Aquifer Performance Testing for Environmental and Groundwater Resource Applications

Todd Halihan

Oklahoma State University

Aquifer Performance Testing

1. Intro to aquifer testing
2. Single well testing
3. Steady state well testing
4. Transient well testing
5. Testing with the air, moon, and sun

1. Intro to Aquifer Testing

Aquifer Tests

Nearly Identical Names

1. Aquifer Tests
2. Pumping Tests
3. Pump Tests – Incorrect, but common slang

Purpose of an Aquifer Test

The Why? is Important!

1. We want to test the well itself
2. We want to test a well field
3. We want to test aquifer properties
   - Physical: T,S, etc.
   - Biochemical
   - Connections

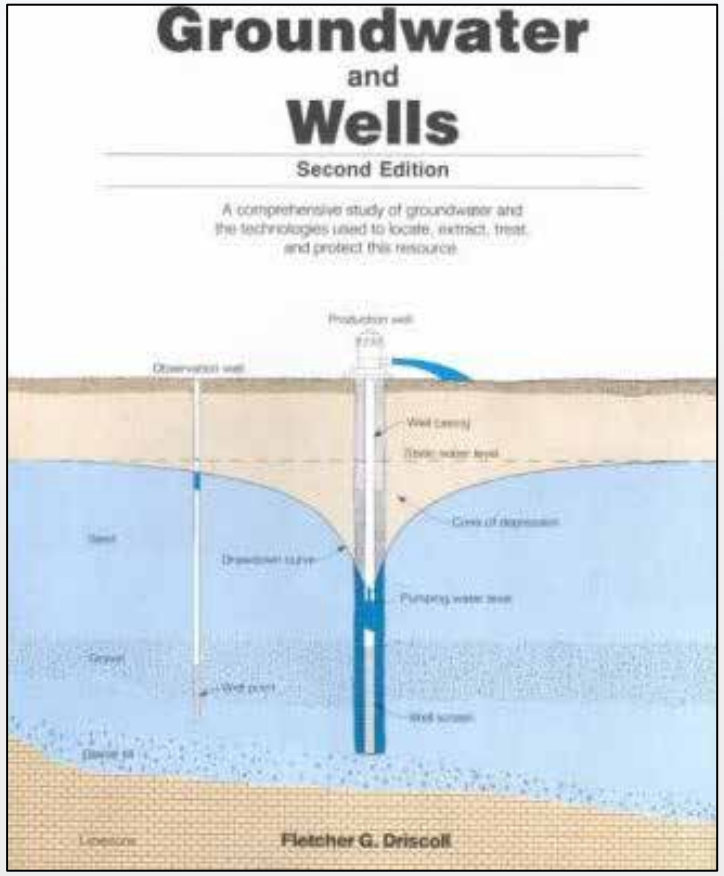
Well Safety

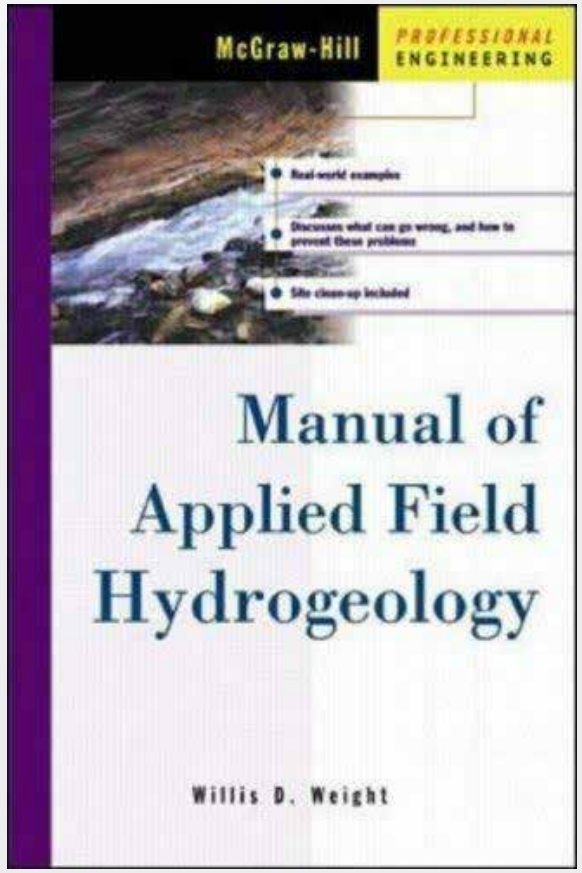
1. Understand the procedures that are to be performed
2. Have a health and safety plan
3. Hoses can burst and swing with a lot of force
4. Wells can respond in strange ways: beware the well witches

Witch's well
NJ, USA

Ratva witches' wells,
Estonia
(Photo: Rene Kundla)

Some Guidebooks





What Data Can You Collect?

1. Water Level in the Well
2. Water Level in Nearby Wells
3. Chemistry in Wells
4. Inject Tracer and Look in Other Wells

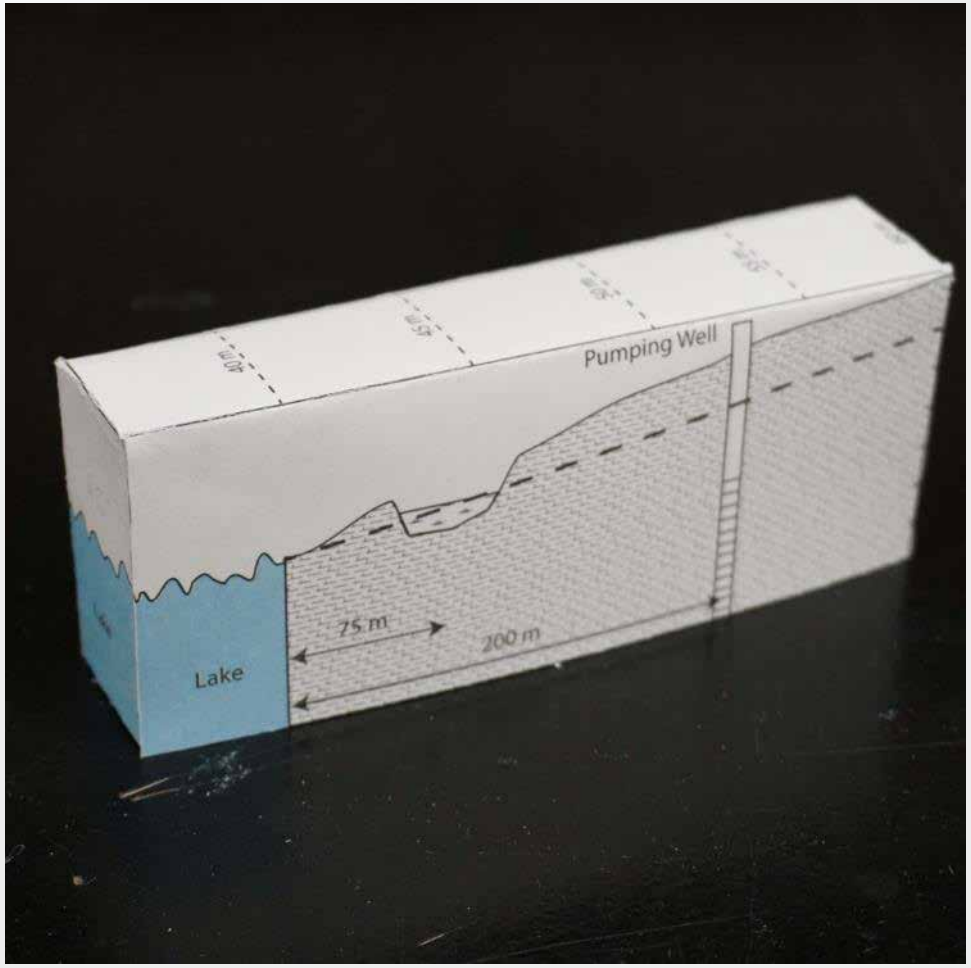
How Do You Measure Water Level?

Water Level Tape
Water Tape
E-line
Chalked Steel Tape

Pressure Transducer
(Vented or Unvented)

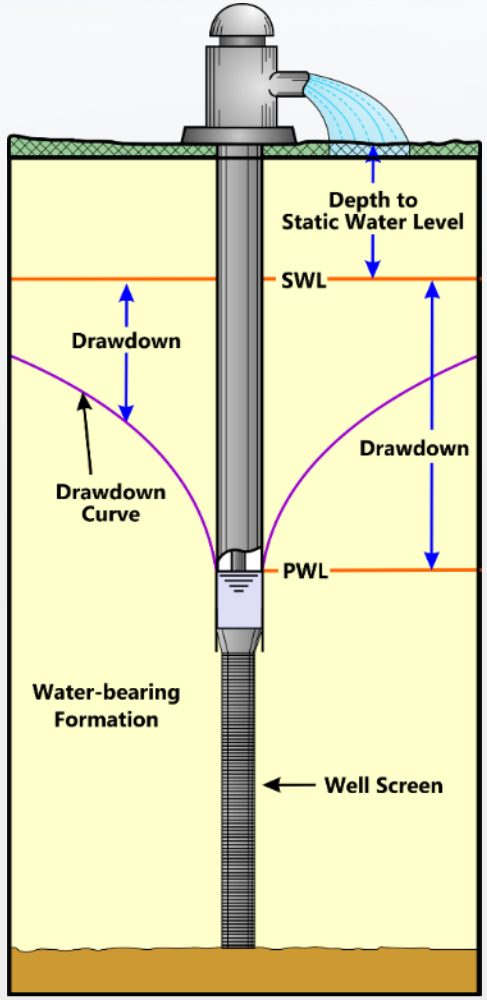
Sonic Water Level Meter

2. Single well testing



- Foldable well hydraulics
- SUNY Buffalo

Single Well Testing



Pump Water Out

Water drops quickly at first and then slows down unless the aquifer can't supply enough water (then it goes dry).

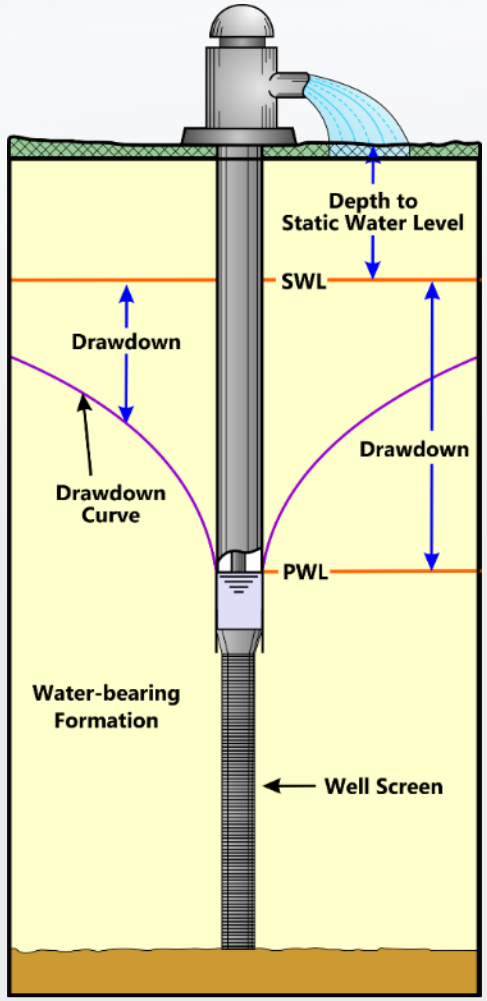
Pump Water In

Opposite happens, water goes up quickly at first. **Need to make sure it is legal to pump material into well.**

Commonly, 24-72 hours

Reach steady state, water level doesn't change

Single Well Testing: Specific Capacity



The Why?

Is my pump the right size?
Do I need to develop my well?

Pump Size

Specific Capacity Test

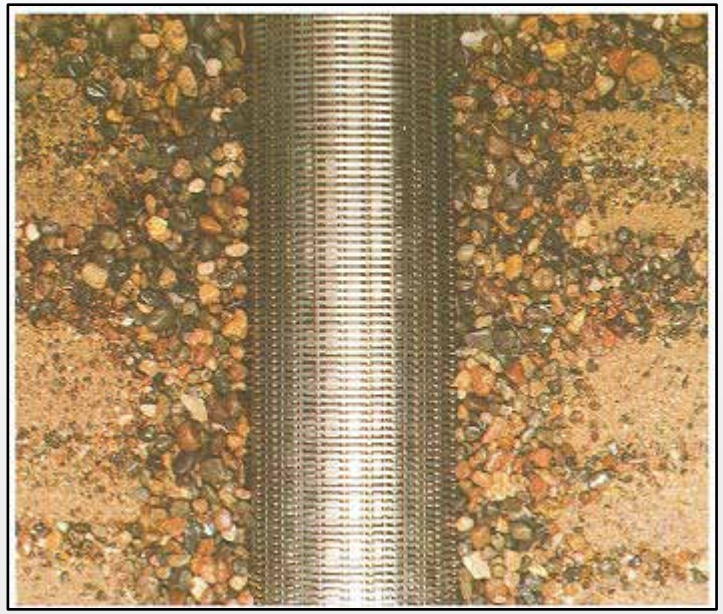
Run pump for a couple of hours, compare well discharge, Q, to drawdown, $h_0 - h$

SC = Q/(h0 – h) [gal/min/ft] [liter/s/m]

Well Development

Ensure well is in communication with aquifer

Single Well Testing



Sterrett, Robert J. 2007
Groundwater and Wells

Well Development

Ensure well is in communication with aquifer

- Often Ignored
- Cleaning fines from well bore
- Reduce well loss or well efficiency

Skin Effect

- Commonly reduced well flow with fines
- May be reduced due to bacterial effects
- In hard rock boring, may increase flow with fractures

Single Well Testing: Slug Tests

Fiore, 2014
USGS Open-File Report 2014-1020

Slug Tests

Can measure aquifer hydraulic conductivity within a meter (a few feet) of a well quickly

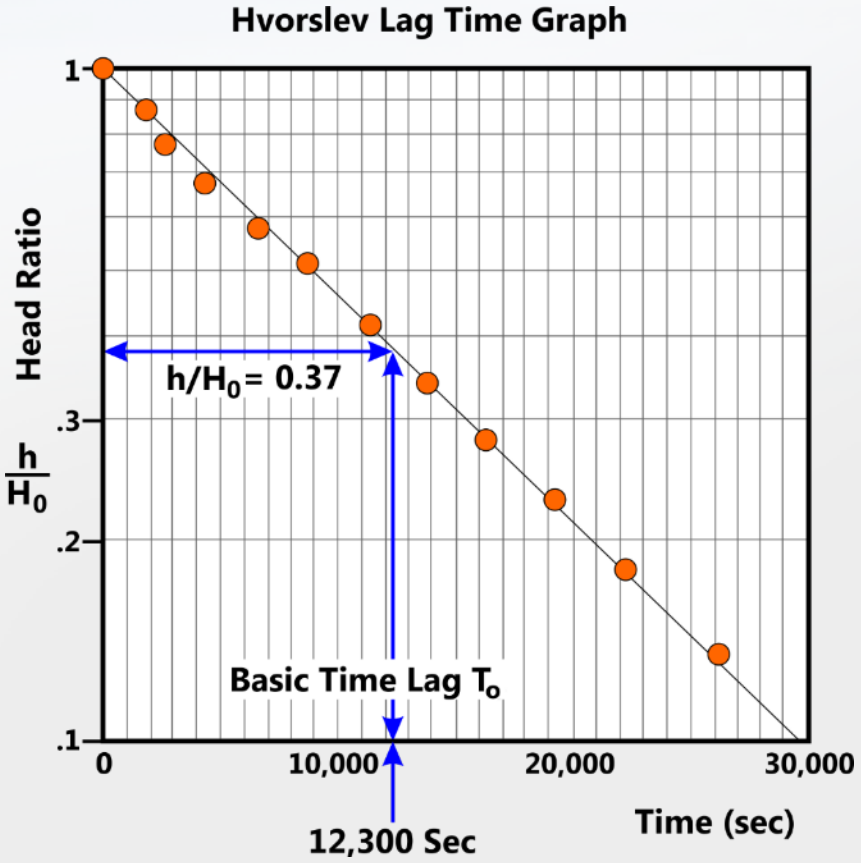
Slug In Test

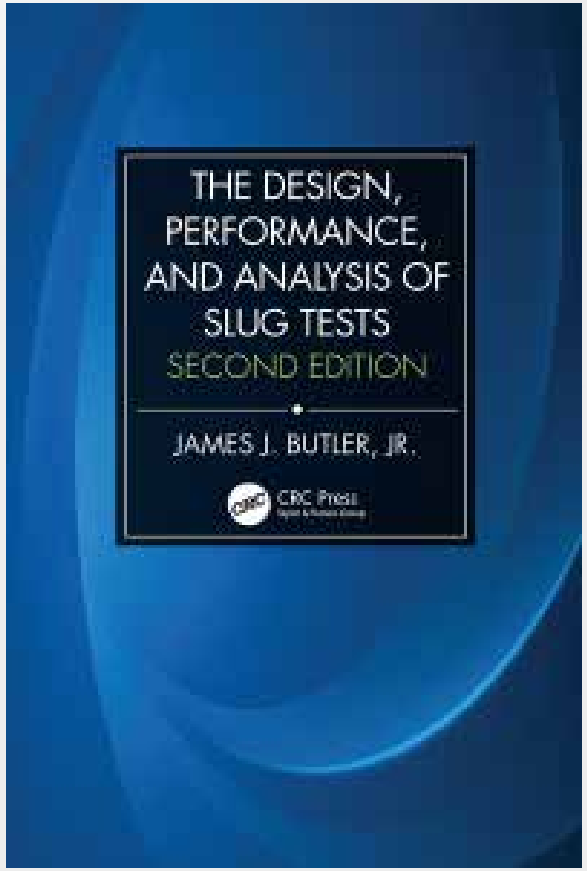
- Commonly use a weighted piece of PVC on a rope
- Dropped in well, water level goes up, decreases back to normal, calculate K

Slug Out Test

- Slug pulled out of water, water level goes down, increases back to normal, calculate K

Single Well Testing: Hvorslev Analysis





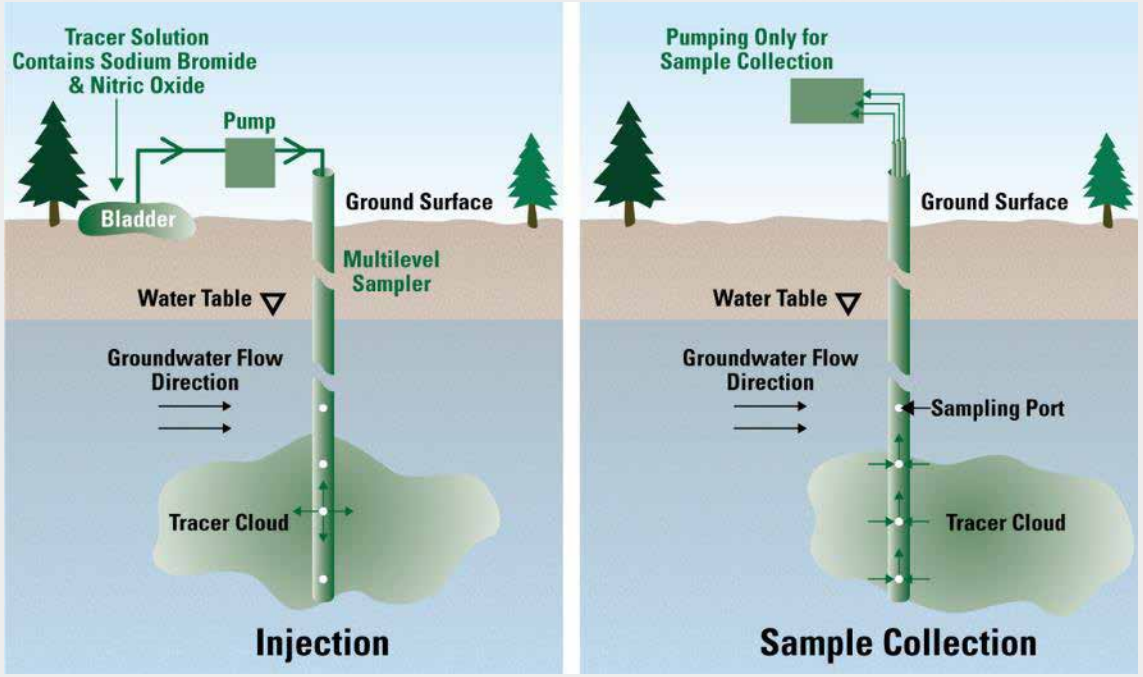
Single Well Testing: Injection Test

- The theory is that you just pump in what you pump out and everything just works backwards
- You now can damage the aquifer, damage the wellbore, and contaminate the well
- In some locations: any injection (even distilled water) needs a special permit

- We commonly inject air
  - Gives microbes oxygen so they can break down contaminants
  - Air sparge well

Single Well Testing: Tracer Test

- We can watch how an aquifer works in a well by injecting tracer for a period of time and then pumping it out.
- When does the tracer come back, if at all?



USGS 2007
Single-well tracer test

Well Packers

- Expandable plugs used to isolate an area of a well
- “Inflating a tire in a well”

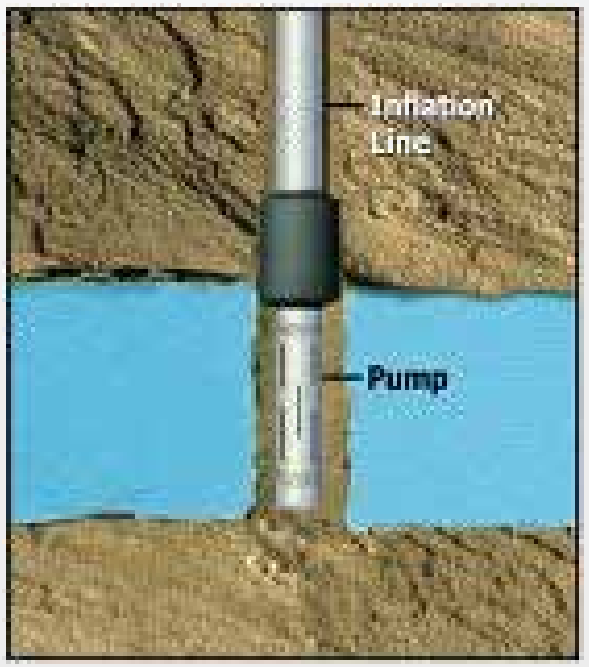
mgs.co.uk

baski.com

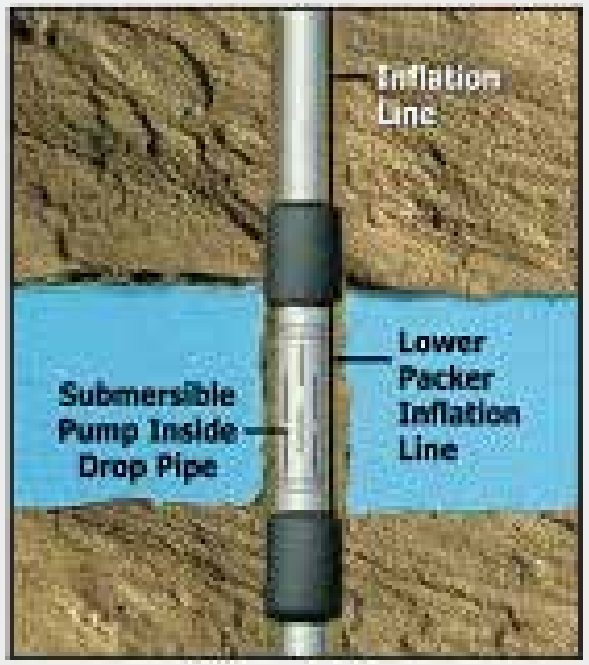
Single Well Testing: Packer Test

- Single packer or double packer testing

Below Packer Sampling



Between Packer Sampling

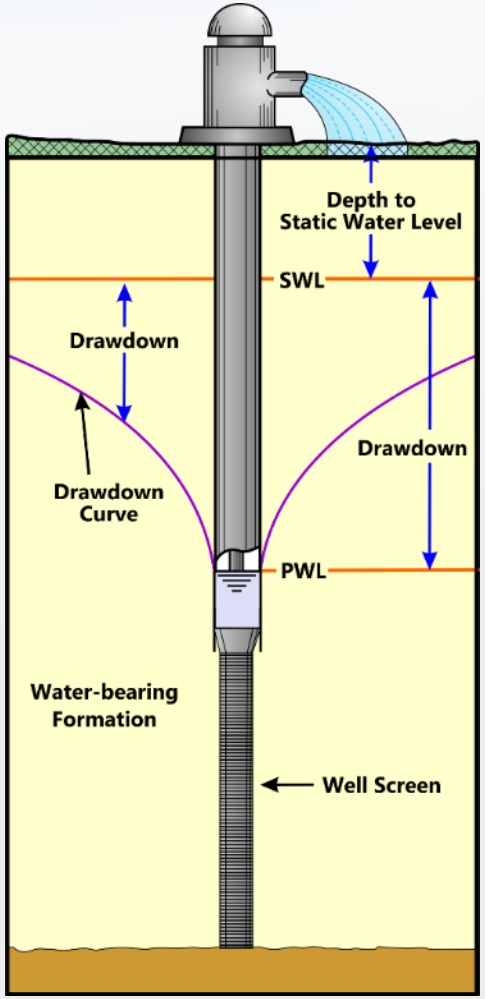


lansas.com

3. Steady state well testing

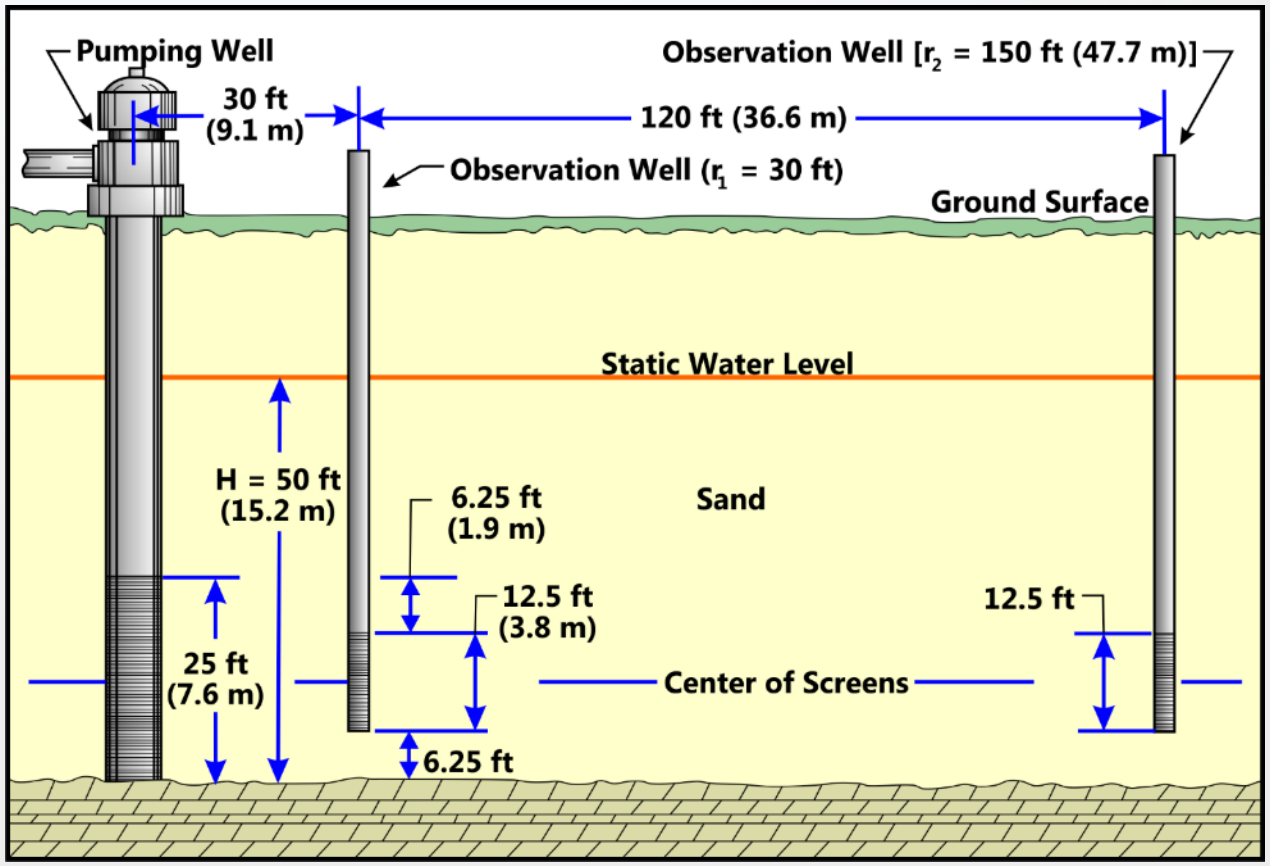
§ No storativity for you! Can get flow parameters, but not storage

Well Terms



- **Steady flow** – steady state flow. A well whose Q and water level is not changing w/r to time. Drawdown cone stable.
- **Unsteady/Transient flow** –Typically, Q remains constant. Water levels changing in the wells.
- **Radial flow** - The flow of water in an aquifer toward a vertically oriented well. Water comes from all compass directions.

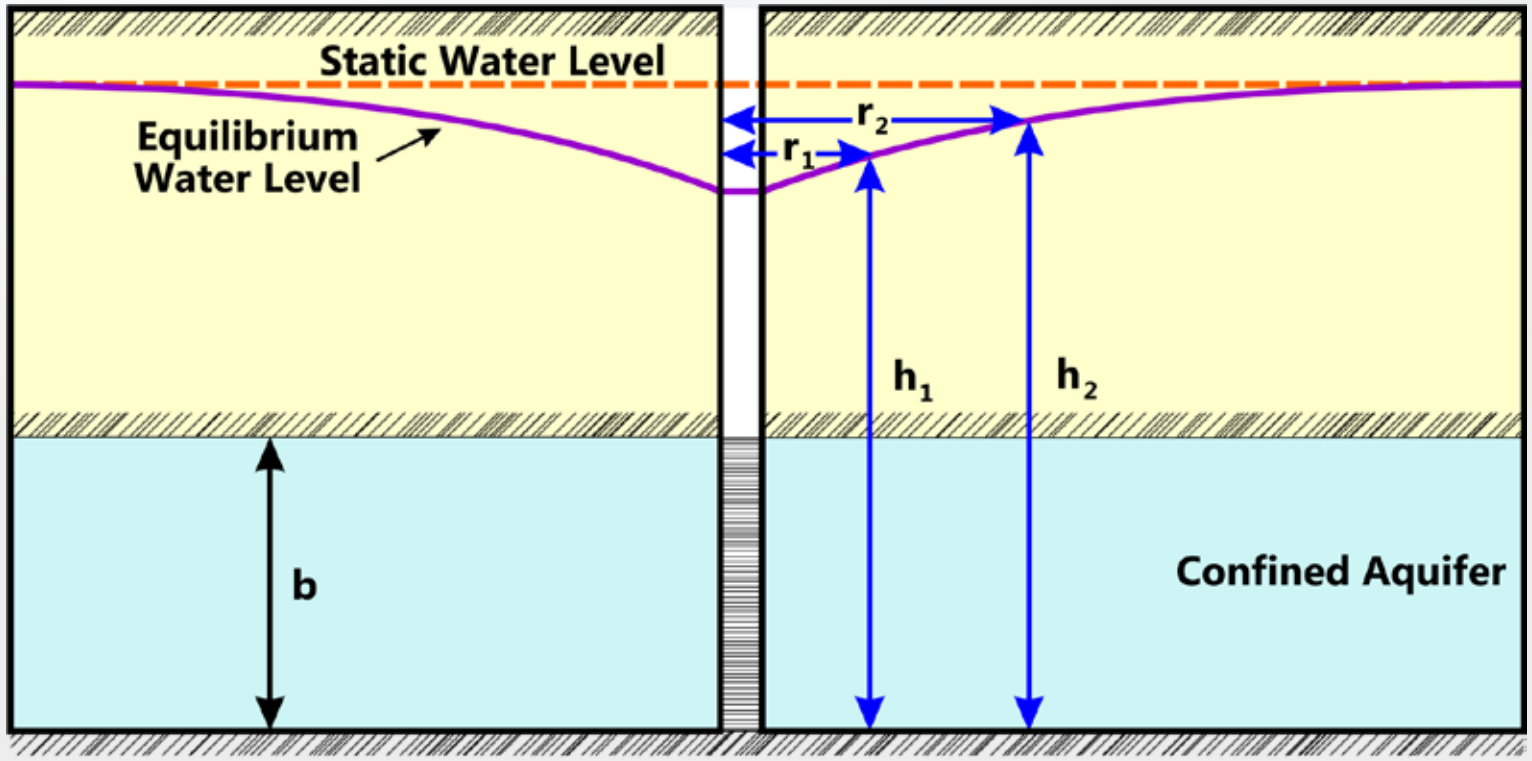
Typical Well Setup for Multiwell Aquifer Testing



For obtaining field data required to calculate K from well hydraulics equations.

Observation wells can be placed farther away from a production well in confined conditions and still provide reliable data.

Equilibrium Steady State Drawdown



Equilibrium drawdown in a confined aquifer.

Thiem Solution: Steady Well Flow

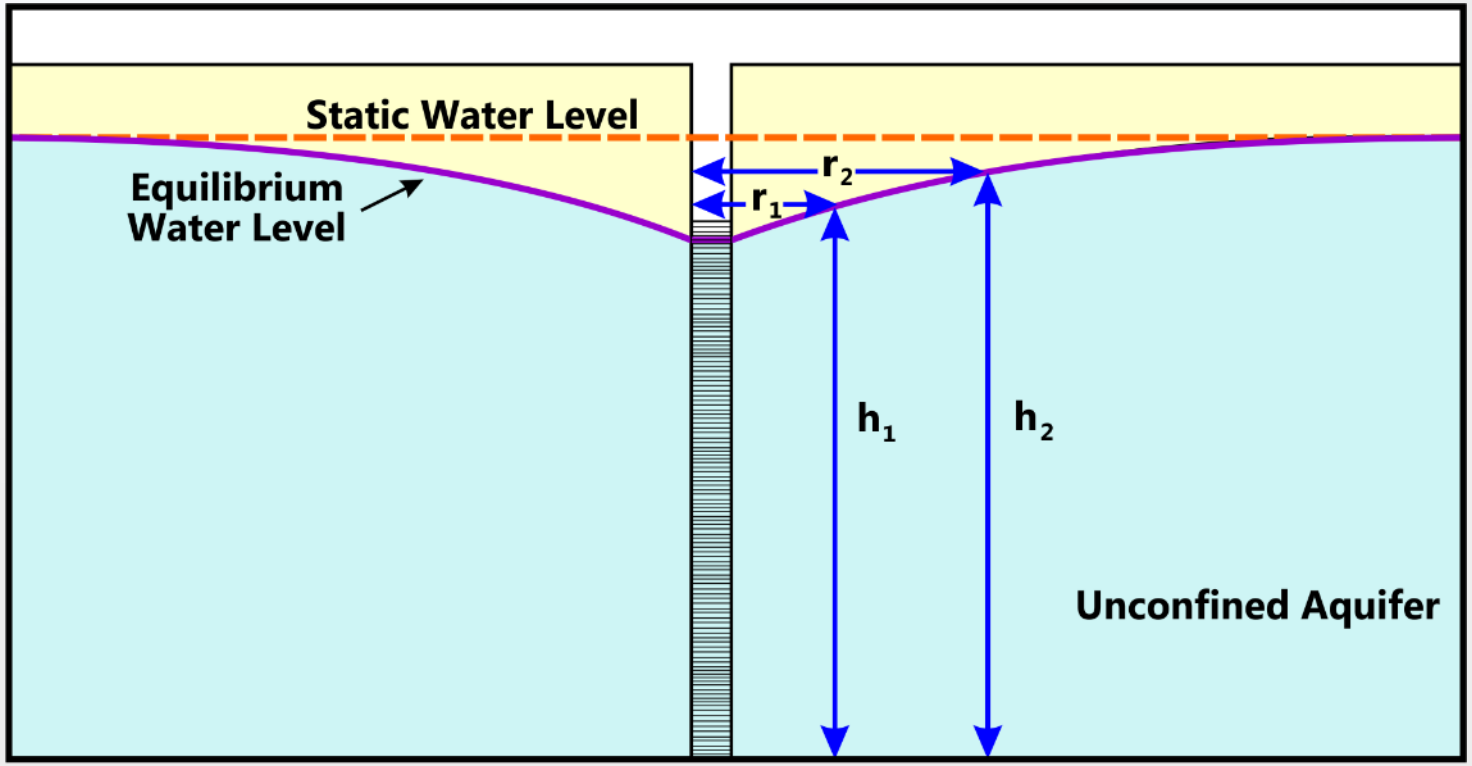
Solving for transmissivity, T

Thiem equation for confined aquifers flowing under steady state conditions:

$$T = \frac{Q}{2\pi(h_2 - h_1)} \ln\left(\frac{r_2}{r_1}\right)$$

Remember, transmissivity is the hydraulic conductivity of the aquifer times the thickness of the aquifer, T = Kb

Unconfined Equilibrium Drawdown



Equilibrium drawdown in an unconfined aquifer.

Unconfined Thiem

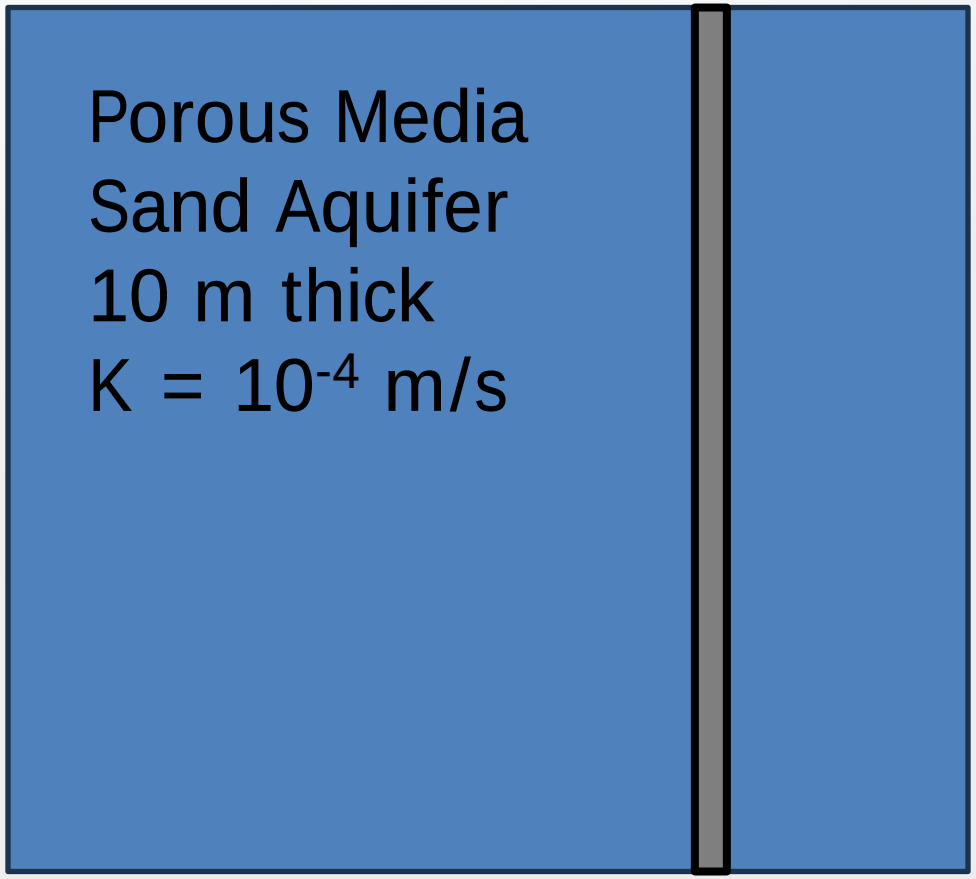
- Under unconfined conditions, the head level in the well is also the aquifer thickness b.

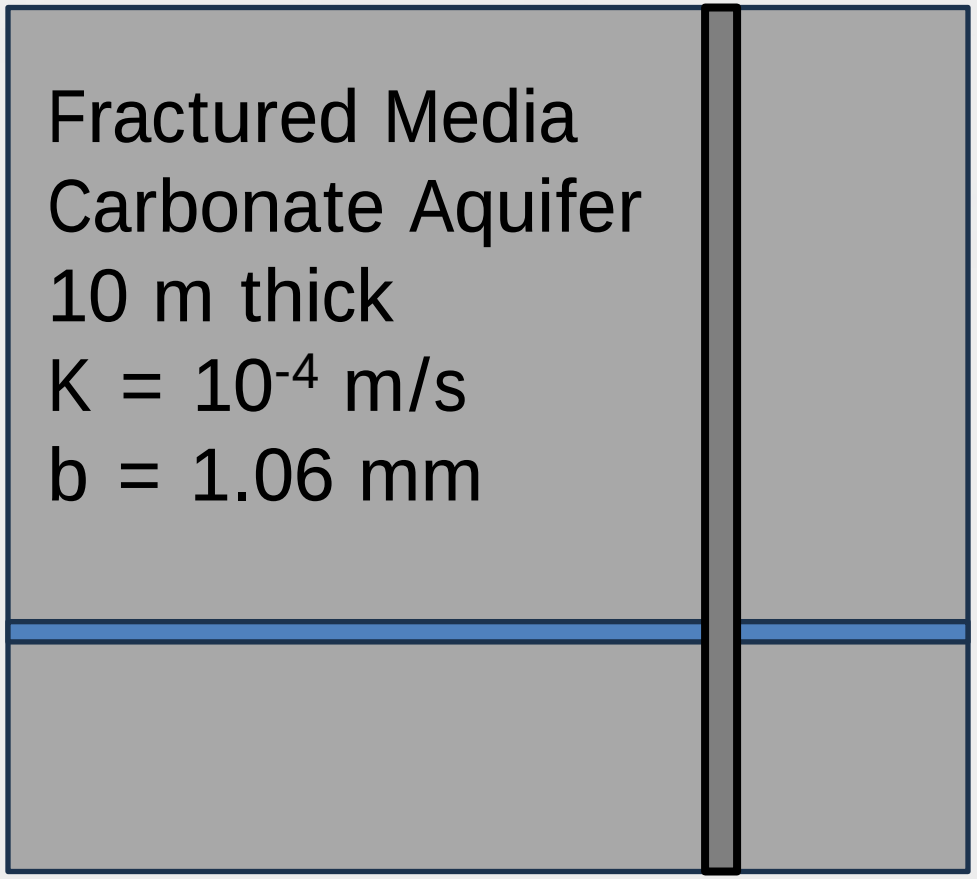
  For unconfined aquifers:

$$K = \frac{Q}{\pi(h_2^{\,2} - h_1^{\,2})} \ln\left(\frac{r_2}{r_1}\right)$$

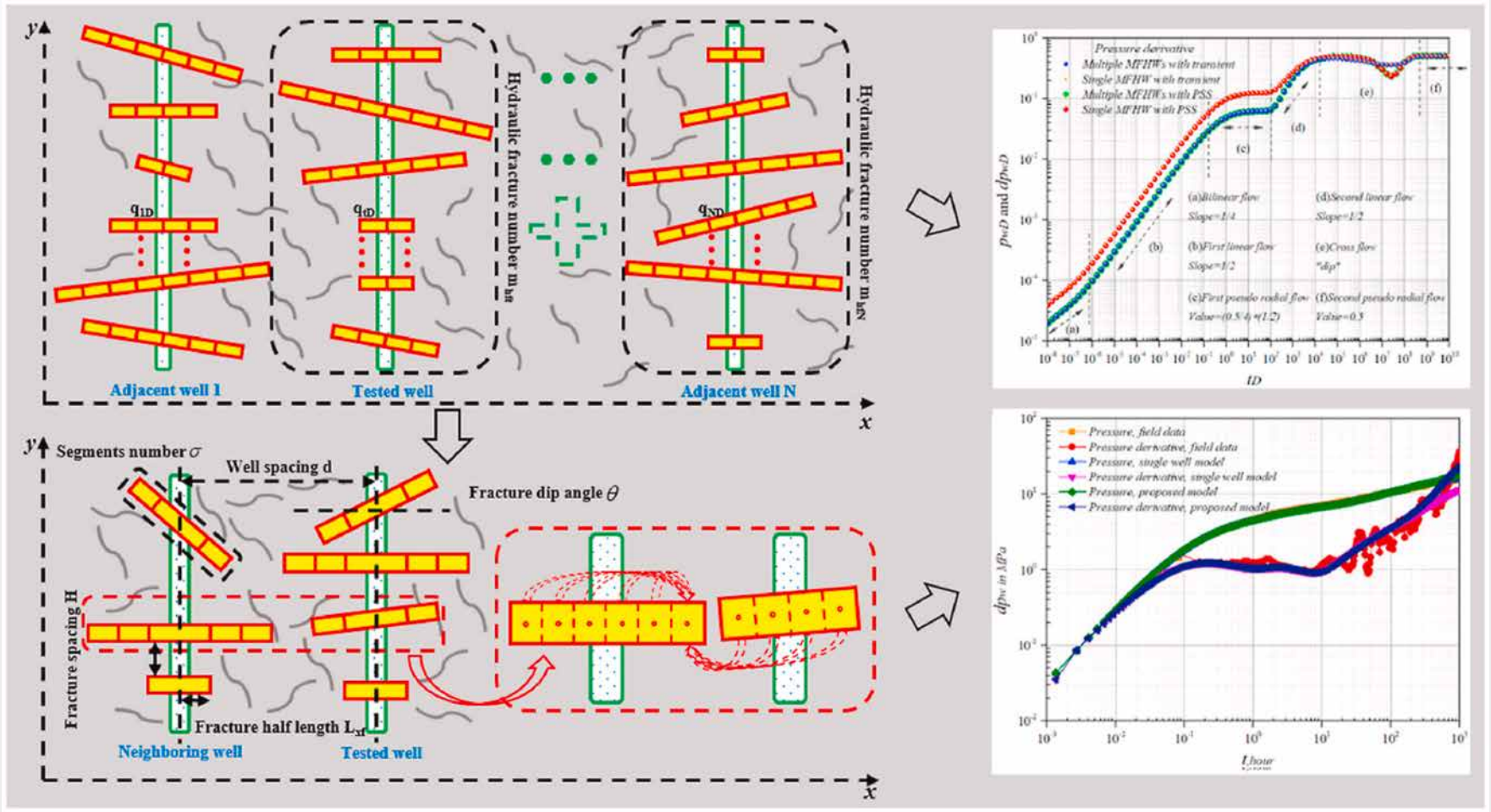
- These equations can also be used for injection wells.
- In this case Q is negative and the drawdown is called “build-up”.

These are identical well tests





4. Transient well testing



Chu et al., 2022

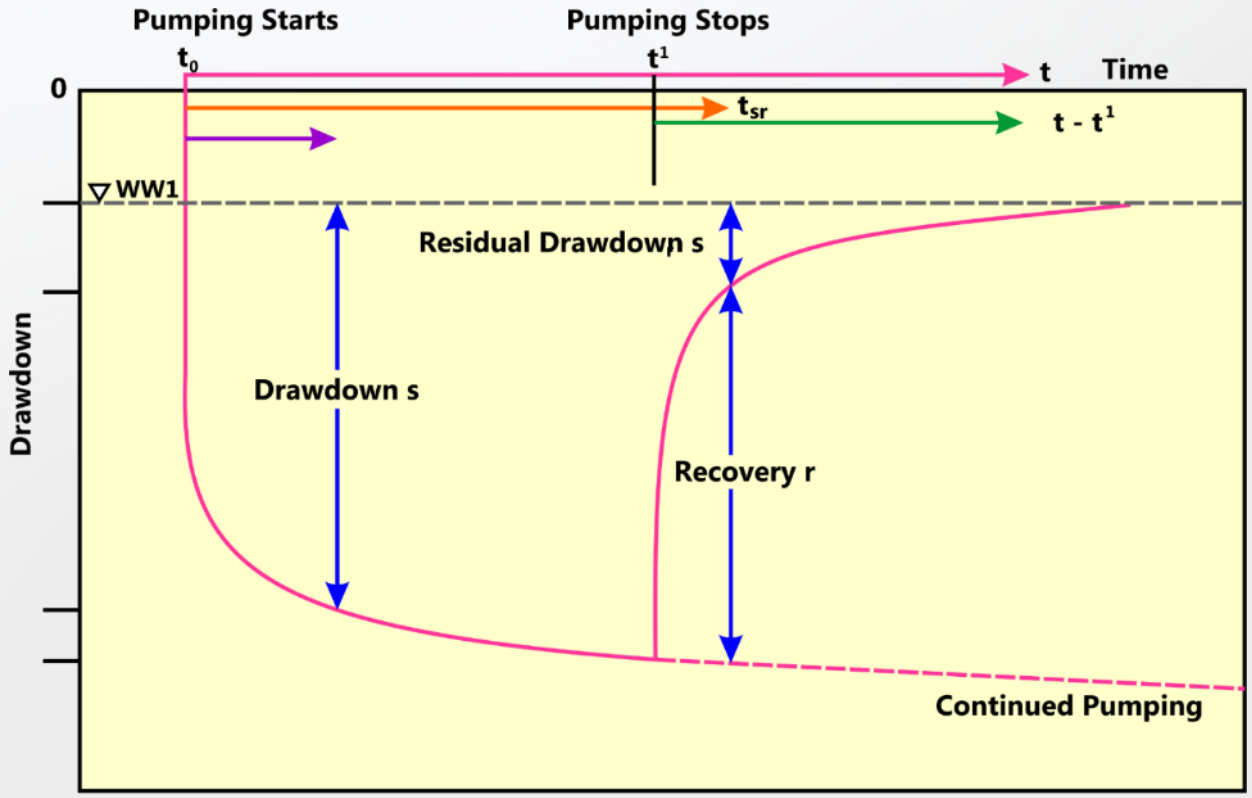
How much water is available?

- To get storage parameter, storativity, S, you must do an unsteady state or transient well test and watch the water draw down or build up to obtain a value for S.

- Transient testing can also show you connections to other aquifers and distance to aquifer boundaries

- The theoretical study is called “Well Hydraulics”

Transient Pumping Tests with Observation Wells



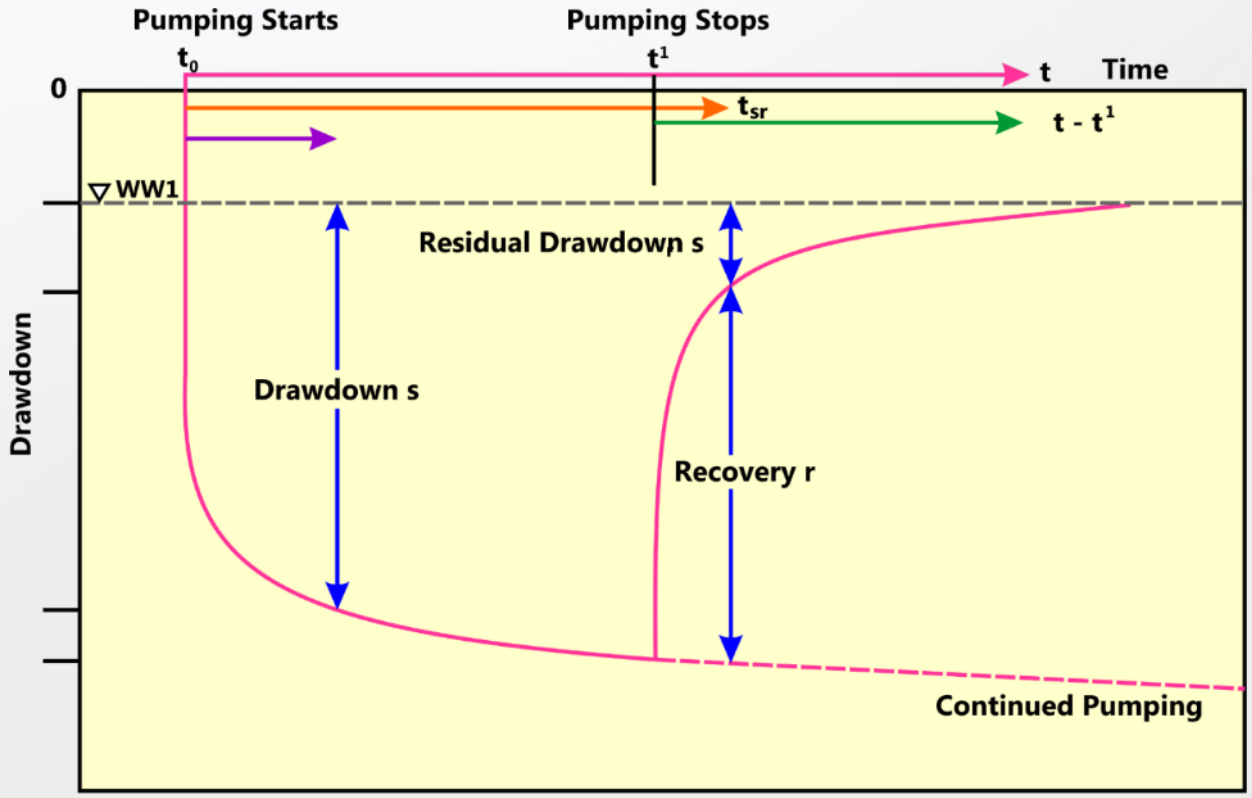
Observed Time-Drawdown and Recovery in One Observation Well

Depiction of drawdown and the subsequent recovery (after pumping has stopped) of the water table (or potentiometric surface) with time in an observation well.

Transient Pumping Tests with Observation Wells

- Drawdown is large early in the pumping test, but the rate of decline slows with time. Water level recovers quickly after the pump is shut off, but the recovery rate also slows with time
- If pumping continues long enough, generally 24-72 hours, the cone of depression may eventually become large enough so that it ceases to expand.
- When the cone of depression ceases to expand, the volume of water passing through a cylindrical annulus around the pumping well, within the radius of the cone of depression, is equal to the volume of water being pumped out of the well. At this point equilibrium conditions (steady state) have been reached.
- If it doesn't do this, the aquifer isn't necessarily "wrong"

Transient Pumping Tests with Observation Wells

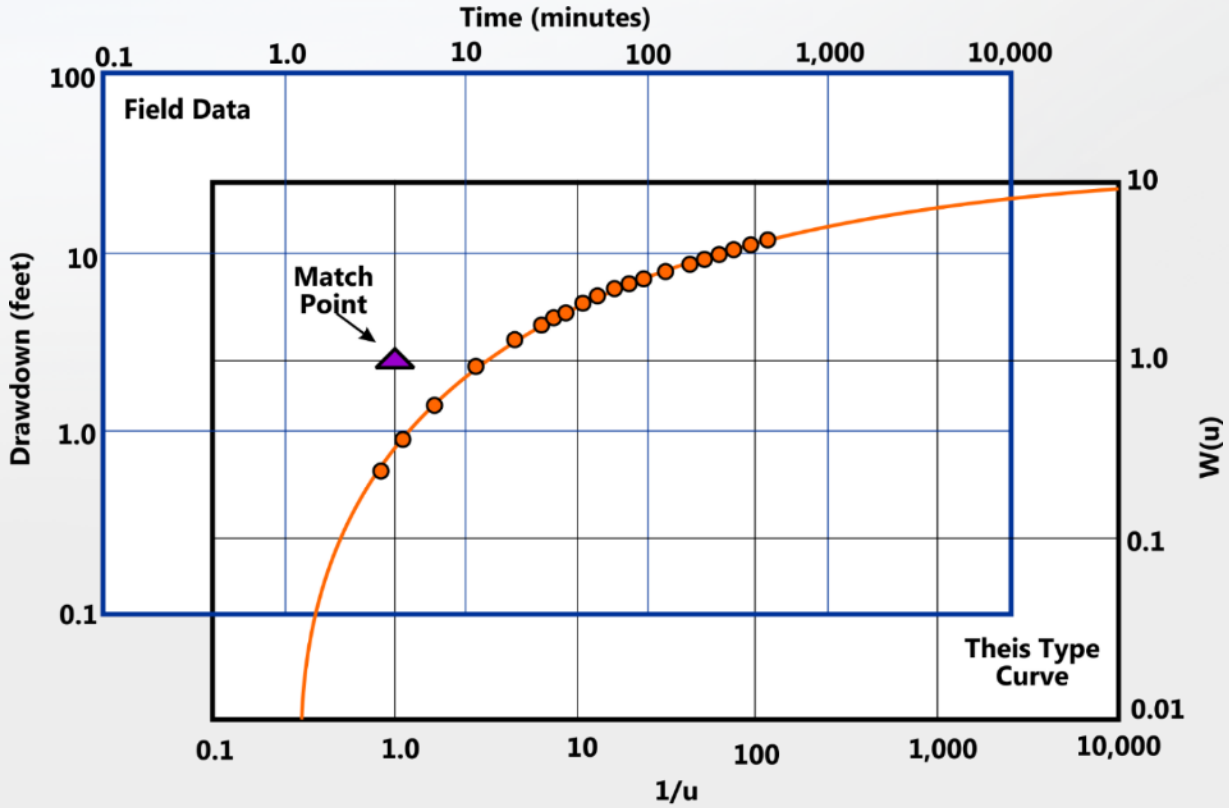


Observed Time-Drawdown and Recovery in One Observation Well

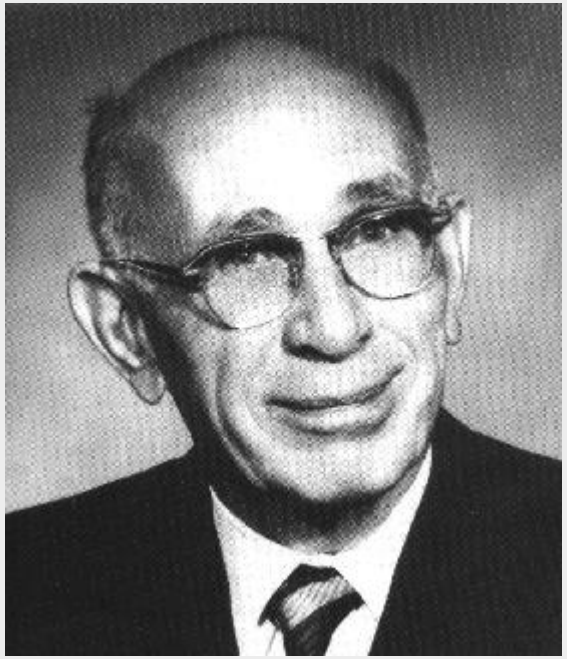
Recovery data are often better than pumping data!

Getting T and S

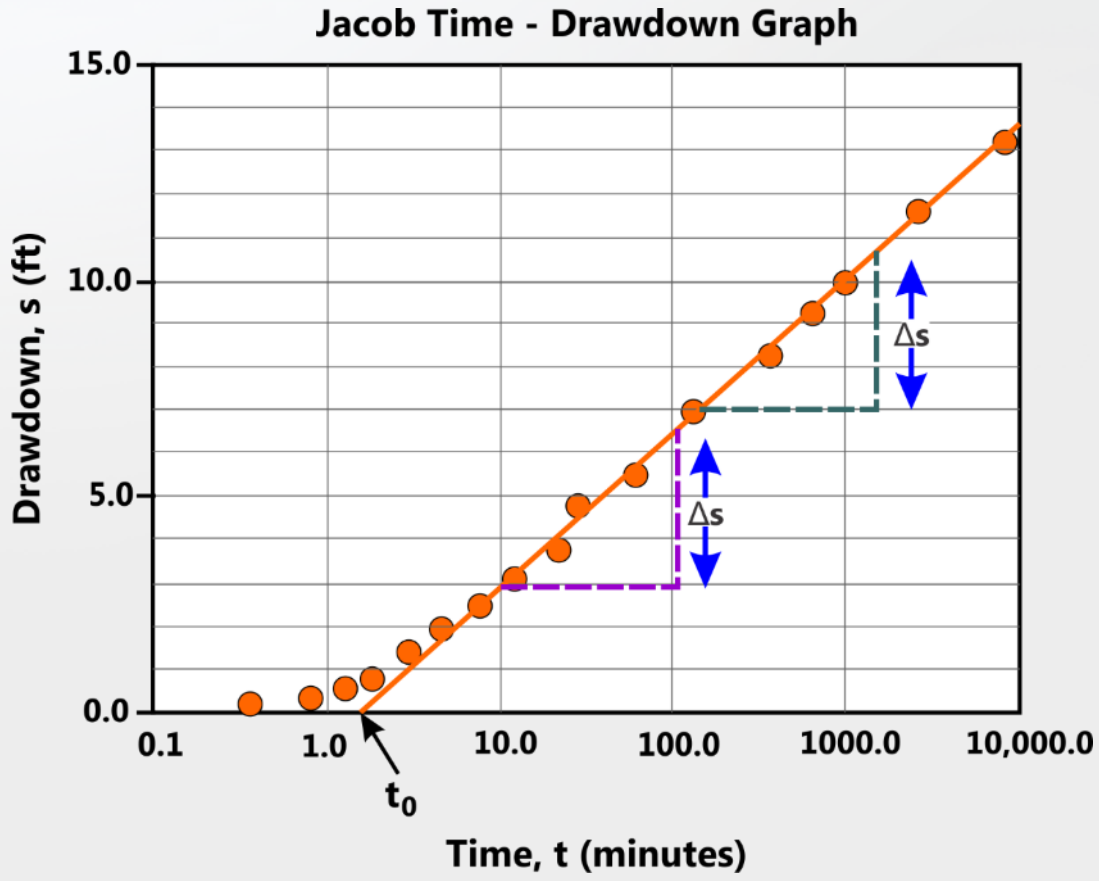
Theis Curve: Transient Solution



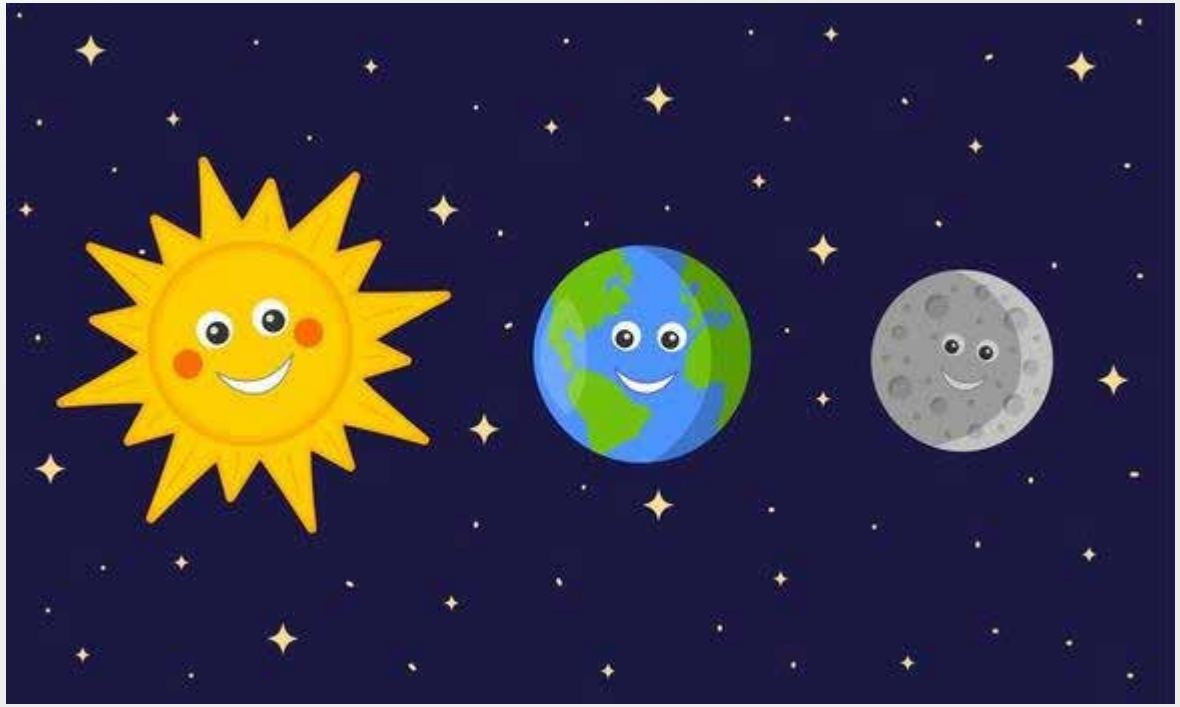
Match of field-data plot to Theis type curve.



Jacob Method Approximation

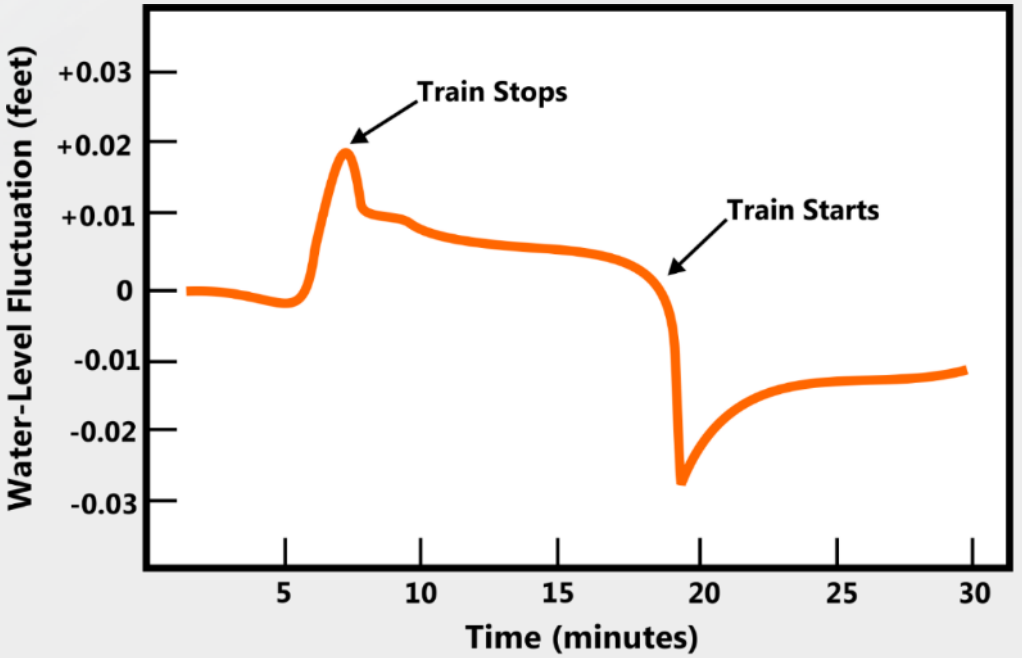


5. Testing with the air, moon, and sun



Just need to stress the aquifer

- A pump is only one way to stress an aquifer
- Moon and sun will generate tidal signatures
- Atmosphere will also generate signatures
- Even trains will generate signatures



Water-level fluctuations observed in an observation well near a railroad station (from Jacob, Trans. Amer. Geophys. Union, v. 20, p. 666-674, 1939. Copyright by Amer. Geophys. Union).

Can you “see” the stress?

- Transducer sensitivity varies
- Want most sensitive (~5 m full range)
- Dataset of ~2 months will get earth tide and atmospheric signatures
- Make sure you have barometric data too

Model and Field Data

- Make sure field data are high quality
- Field data don’t need to fit a Theis curve (or anybody else’s)
- Need to know that the field data are real response of the aquifer

- !!!! Field data QAQC: transducers are cheaper than bad data

End of Aquifer Testing

A Bit of Advice

1. Always know **why** you are testing the aquifer
2. Always have a safe and detailed plan with backup equipment
3. “Wells are holes in the ground that lie.”

Questions?

Todd Halihan

todd.halihan@okstate.edu