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ENVIRONMENTAL AND WATER RESOURCE CONSULTANTS

The Interpretation of Pumping Well Drawdowns

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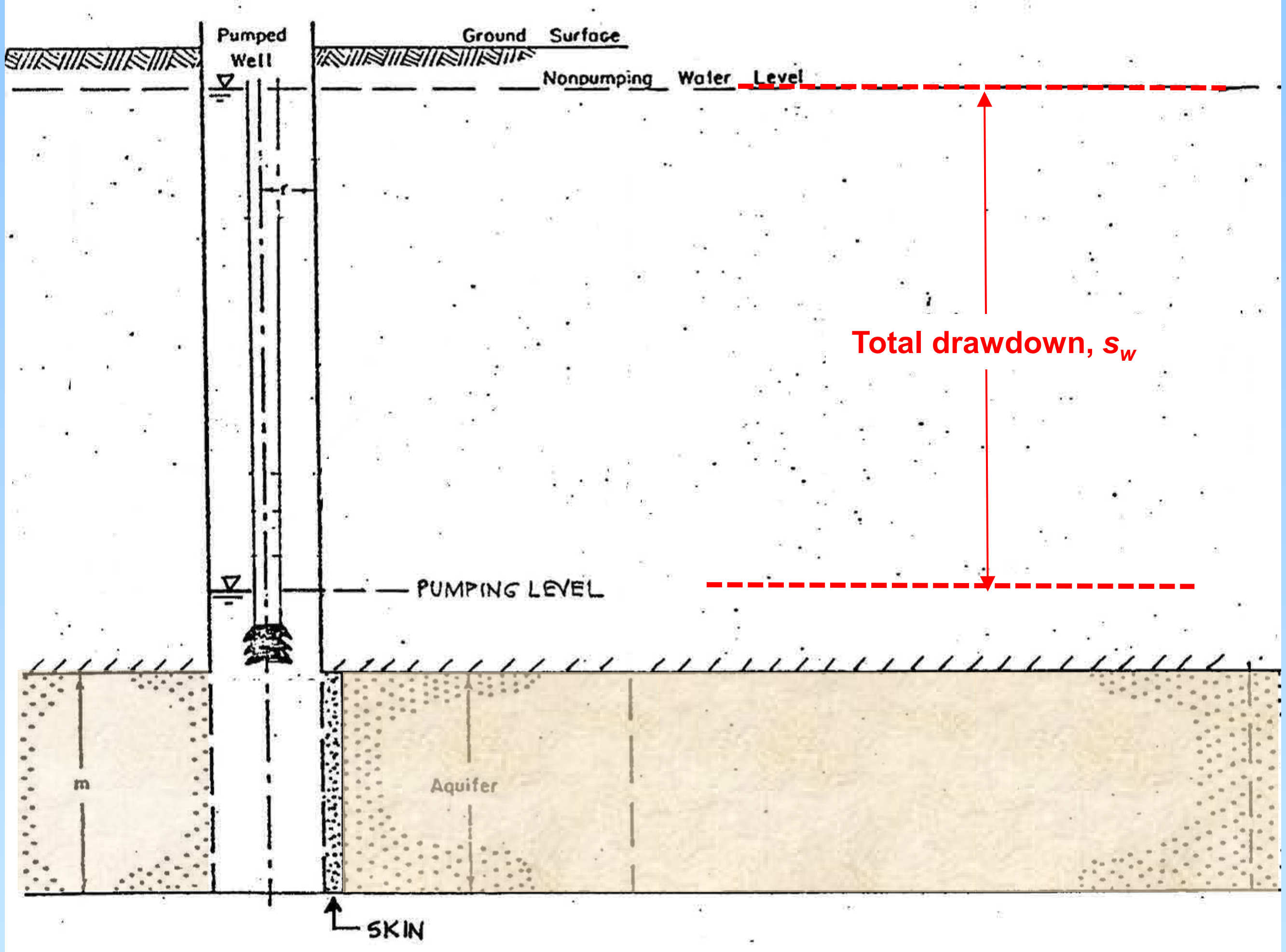
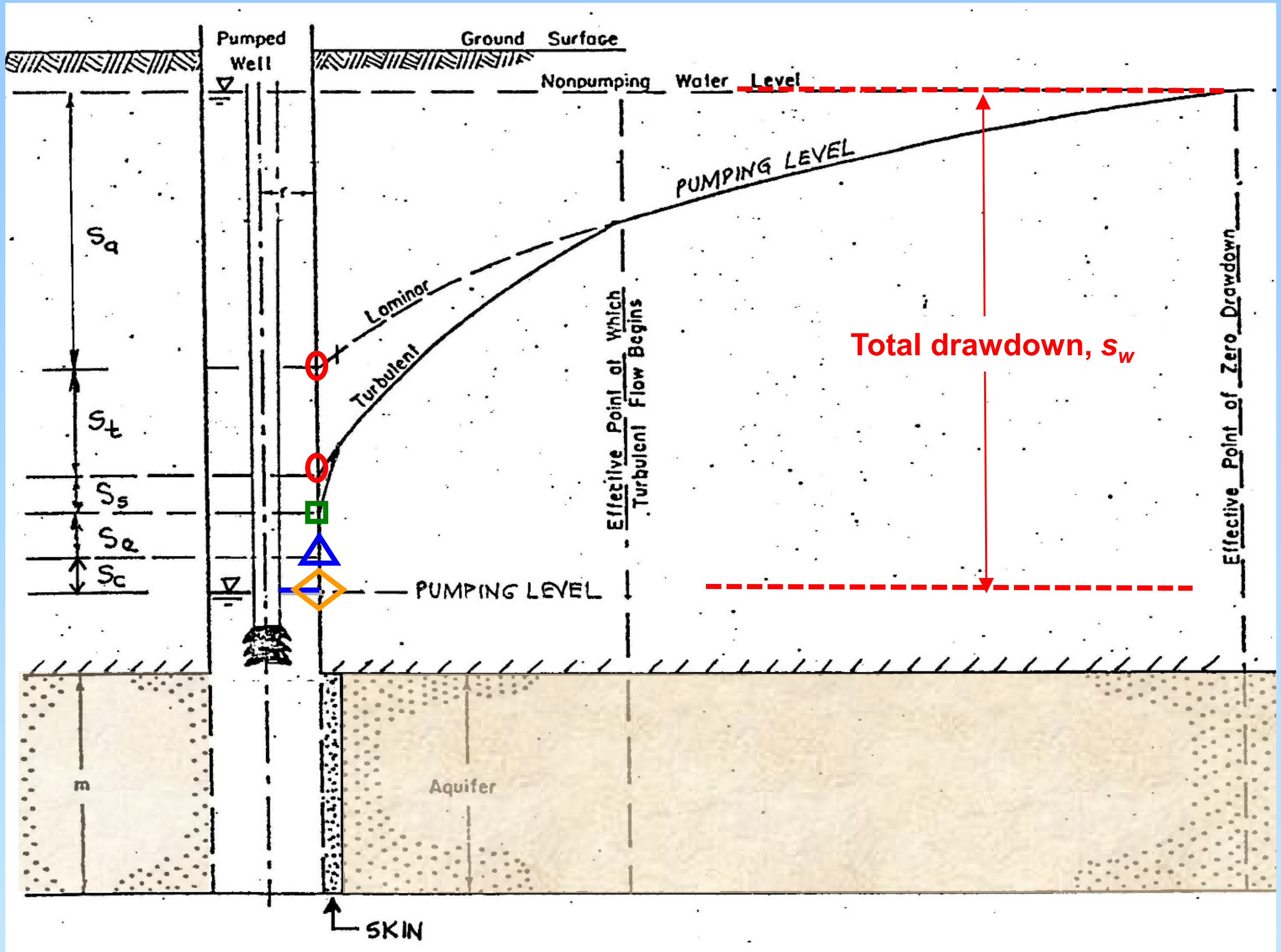
Outline

1. Overview of the hydraulics of pumping wells
2. Preliminary estimation of transmissivity
3. Extended interpretations of pumping well drawdowns
4. Step tests
5. Synthesis of pumping well and observation well drawdowns
6. Estimating the capacity of a production well

Overview of the hydraulics of a pumping well



Components of the drawdown in a pumping well

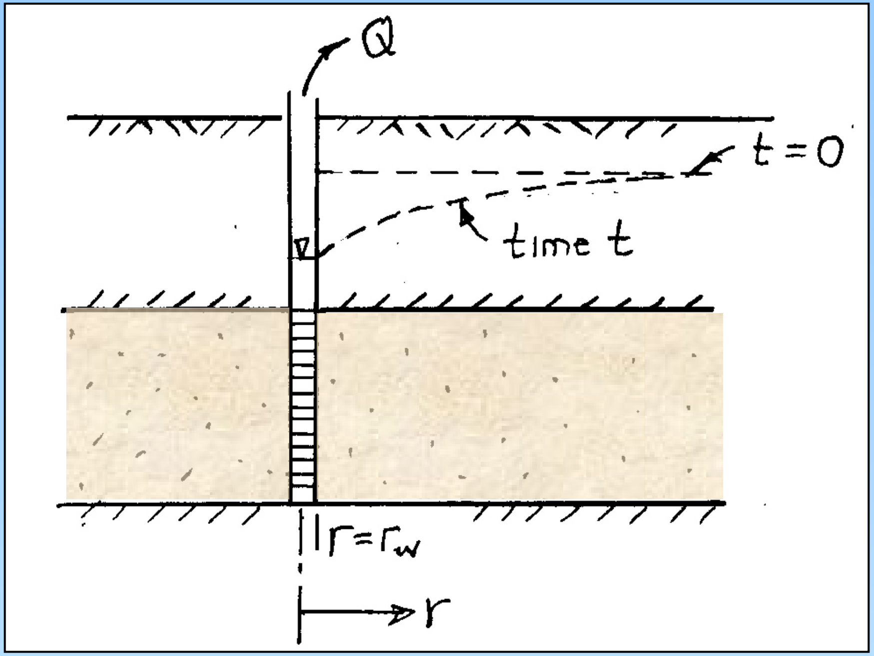


$$s_w(t) = s_a + s_t + s_s + s_e + s_c$$

Analyses for an ideal well

$$s_w = s_{\text{formation}}$$

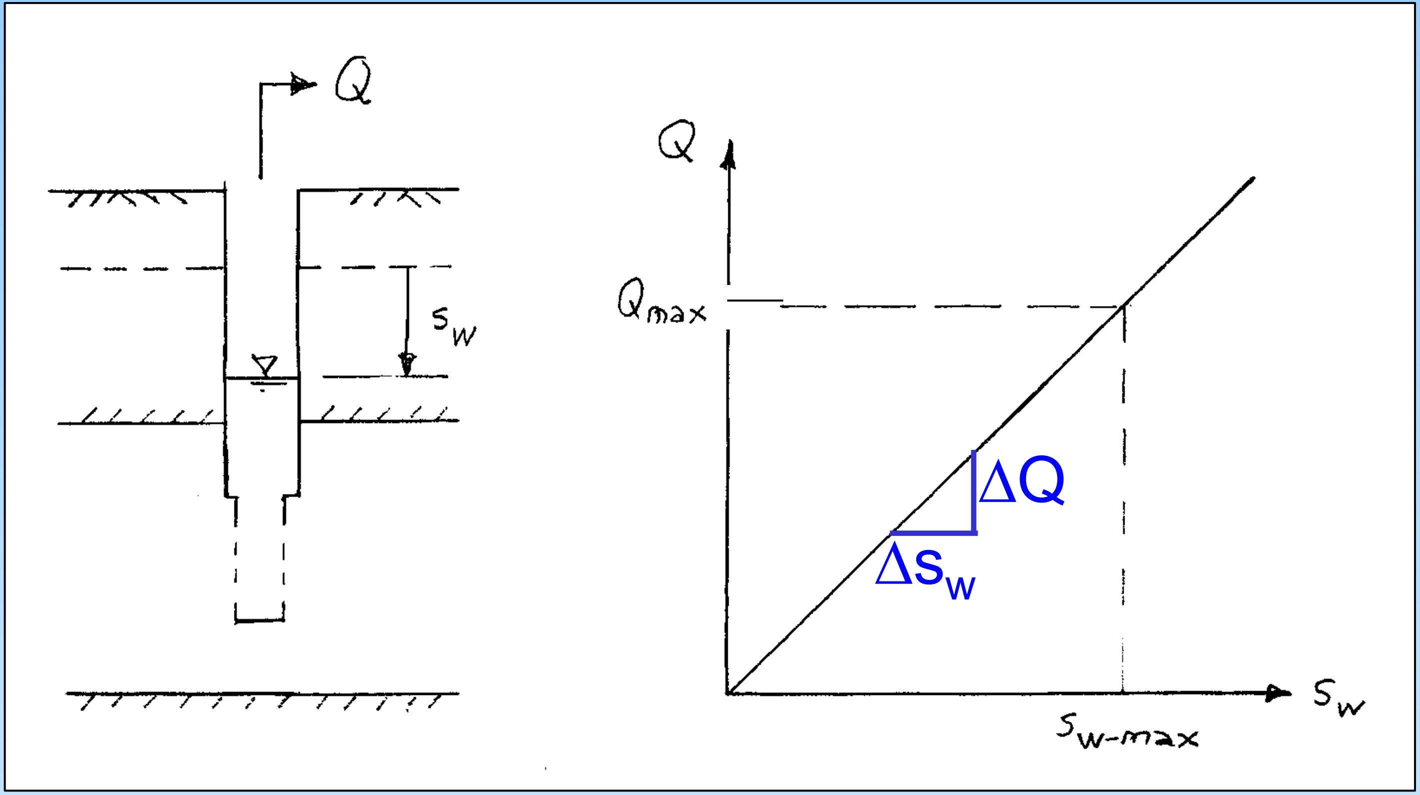
1. Drawdown in the formation, $s_{formation}$



$$s_{\text{formation}}(t) = Q \times F(r = r_w, t)$$

F is any aquifer conceptual model

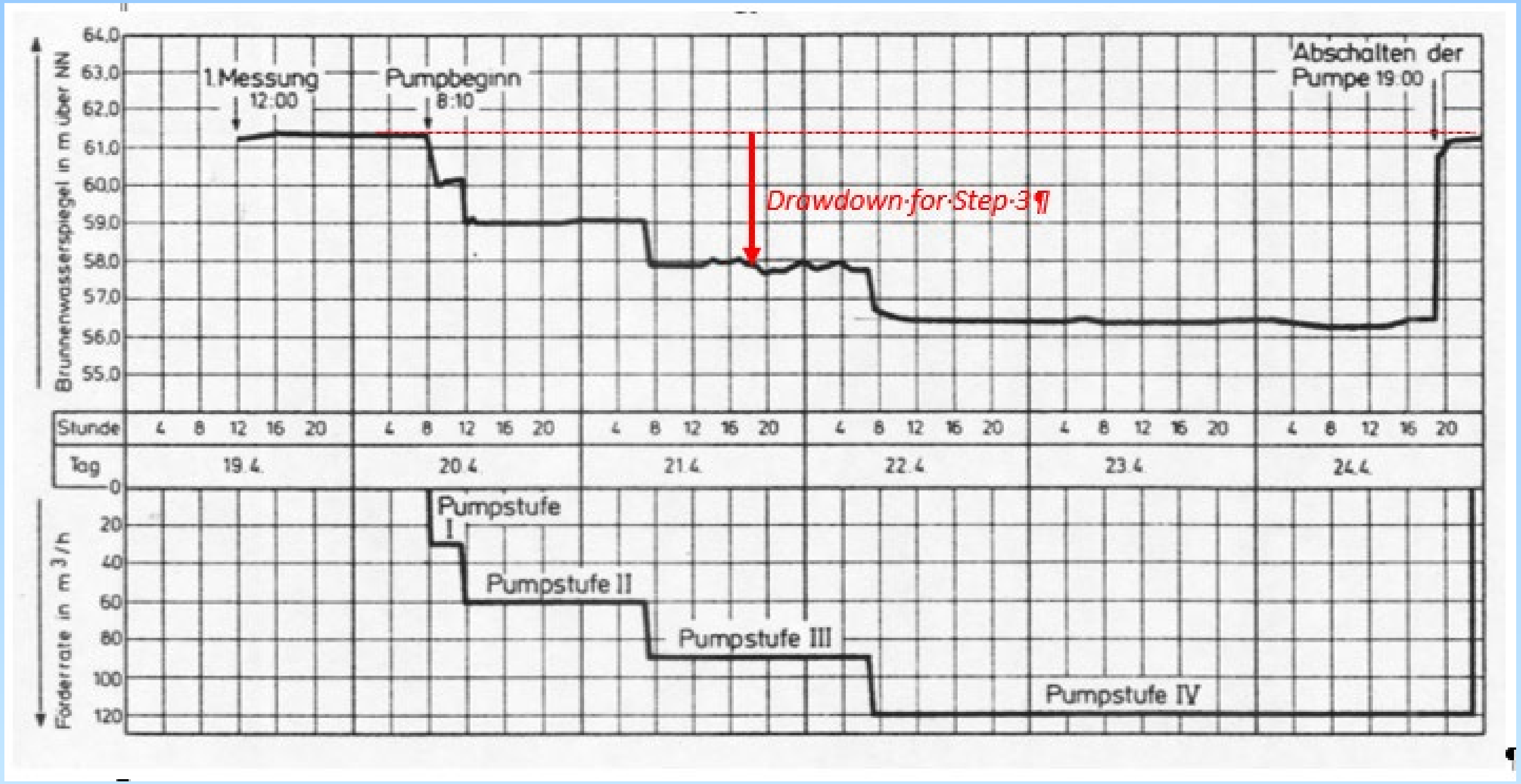
1. Drawdown in the formation: Ideal steady conditions

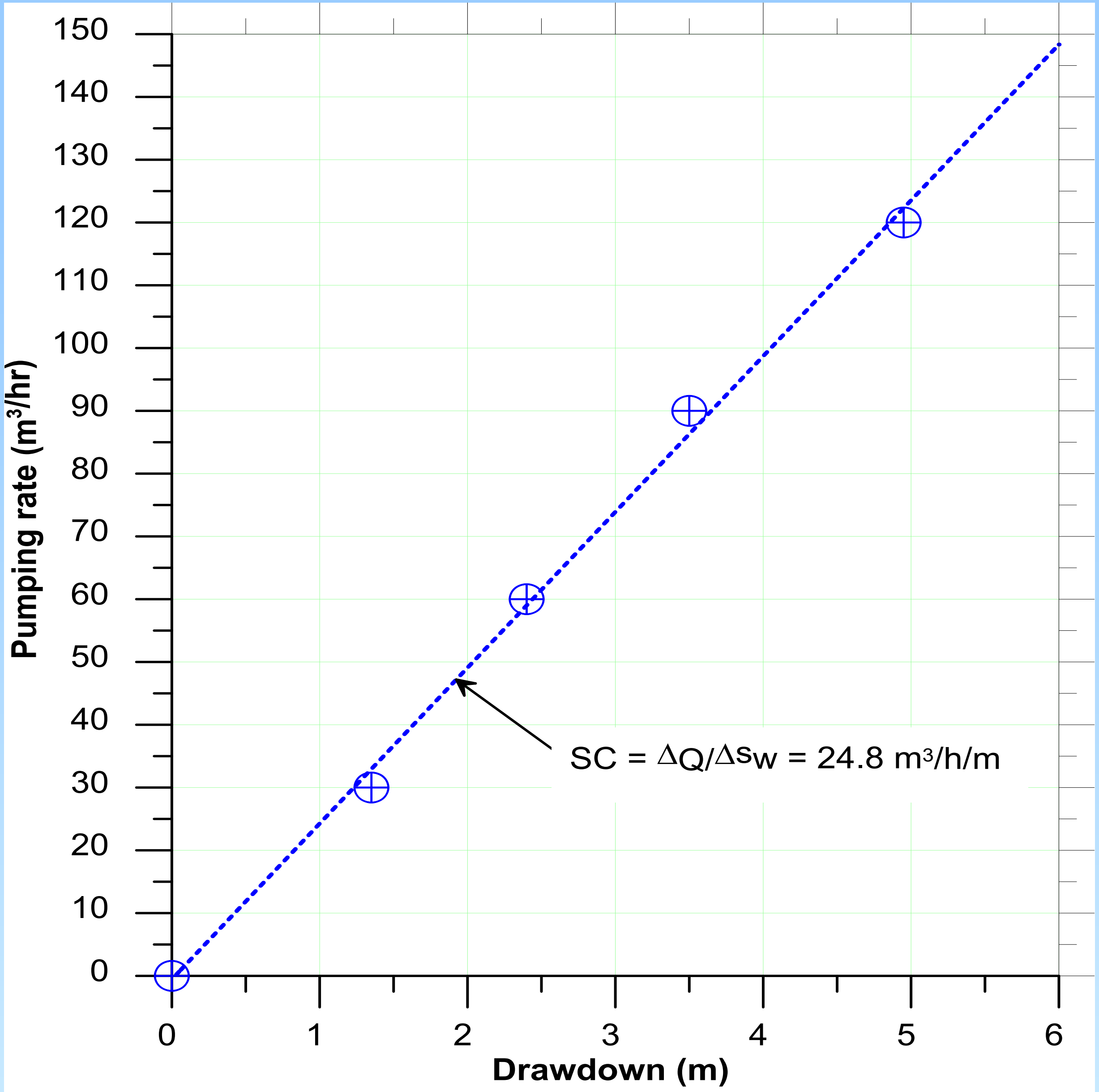


Specific capacity

$$SC = \frac{Q}{s_w} = \frac{\Delta Q}{\Delta s_w}$$

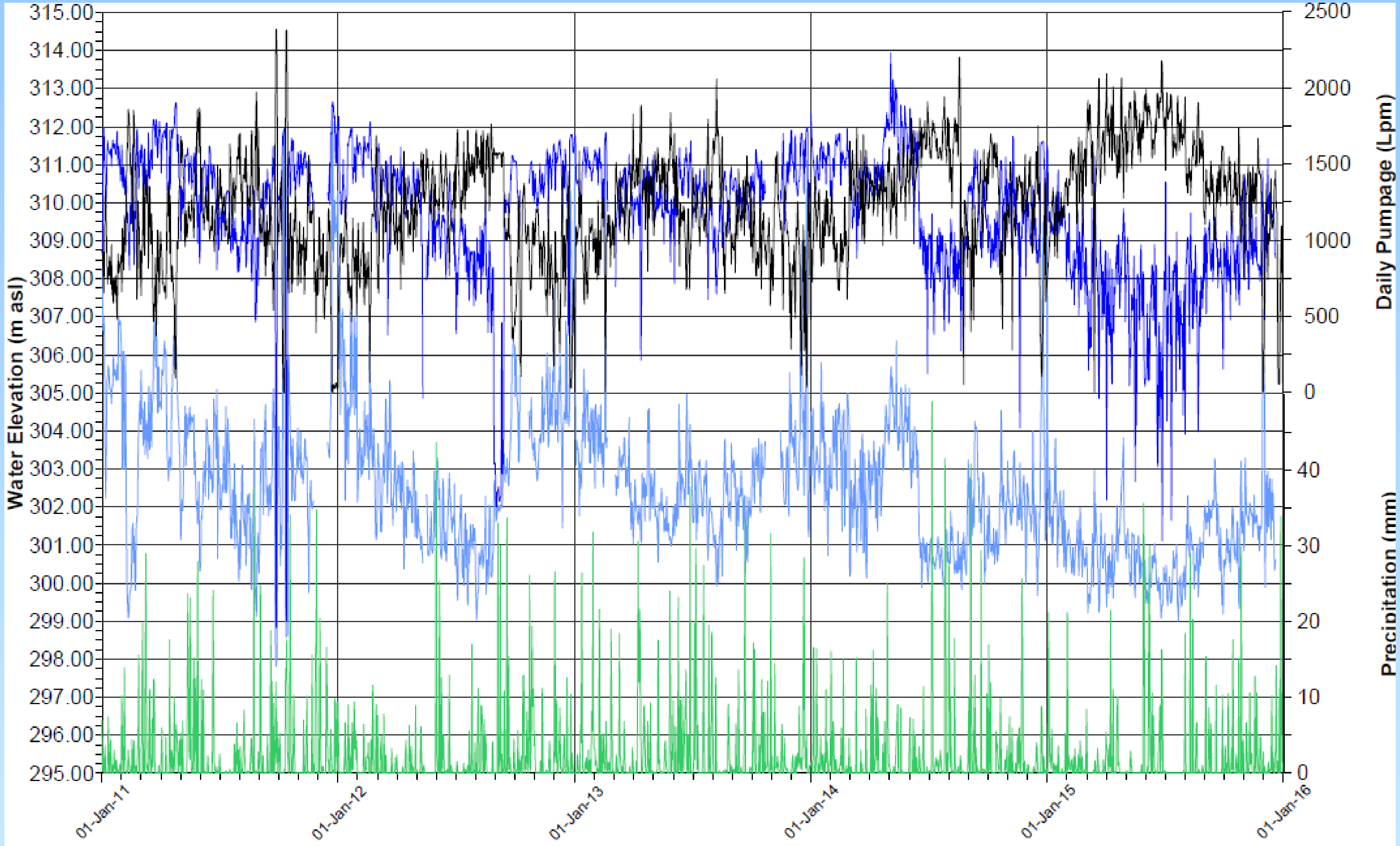
Example: Linnich, Germany





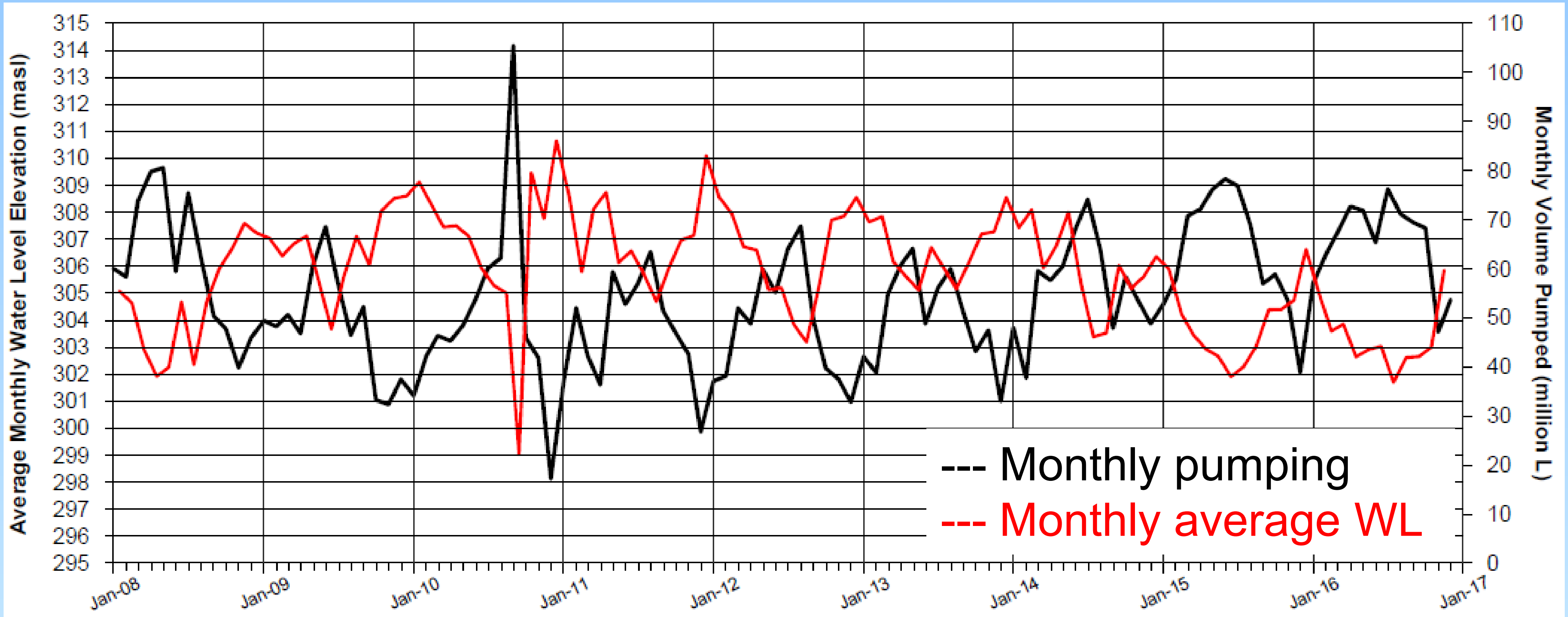
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Pumping rate (m3/hr)
0
1
2
3
4
5
6
Drawdown (m)
SC = ΔQ/ΔSw = 24.8 m3/h/m

Example: TW3-80

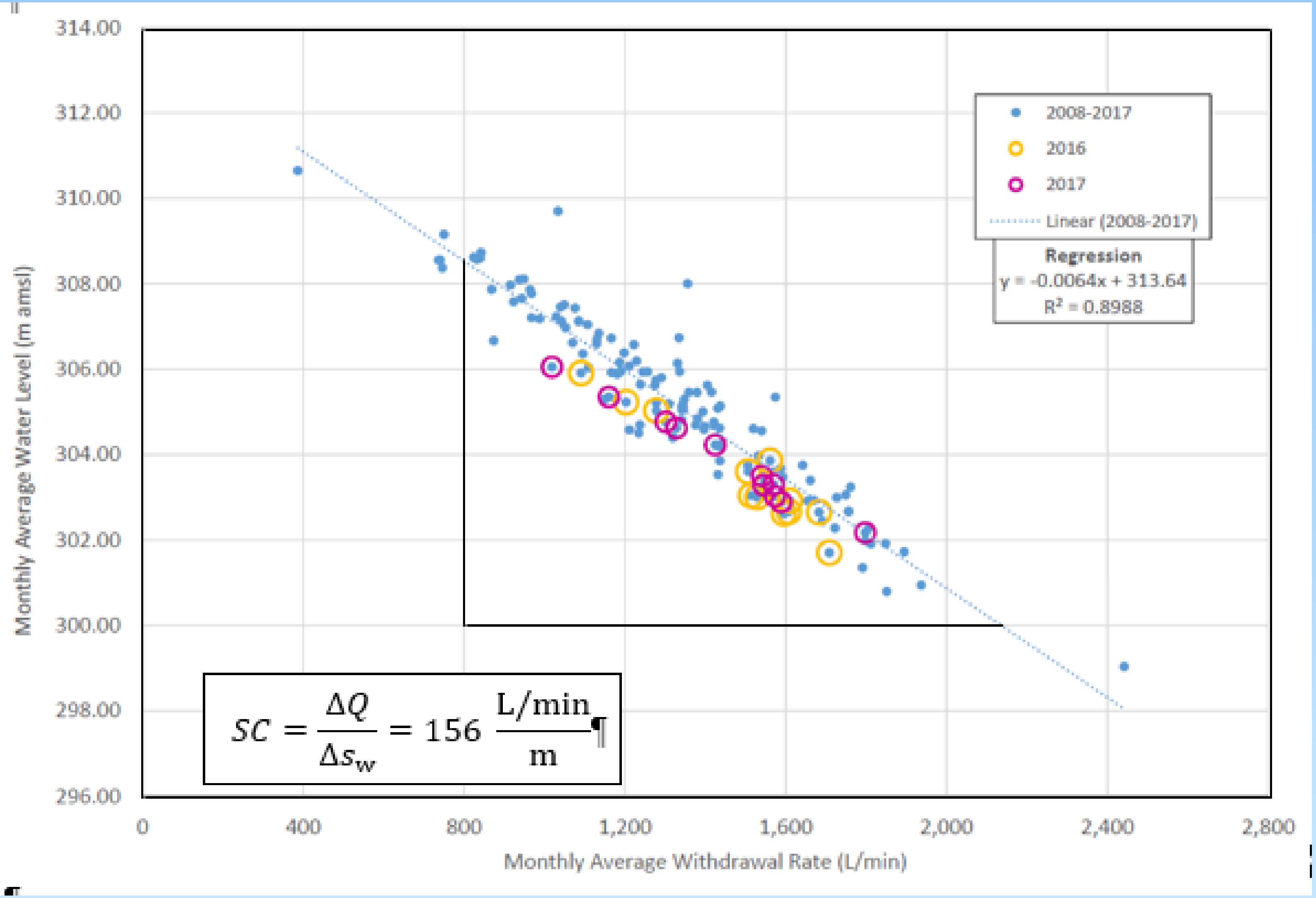


--- Precipitation
--- Daily pumping
--- Daily max WL
--- Daily min WL

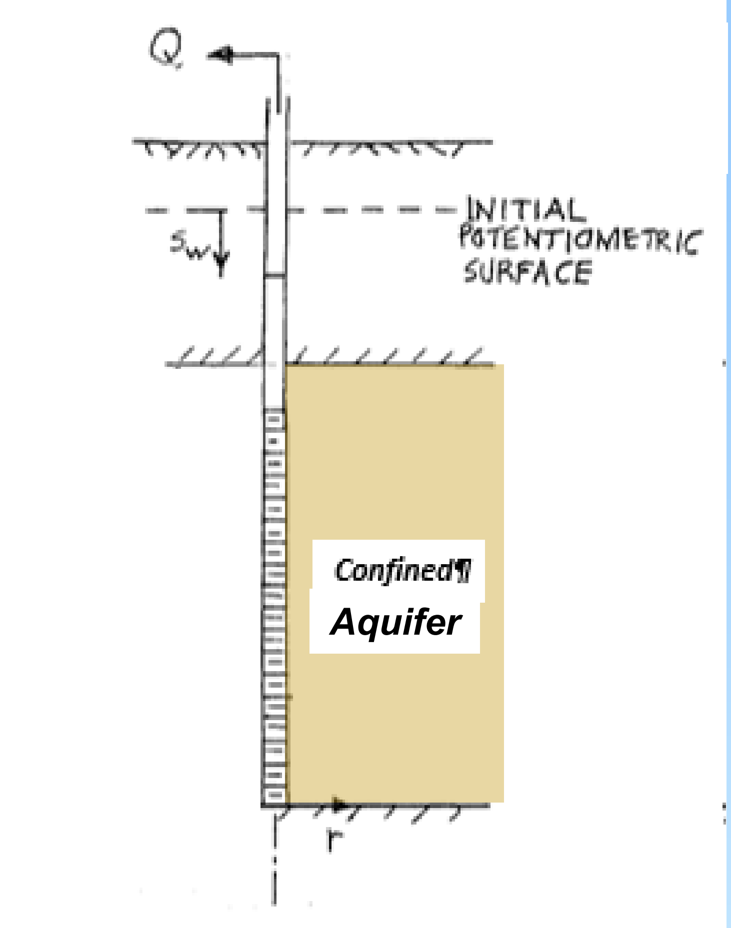
TW3-80 (2)



Average Monthly Water Level Elevation (masl)
Monthly Volume Pumped (million L)
315
314
313
312
311
310
309
308
307
306
305
304
303
302
301
300
299
298
297
296
295
110
100
90
80
70
60
50
40
30
20
10
0
Jan-08
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15
Jan-16
Jan-17
--- Monthly pumping
--- Monthly average WL


314.00
312.00
310.00
308.00
306.00
304.00
302.00
300.00
298.00
296.00
Monthly Average Water Level (m amsl)
0
400
800
1,200
1,600
2,000
2,400
2,800
Monthly Average Withdrawal Rate (L/min)
2008-2017
2016
2017
Linear (2008-2017)
Regression
y = -0.0064x + 313.64
R² = 0.8988
SC = ΔQ/Δs_w = 156 L/min/m

Specific capacity for ideal steady conditions



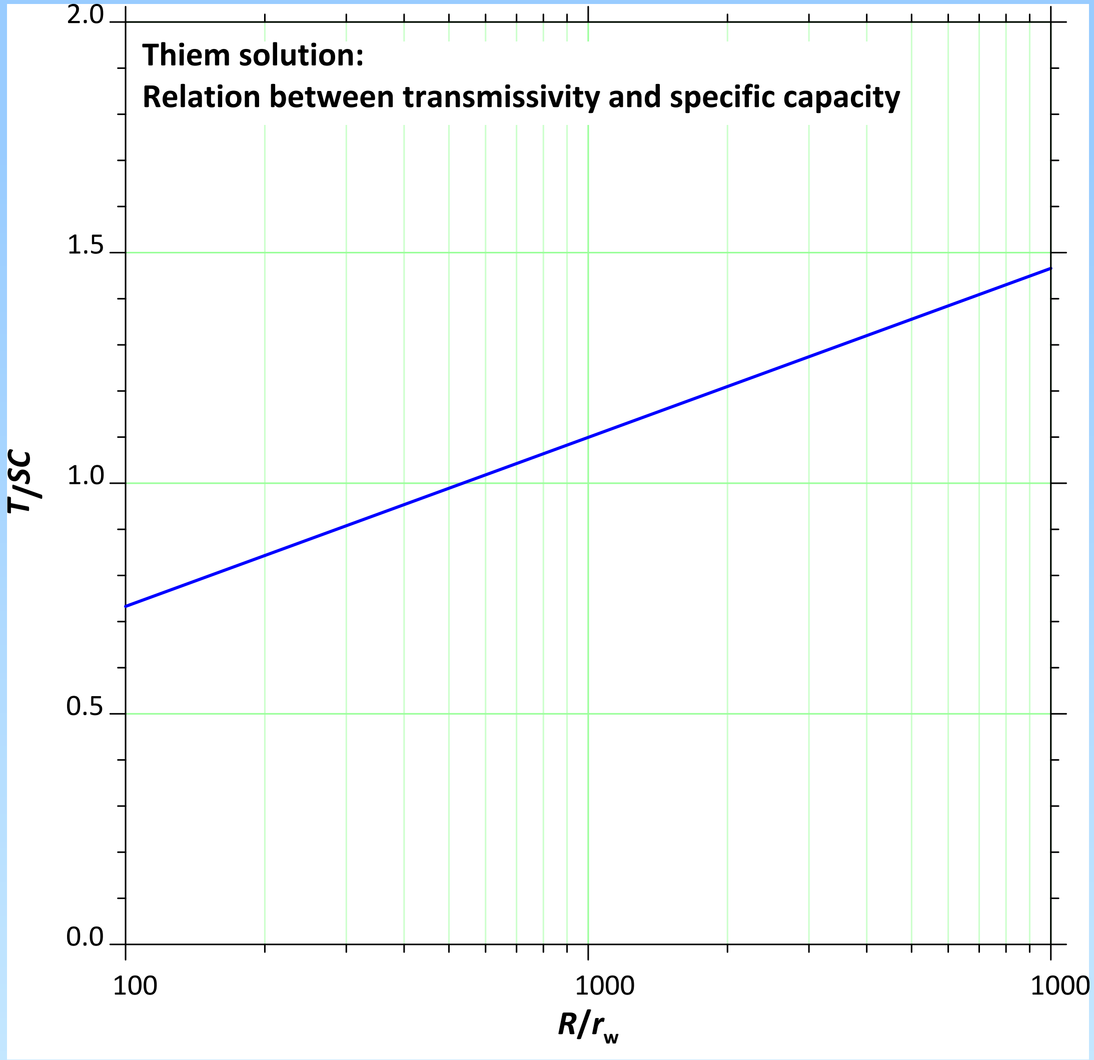
Thiem solution (steady conditions) for an "ideal" well:

$$Q = 2\pi T \frac{(h_R - h_w)}{ln\left\{\frac{R}{r_w}\right\}}$$

$$s_w = h_R - h_w = \frac{Q}{2\pi T} ln\left\{\frac{R}{r_w}\right\}$$

$$SC = \frac{Q}{s_w} = \frac{2\pi}{ln\left\{\frac{R}{r_w}\right\}} T$$

Estimation of transmissivity for ideal steady conditions



$$\frac{T}{SC} = \frac{ln\left\{\frac{R}{r_w}\right\}}{2\pi}$$

Given the specific capacity, *SC*:

$$T \approx SC$$

2. Drawdown in the formation: Ideal transient conditions

One particular model: Theis (1935) evaluated at r_w

$$s_{\mathrm{formation}}(t) = \frac{Q}{4\pi T} W\left\{\frac{r_{\mathrm{w}}^2 S}{4Tt}\right\}$$

Specific capacity for ideal transient conditions

$$s_{\mathrm{formation}}(t) = \frac{Q}{4\pi T} W\left\{\frac{r_{\mathrm{w}}^2 S}{4Tt}\right\}$$

$$SC = \frac{Q}{s_{\mathrm{formation}}(t)} = \frac{4\pi T}{W\left\{\frac{r_{\mathrm{w}}^2 S}{4Tt}\right\}}$$

Estimation of the transmissivity from the specific capacity

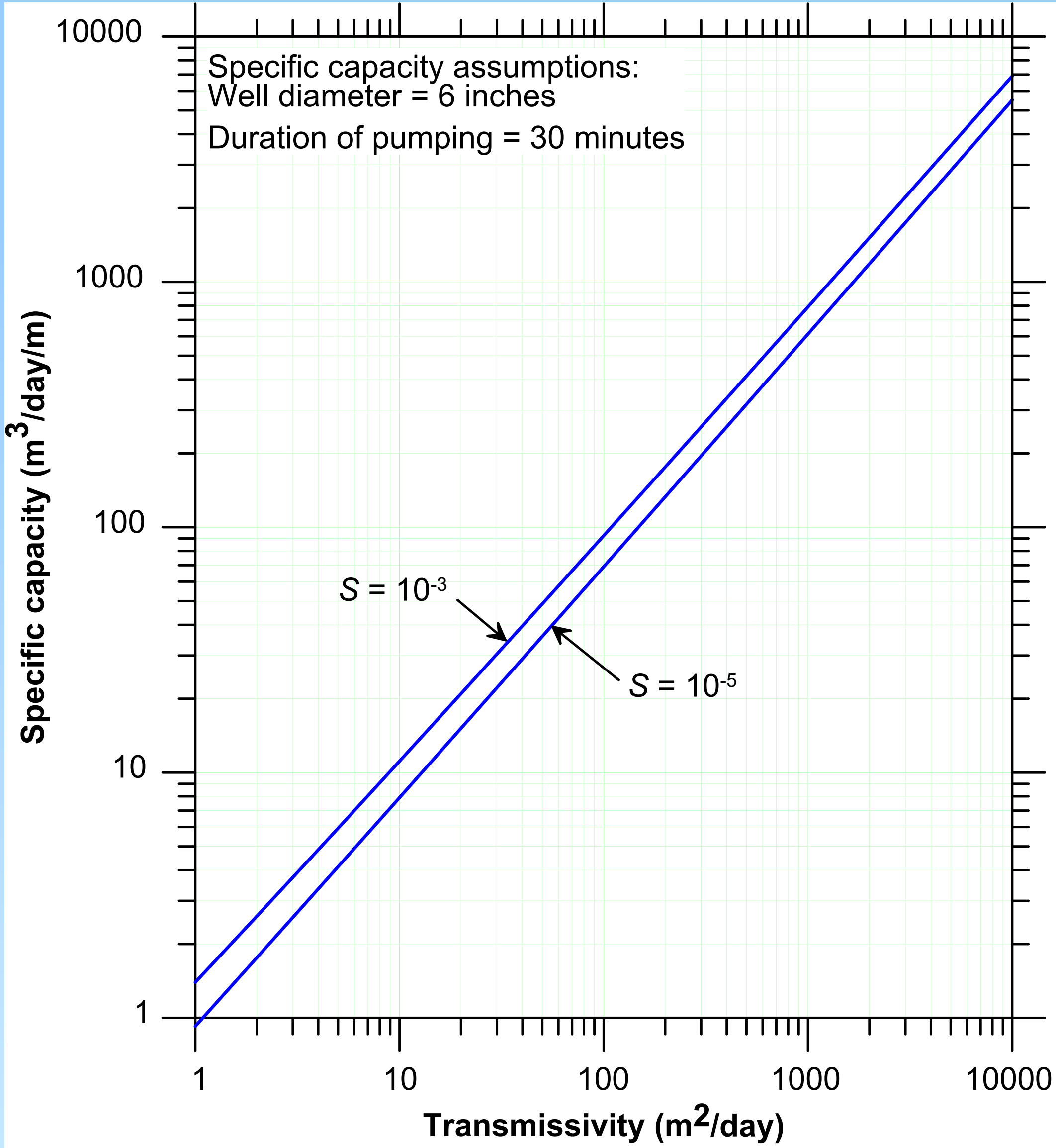
$$SC = \frac{Q}{s_{formation}(t)} = \frac{4\pi T}{W\left\{\frac{r_w^2 S}{4Tt}\right\}}$$

We cannot solve for the transmissivity *T* directly. If we know the specific capacity, we can estimated *T* can be estimation (e.g., Excel Solver).

However, there is a simpler approach.

A simple approach for estimating T for ideal transient conditions

- Specify r_w and t
- Assume S
- Calculate specific capacity for a range of transmissivities.

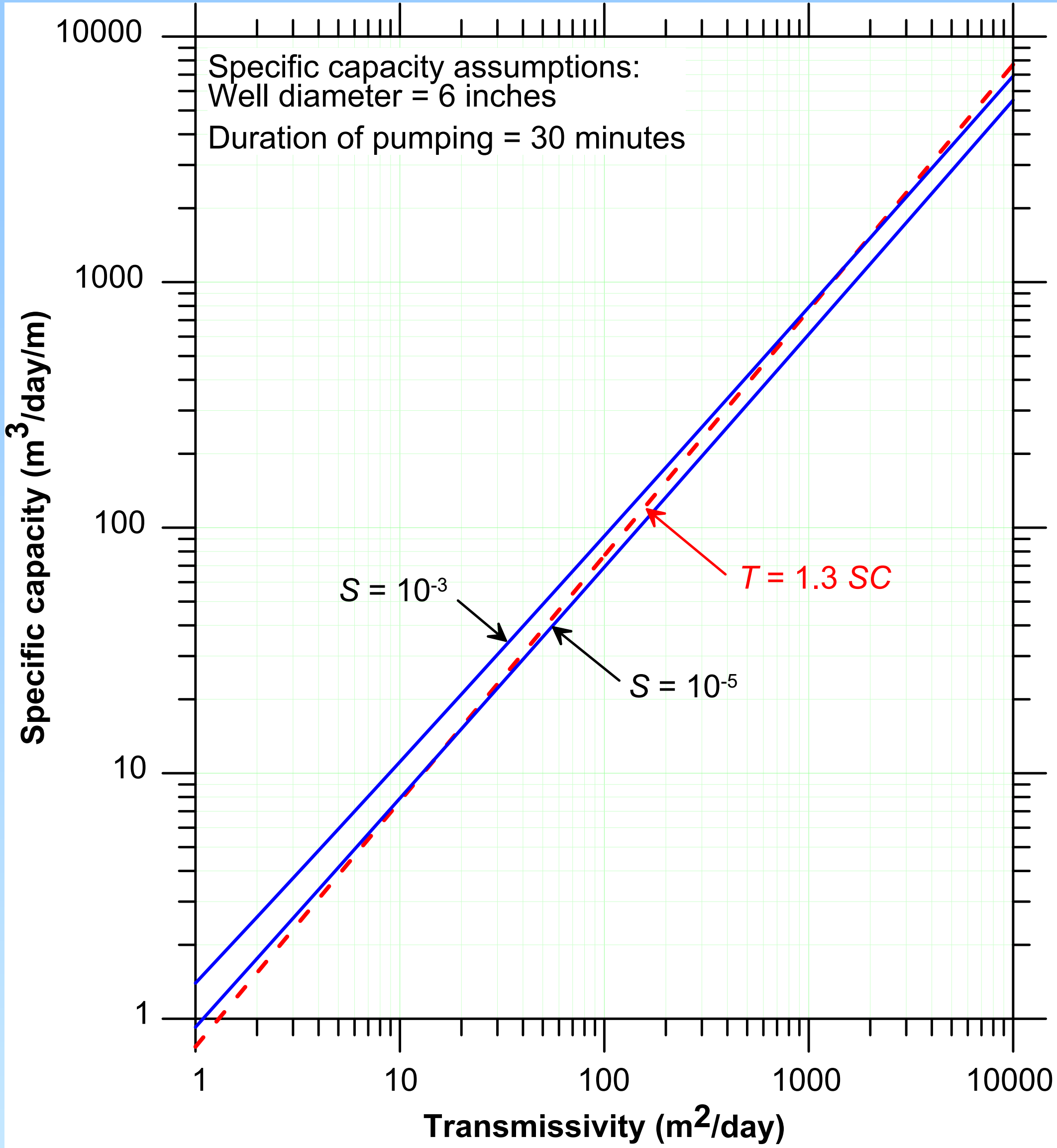


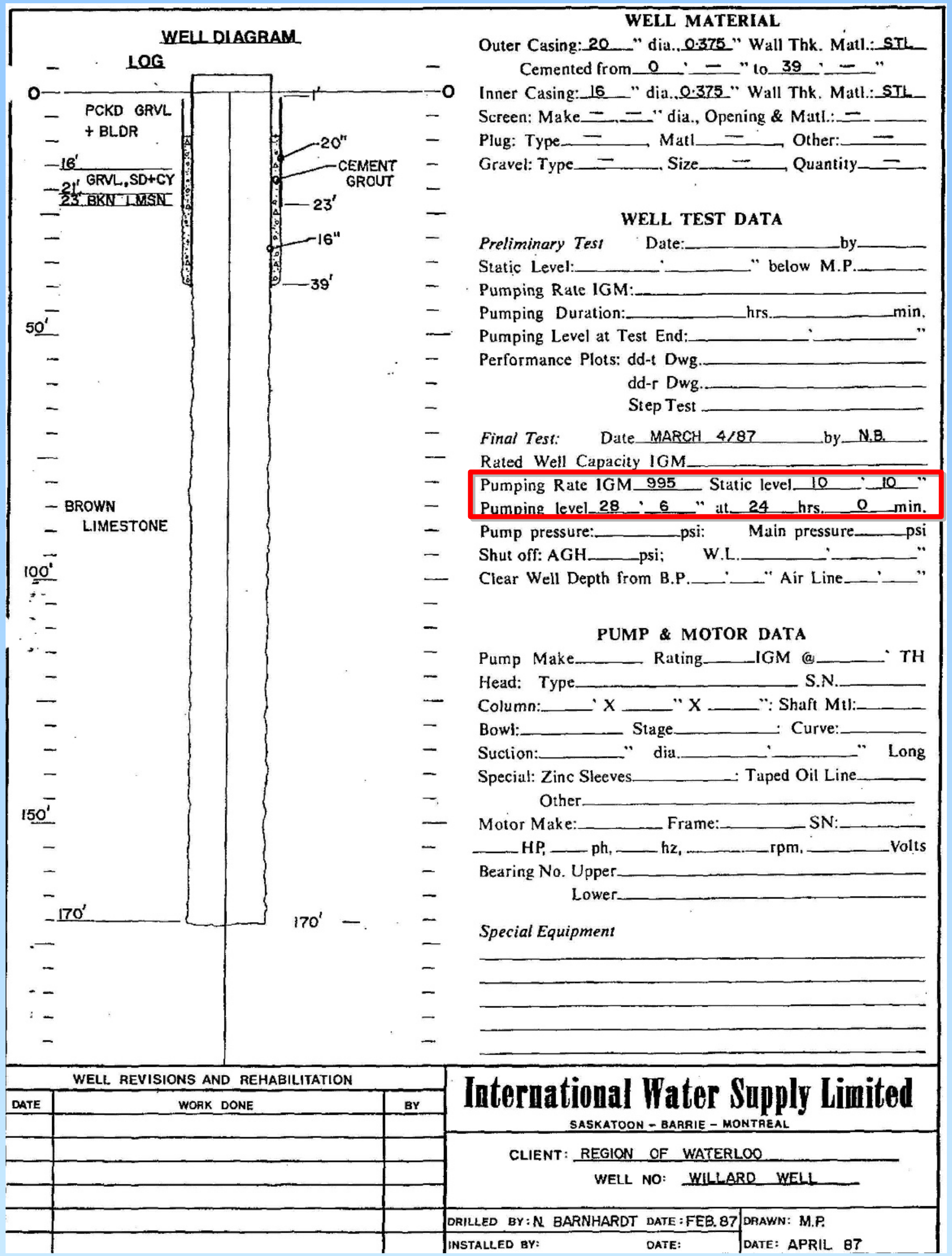
The leading coefficient is insensitive to the specified well diameter. The leading coefficient will vary a bit with the duration of pumping.

- 30 minutes: ~ 1.3
- 1 day: ~ 1.5

Since this calculation yields only a rough estimate of the transmissivity, it is appropriate to again write:

$$T \approx SC$$





WELL DIAGRAM

LOG

0 — PCKD GRVL + BLDR

16' — 21' GRVL, SD+CY

23' BKN LMSN

BROWN LIMESTONE

50'

100'

150'

170'

20" — CEMENT GROUT — 23' — 16" — 39' — 170'

WELL MATERIAL

Outer Casing: 20 " dia., 0.375 " Wall Thk. Matl.: STL

Cemented from 0 ' — " to 39 ' — "

Inner Casing: 16 " dia., 0.375 " Wall Thk. Matl.: STL

Screen: Make — — " dia., Opening & Matl.: —

Plug: Type — , Matl — , Other: —

Gravel: Type — , Size — , Quantity —

WELL TEST DATA

Preliminary Test Date: by

Static Level: ' " below M.P.

Pumping Rate IGM:

Pumping Duration: hrs. min.

Pumping Level at Test End: ' "

Performance Plots: dd-t Dwg.

dd-r Dwg.

Step Test

Final Test: Date MARCH 4/87 by N.B.

Rated Well Capacity IGM

Pumping Rate IGM 995 Static level 10 ' 10 "

Pumping level 28 ' 6 " at 24 hrs. 0 min.

Pump pressure: psi: Main pressure psi

Shut off: AGH psi; W.L. ' "

Clear Well Depth from B.P. ' " Air Line ' "

PUMP & MOTOR DATA

Pump Make Rating IGM @ ' TH

Head: Type S.N.

Column: ' X " X ": Shaft Mtl:

Bowl: Stage : Curve:

Suction: " dia. ' " Long

Special: Zinc Sleeves : Taped Oil Line

Other

Motor Make: Frame: SN:

HP, ph, hz, rpm, Volts

Bearing No. Upper

Lower

Special Equipment

WELL REVISIONS AND REHABILITATION

DATE	WORK DONE	BY

International Water Supply Limited

SASKATOON – BARRIE – MONTREAL

CLIENT: REGION OF WATERLOO

WELL NO: WILLARD WELL

DRILLED BY: N. BARNHARDT DATE: FEB. 87 DRAWN: M.P.

INSTALLED BY: DATE: DATE: APRIL 87

Example calculation

- Q = 995 Igpm (6514 m^3/d)
- Static WL = 10’ 10”
- Pumping WL = 28’ 6” (@ 24 hrs)

s_w = 17.67 ft (5.39 m)

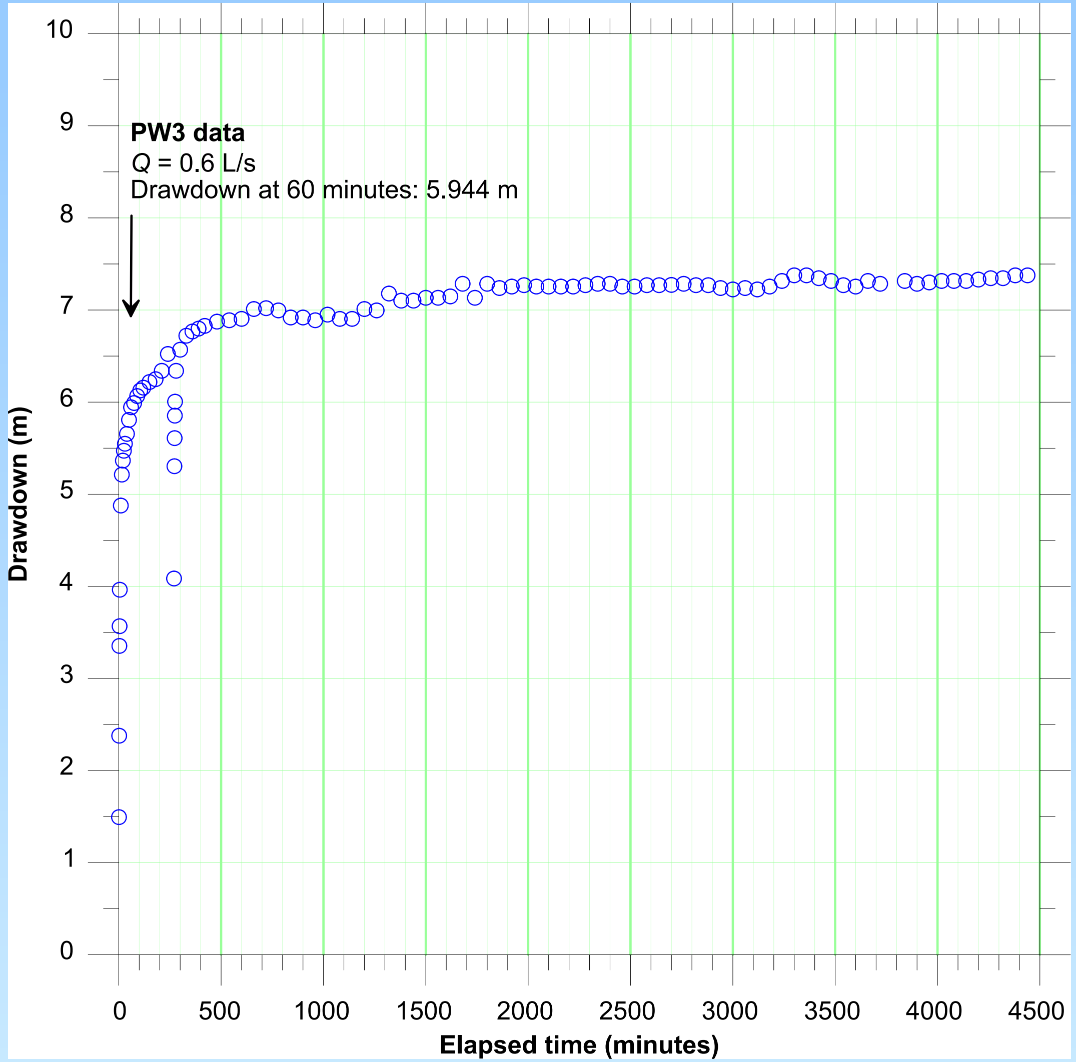
$T \sim 1.5\ (Q/s_w) = 1800\ m^2/d$

$T \cong SC$ … is handy

but …

We have made the big assumption that the drawdown in the well is due solely to head losses in the formation. For this reason, we refer to this transmissivity estimate as a “first-cut” or *reconnaissance-level* estimate.

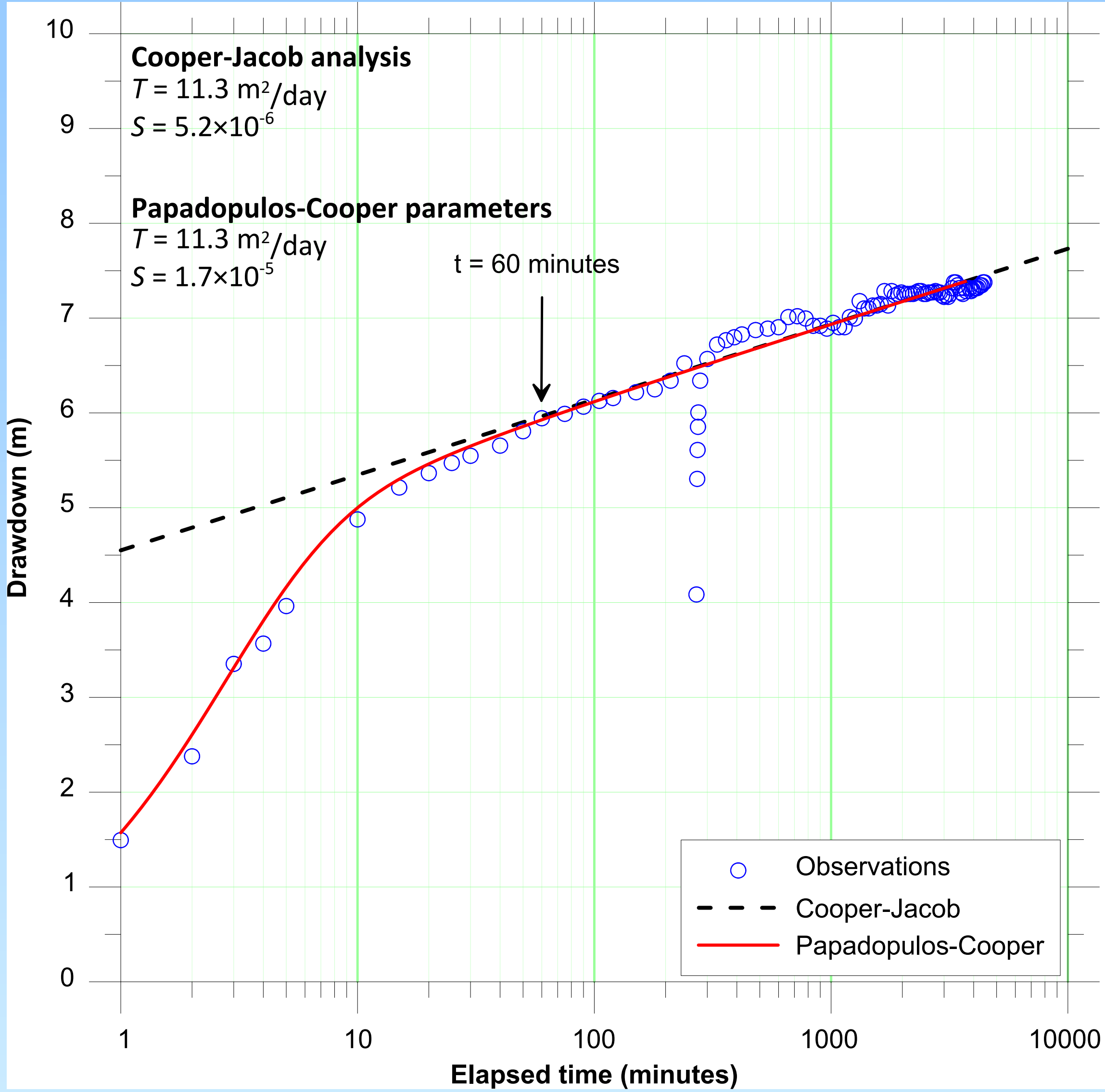
Example: Rosemont, Ontario



$$SC = \frac{(51.8\ \mathrm{m^3/d})}{(5.94\ \mathrm{m})} = 8.7\ \frac{\mathrm{m^2}}{\mathrm{d}}$$

$$T \approx 1.3\ SC = 11.3\ \mathrm{m^2/d}$$

More rigorous analyses



In this case, the close match between the approximate and more rigorous estimates of transmissivity are not by accident.

1. The “instantaneous” drawdown is relatively small.
2. The specific capacity is estimated from the drawdown after wellbore storage effects have dissipated.
3. The drawdowns over the duration of the test are matched closely with the Theis model.

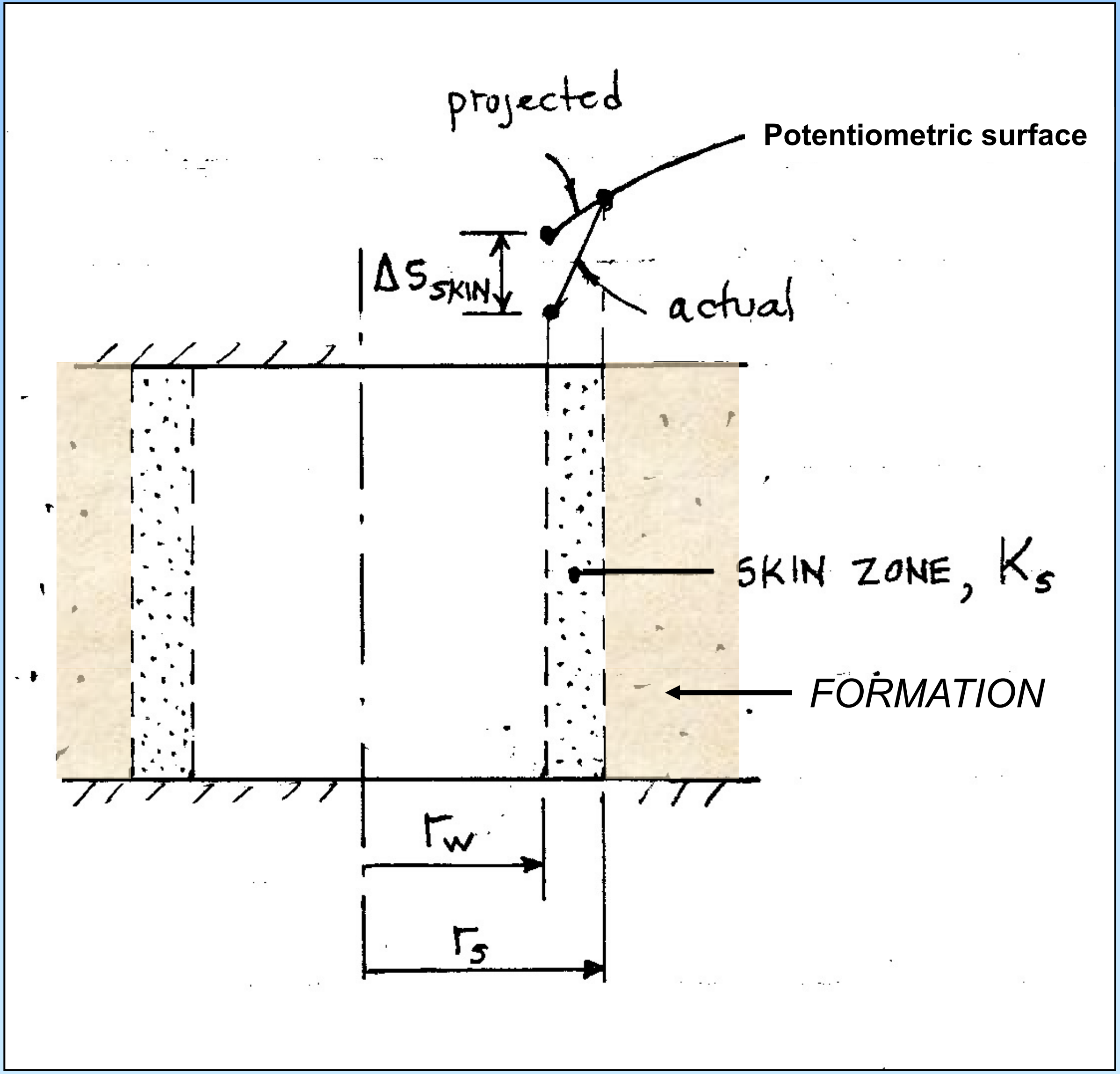
Analyses for a non-ideal well

We consider a simplified model of total well drawdown:

$$s_{\mathrm{w}} = s_{\mathrm{formation}} + \Delta s_{\mathrm{skin}} \quad \leftarrow \textbf{Linear, } \alpha\ Q$$

$$+ \Delta s_{\mathrm{turbulence}} \quad \leftarrow \textbf{Nonlinear, } \alpha\ Q^2$$

Skin losses, Δs_{skin}



Characteristics of skin losses

1. Established relatively early;
2. Constant through time; and
3. Directly proportional to the pumping rate, Q.

Ramey formulation:

$$\Delta s_{\mathrm{skin}} = \frac{Q}{4\pi T} 2S_{\mathrm{w}}$$

S_w is the dimensionless skin factor

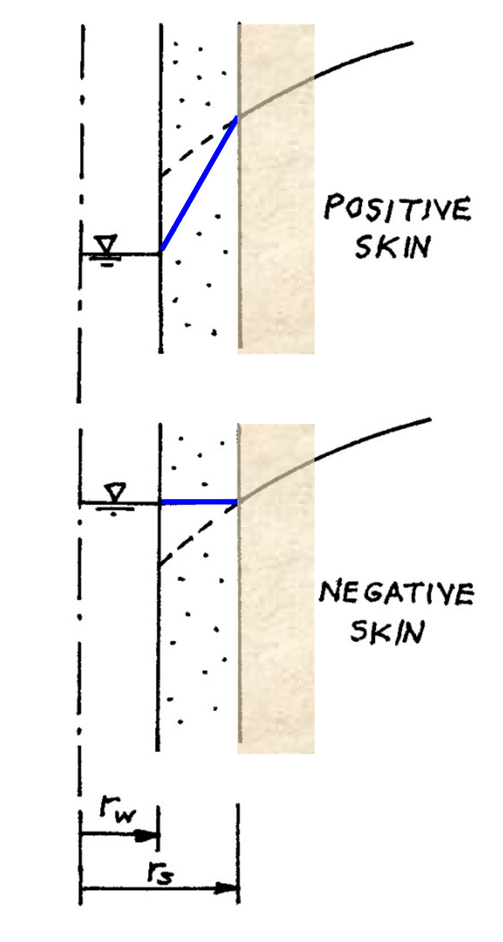
Interpretation of the dimensionless skin factor

$$S_w = \left(\frac{T_{formation} - T_{skin}}{T_{skin}}\right) \ln\left\{\frac{r_s}{r_w}\right\}$$

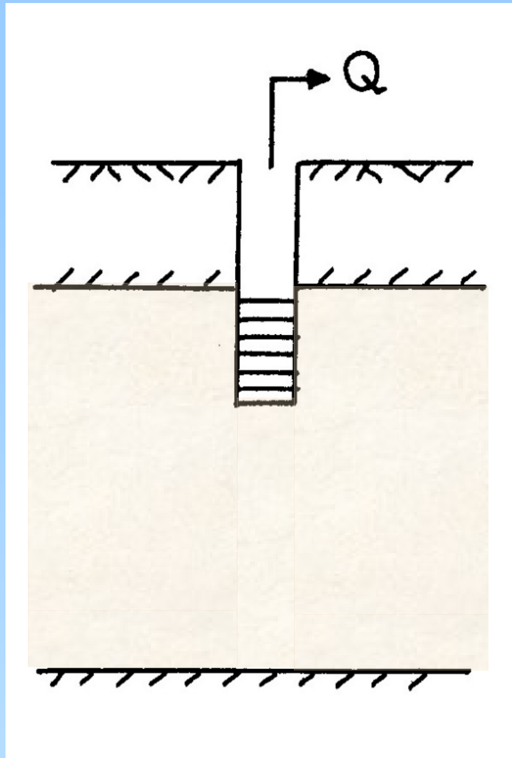
$$T_{skin} < T_{formation} \rightarrow S_w > 0$$

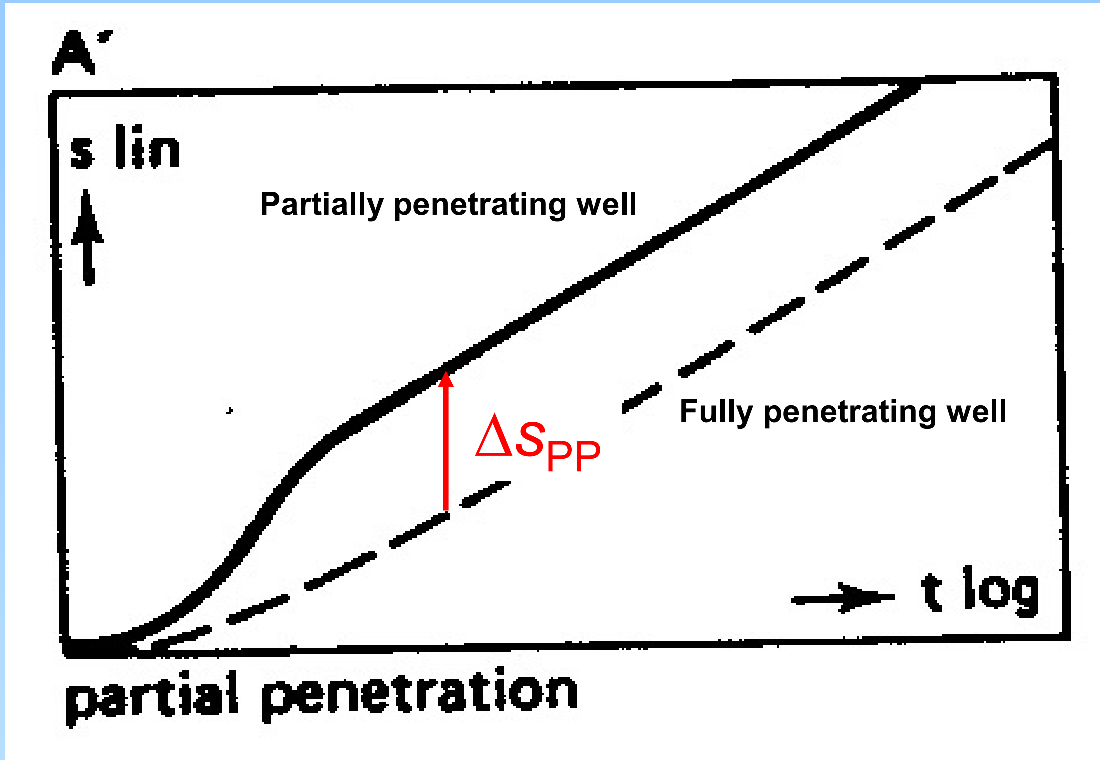
$$T_{skin} > T_{formation} \rightarrow S_w < 0$$

We can't know r_s, so S_w is treated as a lumped fitting parameter.



Additional head losses caused by partial penetration





- Established relatively early;
- Constant through time; and
- Directly proportional to *Q*.

→ Same characteristics as skin losses

Additional head losses caused by partial penetration can be accounted for with a 'pseudo' skin factor, S_{PP}:

$$\Delta s_{\mathrm{PP}} = \frac{Q}{4\pi T} 2 S_{\mathrm{PP}}$$

Pseudo-skin factors, S_{PP}:

- Muskat (1932);
- Kozeny (1933); and
- Brons and Marting (1961)

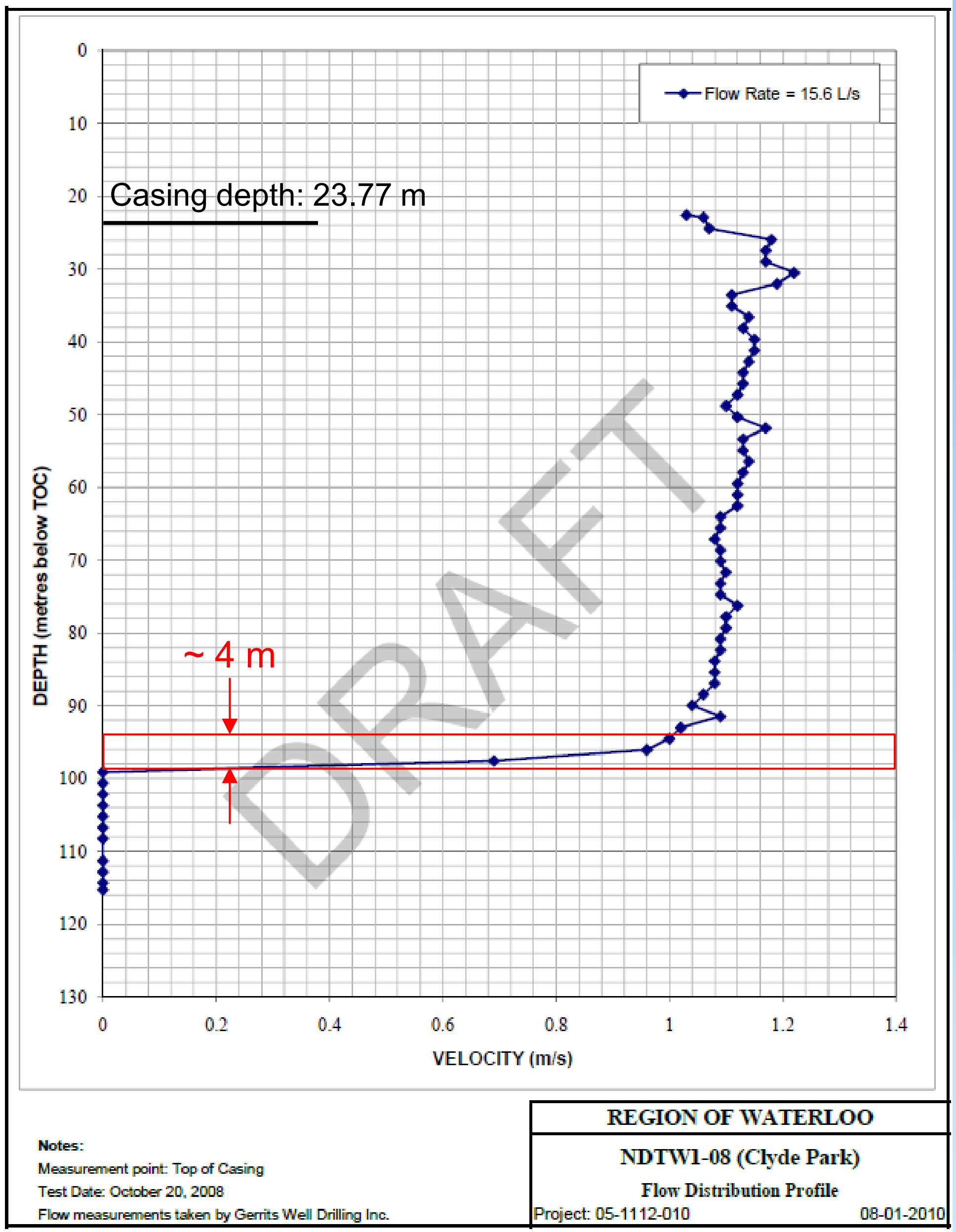
Nonlinear losses, $\Delta s_{\text{turbulence}}$

Jacob (1947) formulation: $$\Delta s_{\text{turbulence}} = CQ^2$$

Rorabaugh (1953) generalization: $$\Delta s_{\text{turbulence}} = CQ^P$$

Turbulent head losses may occur in the well and/or the formation.

Turbulence in the formation?



Estimating the nonlinear well loss coefficient, *C*

i. Rules-of-thumb: Walton (1962)

Condition of well	C (sec^2/ft^5)	C (day^2/ft^5)	C (sec^2/m^5)
Properly designed and developed	$C < 5$	$C < 6.7\times10^{-10}$	$C < 1900$
Mild deterioration	$C < 10$	$C < 1.3\times10^{-9}$	$C < 3800$
Well beyond rehabilitation	$C > 10$	$C > 1.3\times10^{-9}$	$C > 3800$

Watch units!

ii. Rigorous: Step tests

A slightly improved first-cut estimation of transmissivity from the specific capacity

Adjust drawdown to remove additional well losses:

$$s_{\text{w-adj}} = s_{\text{w-obs}} - \Delta s_{\text{skin}} - \Delta s_{\text{turbulence}}$$

$$SC_{\text{adj}} = \frac{Q}{s_{\text{w-adj}}} \Rightarrow T \approx 1.3\, SC_{\text{adj}}$$

See Bradbury and Rothschild (1985) for the application of SC_{adj}

Analysis of transient drawdowns (1): Constant-rate tests

The previous simplified analyses made use of only one drawdown at one time. We can develop more confidence in our analyses if we have a complete record of drawdowns in the pumping well.

General model to match the drawdowns:

$$s_{\mathrm{w}}(t) = s_{\mathrm{formation}}(r_{\mathrm{w}}, t) + \Delta s_{\mathrm{skin}} + \Delta s_{\mathrm{turbulence}}$$

“Extended Theis” model (AQTESOLV Theis step test model)

$$s_{\mathrm{w}}(t) = \frac{Q}{4\pi T} W\left\{\frac{r_w^2 S}{4Tt}\right\} + \frac{Q}{4\pi T} 2S_w + CQ^{\mathrm{P}}$$

“Extended Theis” model (2)

$$s_w(t) = \frac{Q}{4\pi T}\left[-0.5772 - \ln\left\{\frac{r_w^2 S}{4Tt}\right\}\right] + \frac{Q}{4\pi T}2S_w + CQ^P$$

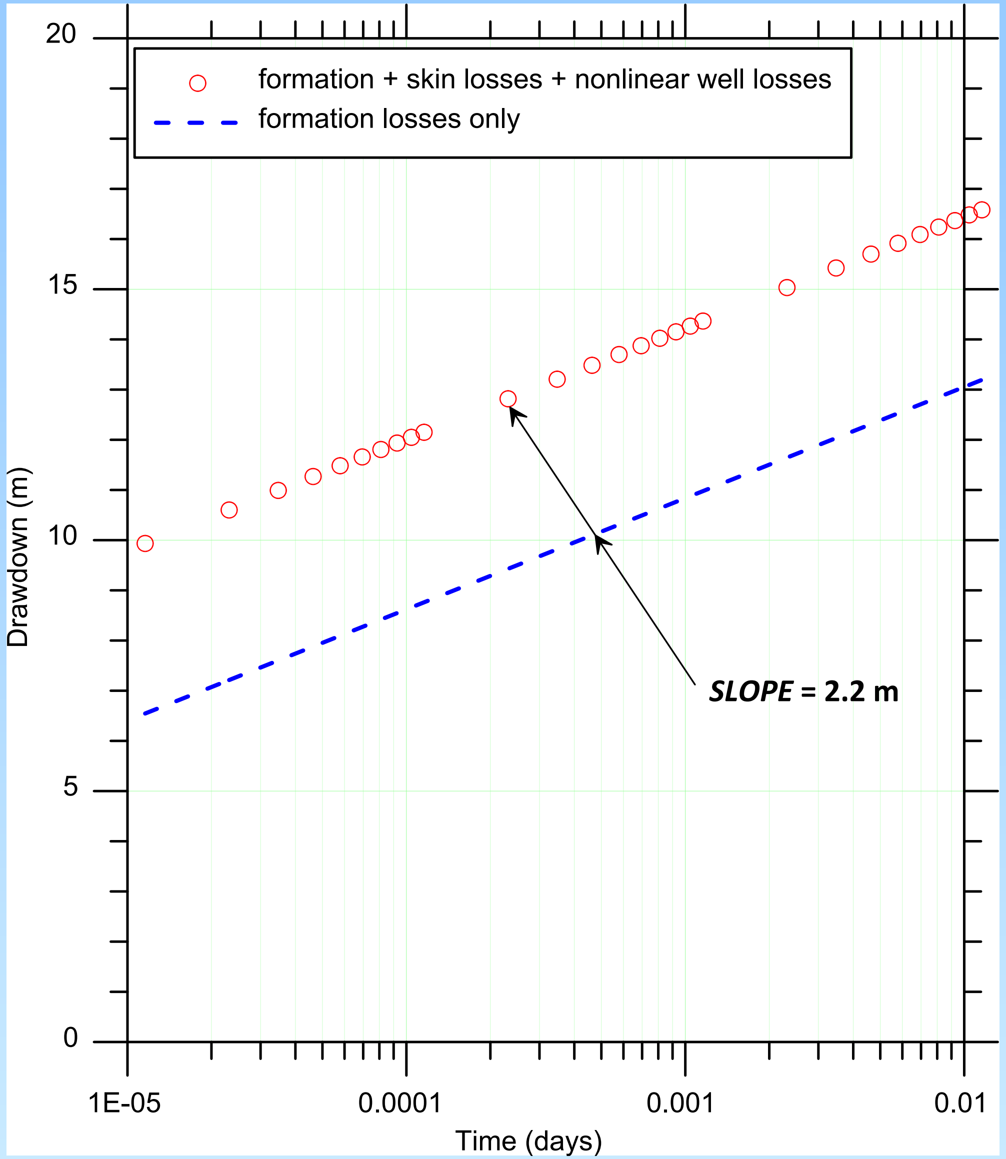
$$= \frac{Q}{4\pi T}\left[-0.5772 - \left(\ln\left\{\frac{1}{t}\right\} + \ln\left\{\frac{r_w^2 S}{4T}\right\}\right)\right] + \frac{Q}{4\pi T}2S_w + CQ^P$$

$$= \boxed{2.303\frac{Q}{4\pi T}\left[\log_{10}\left\{2.246\frac{T}{r_w^2 S}\right\}\right] + \frac{Q}{4\pi T}2S_w + CQ^P}$$

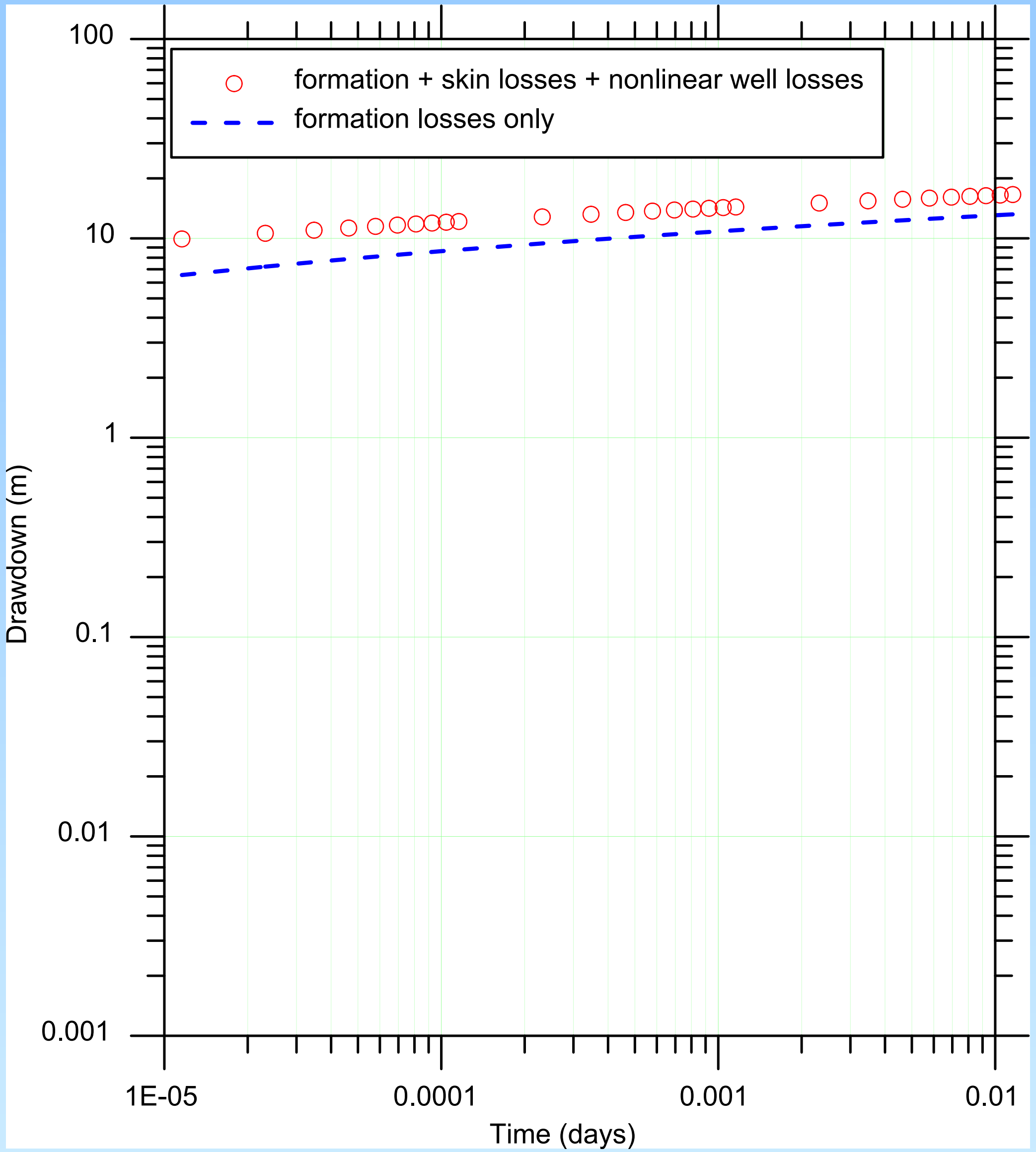
$$+ 2.303\frac{Q}{4\pi T}\log_{10}\{t\}$$

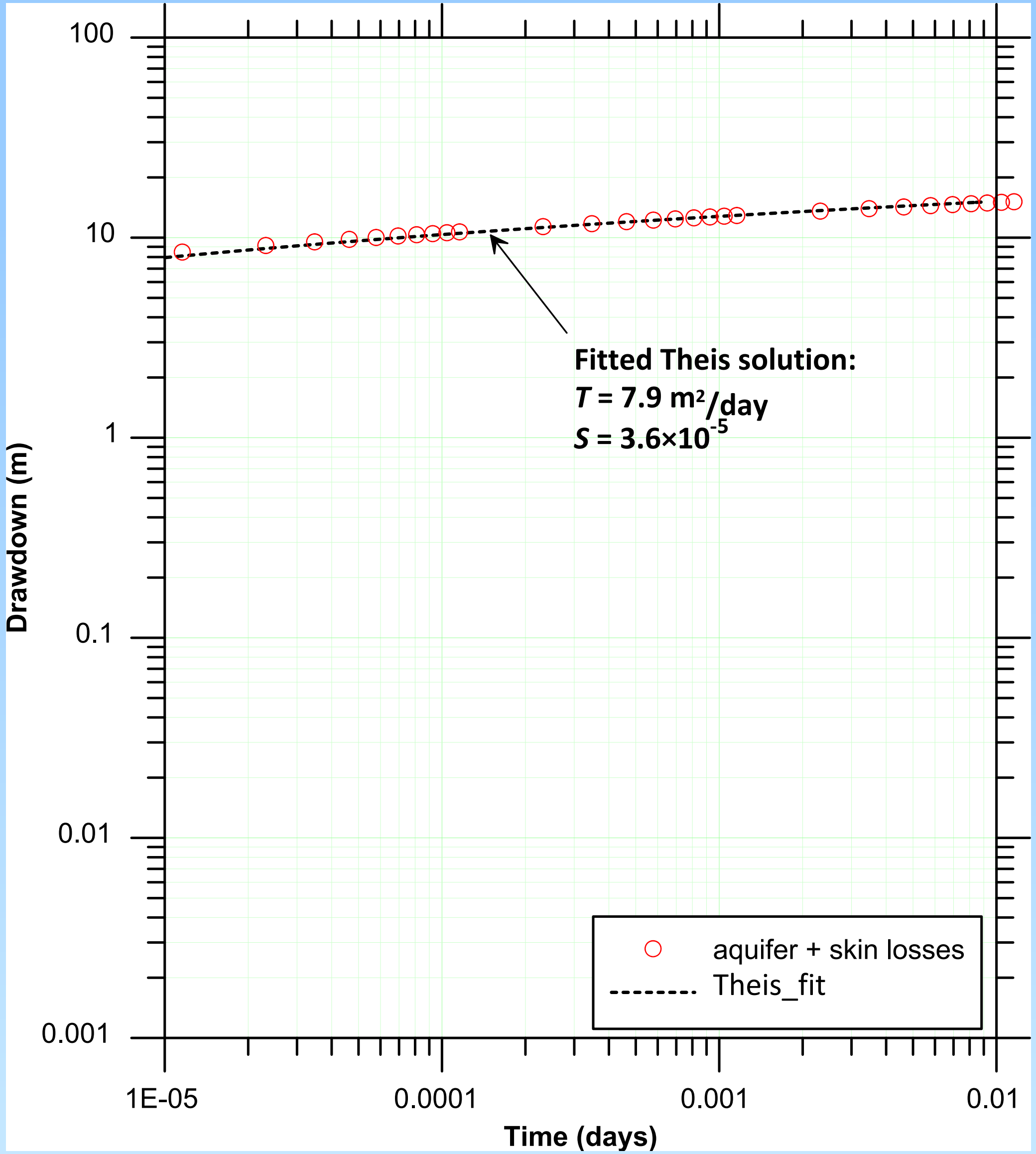
Example time-drawdown record

Specified parameters:
r_w = 0.05 m
T = 8.6 m^2/d
S = 1.0×10^{-4}
S_w = 0.52
C = 1.34×10^{-4} m^{-5}d^2
Q = 104.5 m^3/d



Diagnosis of additional well losses: Log-log plot?





Recall:
T = 8.6 m^2/d
$S = 1.0\times10^{-4}$

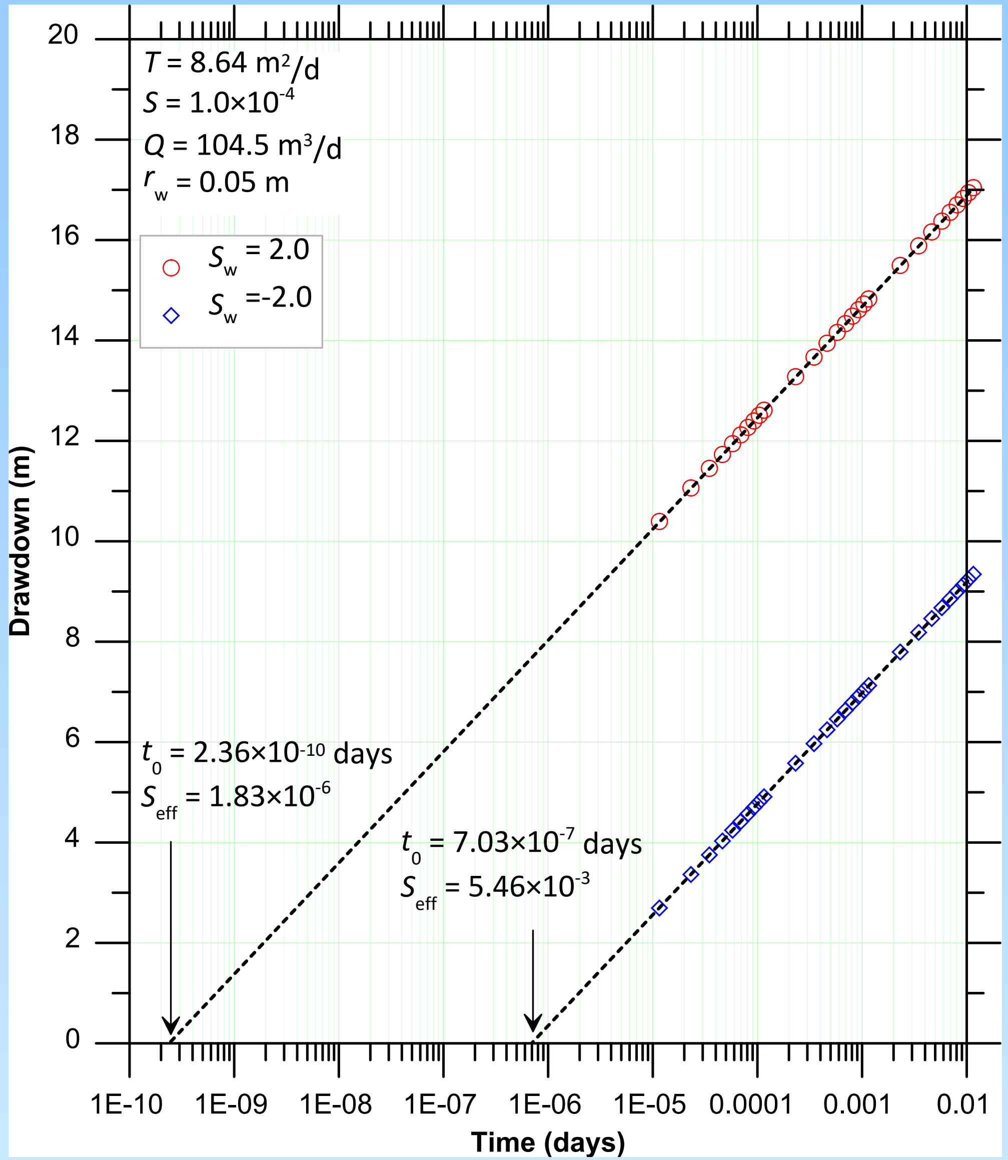
Further thoughts on the apparent storage coefficient

$$s_w(t) = \frac{Q}{4\pi T}\left[-0.5772 - \ln\left\{\frac{r_w^2 S}{4Tt}\right\}\right] + \frac{Q}{4\pi T} 2S_w$$

$$= \frac{Q}{4\pi T}\left[-0.5772 - \ln\left\{\frac{r_w^2 S}{4Tt}\right\}\right] + \frac{Q}{4\pi T}\ln\{EXP\{2S_w\}\}$$

$$s_w(t) = \frac{Q}{4\pi T}\left[-0.5772 - \ln\left\{\frac{r_w^2 (SEXP\{-2S_w\})}{4Tt}\right\}\right]$$

Diagnosis of skin effects



$$S_{\mathrm{eff}} = 2.246\frac{Tt_0}{r_w^2}$$

$$= S \times EXP\{-2S_w\}$$

Checks:

$$S_{\mathrm{w}} = +2.0$$

$$S_{\mathrm{eff}} = 1.8 \times 10^{-6}$$

$$S_{\mathrm{w}} = -2.0$$

$$S_{\mathrm{eff}} = 5.5 \times 10^{-3}$$

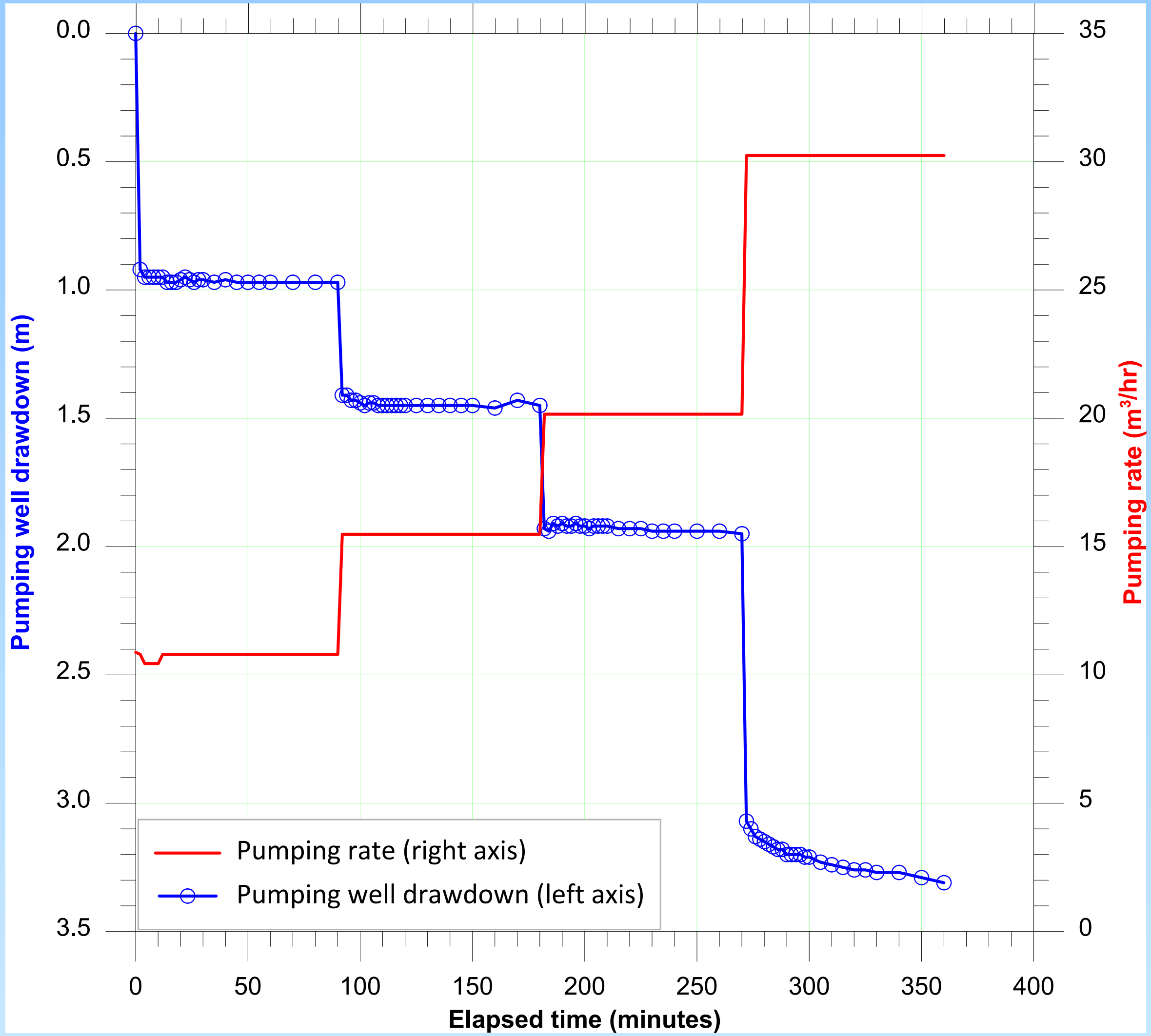
Take-home points (1)

1. Transmissivity estimates derived from Cooper-Jacob analyses are not affected by additional losses, but the results of Theis analyses are.

2. A “strange” estimate of the storage coefficient derived from a Cooper-Jacob analysis points to something missing in the analysis.

3. If we want to refine our interpretation of the additional losses, we require data from more than one pumping rate.

Analysis of transient drawdowns (2): Step tests



Why conduct a step test?

1. Step tests are an essential part of the design of constant-rate pumping tests.

2. Step test are important for understanding the performance of production wells.

3. We can use the results of step tests to “correct” the pumping well drawdowns so that they can be analyzed in conjunction with the data from observation wells.

Case study:
TW14, Flamborough Quarry

TW-14 Hydraulic testing plan

Based on testing elsewhere at the site, a constant-rate pumping test was planned with pumping at 20 L/s for 8 days.

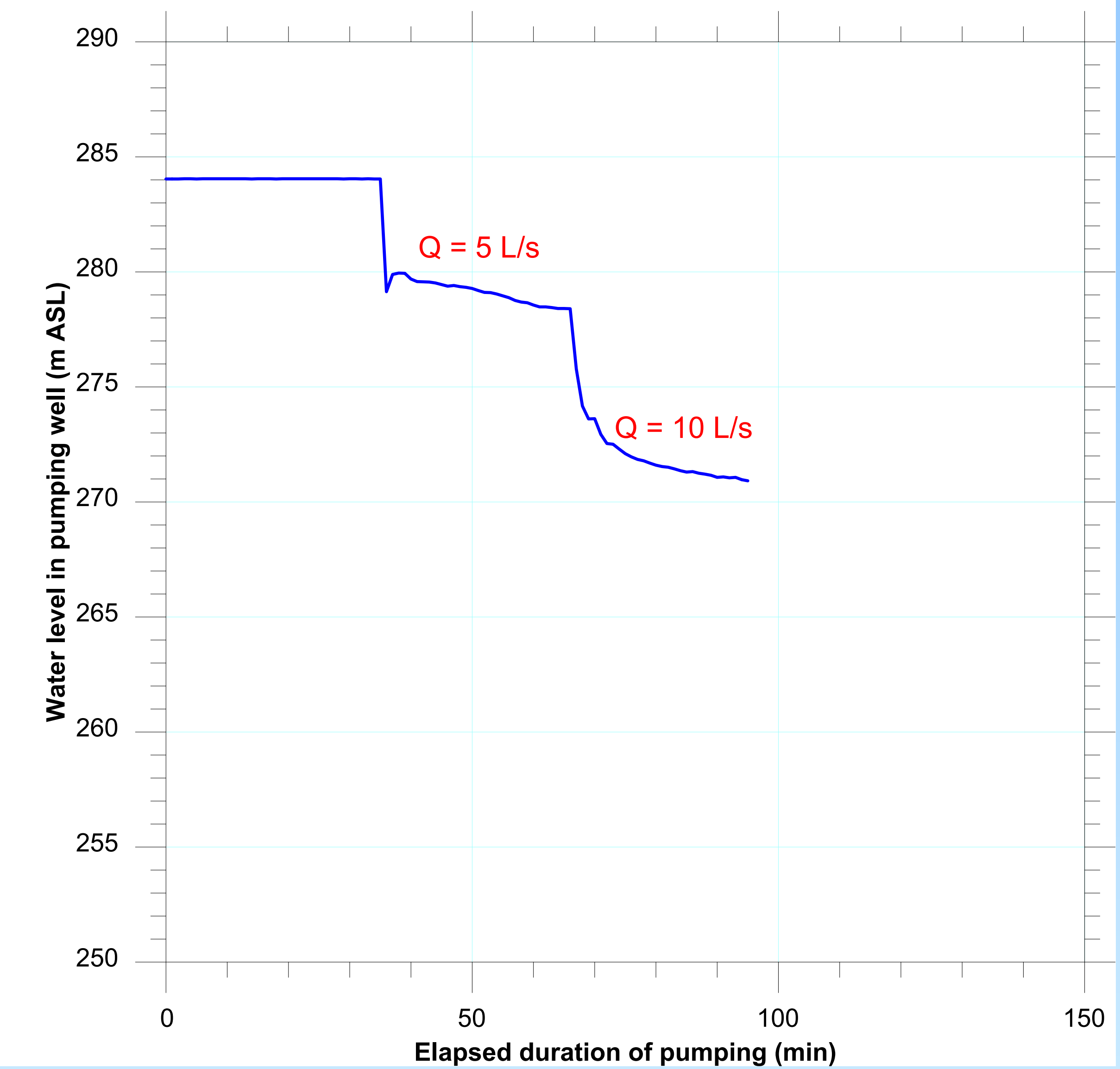
But first, a step test was conducted to confirm that the well could actually be pumped at 20 L/s.

<u>Step test design</u>

5 30-minute steps

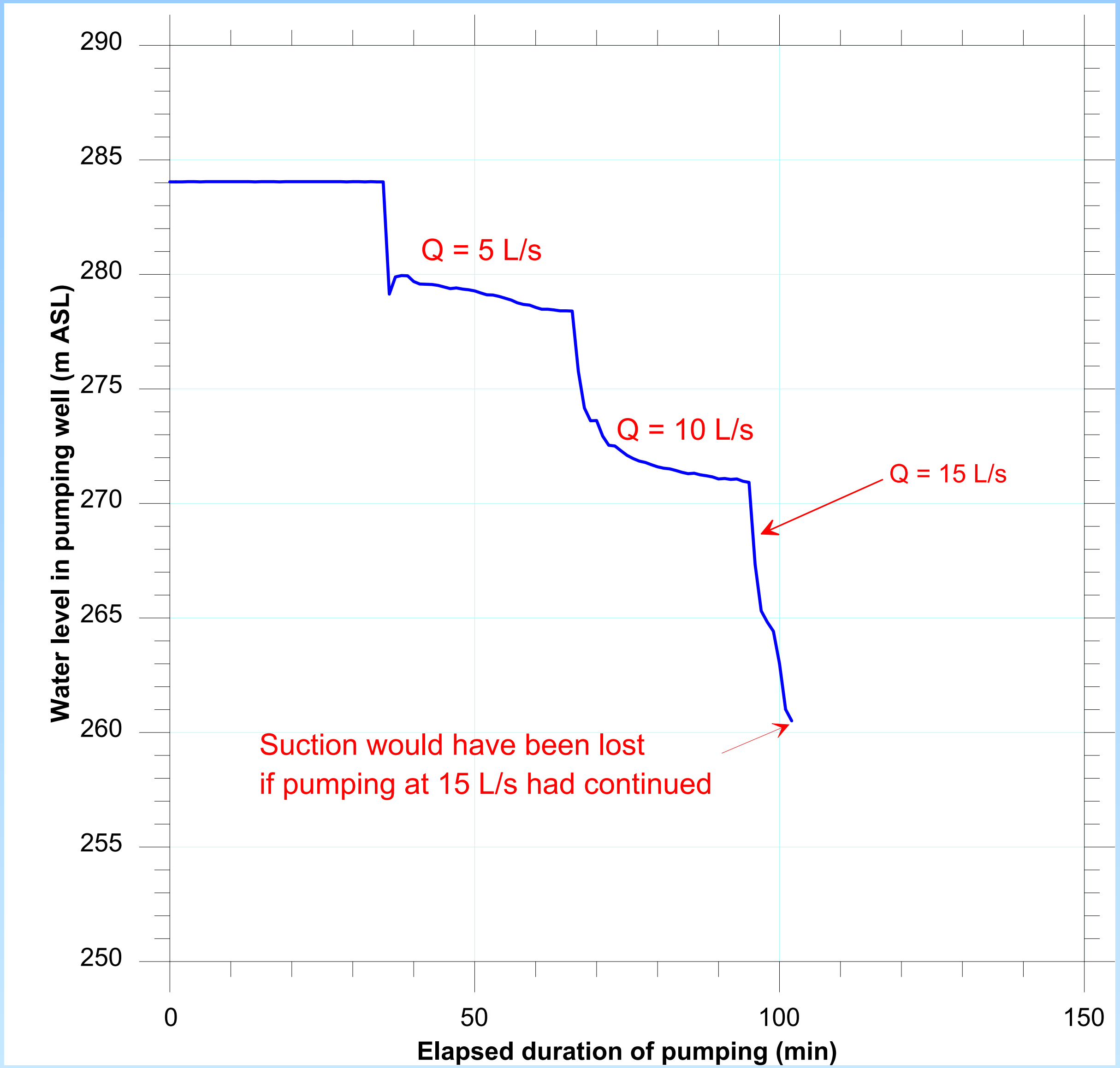
Step	Pumping rate (L/s)
1	5
2	10
3	15
4	20
5	25

Steps 1 and 2



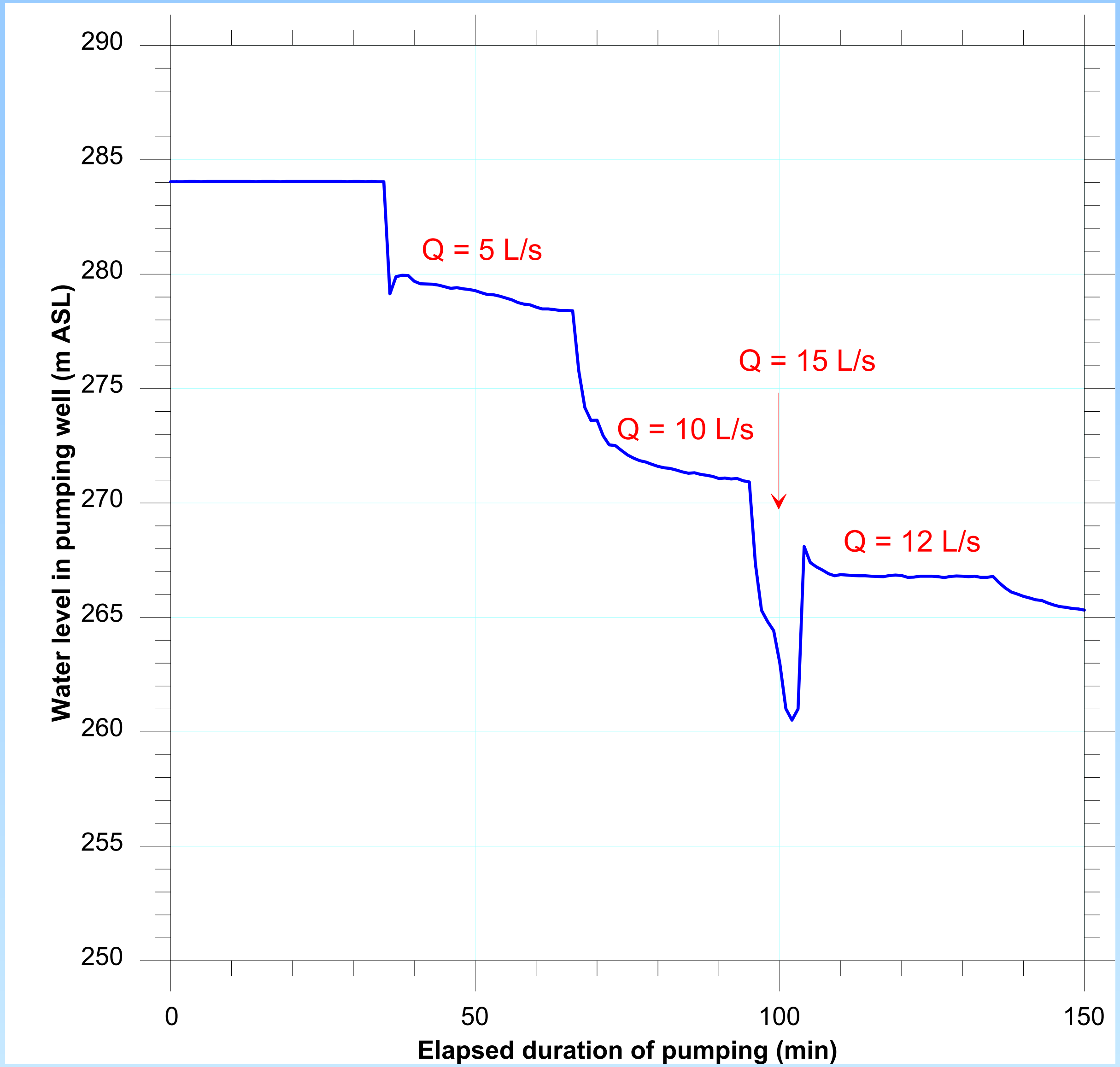
290
285
280
275
270
265
260
255
250
Water level in pumping well (m ASL)
0
50
100
150
Elapsed duration of pumping (min)
Q = 5 L/s
Q = 10 L/s

Step 3



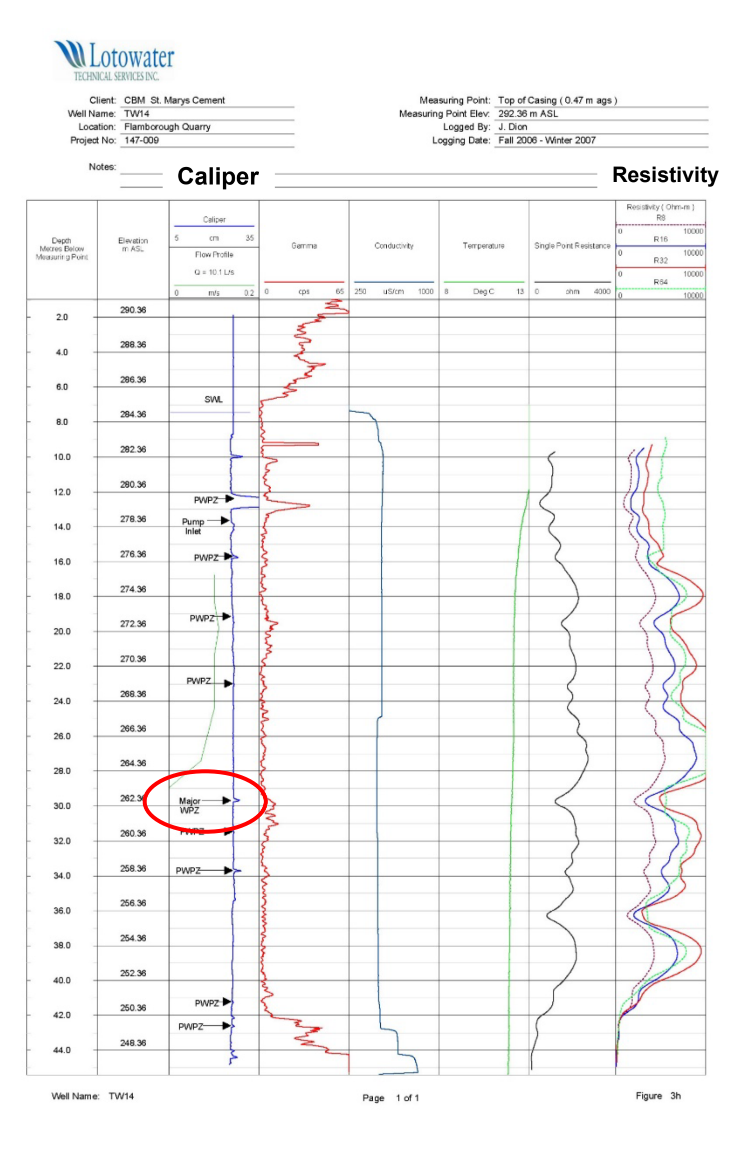
Water level in pumping well (m ASL)
290
285
280
275
270
265
260
255
250
0
50
100
150
Elapsed duration of pumping (min)
Q = 5 L/s
Q = 10 L/s
Q = 15 L/s
Suction would have been lost
if pumping at 15 L/s had continued

Step 4

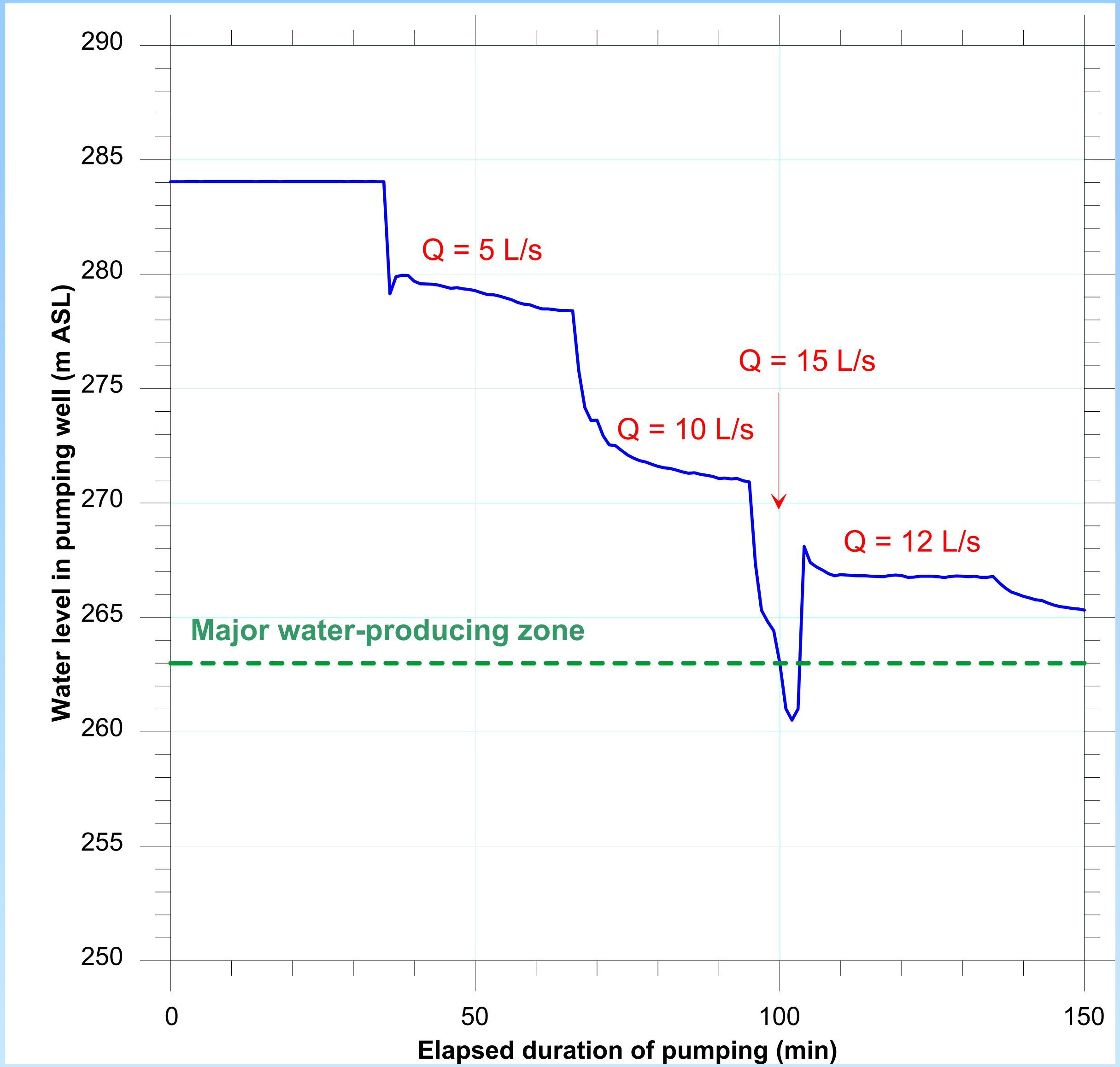

290
285
280
275
270
265
260
255
250
Water level in pumping well (m ASL)
0
50
100
150
Elapsed duration of pumping (min)
Q = 5 L/s
Q = 10 L/s
Q = 15 L/s
Q = 12 L/s

What went wrong?

Geophysical logging

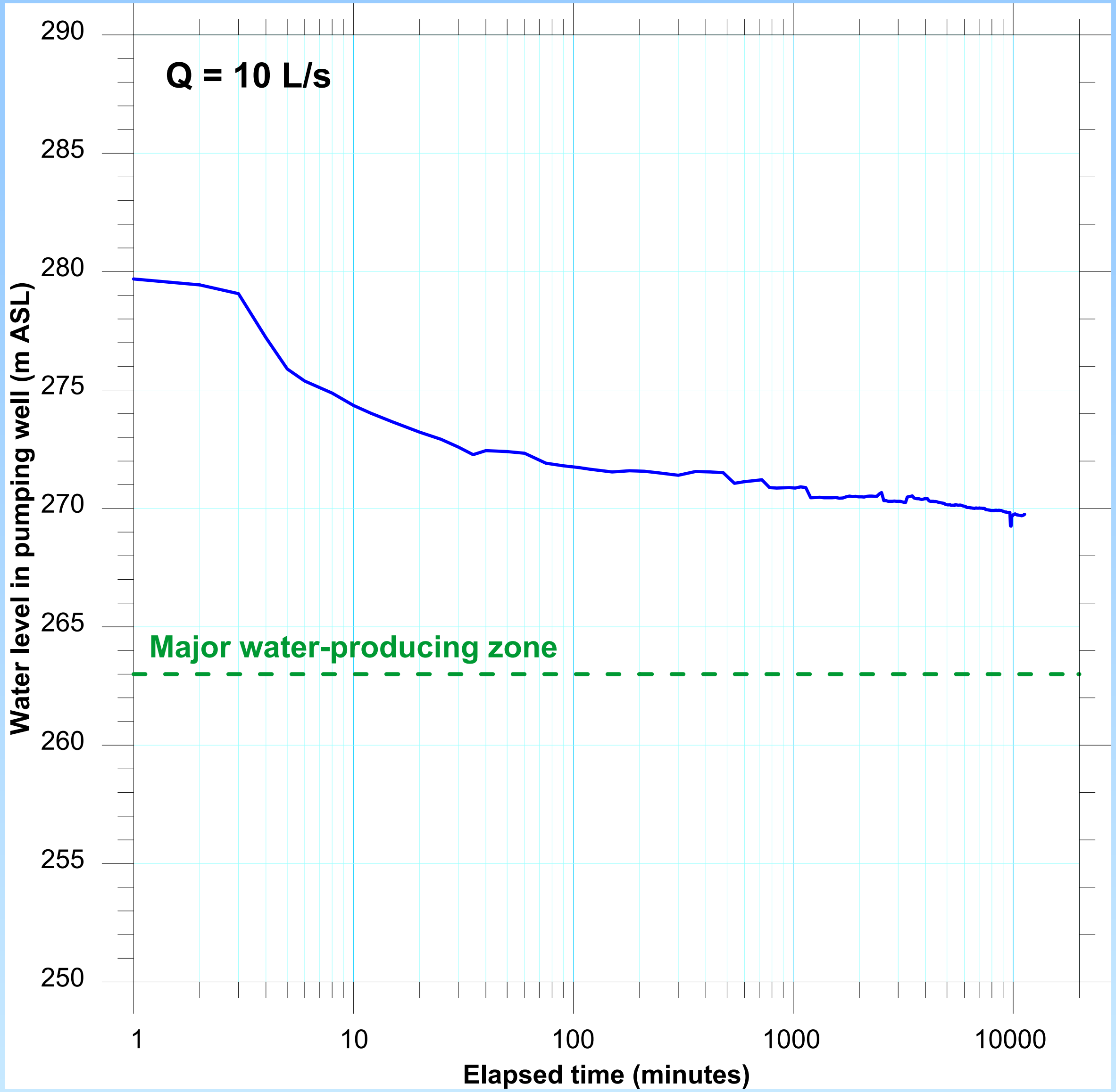


"Major WPZ"

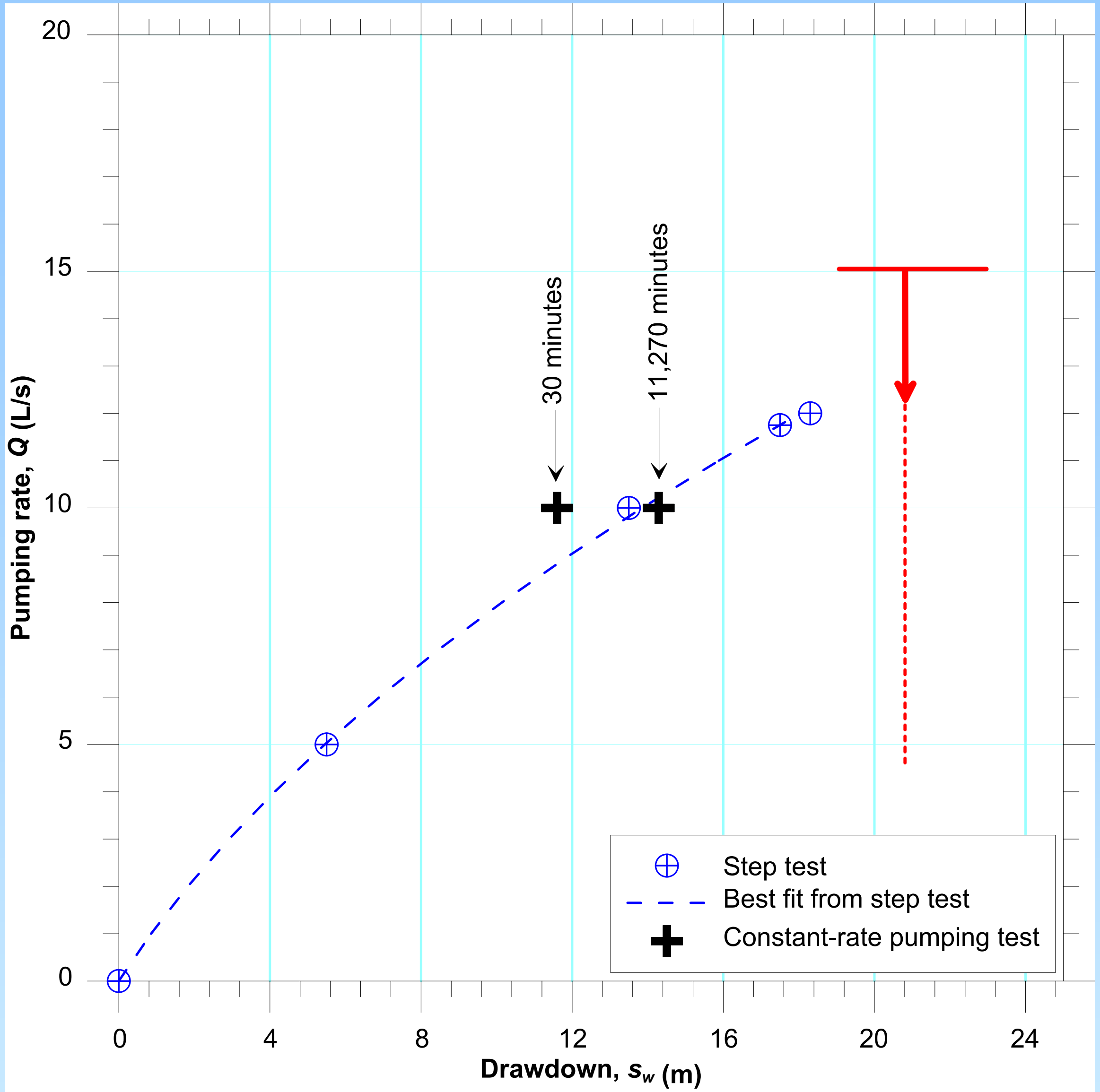


290
285
280
275
270
265
260
255
250
Water level in pumping well (m ASL)
Q = 5 L/s
Q = 10 L/s
Q = 15 L/s
Q = 12 L/s
Major water-producing zone
0
50
100
150
Elapsed duration of pumping (min)

Constant-rate pumping test



Summary of well performance



Interpretation of step tests

Diagnosis of nonlinear well losses: Hantush-Bierschenk analysis

Assume stabilized conditions, with turbulent head losses given by the Jacob (1947) formulation:

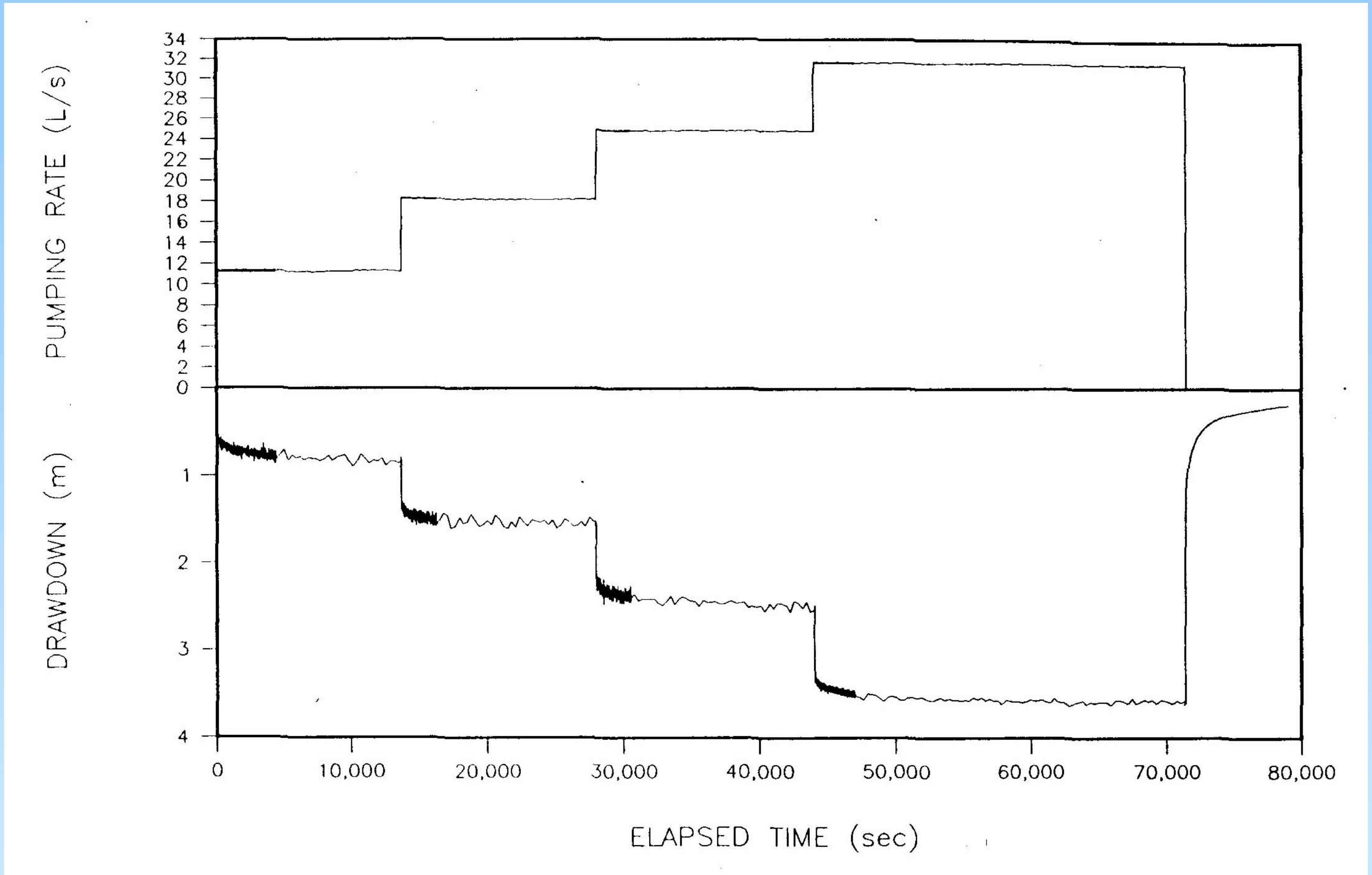
$$s_w = BQ + CQ^2$$

Specific drawdown:

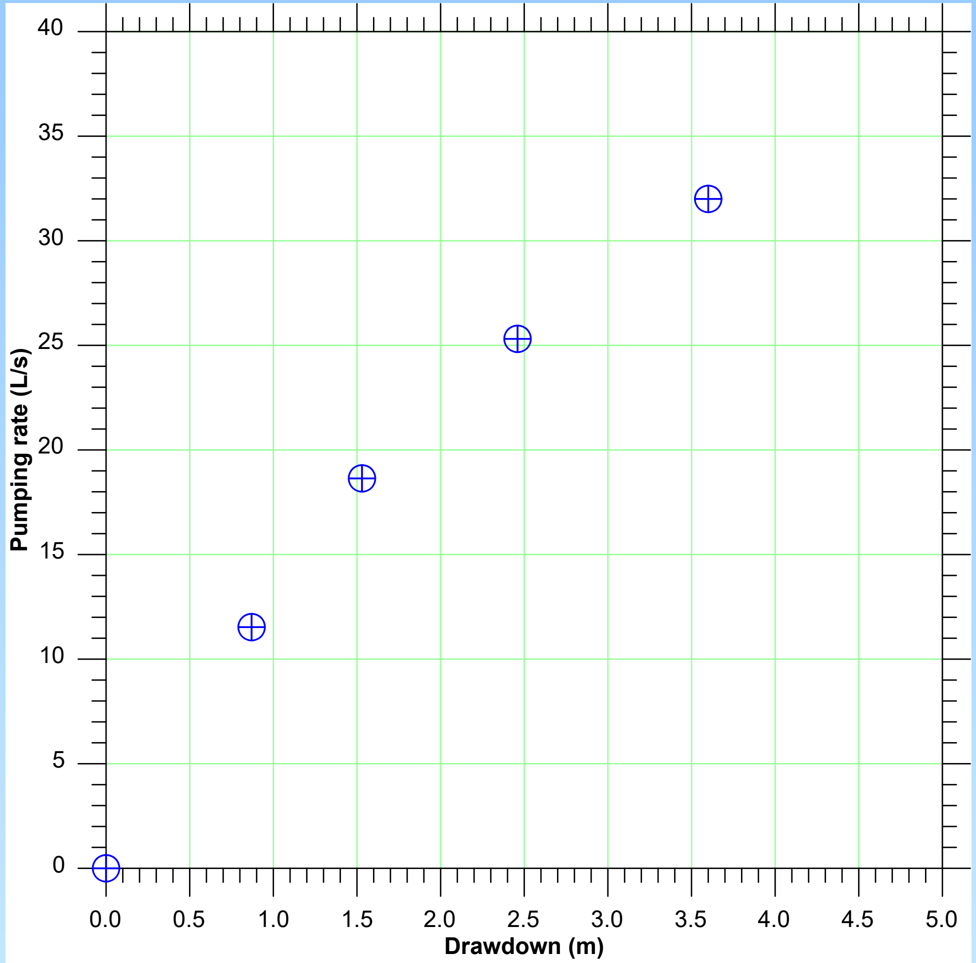
$$\frac{s_w}{Q} = \frac{1}{SC}$$

$$\rightarrow \frac{s_w}{Q} = B + CQ$$

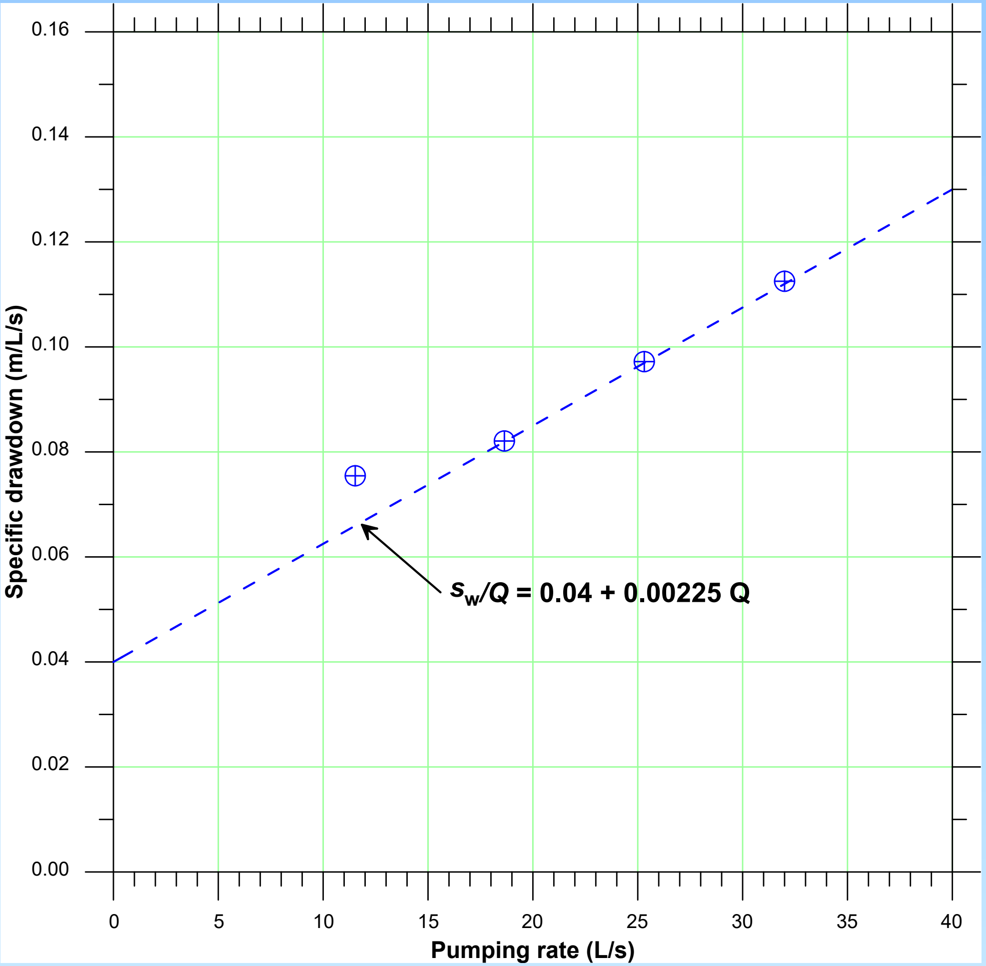
City of Guelph PW06-03



Specific capacity plot: Q vs. s_w

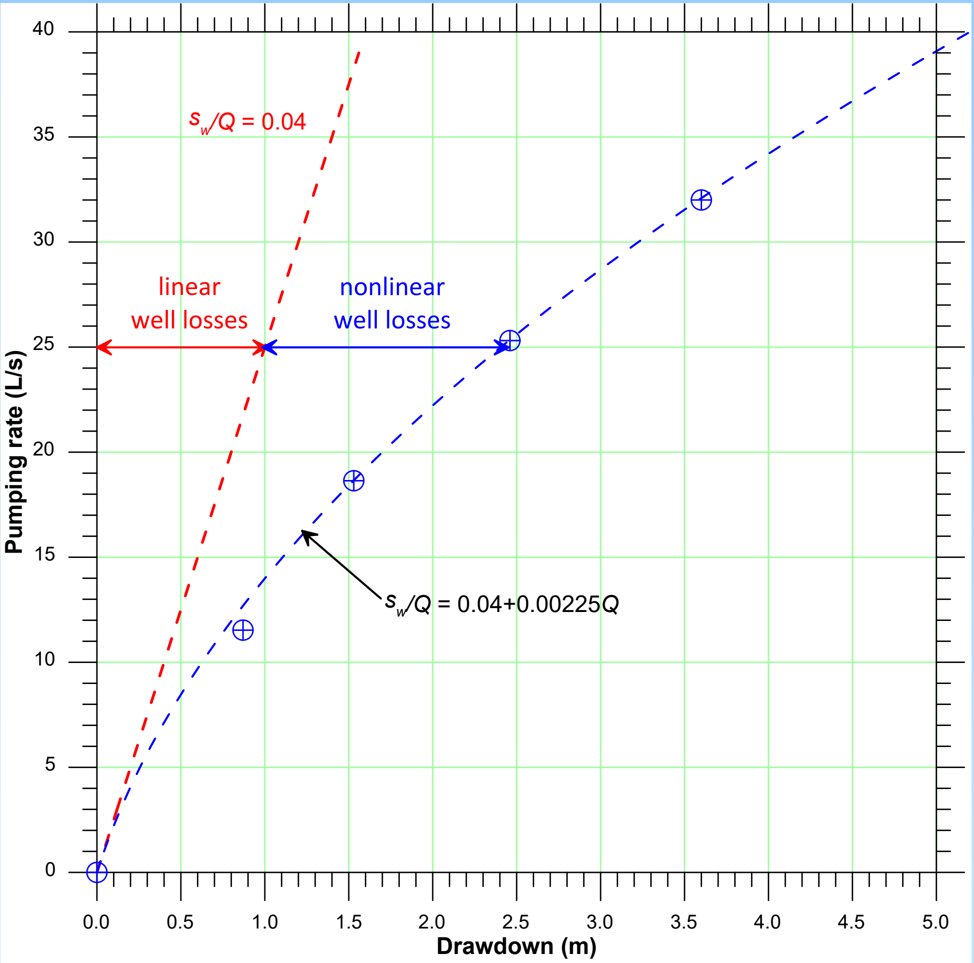


Hantush-Bierschenk plot: s_w/Q vs. Q

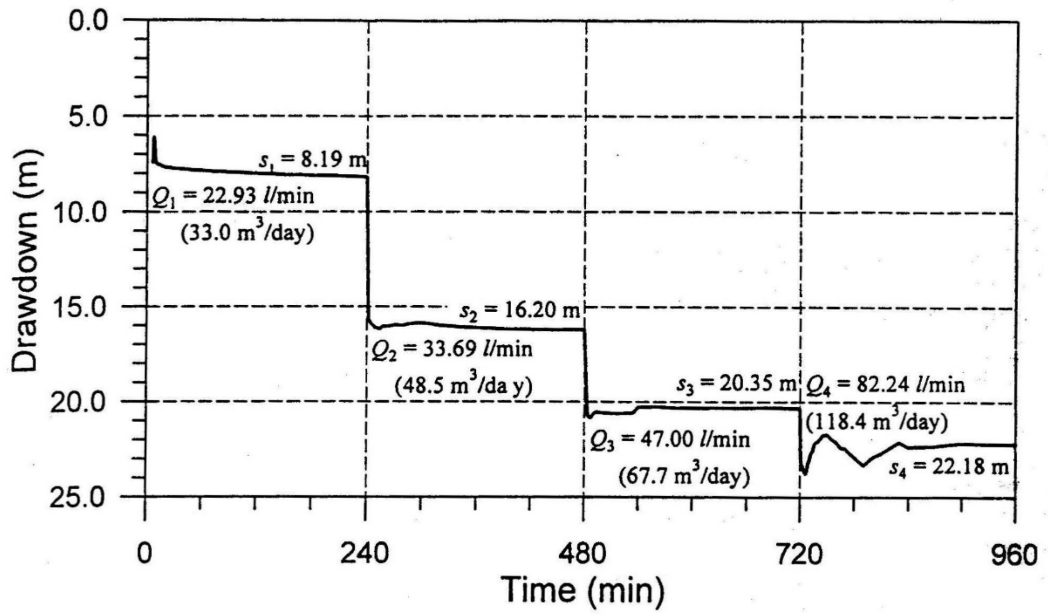


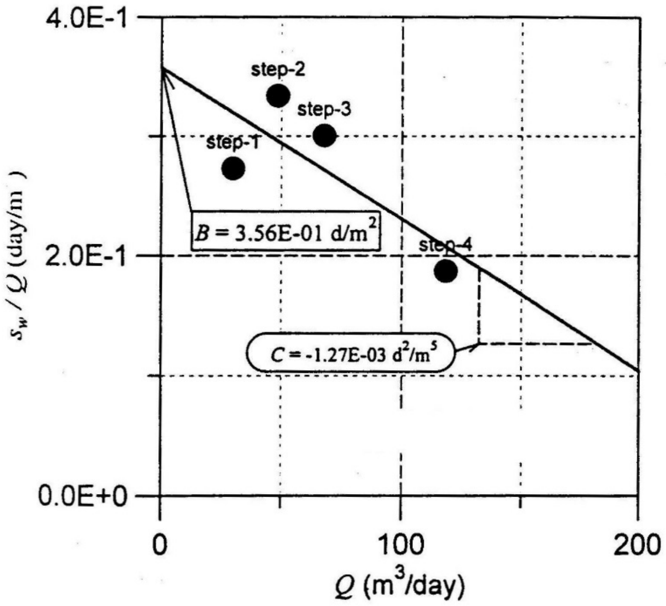
$B = 0.04$ m/(L/s)
$C = 2.25 \times 10^{-3}$ m/(L/s)^2

Inference of linear and nonlinear well losses



BH199





Step	Q (m³/day)	s_w (m)	s_w/Q (m/m³/day)
1	33.0	8.19	0.25
2	48.5	16.20	0.33
3	67.7	20.35	0.30
4	118.4	22.18	0.19

Significance of the parameter *B*

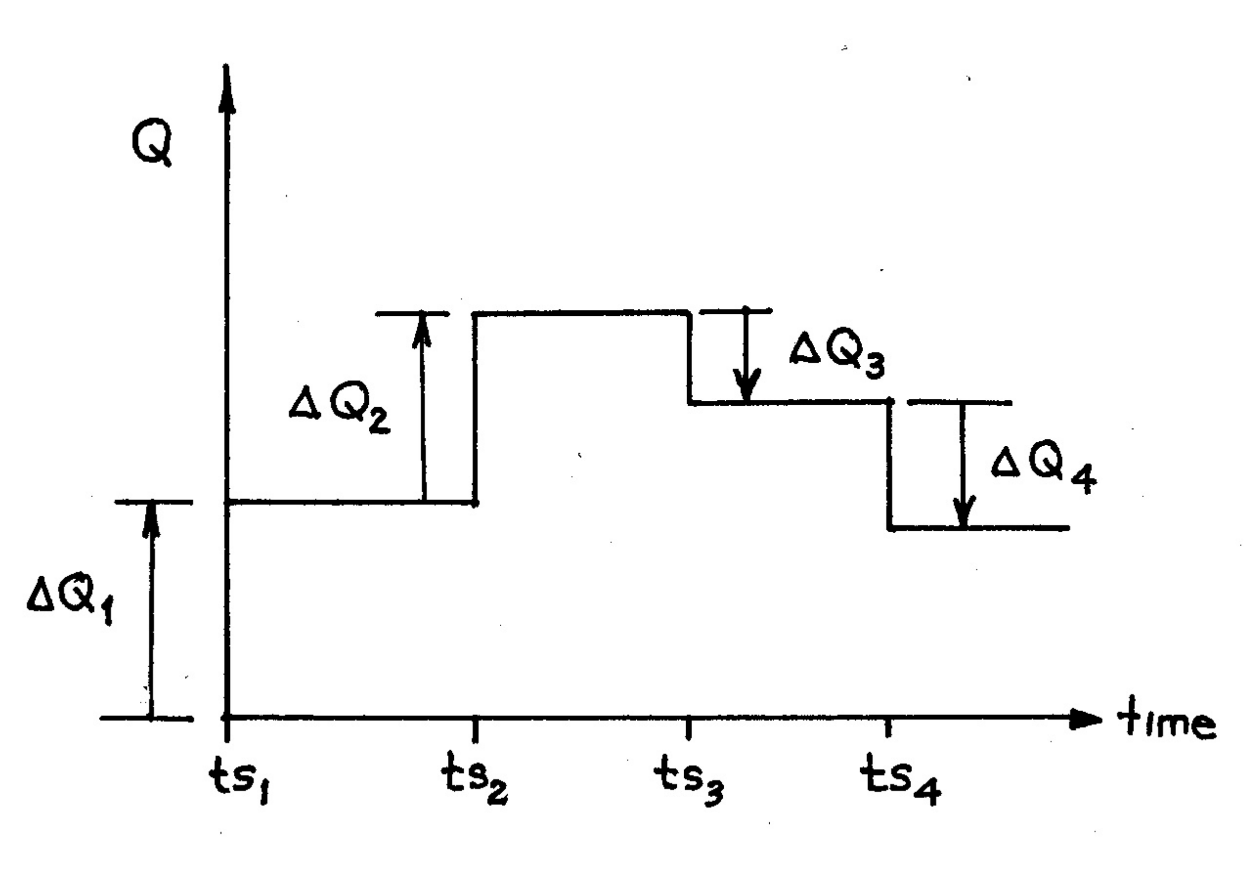
The parameter *B* represents the reciprocal of the specific capacity with the nonlinear well losses removed:

$$SC_{\mathrm{adj}} = \frac{1}{B} = \frac{1}{(0.04\ \mathrm{m/(L/s)})} = 25\ \mathrm{(L/s)/m}$$

$$T \sim 1.3 \times SC_{\mathrm{adj}} = 1.3 \times 25 \mathrm{(L/s)/m} \left| \frac{86.4\ \mathrm{m^3/d}}{\mathrm{L/s}} \right|$$

$$\boldsymbol{\sim 3000\ \mathrm{m^2/d}}$$

Interpretation of the transient drawdown record: Superposition



Generalization of the Theis model

$$s_w(t) = \sum_{n=1}^{NP(t)} \frac{\Delta Q_n}{4\pi T}\left[-0.5772 - \ln\left\{\frac{r_w^2 S}{4T(t - ts_n)}\right\}\right]$$

$$+ \frac{Q(t)}{4\pi T} 2S_w + C\big(Q(t)\big)^2$$

$$Q(t) = \sum_{n=1}^{NP(t)} \Delta Q_n$$

Fitting the generalized Theis model

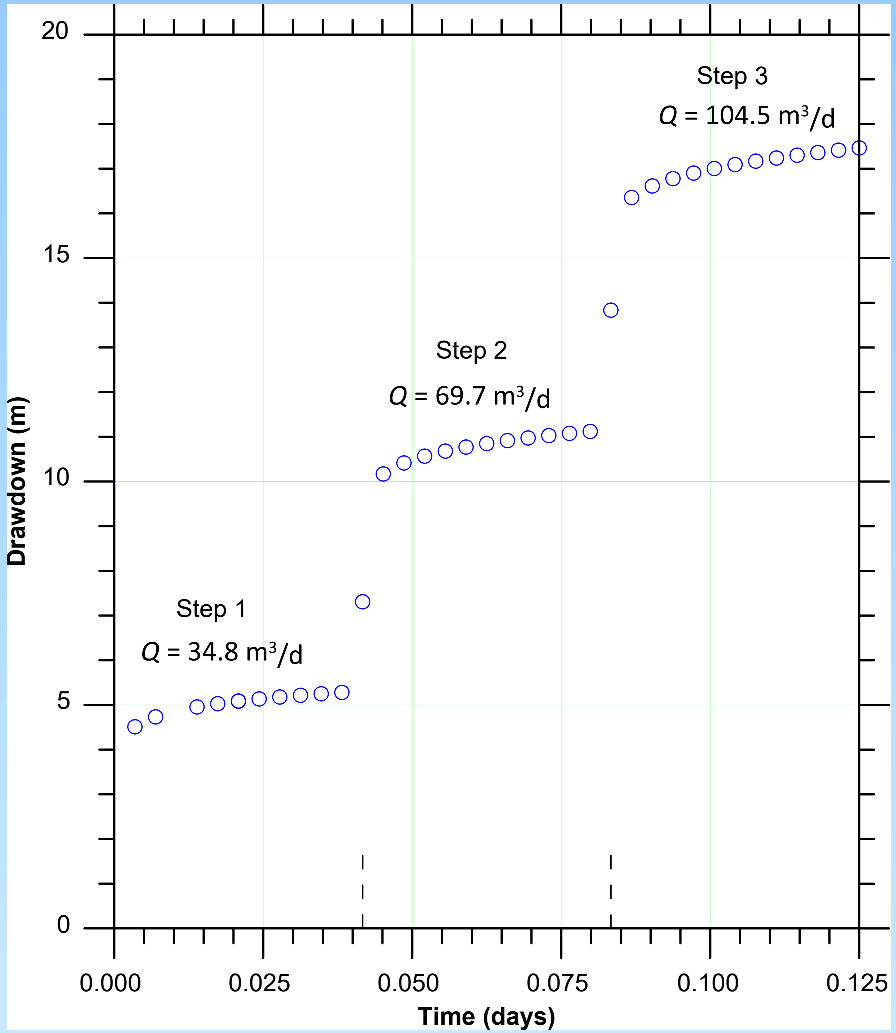
Parameters:

1. Transmissivity, T
2. Storage coefficient, S
3. Dimensionless skin factor, S_w
4. Nonlinear well loss coefficient, C
5. Well loss exponent, P

Example analysis

Specified parameter values:

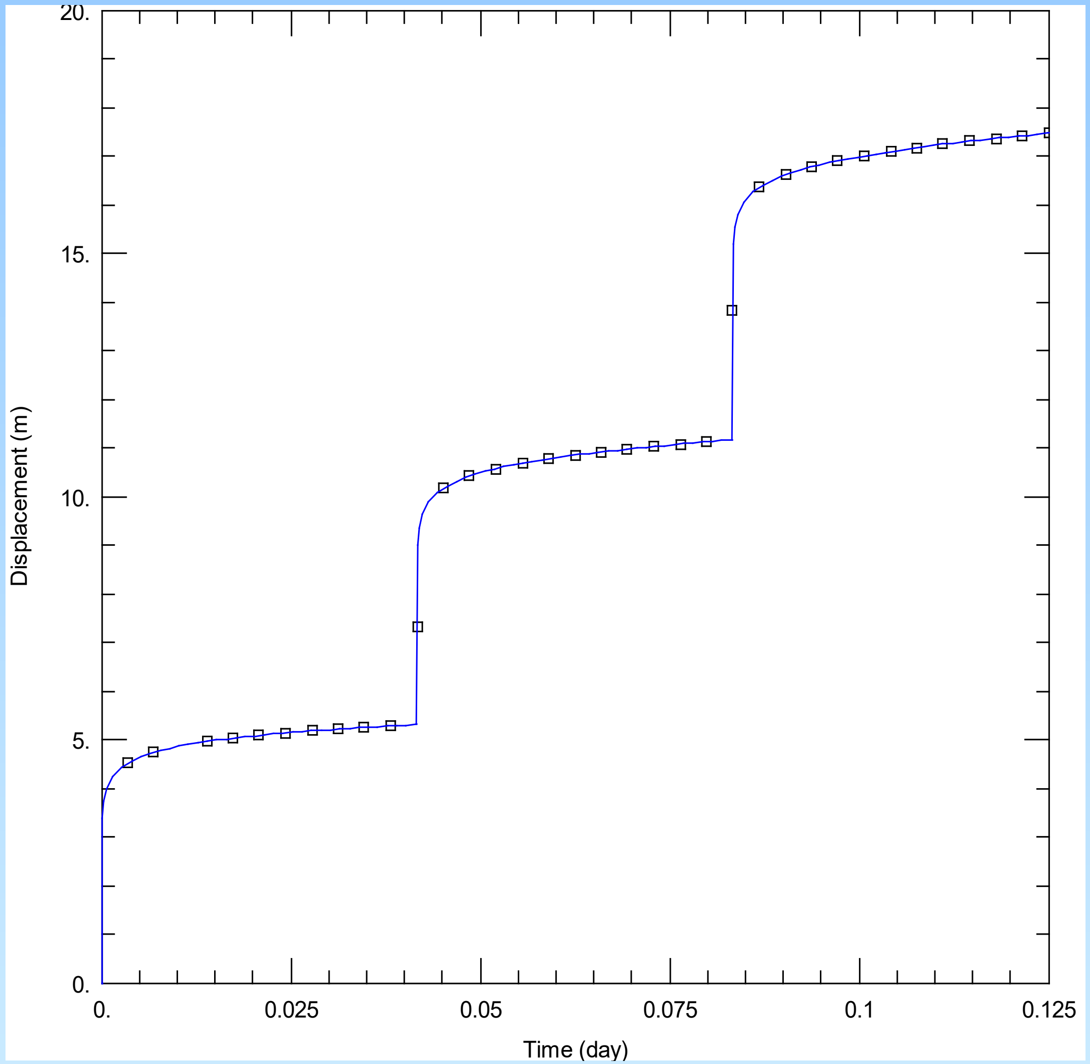
Transmissivity, T : 8.64 m^2/d
Storage coefficient, S : 1.0×10^{-4}
Dimensionless skin factor, S_w : 0.5193
Nonlinear well loss coefficient, C : 1.34×10^{-4} $m^{-5}d^2$
Well loss exponent, P : 2.0



Automatic fit

Fitted parameter values:

Transmissivity, T : 8.65 m^2/d
Storage coefficient, S : 5.55×10^{-5}
Dimensionless skin factor, S_w : 0.2379
Nonlinear well loss coefficient, C : 1.33×10^{-4} $m^{-5}d^2$
Well loss exponent, P : 2.0



Specified vs. fitted parameter values

Parameter	Specified value	Fitted value
Transmissivity, *T*	8.64 m^2/d	8.65 m^2/d
Storage coefficient, *S*	1.0×10^{-4}	5.55×10^{-5}
Dimensionless skin factor, S_w	0.52	0.24
Nonlinear well loss coefficient, *C*	1.34×10^{-4} $m^{-5}d^2$	1.33×10^{-4} $m^{-5}d^2$
Well loss exponent, *P*	2.0	2.0

☆

☆ **Nonuniqueness:**

Multiple parameter sets yield the same match

DIAGNOSTICS REPORT

Diagnostic Statistics

Estimation complete! Parameter change criterion (ETOL) reached.

Aquifer Model: Confined
Solution Method: Theis (Step Test)

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
T	8.649	0.004118	+/- 0.008397	2100.2	m^2/day
S	5.554E-5	4.83E-5	+/- 9.848E-5	1.15	
Sw	0.2379	0.4298	+/- 0.8763	0.5536	
C	0.0001325	1.319E-7	+/- 2.689E-7	1004.7	day^2/m^5
P	2.	not estimated			

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

K = T/b = 0.8649 m/day (0.001001 cm/sec)
Ss = S/b = 5.554E-6 1/m

Parameter Correlations

	T	S	Sw	C
T	1.00	-0.85	-0.85	0.31
S	-0.85	1.00	1.00	-0.21
Sw	-0.85	1.00	1.00	-0.21
C	0.31	-0.21	-0.21	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . 4.392E-5 m^2
Variance . . . . 1.417E-6 m^2
Std. Deviation. . . . . . . 0.00119 m
Mean . . . . -0.0001331 m
No. of Residuals 35
No. of Estimates 4

The storage coefficient and skin factor are perfectly correlated.

Why are the storage coefficient (S) and the skin factor (S_w) perfectly correlated?

Let's go back to the Cooper-Jacob solution, with additional skin losses:

$$s_w \cong \frac{Q}{4\pi T}\left[\left(-0.5772 - \ln\left\{\frac{r_w^2 S}{4Tt}\right\}\right) + 2S_w\right]$$

We can expand this as:

$$s_w = \frac{Q}{4\pi T}\left[-0.5772 - \ln\left\{\frac{r_w^2 S}{4Tt} EXP\{-2S_w\}\right\}\right]$$

In other words, we obtain the same drawdown from:

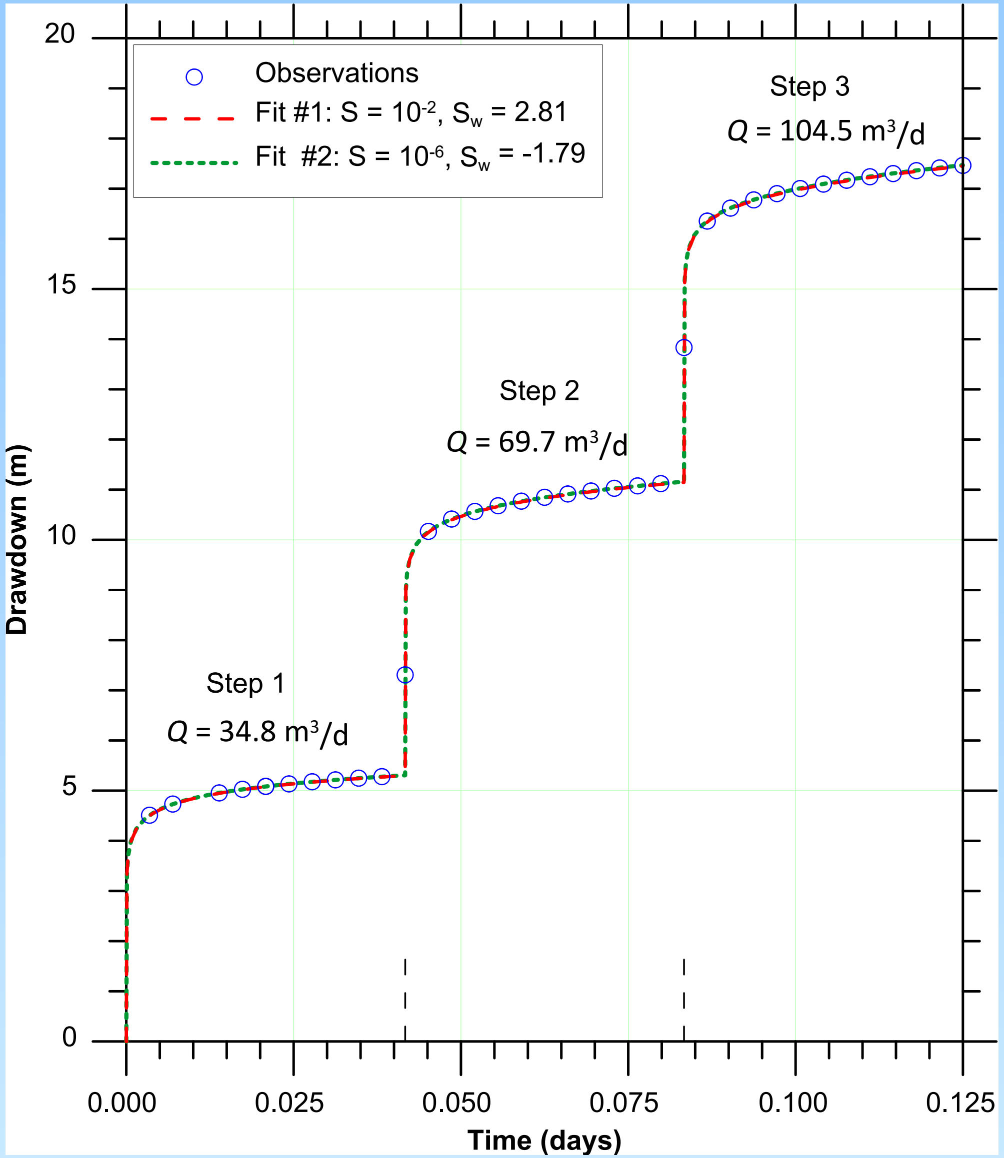
$$s_w = \frac{Q}{4\pi T}\left[\left(-0.5772 - \ln\left\{\frac{r_w^2 S}{4Tt}\right\}\right) + 2S_w\right]$$

as we do from:

$$s_w = \frac{Q}{4\pi T}\left[-0.5772 - \ln\left\{\frac{r_w^2 S_{\mathrm{E}}}{4Tt}\right\}\right]$$

with: $S_{\mathrm{E}} = S\ EXP\{-2S_w\}$

Step test: Fits for S = 1×10^{-2} and 1×10^{-6}



Results of multiple fits

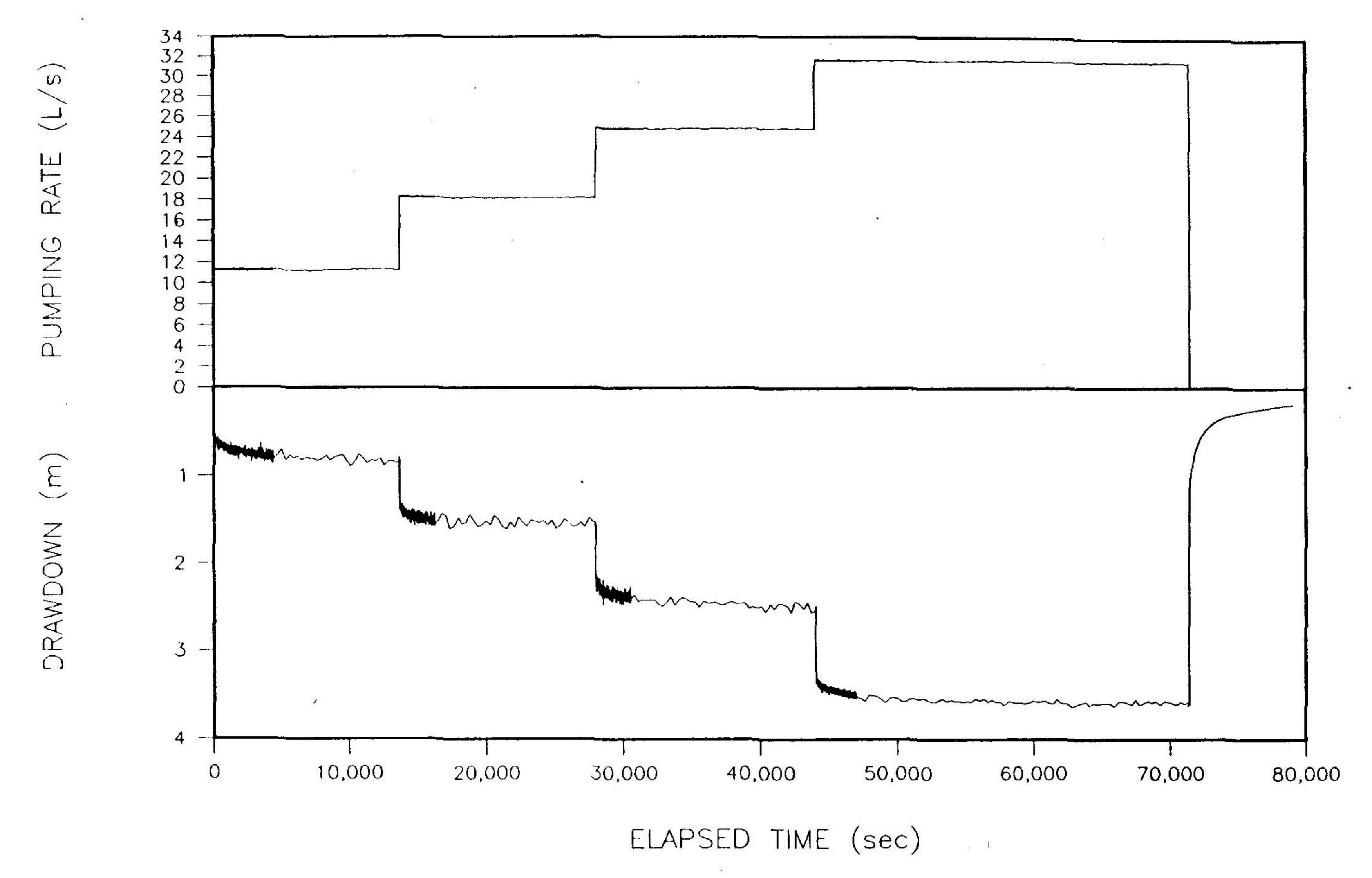
Fixed *S*	**Fitted S_w**	**S EXP{-2S_w}**
1×10^{-6}	-1.785	3.55×10^{-5}
1×10^{-5}	-0.634	3.55×10^{-5}
1×10^{-4}	0.517	3.55×10^{-5}
1×10^{-3}	1.667	3.55×10^{-5}
1×10^{-2}	2.810	3.63×10^{-5}

We cannot estimate the storage coefficient and skin factor separately.

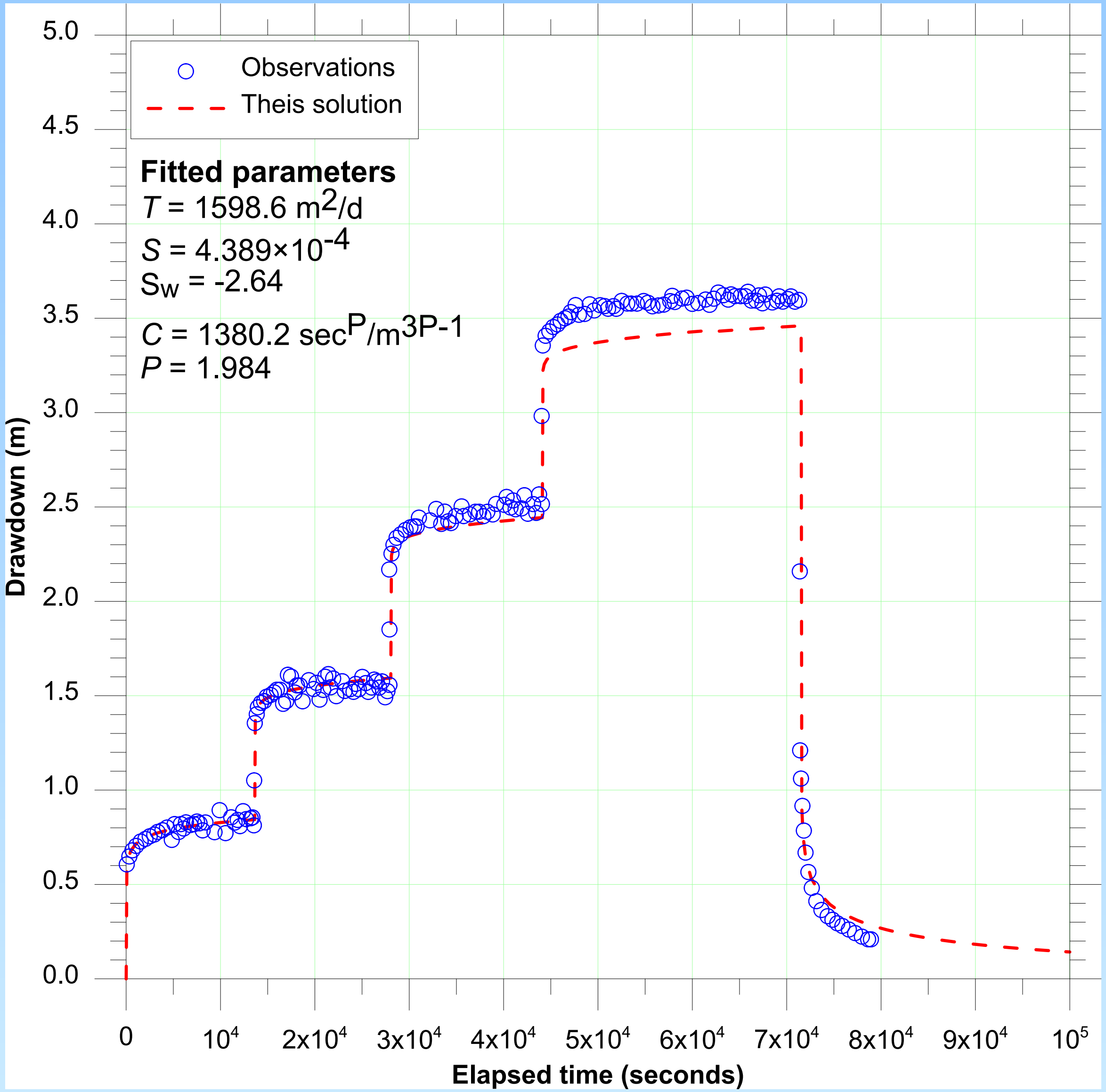
CJN preferred analysis approach: "Constrained" fitting

1. Fix *S* at a realistic value.
2. Neglect skin losses [unless there is a good reason to include them], $S_w = 0.0$
3. Fix *C* from Hantush-Bierschenk analysis
4. Fix $P = 2.0$
5. Assess the significance of *S* with respect to the estimation of transmissivity

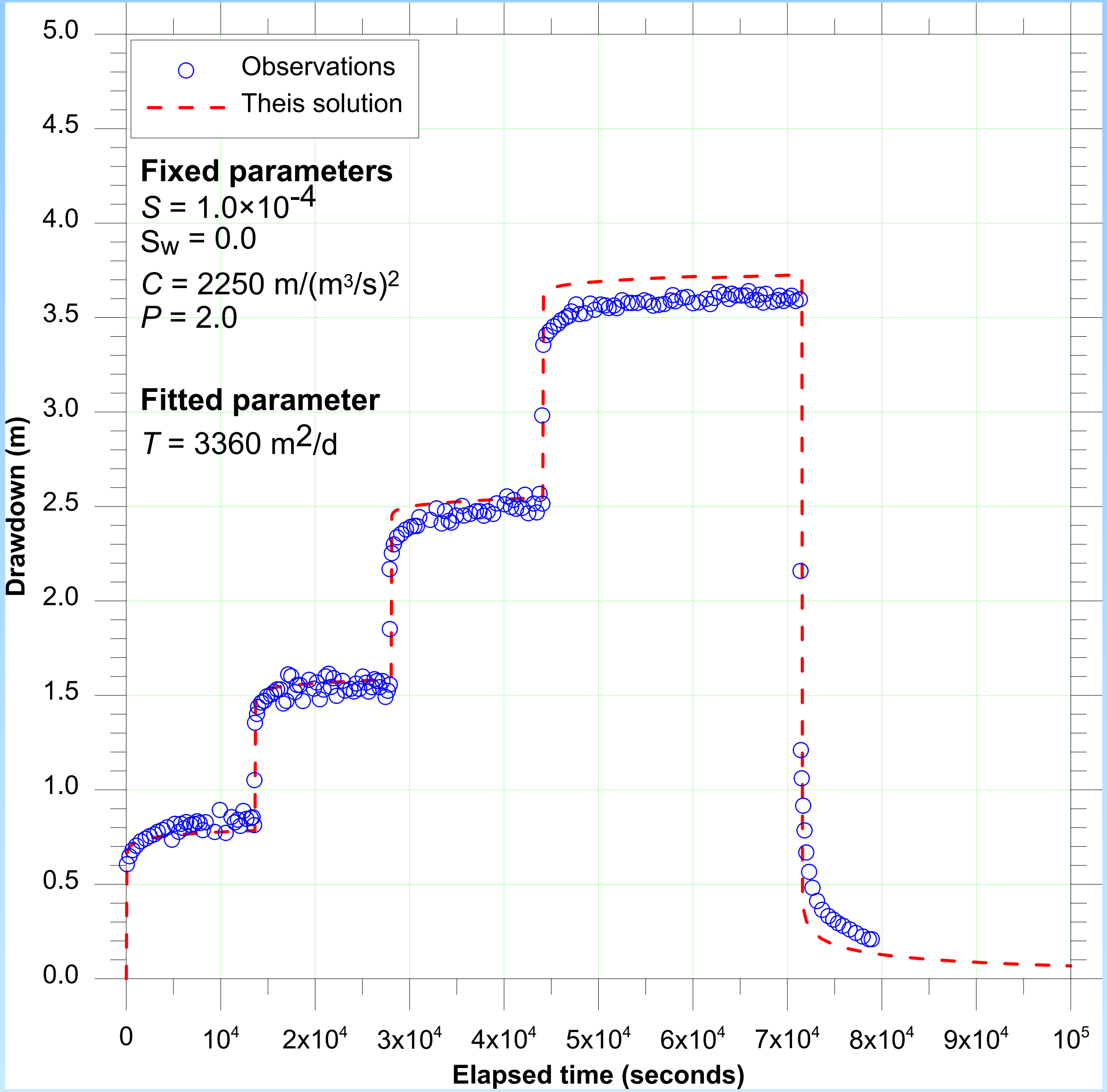
City of Guelph PW06-03 (2)



Analysis #1: Automatic with all parameters adjustable

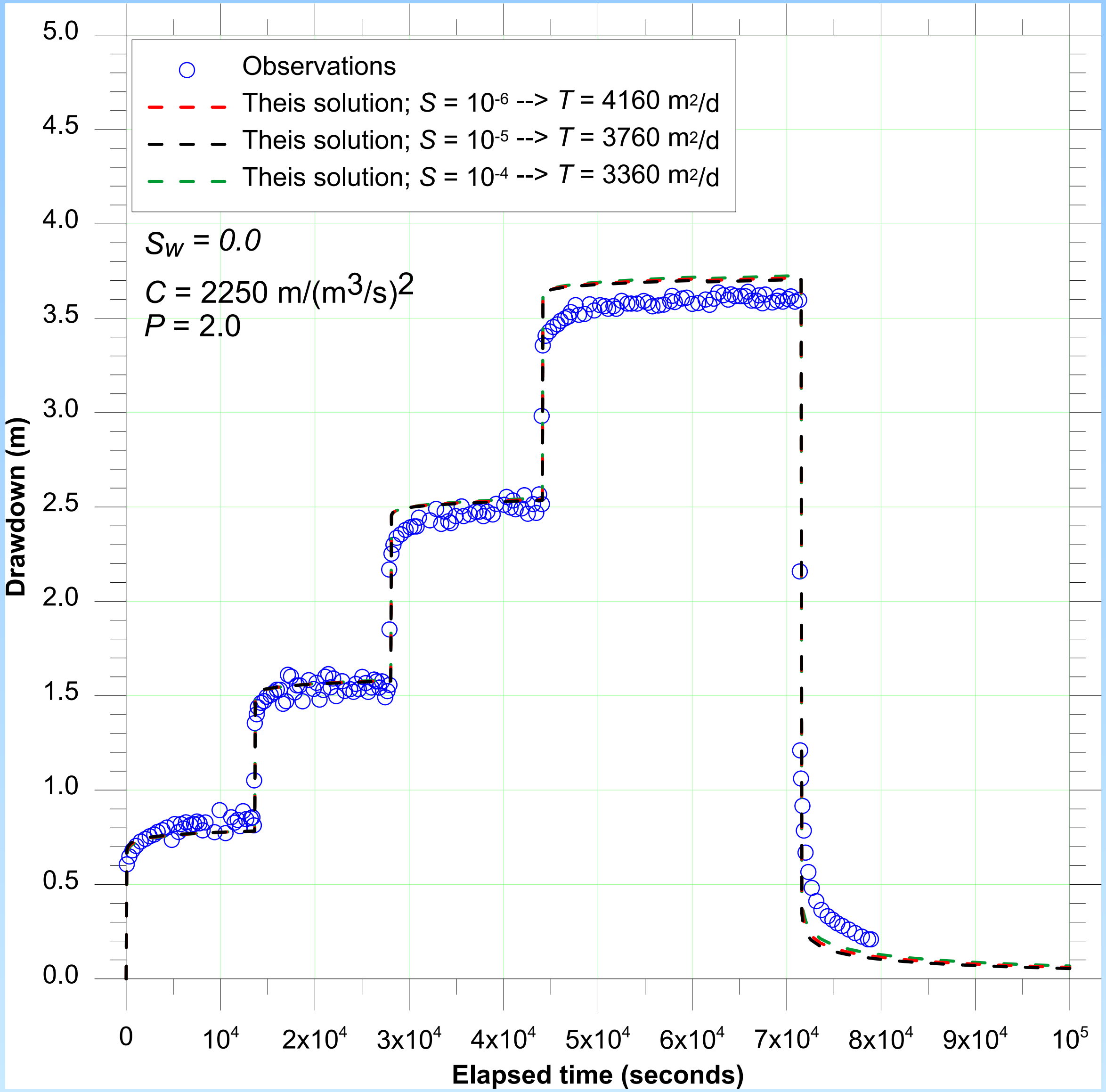


Analysis #2: "Constrained fit"



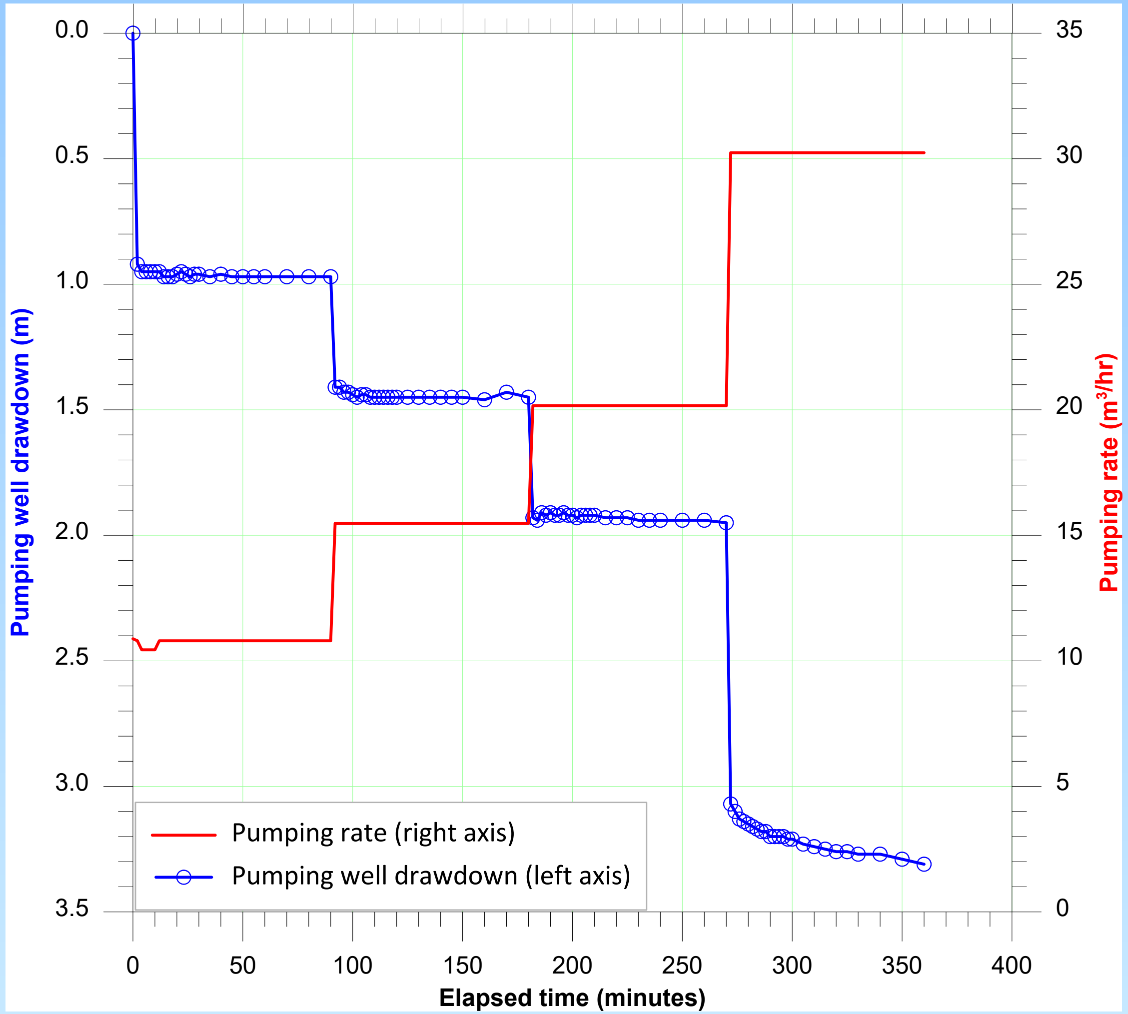
Recall:
T specific capacity ~ 3,000 m^2/d

Significance of the storativity *S*



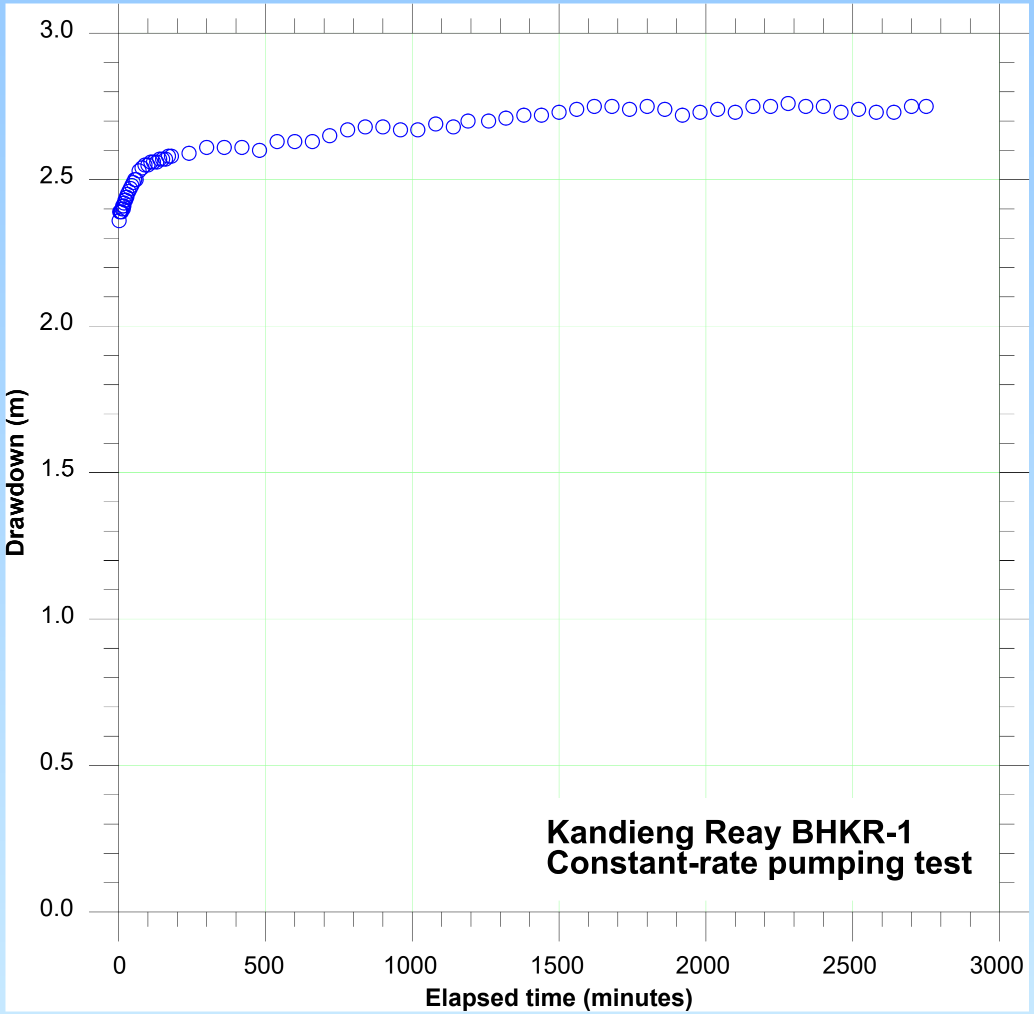
Case study:
Kandieng Reay, Cambodia
Well BHKR-1

1. Step test



0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Pumping well drawdown (m)
35
30
25
20
15
10
5
0
Pumping rate (m3/hr)
0
50
100
150
200
250
300
350
400
Elapsed time (minutes)
Pumping rate (right axis)
Pumping well drawdown (left axis)

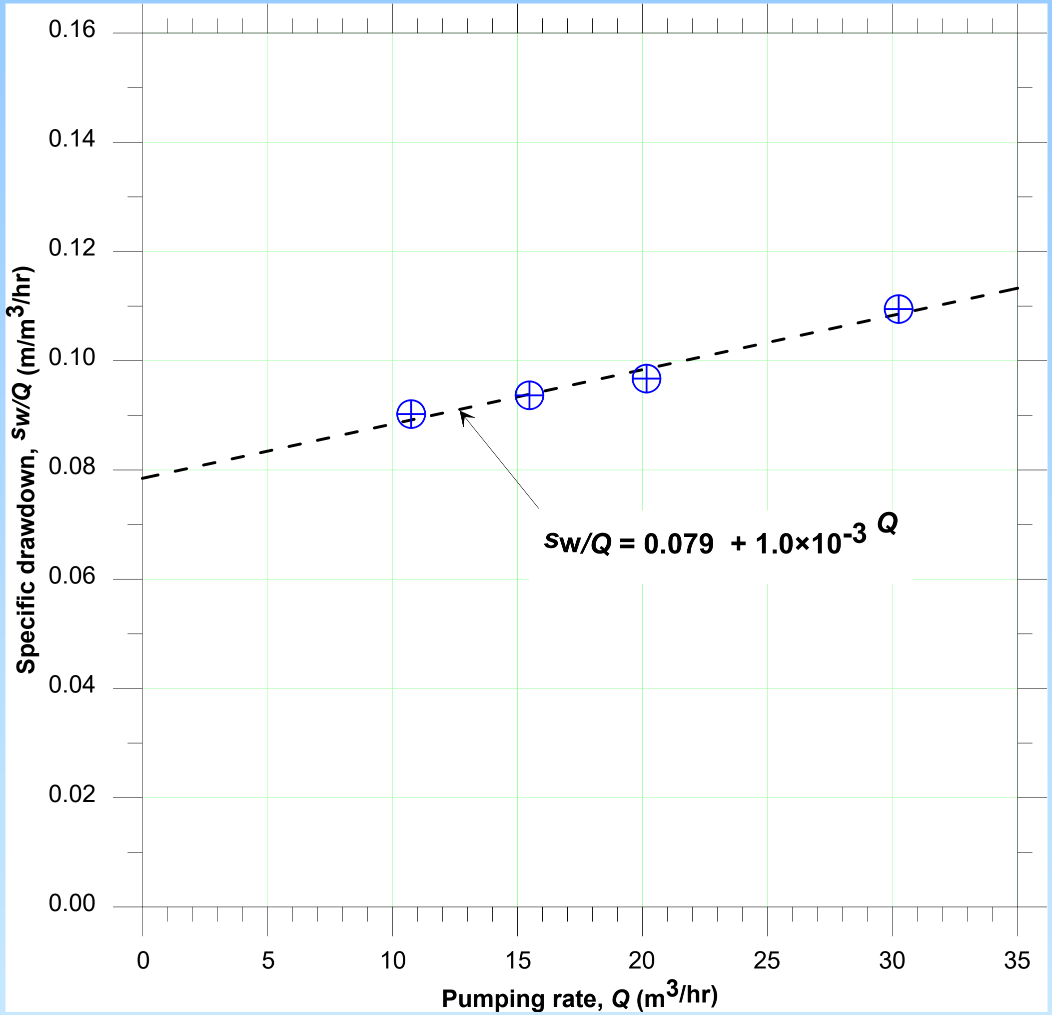
2. Constant-rate test



46 hours of pumping

Q_{avg} = 25.2 m^3/hr

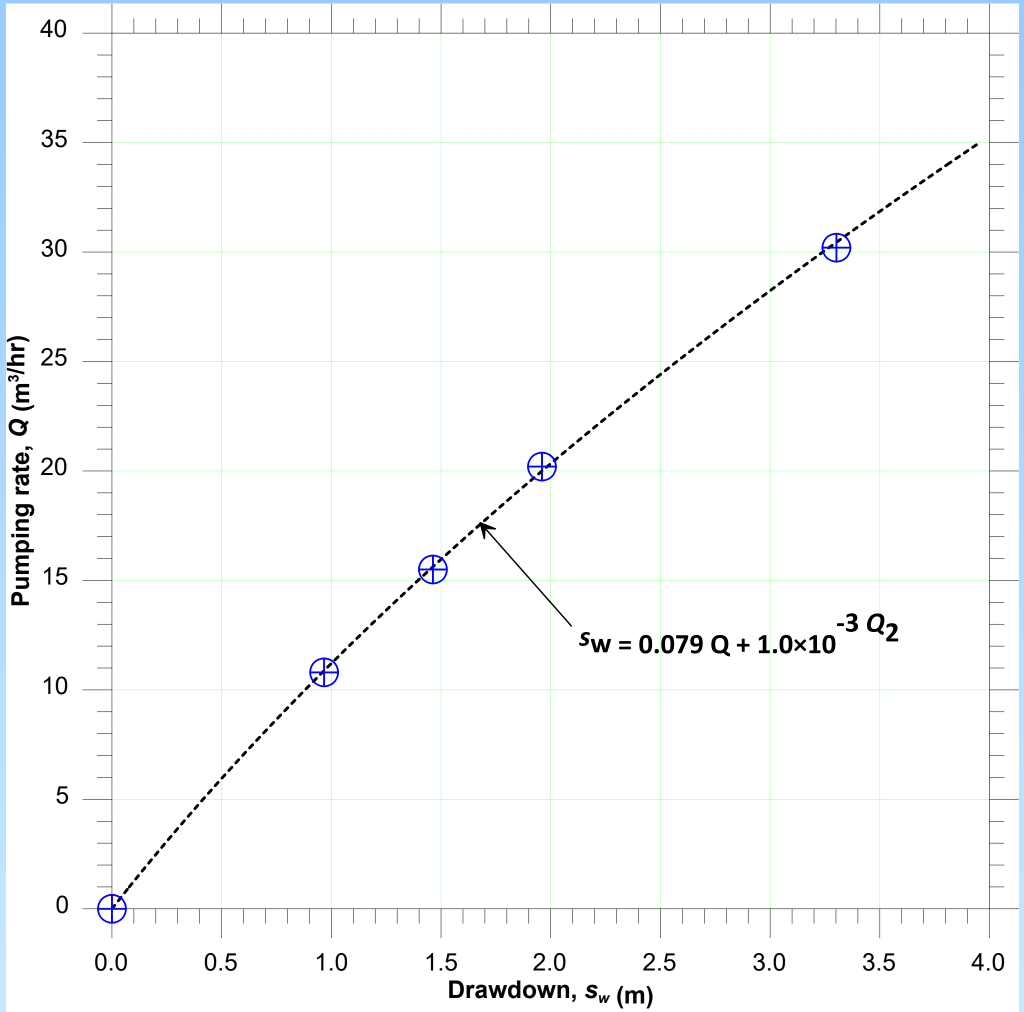
Estimation of nonlinear well losses



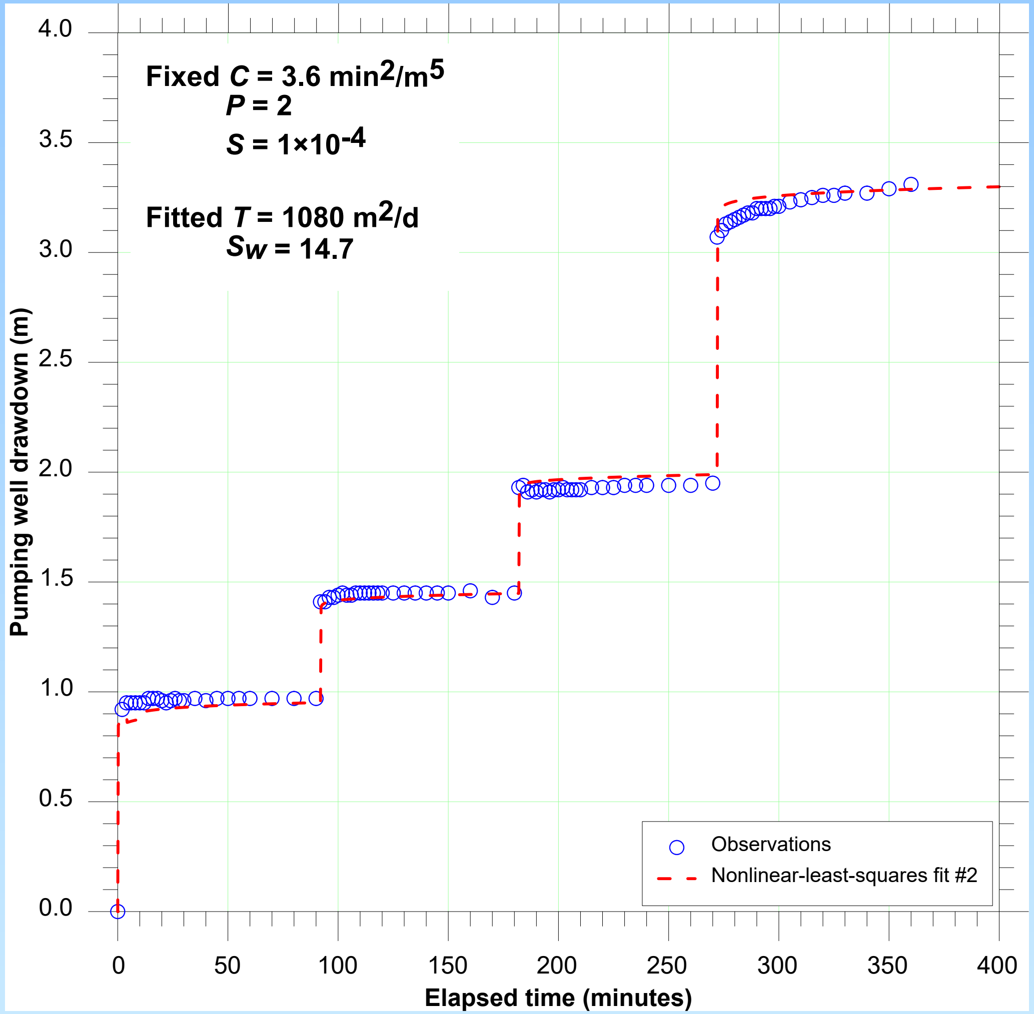
Hantush-Bierschenk plot:

$C = 1.0\times10^{-3}$ m/(m^3/hr)^2

Check on the Hantush-Bierschenk analysis



Constrained step test analysis

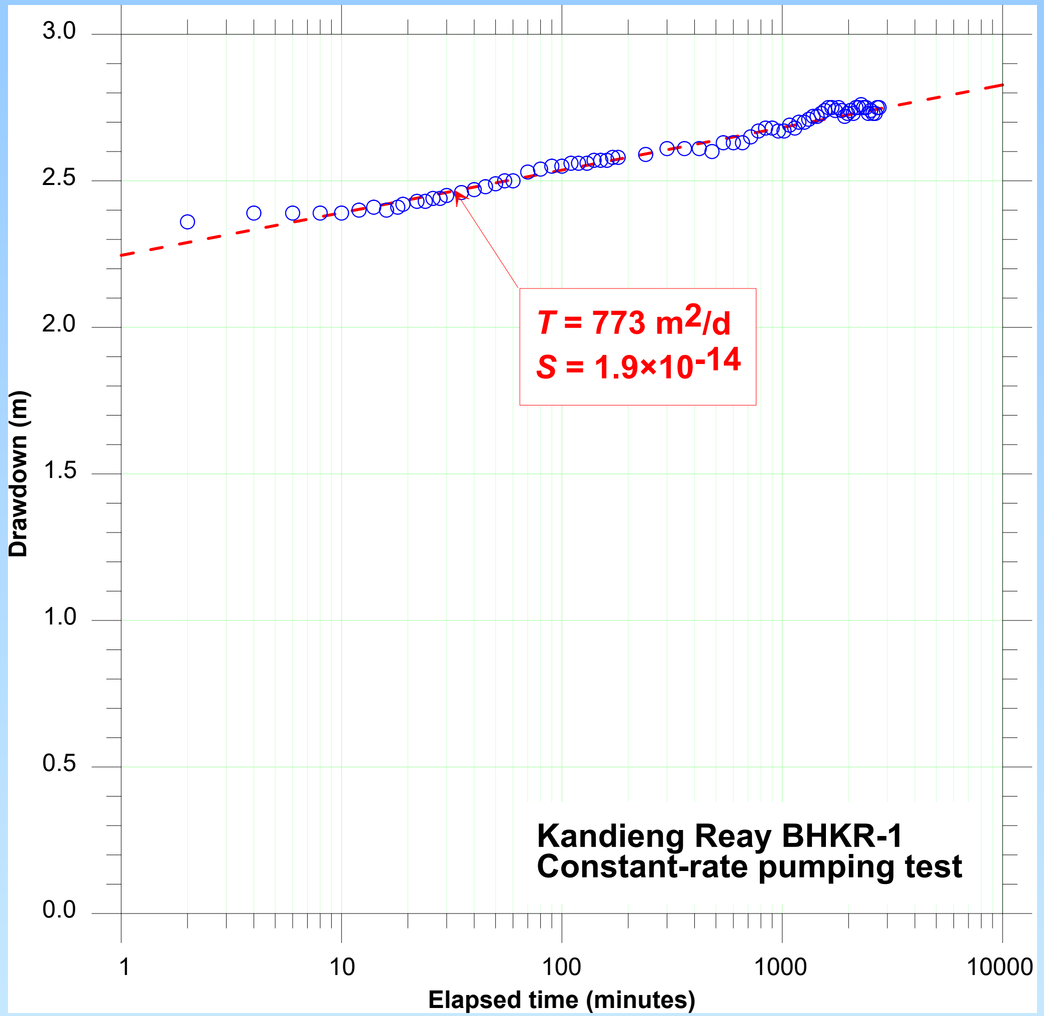


Conversion:

$C = 1.0\times10^{-3}\ \text{m}/(\text{m}^3/\text{hr})^2$

$= 3.6\ \text{m}/(\text{m}^3/\text{min})^2$

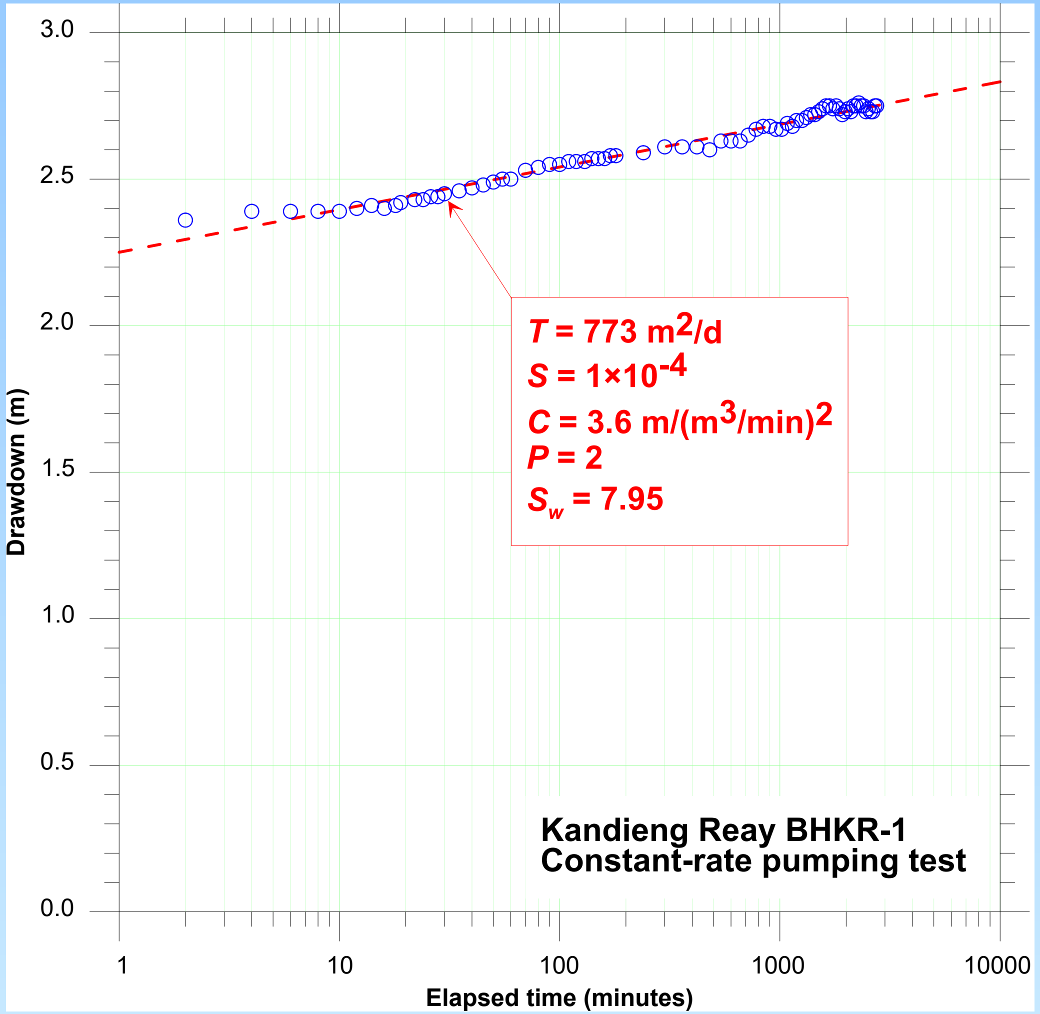
Estimation of the transmissivity



Re: transmissivity estimate from the step test analysis: 1080 m^2/day

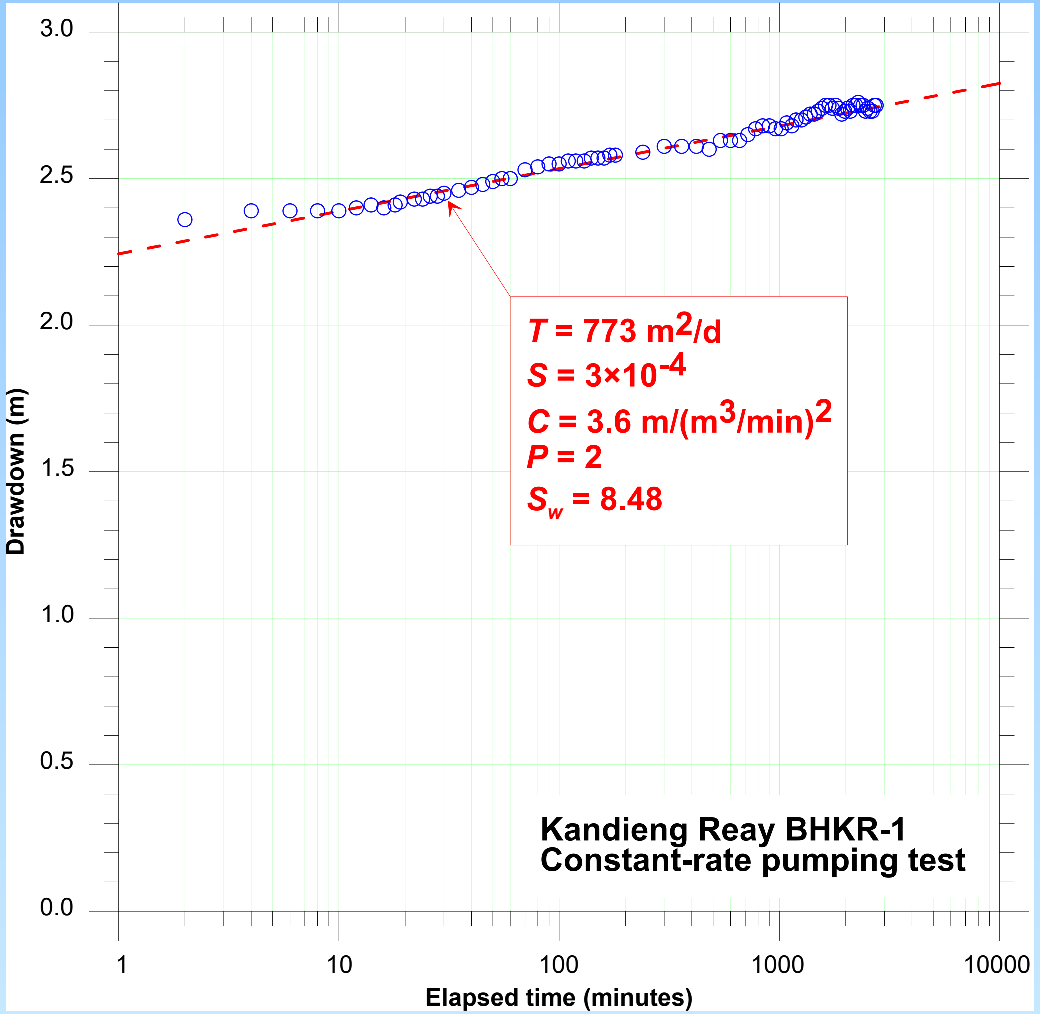
Note the non-physical storativity estimate

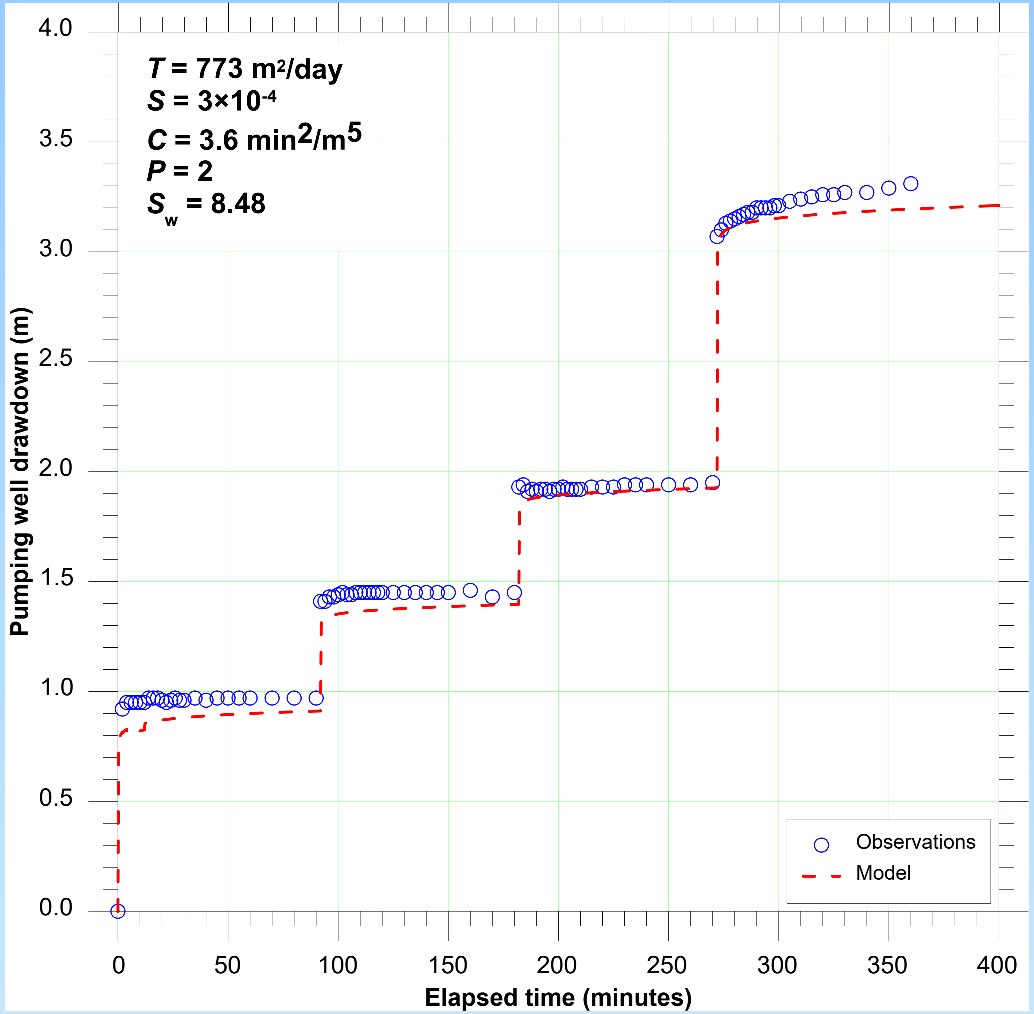
Cooper-Jacob analysis #2



The storativity is fixed to estimate the dimensionless skin factor.

One final iteration





Take-Home Points (2)

4. Step tests are the only definitive method of evaluating non-aquifer well losses.

5. We usually cannot estimate all parameter values. Watch for non-physical parameter estimates and parameter correlation.

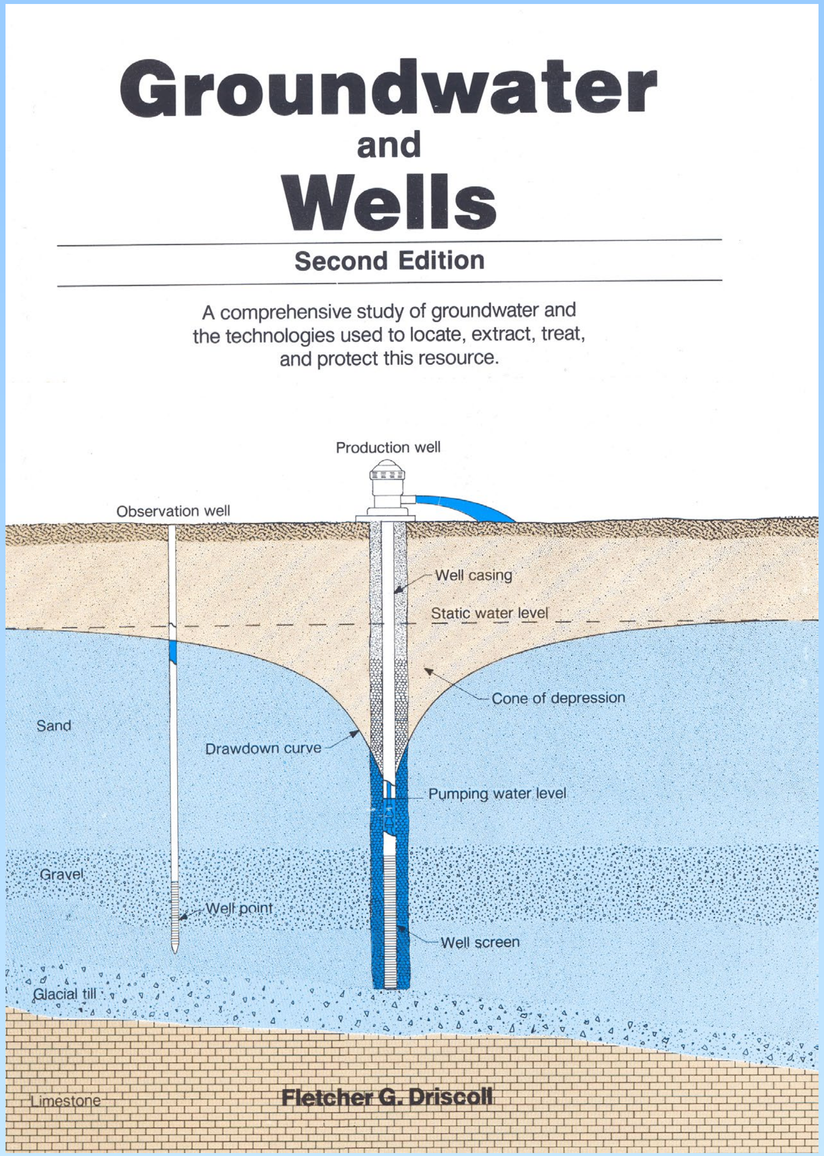
6. Where the data are available, we should try to obtain a consistent set of parameters from step and constant-rate pumping tests.

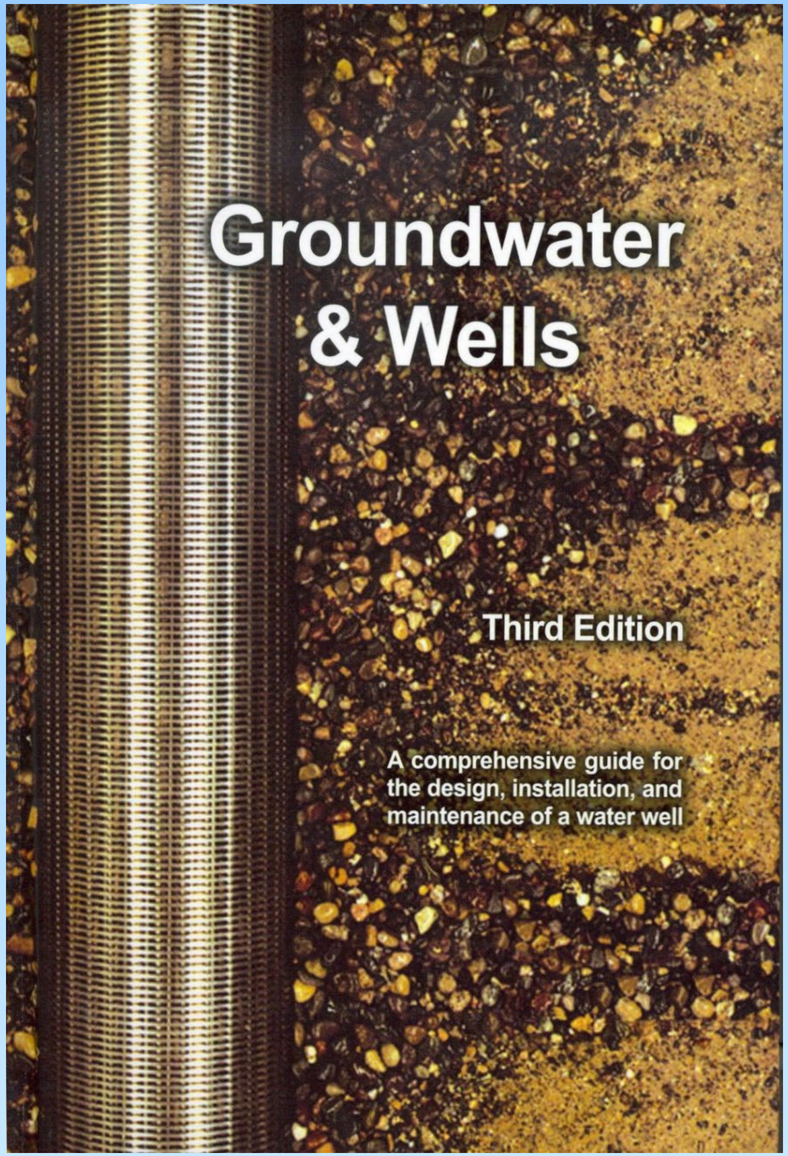
Estimating the Capacity of a Production Well

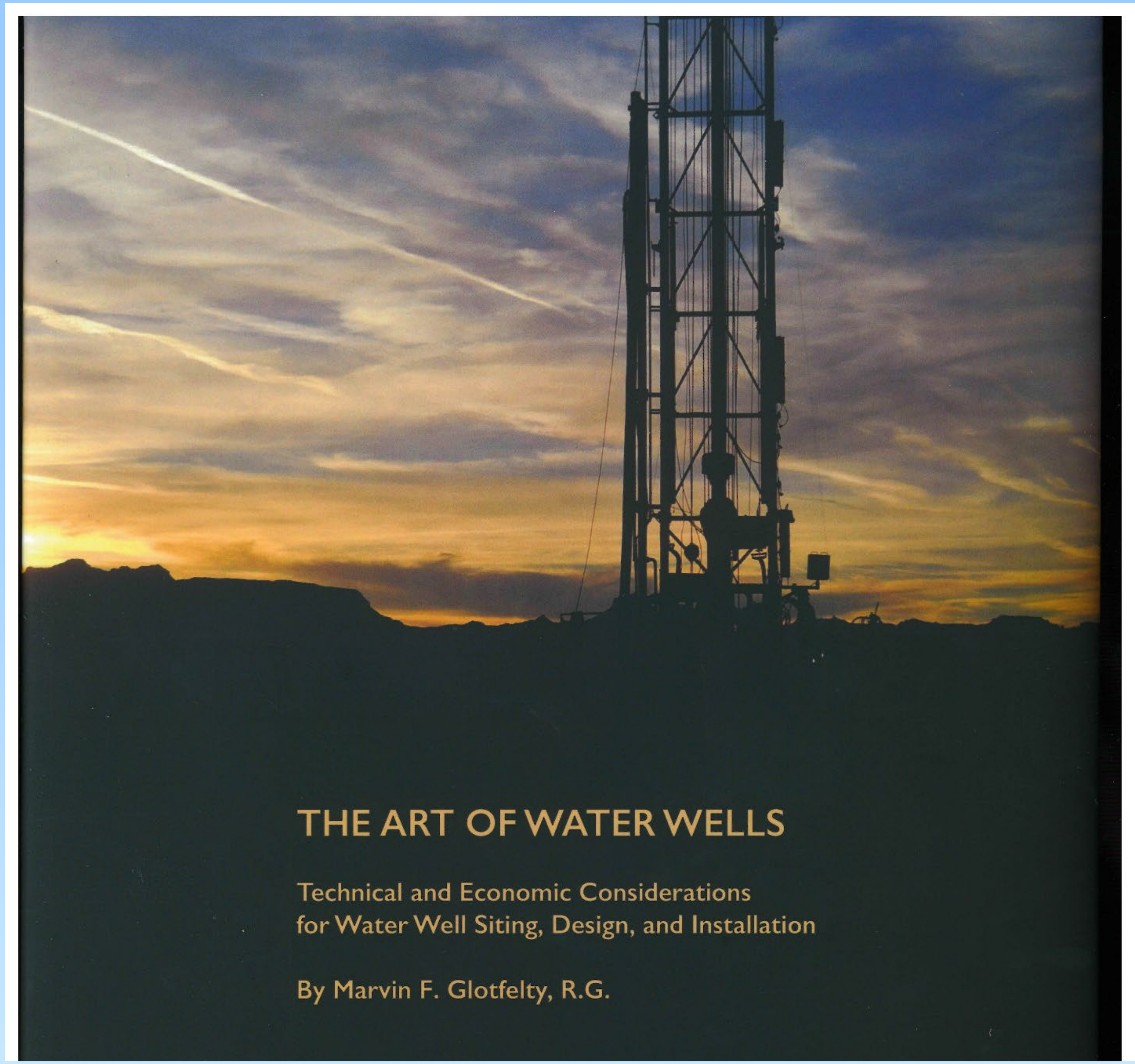
This is a huge topic.

My focus will be on the aquifer, but the design of a well has important implications with respect to its capacity.

Starting point for any self-teaching about production wells






THE ART OF WATER WELLS
Technical and Economic Considerations
for Water Well Siting, Design, and Installation
By Marvin F. Glotfelty, R.G.

Key definitions

1. Safe yield of a well

The average rate at which a well can be pumped without the water level in the well declining below a specified minimum level.

2. Sustainable yield of a well

The average rate at which a well can be pumped without causing unacceptable impacts.

For <u>this</u> presentation:
Safe yield = Long-term capacity

General approach for estimating the long-term capacity of a production well

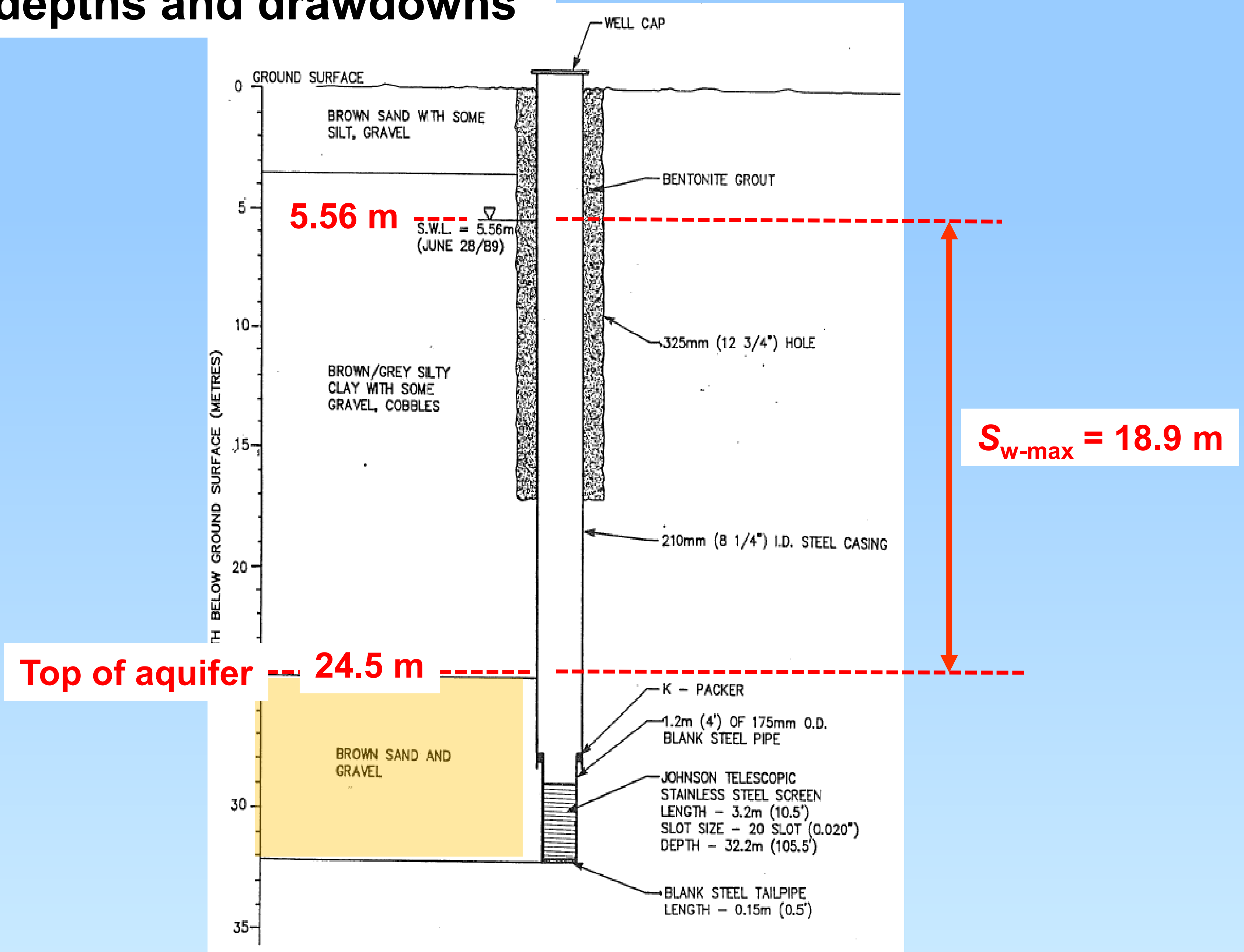
$$Q_{\max} = Q_{test} \times \frac{s_{w-max}}{s_{w-test}(t^*)}$$

t^* = lifespan of the well

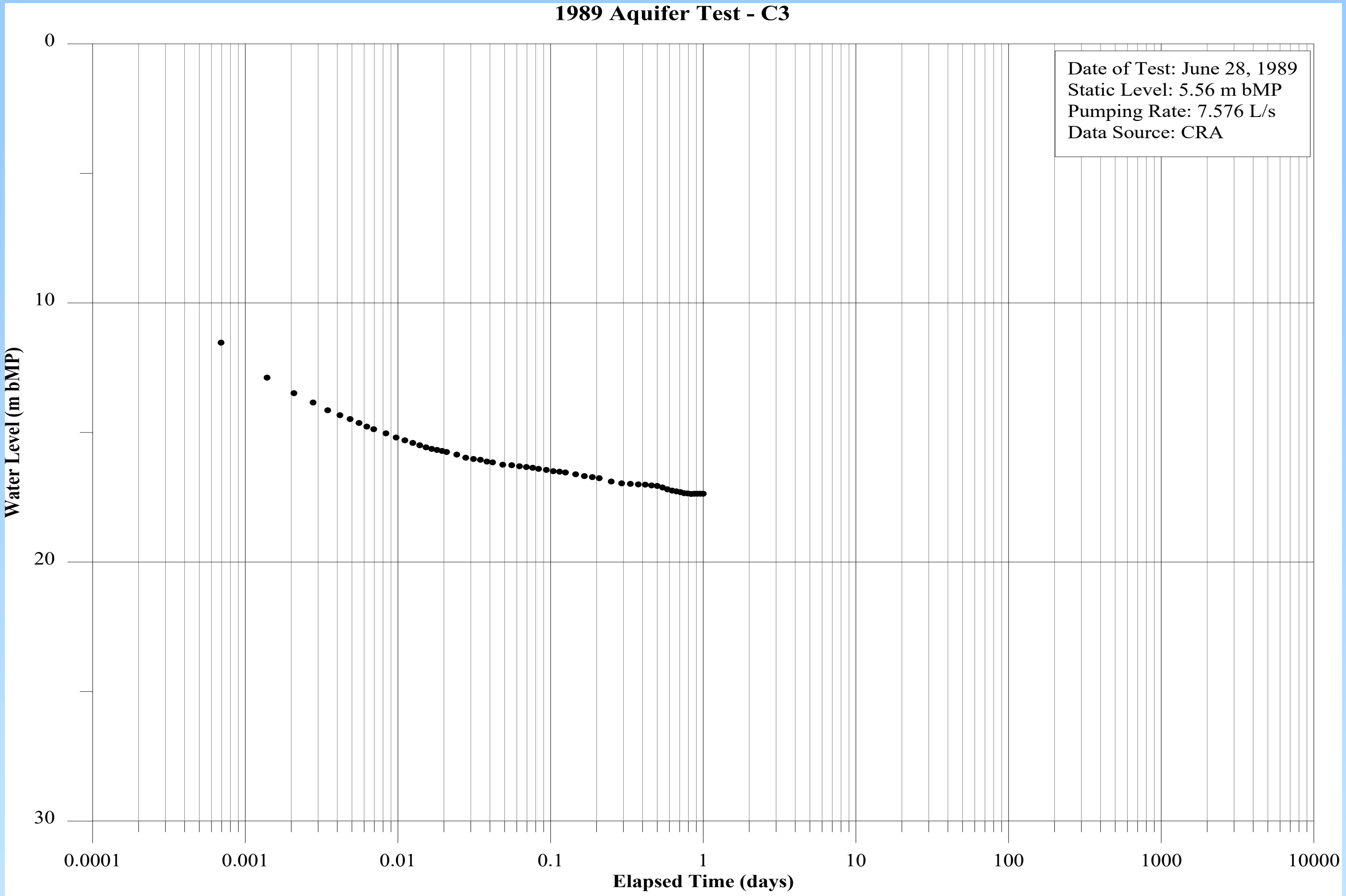
$s_{w\text{-}test}(t^*)$ = drawdown extrapolated to t^*

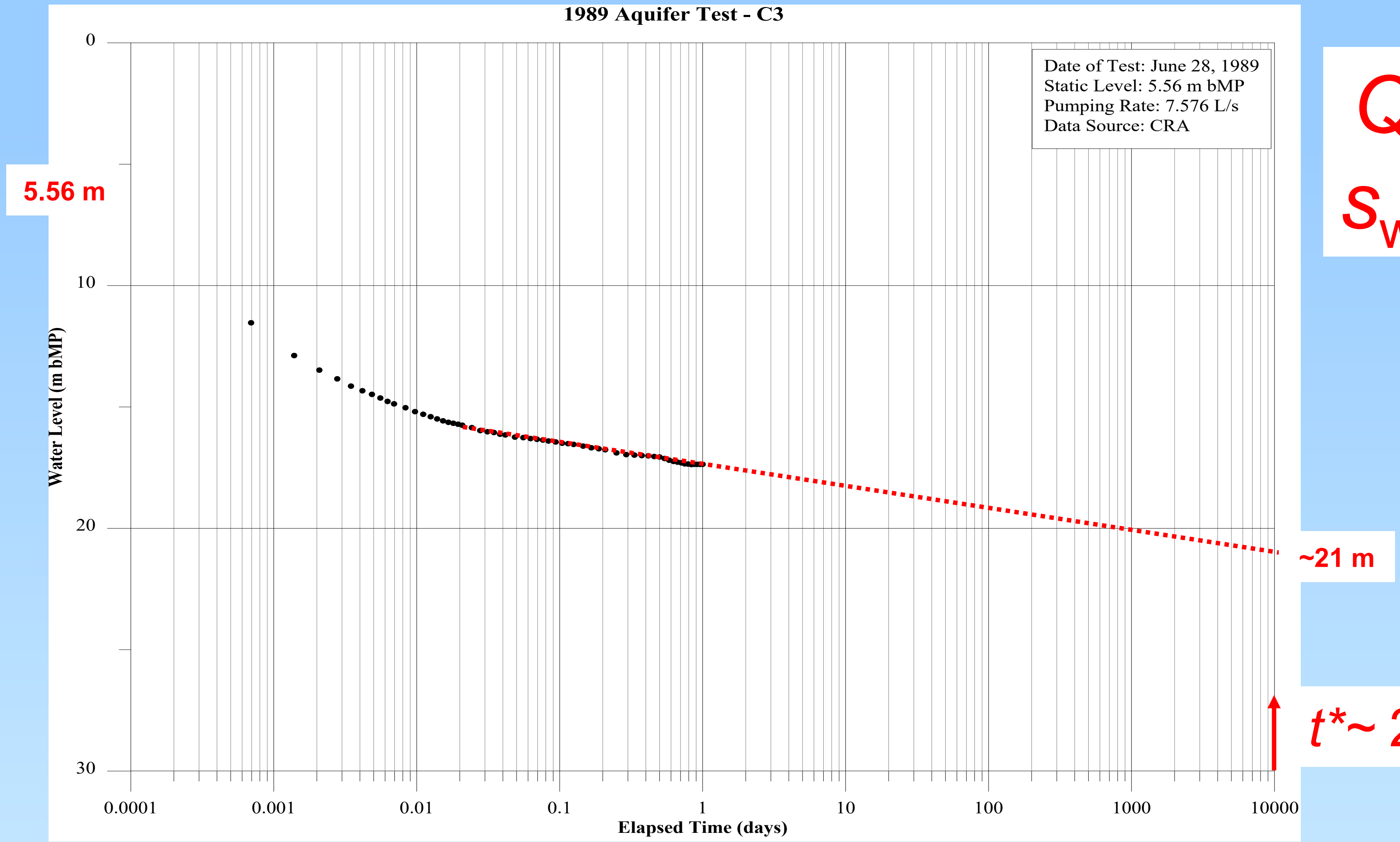
Case study: Conestogo C3

Key depths and drawdowns



24-hour pumping test





Q_{test} = 7.576 L/s
s_w (t^*) = 15.44 m

t^*~ 25 years

Estimation of well capacity

$$s_{\mathrm{w-max}} = 18.9\ \mathrm{m}\ - 1.5\ \mathrm{m}$$
$$= 17.4\ \mathrm{m}$$

$$Q_{\mathrm{max}} = (7.576\ \mathrm{L/s}) \times \frac{(17.4\ \mathrm{m})}{(21\ \mathrm{m} - 5.56\ \mathrm{m})}$$
$$= \mathbf{8.5\ L/s}$$

- What is the underlying conceptual model?
- How might we be wrong?

Take-home lessons (3)

1. Even something as apparently simple as the estimation of the long-term capacity of a production well is a subtle undertaking.
2. Every analysis we conduct has an underlying conceptual model. It is crucial to be aware of the assumptions implicit in the conceptual model.
3. A good hydrogeologist develops an appreciation of how conditions at a site might deviate from the conceptual model, and an understanding of how those deviations might affect the results of the analysis.