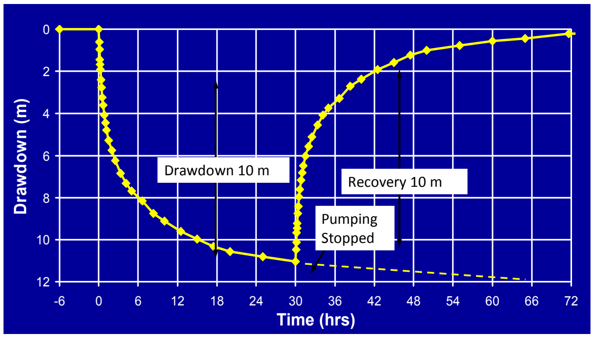
Recovery Curve



The recovery curve on a linear scale appears as an inverted image of the drawdown curve. The dotted line represent the continuation of the drawdown curve.

Recovery Data

- When pumping is halted, water levels rise towards their pre-pumping levels.
- The rate of recovery provides a second method for calculating aquifer characteristics.
- Monitoring recovery heads is an important part of the well-testing process.
- Observation well data (from multiple wells) is preferable to that gathered from pumped wells.
- Pumped well recovery records are less useful but can be used in a more limited way to provide information on aquifer properties.

Superposition

- The drawdown (s) for a well pumping at a constant rate (Q) for a period (t) is given by:

$$s = h_o - h = \frac{Q}{4\pi T} W(u) \quad \text{where } u = \frac{r^2 S}{4Tt}$$

- The effects of well recovery can be calculated by adding the effects of a pumping well to those of a recharge well using the superposition theorem.
- The drawdown (s_r) for a well recharged at a constant rate (-Q) for a period ($t' = t - t_r$) starting at time t_r is given by:

$$s_r = \frac{-Q}{4\pi T} W(u') \quad \text{where } u' = \frac{r^2 S}{4Tt'}$$

- The total drawdown for $t > t_r$ is:

$$s' = s + s_r = \frac{Q}{4\pi T}(W(u) - W(u'))$$

Residual Drawdown and Recovery

- The total drawdown for $t > t_r$ is:

$$s' = s + s_r = \frac{Q}{4\pi T}(W(u) - W(u'))$$

- The Cooper-Jacob approximation can be applied giving:

$$s' = s + s_r = \frac{Q}{4\pi T}\left(\ln\left(\frac{2.25Tt}{r^2 S}\right) - \ln\left(\frac{2.25Tt'}{r^2 S}\right)\right)$$

- Simplification gives the residual drawdown equation:

$$s' = s + s_r = \frac{Q}{4\pi T} \ln\left(\frac{t}{t'}\right)$$

- The equation predicting the recovery is:

$$s_r = \frac{-Q}{4\pi T} \ln\left(\frac{2.25Tt'}{r^2 S}\right)$$

For $t > t_r$, the recovery s_r is the difference between the observed drawdown s' and the extrapolated pumping drawdown (s).

Time-Recovery Analysis

- For a constant rate of pumping (Q), the recovery any time (t') after pumping stops:

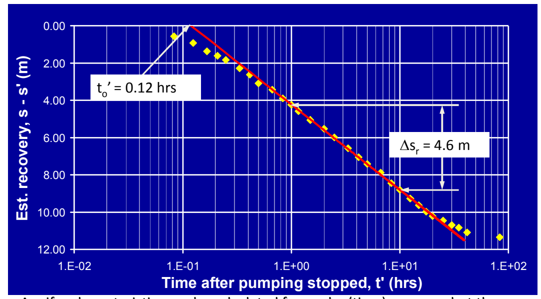
$$T = \frac{Q}{4\pi\Delta(s - s')} = \frac{-Q}{-4\pi\Delta s_r} = \frac{Q}{4\pi\Delta s_r}$$

- The storage coefficient can be estimated for an observation well using:

$$S = \frac{4Tt_o'}{r^2}$$

- It is necessary to use an observation well for this calculation because well bore storage effects render any calculation based on r_w potentially subject to huge errors.

Time-Recovery Graph



Aquifer characteristics can be calculated from a log(time)-recovery but the drawdown (s) curve for the pumping phase must be extrapolated to estimate recovery (s - s')

Time-Residual Drawdown Analysis

- For a constant rate of pumping (Q), the recovery any time (t') after pumping stops:

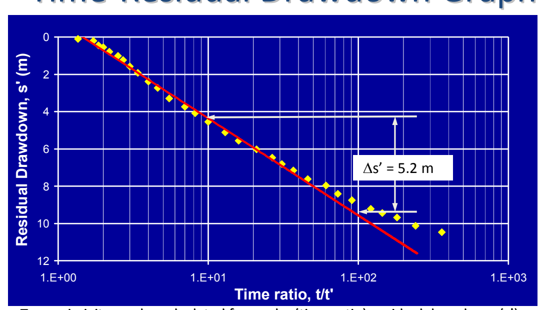
$$T = \frac{Q}{4\pi\Delta s'}$$

- For the example, Δs_r = and Q = 1100 m^3/d so:

$$T = 1100 / (12.56 \times 5.2) = 17 \text{ m}^2\text{/d}$$

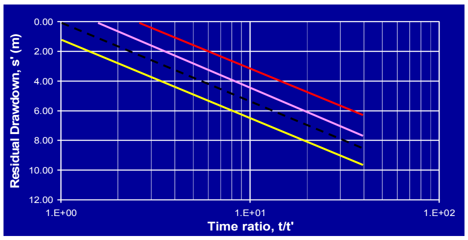
- Notice that the graph plots t/t' so the points on the LHS represent long recovery times and those on the RHS short recovery times.
- The storage coefficient cannot be estimated for the residual drawdown plot because the intercept $t / t' \rightarrow 1$ as $t' \rightarrow \infty$.
- This more obvious, remembering $t' = t - t_r$ where t_r is the elapsed pumping time before recovery starts.

Time-Residual Drawdown Graph



Transmissivity can be calculated from a log(time ratio)-residual drawdown (s') graph by determining the gradient. For such cases, the x-axis is log(t/t') and thus is a ratio.

Residual Drawdown for Real Aquifers



- Theoretical intercept is 1
- >> 1 indicates a recharge effect
- >1 may indicate greater S for pumping than recovery ?consolidation
- < 1 indicates incomplete recovery of initial head - finite aquifer volume
- << 1 indicates incomplete recovery of initial head - small aquifer volume

Diameter of the well= 0.3 m
Q= 1080 lpm

Pumping time (t) = one day 1440 minutes
Drawdown = 1.85 m

Calculate T and S

Recovery time (minutes)- t'	Time since pumping started (1440+t')	Ratio (t/t')	Residual drawdown (m)
1	1441	1441	0.875
2	1442	721	0.735
3	1443	481	0.694
4	1444	361	0.662
5	1445	289	0.64
6	1446	241	0.625
8	1448	181	0.59
10	1450	145	0.57
12	1452	121	0.556
16	1456	91	0.535
20	1460	73	0.498
30	1470	49	0.458
40	1480	37	0.423
45	1485	33	0.41
60	1500	25	0.383

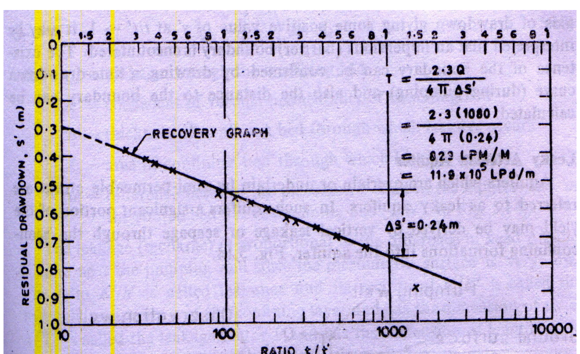


Fig. 5.12 Time-drawdown graph—Theis recovery, Example 5.9.

$$s_{t_1} = \frac{2.3\,Q}{4\pi T}\log_{10}\frac{2.25\,Tt_1}{r^2 S}$$

$$1.85 = \frac{2.3\,(1{,}080)}{4\pi\,(823.6)}\log_{10}\frac{2.25\,(0.823)\,1{,}440}{(0.15)^2\,S}$$

$$\log_{10}\frac{119000}{S} = 7.708$$

$$S = 0.00233$$

END