Hydraulic Conductivity Assessment in Prairie Tills

Sheila Duchek, M.Sc., P.Geo.; SNC-Lavalin Inc.
October 15, 2020

Virtual
remediation technologies symposium 2020
Together Apart

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Our vision

We strive to be the premier engineering solutions partner, committed to delivering complex projects from vision to reality for a sustainable lifespan.

Presentation Outline

- Prairies geology and the origin of till
- Till and groundwater flow
- Importance of accurate hydraulic conductivity values
- Hydraulic methods - experimental
- Correlation methods - empirical
- Putting it all together: multiple lines of evidence approach to site characterization

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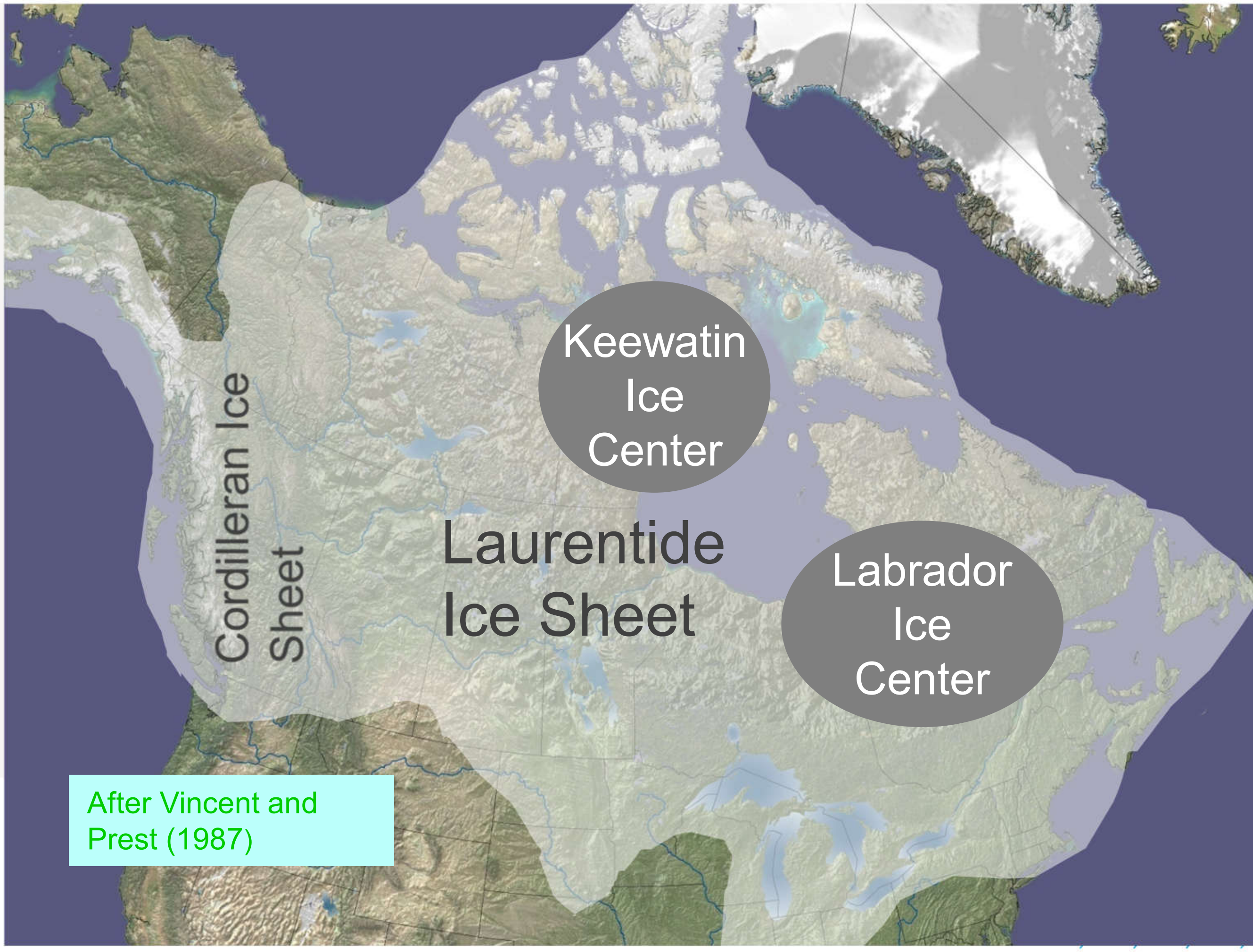

Keewatin Ice Center
Cordilleran Ice Sheet
Laurentide Ice Sheet
Labrador Ice Center
After Vincent and Prest (1987)

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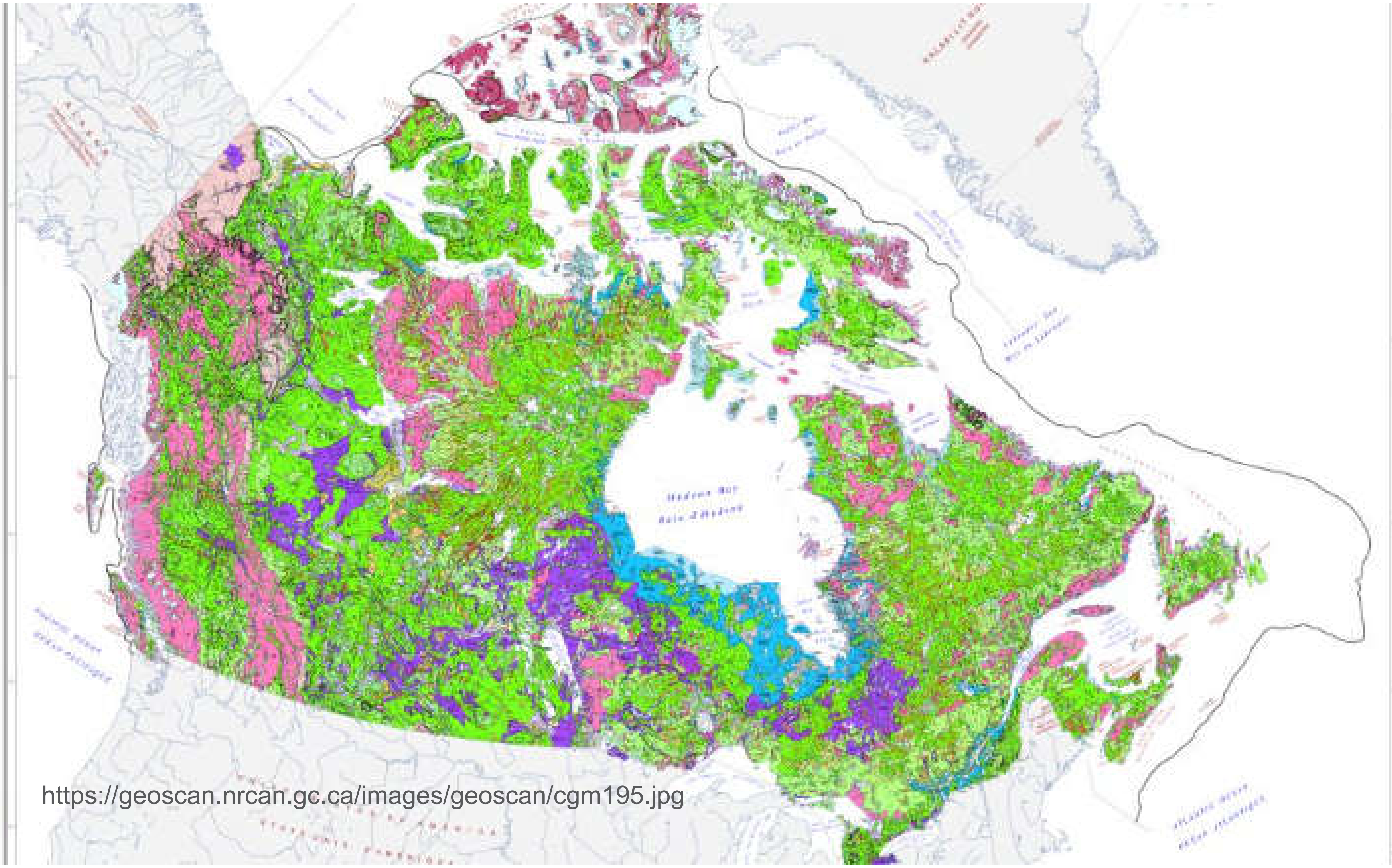


https://geoscan.nrcan.gc.ca/images/geoscan/cgm195.jpg

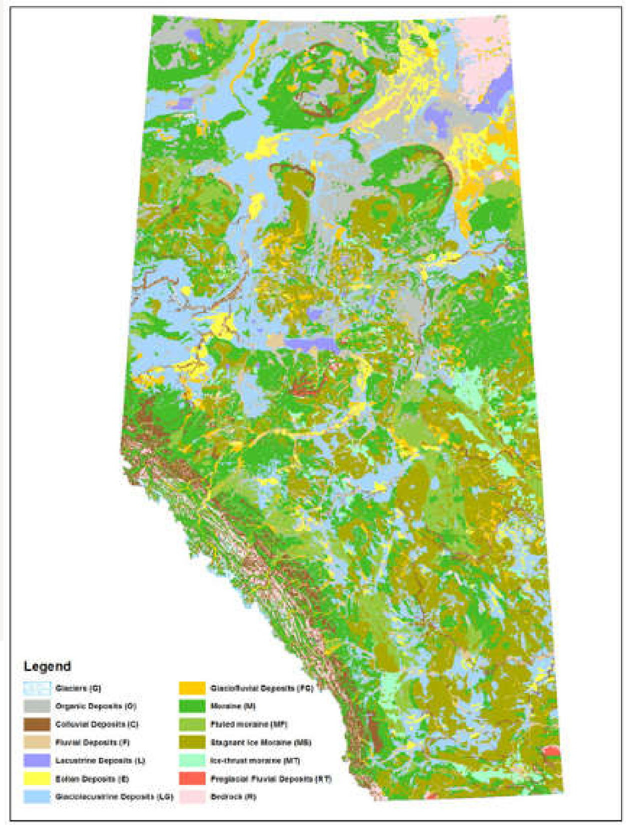
Quaternary Geology of Alberta

Drift Thickness of Alberta

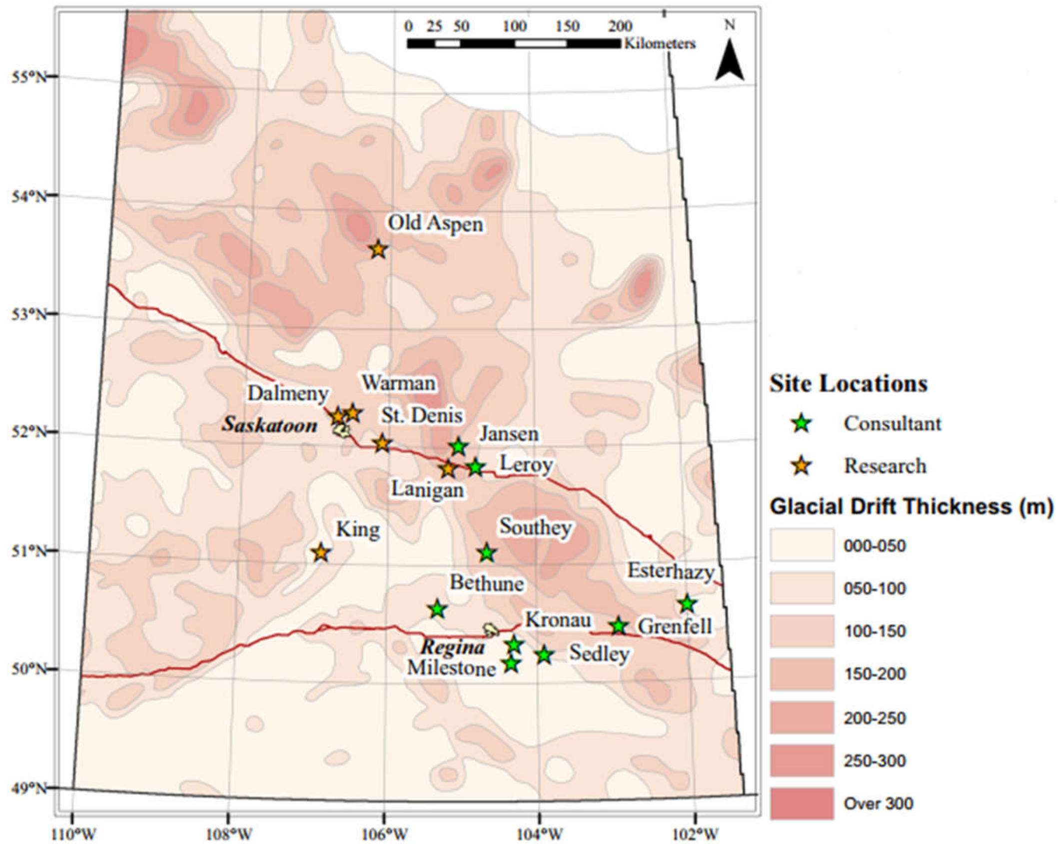
https://static.ags.aer.ca/files/document/MAP/Map_227.pdf

Surficial Geology of Alberta

https://www.ags.aer.ca/publications/MAP_601.html



Quaternary Geology of Saskatchewan



Taken from Ferris, D., Potter,. G., Ferguson, G. Characterization of the hydraulic conductivity of glacial till aquitards. Hydrogeology Journal, May 2020. https://doi.org/10.1007/s10040-020-02161-7

Mossop GD, Shetsen I (1994) Geological atlas of the Western Canada Sedimentary Basin. Canadian Society of Petroleum Geologists and Alberta Research Council, Edmonton, AB

Groundwater Flow Properties of Till

- Flow through glacial deposits is complex
- Till fabric may be massive and dominated by clay particles
- Till fabric can be layered in sheets, with lenses of higher permeability
- Flow may be controlled by fractures
- Till thickness can be variable from thin veneer to >100m thick
- Degree of weathering affect flow patterns

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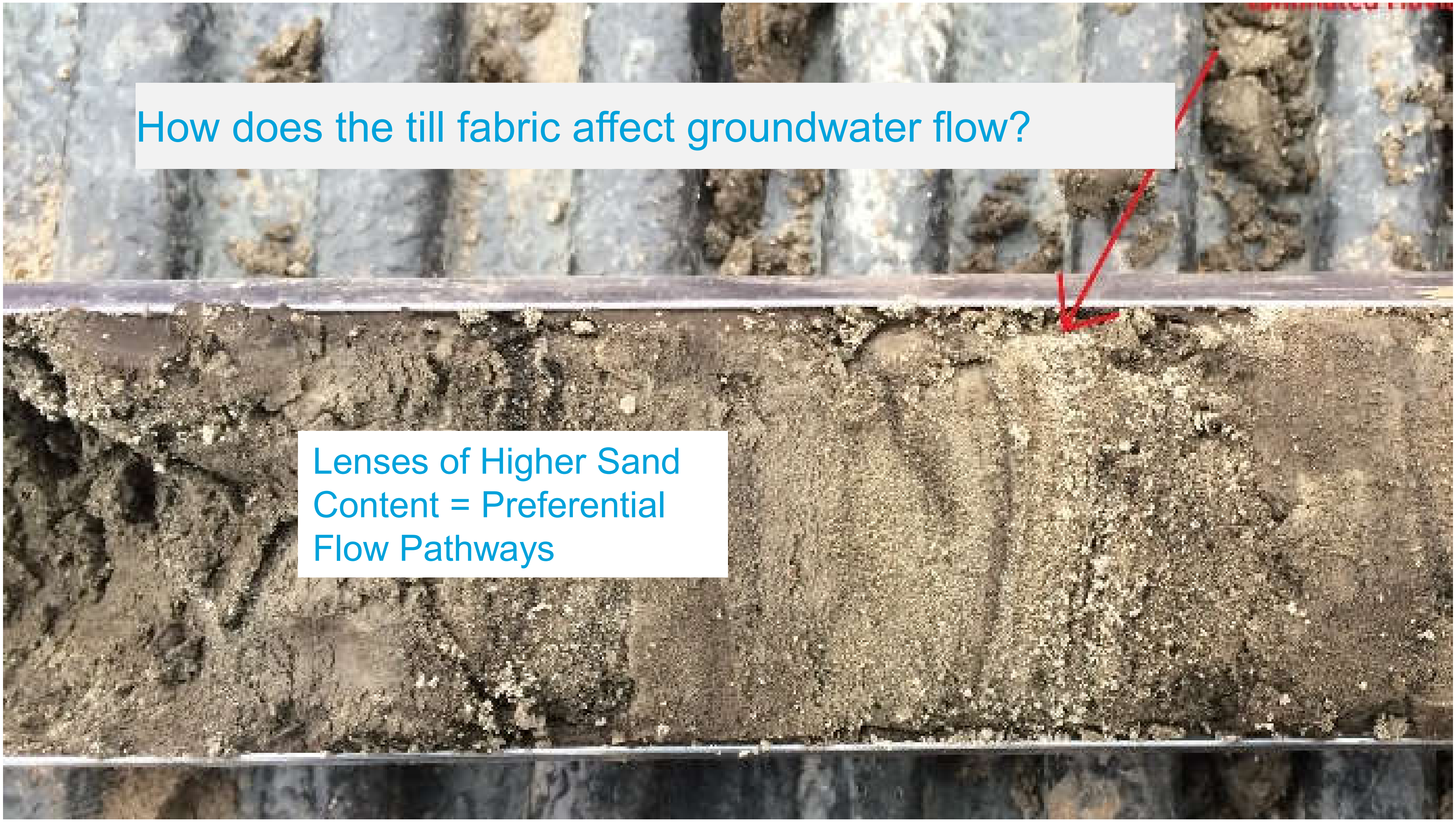
How does till fabric affect groundwater flow?

Massive, blocky texture, with wide range of grain sizes

How does the till fabric affect groundwater flow?

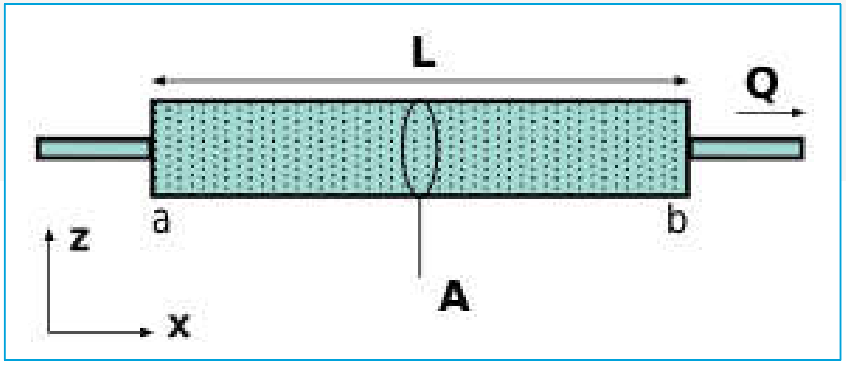


Why is Hydraulic Conductivity Characterization Important?

If you are studying how water moves, which is vitally important to the CSM, then you need to evaluate hydraulic conductivity, as this one important parameter governs water flow.

Darcy’s Law is the equation that describes fluid flow through porous media and it forms the basis of hydrogeology.

$$Q = \frac{kA}{\mu L} \Delta p$$



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Alberta Government

Alberta Tier 2 Soil and Groundwater Remediation Guidelines

January 10, 2019

https://open.alberta.ca/dataset/aa212afe-2916-4be9-8094-42708c950313/resource/157bf66c-370e-4e19-854a-3206991cc3d2/download/albertatier2guidelines-jan10-2019.pdf

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DUA Pathway Exclusion Assessment

- Does the aquifer have a bulk K of 1 x 10^{-6} m/s or greater and can deliver 0.76L/s, with a thickness greater than 0.5m?
- Is the aquifer currently being used for domestic purposes?
- Is the aquifer determined by AEP to be a DUA?
- Is there a minimum 5.0 m thickness of uncontaminated, massive, undisturbed, unfractured, fine-grained material meeting appropriate guidelines with a bulk hydraulic conductivity ≥1 x 10^{-7} m/s?
- Is there an equivalent thickness of natural, undisturbed geologic material that is more than 5.0 m thick and is supported by technical information regarding the lithological properties, prepared by the professional conducting the site assessment and accepted by AEP?

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DUA Pathway Exclusion Assessment

- Does the aquifer have a bulk K of 1×10^{-6} m/s or greater?
- Is the aquifer currently being used for domestic purposes?
- Is the aquifer determined by AEP to be a DUA?
- Is there a minimum 5.0 m thickness of uncontaminated, massive, undisturbed, unfractured, fine grained material meeting appropriate guidelines with a bulk hydraulic conductivity < or = to 1×10^{-7} m/s?
- Is there an equivalent thickness of natural, undisturbed geologic material that is more than 5.0 m thick and is supported by technical information regarding the lithological properties, prepared by the professional conducting the site assessment and accepted by AEP?

Hydraulic Conductivity Values Are Very Important!

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So…
What happens if there is NO groundwater?
Or… the wells are sooo slow to recover?

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Determining Hydraulic Conductivity Methods

Hydraulic Methods
(Experimental Approach) →
- In Situ Field Measurements
- Laboratory Methods

Correlation Methods
(Empirical Approach) →
- Grain Size Distribution
- Pore Size Distribution
- Soil Texture

Based on R.J.Oosterbaan, 1994

R.J. Oosterbaan, H.J. Nijland, H.P. Ritzema, *Drainage Principles and Applications*, I.L.R.I., 16, 435 (1994)

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Determining Hydraulic Conductivity Methods

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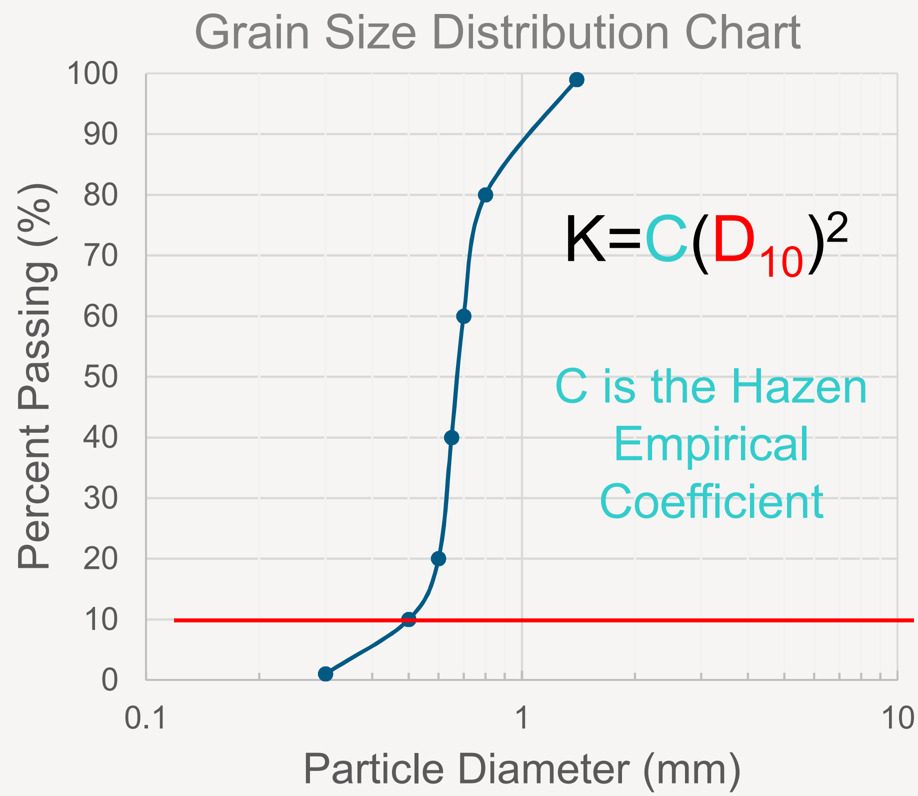
Correlation Methods:
Bear (1972) Dynamics of Fluids in Porous Media

K (cm/s)	10^2	10^1	$10^0=1$	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}
K (ft/day)	10^5	10,000	1,000	100	10	1	0.1	0.01	0.001	0.0001	10^{-5}	10^{-6}	10^{-7}
Relative Permeability	Pervious				Semi-Pervious				Impervious				
Aquifer	Good					Poor				None			
Unconsolidated Sand & Gravel	Well Sorted Gravel		Well Sorted Sand or Sand & Gravel			Very Fine Sand, Silt, Loess, Loam							
Unconsolidated Clay & Organic					Peat		Layered Clay			Fat / Unweathered Clay			
Consolidated Rocks	Highly Fractured Rocks				Oil Reservoir Rocks			Fresh Sandstone		Fresh Limestone, Dolomite		Fresh Granite	

Grain Size Analysis

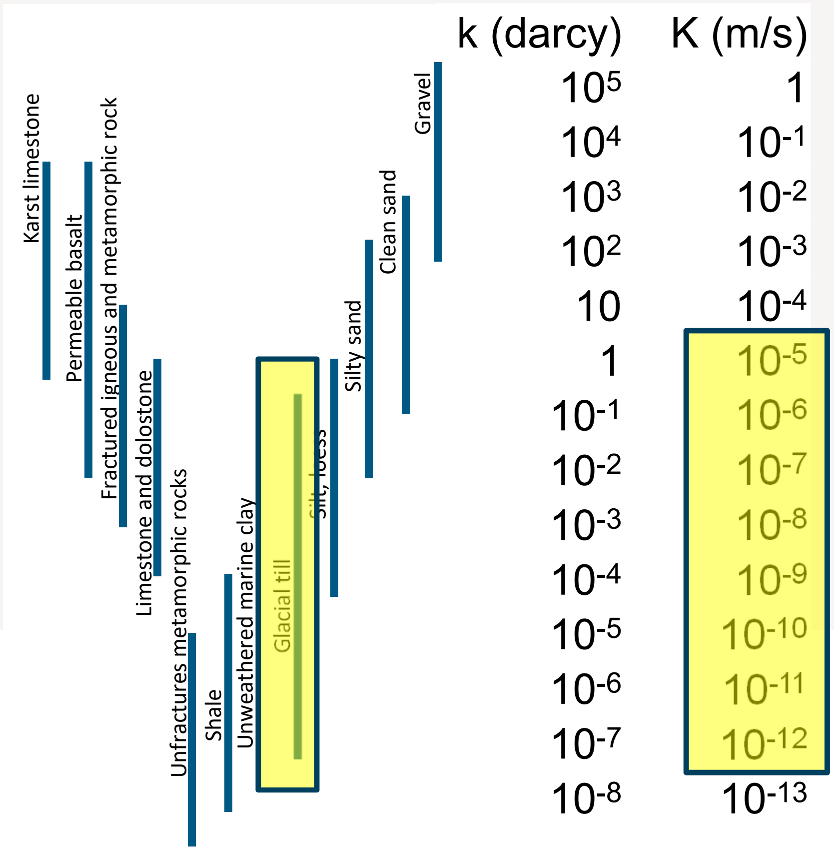
Credits: Prof. Susan Burns, Georgia Tech University, Department of Civil and Environmental Engineering



$$K=C(D_{10})^2$$

C is the Hazen Empirical Coefficient

Ranges of Values of Hydraulic Conductivity and Permeability for Various Geologic Materials – Freeze & Cherry, 1979



Determining Hydraulic Conductivity Methods

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Correlation Methods (Empirical Approach)

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Saskatoon Geosciences and Materials Testing Laboratory

Ex-Situ Laboratory Testing

Advantages

- Easy to obtain samples
- May provide data when field resources are limited (i.e., time constraints and costs)
- Relatively inexpensive analysis
- Data can support multiple lines of evidence

Ex-Situ Laboratory Testing

Challenges

- Samples may be biased, depending on collection
- Depositional environment not always preserved
- Anisotropy not easily maintained in sample
- Results not accepted by regulatory body in Alberta

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Determining Hydraulic Conductivity Methods

Hydraulic Methods
(Experimental Approach)

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Correlation Methods
(Empirical Approach)

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HPT – Hydraulic Profiling Tool

- Provides vertical profile in a single borehole
- Identifies lithology and fluid properties
- Measures bulk formation electrical conductivity
- Estimates hydraulic conductivity by injecting clean water into formation as probe is advanced. Low pressure response corresponds to higher k-values.
- Hydraulic conductivity value range between $2x10^{-4}$ and $3x10^{-7}$ m/s

McCall, W., & Christy, T. M. (2020). The Hydraulic Profiling Tool for Hydrogeologic Investigation of Unconsolidated Formations. *Groundwater Monitoring & Remediation, 40*(no. 3), 89-103. doi:10.1111/gwmr.12399

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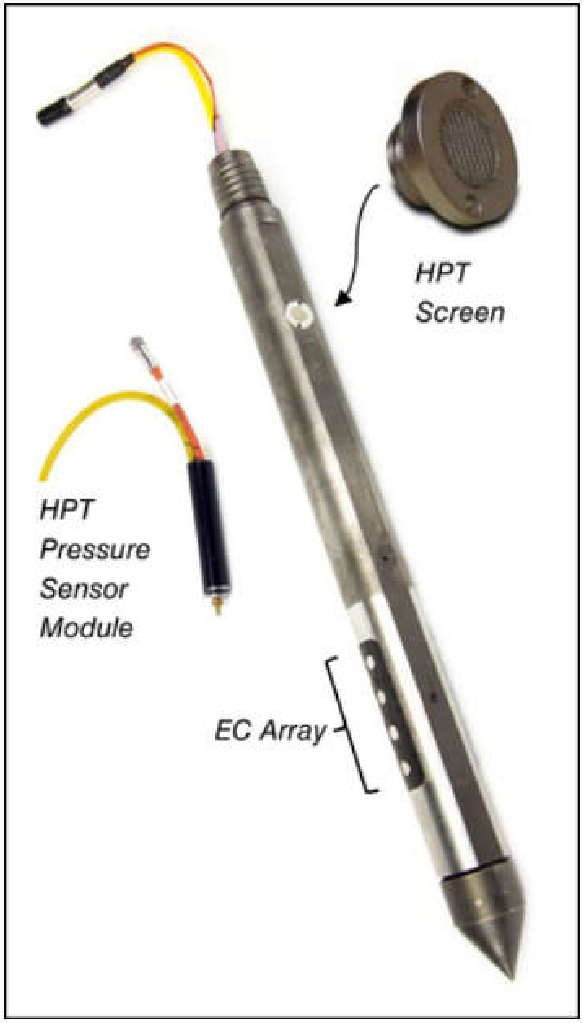

Direct Push Permeameter

- Obtains high resolution data over a vertical profile of unconsolidated sediment
- Uses pressure transducers above and below tool to measure change in pressures as water is injected, then stopped, and as pressure dissipates.

Direct Push Cone Penetration Testing

- Measures resistance on the conical tip of the cylindrical rod as it is pushed through soil at a constant rate.
- Hydraulic conductivity profiles are obtained from pore-water pressure measurements.

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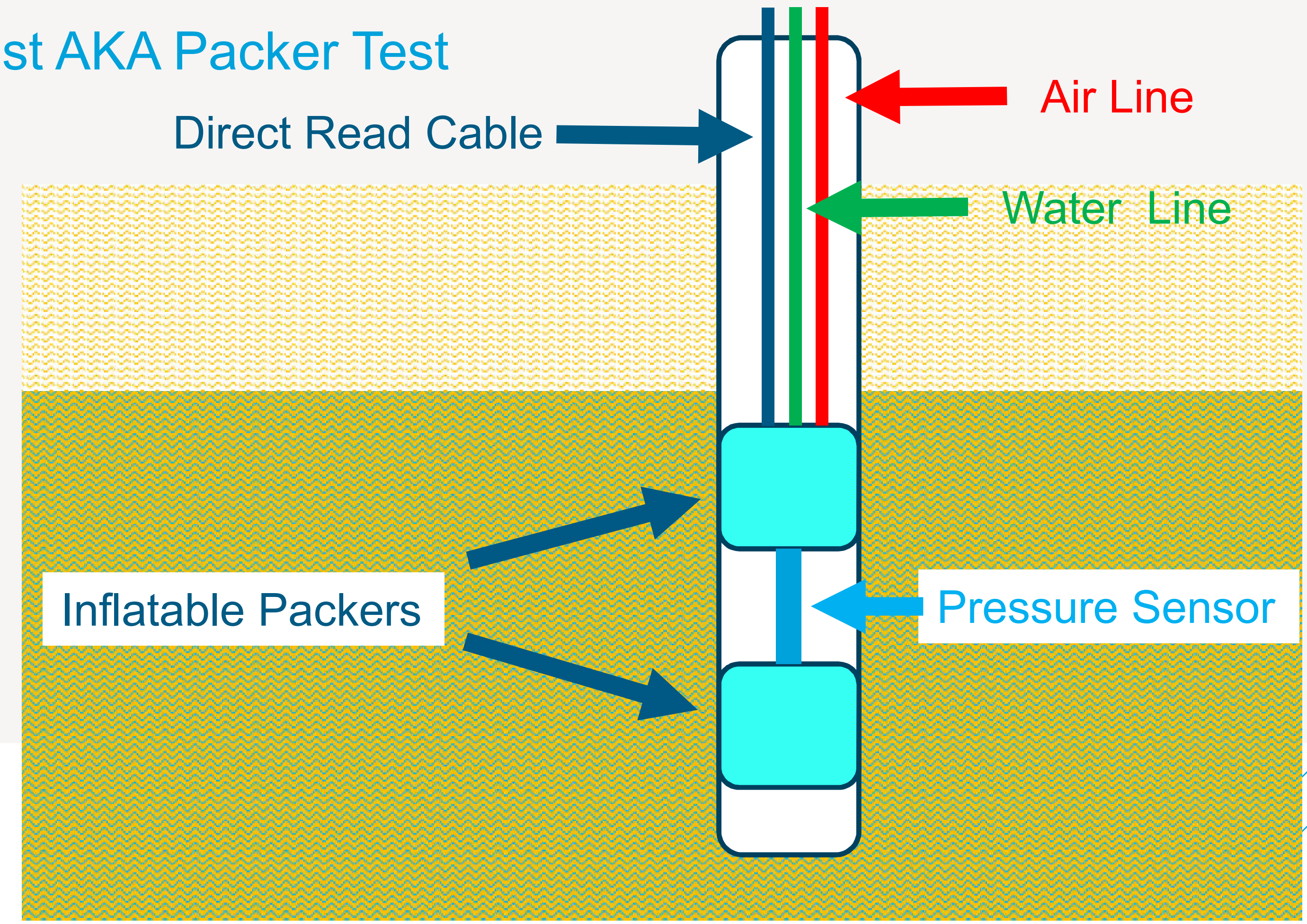
Lugeon Test AKA Packer Test



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Hydraulic Conductivity – In-Situ Methods

- Rising Head Test
- Constant Rate Test
- Falling Head Test
- Double Tube
- Infiltrometer
- Guelph Permeameter

- Below Groundwater Surface
  (Based on Darcy's Law)

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Hydraulic Conductivity – In-Situ Methods

- Rising Head Tests – standard methods
- Constant Rate Testing
- Falling Head Tests
- Double Tube
- Infiltrometer
- Guelph Permeameter

- Above Groundwater Surface

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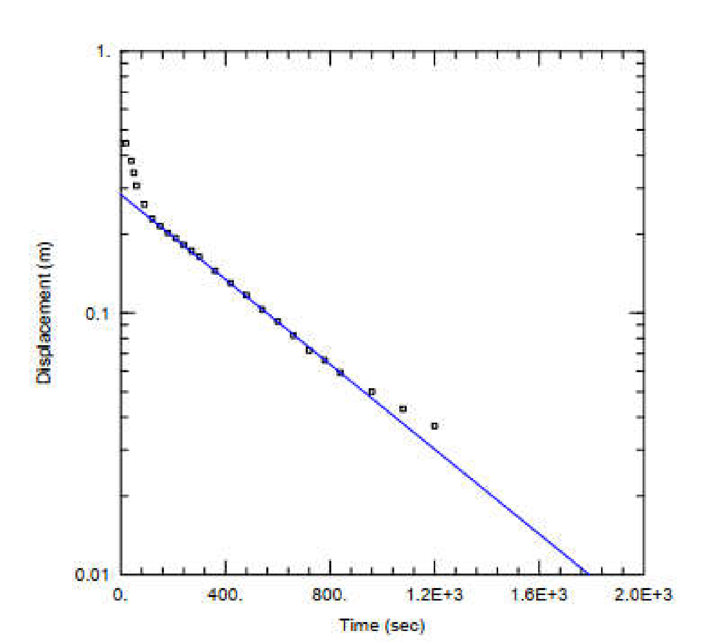
In-Situ Hydraulic Conductivity Test: Rising Head



Aquifer Model: Unconfined
K: 1.06E-6 m/s
Solution Method: Bouwer-Rice

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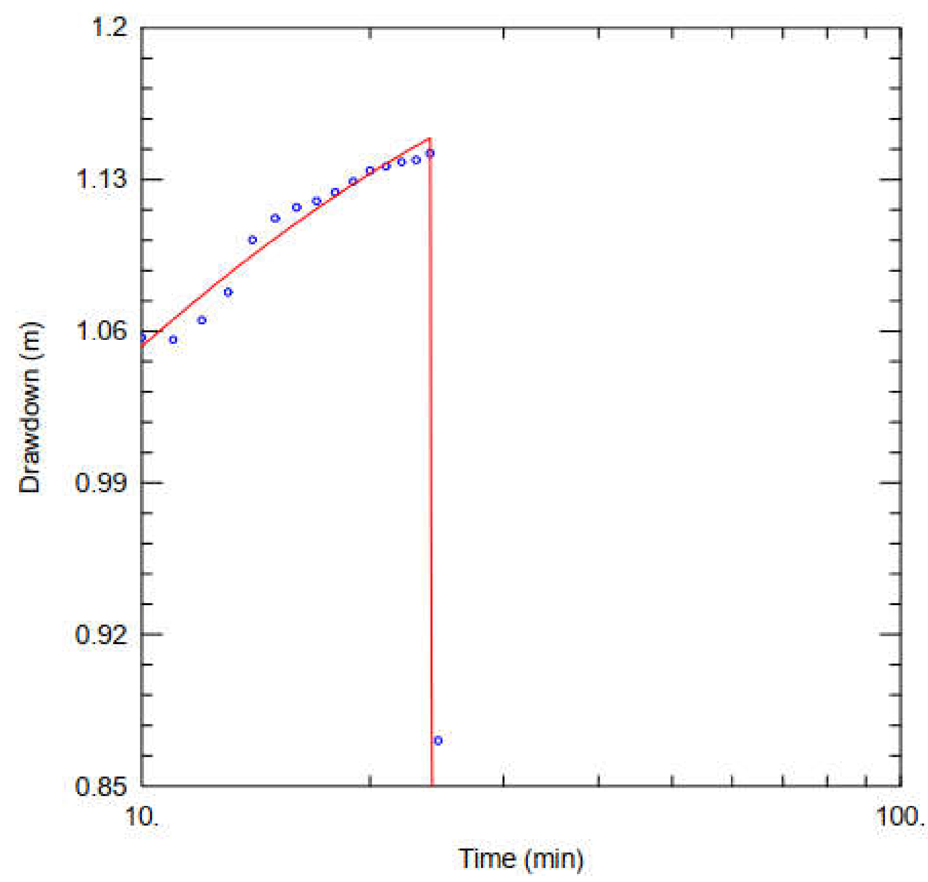
In-Situ Constant Rate Test

Aquifer Model: Unconfined
Solution Method: Neuman
T=3.6E-5 m^2/s
K=9.0E-6 m/s



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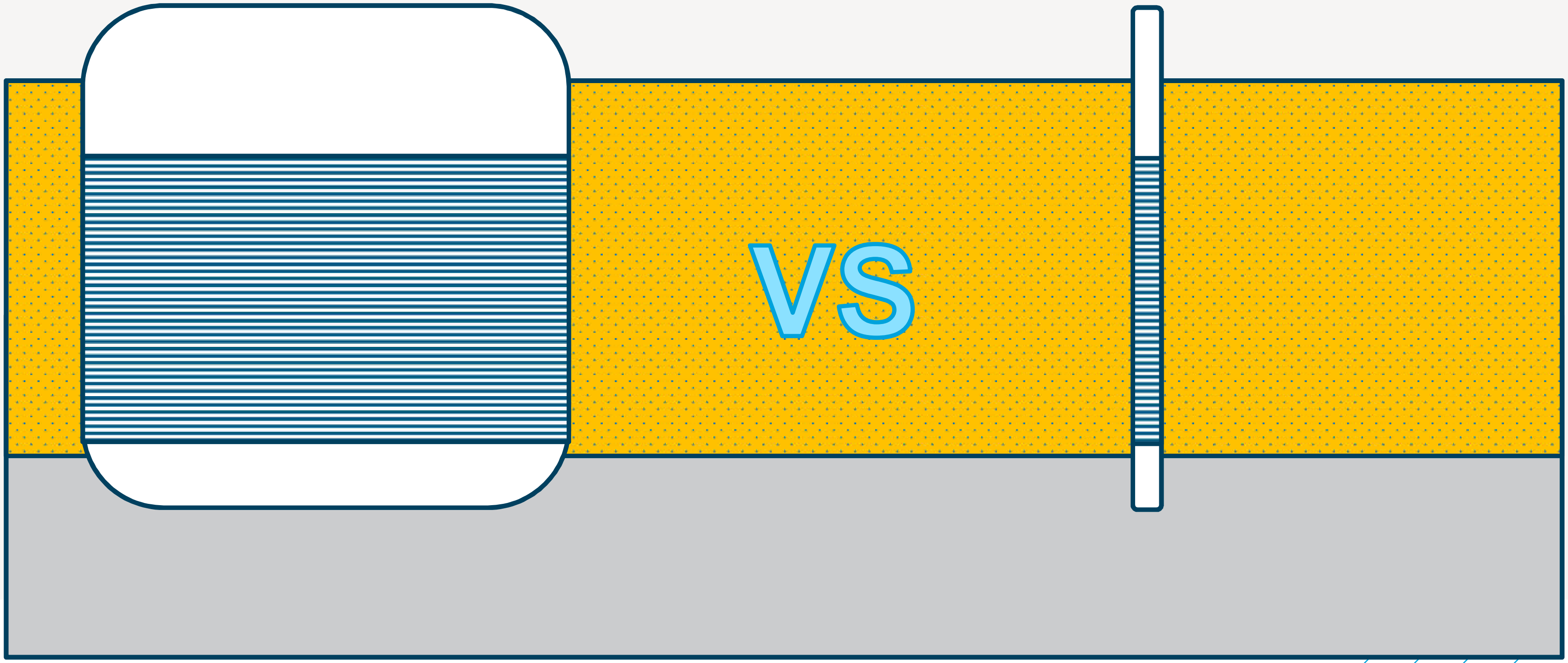
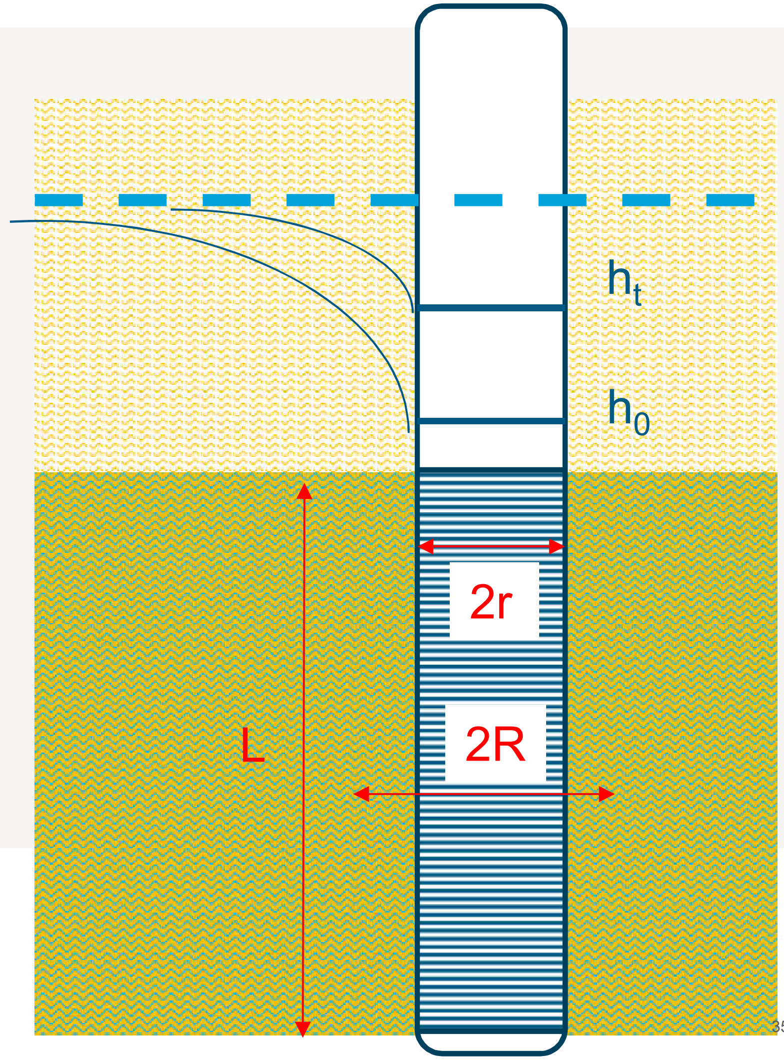
Change Diameter of Well Casing



Effect of Radius and Darcy's Law

$$Q = \frac{KA(\Delta h)}{L}$$

$$K = \frac{\Delta V \; L}{\Delta t \, A h}$$



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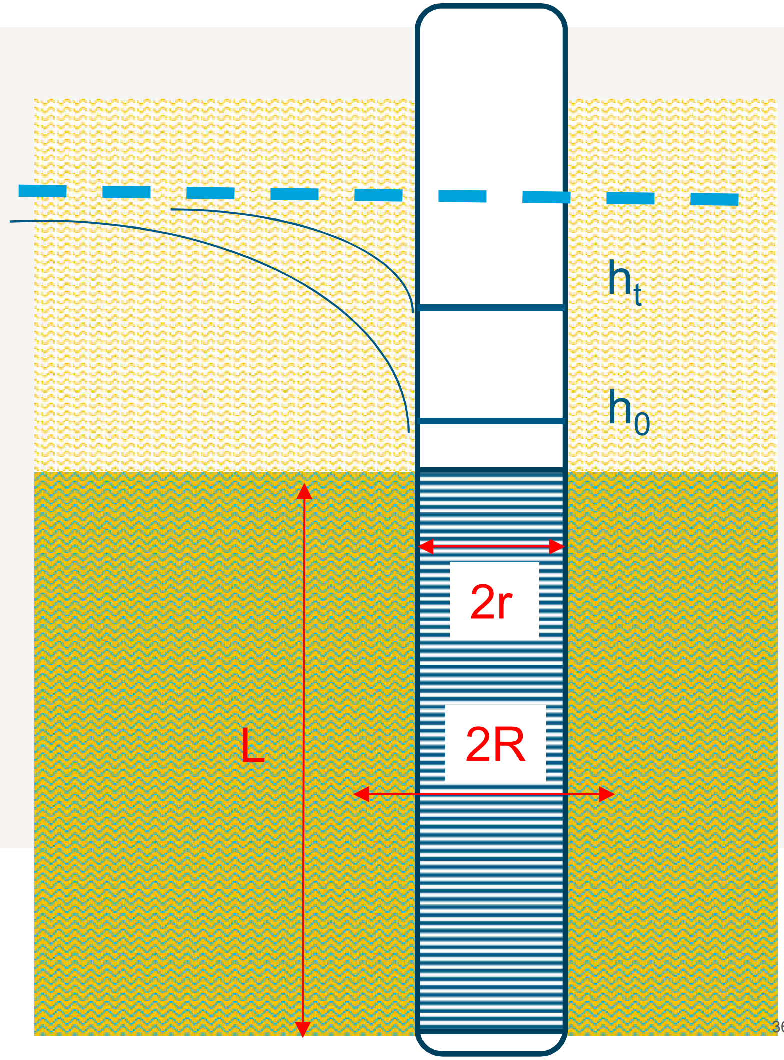
Effect of Radius

$$K = \frac{\Delta V\ L}{\Delta t\ Ah}$$

$$K = \frac{r^2 * \ln(L/R) * \ln(h_1/h_2)}{2L\,(t_2 - t_1)}$$



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What is the implication of insufficient displacement on a K-test?

- Precision of instrumentation becomes problematic – water level tapes are to mm and accuracy of pressure sensors varies by brand and model
- Must consider the well construction details – typically most water table wells have 3 m screen. The test design should be done in consideration with well completion design
- Don’t get hasty and cut the test too short, you could lose important data!
- *“If an aquifer test does not continue long enough, the resulting limited data set may not indicate the true nature of the zones of interest” – Sterrett, 2007*

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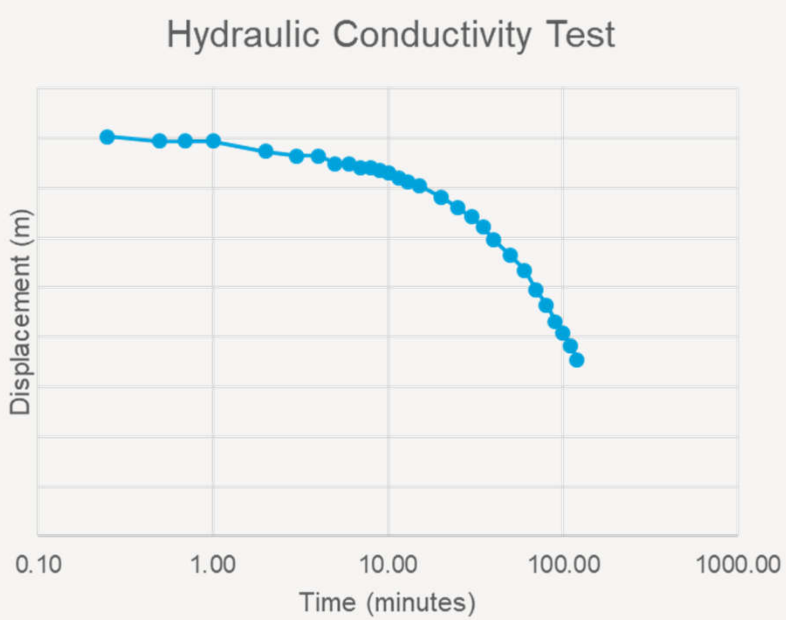
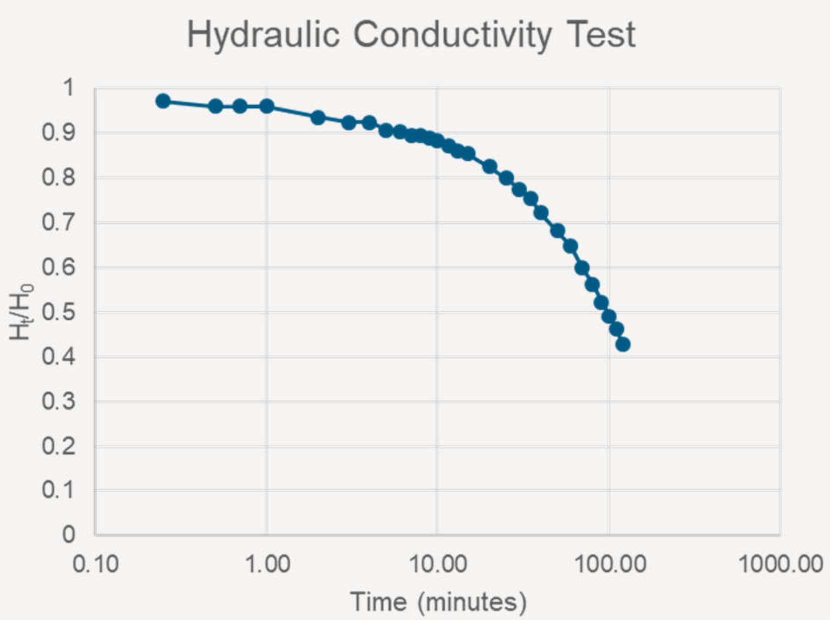

Hydraulic Conductivity Test
Displacement (m)
0.10
1.00
10.00
100.00
1000.00
Time (minutes)


Hydraulic Conductivity Test
H_t/H_0
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.10
1.00
10.00
100.00
1000.00
Time (minutes)

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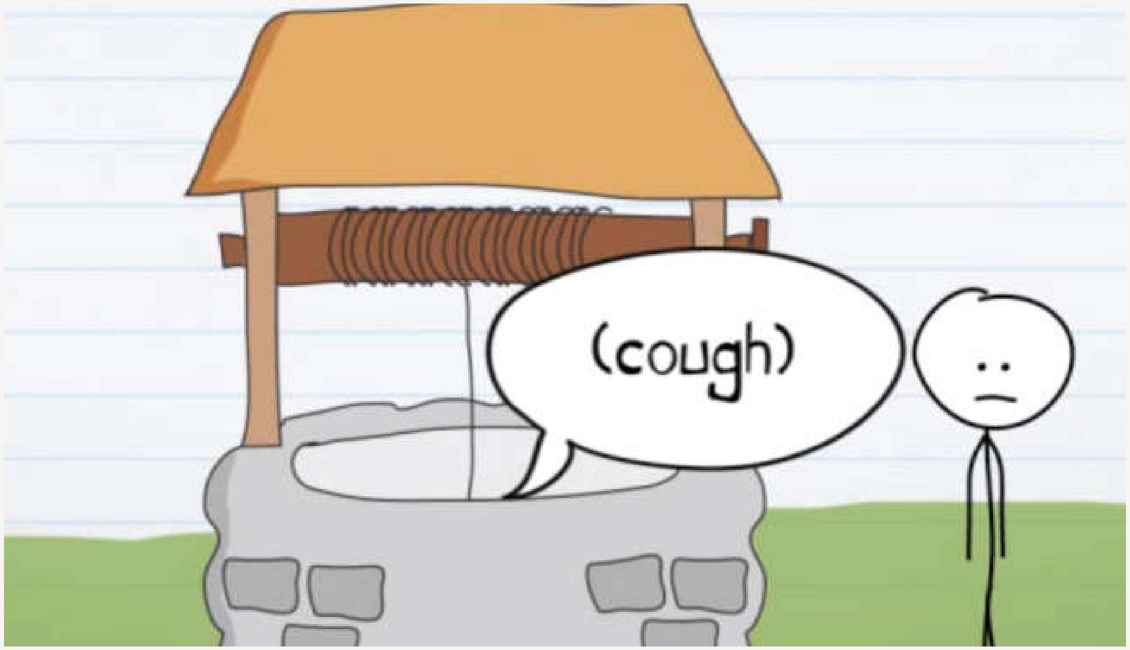
What about dry wells? How do we determine a K-Value?



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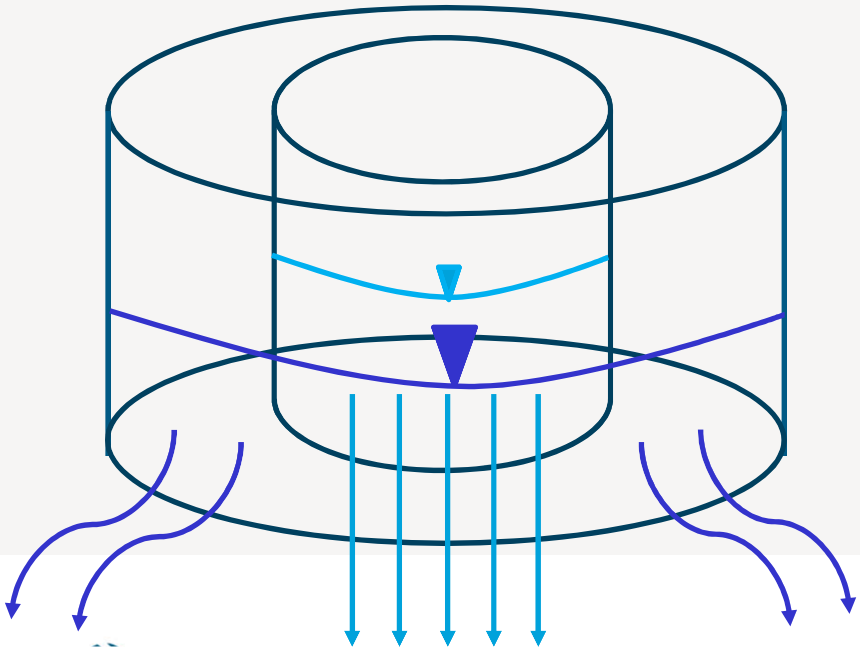
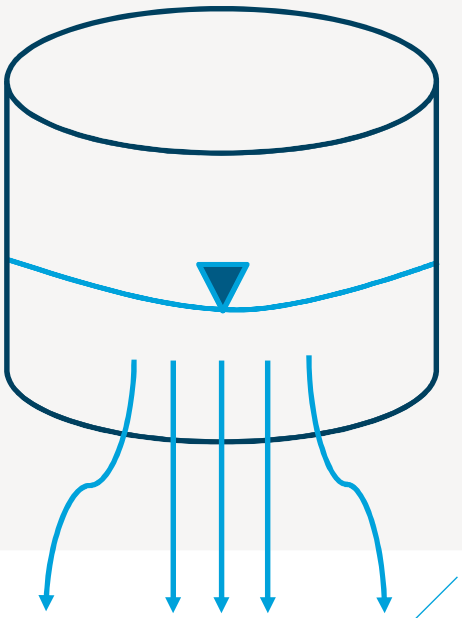
Double Tube Method
(Bouwer, H. 1961)



Single Ring Method
(AKA Infiltrometer)



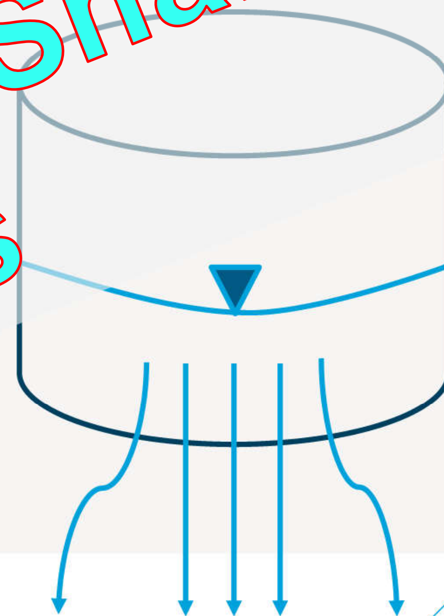
Bouwer, H. 1961. A Double Tube Method for Measuring Hydraulic Conductivity of Soil in Situ above a Water Table. Soil Science Society of America Journal. September 1961.
https://acsess.onlinelibrary.wiley.com/doi/10.2136/sssaj1961.03615995002500050009x

Double Tube Method

(Bouwer, H. 1961)

Single Ring Method

(AKA Infiltrometer)



Limited to Very Shallow Depths

Bouwer, H. 1961. A Double Tube Method for Measuring Hydraulic Conductivity of Soil in Situ above a Water Table. Soil Science Society of America Journal. September 1961. https://acsess.onlinelibrary.wiley.com/doi/10.2136/sssaj1961.03615995002500050009x

Guelph Permeameter

- An in-hole constant-head permeameter, using Marriotte Principle.
- Measures steady-state rate of water recharge into unsaturated soil from a cylindrical well hole.
- Depth is 80 cm.

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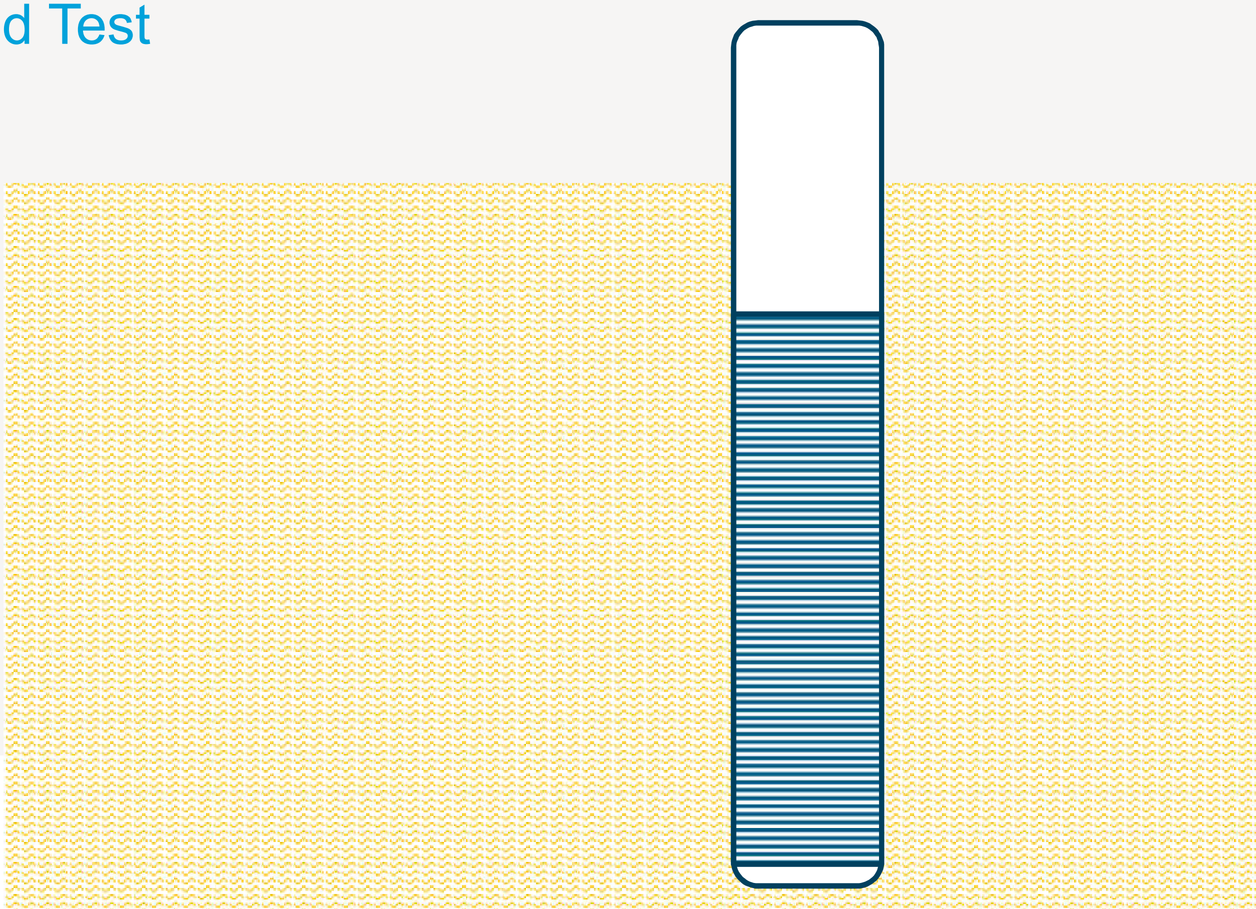
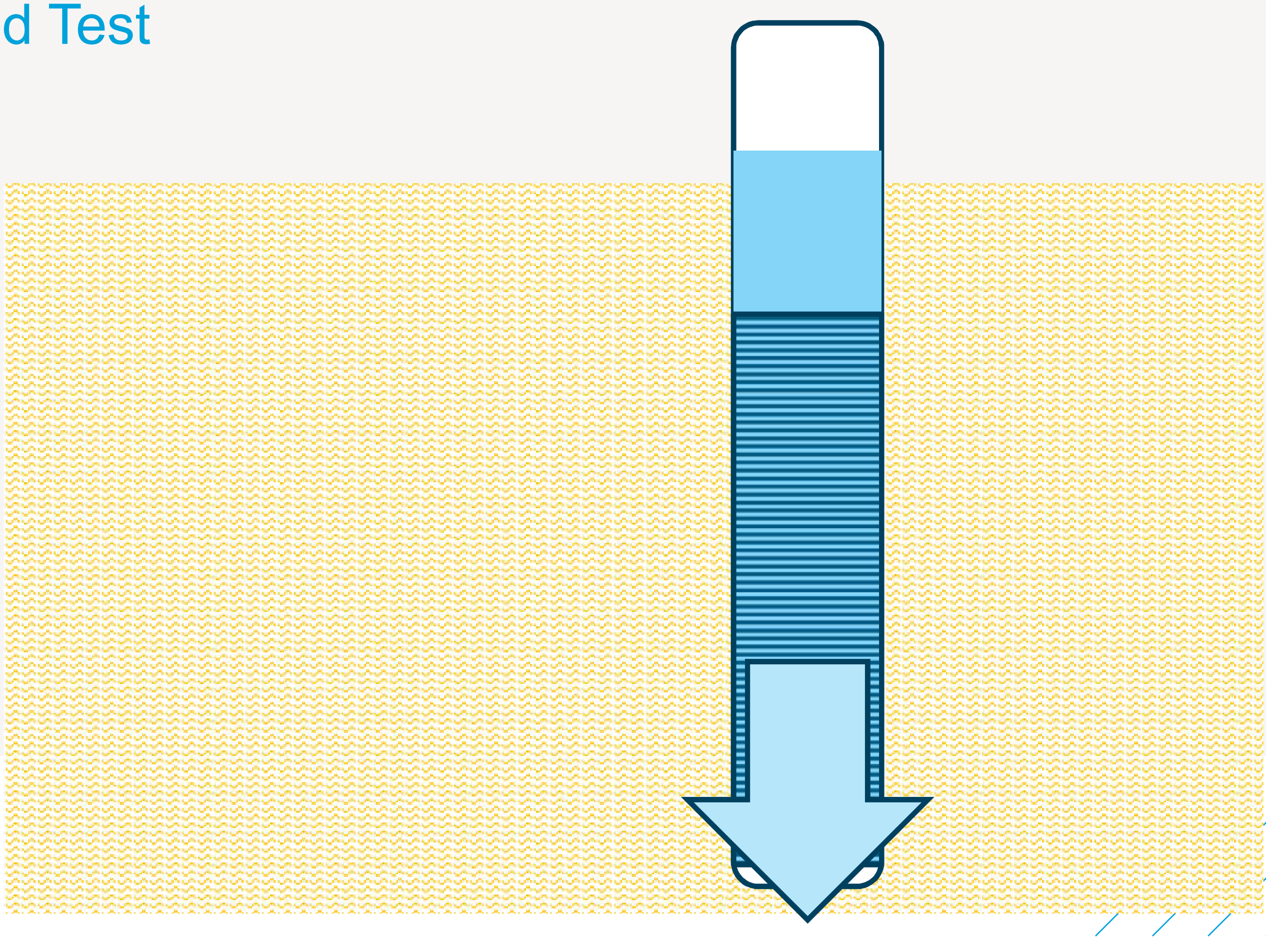
https://www.soilmoisture.com/pdfs/Resource_Instructions_0898-2800_2800K1%20Guelph%20Permeameter%20.pdf

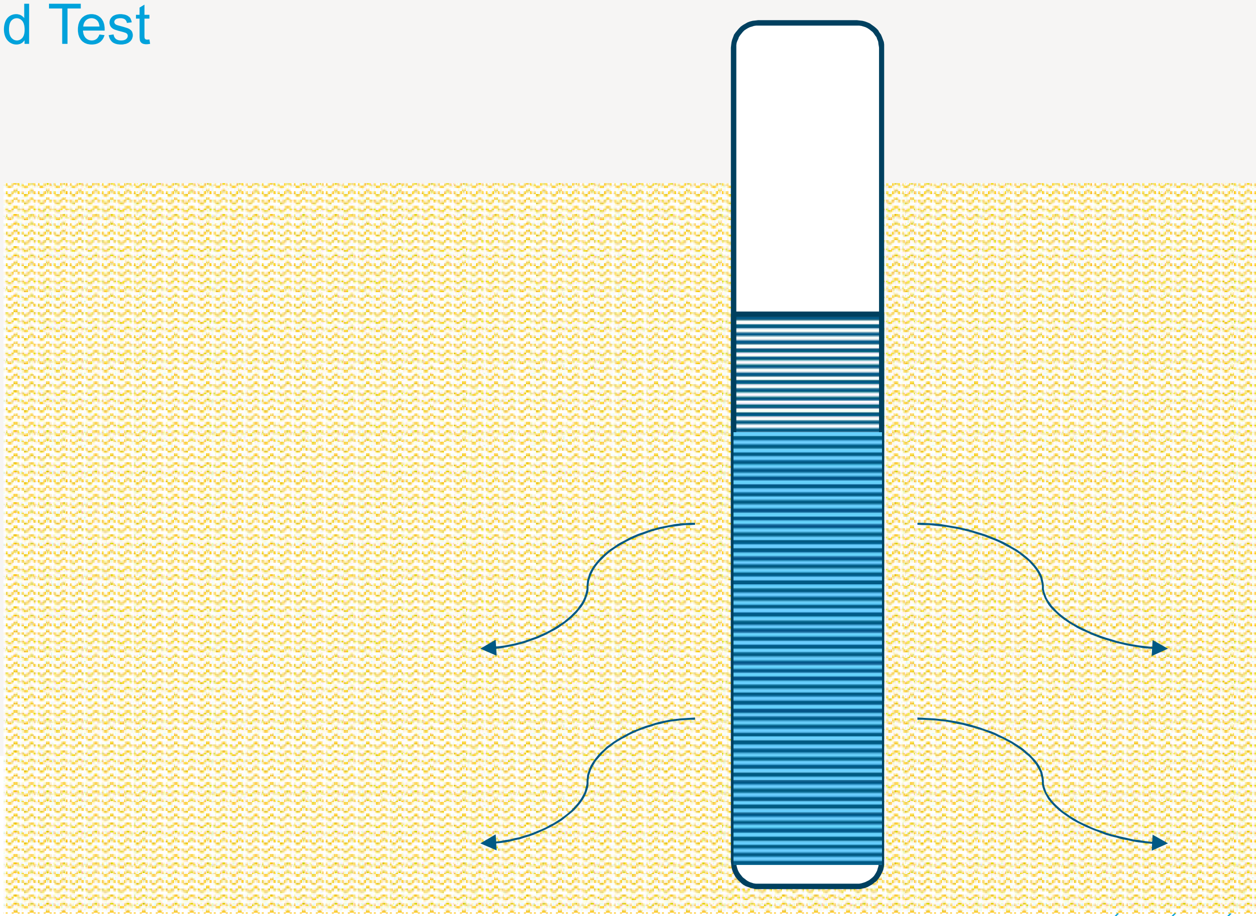
Falling Head Test



Falling Head Test

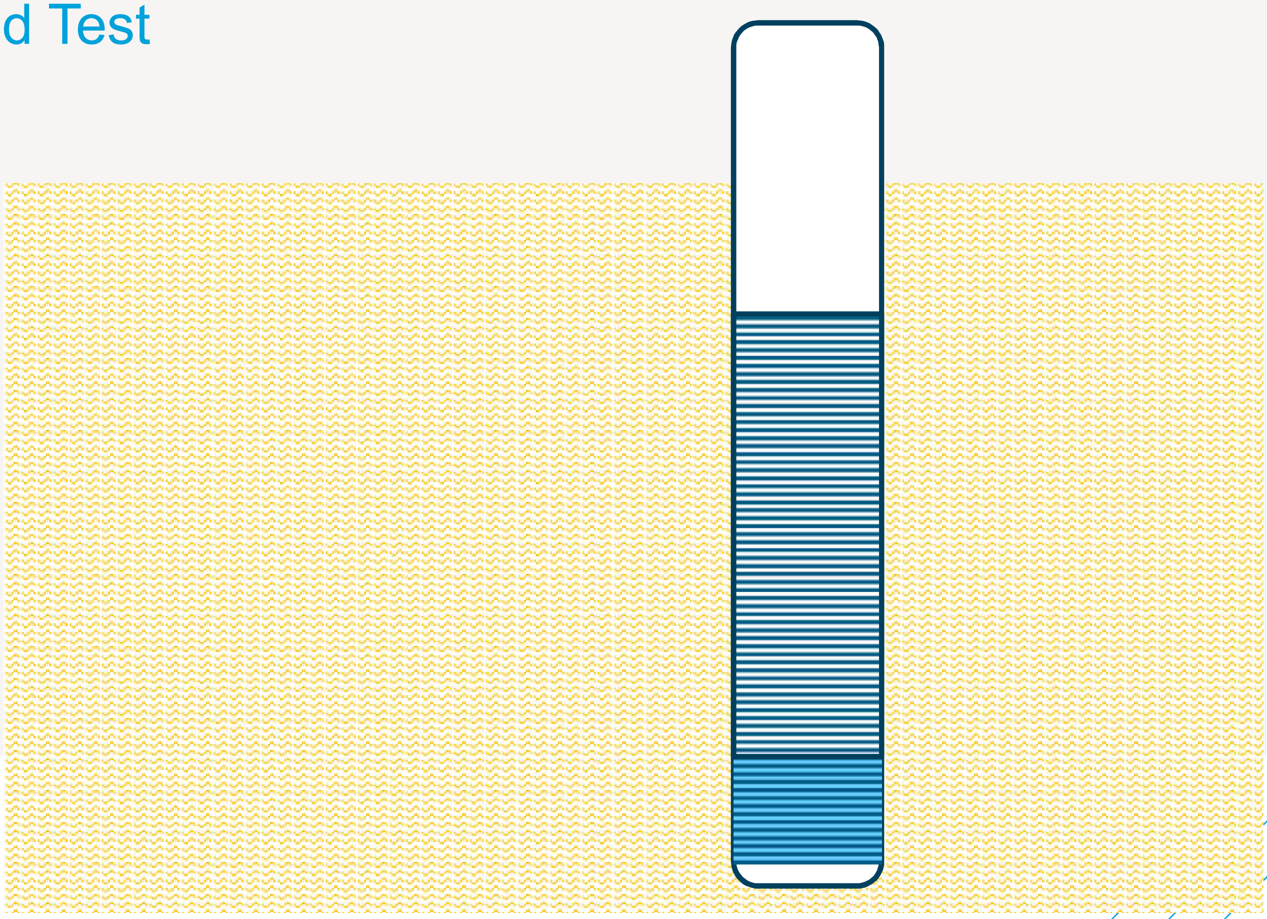


Falling Head Test



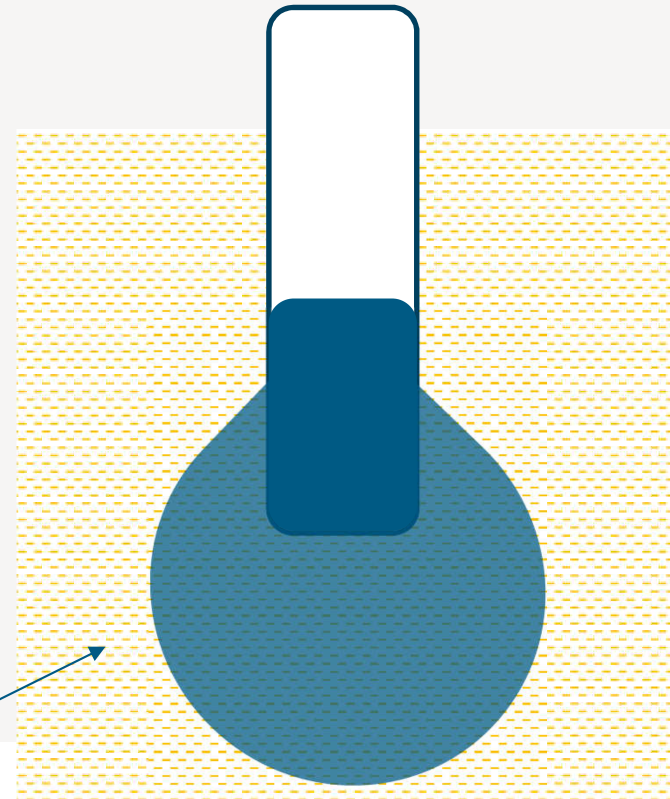
Falling Head Test

t = end of test



Saturation Bulb

Note: when determining hydraulic conductivity from in-situ and above water table elevations, the test is only valid if it has been made when a saturation bulb has been established.



Saturated soil around the borehole = Saturation Bulb

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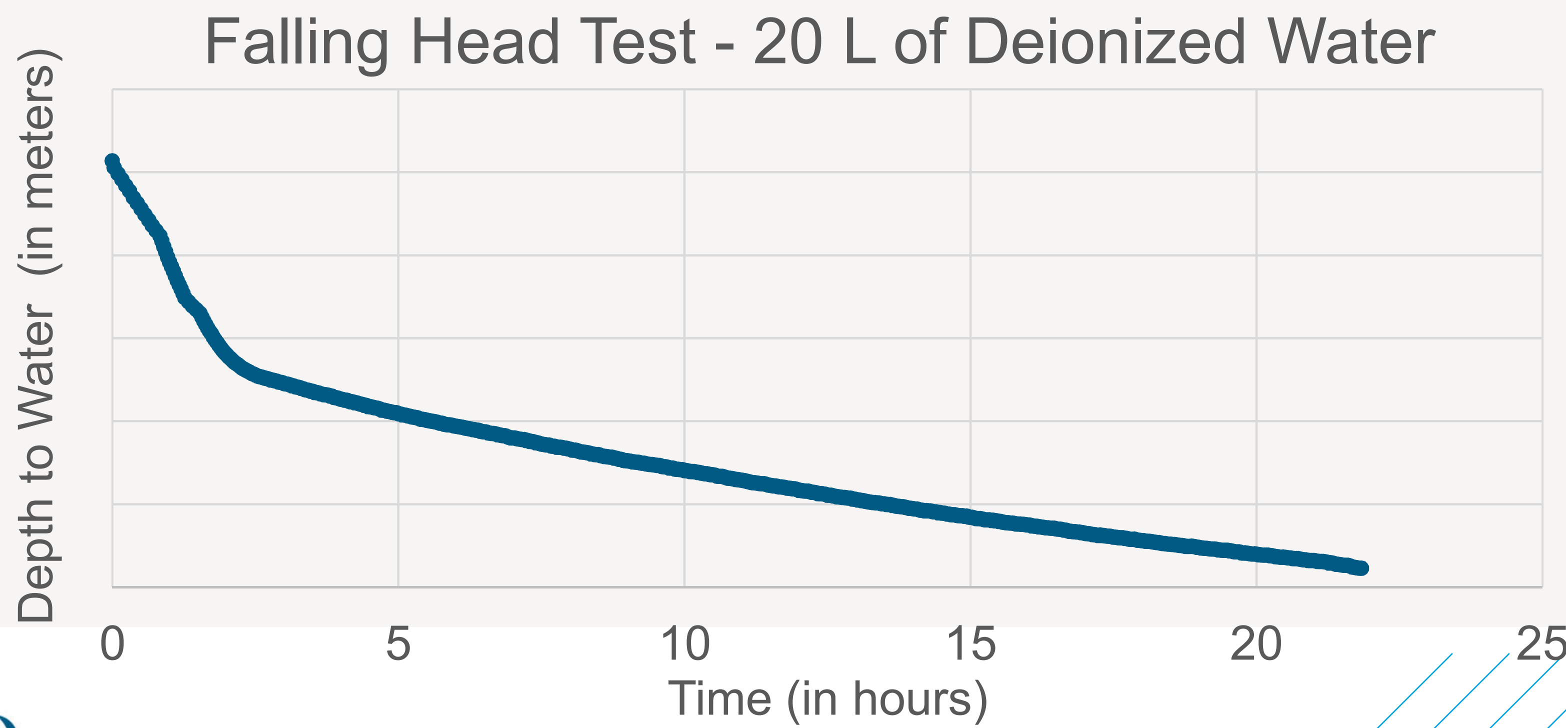
Example of Successful Falling Head Test Data



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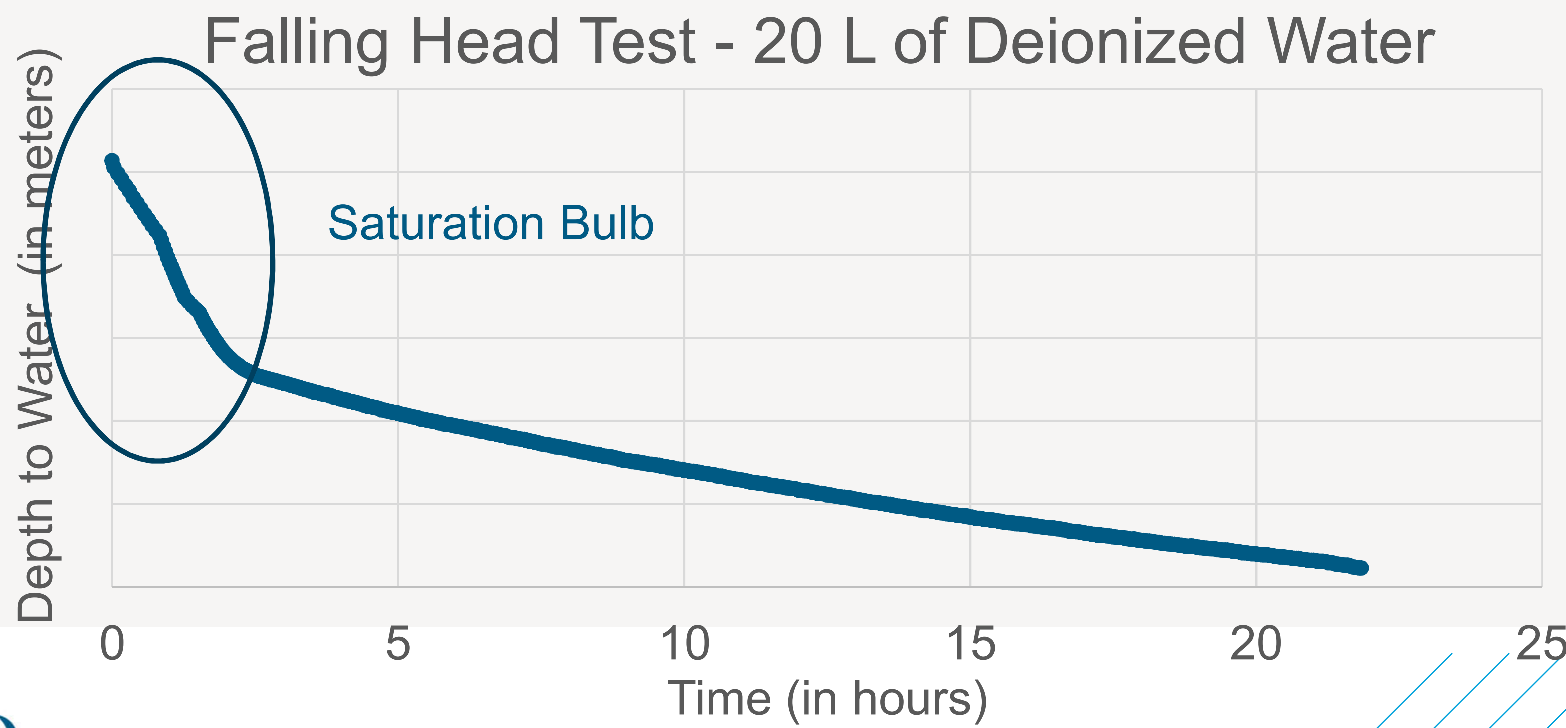
Example of Successful Falling Head Test Data



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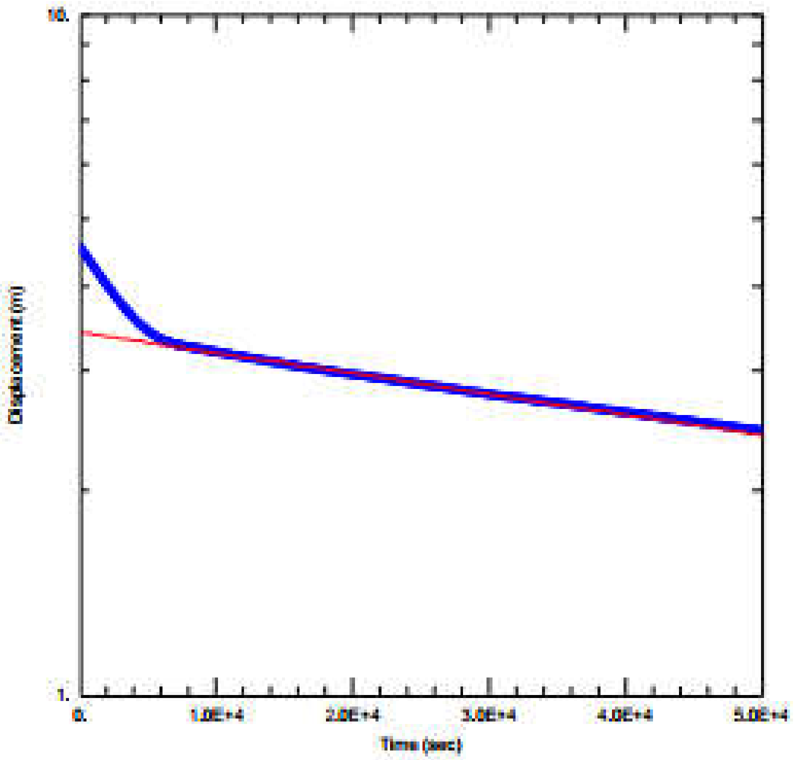
Output of Falling Head Test



SOLUTION

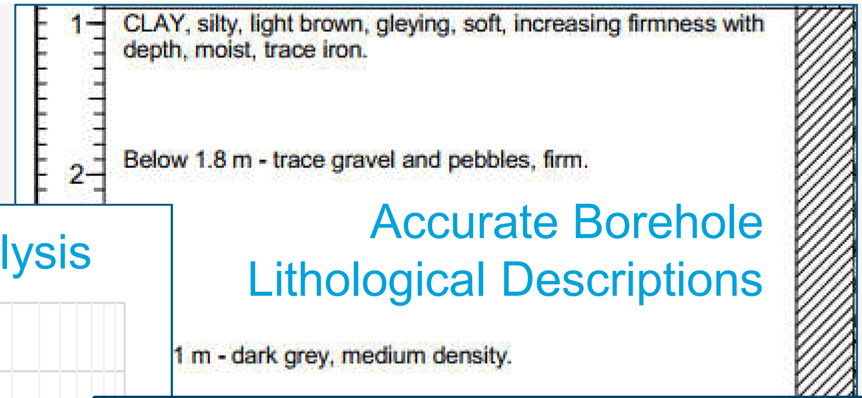
Aquifer Model: Unconfined

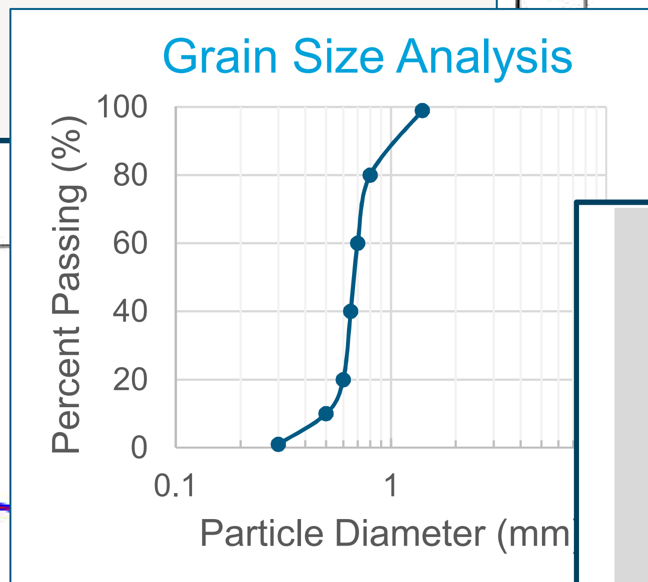
Solution Method: Bouwer-Rice

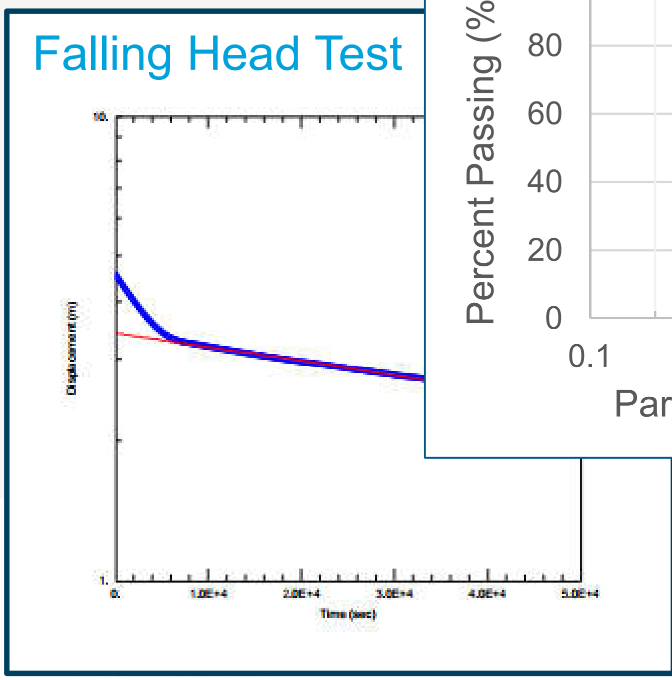
K = 1.275E-8 m/sec

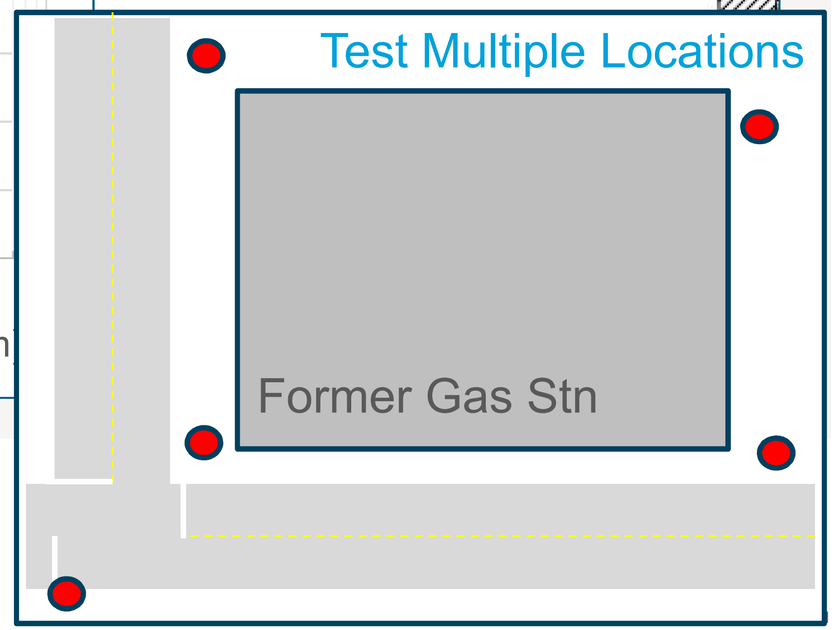
y0 = 3.417 m

Multiple Lines of Evidence: Putting it all together!









Summary

- Discussed the origin of till in the Prairies
- Groundwater flow through till materials
- Importance of accurate hydraulic conductivity values
- Reviewed various methods of determining hydraulic conductivity, including in-situ and ex-situ methods, methods based on Darcy's Law and those determined by empirical correlations.
- Multiple lines of evidence, which is a commonly applied approach to site characterization holds true with hydraulic conductivity testing methods. Generally, more than one testing method should be presented.

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Our values are the essence of our company's identity. They represent how we act, speak and behave together, and how we engage with our clients and stakeholders.

SAFETY

We put safety at the heart of everything we do, to safeguard people, assets and the environment.

INTEGRITY

We do the right thing, no matter what, and are accountable for our actions.

COLLABORATION

We work together and embrace each other's unique contribution to deliver amazing results for all.

INNOVATION

We redefine engineering by thinking boldly, proudly and differently.

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