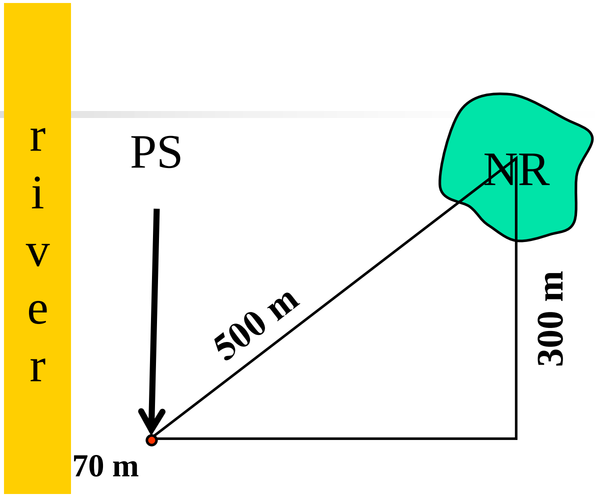
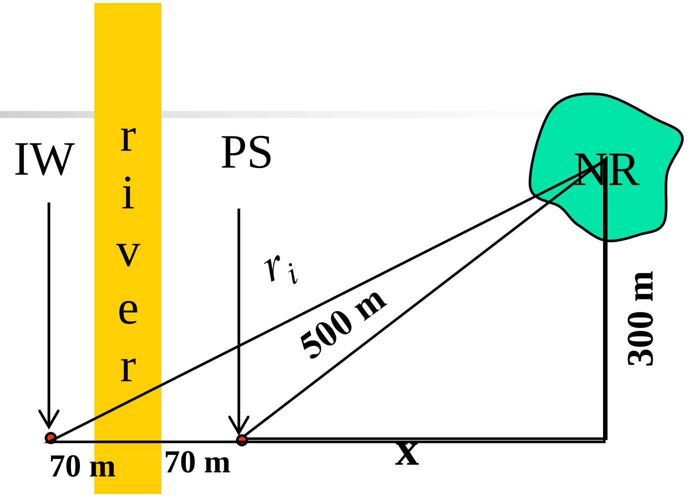
Example:



- Groundwater is pumped from a confined aquifer. The pumping discharge is 314.2 m^3 day^{-1}. The saturated depth of the aquifer is 50 m; the hydraulic conductivity of the aquifer equals 10 m day^{-1} and the storage coefficient of the aquifer is 0.0001. A river is located at a distance of 70 m of the pumping station (PS), and the midpoint of a nature reserve (NR) is located at a distance of 500 m from the pumping well.

Solution



- Pythagoras: $x^2 + 300^2 = 500^2 \Rightarrow x = 400\ m$
- *r of the image recharge well* $(r_i) = [(400 + 2x70)^2 + 300^2]^{1/2} = 619.14\ m$
- The drawdown at NR could be estimated by Copper Jacob equation, since the image well is an injection well the drawdown at NR will be obtained by subtracting the drawdown due to the image (injection) well from the drawdown caused by pumping well.

$$s = \frac{2.3Q}{4\pi bK}\log\left(\frac{2.25Tt}{r_p^2 bSc}\right) - \frac{2.3Q}{4\pi bK}\log\left(\frac{2.25Tt}{r_i^2 bSc}\right) = \frac{2.3Q}{4\pi bK}\left(\log\left(\frac{2.25Tt}{r_p^2 bSc}\right) - \log\left(\frac{2.25Tt}{r_i^2 bSc}\right)\right) = \frac{2.3Q}{4\pi bK}\log\left(\frac{r_i^2}{r_p^2}\right)$$

$$= \frac{2.3 \times 314.2 m^3/d}{4\pi \times 50 \times 10 m/d}\log\left(\frac{(619.14)^2}{500^2}\right) = 0.021 m = 2.1 cm$$

7. Pumping Wells

- The drawdown observed in a pumping well has two component parts:
  - **Aquifer loss**
    - Drawdown due to laminar flow in the aquifer
  - **Well loss**
    - Drawdown due to turbulent flow in the immediate vicinity of the well through the screen and/or gravel pack
- Well loss is usually assumed to be proportional to the square of the pumping rate: $s_w = CQ^2$
- The total drawdown at a pumping well is given by:

$$s_t = s + s_w = \frac{Q}{4\pi T} W(u) + CQ^2 = BQ + CQ^2$$

Well Efficiency

- The ratio of the aquifer loss and total drawdown (s/s_t) is known as the well efficiency.

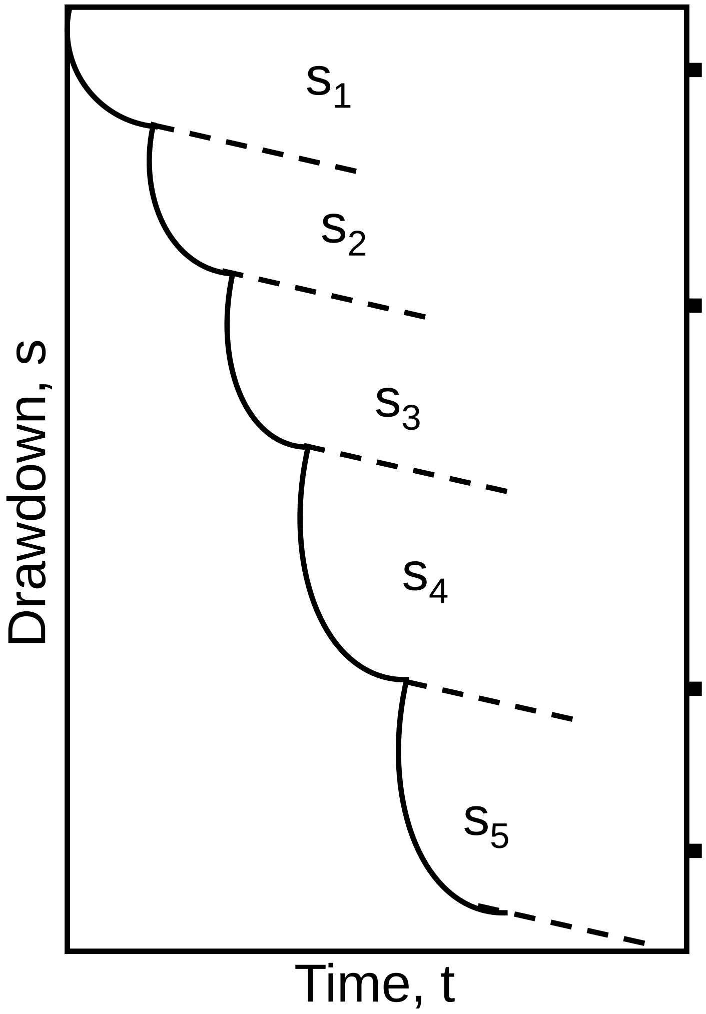
$$\frac{s}{s_t} = \frac{W(u)}{W(u) + 4\pi TCQ} = \frac{B}{B + CQ}$$

- Mogg (1968) defines well efficiency at a fixed time (t = 24 hrs). Thus, writing W(u) as the Cooper-Jacob approximation gives:

$$\frac{s}{s_t} = \frac{1}{1 + 4\pi TCQ / \left[\ln\left(2.25Tt / S\right) - 2\ln\left(r_w\right)\right]} = \frac{1}{1 + CQ / B(r_w)}$$

- Written in this form it is clear that well efficiency reduces with pumping rate (Q) and increases with well radius (r_w), where B is inversely related to well radius.
- The specific capacity is given by: $\frac{Q}{s_t} = \frac{1}{B + CQ}$

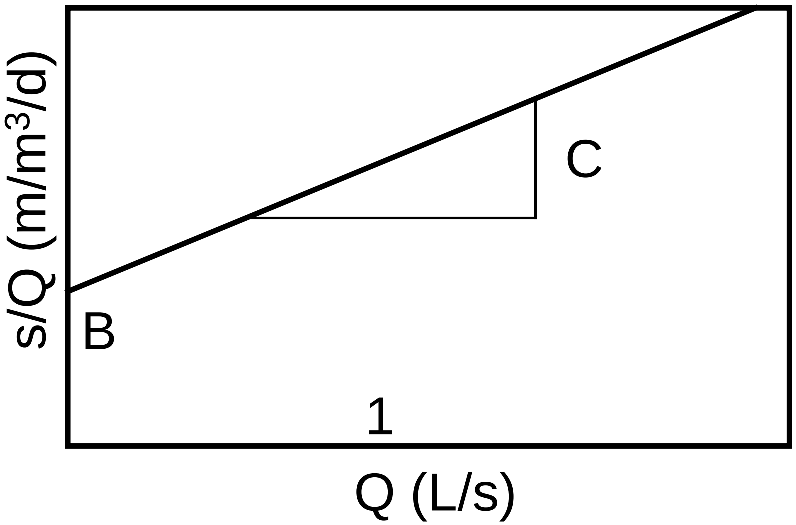
Step-Drawdown Test



- Step-drawdown tests are tests at different pumping rates (Q) designed to determine well efficiency.
- Normally pumping at each successively greater rate $Q_1 < Q_2 < Q_3 < Q_4 < Q_5$ takes place for 1-2 hours (Δt) and for 5 to 8 steps. The entire test usually takes place in one day.
- Equal pumping times (Δt) simplifies the analysis.
- At the end of each step, the pumping rate (Q) and drawdown (s) is recorded.

Step-Drawdown Test Analysis

- Step-drawdown tests are analyzed by plotting the reciprocal of specific capacity (s/Q) against the pumping rate (Q).



- The intercept of the graph at Q=0 is B = W(u)/(4πT) and the slope is the well loss coefficient, C.
- B can also be obtained independently from a Theis or Cooper-Jacob analysis of a pump test.
- For Q = 2700 m^3/d and s = 33.3 m the B = 0.012 m/m^3/d
- If C = 4 x 10^{-5}, then CQ^2 = 18.2 m
- The well efficiency is (33.3 – 18.2) /33.3 = 45.3%

- A well efficiency of 70% or more is usually acceptable.
- If a newly developed well has less than 65% efficiency, it should not be accepted.
- **A qualitative "Rule of Thumb" to recognize an inefficient well is:**
  - If the pump is shut off after 1 hour of pumping and 90% or more of the drawdown is recovered after 5 minutes, it can be concluded that the well is unacceptably inefficient.

Well Yield

Well yield			Nom. pump dia.		Opt. casing dia.		Min. casing dia.	
US gpm	**L/s**	**m³/d**	**in**	**mm**	**in**	**mm**	**in**	**mm**
< 100	< 6.4	550	4	100	6	150	5	130
< 170	< 11	950	5	130	8	200	6	150
< 350	< 22	1900	6	150	10	250	8	200
< 700	< 44	3800	8	200	12	300	10	250
< 1000	**< 64**	**5500**	**10**	**250**	**14**	**360**	**12**	**300**
< 1800	< 110	9800	12	300	16	410	14	360
< 3000	< 190	16000	14	360	20	510	16	410
< 3800	< 240	21000	16	410	24	610	20	510
< 6000	< 380	33000	20	510	30	760	24	610

- The chart is used to select casing sizes for a particular yield. The main constraint is pumping equipment.
- For example, if the well is designed to deliver 4,000 m^3/d, the optimum casing dia. is 360 mm (2 nom. sizes > pump dia.) and the minimum 300 mm.
- The drilled well diameter would have to be 410 to 510 mm to provide at least a 50 mm grout/cement annulus.

Pump Test Planning

- Several preliminary estimates are needed to design a successful test:
  - Estimate the maximum drawdown at the pumped well
  - Estimate the maximum pumping rate
  - Evaluate the best method to measure the pumped volumes
  - Plan discharge of pumped volumes distant from the well
  - Estimate drawdown at observation wells
  - Simulate the test before it is conducted
  - Measure all initial heads several times to ensure that steady-conditions prevail
  - Survey elevations of all well measurement reference points

Number of Observation Wells

- Number depends on test objectives and available resources for test program.
  - Single well can give aquifer characteristics (T and S). Reliability of estimates increases with additional observation points.
  - Three wells at different distances are needed for time-distance analysis
  - No maximum number; because anisotropy, homogeneity, and boundaries can be deduced from response

Pump Test Measurements

- The accuracy of drawdown data and the results of subsequent analysis depends on:
  - Maintaining a constant pumping rate
  - Measuring drawdown at several (>2) observation wells at different radial distances
  - Taking drawdown at appropriate time intervals at least every min (1-15 minutes); (every 5 minutes) 15-60 minutes; (every 30 minutes) 1-5 hrs; (every 60 minutes) 5-12 hrs; (every 8 hrs) >12 hrs
  - Measuring barometric pressure, stream levels, etc as necessary over the test period

Pump Test Measurements

- Measuring both pumping and recovery data
- Continuing tests for no less than 24 hours for a confined aquifers and 72 hours for unconfined aquifers in constant rate tests
- Collecting data over a 24 hour period for 5 or 6 pumping rates for step-drawdown tests

Measuring Pumping Rates

- Control of pumping is normally required as head and pump rpm changes. Frequent flow rate measurements are needed to maintain constant rate.
- Lower rates
  - Periodic measurements of time to fill a container of known volume
  - "v" notch weir - measure head (sensitive at low flows)
- Higher rates
  - Impellor driven water meter - measure velocity (insensitive)
  - Circular orifice weir - measure head $v=(2gh)^{1/2}$
  - Rectangular notch weir - measure head
  - Free-flow Parshall flume (drop in floor) - measure head
  - Cutthroat flume (flat floor) – measure head

Measuring Drawdown

- Pumped wells
  - Heads are hard to measure due to turbulence and pulsing.
  - Data cannot reliably estimate storage.
- Observation wells
  - Smallest possible diameter involves least time lag
  - Screens usually 1-2 m; longer is better but not critical. It should be at same depth as centre of production section
  - If too close (< 3 to 5 x aquifer thickness) can be strongly influenced by anisotropy (stratification)
  - If too far away (>200 m unconfined) $\Delta h(t)$ increases with time so a longer test is required – boundary and other effects can swamp aquifer response

Drawdown Instrumentation

- Dip meters
  - Let cable hang to remove kinks
  - Rely on light or buzzer, have spare batteries
- Steel tapes
  - Read wetted part for water level (chalking helps)
  - Hard to use where high-frequency readings are needed
- Pressure gauges
  - Measure head above reference point
  – need drawdown estimates to set gauge depth
- Pressure transducers/data loggers
  - Hang in well and record at predetermined interval
  - Remote sites (no personnel) and closest wells (frequency)