Through the hidden veins of the earth:
How do water and solutes get to Silver Springs?

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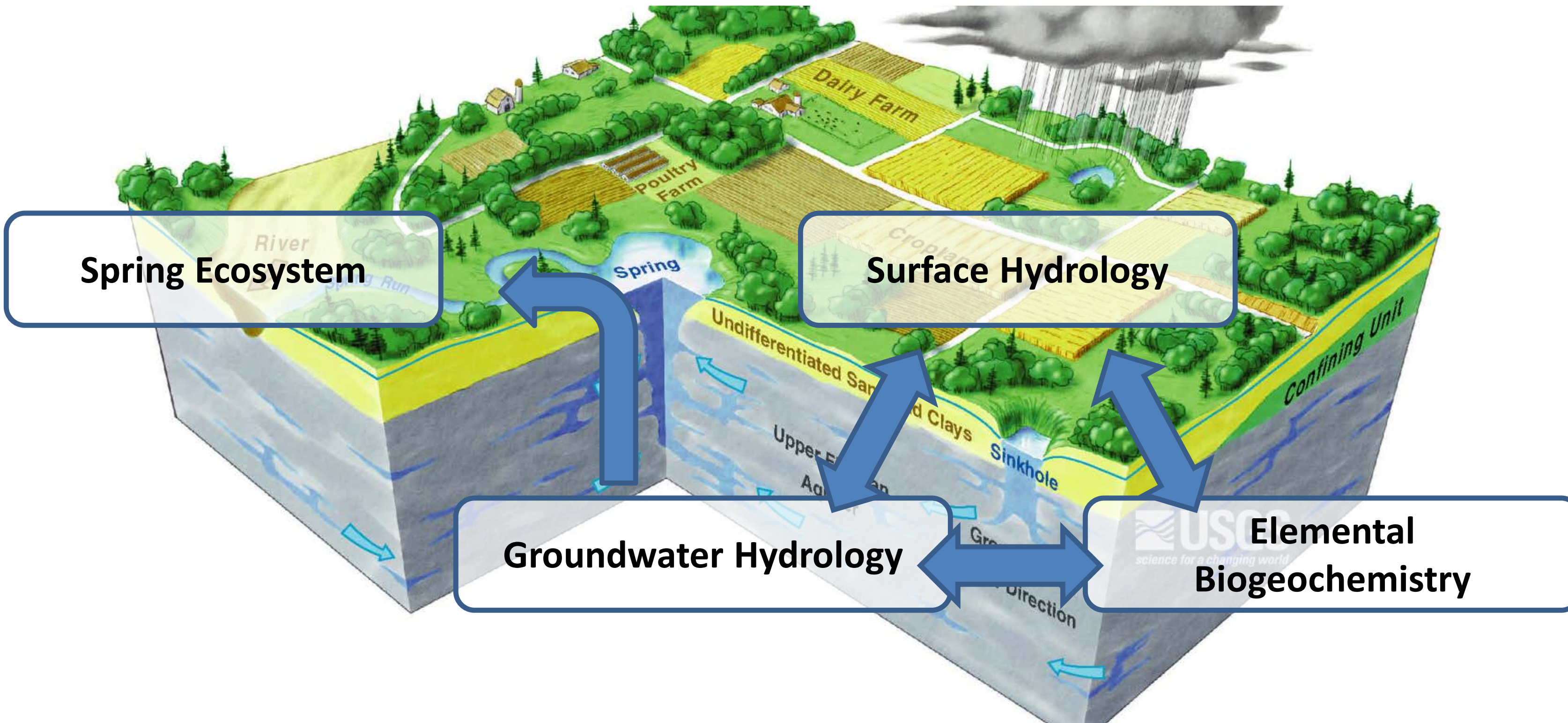
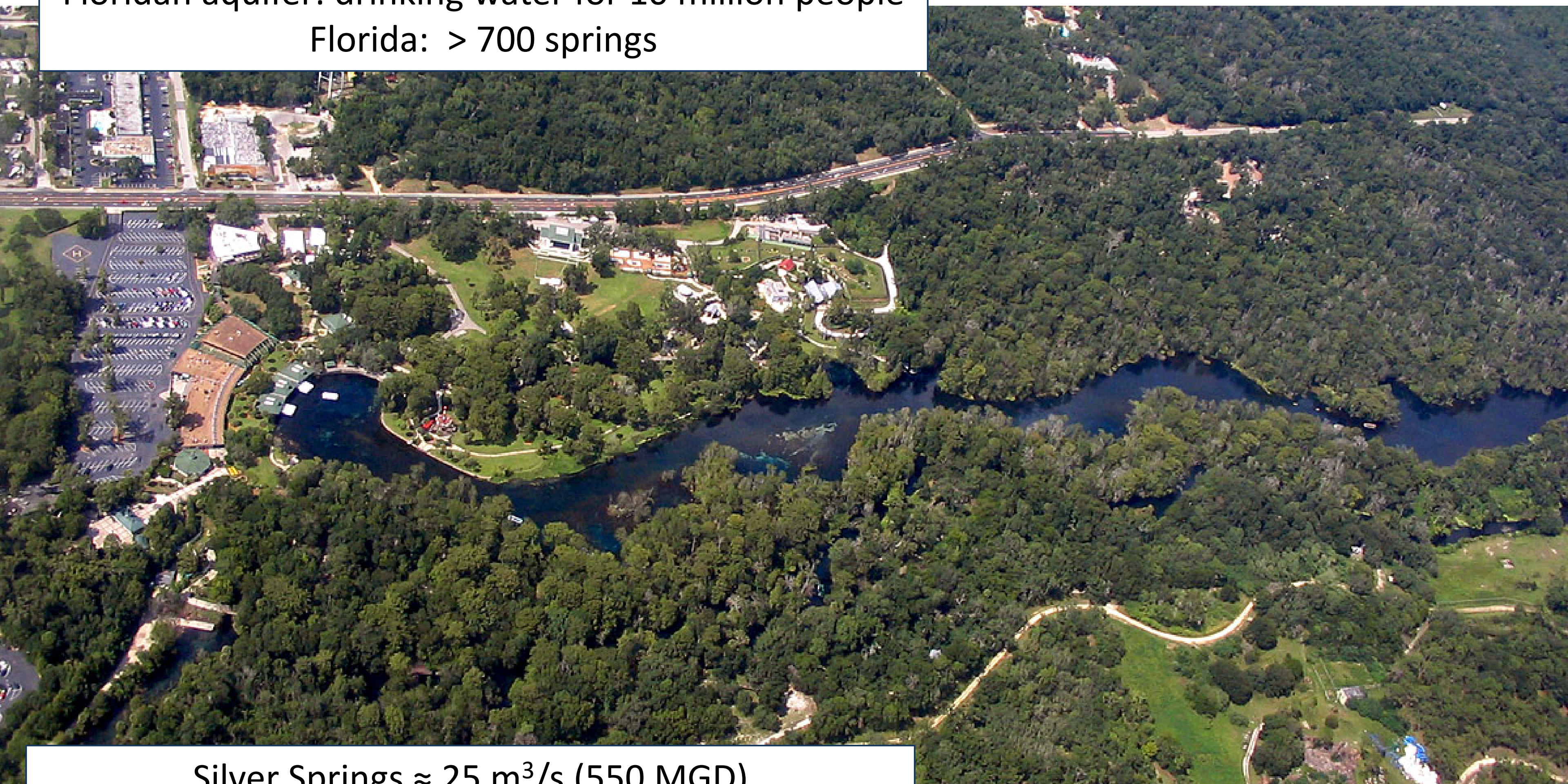


Silver Springs: First magnitude discharge

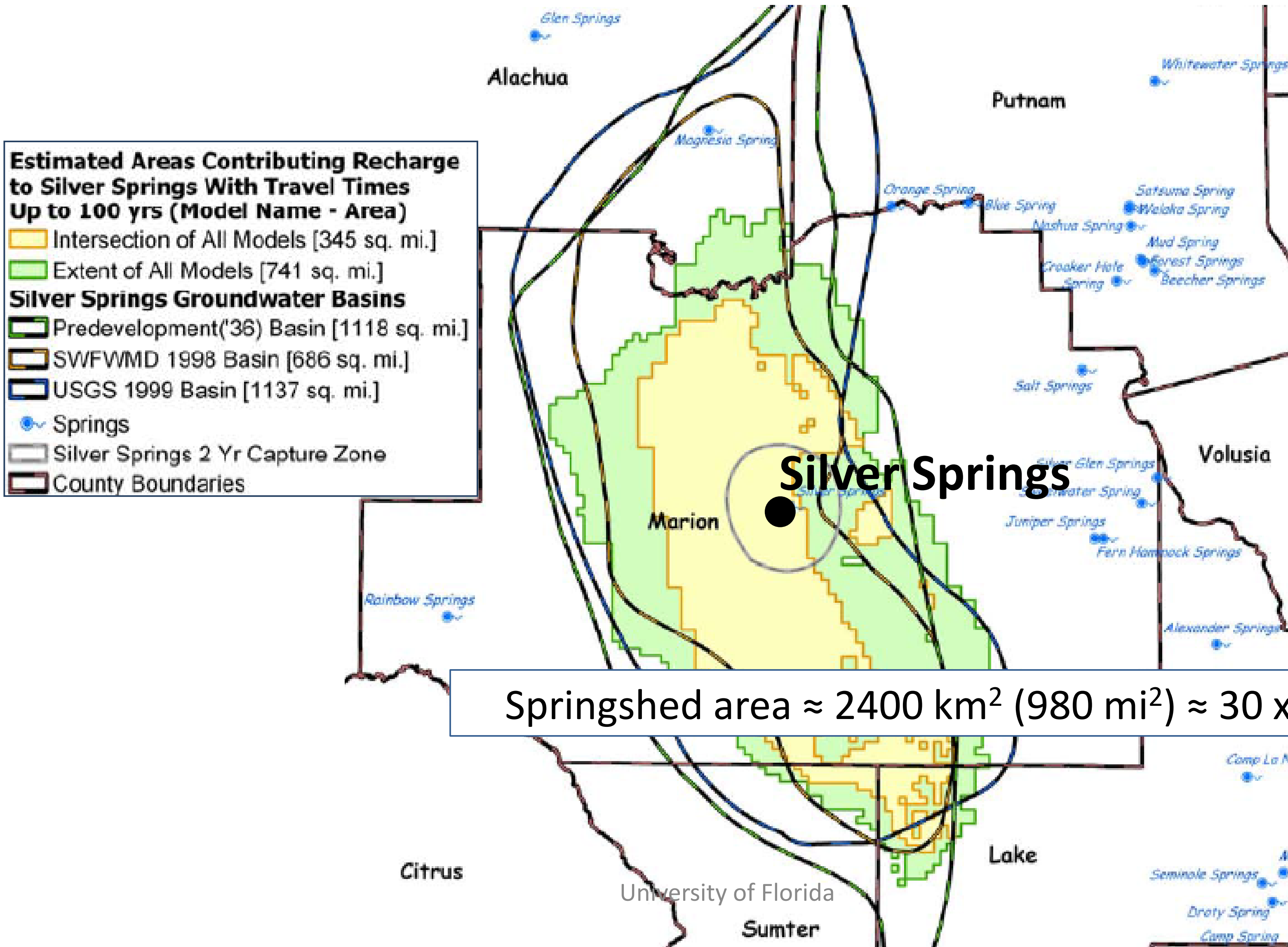
Floridan aquifer: drinking water for 10 million people
Florida: > 700 springs



Silver Springs ≈ 25 m^3/s (550 MGD)
"First magnitude" > 2.8 m^3/s (USA ~ 75, Florida ~25)

Springshed size + geometry

based on heads vs numerical porous media models



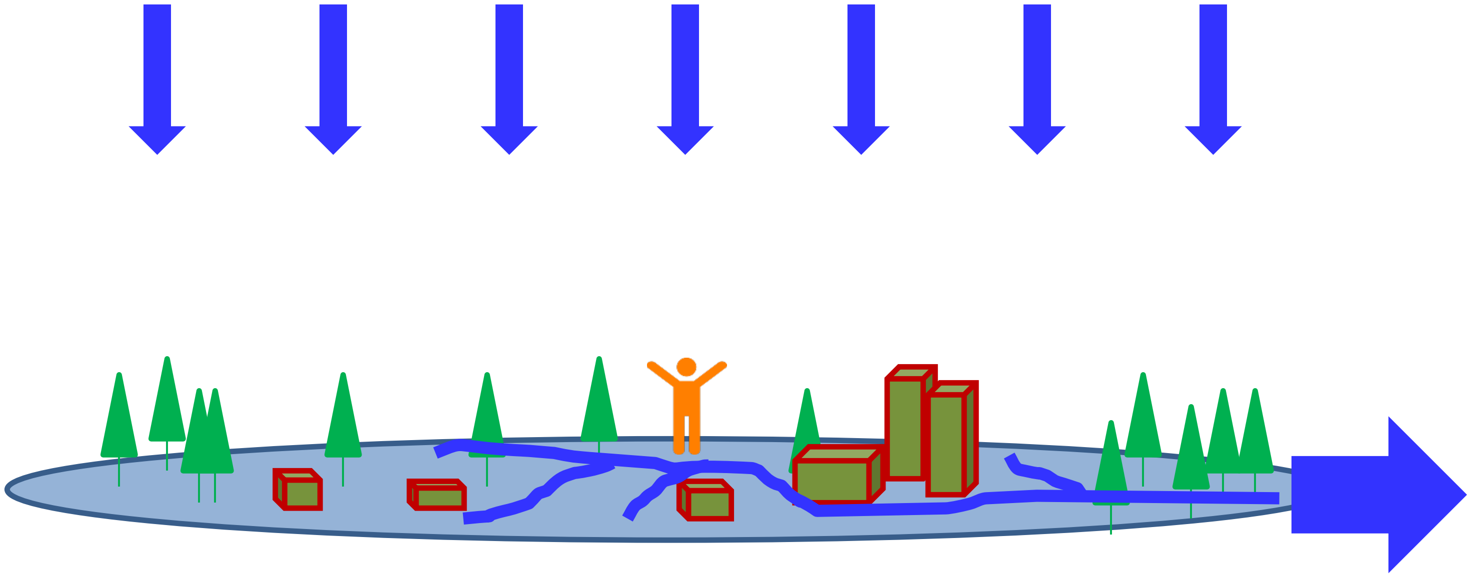
Springshed area ≈ 2400 km^2 (980 mi^2) ≈ 30 x 80 km

problem description

over several decades, discharge has been declining and nitrate concentrations rising

why? where? how?

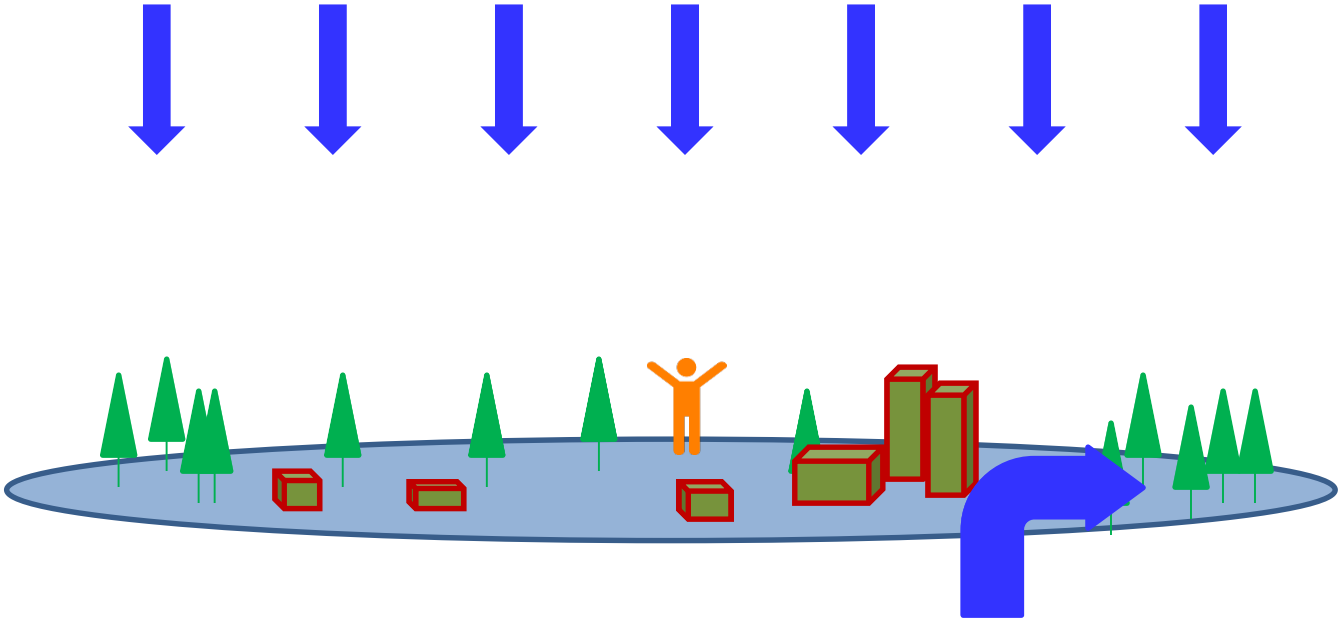
parsimonious models to assist resource managers

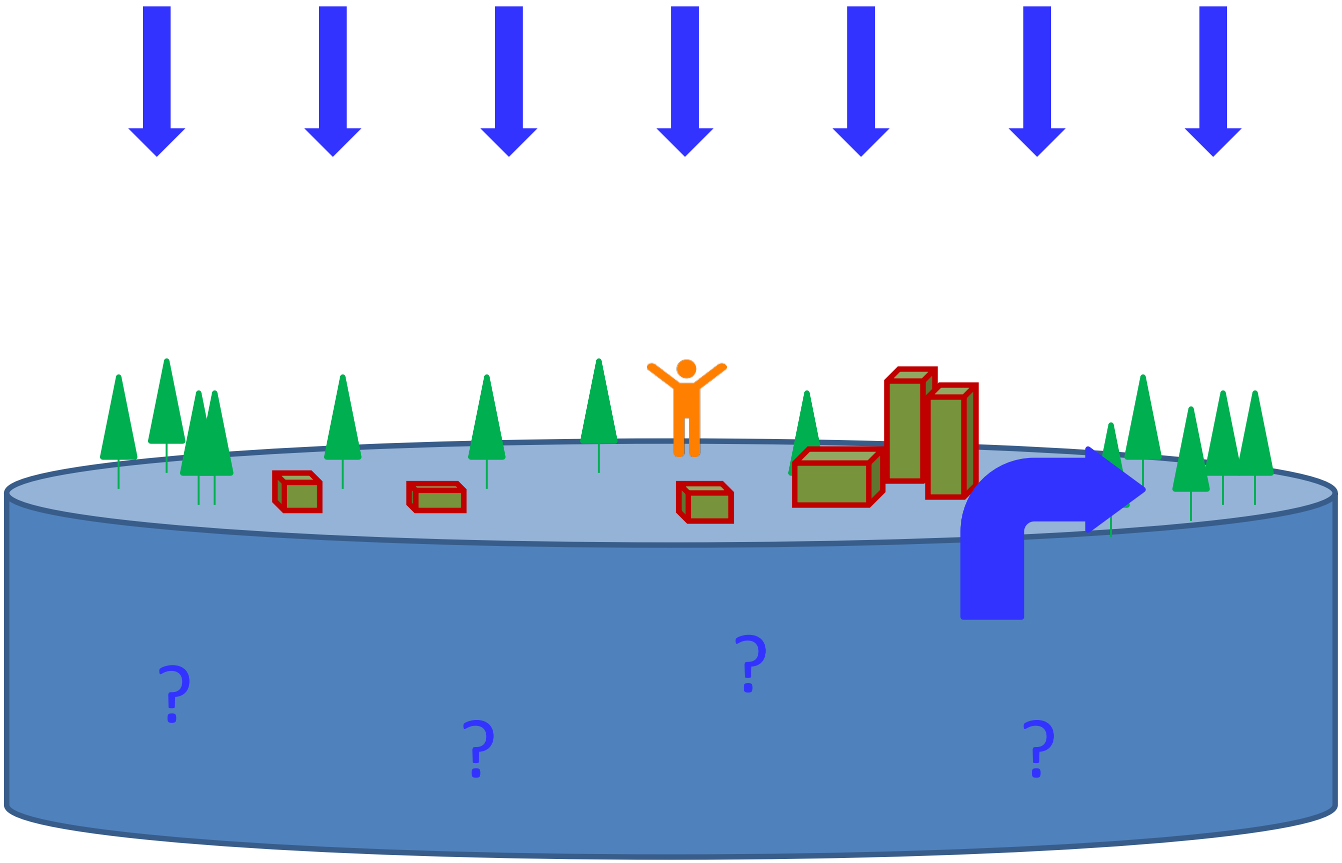


<u>A watershed</u>

"that area of land, a bounded hydrologic system, within which all living things are inextricably linked by their common water course and where, as humans settled, simple logic demanded that they become part of a community."

John Wesley Powell, 1890

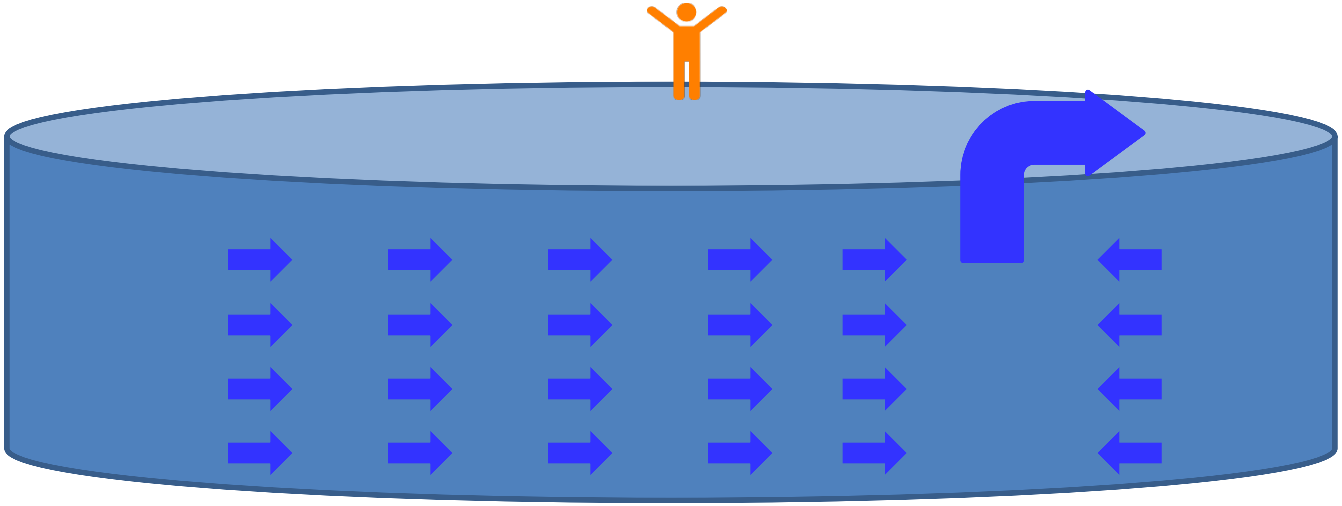


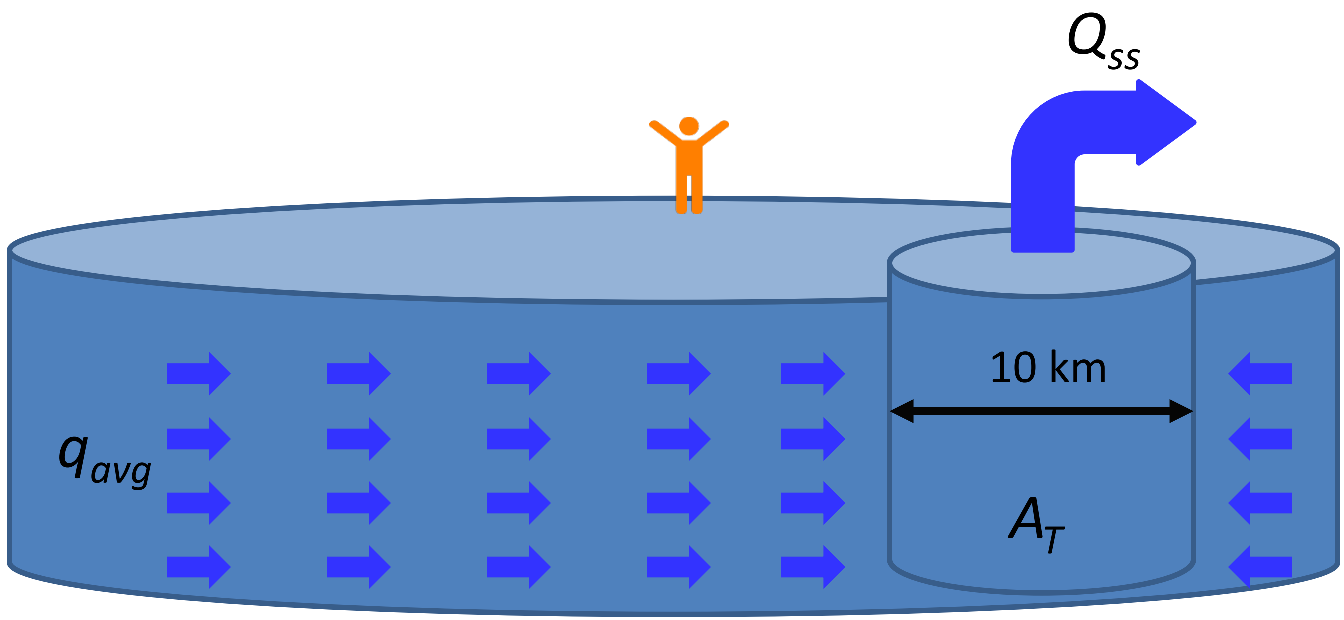


"In the case of a well sunk by a proprietor in his own land, the water which feeds it from a neighboring soil does not flow openly in the sight of the neighboring proprietor, but through the *hidden veins of the earth beneath its surface; no man can tell what changes these underground sources have undergone in the progress of time.*"

Acton v. Blundell

Texas case based on principles of English common law, 1843





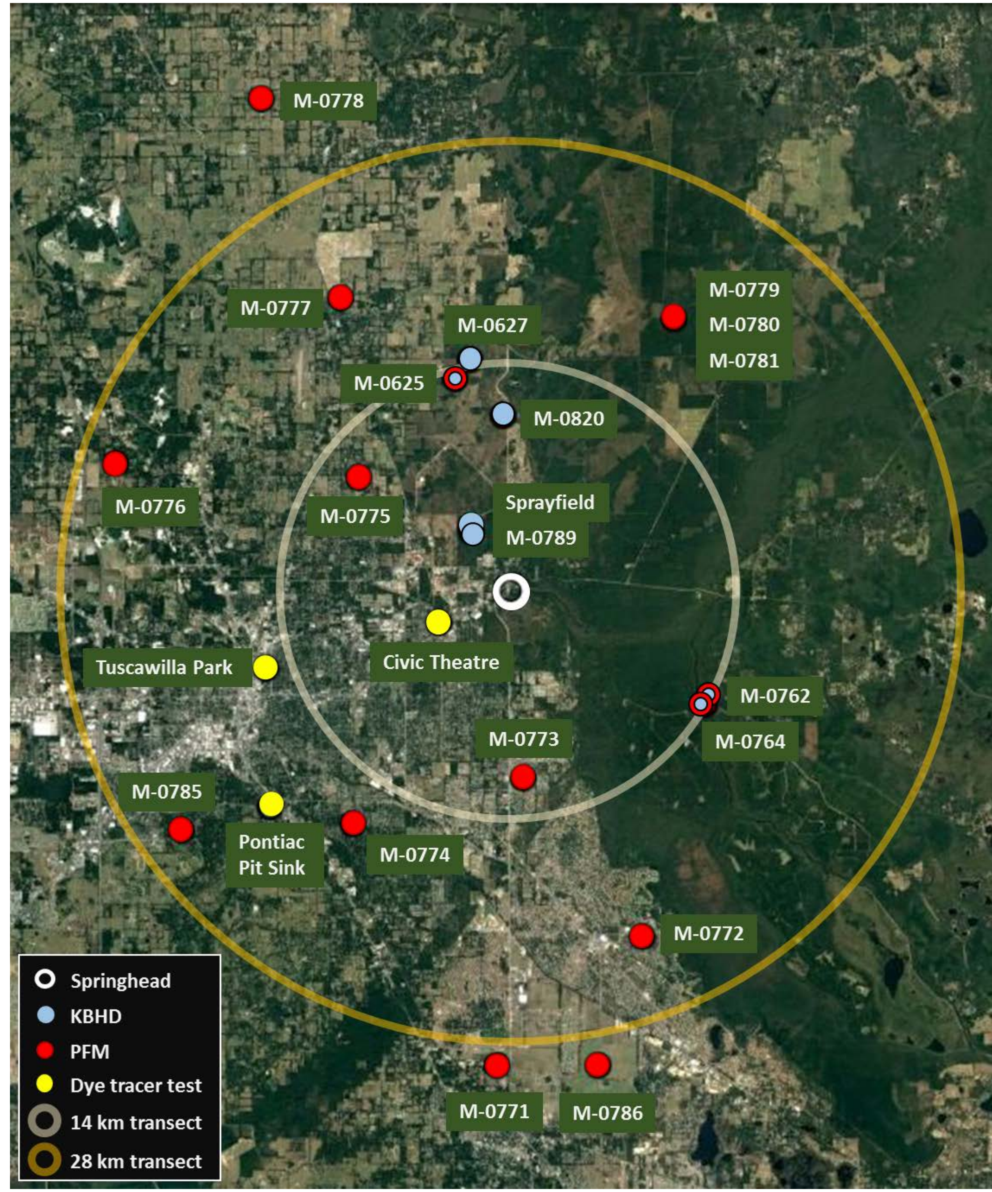
$Q_{ss} = q_{avg} A_T$

$A_T = (\pi d) h$

$q_{avg} = A_T / Q_{ss}$

	10-km transect	**20-km transect**
Spring flow	20 m^3/s	20 m^3/s
Depth	50 m	50 m
Perimeter	31 km	63 km
q_{avg}	**1.1 m/d**	**0.55 m/d**

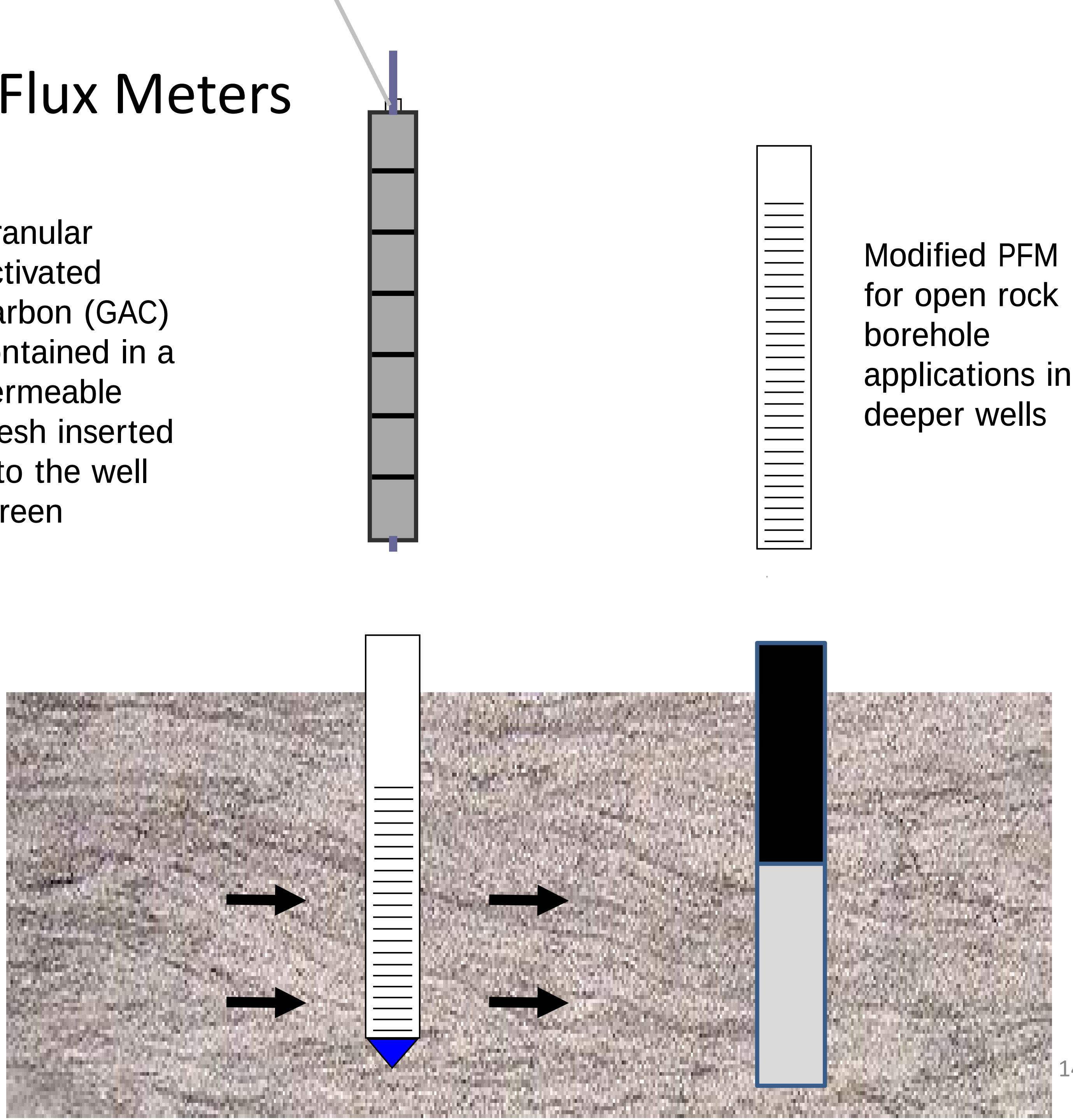
Method	PFM (16 wells)	KBHD (7 wells)	DTT (3 sites) Introduction location
	M-0625 (3)	M-0625 (2)	Civic Theatre Drainage Retention Area (8)
	M-0762 (3)	M-0627 (1)	Tuscawilla Park Stormwater Drainage well (1)
	M-0764 (3)	M-0762 (2)	Pontiac Pit Sink (3)
	M-0771 (3)	M-0764 (1)	
	M-0772 (3)	M-0789 (6)	
	M-0773 (3)	M-0820 (4)	
	M-0774 (3)	Sprayfield (5)	
	M-0775 (3)		
	M-0776 (3)		
	M-0777 (3)		
	M-0778 (3)		
	M-0780 (3)		
	M-0781 (3)		
	M-0785 (3)		
	M-0786 (3)		
	M-0787 (3)		
Total	48	21	12

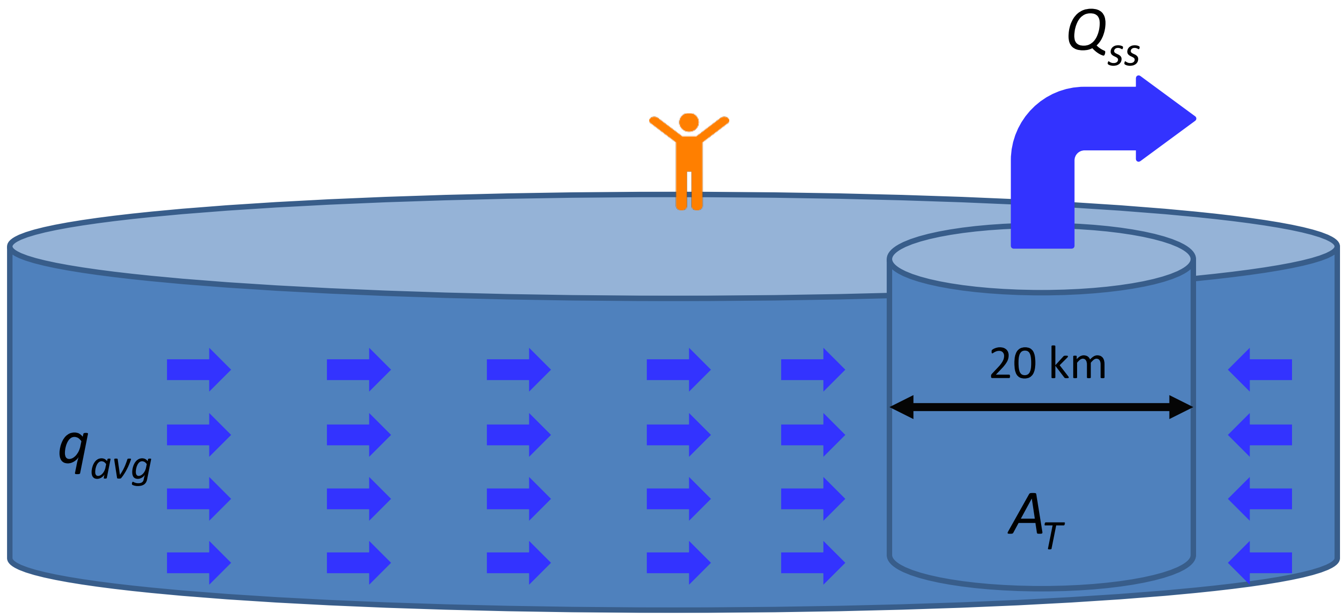


Passive Flux Meters

Granular Activated Carbon (GAC) contained in a permeable mesh inserted into the well screen

Modified PFM for open rock borehole applications in deeper wells





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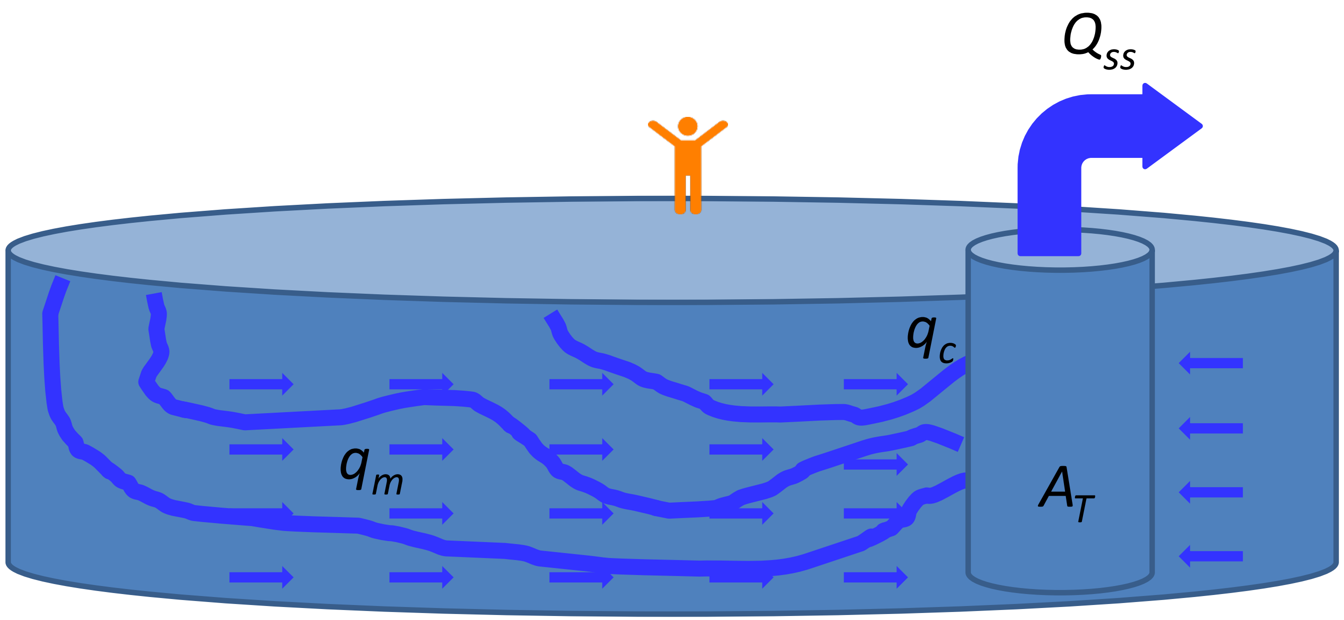
q_{avg}	**1.1 m/d**	**0.55 m/d**

$$Q_{ss} = q_{avg} A_T$$
$$A_T = (\pi d) h$$
$$q_{avg} = A_T / Q_{ss}$$

PFMs (n=16 wells)

0.06 ± 0.02 m/d

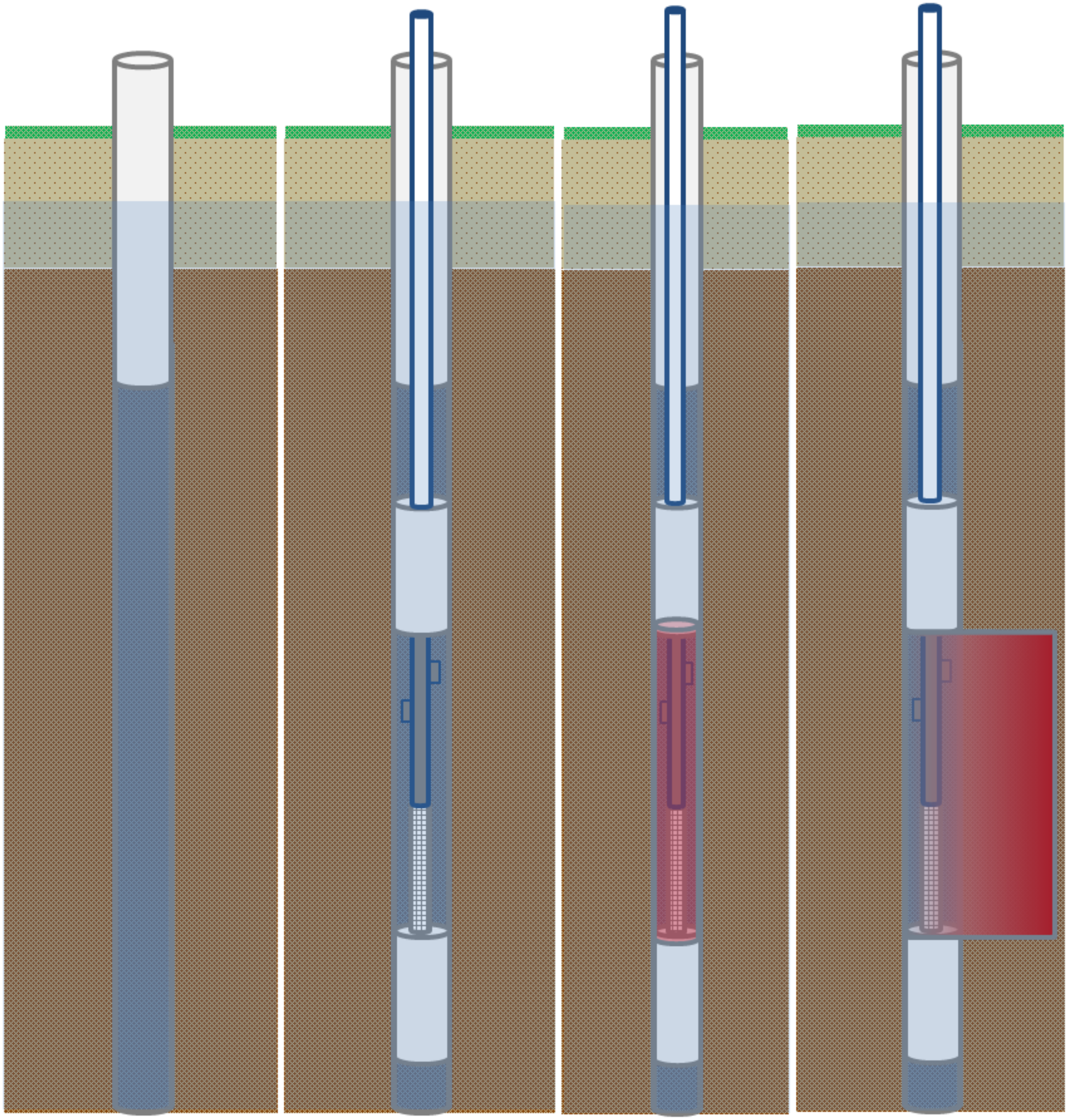


$Q_{ss} = q_{avg}A_T$
$Q_{ss} = Q_m + Q_c$
$Q_{ss} = q_m A_m + q_c A_c$
$A_T = A_m + A_c$

$\underline{\underline{A_c/A_T = (q_{avg} - q_m)/(q_c - q_m)}}$

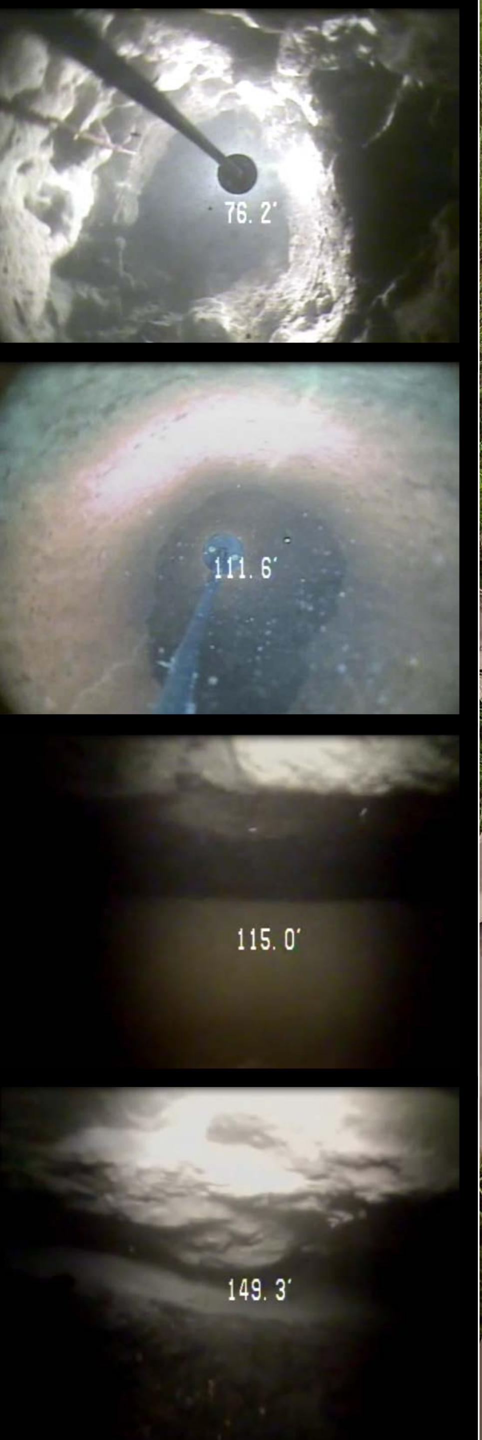
	10-km transect	20-km transect
q_{avg}	1.1 m/d	0.55 m/d
q_m	??	??
q_c	??	??
A_c/A_T		
Q_c/Q_{ss}		

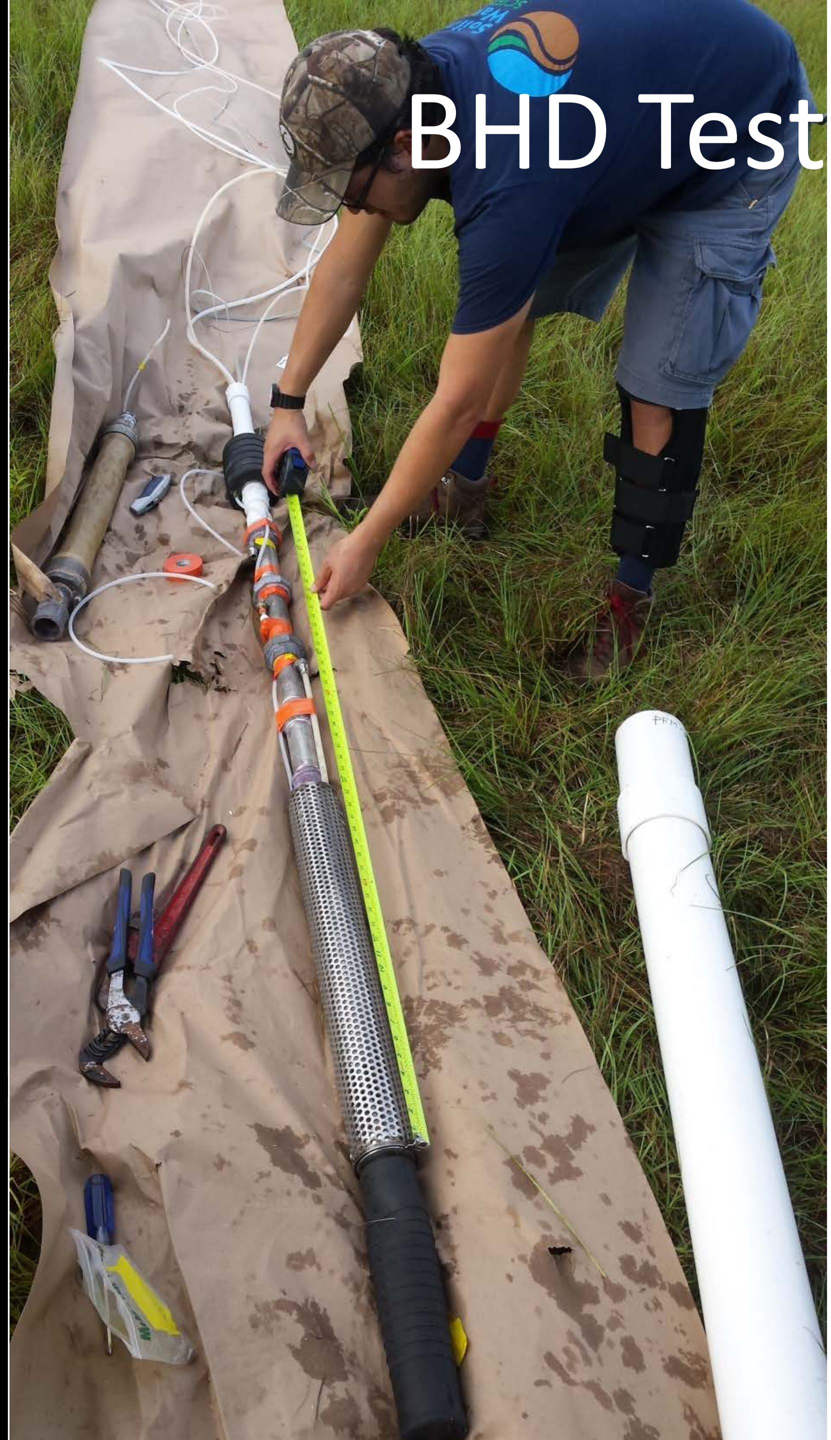
Borehole dilution concept



BHD test measures the rate at which a **pulse** of tracer is **diluted** in an **isolated** section of the borehole.

Dilution is attributed to horizontal water velocity





BHD Test Procedure

- Identify areas of interest
- Assemble KBHD device
- Deploy to target depth

M0789 - 122 ft

https://www.youtube.com/watch?v=eQlfhUgzJ7g

M0625


KBHD ready for deployment in well M-789 (4”) setup for 3 m testing interval)


KBHD inside M-0625 (6”) setup for 1.8 m testing interval

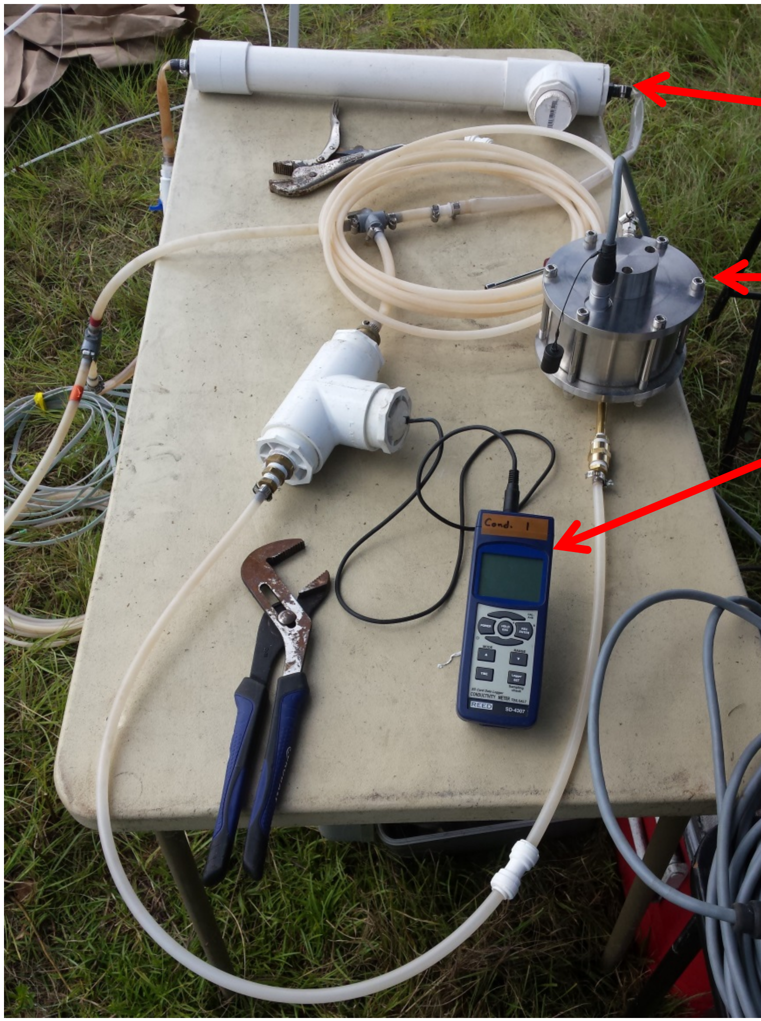
KBHD inside M-0625 placement at 111-117 ft

KBHD inside Sprayfield well (4"), deployed in 83-88 ft. interval

BHD Test Procedure

- Purge well
- Inflate packers
- Release KCl + Rhodamine pulse
- Start recirculation
- Monitor electrical conductivity and flourescence
- Purge well back to background conductivity levels

BHD Test Procedure

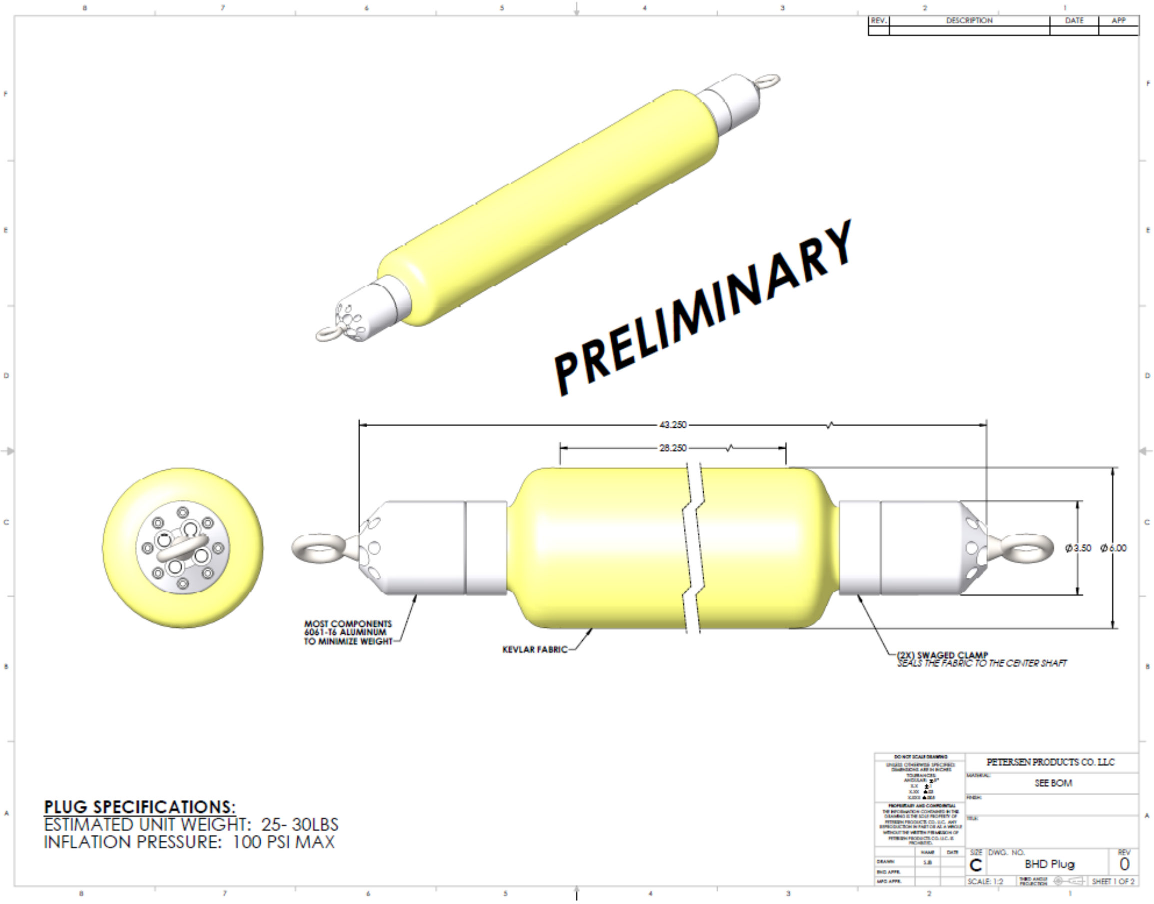


Pulse reservoir (KCl + Rhodamine solution)

Flourometer

Conductivity meter


PIPET BULBS
MAGNETIC STIRBAR
SYRINGES
FILTERS



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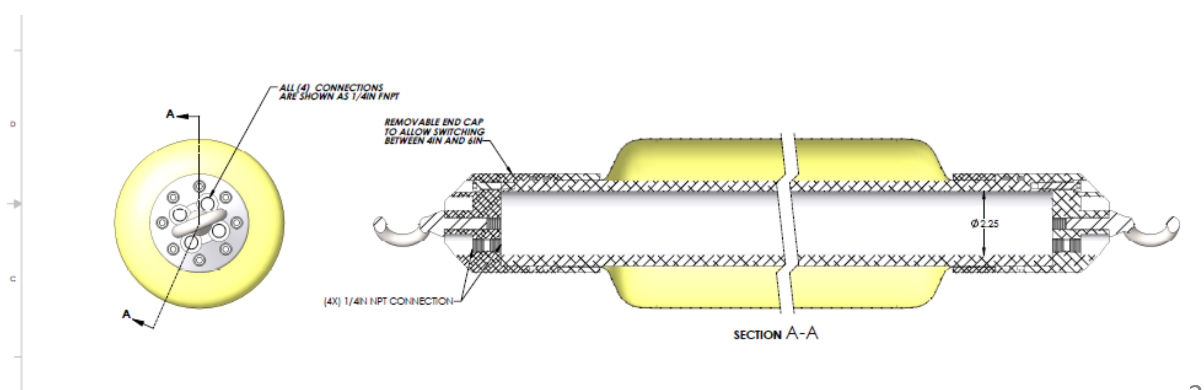
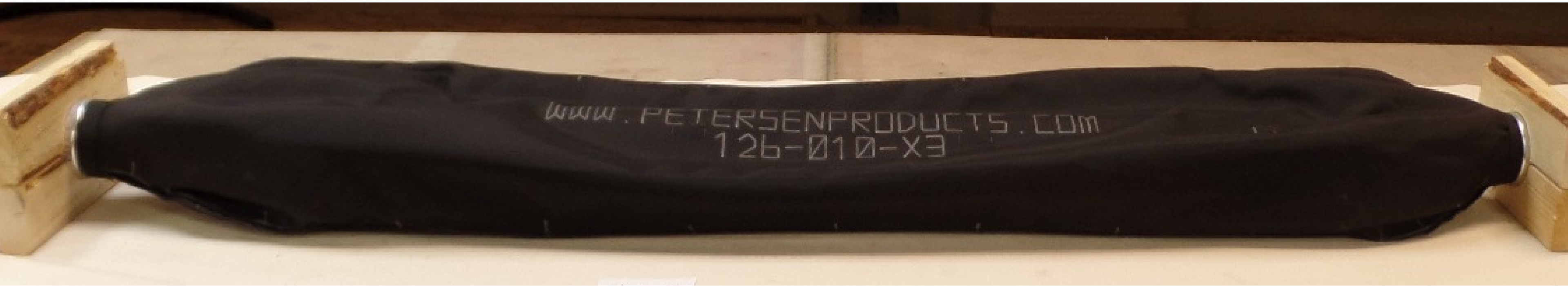


ALL (4) CONNECTIONS ARE SHOWN AS 1/4IN FNPT
REMOVABLE END CAP TO ALLOW SWITCHING BETWEEN 4IN AND 6IN
Ø2.25
(4X) 1/4IN NPT CONNECTION
SECTION A-A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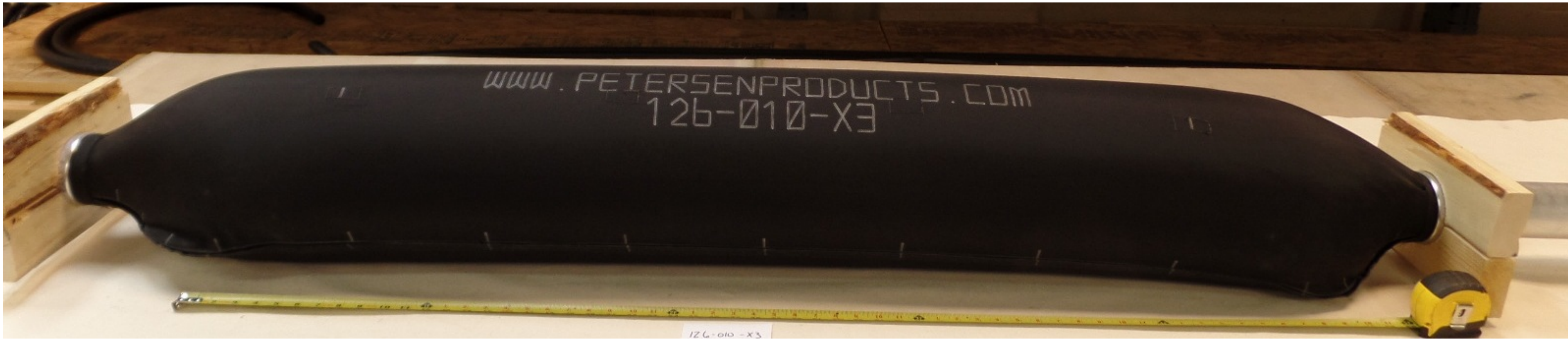
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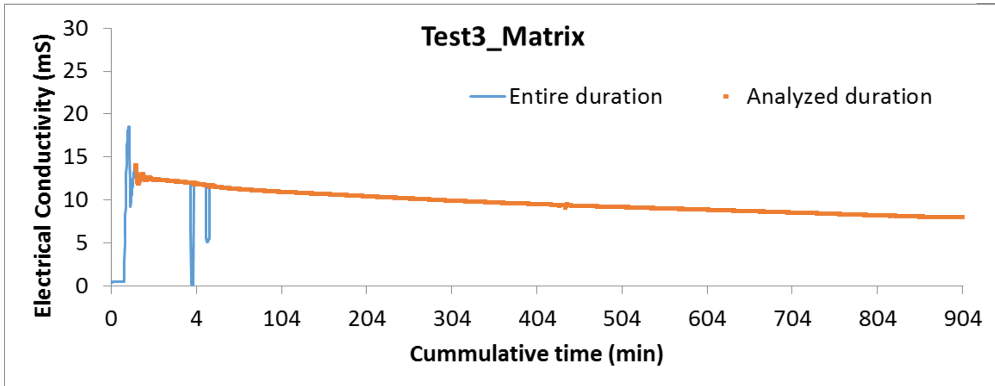
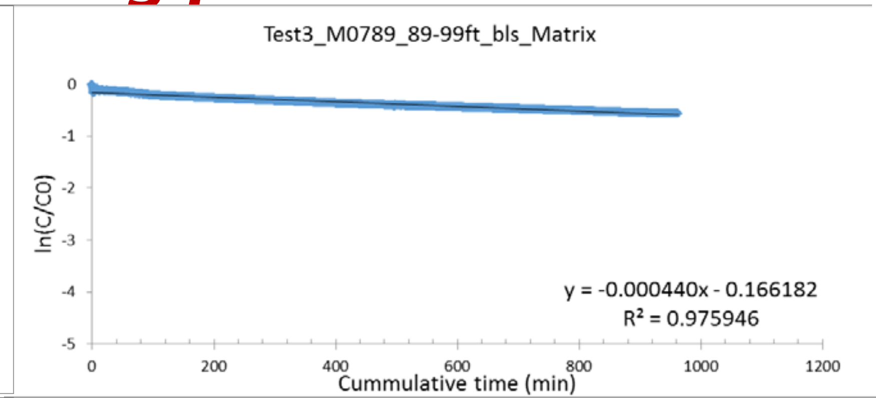
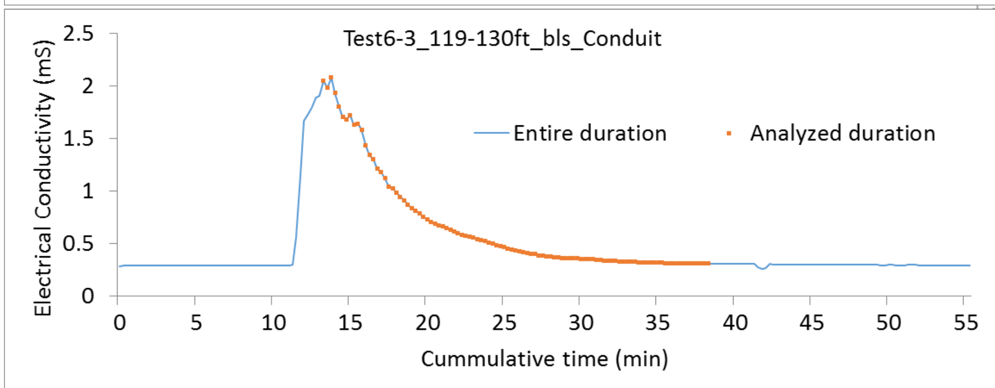
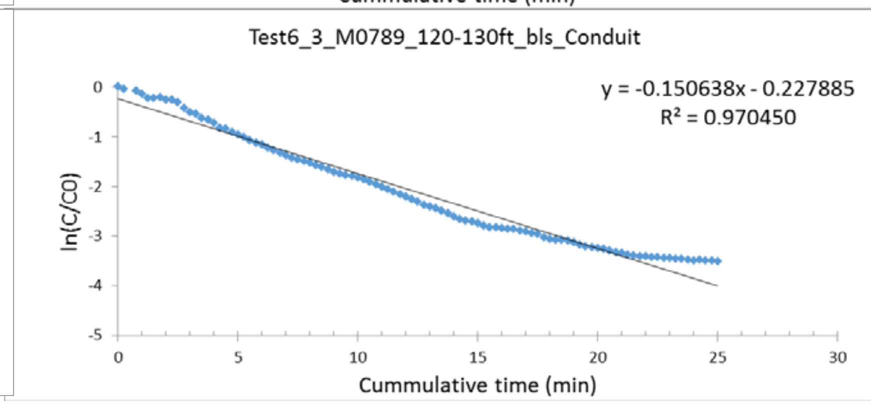
matrix vs conduit

variable monitoring periods









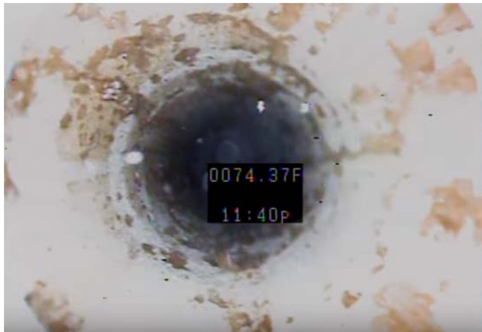
Two tests performed on M0789, at different target depths

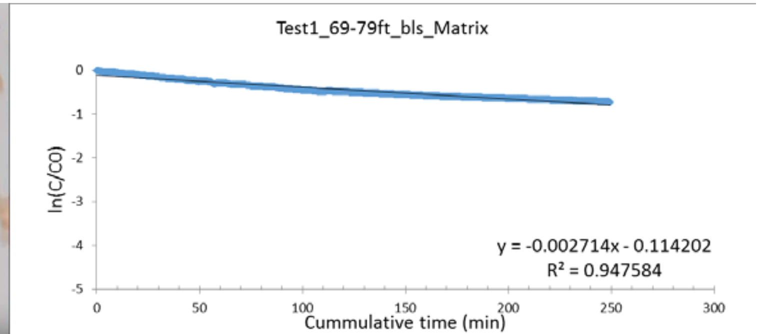
- Test 3: 16 hours
- Test 6-3: 25 minutes

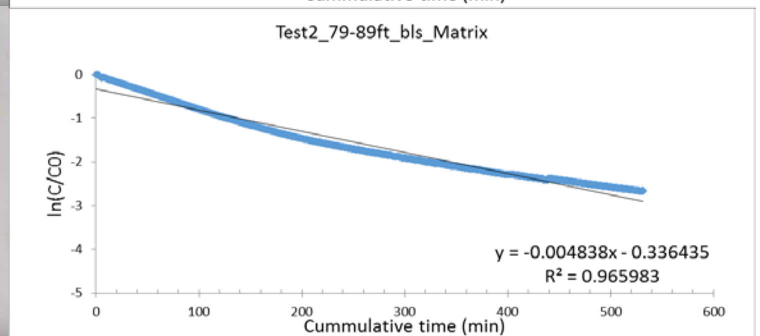
Test 3 never reached background: final conductivity ~8mS

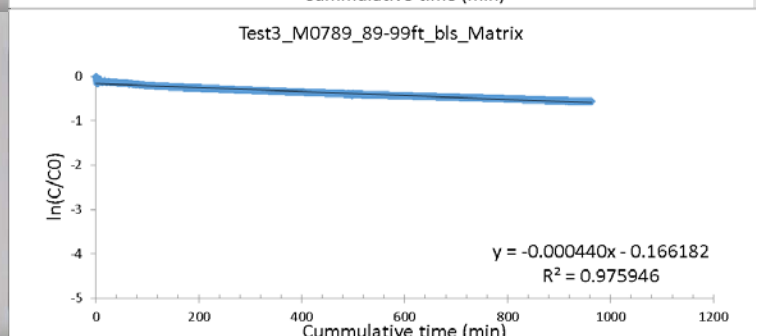
Well M789

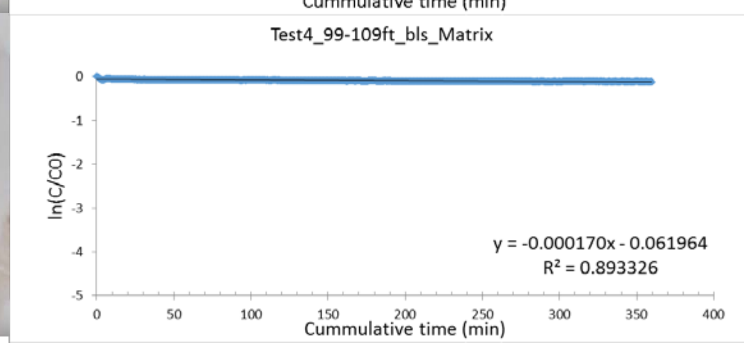
- Video logs vital for identifying potential test depths



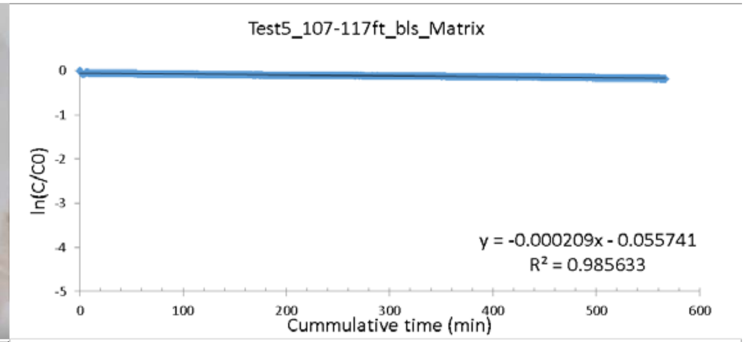


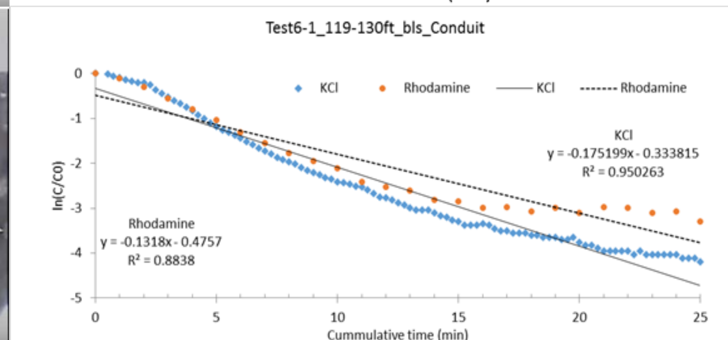


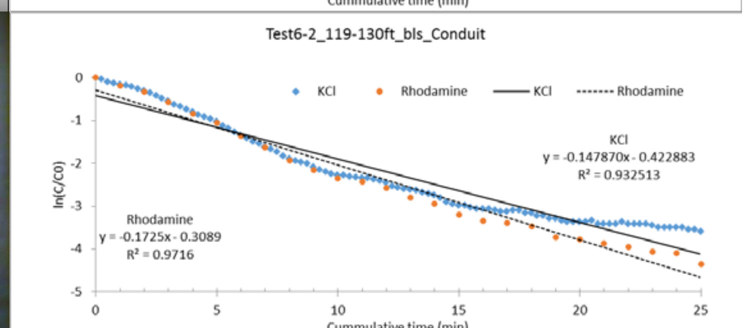


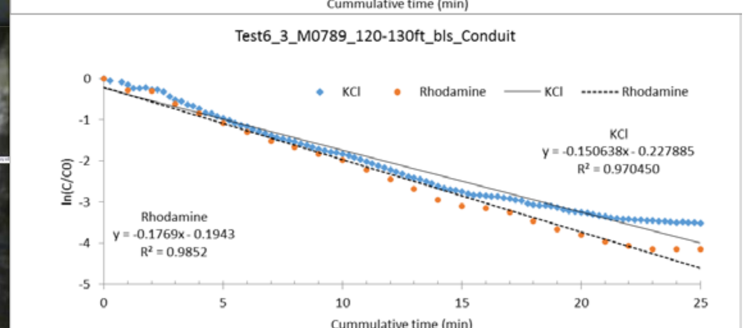


Well M789

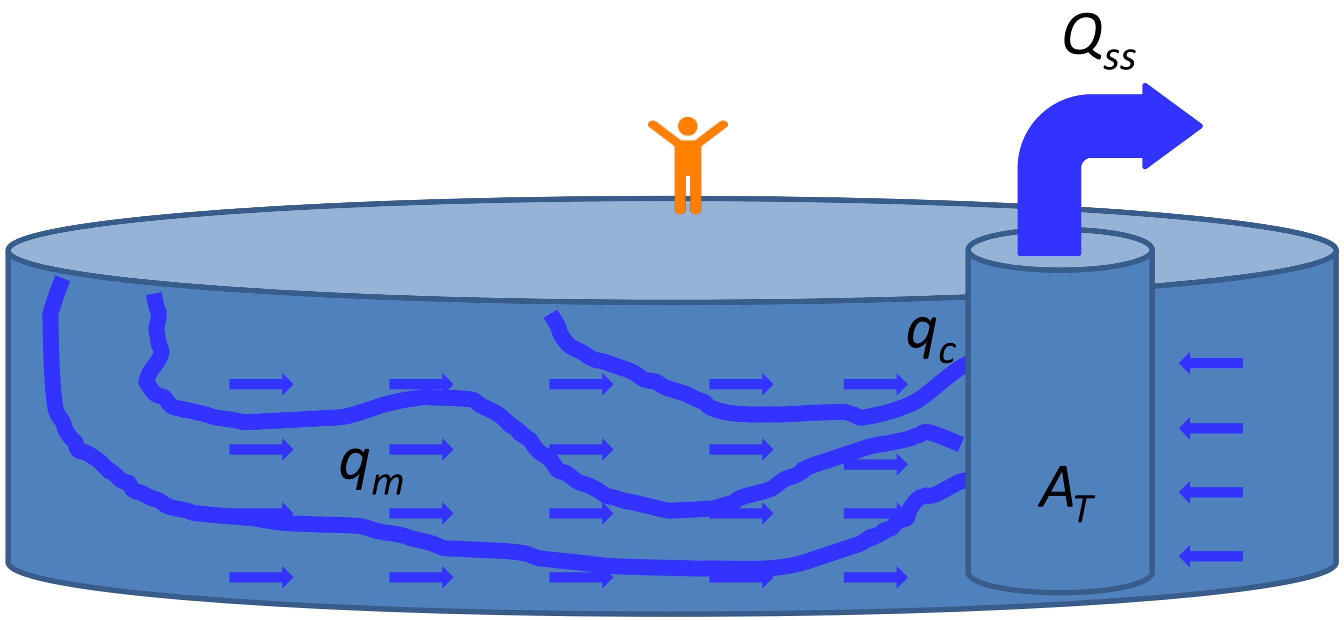








Test Number	Depth (ft bls)	KCl q(cm/day)	Rhodamine q (cm/day)
1	69-79	16.0	
2	79-89	28.4	
3	89-99	2.6	
4	99-109	1.0	
5	107-117	1.2	
6-1	120-130	1030.2	775.0
6-2	120-130	869.5	1014.3
6-3	120-130	885.8	1040.2



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$Q_{ss} = Q_m + Q_c$

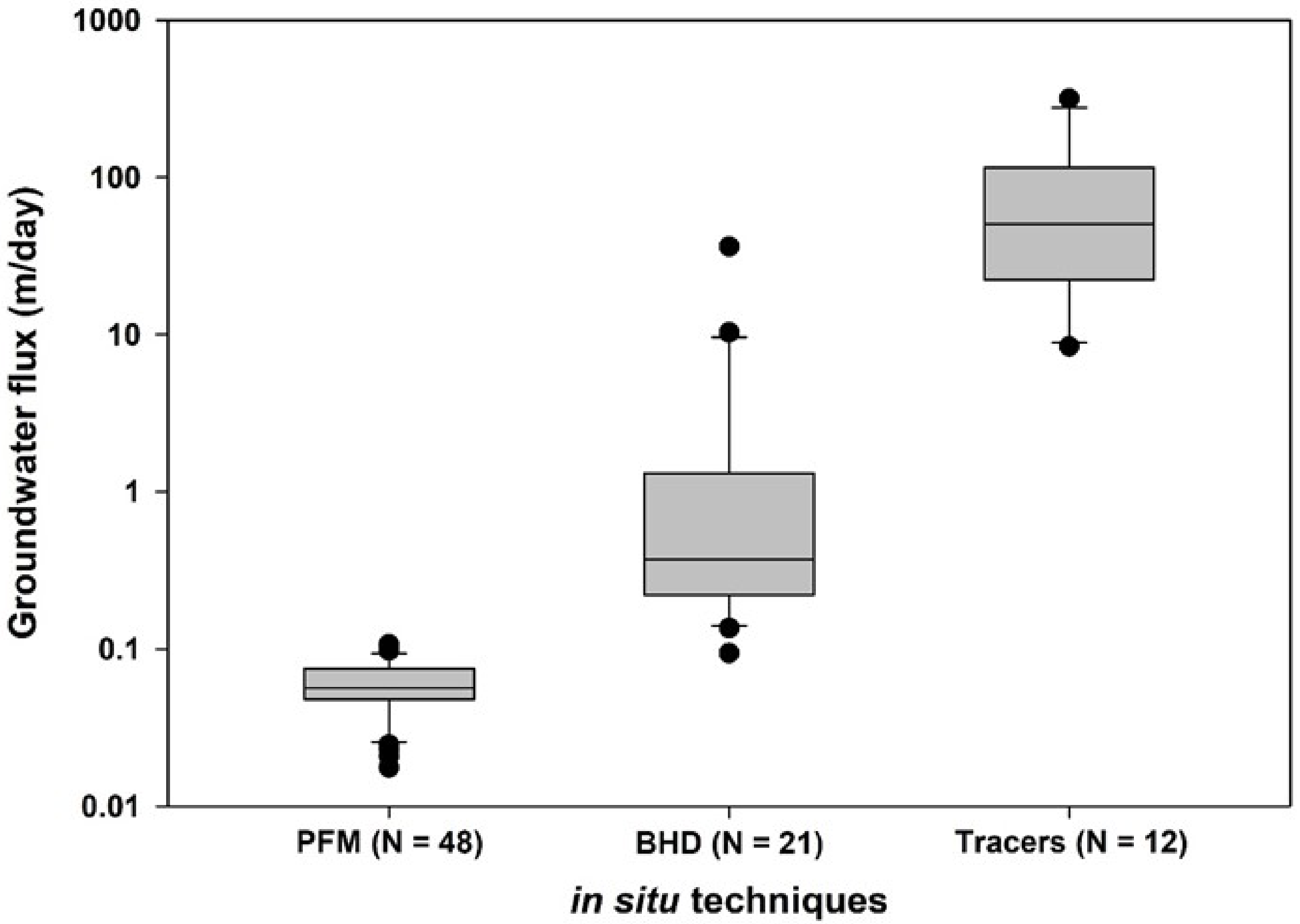
$Q_{ss} = q_m A_m + q_c A_c$

$A_T = A_m + A_c$

$A_c/A_T = (q_{avg} - q_m)/(q_c - q_m)$

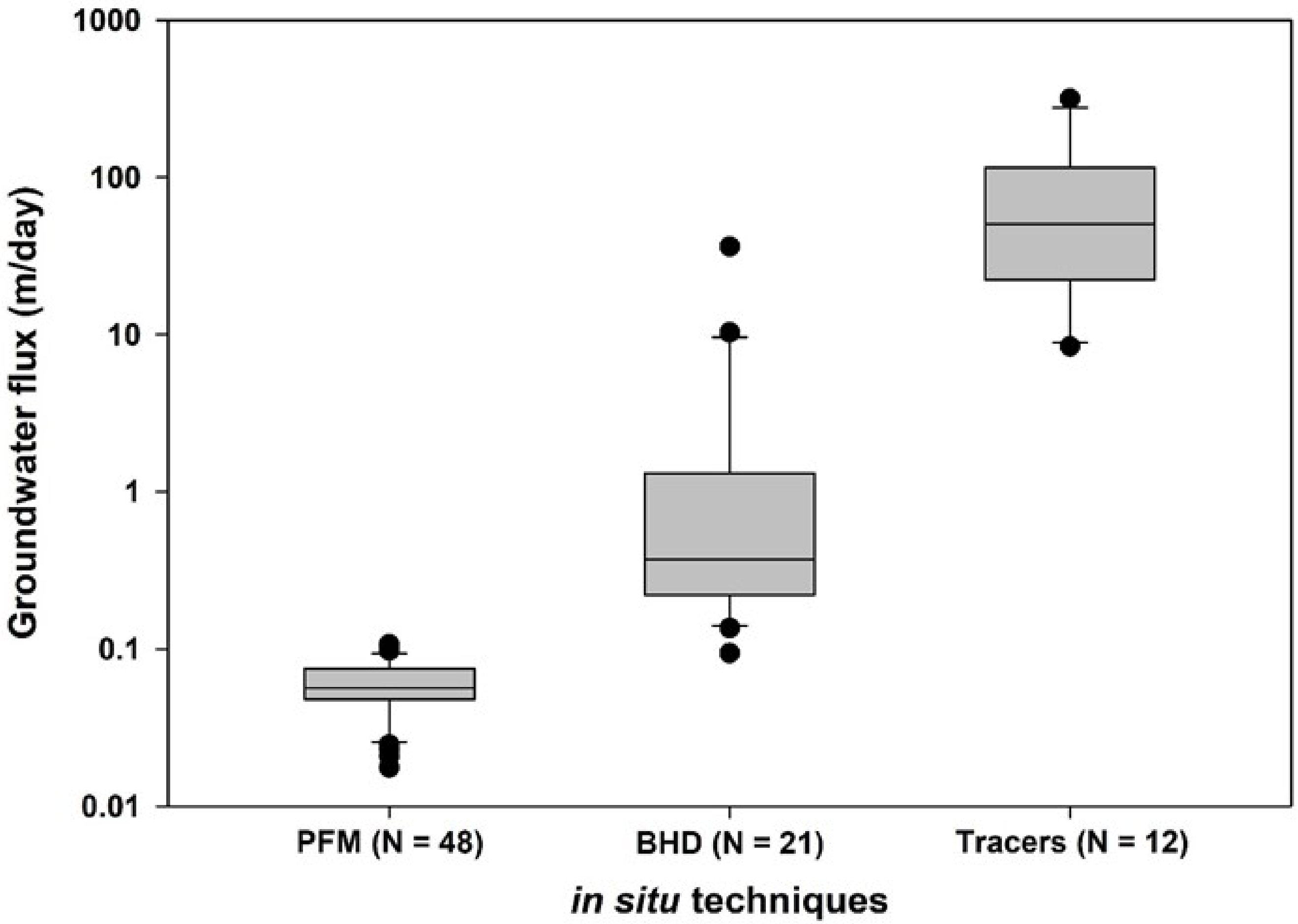
	10-km transect	**20-km transect**
q_{avg}	1.1 m/d	0.55 m/d
q_m	0.06 m/d	0.06 m/d
q_c	??	??
A_c/A_T		
Q_c/Q_{ss}		

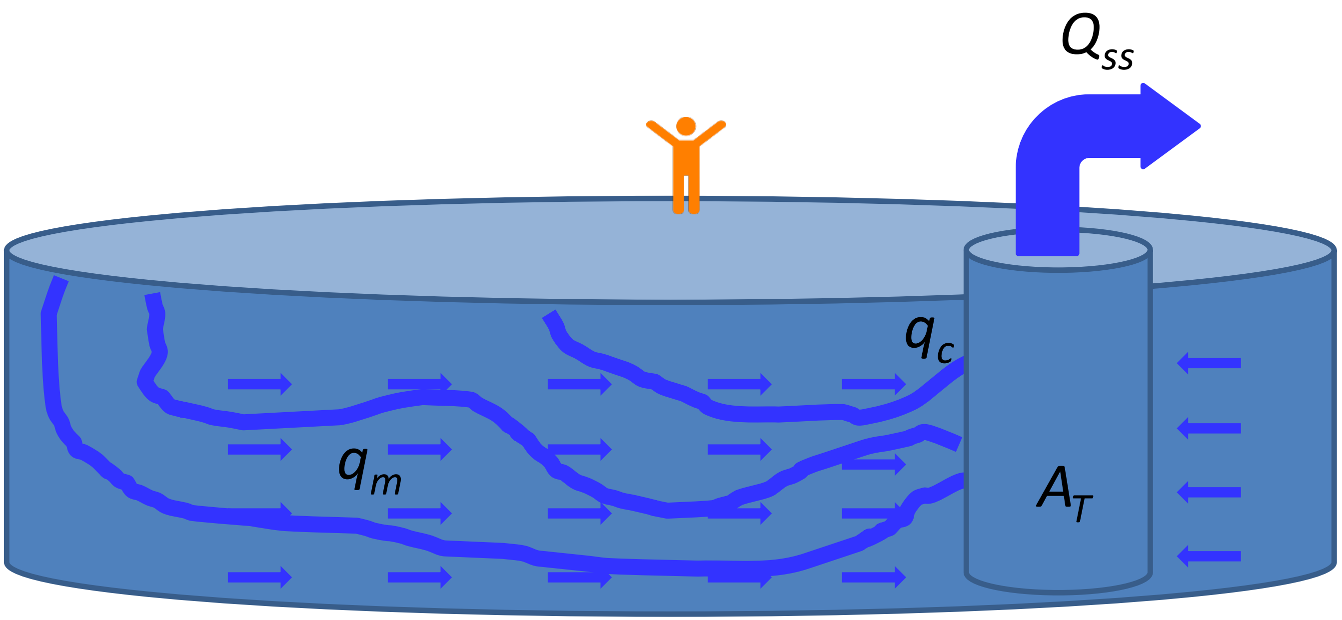
Matrix < 0.1 m/day < Conduit



Matrix < 0.1 m/day < Conduit

	Matrix	Conduit
Average velocity (m/day)	**0.06**	**30.08**





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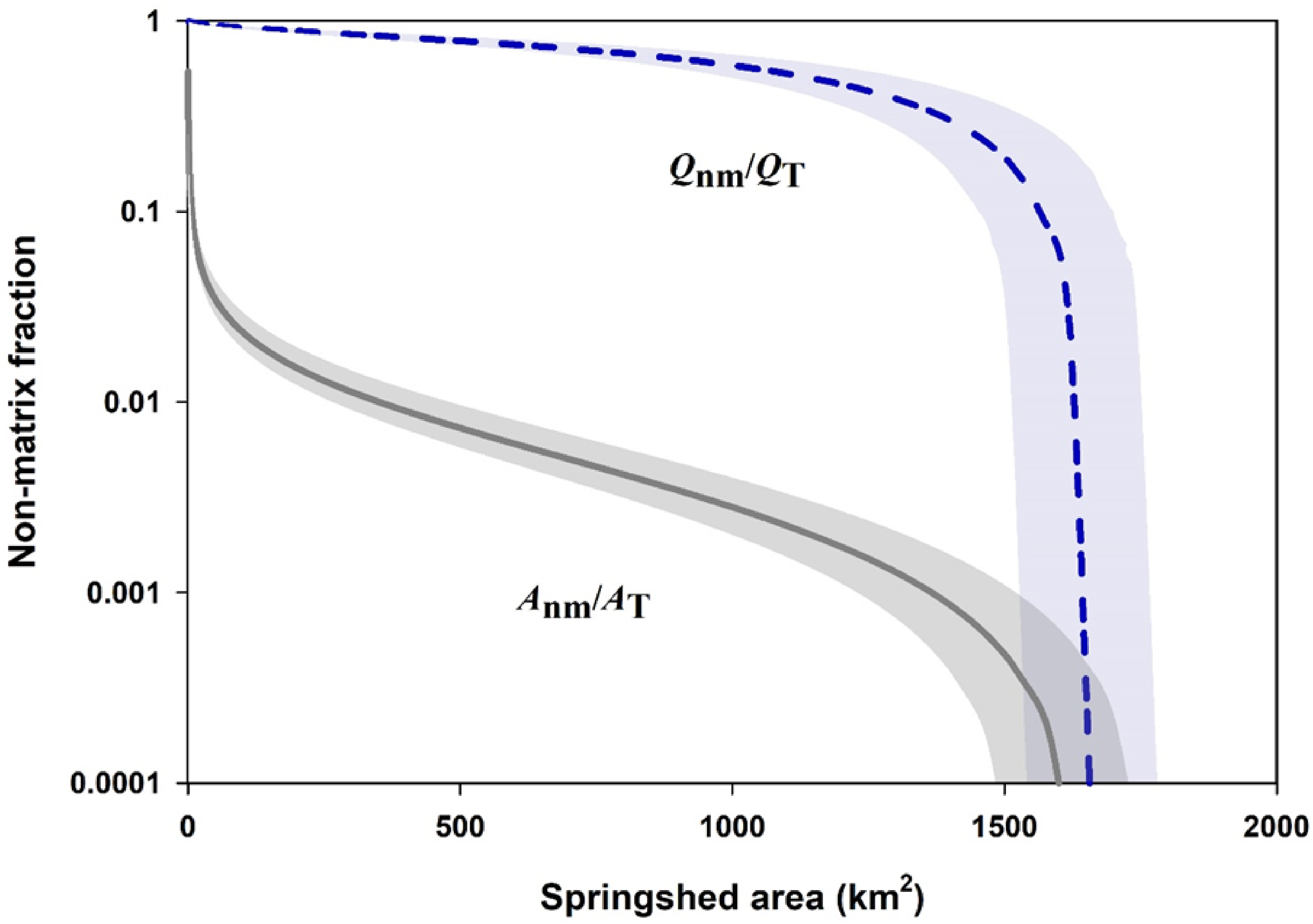
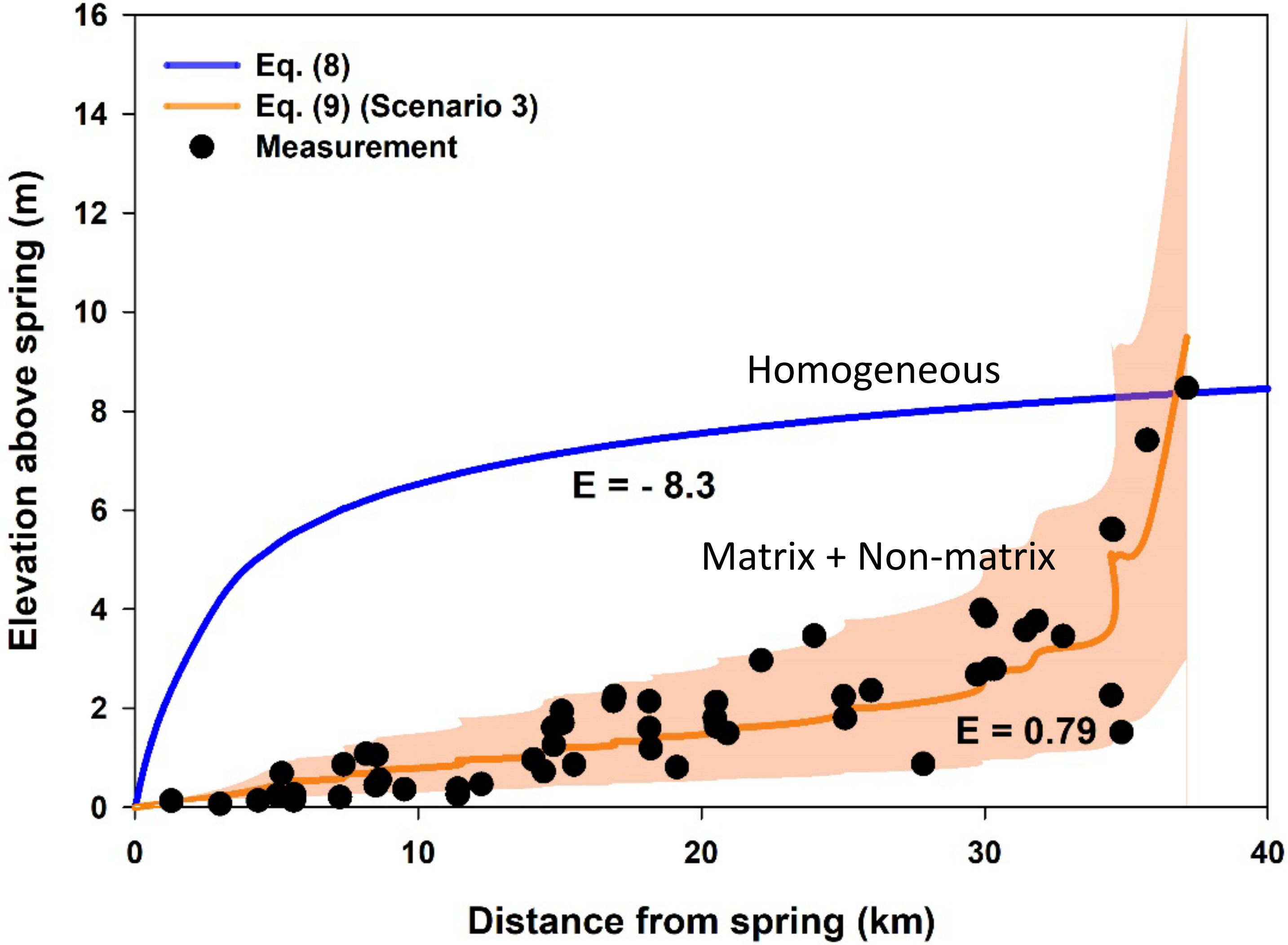
$Q_{ss} = q_mA_m + q_cA_c$
$A_T = A_m + A_c$

$A_c/A_T = (q_{avg} - q_m)/(q_c - q_m)$

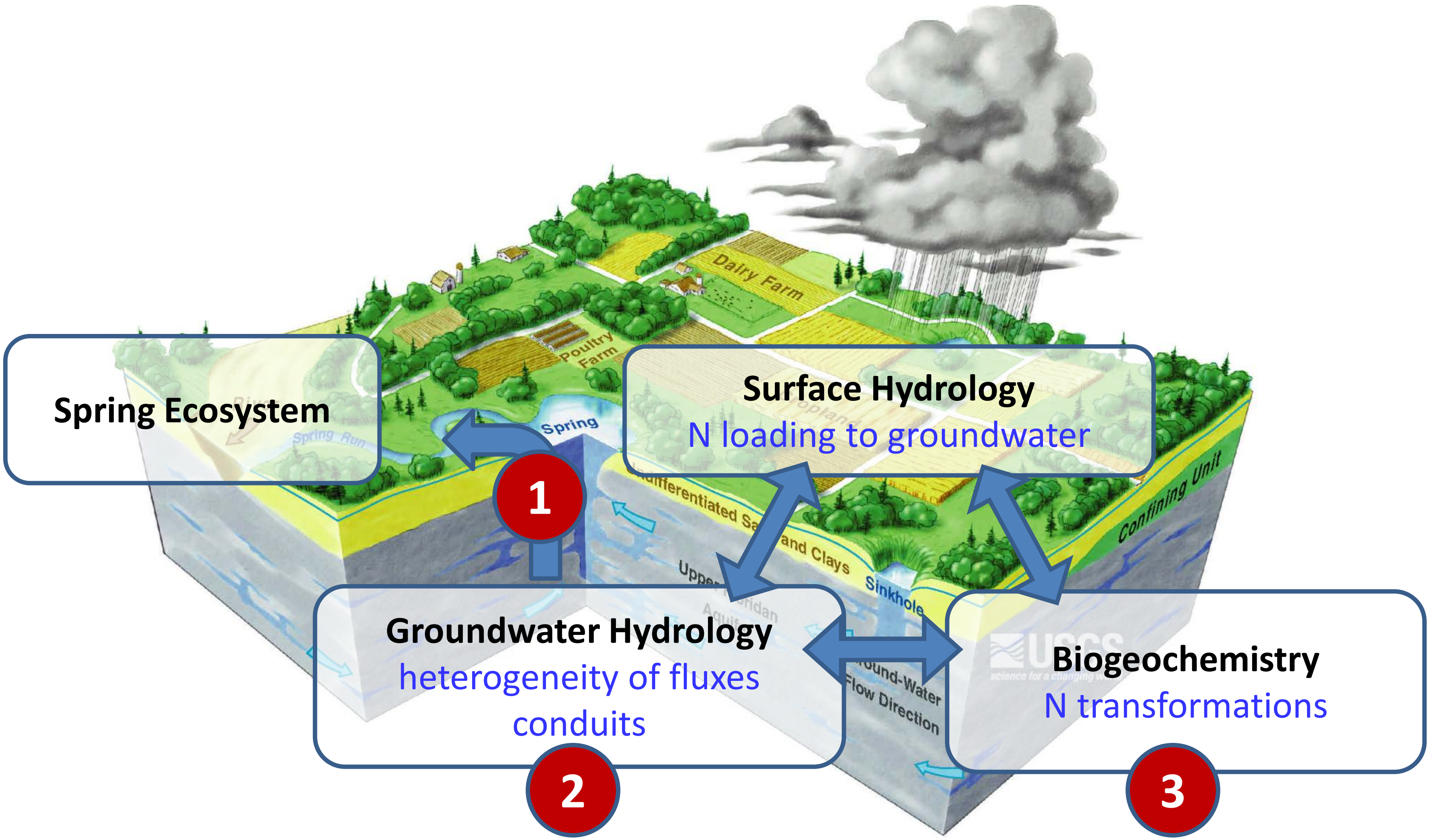
	10-km transect	20-km transect
q_{avg}	1.1 m/d	0.55 m/d
q_m	0.06 m/d	0.06 m/d
q_c	30 m/d	30 m/d
A_c/A_T	0.03	0.016
Q_c/Q_{ss}	0.95	0.89



For q_m = 0.06 m/d
q_c = 30 m/d



For q_m = 0.06 m/d
q_c = 30 m/d


Spring Ecosystem
Surface Hydrology
N loading to groundwater
Groundwater Hydrology
heterogeneity of fluxes
conduits
Biogeochemistry
N transformations
1
2
3
Dairy Farm
Poultry Farm
Spring
Spring Run
Sinkhole
Confining Unit
and Clays
Ground-Water
Flow Direction

in conclusion

- in situ measurements of groundwater fluxes
  - Passive Flux Meters – mostly rock matrix ~ 0.06 m/d
  - Borehole Dilution Tests – mostly conduits ~ 1 m/d
  - Dye Tracer Tests – only conduits > 10 m/d
- spring flow is almost all from fast-moving conduits
  - conduits represent a tiny fraction of the aquifer volume
  - groundwater storage is almost all in slow-flowing rock matrix

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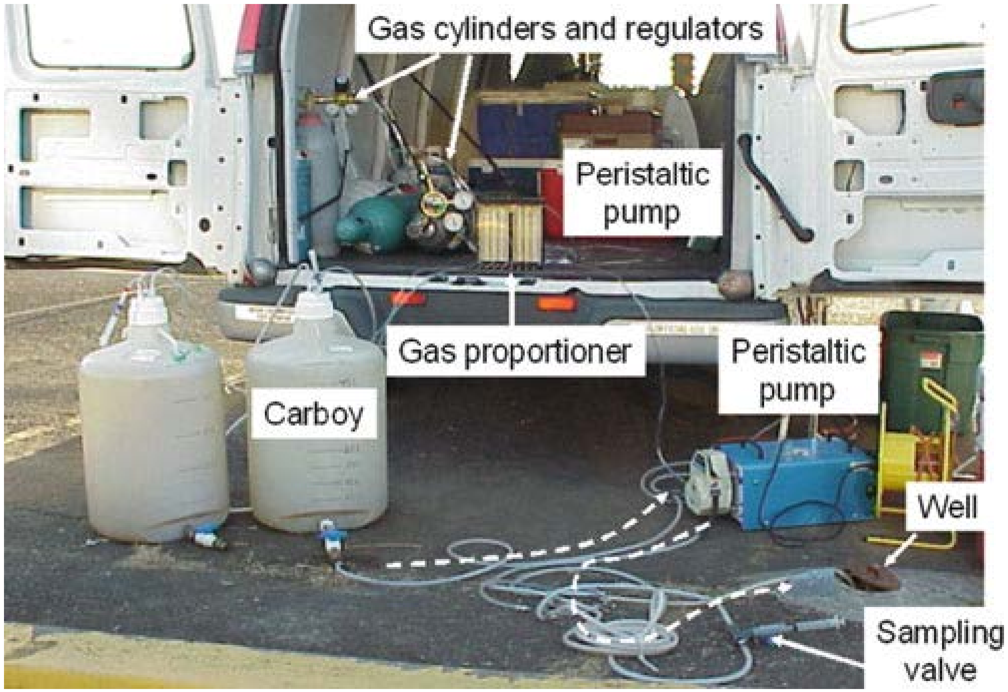
Push-Pull Test implementation

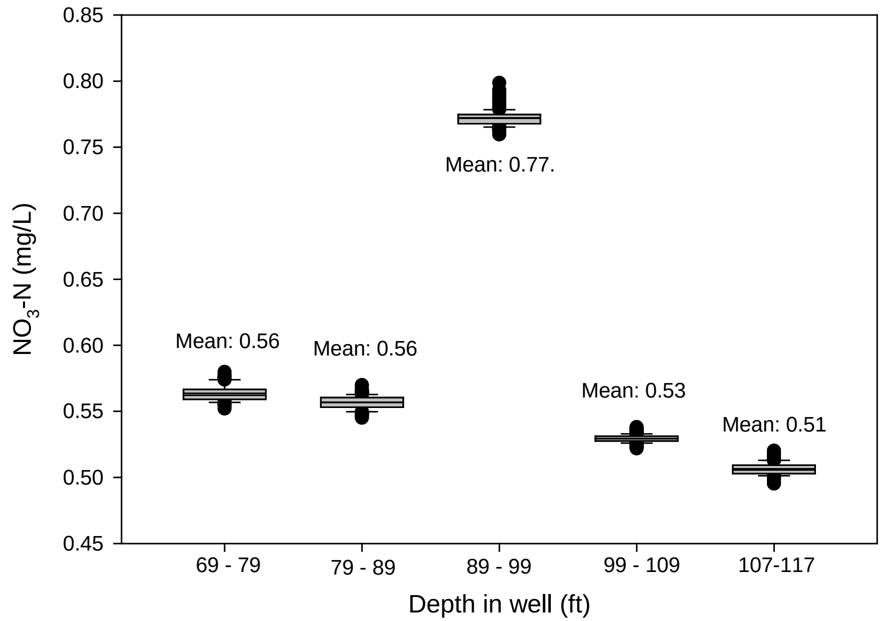


Controlled injection of a prepared test solution ("push") into an aquifer followed by the extraction of the test solution ("pull").

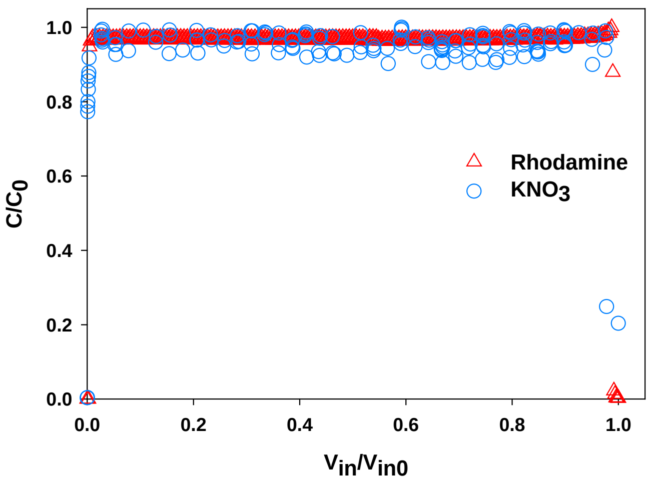
The injected test solution consists of a nonreactive tracer and NO_3^-.

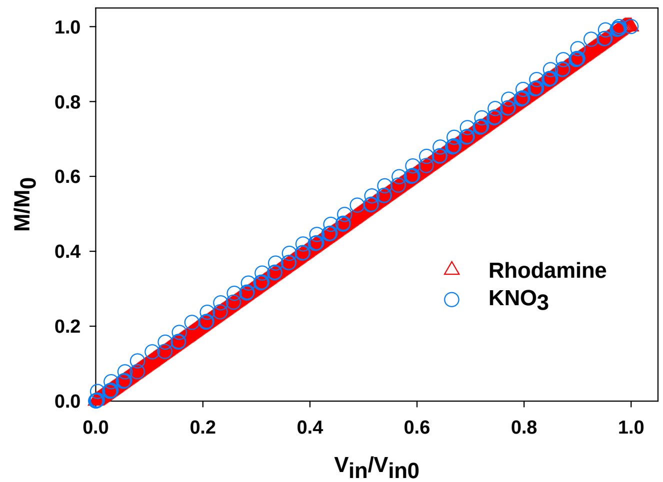
Push-Pull Test at M0789 (89-99ft)

Background Nitrate



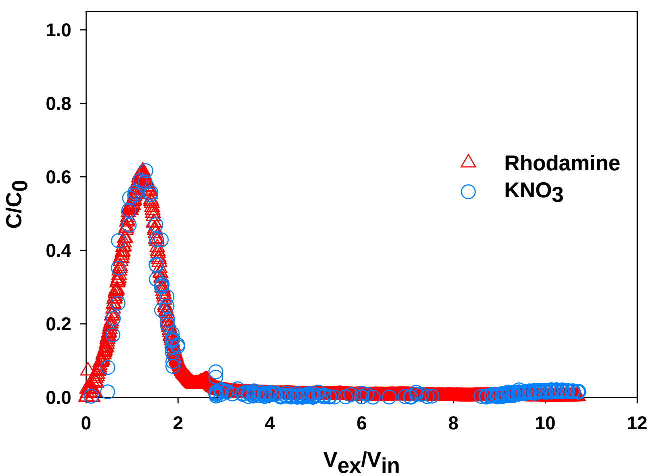
M0798 at 89-99ft

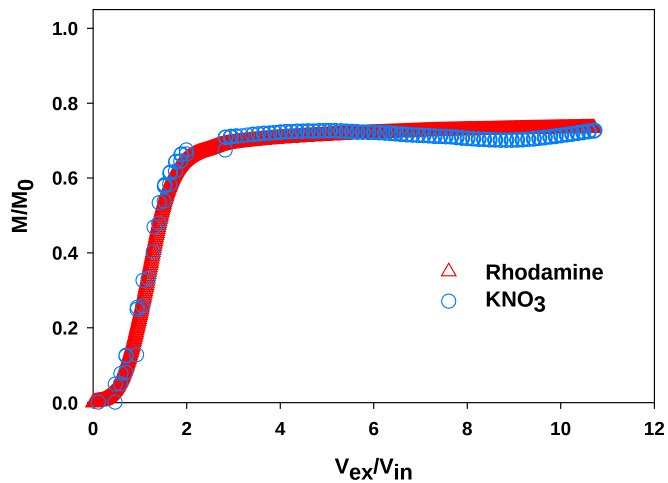




PUSH

PULL





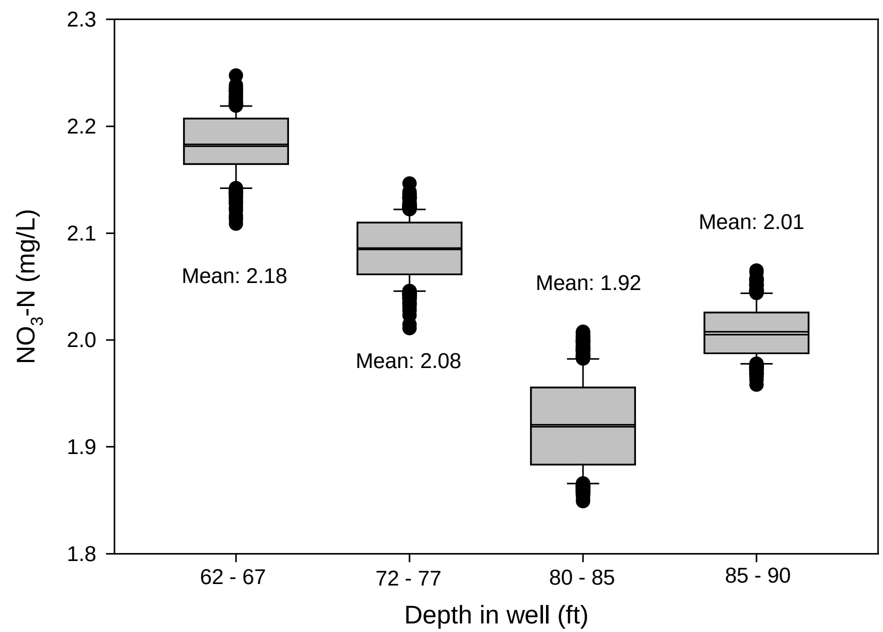
Mass Recovery

Rhodamine: **73.3%**

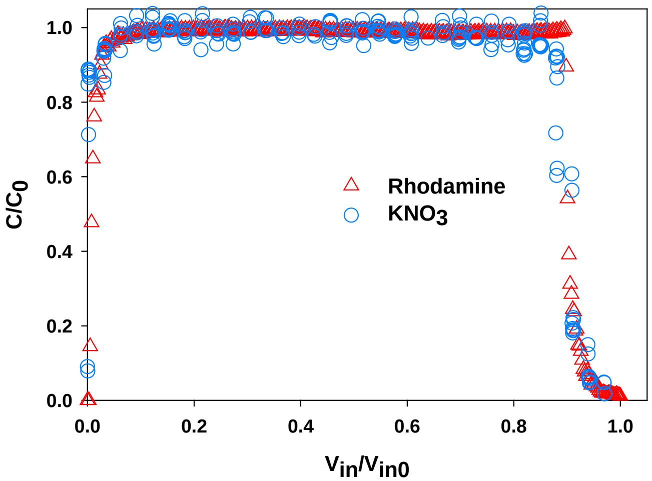
KNO_3: **73.2%**

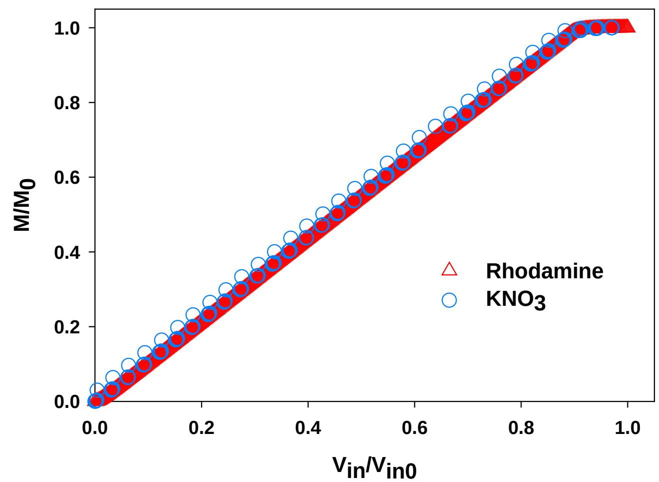
Push-Pull Test at Sprayfield (59-69ft)

Background Nitrate



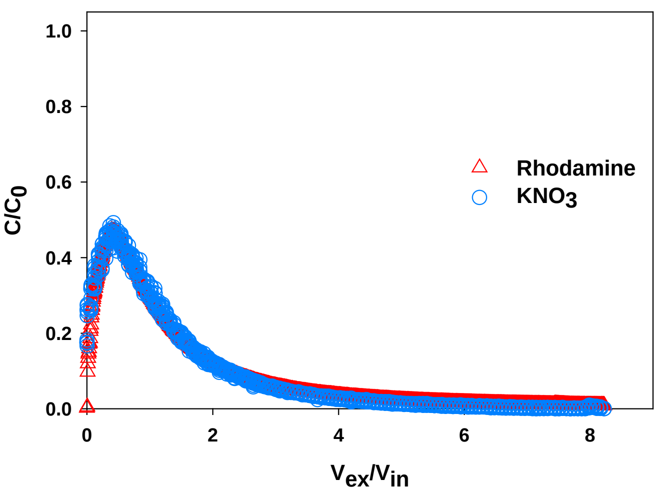
Sprayfield at 59-69ft

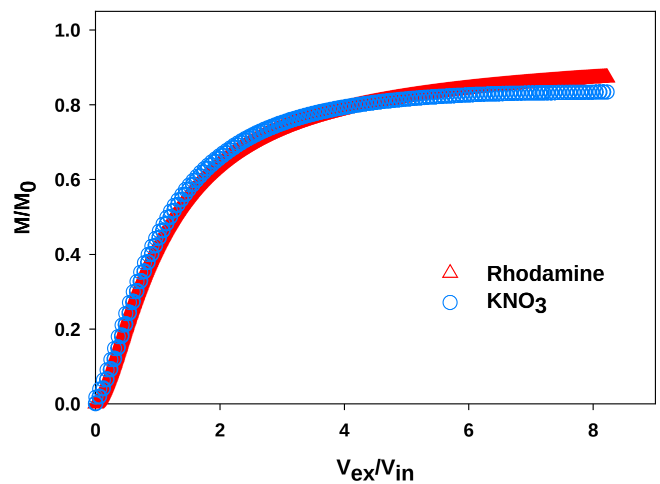




PUSH

PULL





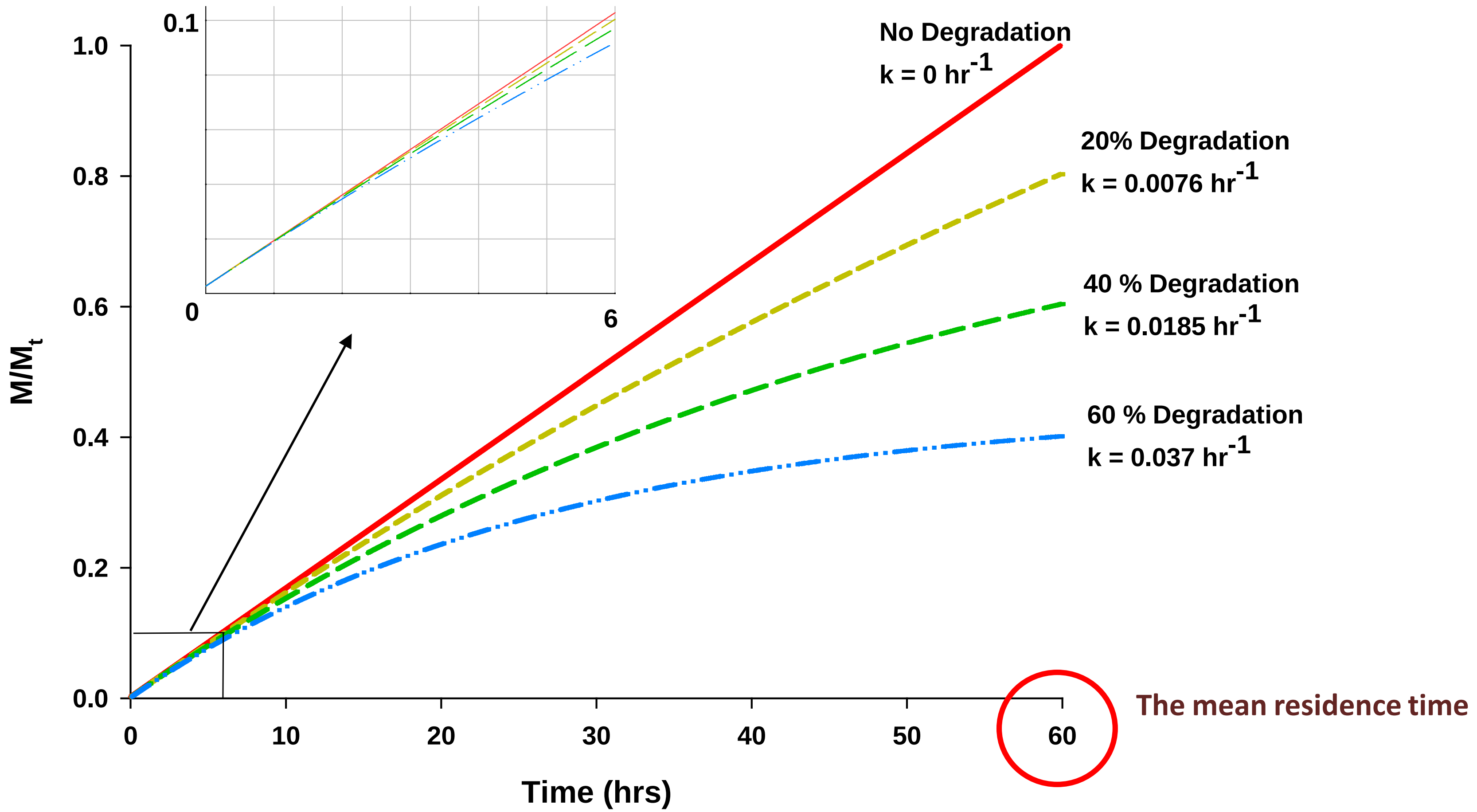
Mass Recovery

Rhodamine: **87.3%**

KNO_3: **83.4%**

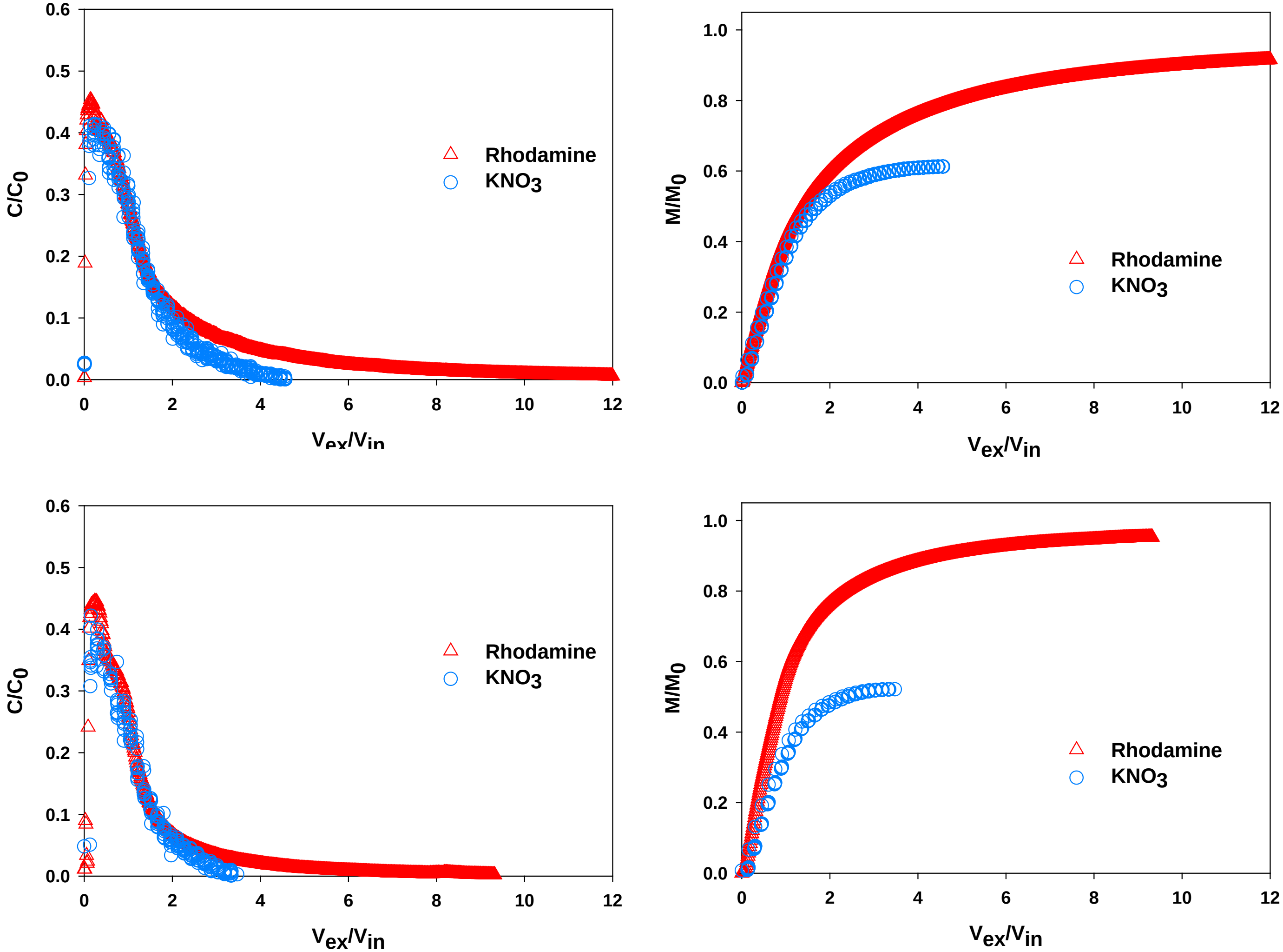
No denitrification ???

Estimation of First-order rate constant



Push-Pull Test M779 at 135-145ft

NO nitrate at three wells



M779 at 135-145ft

Mass Recovery

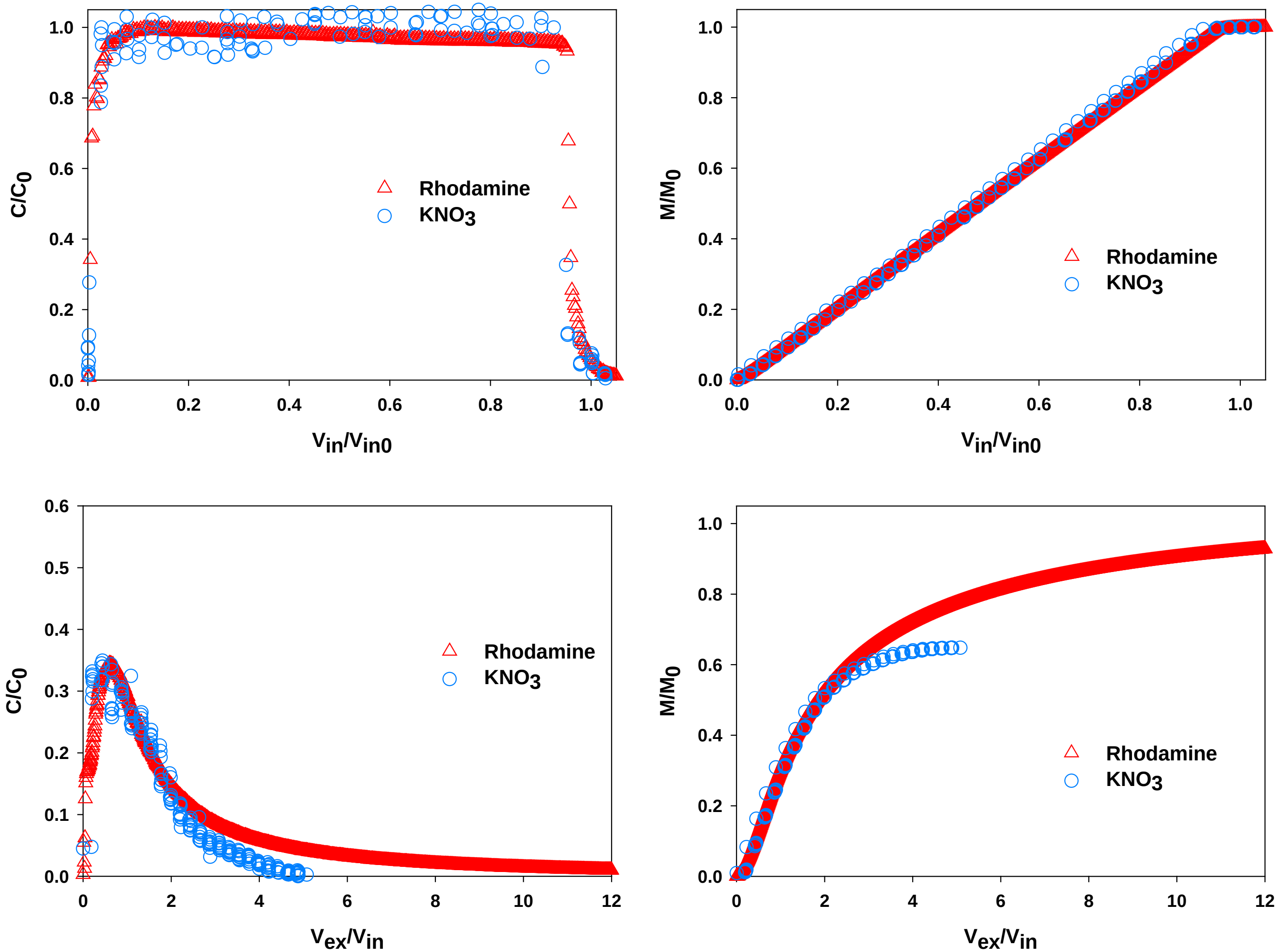
Rhodamine: **93.9%**

KNO_3: **61.2%**

Mass Recovery

Rhodamine: **95.3%**

KNO_3: **52.1%**

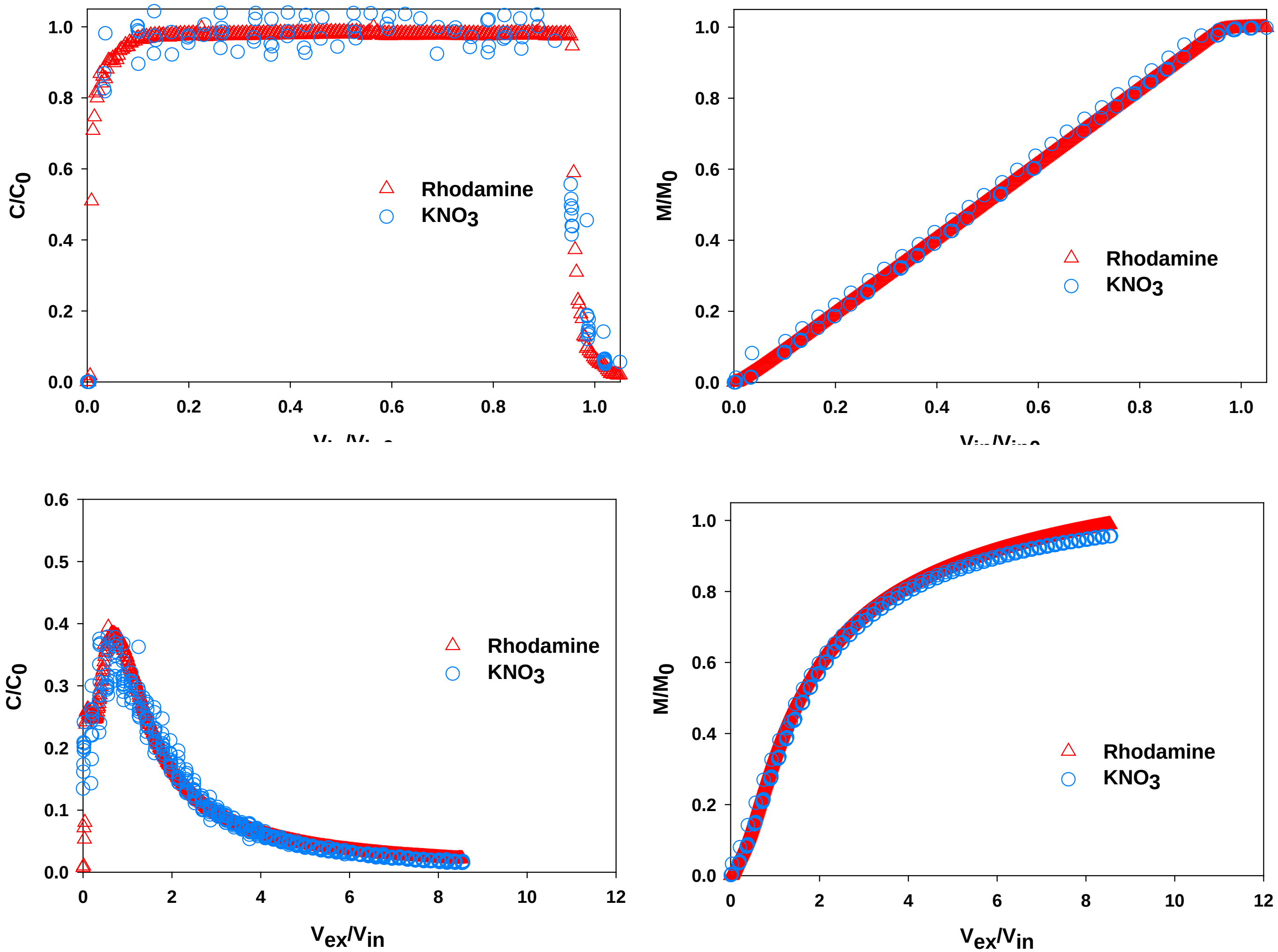


M780 at 59-69ft

Mass Recovery

Rhodamine: **97.1%**

KNO_3: **64.8%**



M781 at 25-35 ft

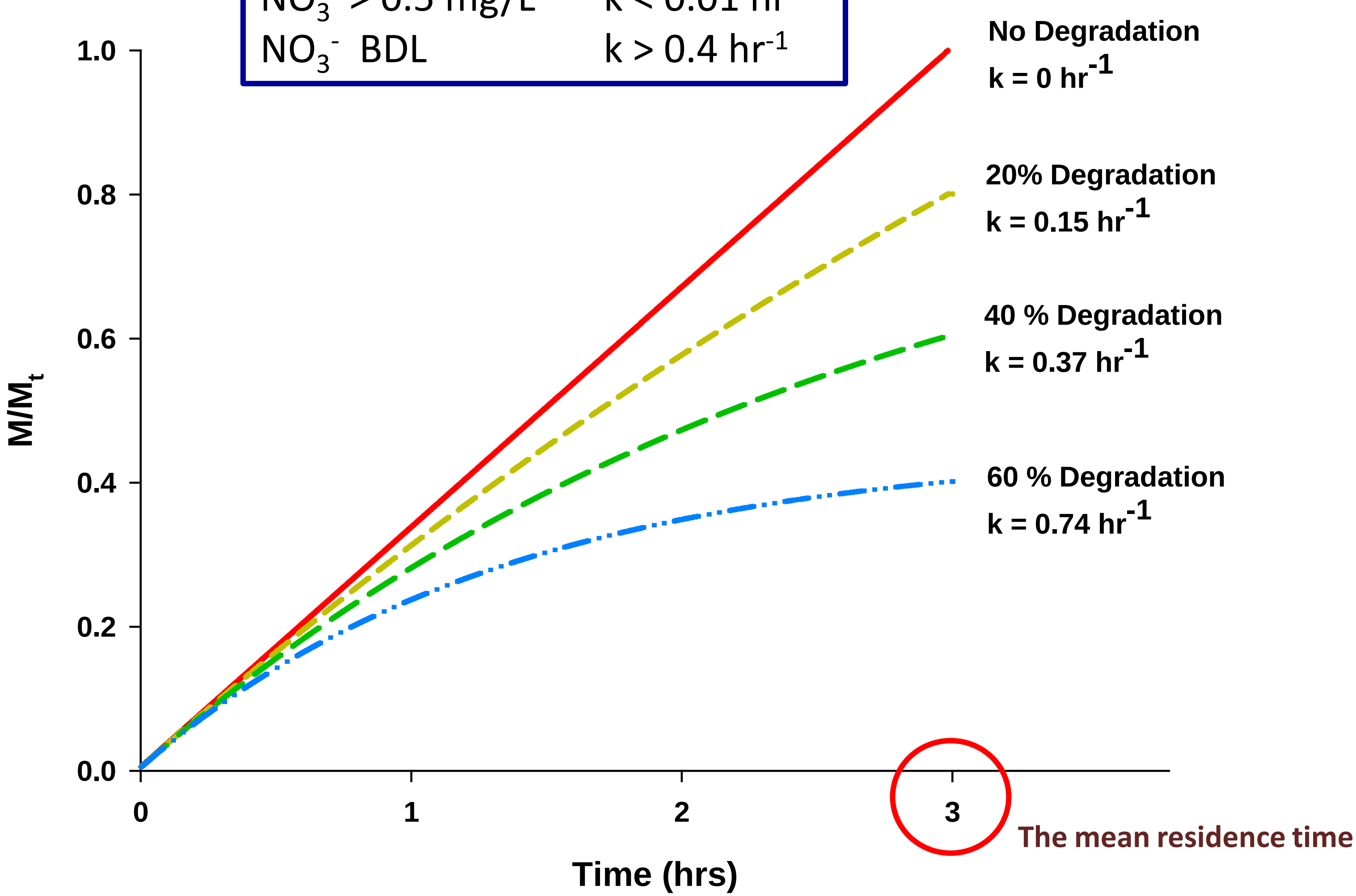
Mass Recovery

Rhodamine: **98.8%**

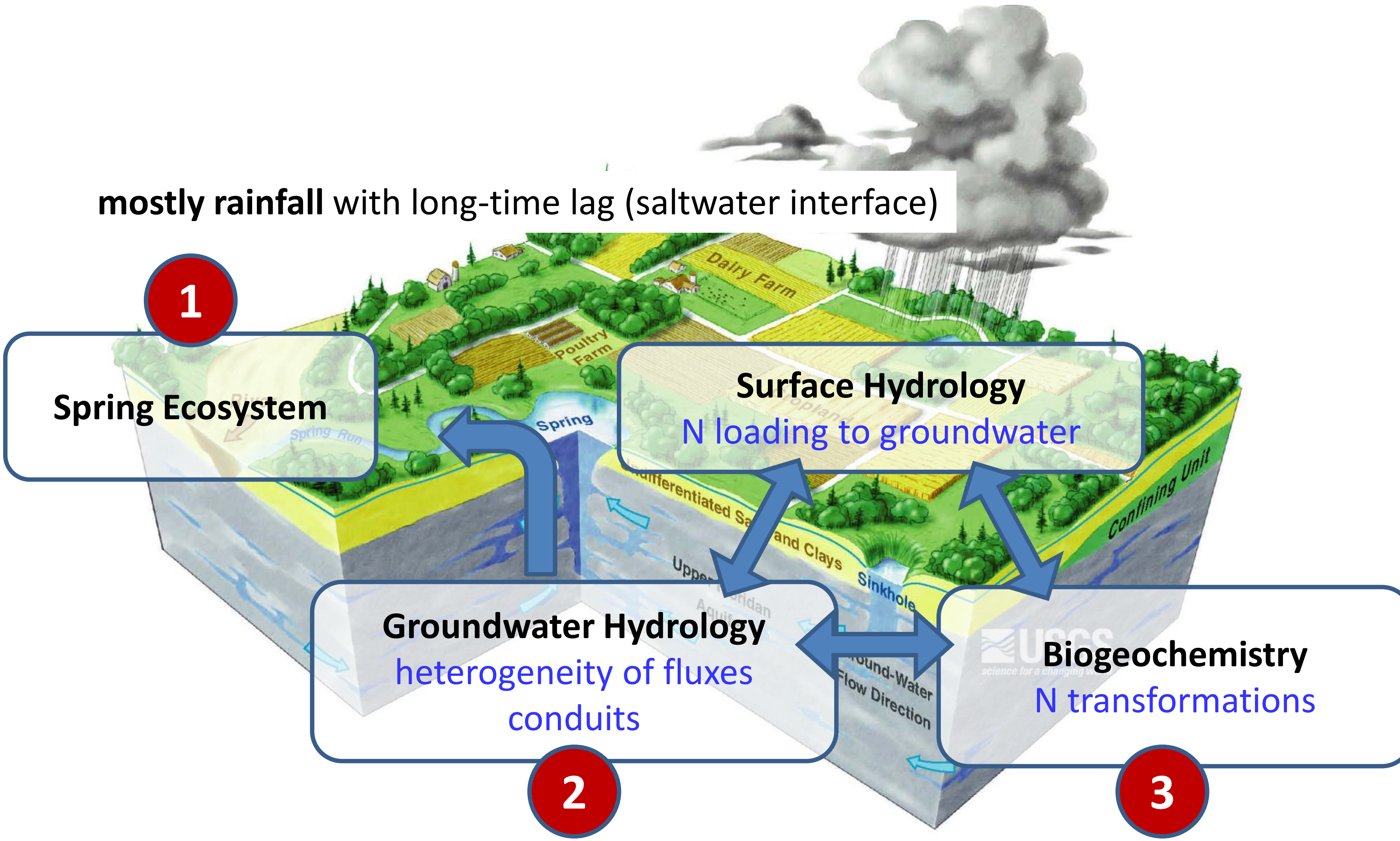
KNO_3: **95.6%**

Estimation of First-order rate constant

NO_3^- > 0.5 mg/L	k < 0.01 hr^{-1}
NO_3^- BDL	k > 0.4 hr^{-1}



mostly rainfall with long-time lag (saltwater interface)



mostly conduits (flow)
mostly matrix (area)

mostly inert
H_2S smell = not inert