QUANTIFYING HYDRAULIC CONDUCTIVITY IN MINE DRAINAGE PASSIVE TREATMENT SYSTEM VERTICAL FLOW BIOREACTORS

Presentation at the
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TF, ASMR, and ARRI
by

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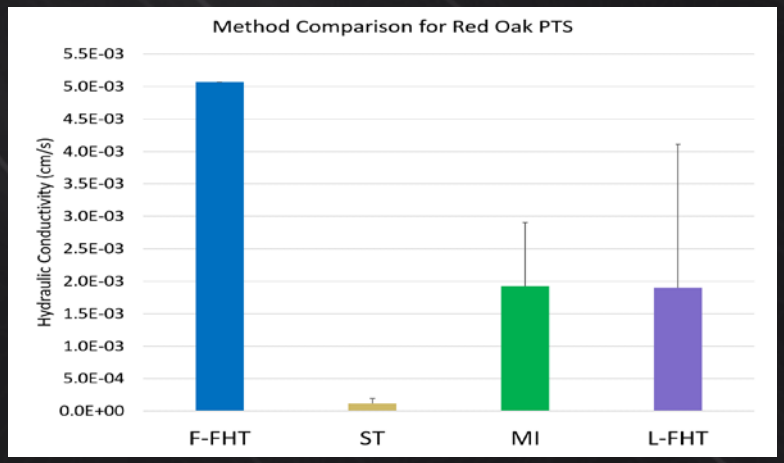
Outline

Introduction

Methods

Results



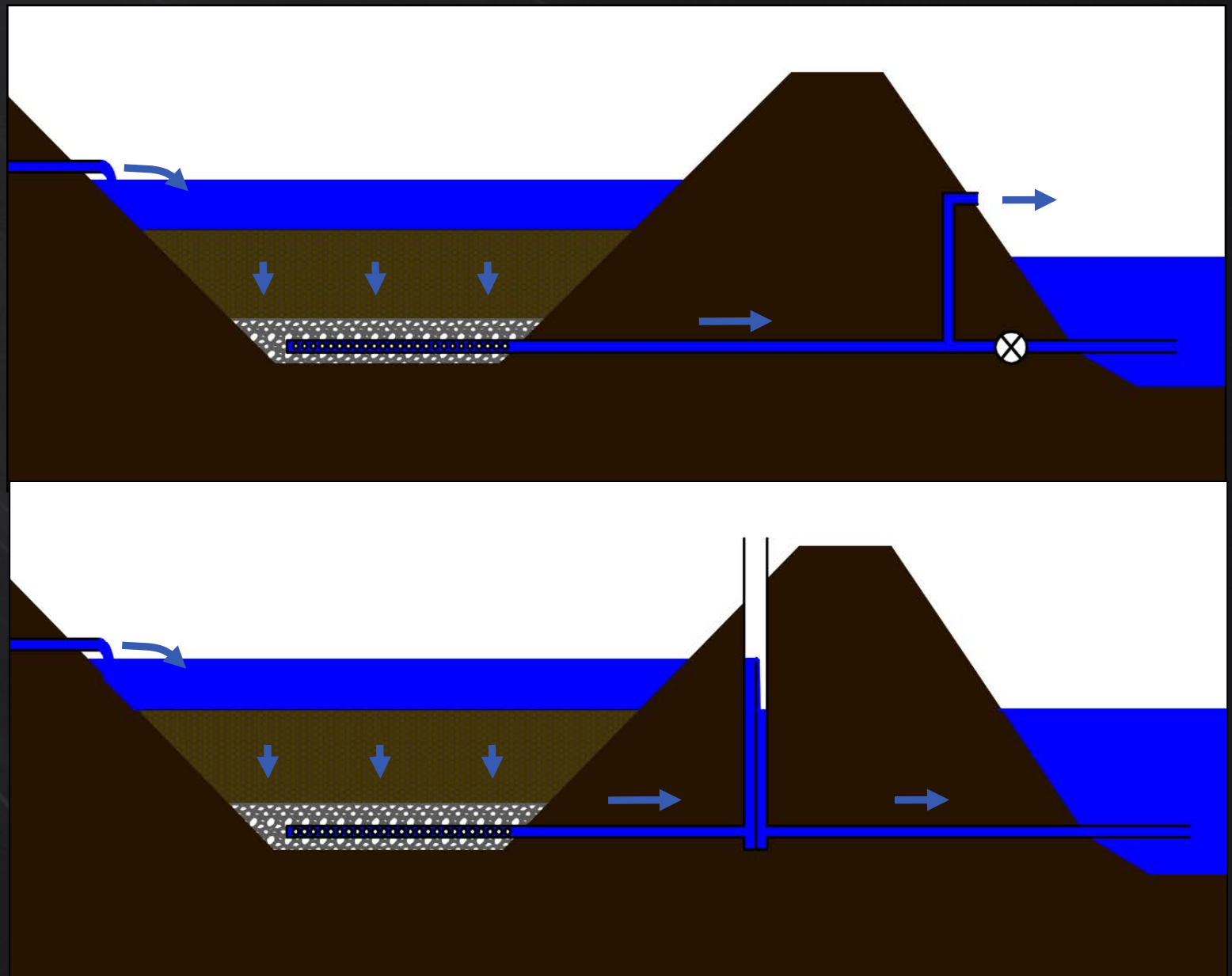
Conclusions

Introduction to Vertical Flow Bioreactors

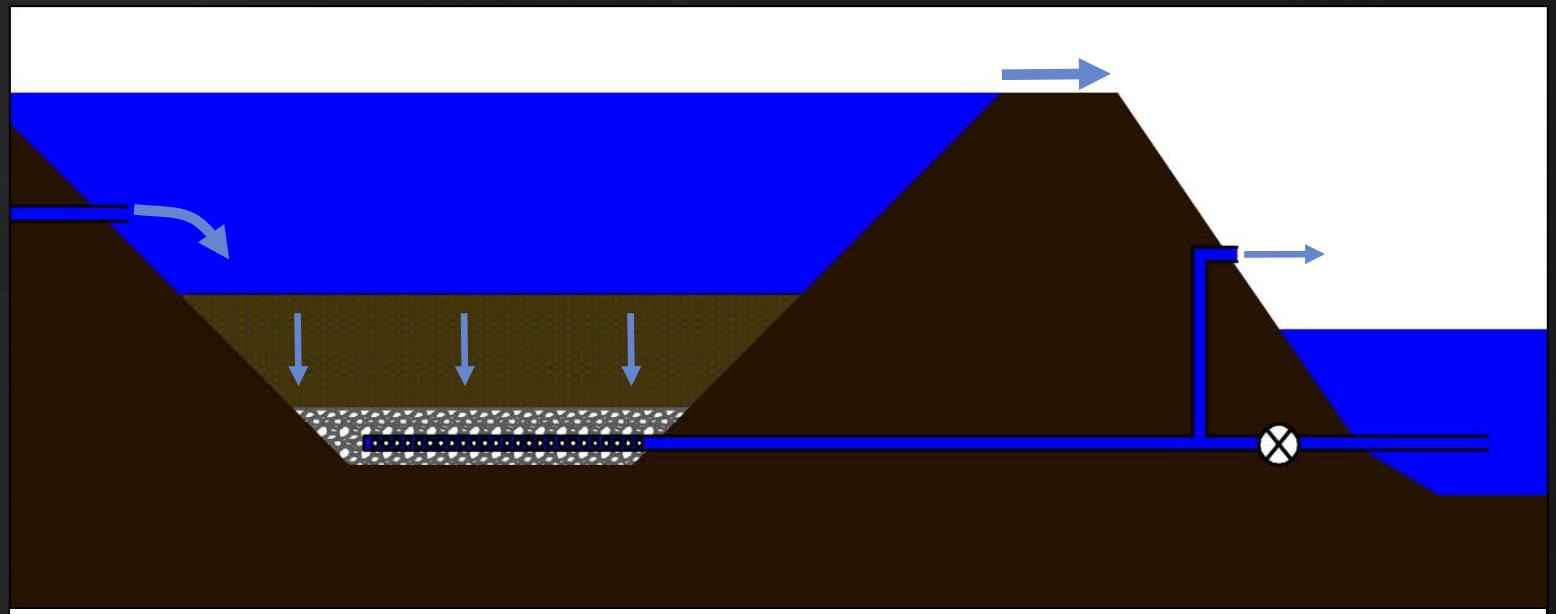
Typical Vertical Flow Bioreactor (VFBR)

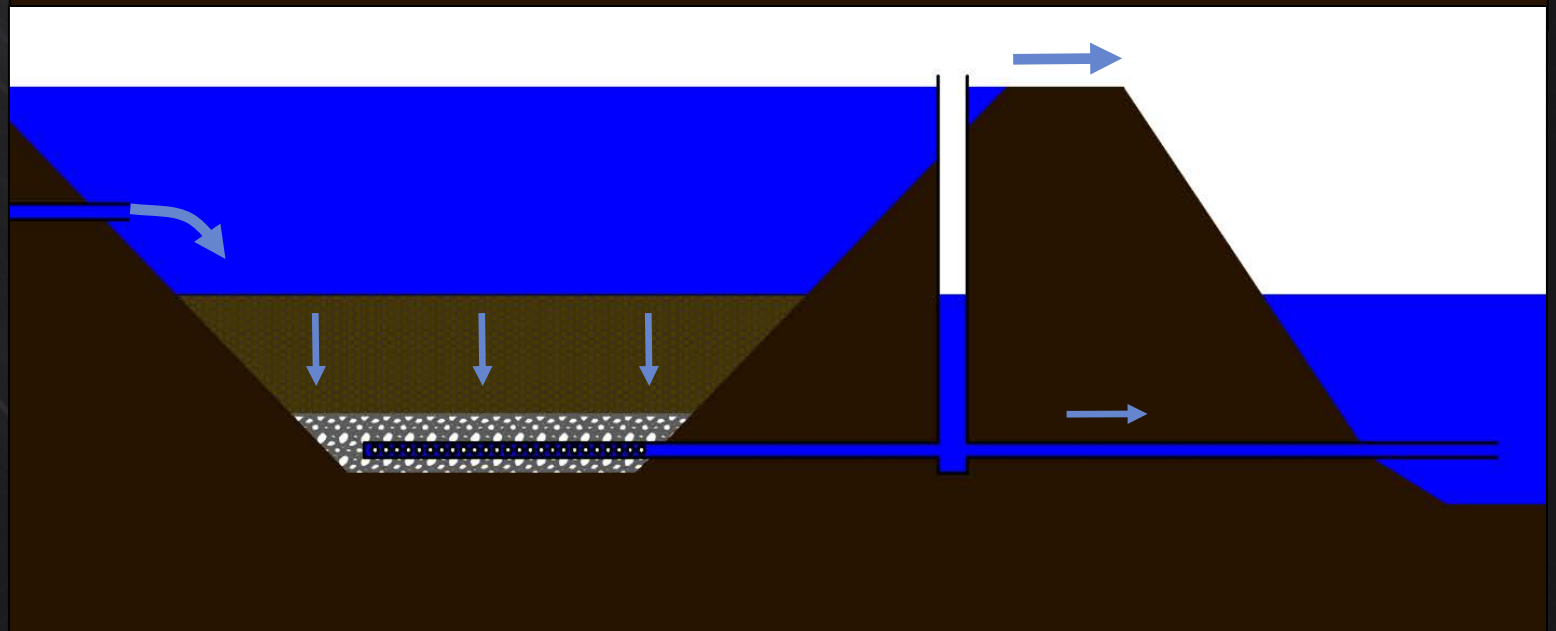
- Anaerobic cells
- Consists of:
  - Drainage system
  - Limestone
  - Organic mix
  - Open water
- Metal sulfides
- Alkalinity

Typical Cross Section of a VFBR



Operation and Maintenance Issues





Hypotheses

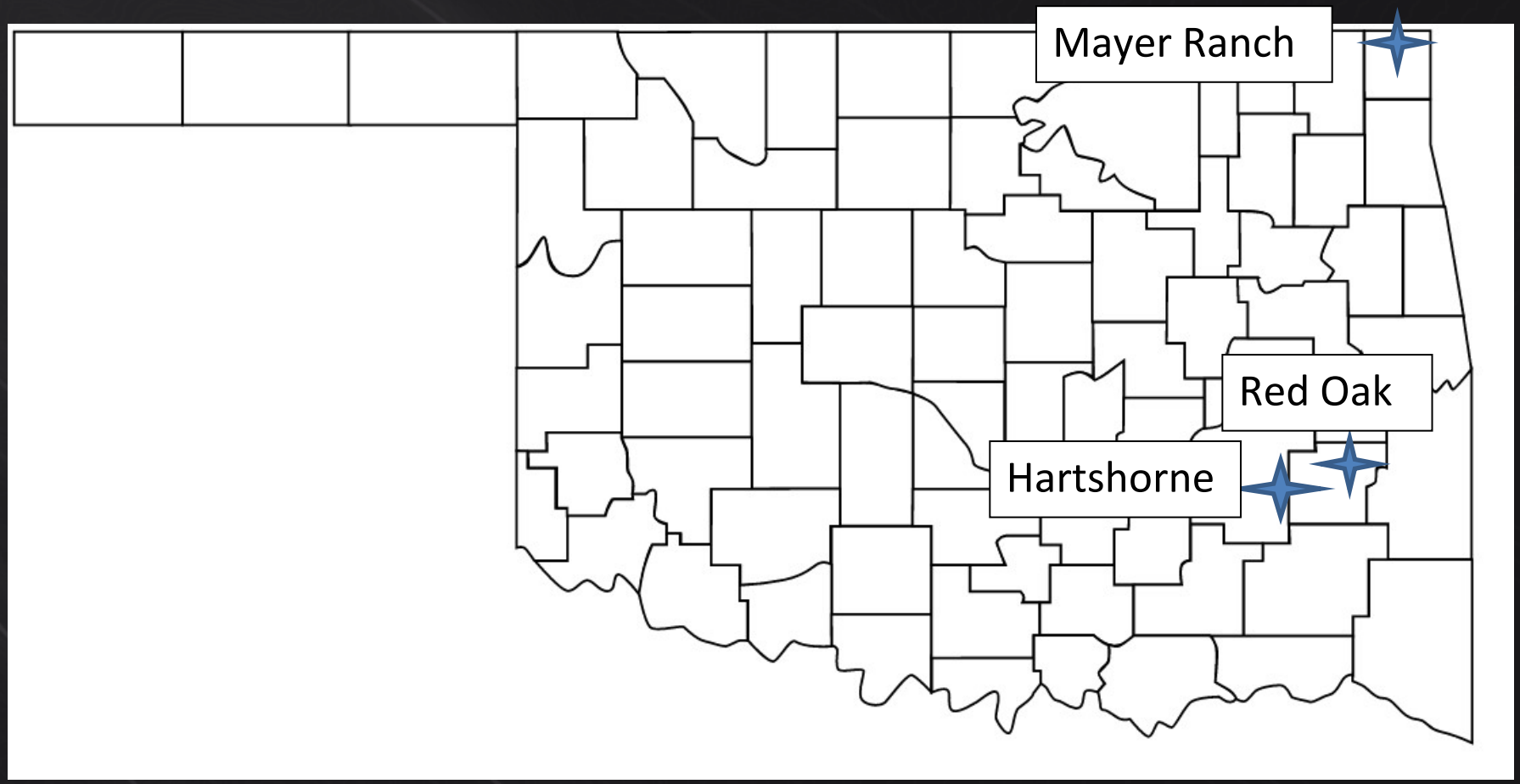
1. The hydraulic conductivity of VFBRs that have been in operation for an extended period of time differ from when the system was installed.

2. A comparison of several different methods will return statistically similar results.

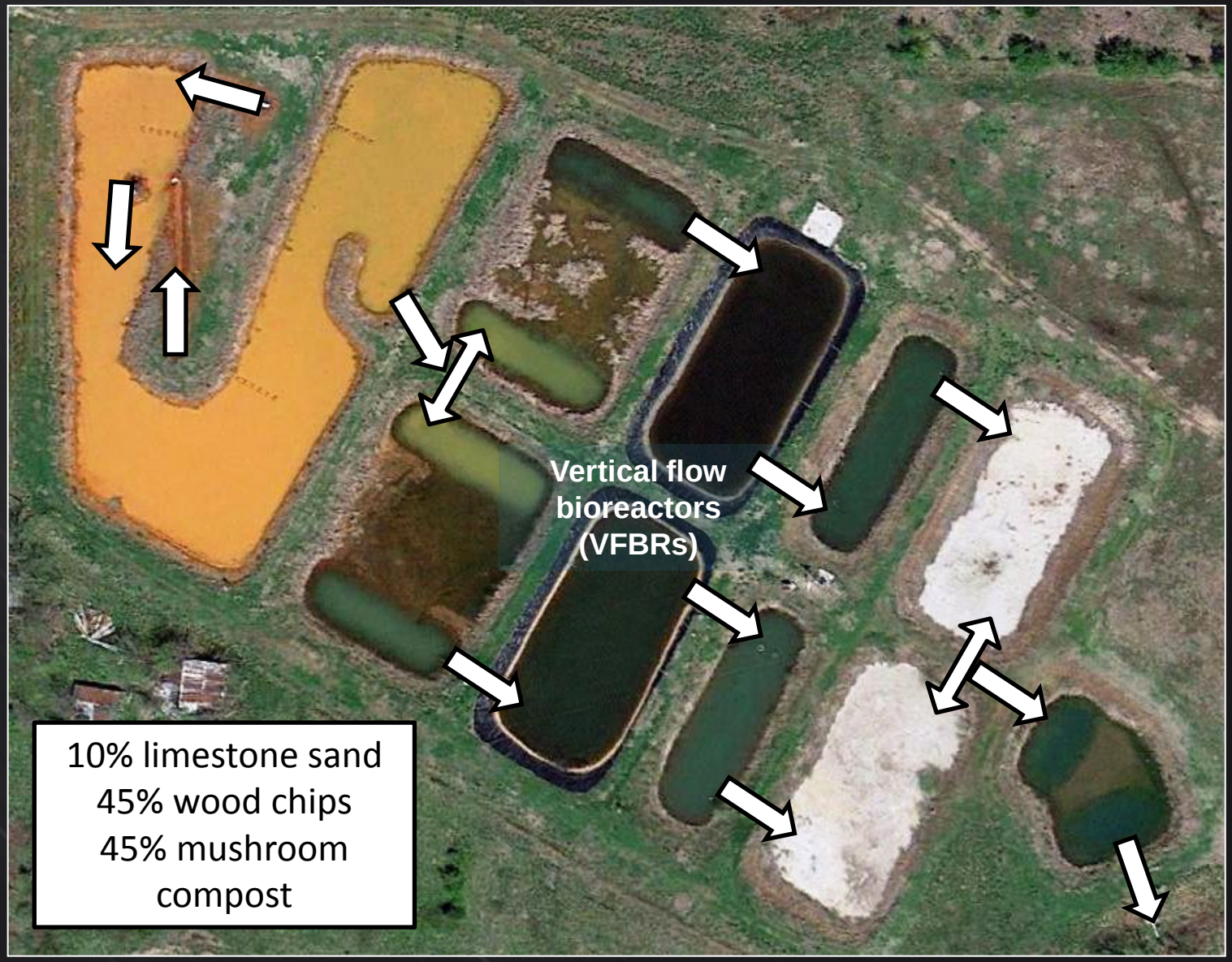
3. The comparison of hydraulic conductivity and treatment media characteristics will show a trend that will be able to predict the hydraulic conductivity based on a characteristic of the treatment media.

Methods

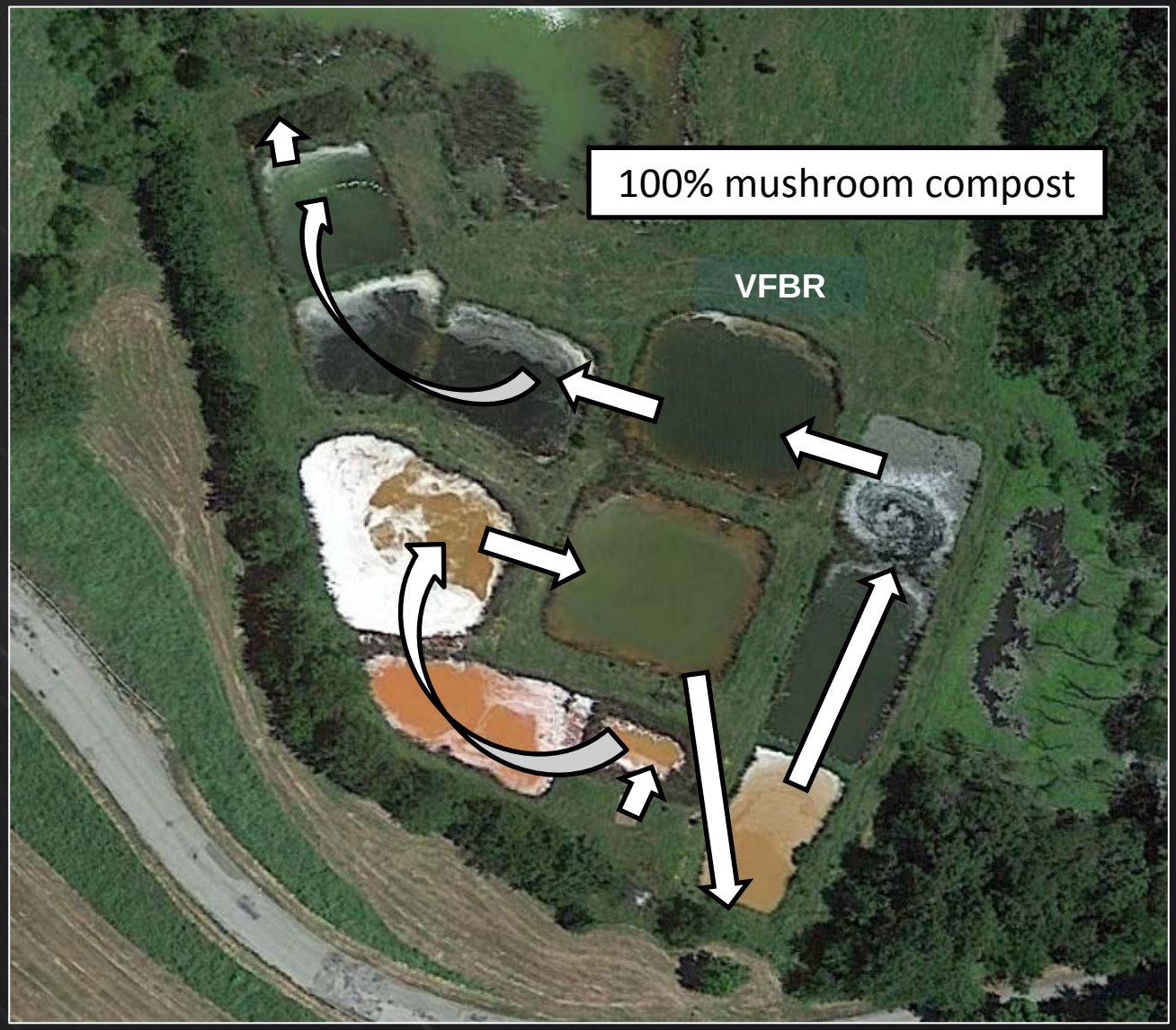
Sites



Sites - Mayer Ranch PTS (MR)



Sites – Hartshorne PTS (H)



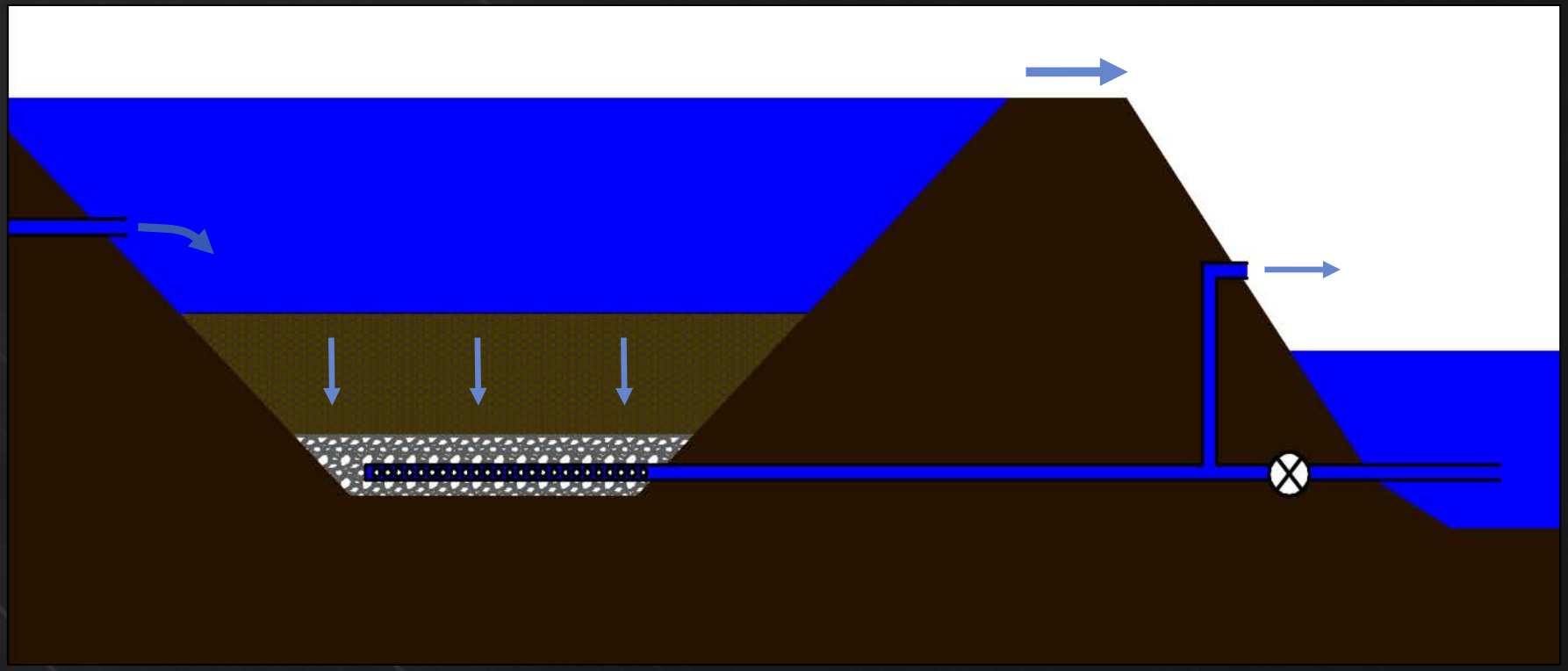
Sites – Red Oak PTS (RO)

PTS	Red Oak	Mayer Ranch	Mayer Ranch	Hartshorne
Location	RO	C3N	C3S	H
Year Constructed (age)	2001 (15)	2008 (8)	2008 (8)	2007 (9)
Designed Thickness (m)	1	0.5	0.5	0.5
Volume (m^3)	388	302	278	101
Measured Thickness (m)	-	0.37	0.29	0.35
Design Flow (lpm)	75.7	246	246	37.9
Hydraulic Loading Rate (cm/s)	1.17E-02	2.35E-02	2.56E-02	1.16E-02

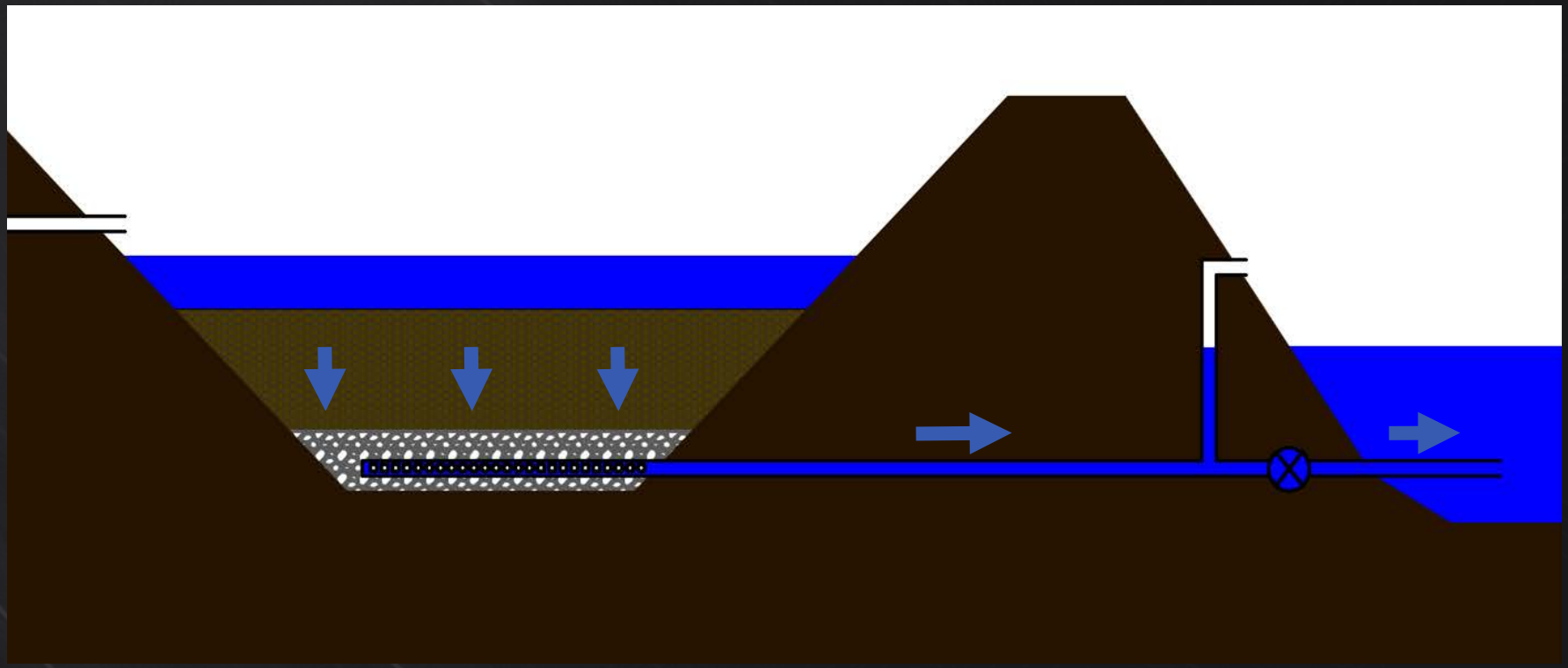
Method Comparison

Test	Parameter measured	Justification
Falling Head Permeability – Field	K	method comparison
Falling Head Permeability – Laboratory	K	method comparison
Modified Single Ring Infiltrometer Test	K	method comparison, sample collection
Slug Test	K	method comparison
Bulk Density	ρ_b	phys. of org. sub., sample collection
Particle Density	ρ_p	phys. characterization of org. sub.
Loss on Ignition	SOM	chem. characterization of org. sub.
Particle Size Analysis	particle size distribution	phys. characterization of org. sub.

Field Falling Head Test (F-FHT)



Field Falling Head Test (F-FHT)



Falling Head Test

$$K = \frac{aL}{At} \ln\left(\frac{h_o}{h_1}\right)$$

Where:

K = hydraulic conductivity

a = area of the VFBR

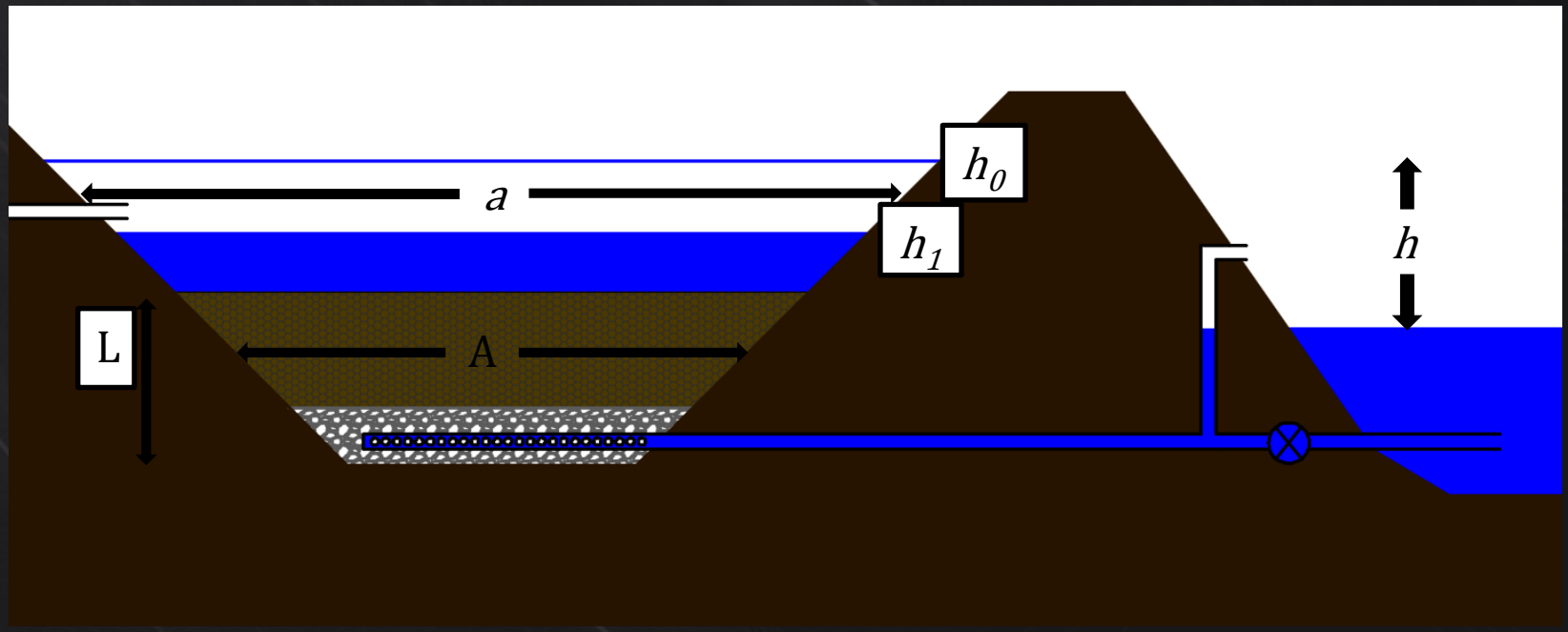
L = length of the treatment system

A = ave. area treatment system

h_0 = initial height of water

h_1 = final height of the water

t = time required to get head drop

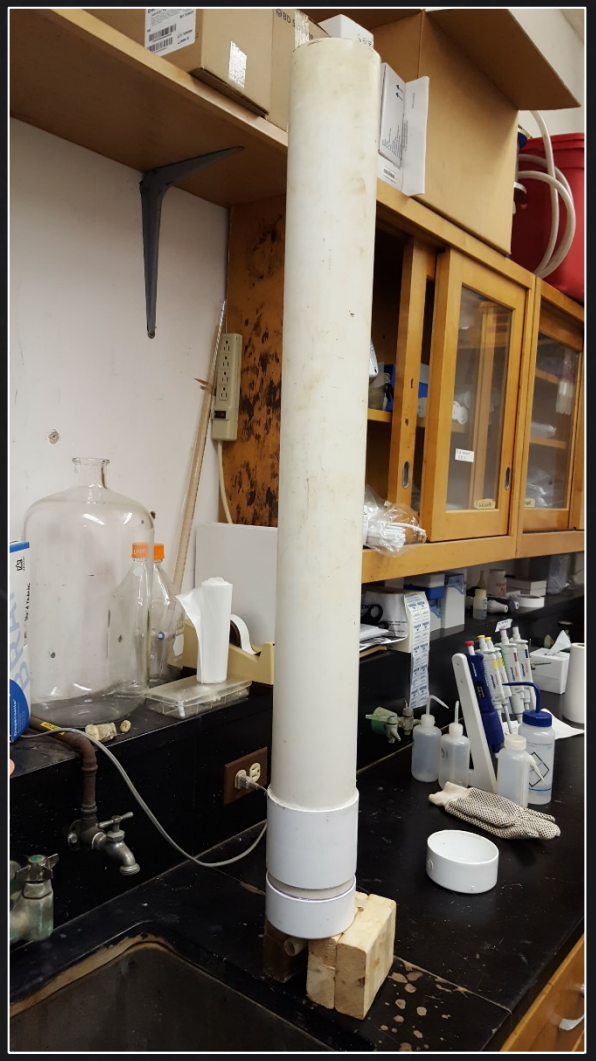


Modified Infiltrometer (MI)

- All sites
- Created for this study
- In situ falling head test
- Same equation as F-FHT
- Point measurement
- Saved cores

Laboratory Falling Head Test (L-FHT)

- All sites
- Sampled from cores
- Same equation as F-FHT
- Point measurement



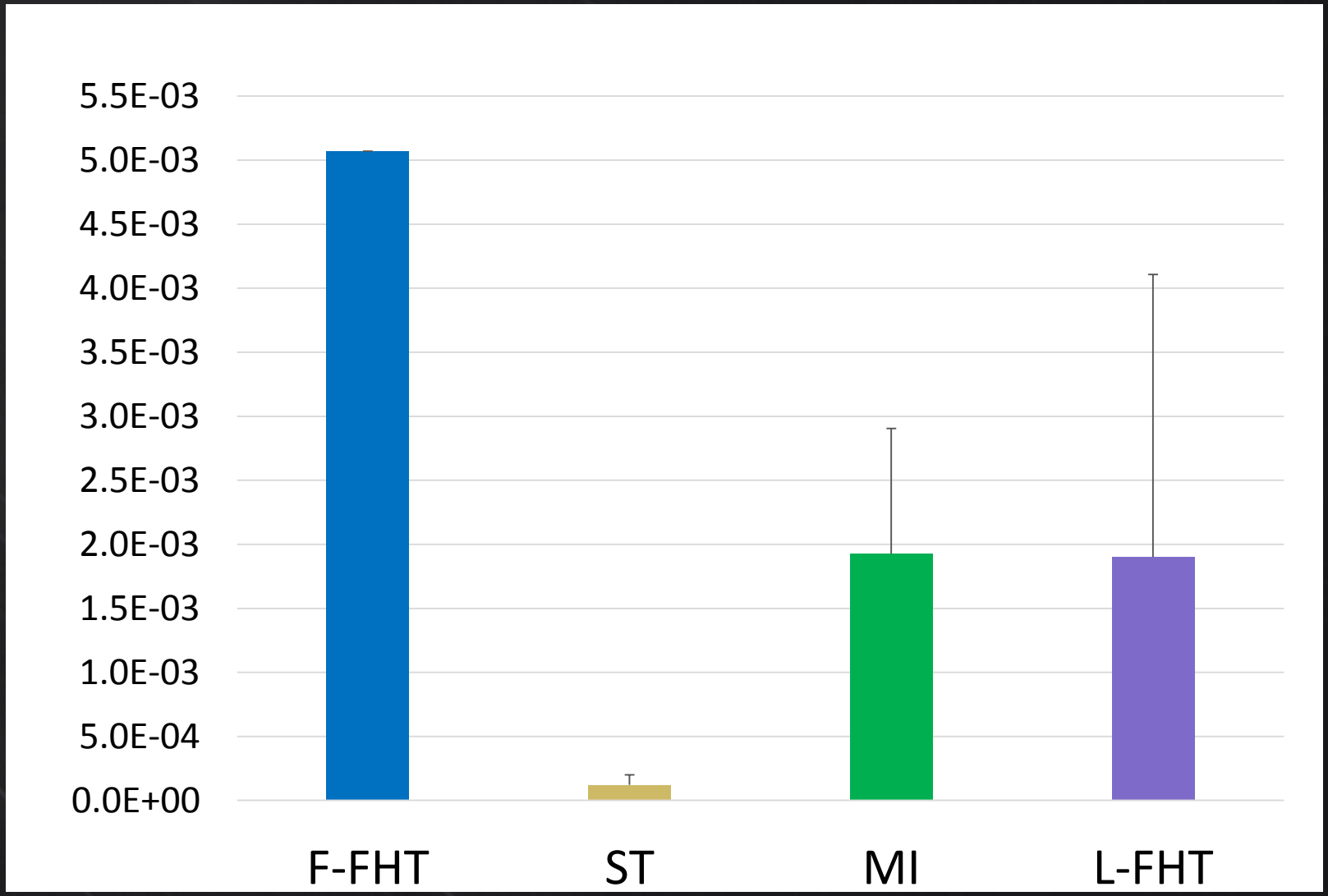
Slug Test (ST)

- Mayer Ranch and Red Oak PTS
- MR – porewater samples (horizontal)
- RO – piezometers (vertical)
- Installed during construction
- Bower and Rice equations

$$K = \frac{r_c^2 \ln\left(\frac{R_e}{r_w}\right)}{2L_e} \frac{1}{t} \ln\left(\frac{y_o}{y_t}\right)$$

$$\ln\left(\frac{R_e}{r_w}\right) = \left[\frac{1.1}{\ln\left(\frac{L_w}{r_w}\right)} + \frac{A + B\ln\left[\frac{H - L_w}{r_w}\right]}{\frac{L_e}{r_w}}\right]^{-1}$$

Results


5.5E-03
5.0E-03
4.5E-03
4.0E-03
3.5E-03
3.0E-03
2.5E-03
2.0E-03
1.5E-03
1.0E-03
5.0E-04
0.0E+00
F-FHT
ST
MI
L-FHT

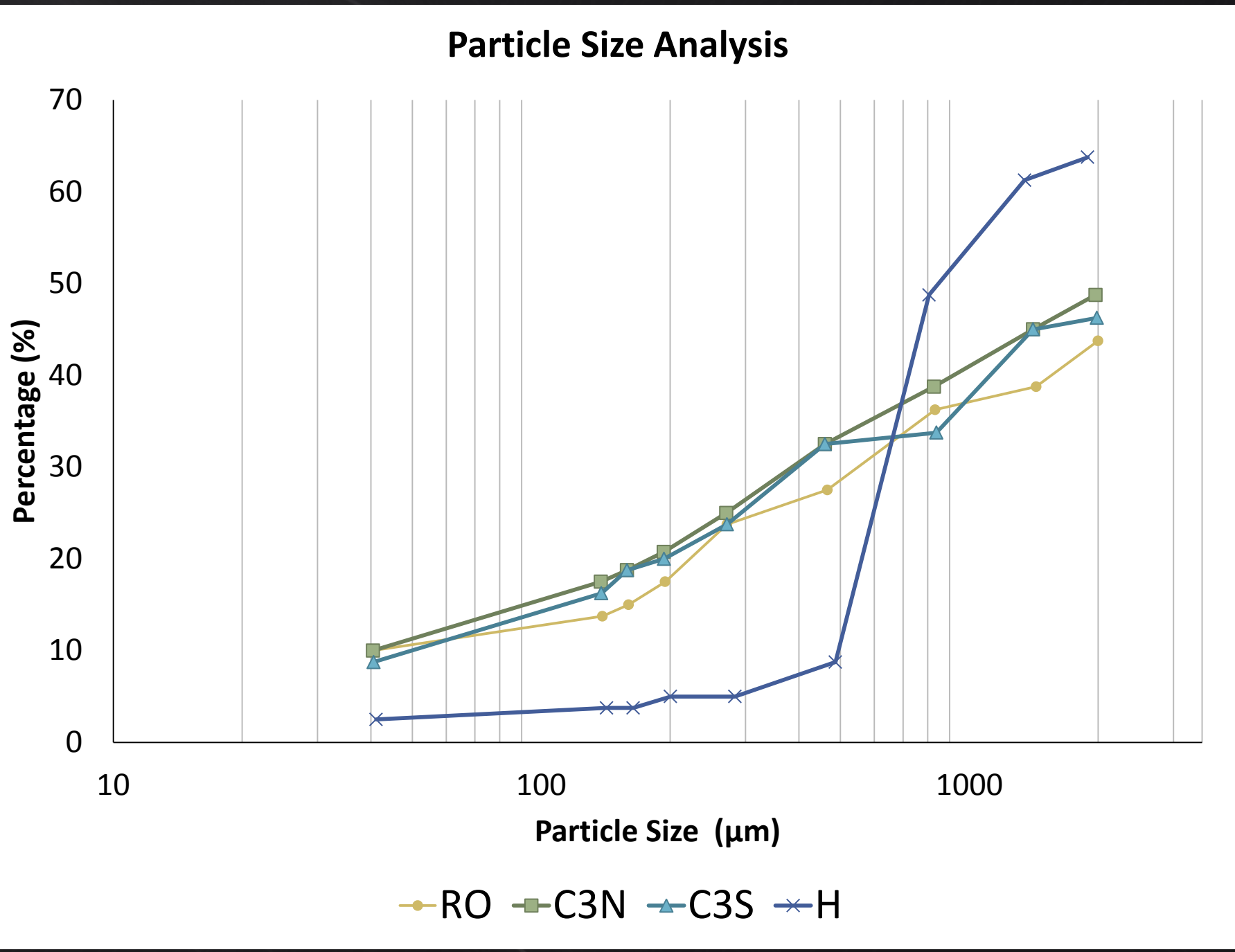
Particle Size Analysis – 2000 µm

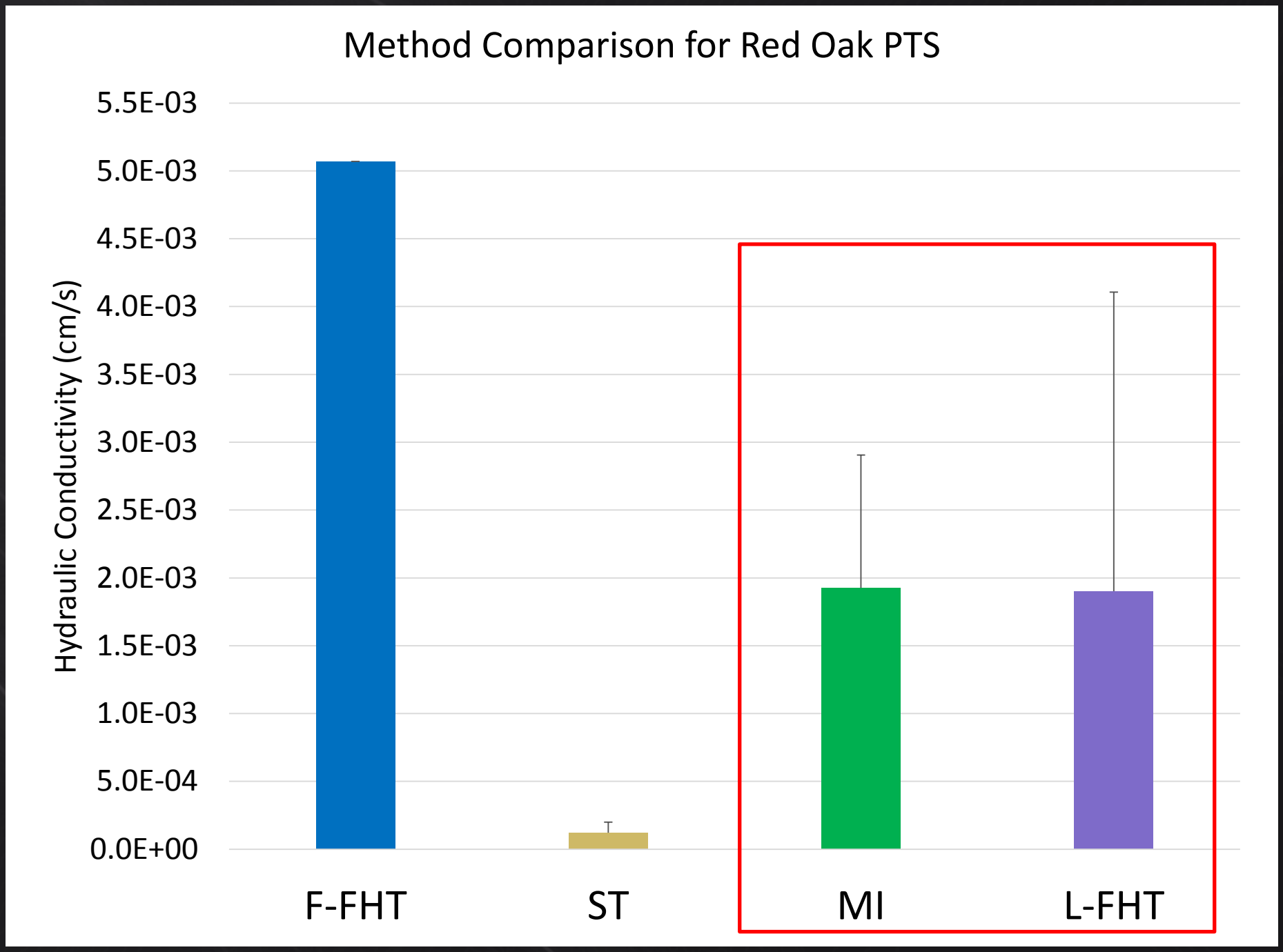
Red Oak PTS

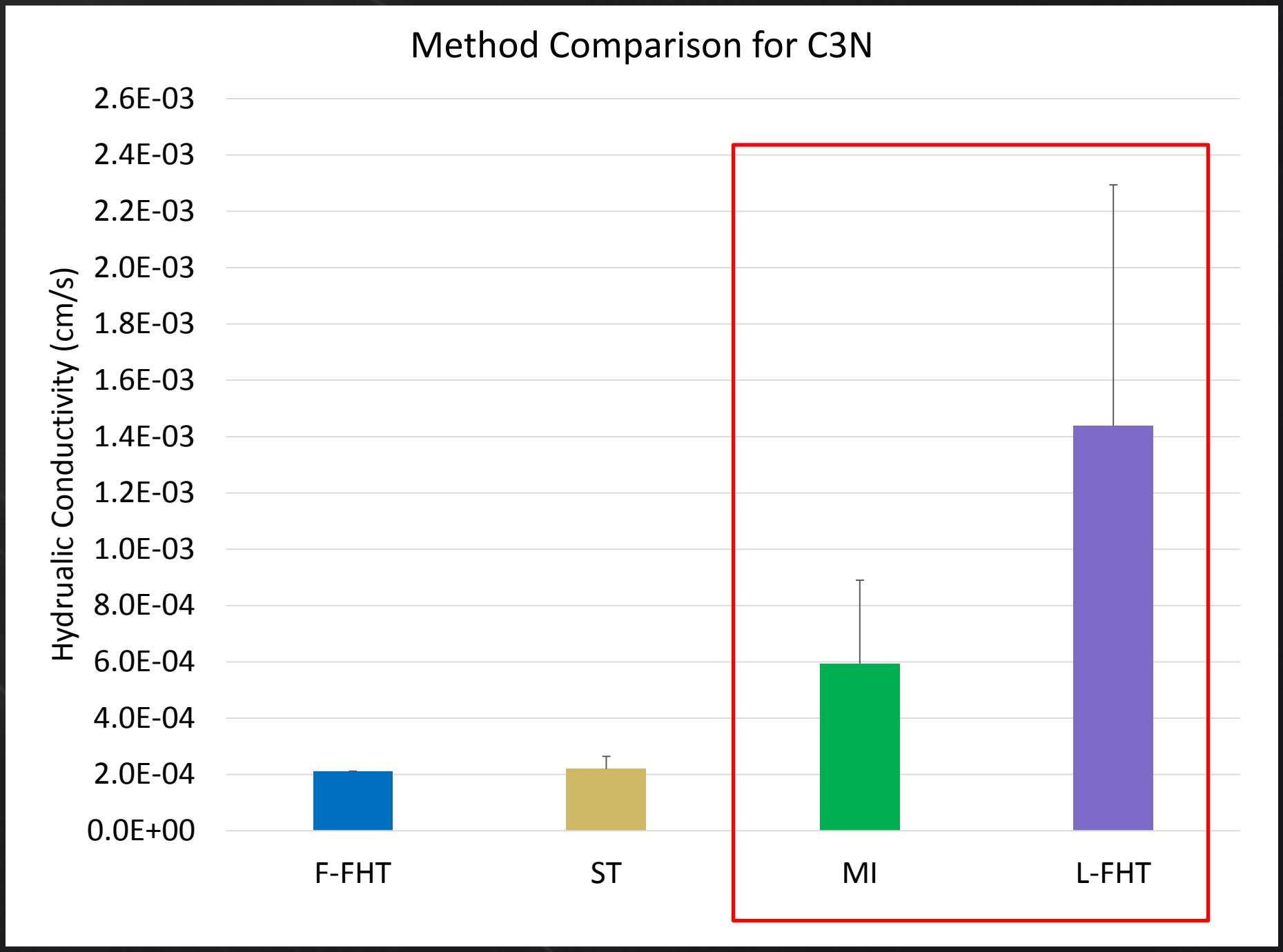
Hartshorne PTS

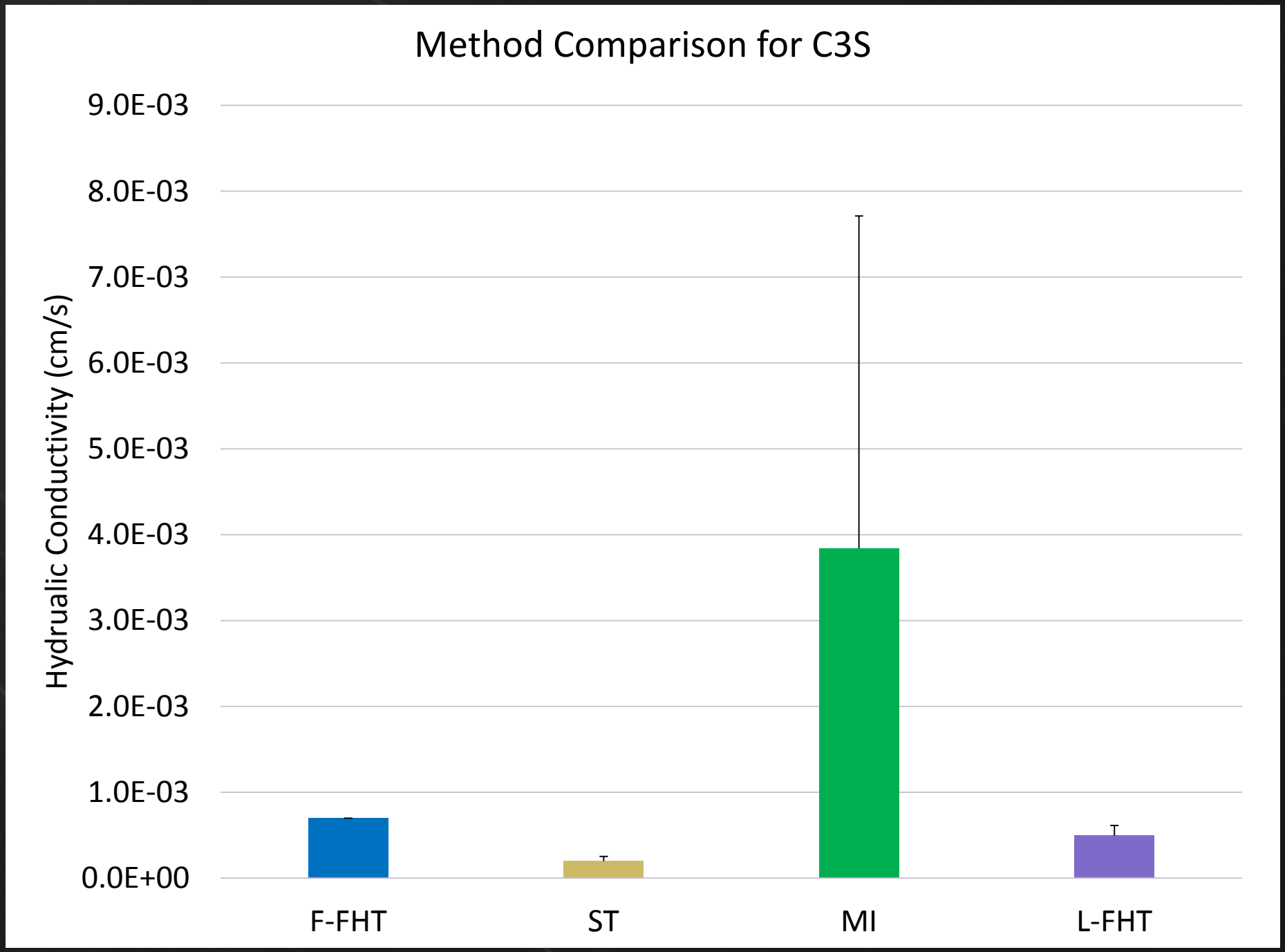
Mayer Ranch PTS – C3N

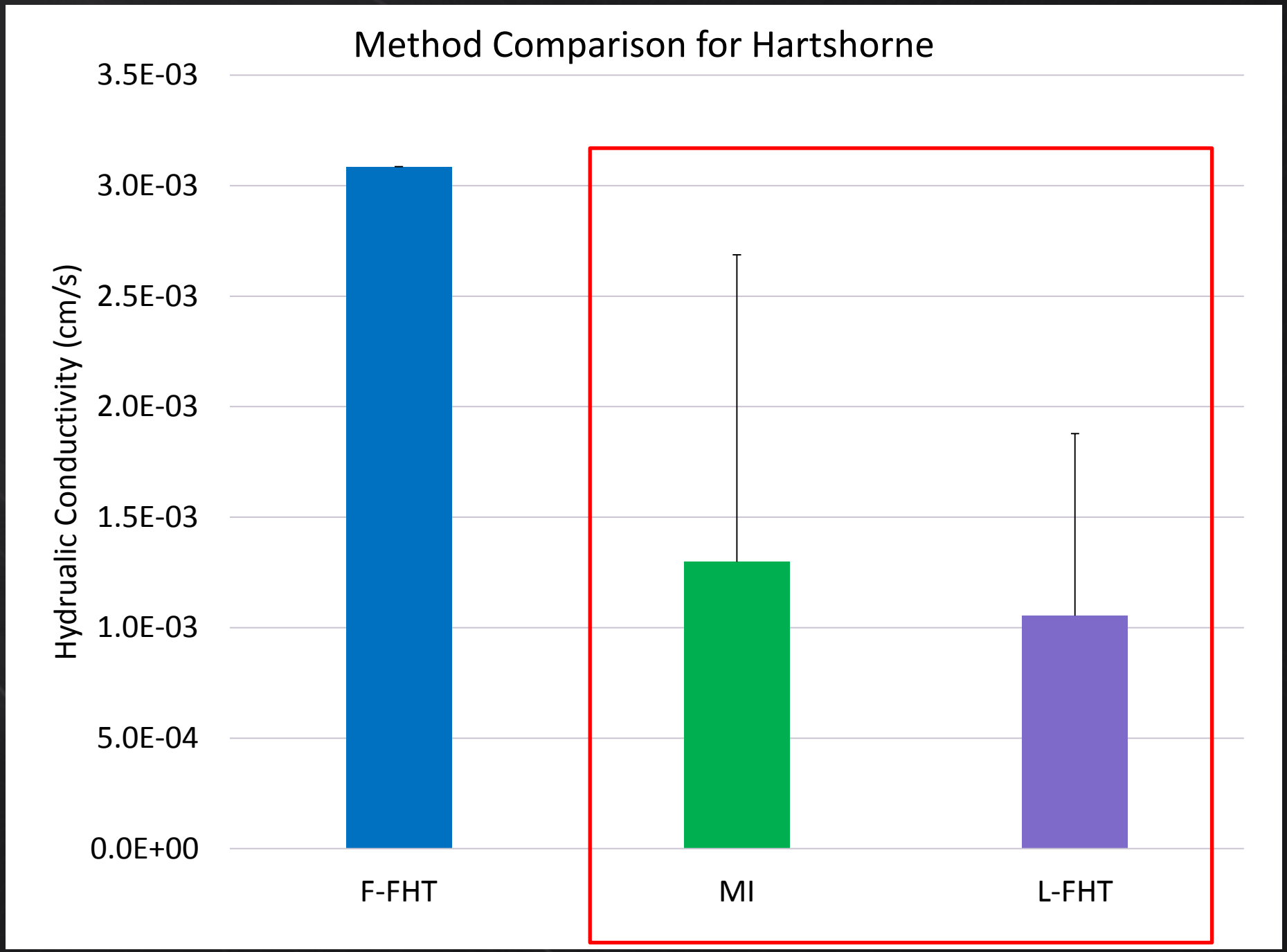
Mayer Ranch PTS – C3S

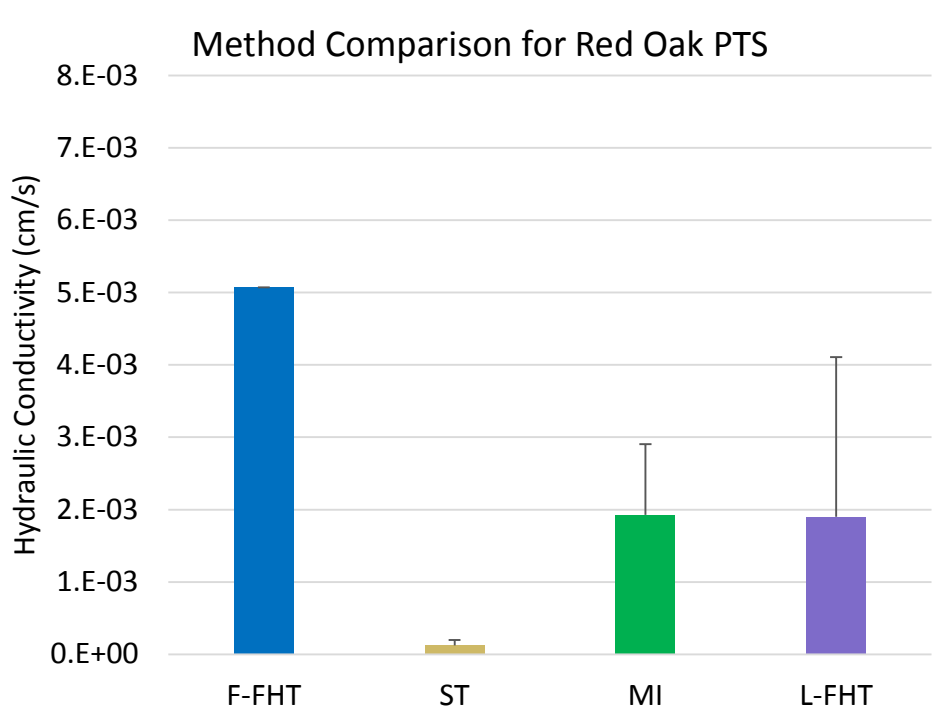

Particle Size Analysis
70
60
50
40
30
20
10
0
Percentage (%)
10
100
1000
Particle Size (µm)
RO
C3N
C3S
H

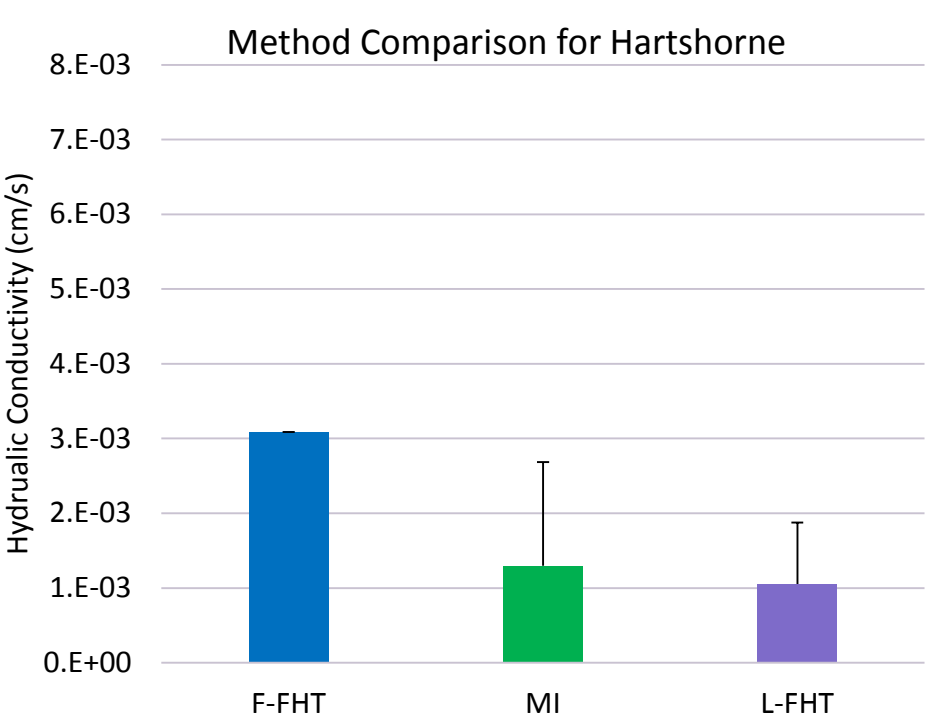

Method Comparison for Red Oak PTS
Hydraulic Conductivity (cm/s)
5.5E-03
5.0E-03
4.5E-03
4.0E-03
3.5E-03
3.0E-03
2.5E-03
2.0E-03
1.5E-03
1.0E-03
5.0E-04
0.0E+00
F-FHT
ST
MI
L-FHT

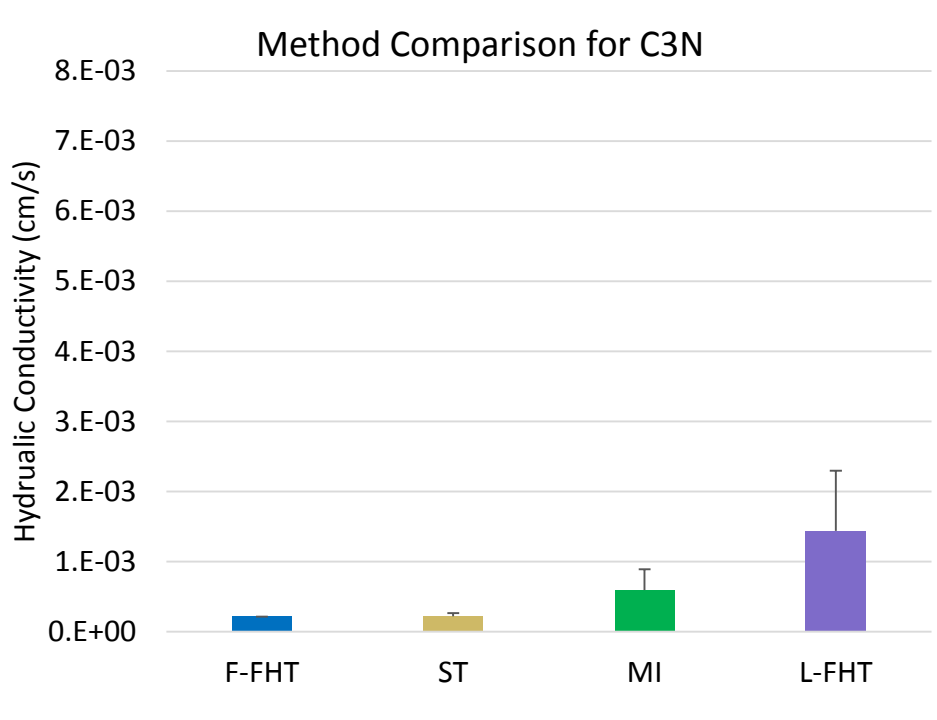

Method Comparison for C3N
Hydrualic Conductivity (cm/s)
2.6E-03
2.4E-03
2.2E-03
2.0E-03
1.8E-03
1.6E-03
1.4E-03
1.2E-03
1.0E-03
8.0E-04
6.0E-04
4.0E-04
2.0E-04
0.0E+00
F-FHT
ST
MI
L-FHT

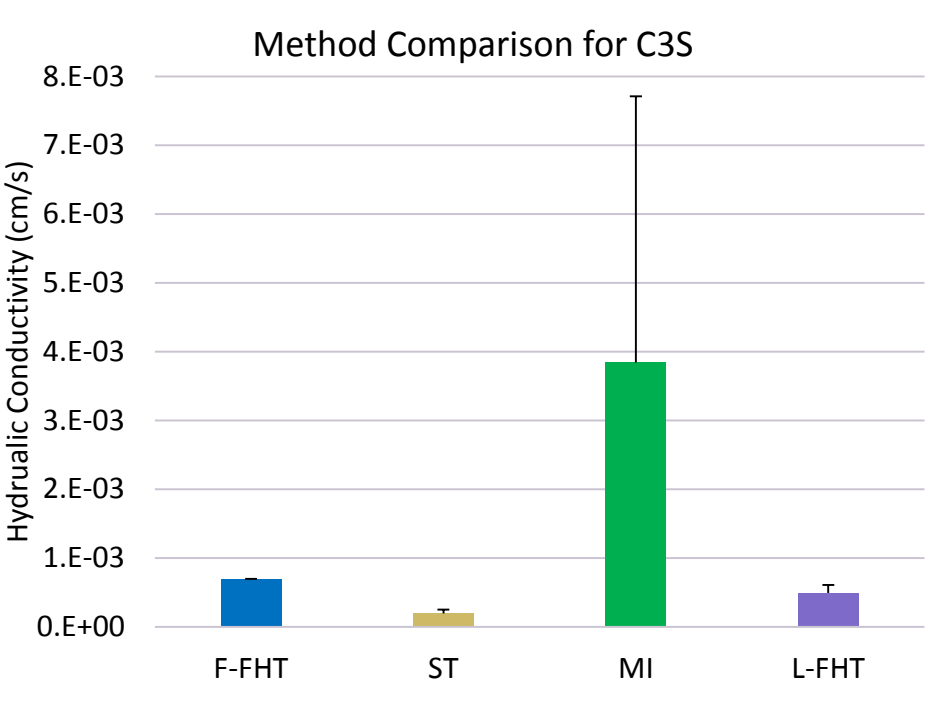

Method Comparison for C3S
Hydrualic Conductivity (cm/s)
9.0E-03
8.0E-03
7.0E-03
6.0E-03
5.0E-03
4.0E-03
3.0E-03
2.0E-03
1.0E-03
0.0E+00
F-FHT
ST
MI
L-FHT


Method Comparison for Hartshorne
Hydrualic Conductivity (cm/s)
3.5E-03
3.0E-03
2.5E-03
2.0E-03
1.5E-03
1.0E-03
5.0E-04
0.0E+00
F-FHT
MI
L-FHT


Method Comparison for Red Oak PTS
Hydraulic Conductivity (cm/s)
8.E-03
7.E-03
6.E-03
5.E-03
4.E-03
3.E-03
2.E-03
1.E-03
0.E+00
F-FHT
ST
MI
L-FHT

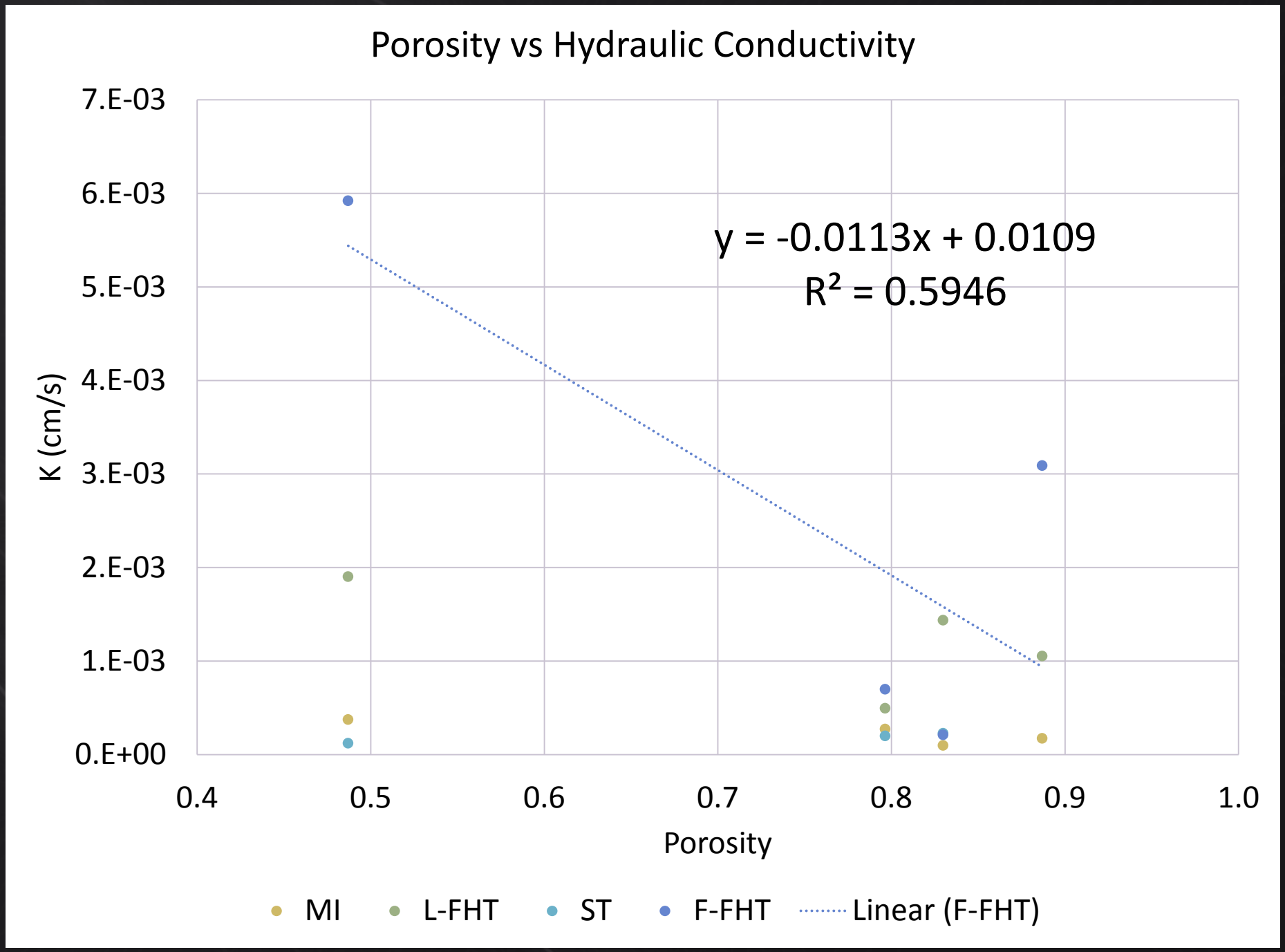

Method Comparison for Hartshorne
Hydraulic Conductivity (cm/s)
8.E-03
7.E-03
6.E-03
5.E-03
4.E-03
3.E-03
2.E-03
1.E-03
0.E+00
F-FHT
MI
L-FHT

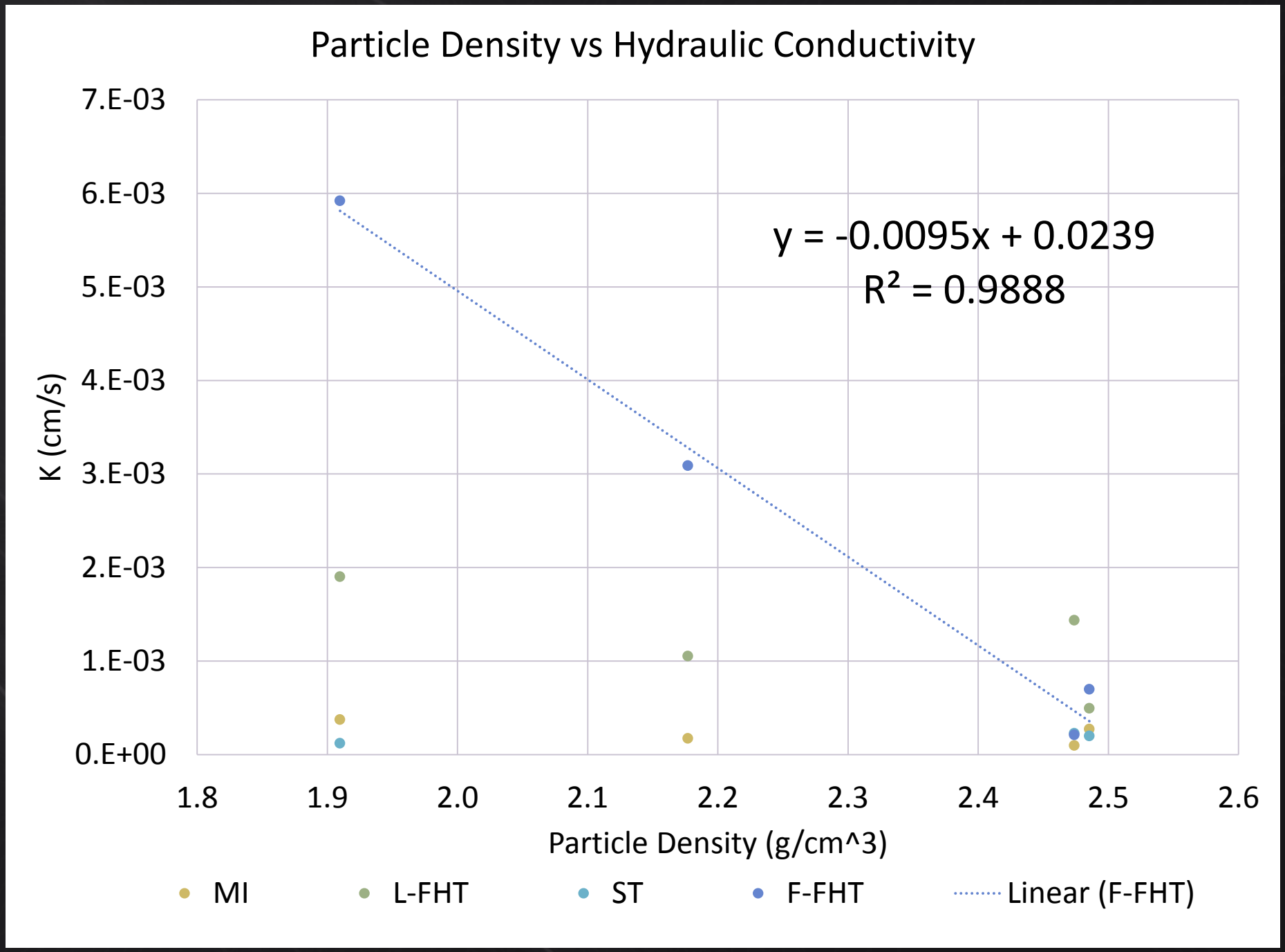

Method Comparison for C3N
Hydraulic Conductivity (cm/s)
8.E-03
7.E-03
6.E-03
5.E-03
4.E-03
3.E-03
2.E-03
1.E-03
0.E+00
F-FHT
ST
MI
L-FHT


Method Comparison for C3S
Hydraulic Conductivity (cm/s)
8.E-03
7.E-03
6.E-03
5.E-03
4.E-03
3.E-03
2.E-03
1.E-03
0.E+00
F-FHT
ST
MI
L-FHT

Comparing Hydraulic Conductivities

Location	RO	C3N	C3S	H
Measured Hydraulic Conductivity (cm/s)	1.39E-03	5.20E-04	1.35E-03 (6.53E-04)	1.49E-04
Original Hydraulic Conductivity (cm/s)	-	9.70E-02	9.70E-02	-
Hydraulic Loading Rate (cm/s)	1.17E-02	2.35E-02	2.56E-02	1.16E-02
Percent Decrease Per Year (%)	5.8%	12.4%	12.3%	11.0%


Porosity vs Hydraulic Conductivity
7.E-03
6.E-03
5.E-03
4.E-03
3.E-03
2.E-03
1.E-03
0.E+00
K (cm/s)
y = -0.0113x + 0.0109
R² = 0.5946
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Porosity
MI
L-FHT
ST
F-FHT
Linear (F-FHT)


Particle Density vs Hydraulic Conductivity
7.E-03
6.E-03
5.E-03
4.E-03
3.E-03
2.E-03
1.E-03
0.E+00
K (cm/s)
y = -0.0095x + 0.0239
R² = 0.9888
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
Particle Density (g/cm^3)
MI
L-FHT
ST
F-FHT
Linear (F-FHT)

Conclusions – Method Comparison

Method	Strength	Weakness
F-FHT	most representative easy to complete	takes time site limitations
MI	lower variability in situ	intensive labor
L-FHT	easy to complete	higher variability potential disturbance
ST	lower variability easy to complete	has to be installed during construction

Conclusions

- The hydraulic conductivity of the VFBRs has decreased
- Trends existed between hydraulic conductivity and porosity/particle density
- Weak or no trends in other parameters
- Best method depends on the situation

Update!

- Flipped the VFBRs at MRPTS
- Initial data indicates a dramatic increase in hydraulic conductivity!!!!
- >3 days to drain, improved to ~3 hours

Questions?

Location	RO	C3N	C3S	H
Measured Hydraulic Conductivity (cm/s)	1.39E-03	5.20E-04	1.35E-03 (6.53E-04)	1.49E-04
Original Hydraulic Conductivity (cm/s)	-	9.70E-02	9.70E-02	-
Hydraulic Loading Rate (cm/s)	1.17E-02	2.35E-02	2.56E-02	1.16E-02
Percent Decrease Per Year (%)	5.8%	12.4%	12.3%	11.0%