time	Elapsed Time (mins)	Hydrant Flow Rate (gpm)	Totalizer Reading (gallons)	IW-1			IW-2			IW-3			IW-4			IW-5			Molasses	
				Flow Rate (gpm)	Totalizer Reading (gallons)	Wellhead Pressure (psi)	Flow Rate (gpm)	Totalizer Reading (gallons)	Wellhead Pressure (psi)	Flow Rate (gpm)	Totalizer Reading (gallons)	Wellhead Pressure (psi)	Flow Rate (gpm)	Totalizer Reading (gallons)	Wellhead Pressure (psi)	Flow Rate (gpm)	Totalizer Reading (gallons)	Wellhead Pressure (psi)	Flow Rate (gpm)	Tank Level (gallons)
0930		various																		
1000	30	70	94100	70	94100	15	6850	15	14	110	18	0	480							0.0058' / gal
1030	1200	70	99300	70	99300	14	7020	14	14	110	18	0	480							
1045	1220	72	99800	72	99800	14	7020	14	14	110	18	0	480							
1100	3700	76	99800	76	99800	14	7020	14	14	110	18	0	480							
1115	4100	60	90000	60	90000	10	1090	10	11	110	18	0	480							
1145	5600	48	90100	48	90100	11	1100	11	11	110	18	0	480							
1215	7500	73	70300	73	70300	14	1090	14	14	110	18	0	480							
1305	4100	75	97200	75	97200	14	1100	14	14	110	18	0	480							
1315	4150	100	90700	100	90700	20	1100	20	13	110	18	0	480							
1325	4650	180	90800	180	90800	22	1100	22	13	110	18	0	480							
1340	4950	170	91000	170	91000	17	1100	17	13	110	18	0	480							
1400	15800	100	91000	100	91000	17	1100	17	13	110	18	0	480							
1423	18200	100	91400	100	91400	17	1100	17	13	110	18	0	480							
1430	18400	100	91500	100	91500	17	1100	17	13	110	18	0	480							
1510	60	91600																		
1545	40	91900																		
1555	30	92000																		

off

*10:20
12:30
15:00
17:00
19:00
21:00*

*Leave: 2 H45 @ 70 GPM = 8400
1500 gal*

8900 → stop water on 3 @ 915,470

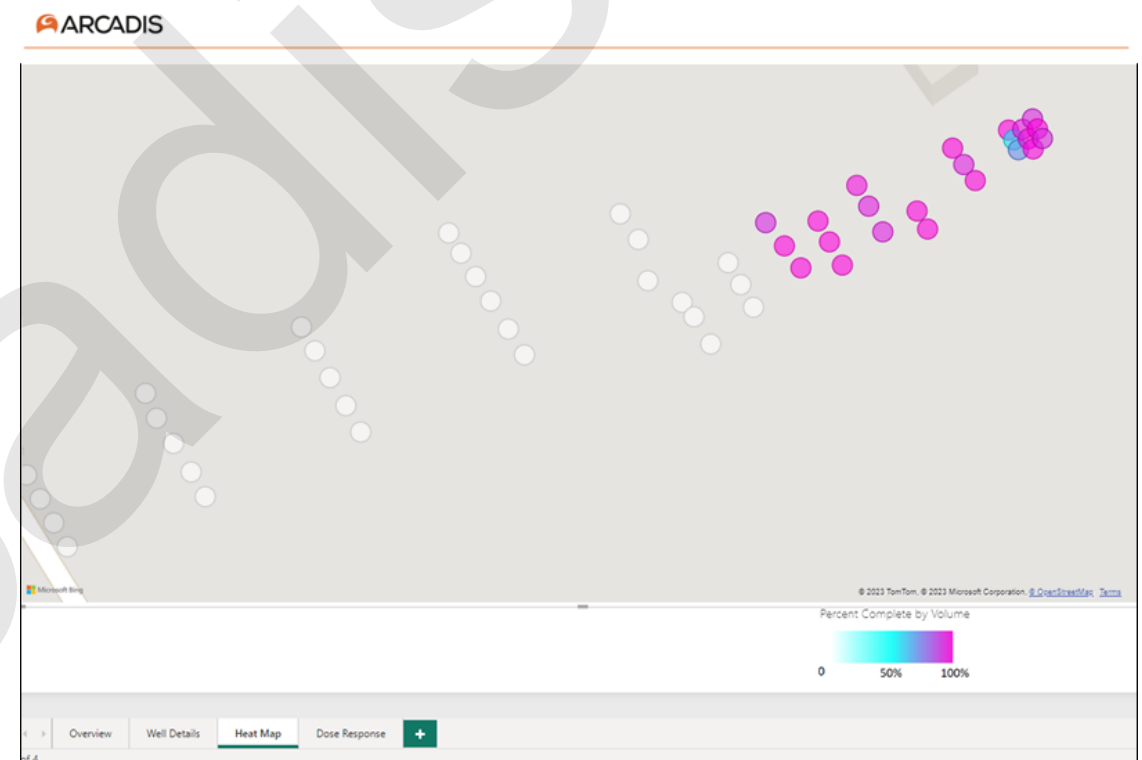
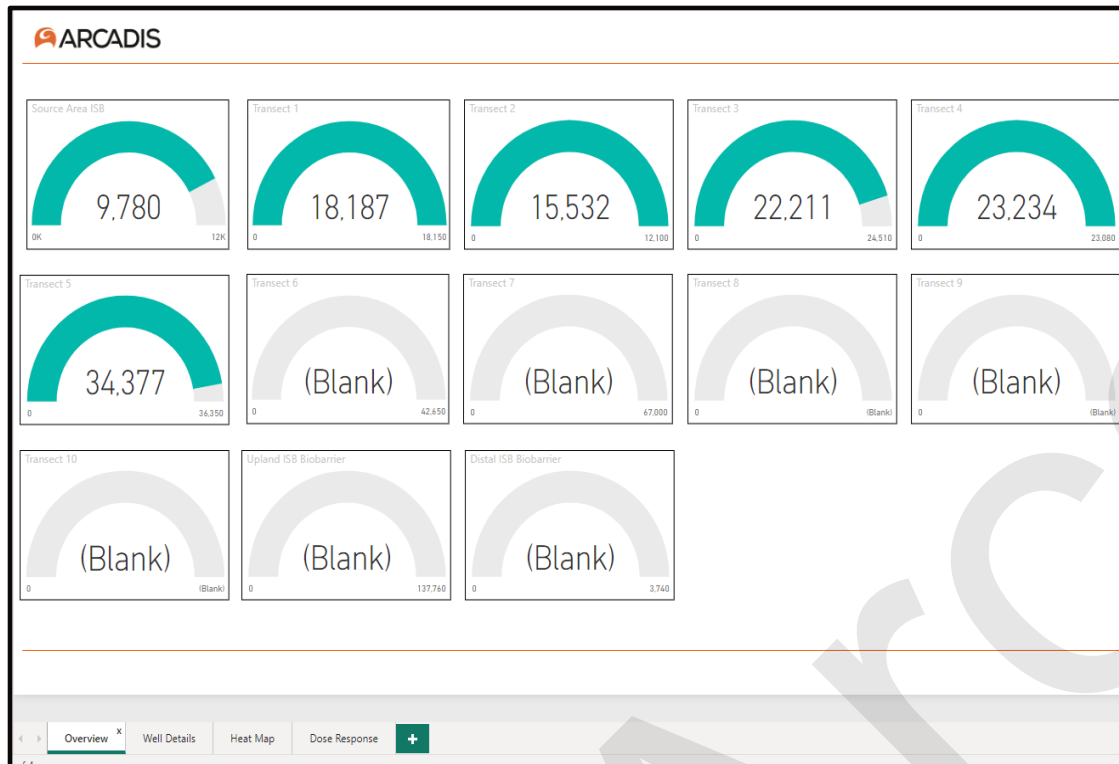
Molasses on

Molasses off - molasses below cone, unable to read volume used

Molasses out.

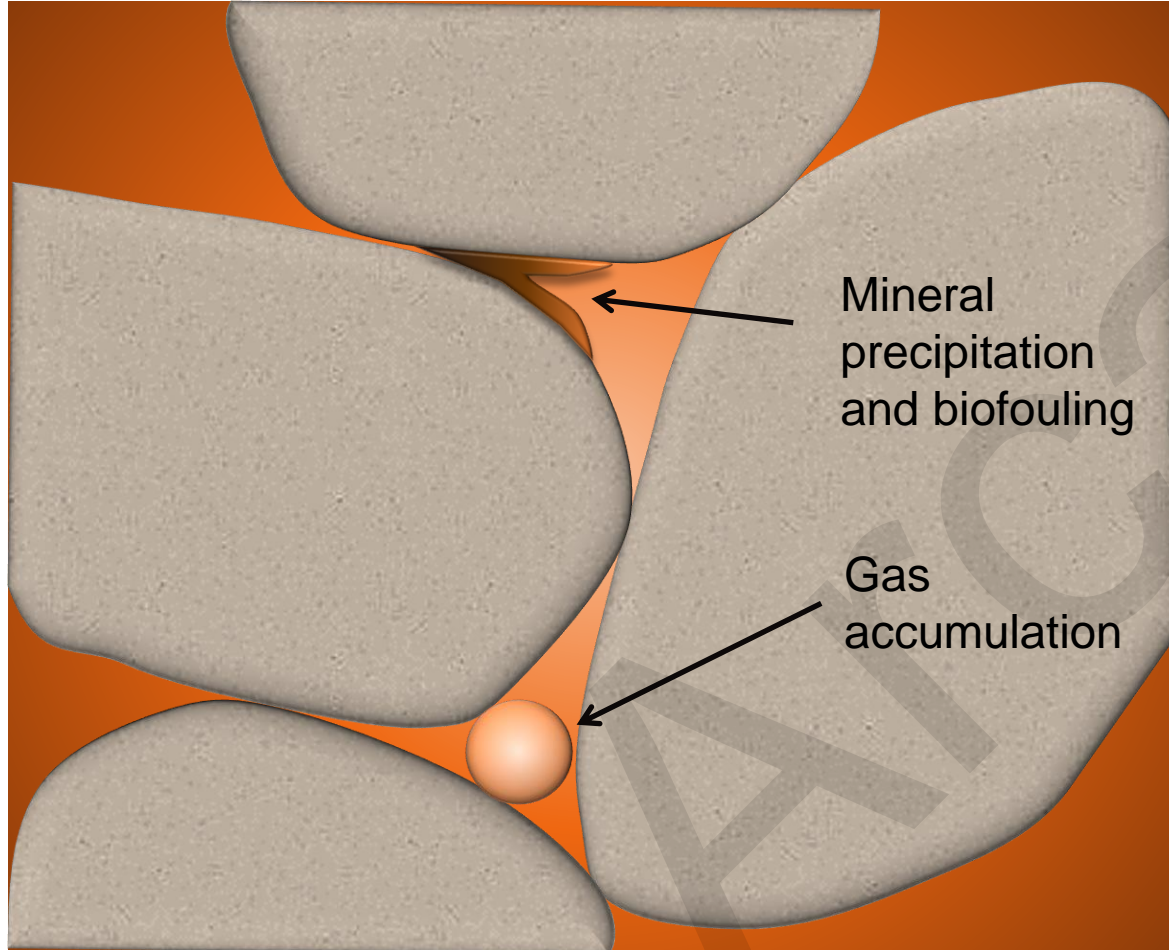


Field Data Collection and Power BI



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

Porosity Reduction



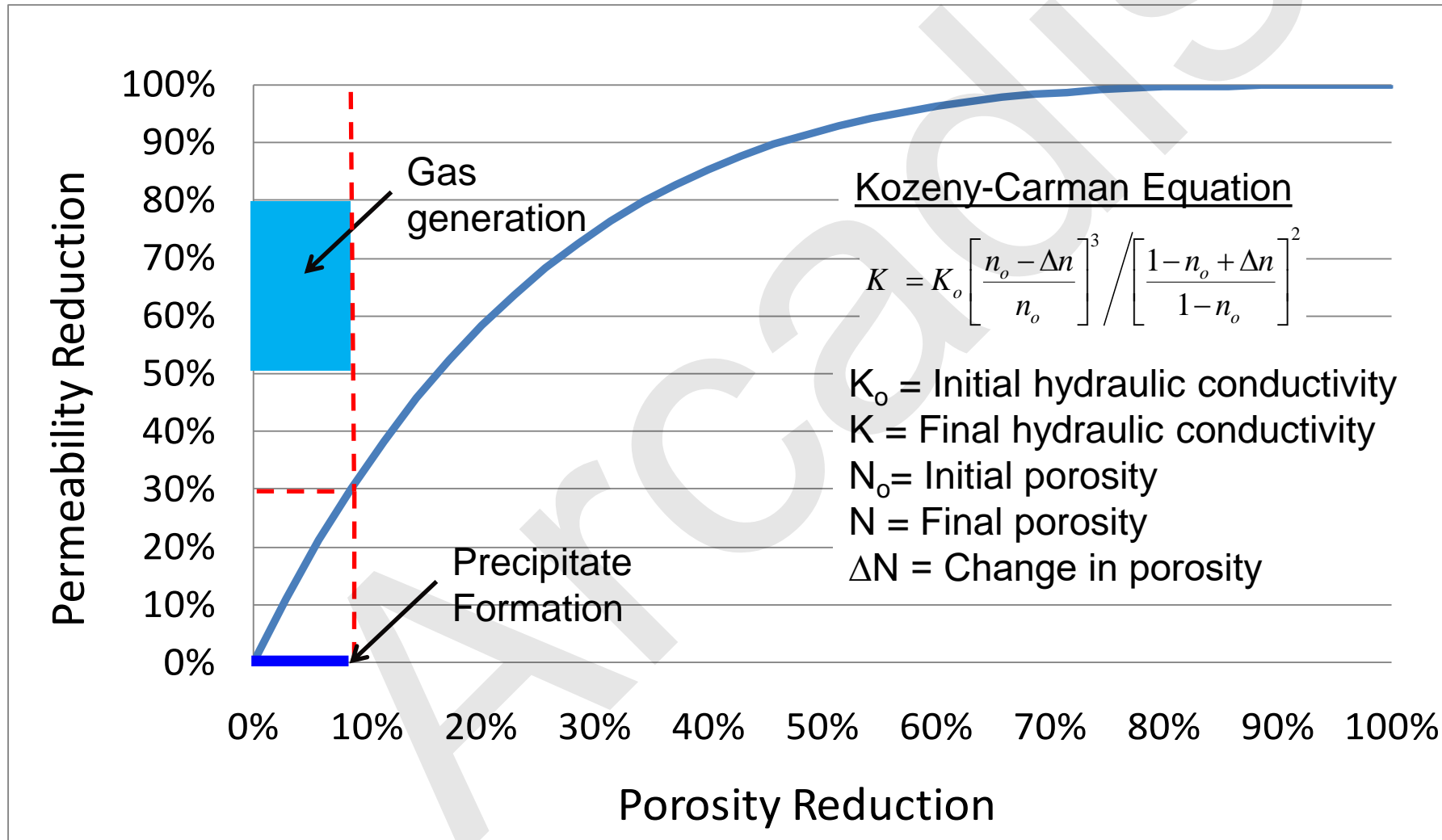
Mineral precipitation and biofouling

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

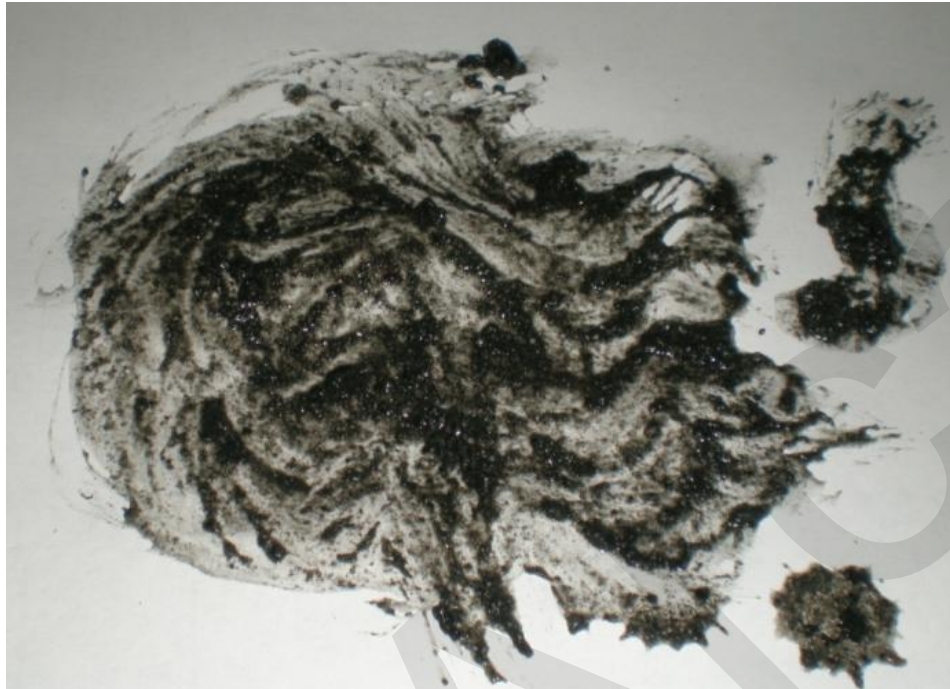
Gas accumulation

- Rapid formation
- Transient
- Large reduction in injection capacity

Porosity Reduction



Well Fouling

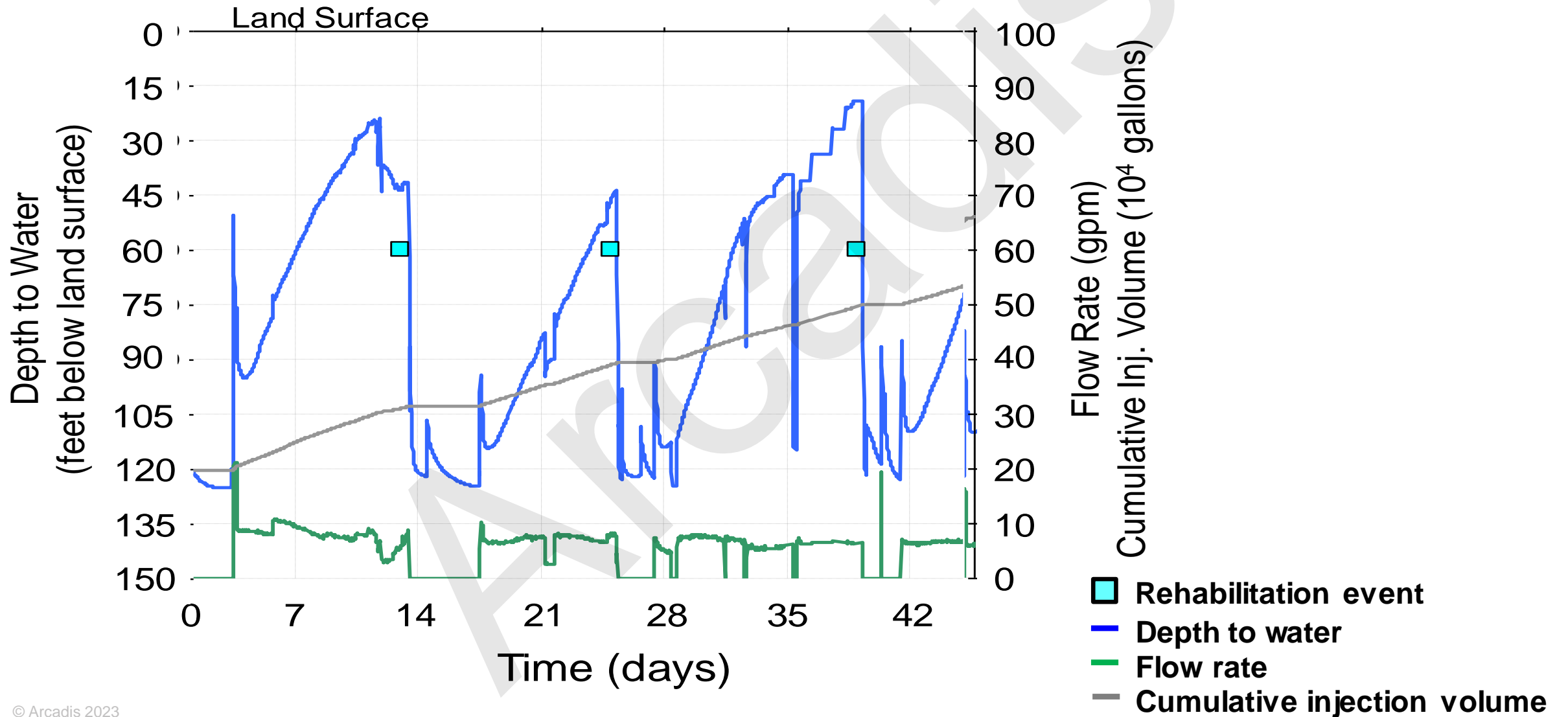


*Mineral Precipitation:
Granular texture, low visible
extra cellular polymer (ECP)*



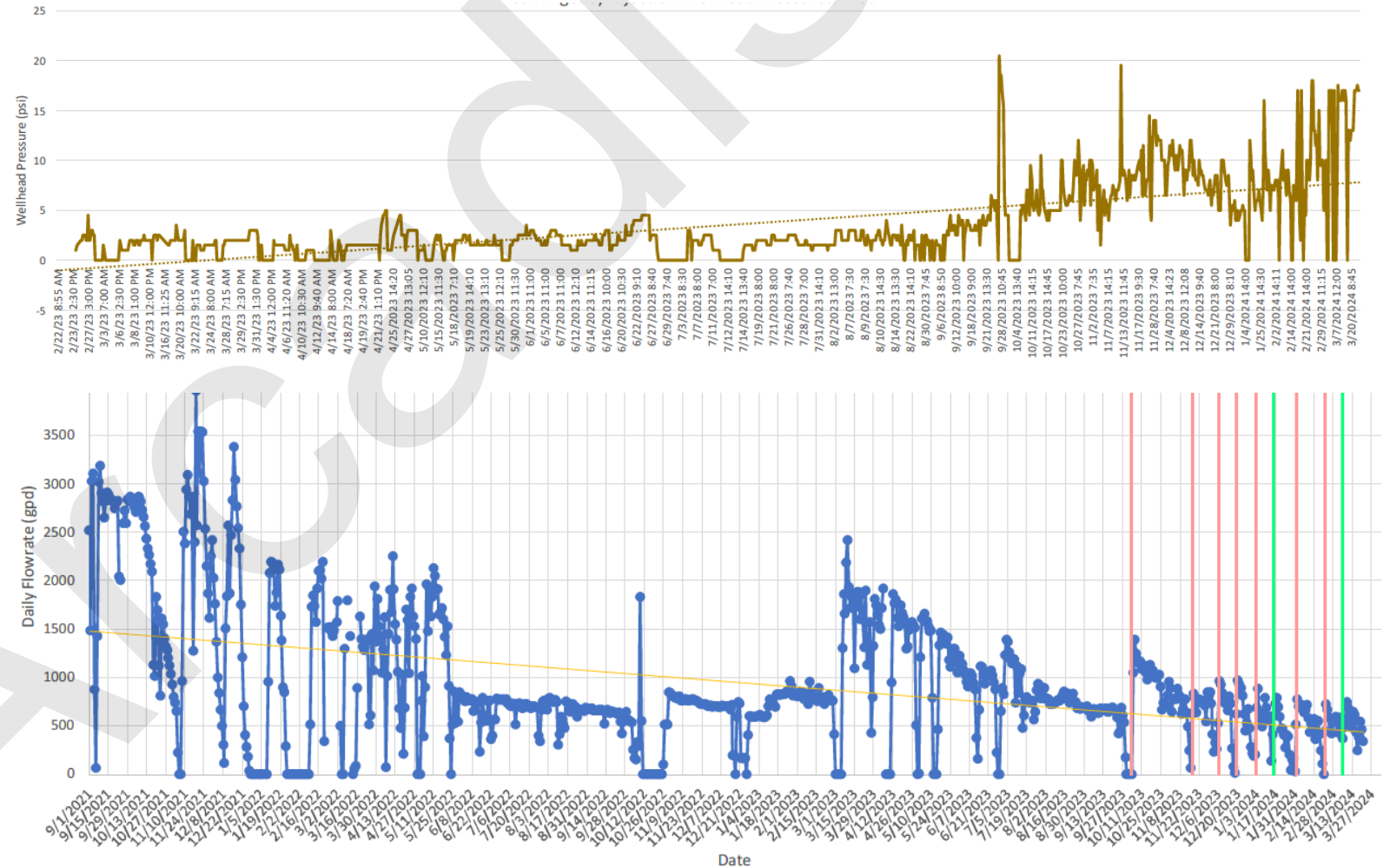
*Biomass: Gelatinous texture,
large quantities of ECP*

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

Physical

Well Installation

Surge block
Air Lifting

Well Maintenance

Brushing
Surging
Jetting

Chemical

Mud Dispersants

Acids
Antibacterial Agents



- Reduces some information about the source of fouling
- Screen interference/clays
- Dosage calculation is available

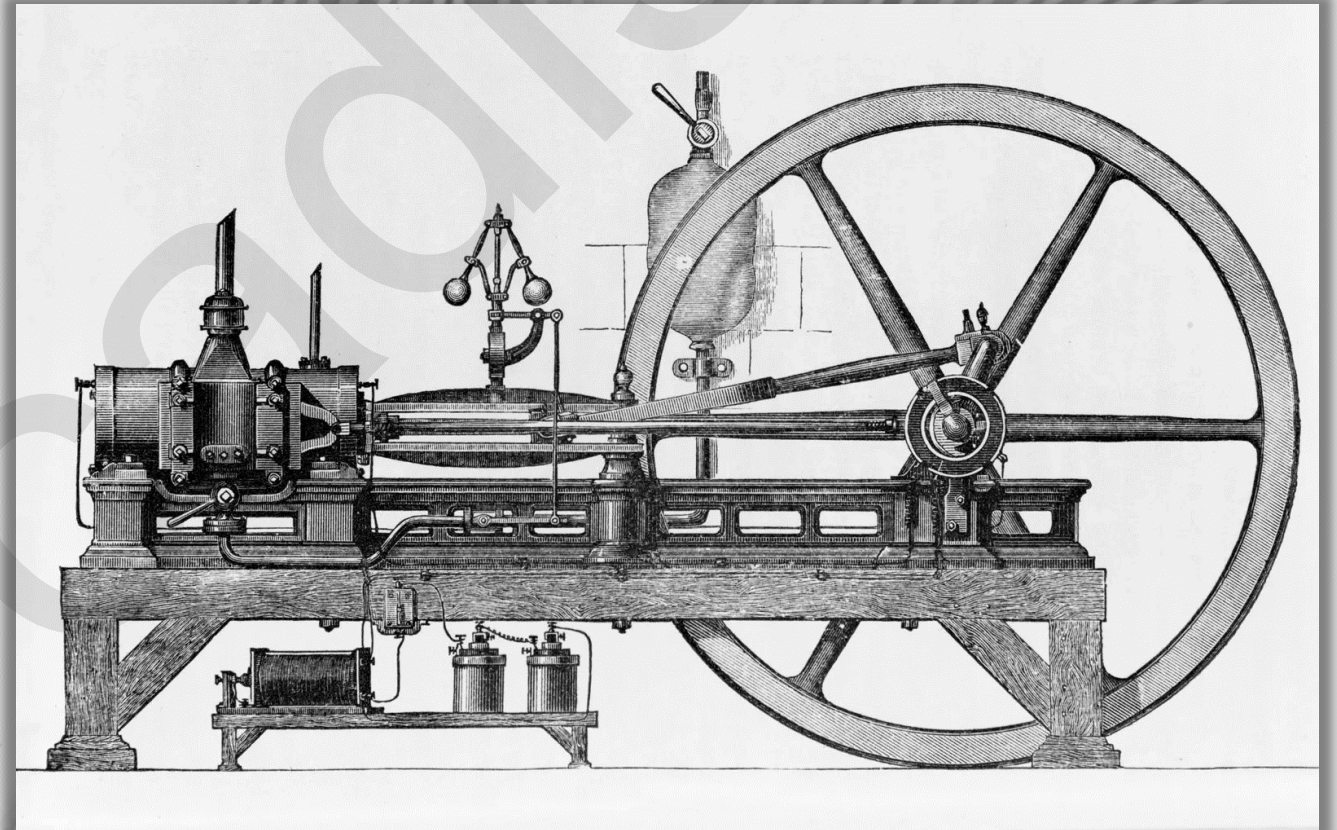


Airlift pump

Our Best Innovation: YOU

Adaptive operations include:

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



Thank You

The background of the slide is a solid black color. On the right side, there is a complex pattern of thin, white, wavy lines that resemble topographic contour lines or a wood grain texture. These lines flow from the top right towards the bottom left, creating a sense of movement and depth. The lines are closely spaced in some areas and more widely spaced in others, forming various shapes and curves.