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Improved Methods For Estimating K with Hydraulic Profiling Tool (HPT)

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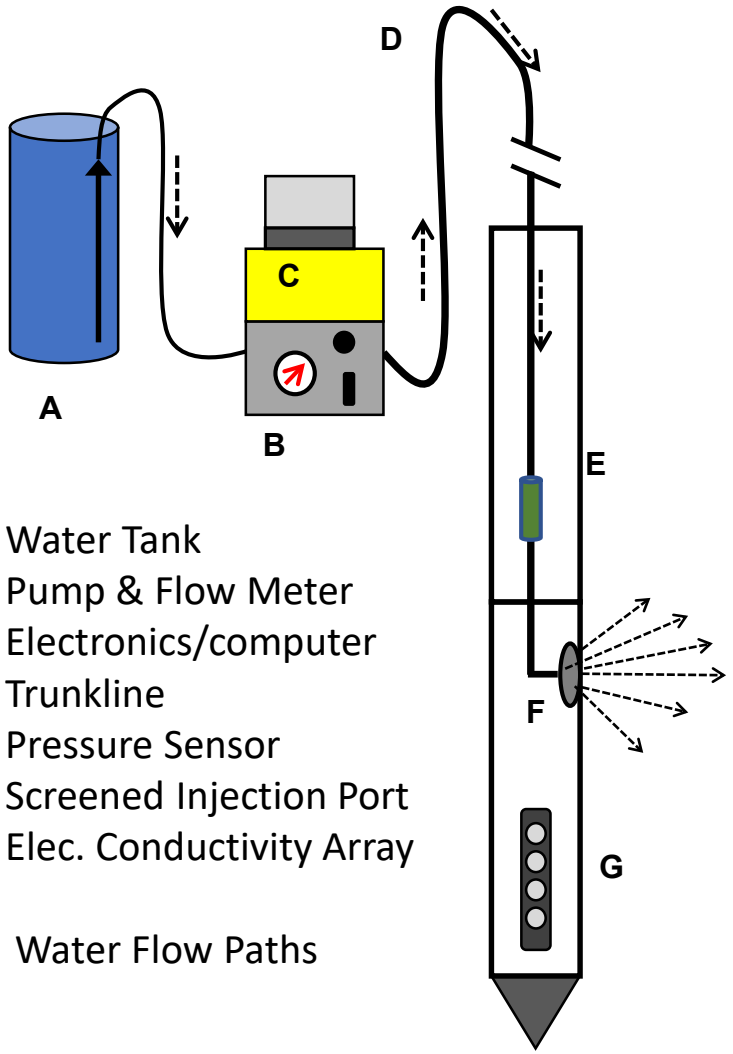
Outline

- Introduction of Hydraulic Profiling Tool (HPT)
- Challenges
  - Low K zone
  - Lack of analytical methods
- Approaches
  - Physical improvement
  - Analytical method
- Field Validation
  - Testing tool and equation

Hydraulic Profiling Tool (HPT)

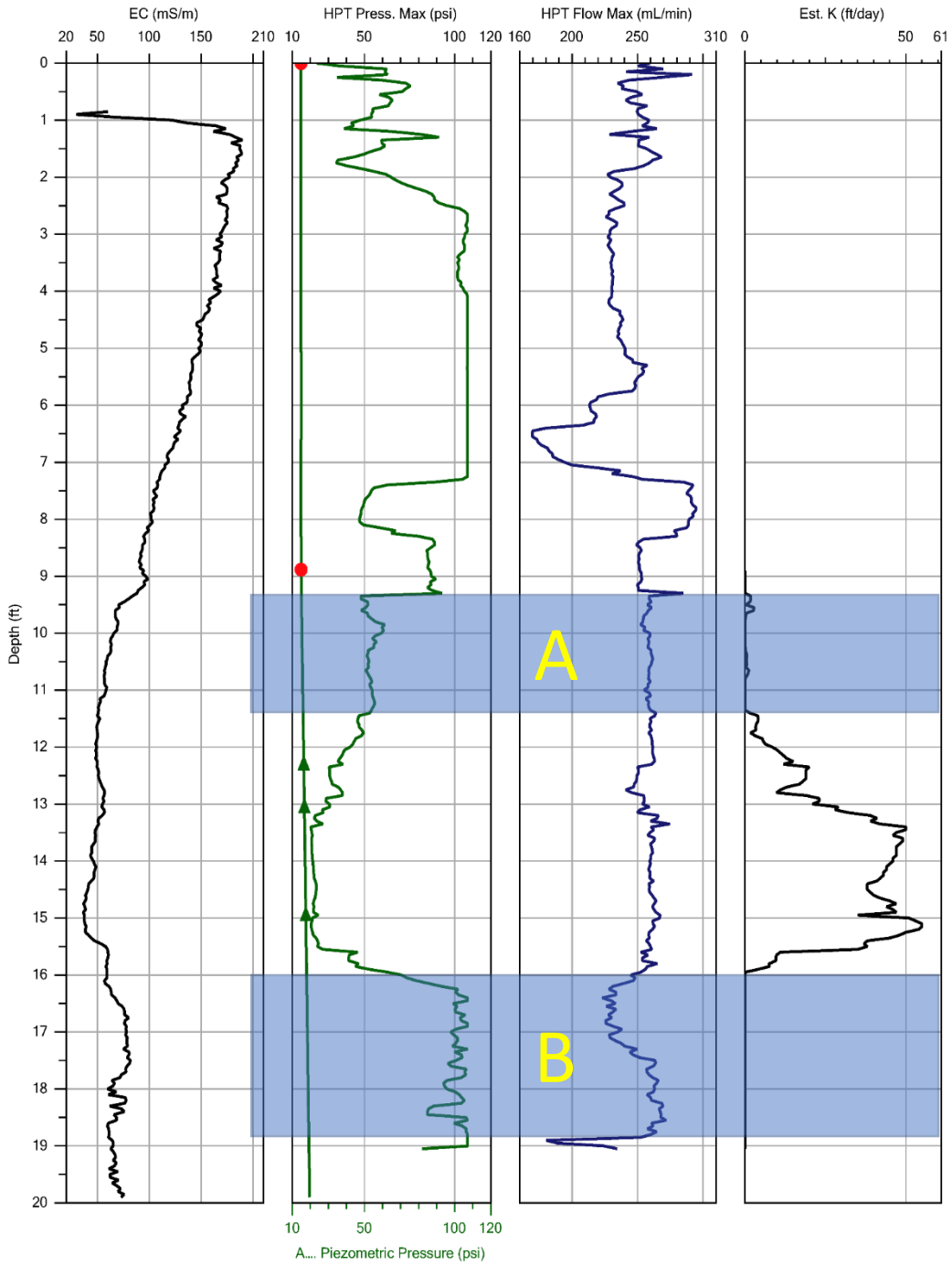


A) Water Tank
B) Pump & Flow Meter
C) Electronics/computer
D) Trunkline
E) Pressure Sensor
F) Screened Injection Port
G) Elec. Conductivity Array

↘ Water Flow Paths

- Operation
  - ✓ Boring Speed: 2 [cm/s]
  - ✓ Injection flow rate (Q) 50-500 [mL/min]
  - ✓ Monitor injection pressure (P)
- Benefits
  - ✓ High resolution vertical profiles
  - ✓ Fast and cost effective
  - ✓ Less disturbance

Estimates **hydraulic conductivity (K)** from the relationship to the **flow rate (Q)** and **pressure (P)**



HPT output

- K estimation
  - From Flow Rate [ml/min] and Pressure [psi]
  - Electrical Conductivity is supplementary
- Limitations
  - Low K zones measurement
  - Limited understanding about acquired data
- Challenges
  - Pressure build up
  - Data analysis procedures

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Objectives

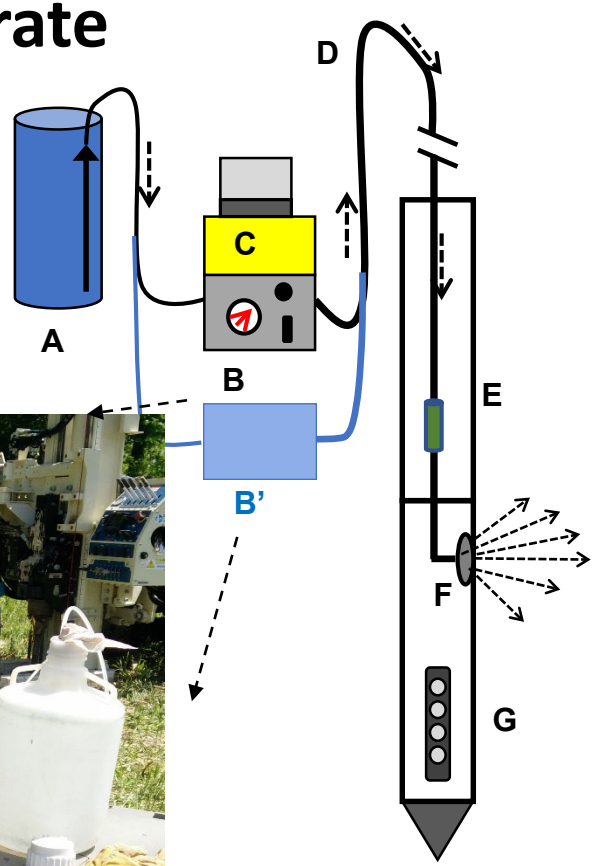
How can we improve accuracy of K measurements in Lower K zones?

1. **Lower the pressure (Physical improvement)**
2. **Improve analytical method**

Lower the Pressure

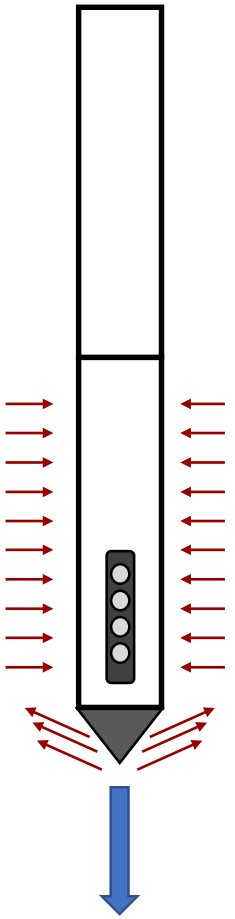
1. Reduce injection rate

- Attach flow control boxes
- Flow rate range:
  1 – 100 [ml/min]



2. Slower rod advancement

- Boring activity cause material displacement
- At 2cm/s, material displacement is equivalent to a water injection rate of **1800 [ml/min]**
- Less significant pressure compare to the direct injection due to the area difference



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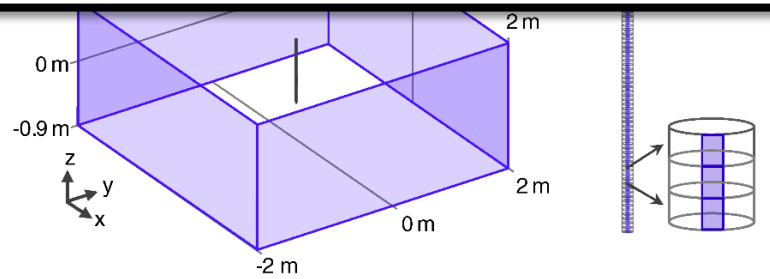
Numerical Sim
Physical Modi

Groundwater

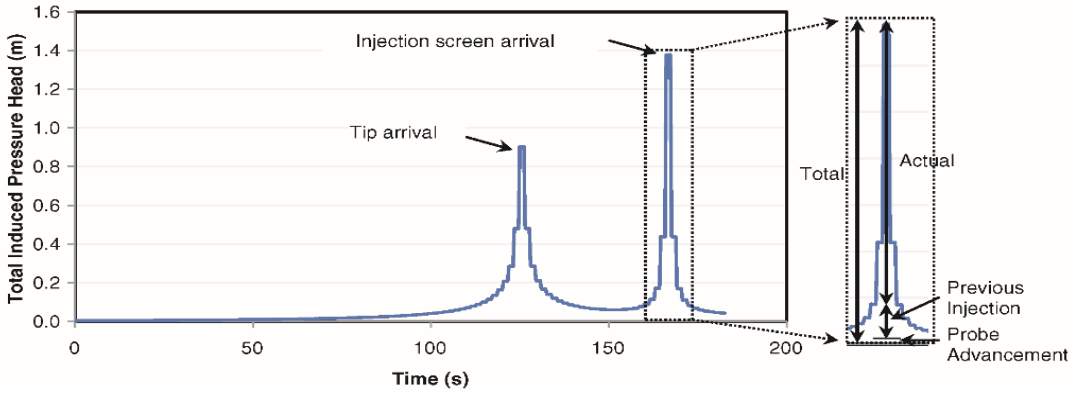
Simulation Assessment of Direct Push Injection Logging for High-Resolution Aquifer Characterization

by Gaisheng Liu[1,2], Robert C. Borden[3], and James J. Butler Jr.[1]

- Model setup
  - ✓ Simulated water injection po
  - ✓ Fine mesh around injection screen 0.2 [cm]
  - ✓ Varying K, Ss, and Rod Speed



- Output
  - ✓ Three sources of pressure:
    [**Injection**; previous injection; **probe moving**]
  - ✓ Injection and probe moving are considered
  - ✓ Contribution from previous depth is proportional



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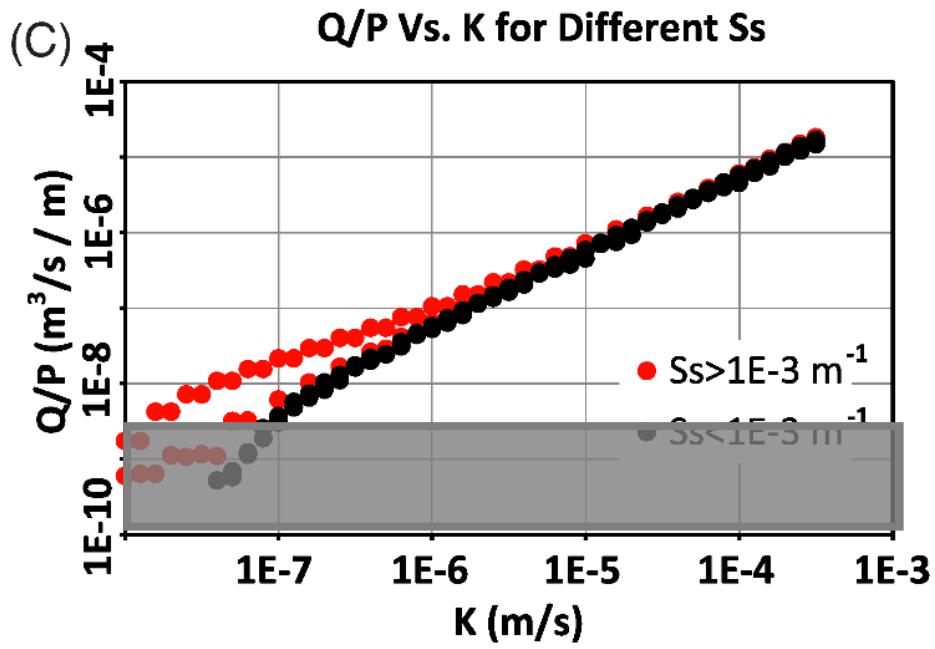
Site Condition for Q/P vs. K

- Pressure Behavior is different for specific storage and K

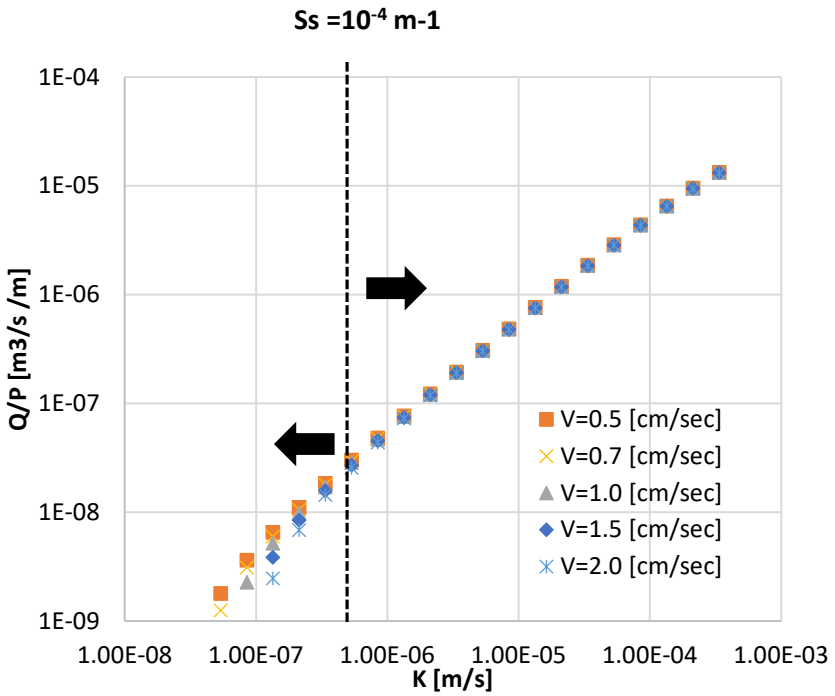


Q/P is		K	
		< 10^{-6} [m/s]	> 10^{-6} [m/s]
Ss	< 10^{-3} [1/m]	f(K & Ss_{min})	f(K)
	> 10^{-3} [1/m]	f(K & Ss)	f(K)

*If Q/P is less than $5x10^{-9}$ [m3/s/m], measurement limit problem arises

Operational Condition for Q/P vs. K

- Pressure from Injection and Rod Advancement (operational)
- Slower Rod speed:
  1) Reduces pressure from rod movement
  2) Gives more time to recover
  3) Increases pressure from injection



[Recommendation] Rod Advancement Speed =		K	
		< $5x10^{-7}$ [m/s]	> $5x10^{-7}$[m/s]
Ss	< 10^{-3} [1/m]	0.5 [cm/sec]	2 [cm/s]
	> 10^{-3} [1/m]	0.5 [cm/sec]	2 [cm/s]

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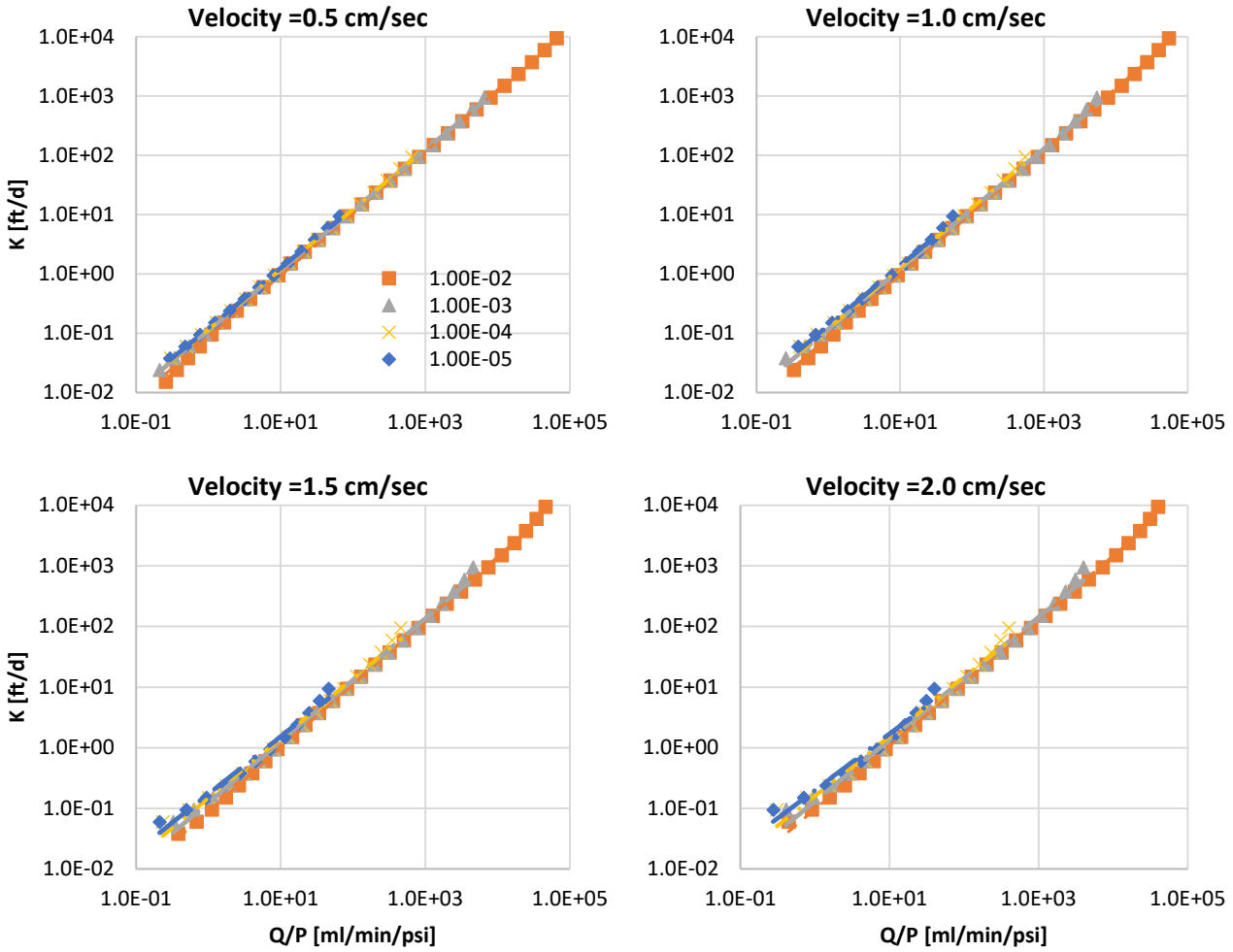
HPT (Q/P) and K relationship



$$[K] = a * [Q/P]^b$$

	SS [1/m]	a	b	R^2
V = 0.5 [cm/sec]	0.01	0.085	1.04	0.99
	0.001	0.109	1.02	0.99
	0.0001	0.115	1.01	0.99
	0.00001	0.121	1.01	0.99

	SS [1/m]	a	b	R^2
V = 1.0 [cm/sec]	0.01	0.085	1.05	0.99
	0.001	0.116	1.01	0.99
	0.0001	0.121	1.02	0.99
	0.00001	0.134	1.01	0.99

	SS [1/m]	a	b	R^2
V = 1.5 [cm/sec]	0.01	0.089	1.05	0.99
	0.001	0.124	1.10	0.99
	0.0001	0.147	0.99	0.99
	0.00001	0.173	0.95	0.98

	SS [1/m]	a	b	R^2
V = 2.0 [cm/sec]	0.01	0.097	1.04	0.99
	0.001	0.132	1.01	0.99
	0.0001	0.161	0.98	0.98
	0.00001	0.200	0.93	0.97

New vs. Current Method

McCall (2010) equation

[Est. K] = 20.644 x Ln[Q/P]-41.71

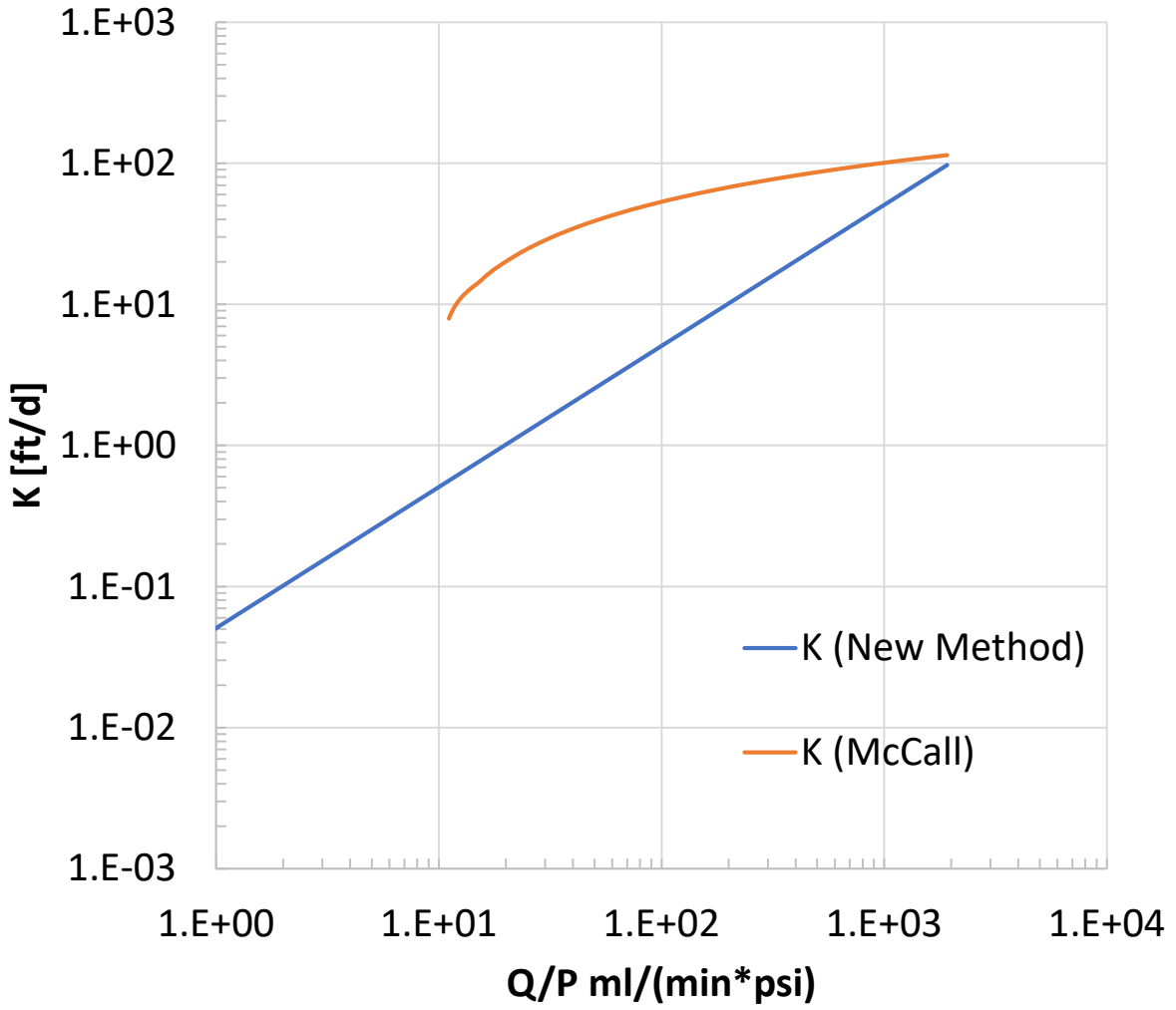
- Logarithmic function

New equation *[When K>10^{-6} m/s]*

[Est. K] = 0.1224 x [Q/P]

- Linear function

*K = [ft/day] & Q/P = [ml/min/psi]



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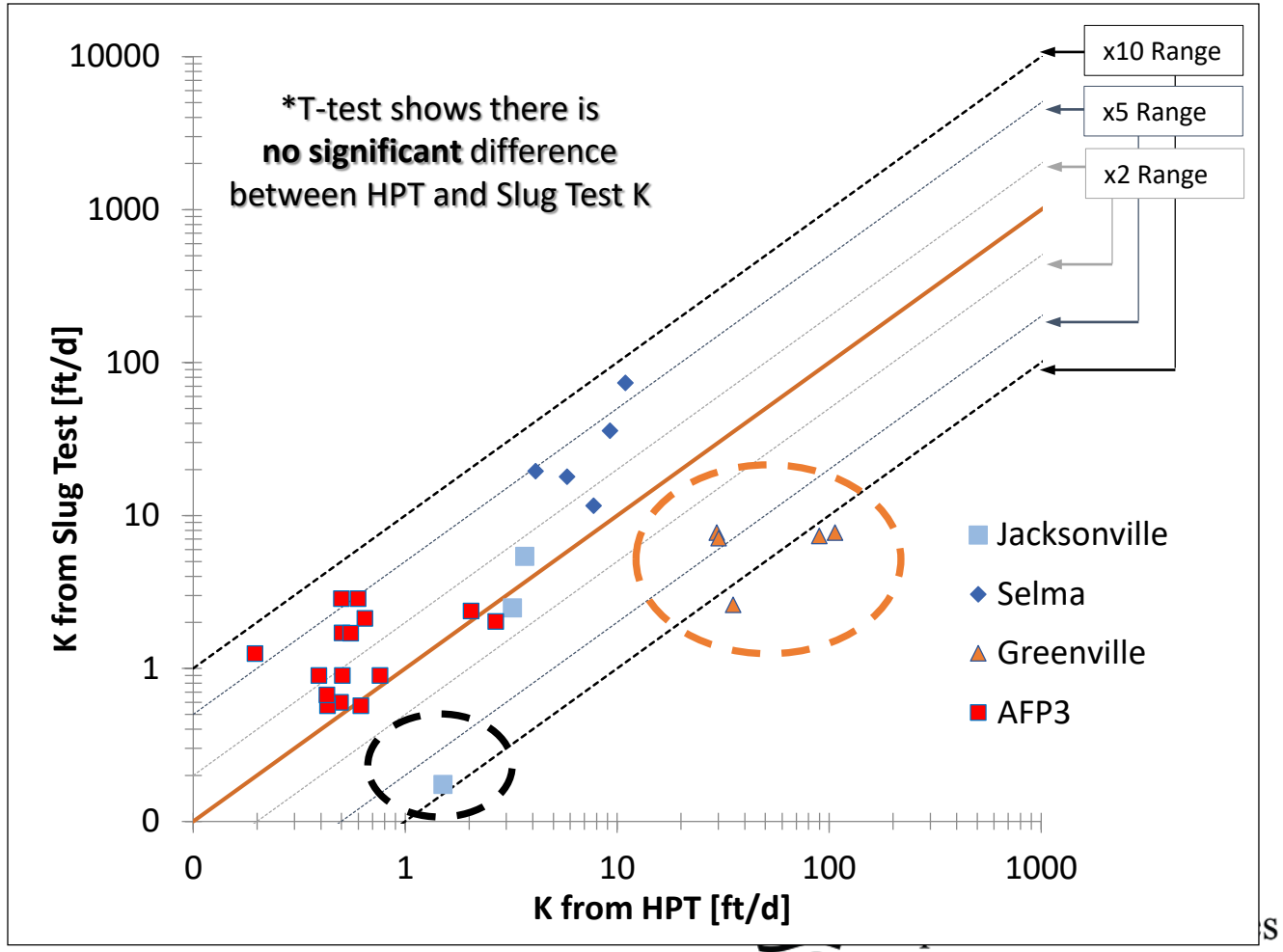
Field Data with New Method

- Standard HPT (2cm/sec)
- Approximately 90% of HPT-K are within 1 order Slug Test-K
- Jacksonville (Black):
  Slug Test shows 0.17 ft/day
  Incorrect measurement from HPT
- Greenville (Orange):
  Partially Submerged MW
- Skin effect? Slug Test K /HPT K ratio

Site	Slug K/ HPT K		
	Mean	Stdev	n
Jacksonville	1.13	0.50	2
Selma	3.99	1.95	5
Greenville	0.12	0.10	5
AFP3	2.69	1.84	14
Total	2.33	2.02	26



Lesson Learned

- Hydraulic Conductivity in lower K zones can be measured
- Lower Pressure by
  - Lowering injection rate & Slower rod advancement
- Slower rod advancement is recommended depending on
  - Specific Storage & Target K
- Linear relationship between K and Q/P from HPT
  - If $K > 10^{-6}$ [m/s] (= 0.3 ft/day), ***Est. K (ft/d) = 0.1224 x [Q/P]***
  - If $K < 10^{-6}$ [m/s], ***Est. K (ft/d) = a x $[Q/P]^b$*** ➔ ***a & b will be vary for conditions***
- Skin Effect:
  - HPT boring could have skin effect from probe advancement
  - Skin factor (Sf) varies from 0.12 to 4

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QUESTIONS ?

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