



S.S. PAPADOPULOS & ASSOCIATES, INC.
ENVIRONMENTAL AND WATER RESOURCE CONSULTANTS

Foundations of Pumping Test Interpretation

2. “Real” aquifers

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S.S. Papadopoulos & Associates, Inc.

Outline

1. Proposed approach with the composite plot
2. Assessment of the proposed approach for estimating the bulk-average transmissivity
3. Case study #1: Cambridge NDPW1-08
4. Case study #2: Elmira EW-3

Real aquifers are heterogeneous

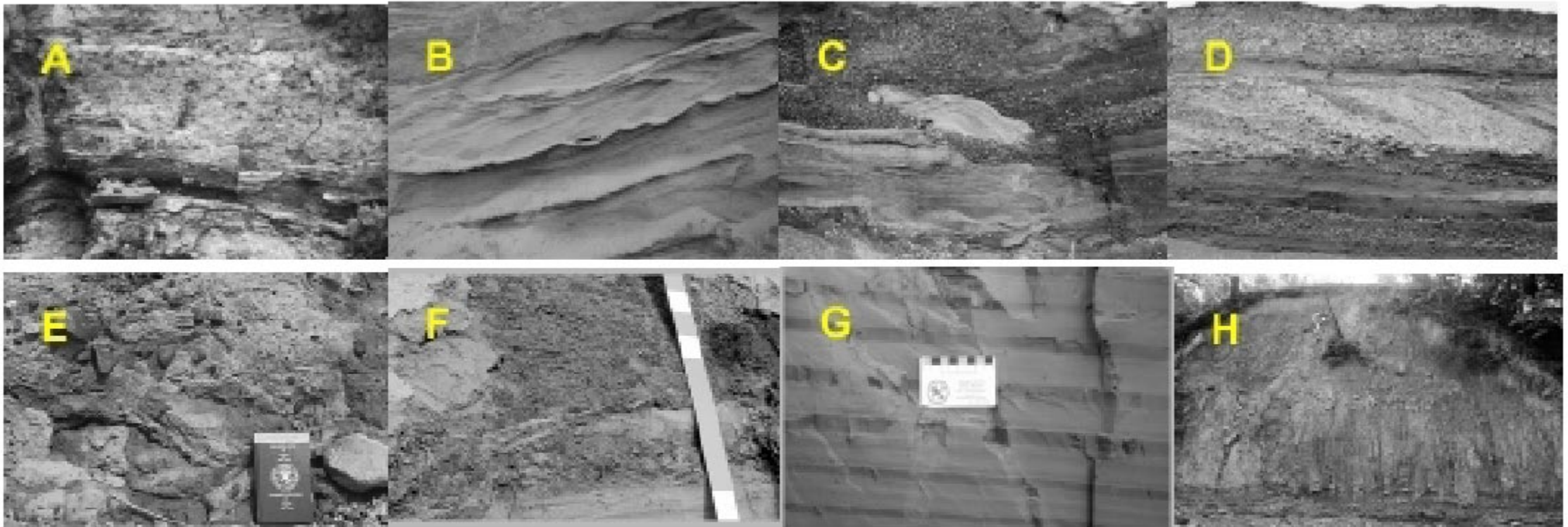


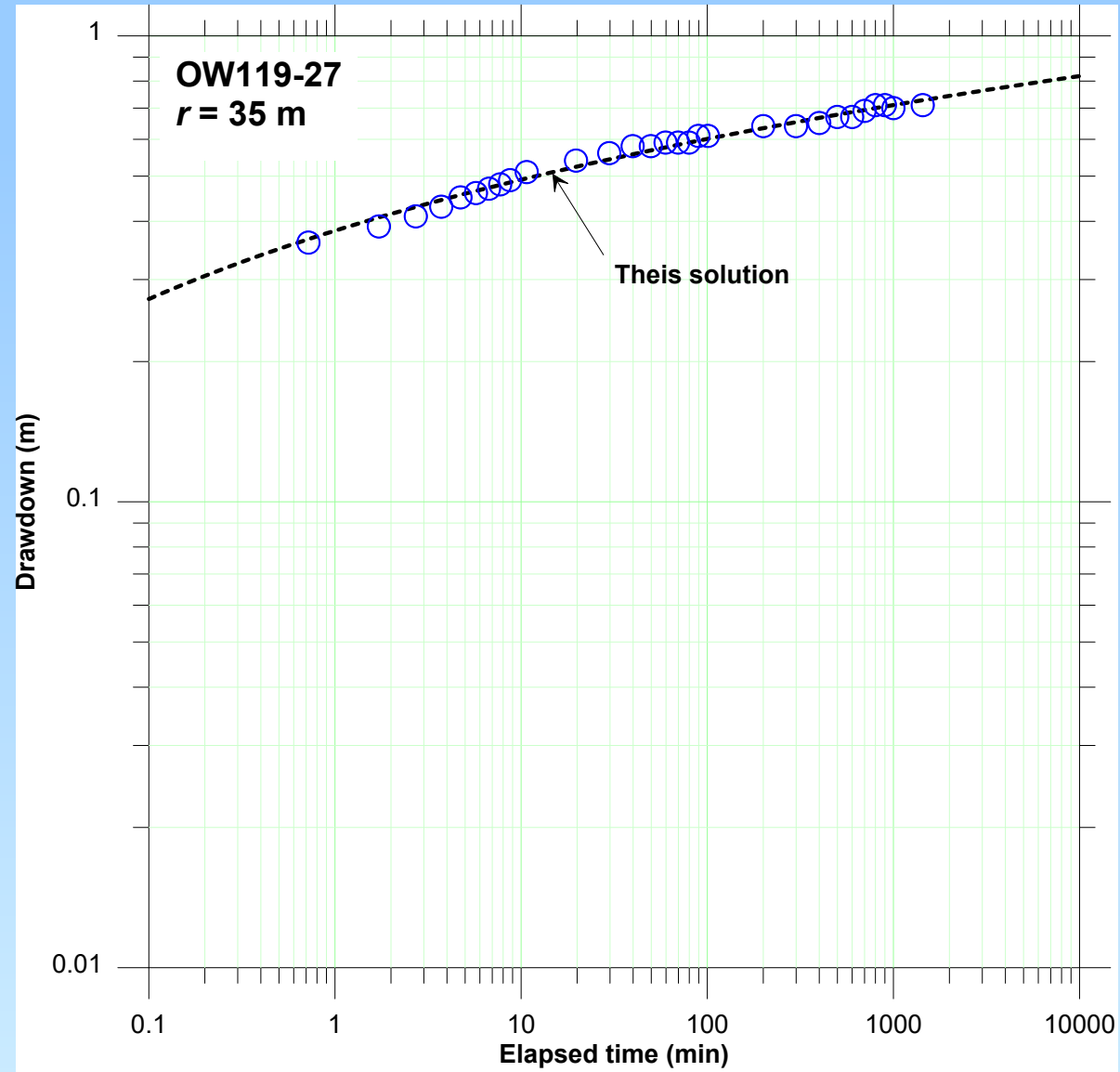
Figure 5. Major types of sediment and rock in the ORM/GTA **a)** Halton interbedded sediments; **b)** ORM fine sand and silt; **c)** ORM gravel; **d)** channel gravel; **e)** Newmarket Till; **f)** lower sediments, Scarborough sand and organics; **g)** lower sediment, rhythmites; **h)** Shale-carbonate bedrock (below shovel) overlain by Newmarket and Halton Tills, Etobicoke Creek

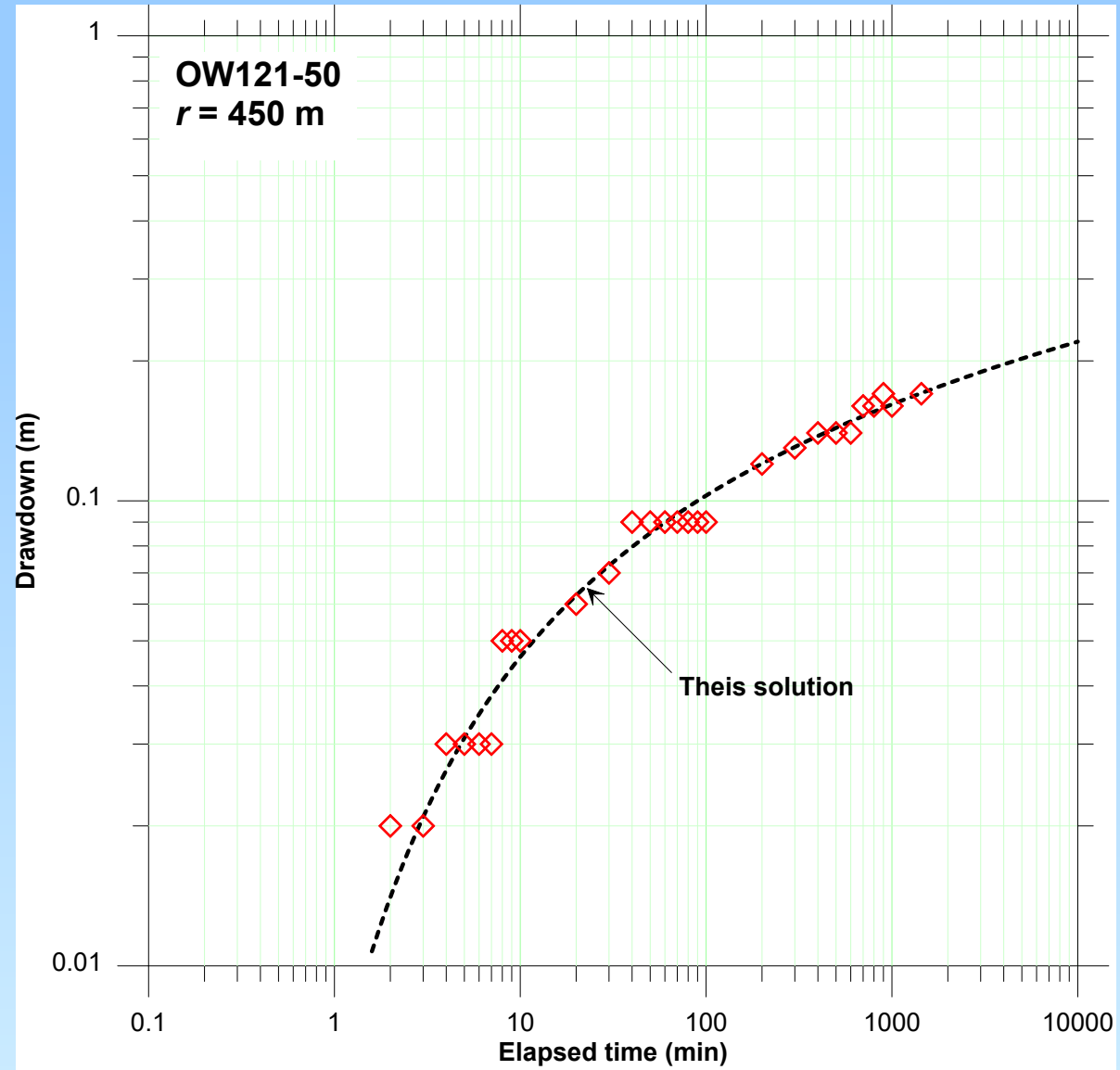
Sharpe et al. (1999) Current Research 1999-E; Geological Survey of Canada, p. 123–136.

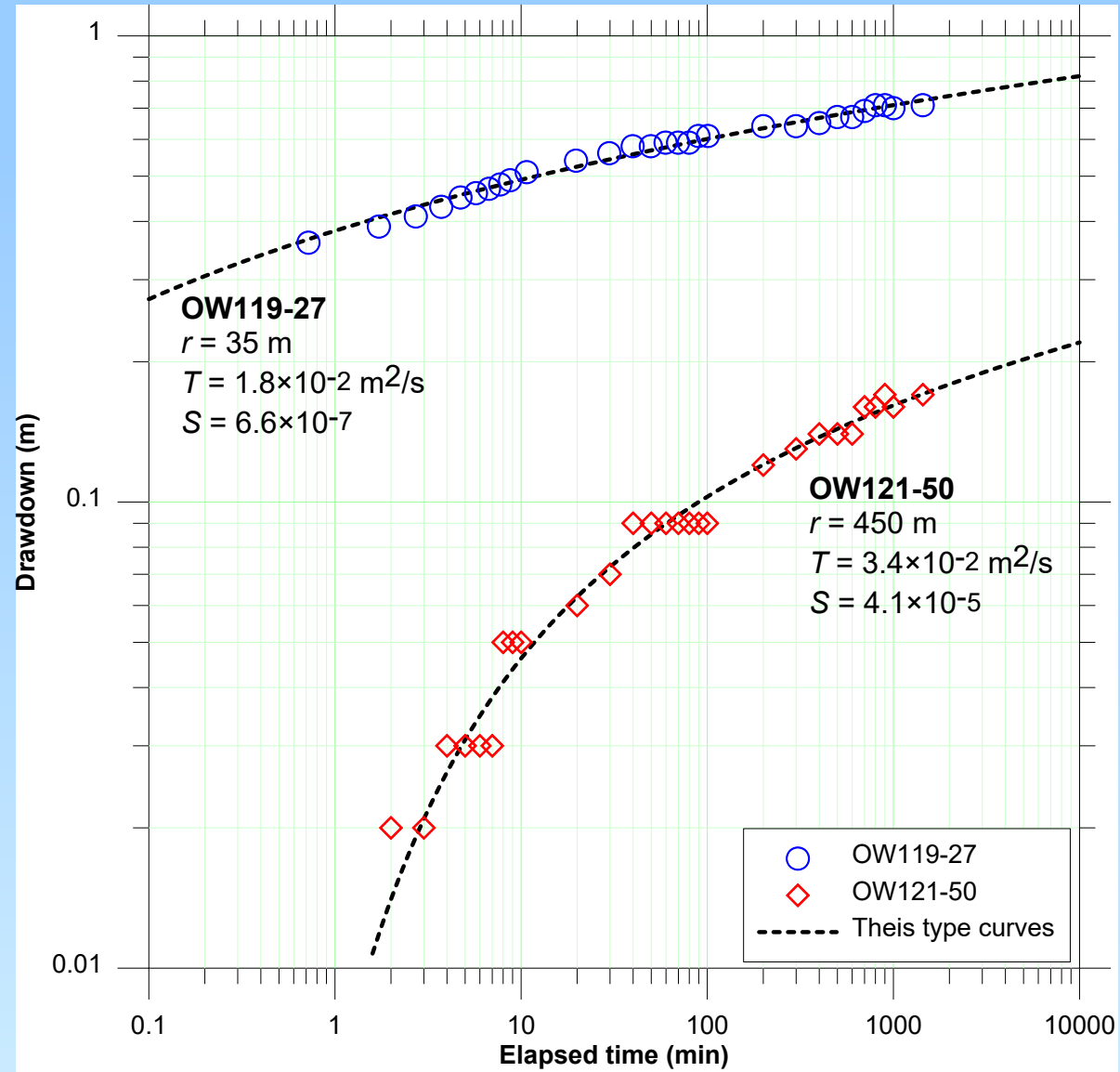
Real aquifers are heterogeneous (2)



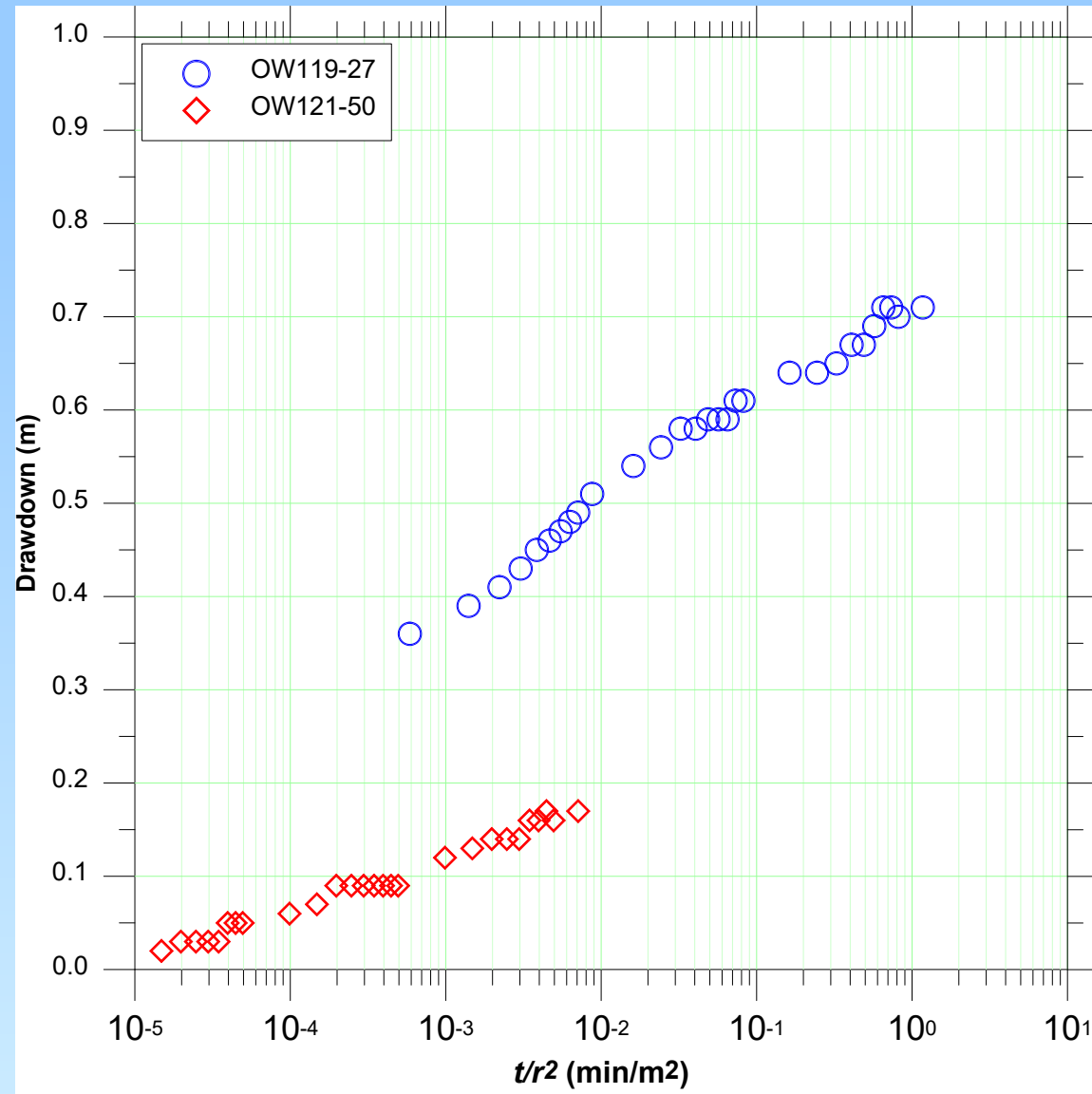
Case study

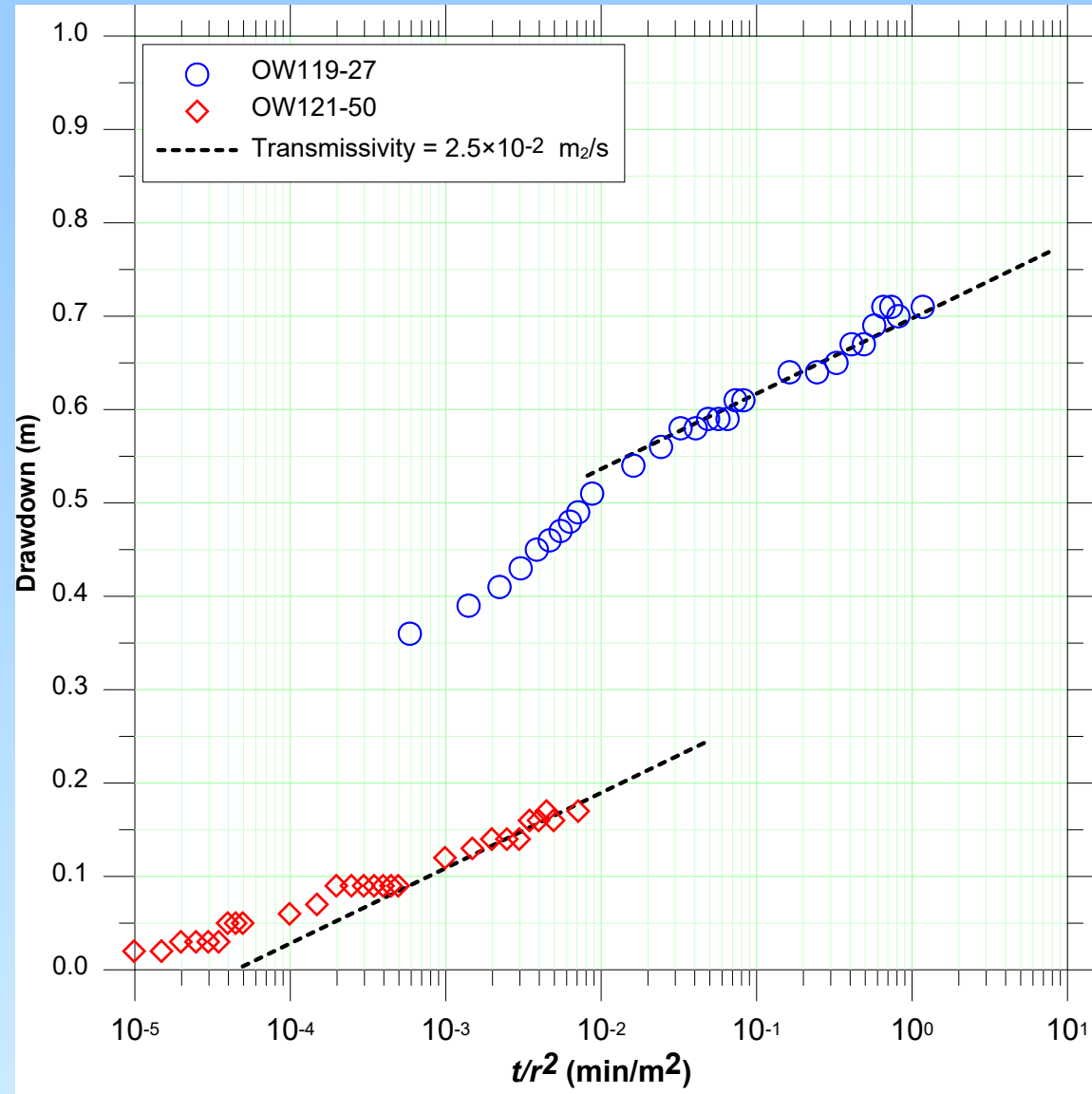






Proposed approach



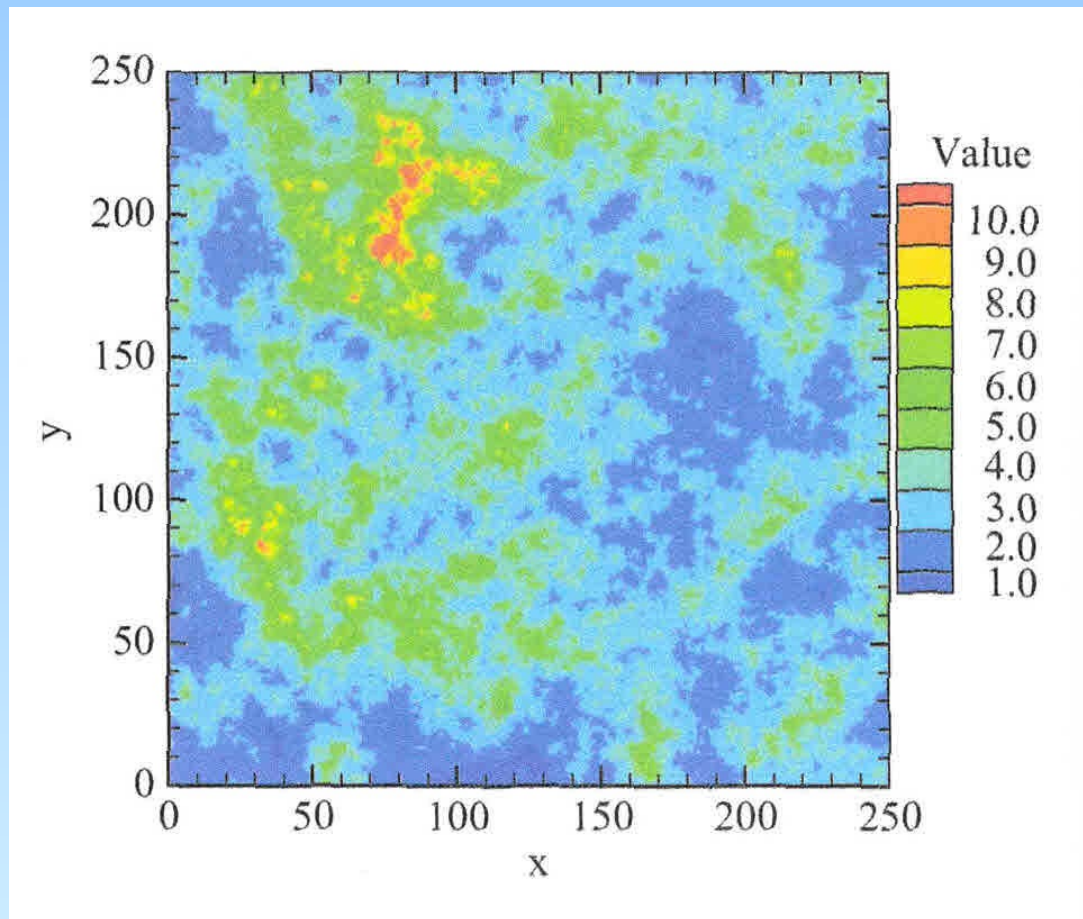


Assessment of the proposed approach

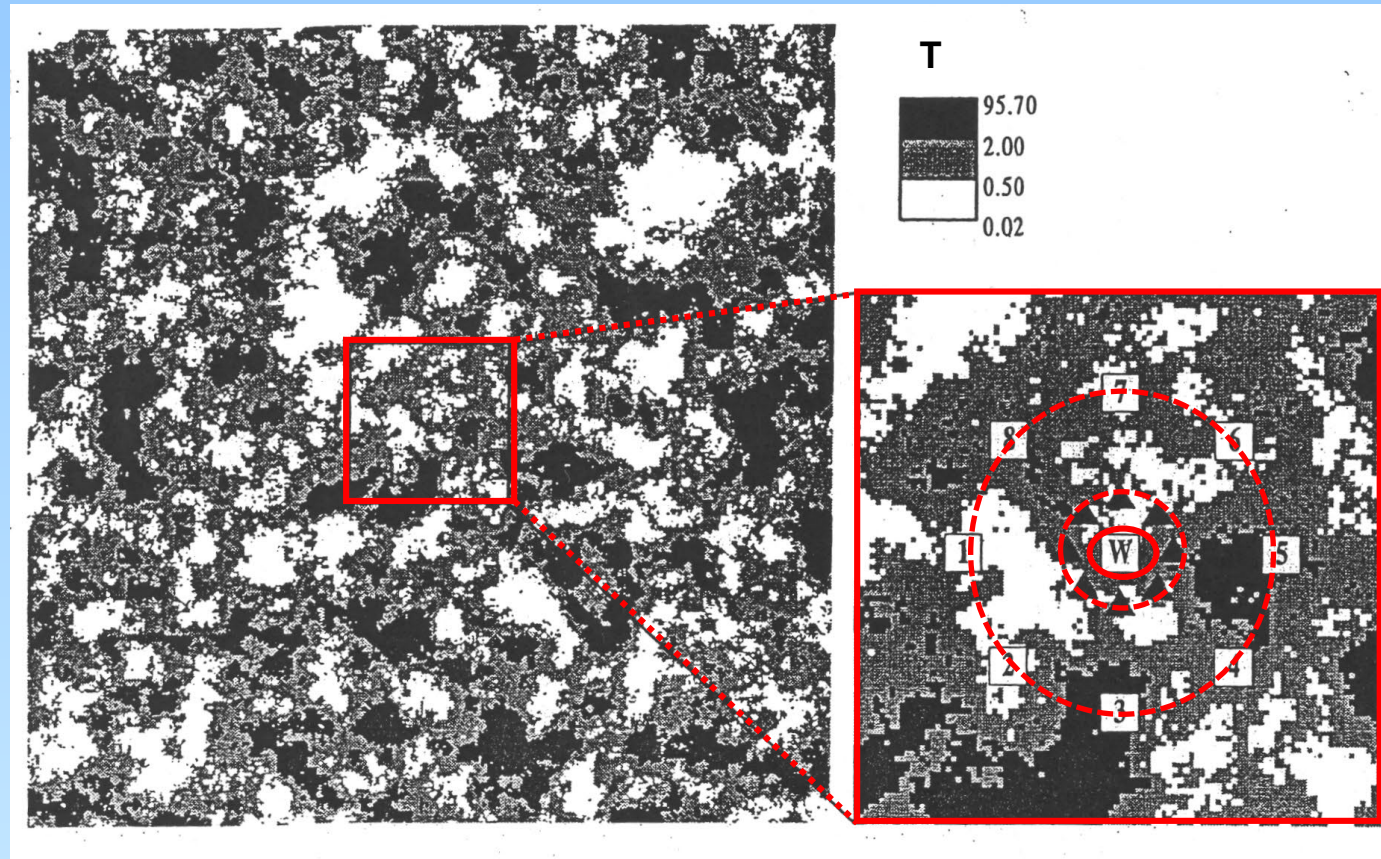
1. Pumping tests in homogeneously heterogeneous aquifers (random fields)
2. Pumping tests in aquifers with discrete zones

Conceptual model #1

Pumping tests in homogeneously heterogeneous aquifers
(random fields)



Meier et al. (1998): Numerical simulation of pumping tests in random- T fields



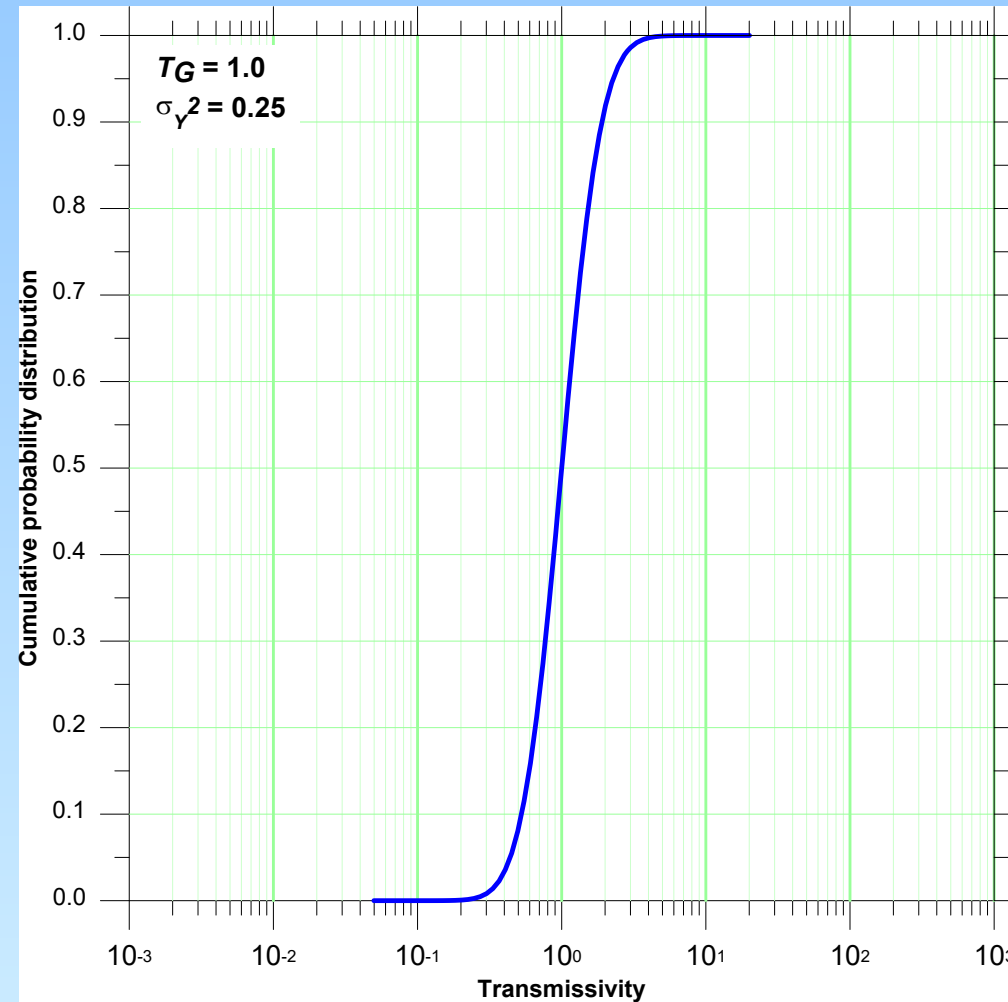
Lognormal transmissivity:
 $\ln(T) = y = N(\ln\{T_G\}, \sigma_y)$

T_G = Geometric mean transmissivity
 σ_y^2 = Variance of the log-transmissivity

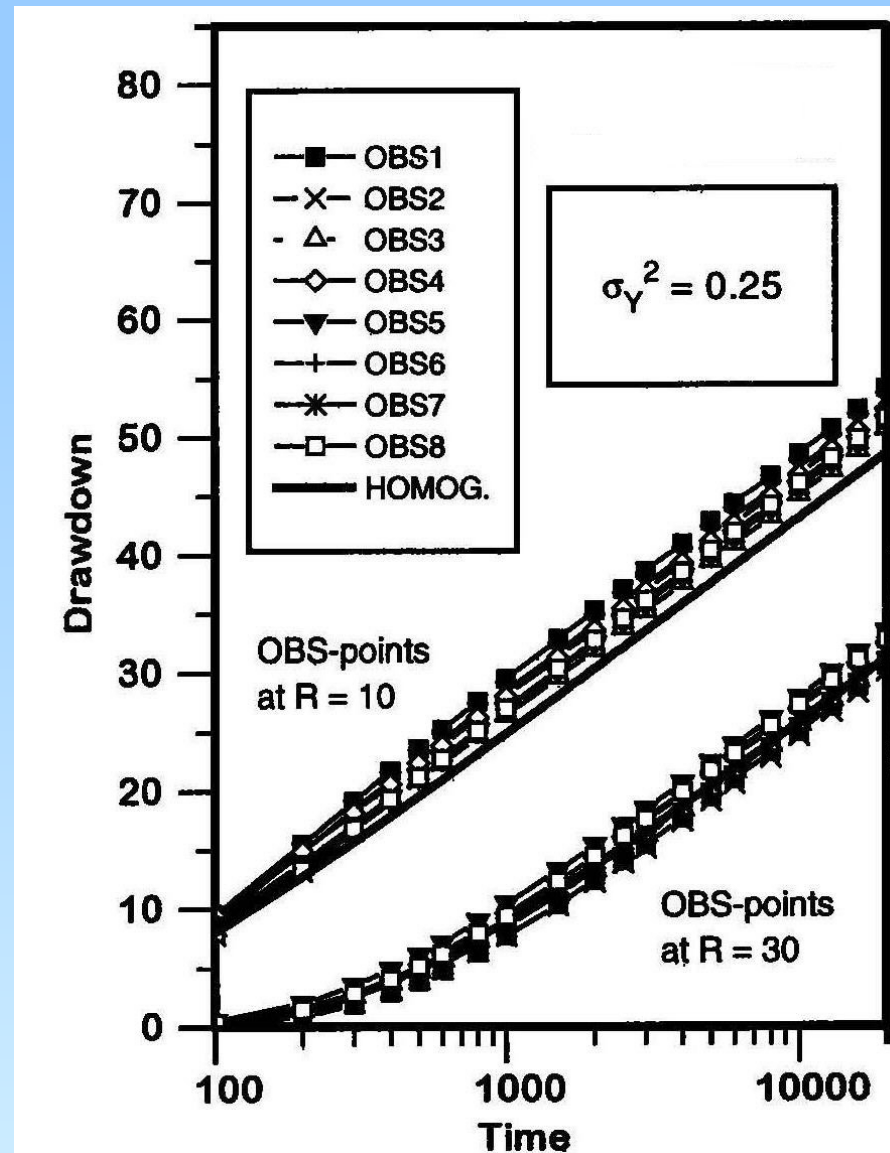
Cumulative probability plot for transmissivity

Case 1

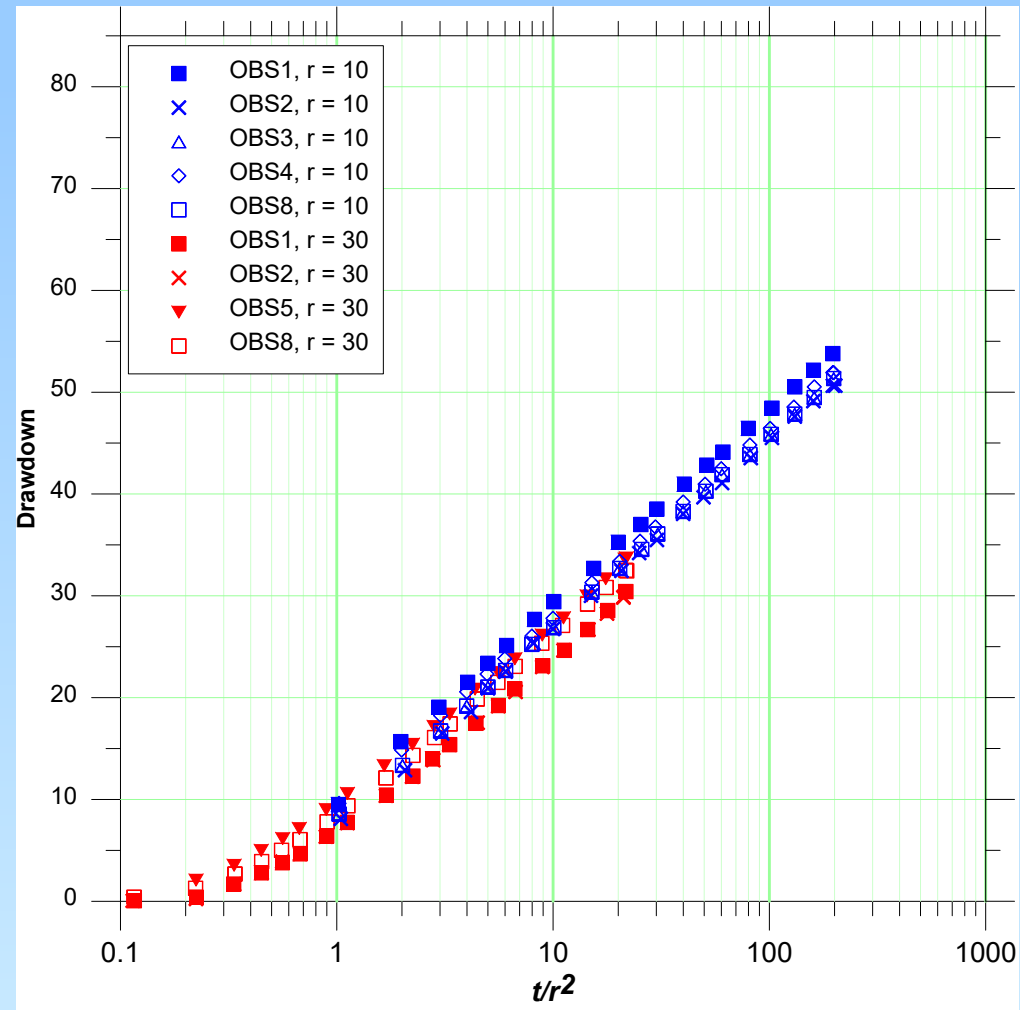
$$T_G = 1.0$$
$$\sigma_y^2 = 0.25$$

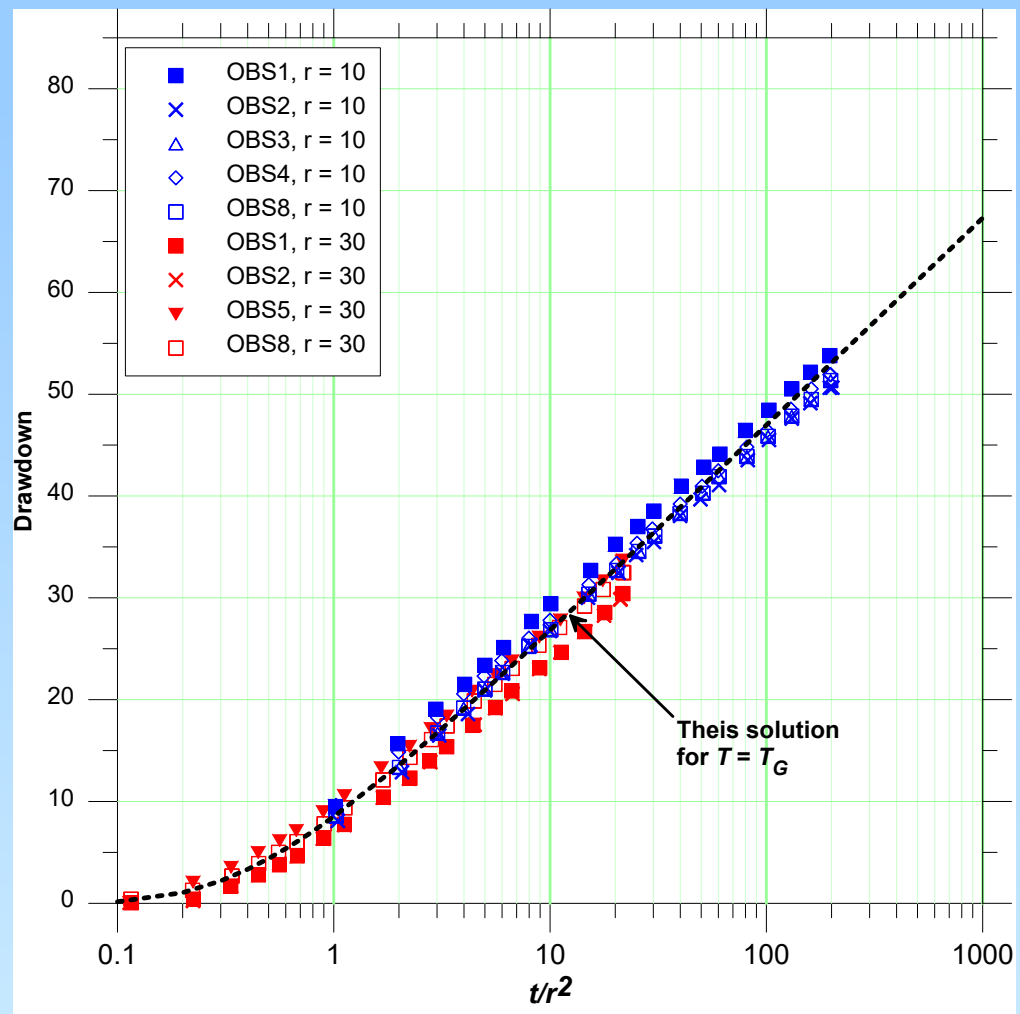


Simulated drawdowns



Simulated drawdowns on a composite plot





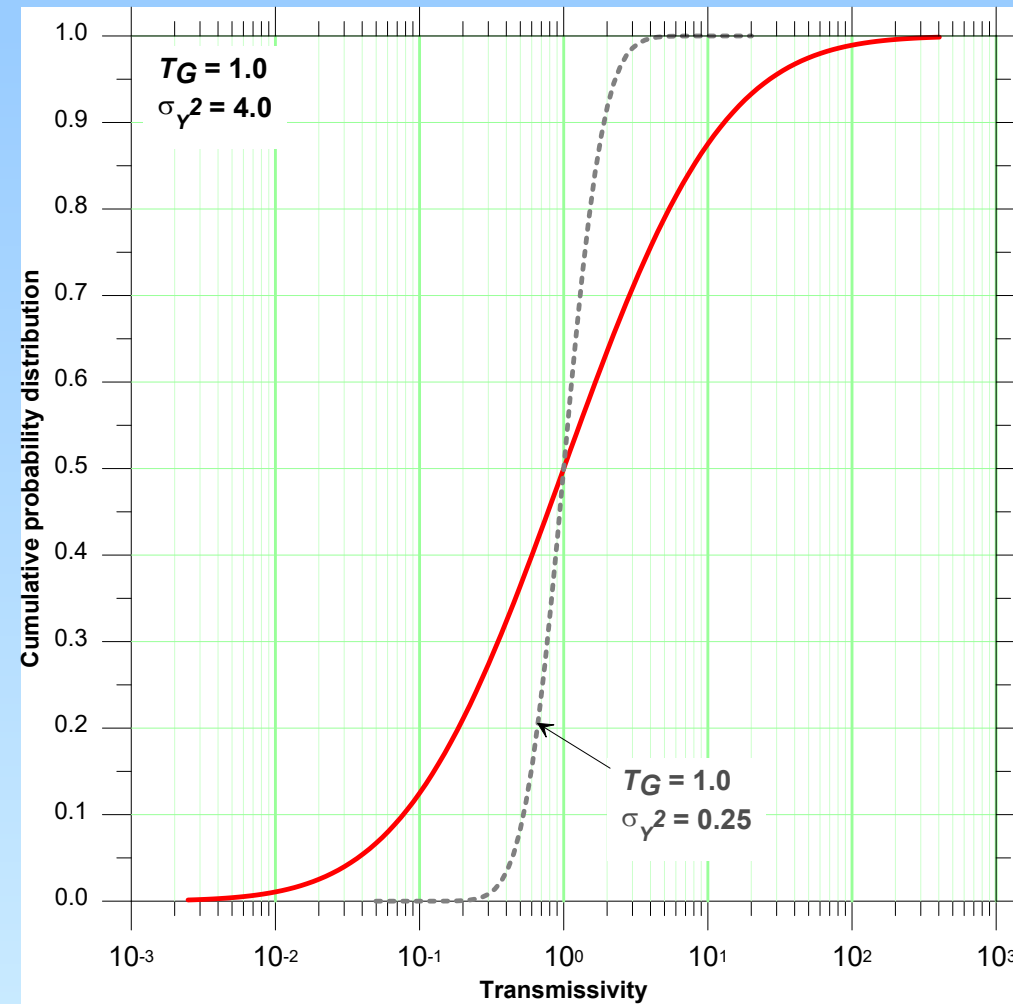
Cumulative probability plot for transmissivity

Case 2

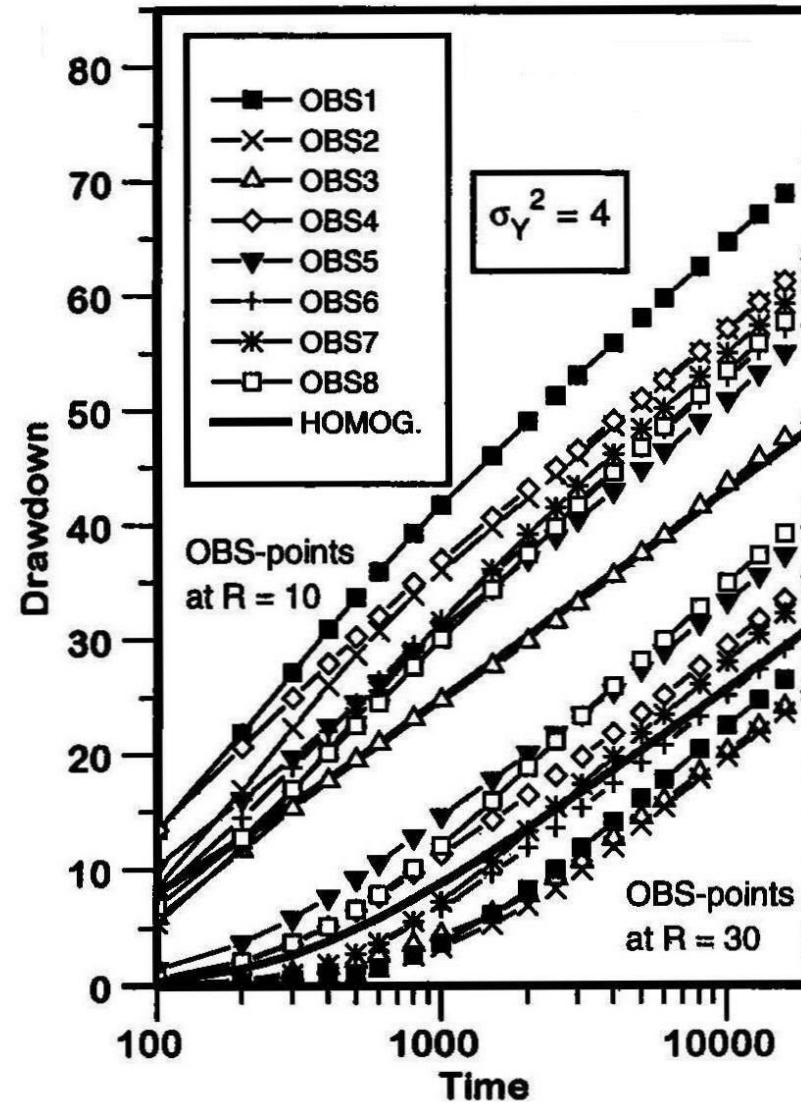
$$T_G = 1.0$$

$$\sigma_y^2 = 4.0$$

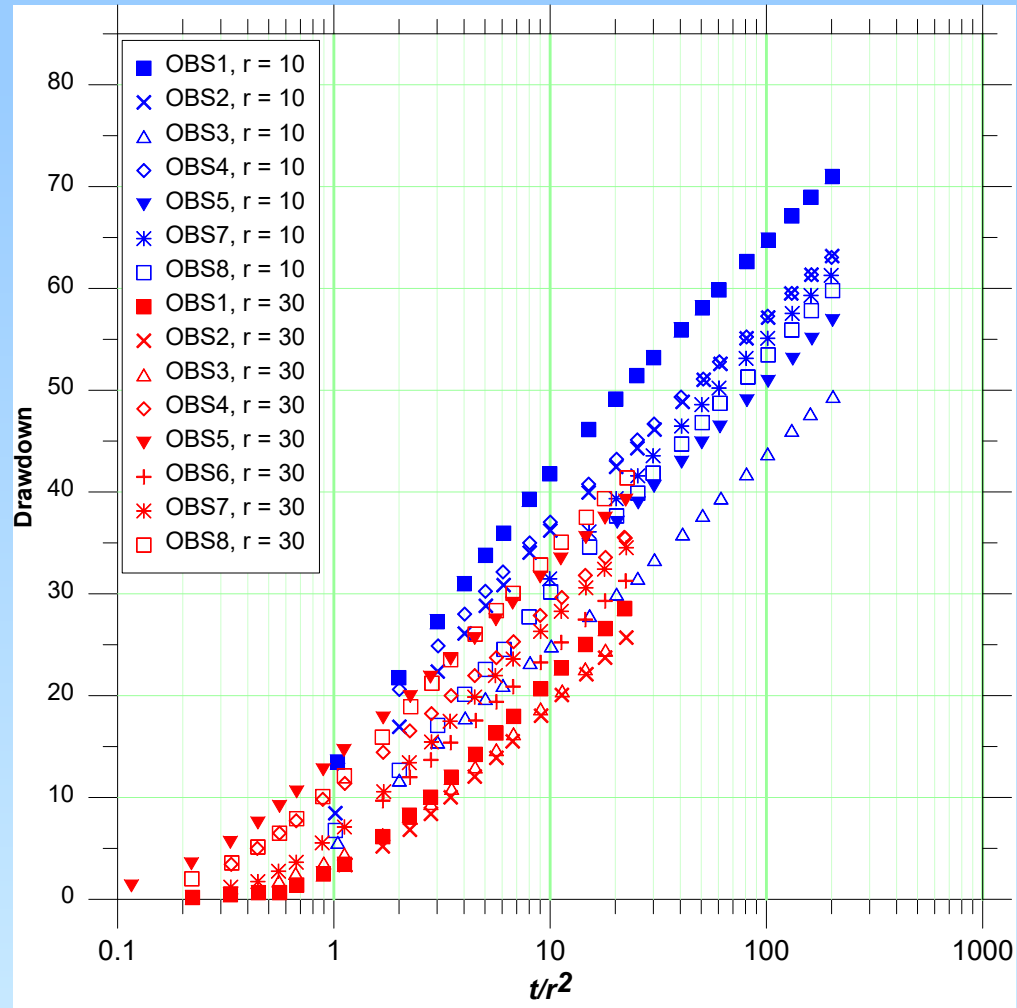
[>> 0.25 of Case 1]

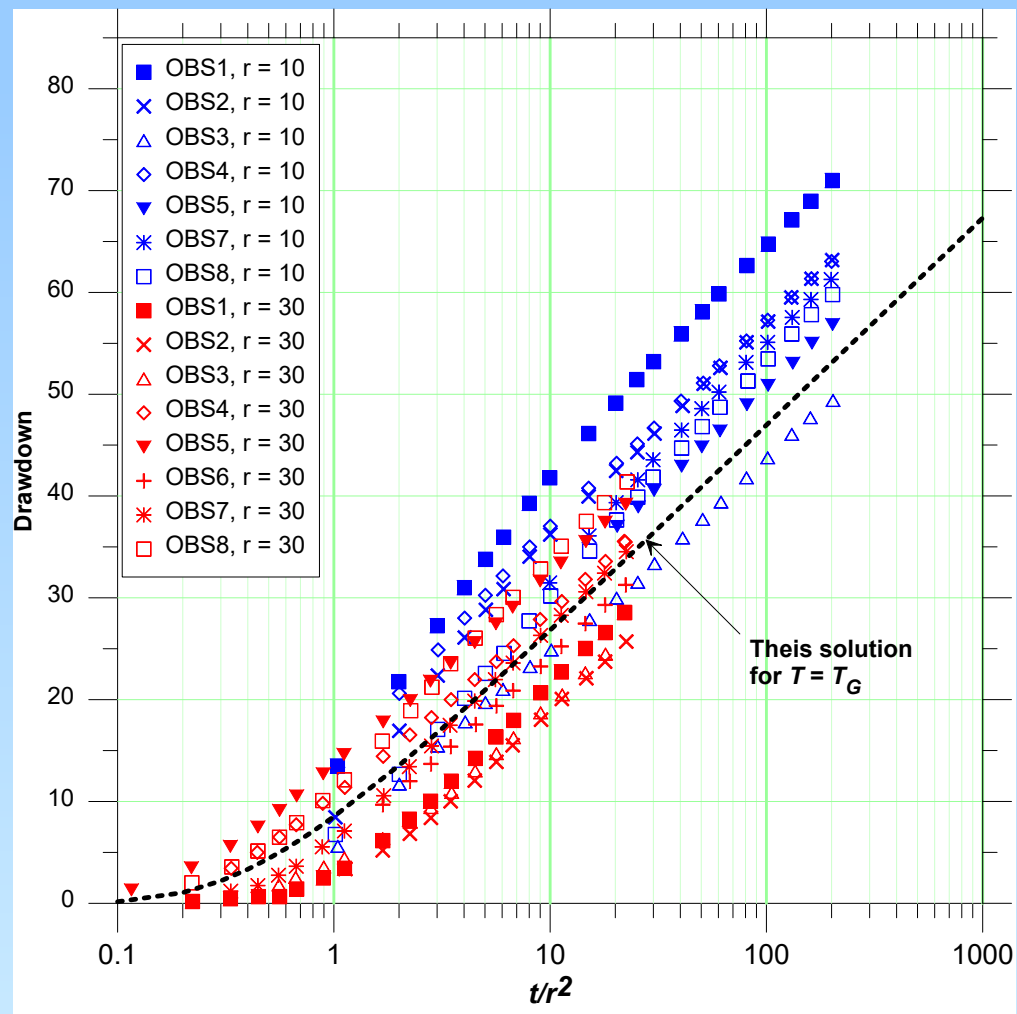


Simulated drawdowns

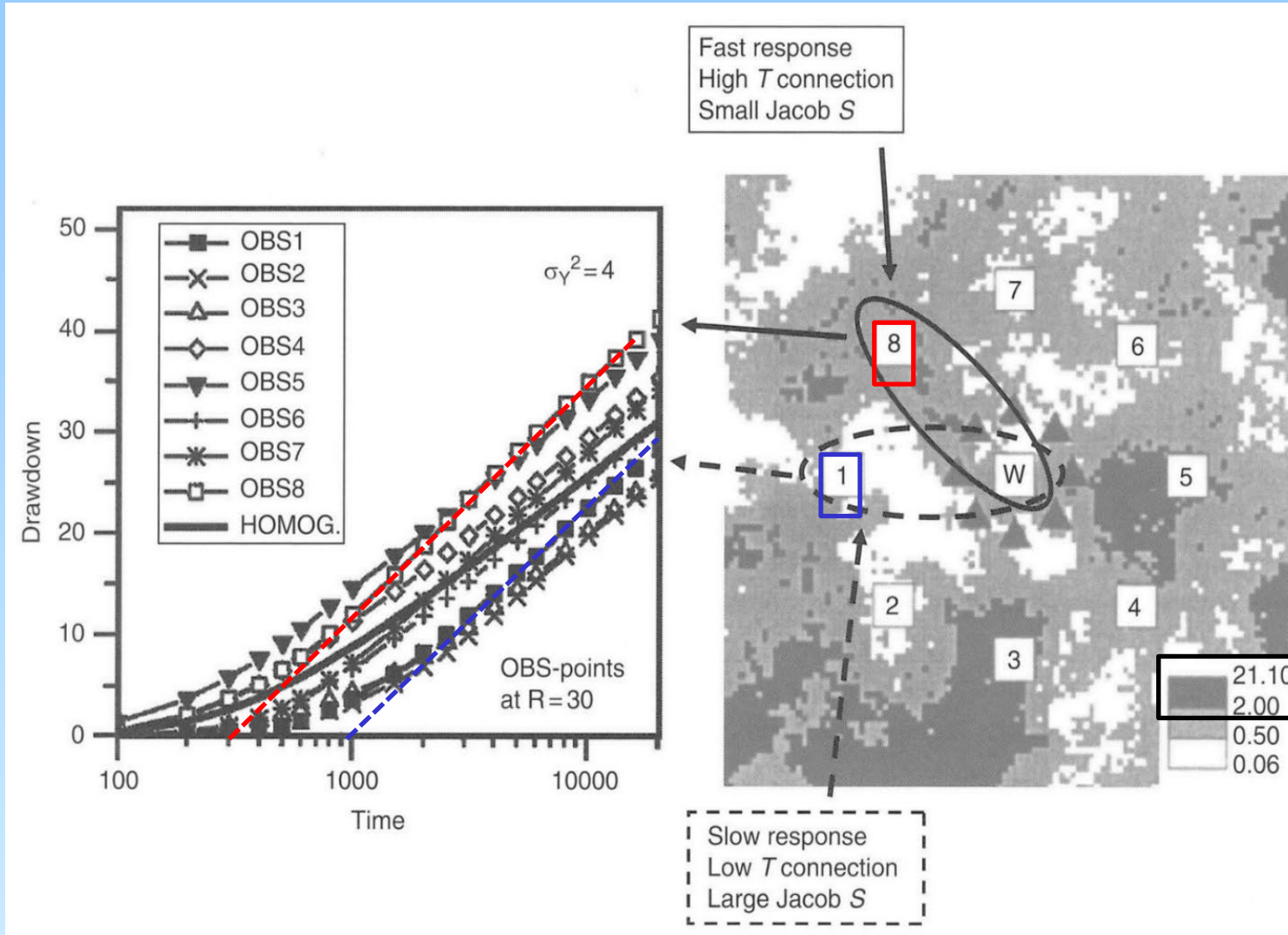


Simulated drawdowns on a composite plot





Inference of hydraulic *connectivity*

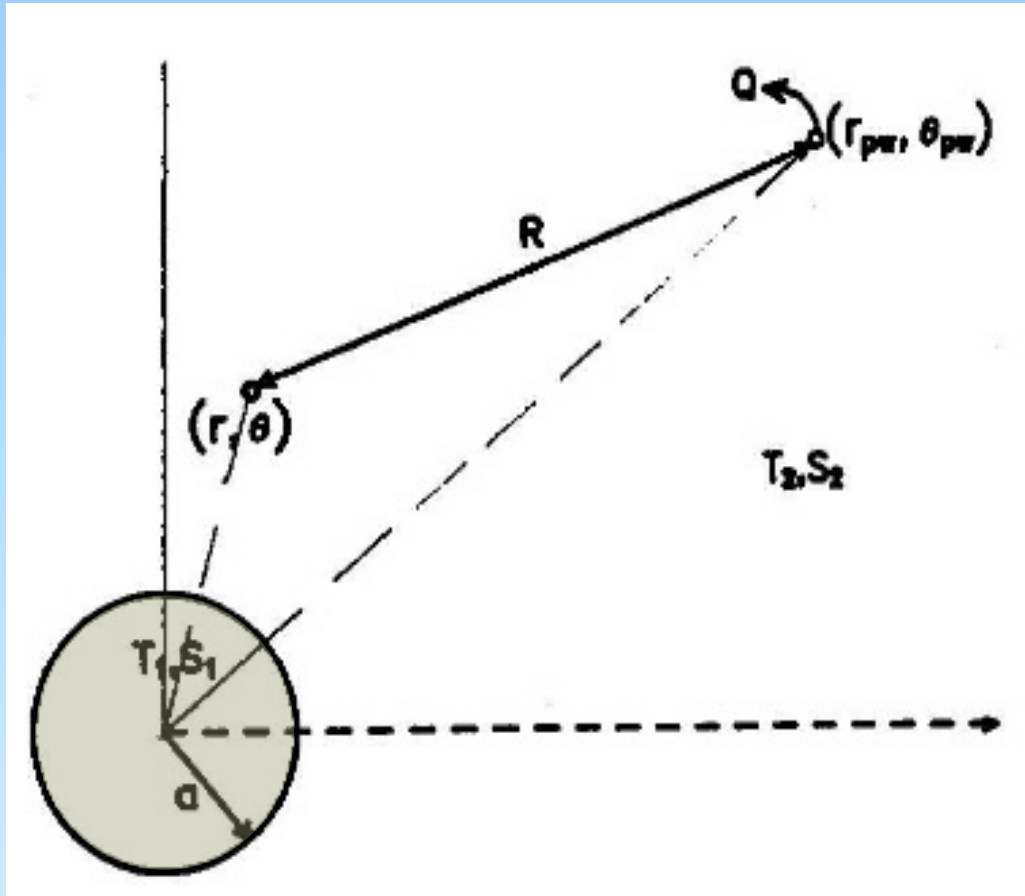


Conceptual model #1

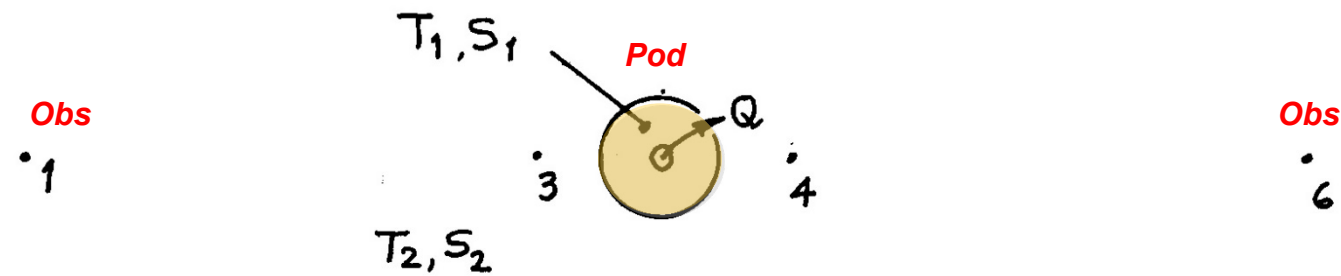
Tentative conclusion:

The results of the Meier and others (1998) simulations suggest that it may be possible to estimate an effective, *bulk-average*, transmissivity from a pumping test in a *homogeneously heterogeneous* aquifer, even for aquifers in which the degree of heterogeneity is relatively large.

Conceptual model #2: Zones of different transmissivity (*pods*) (Butler and Liu, 1993)



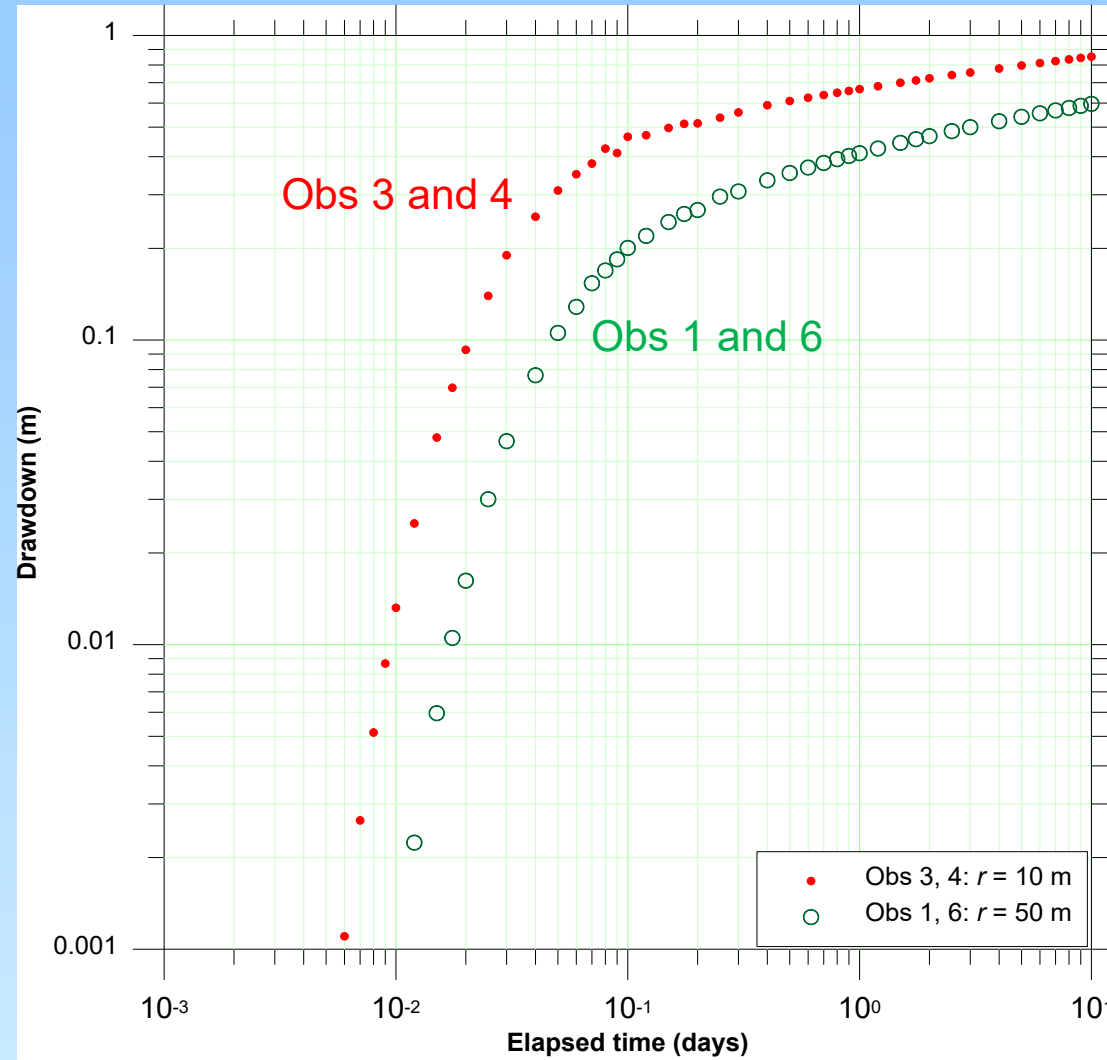
“Pod problem” #1



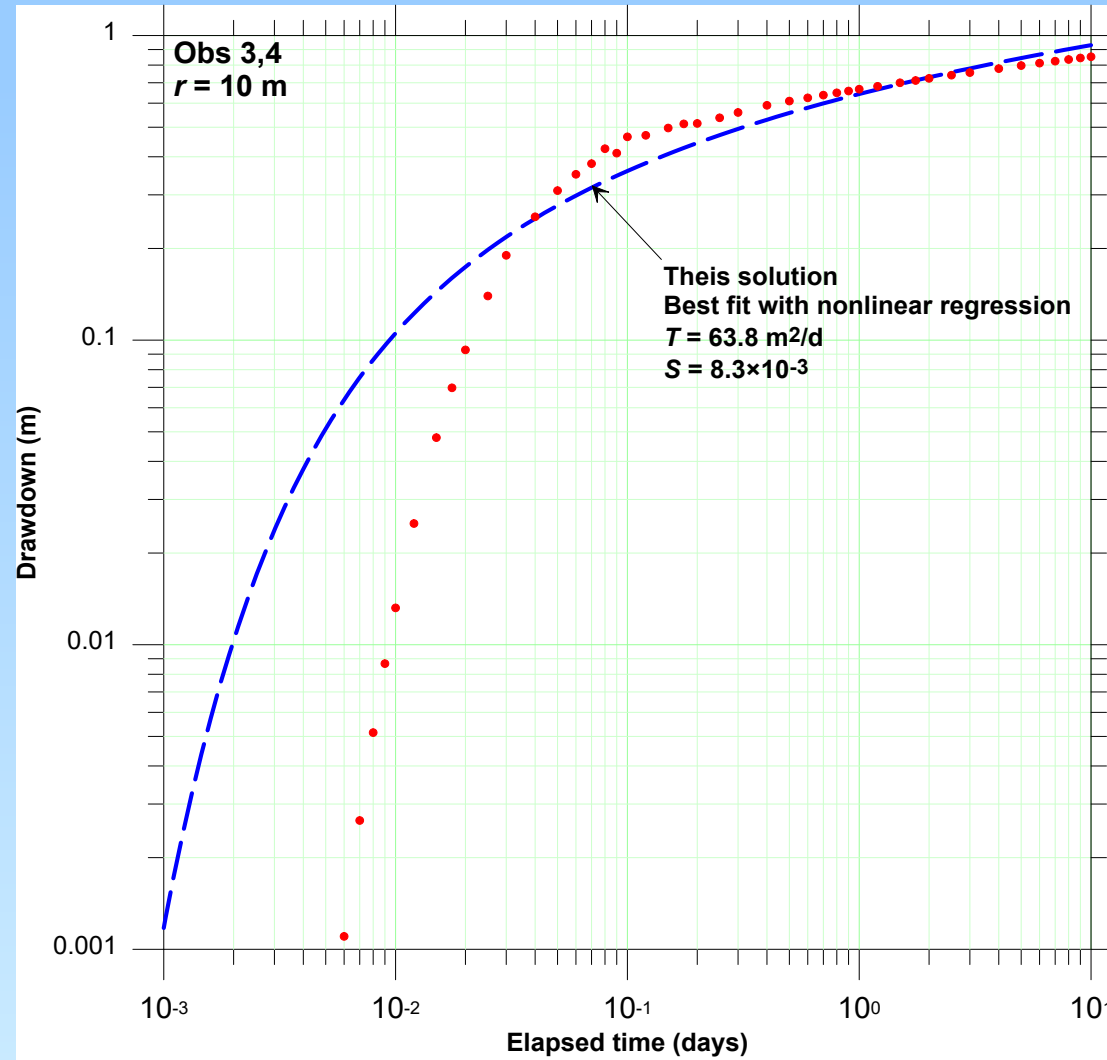
$T_2 = 100 \text{ m}^2/\text{d}$ [formation]

$T_1 = 0.1 \text{ m}^2/\text{d}$ [pod containing the pumping well]

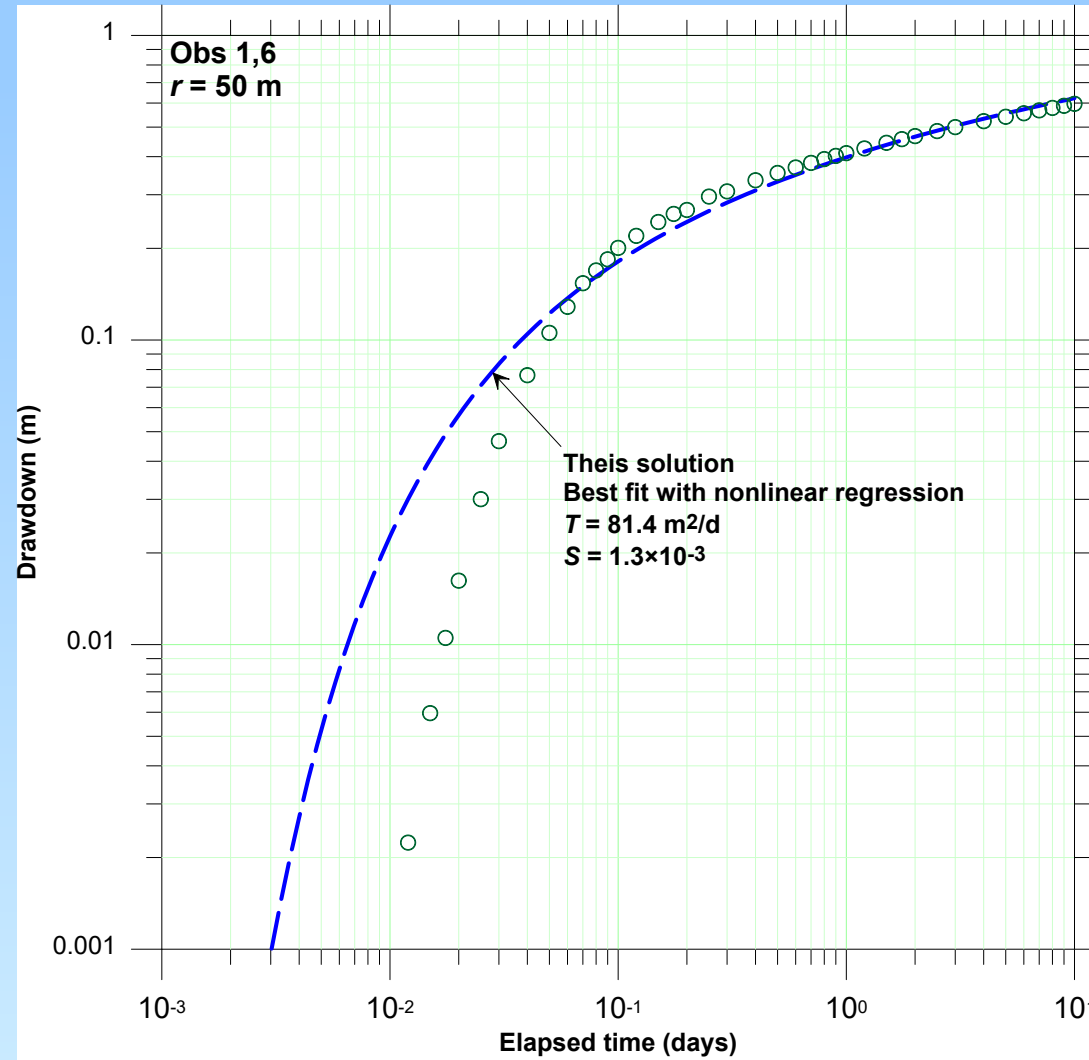
Individual time-drawdown plots



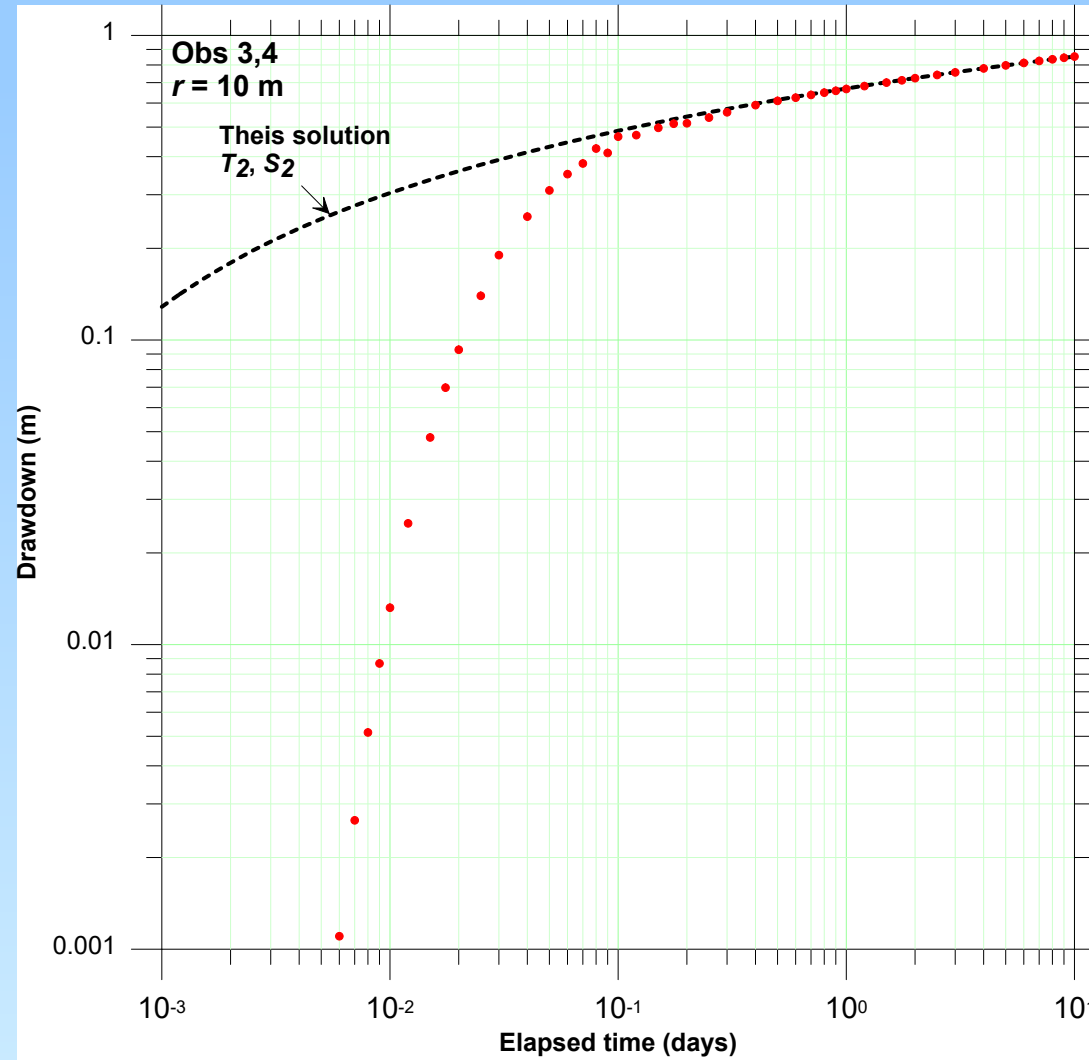
Theis analysis (Naïve approach, Part 1)



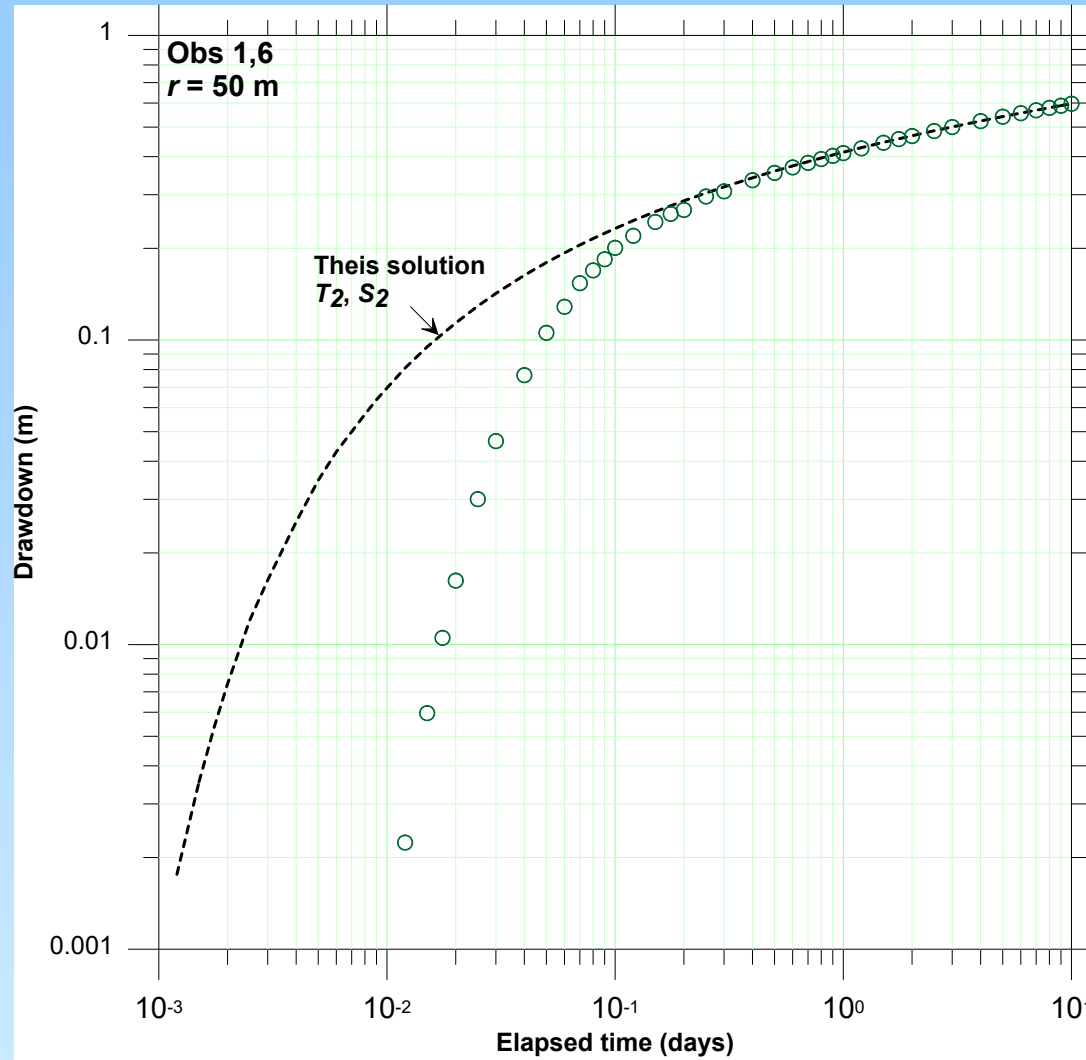
Theis analysis (Naïve approach, Part 2)



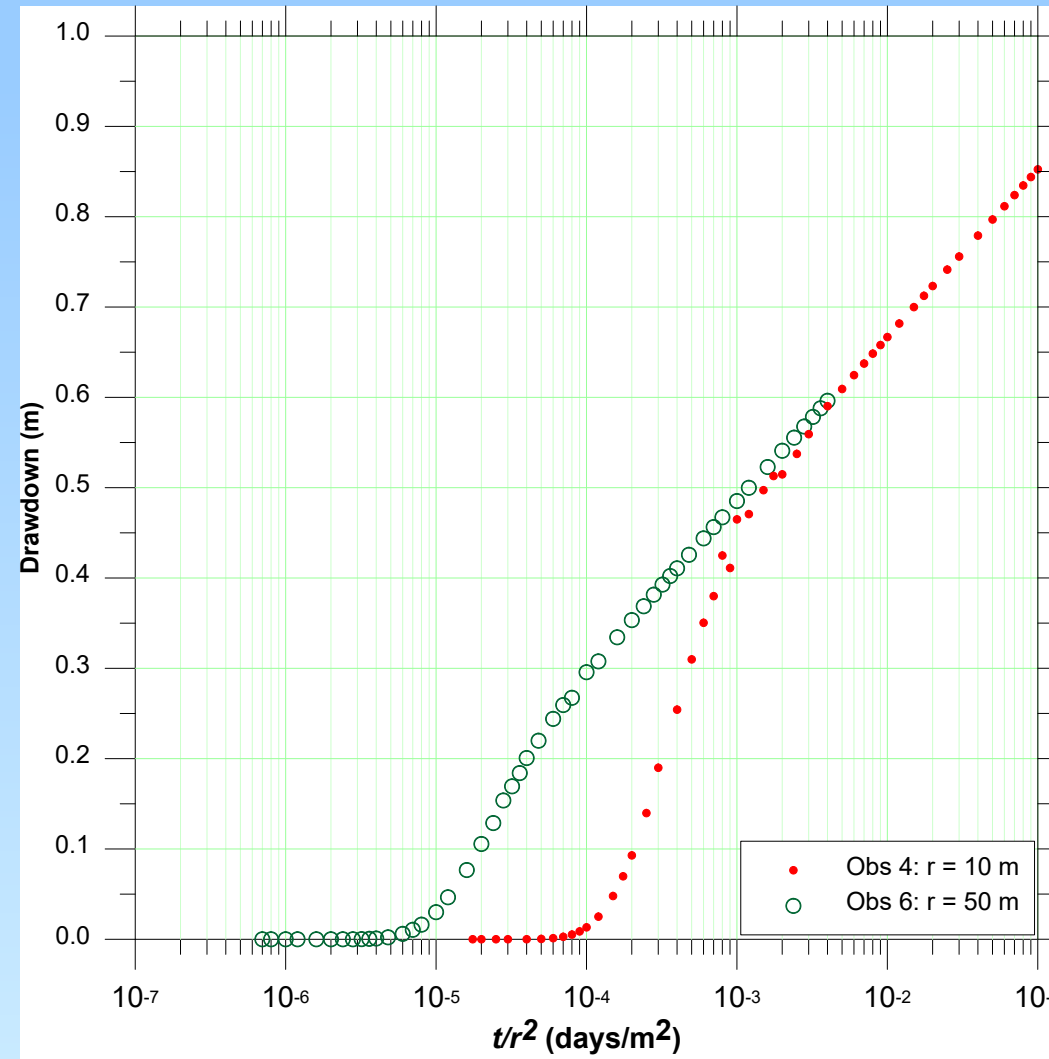
Theis analyses with formation properties (Answer at the back of the book)



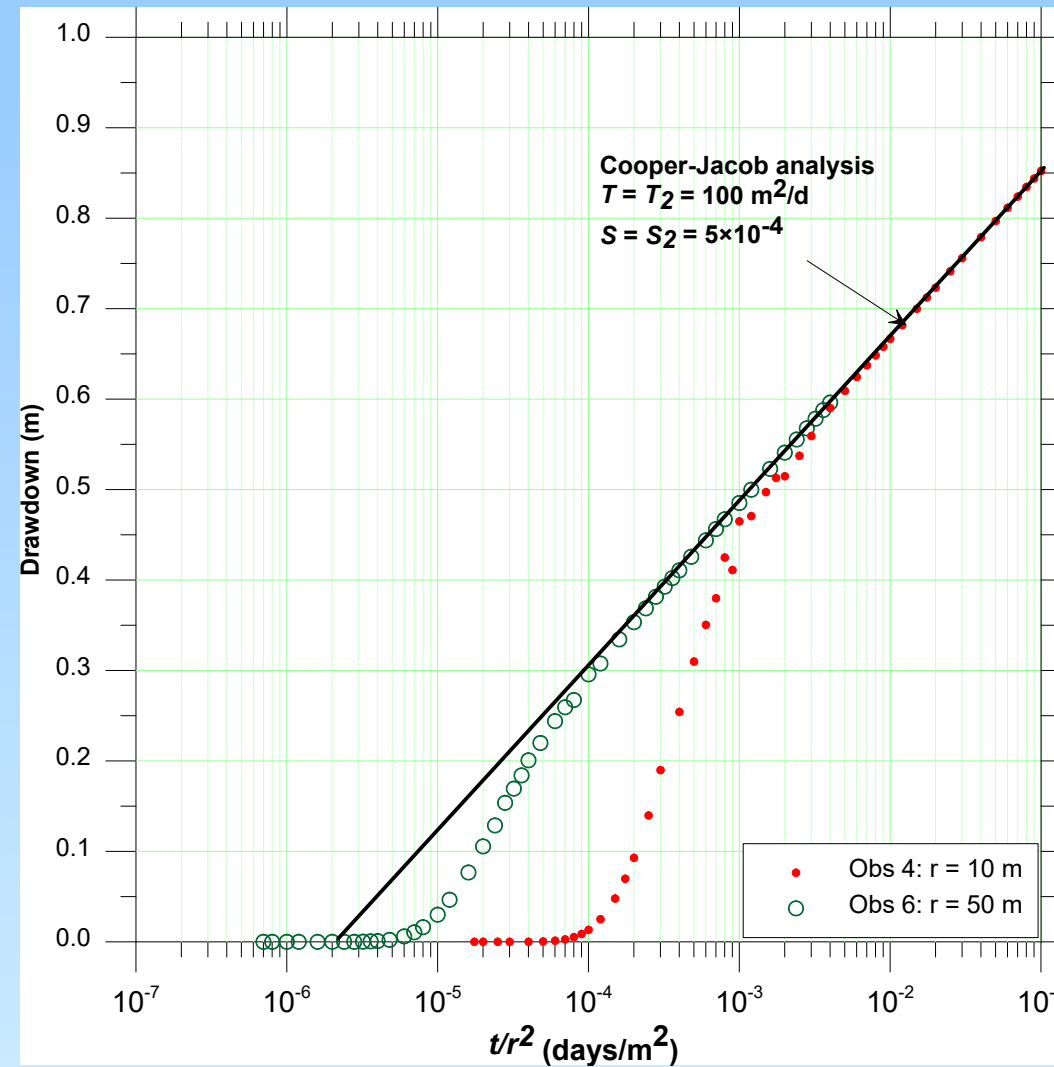
Theis analyses with formation properties (Answer at the back of the book, Part 2)



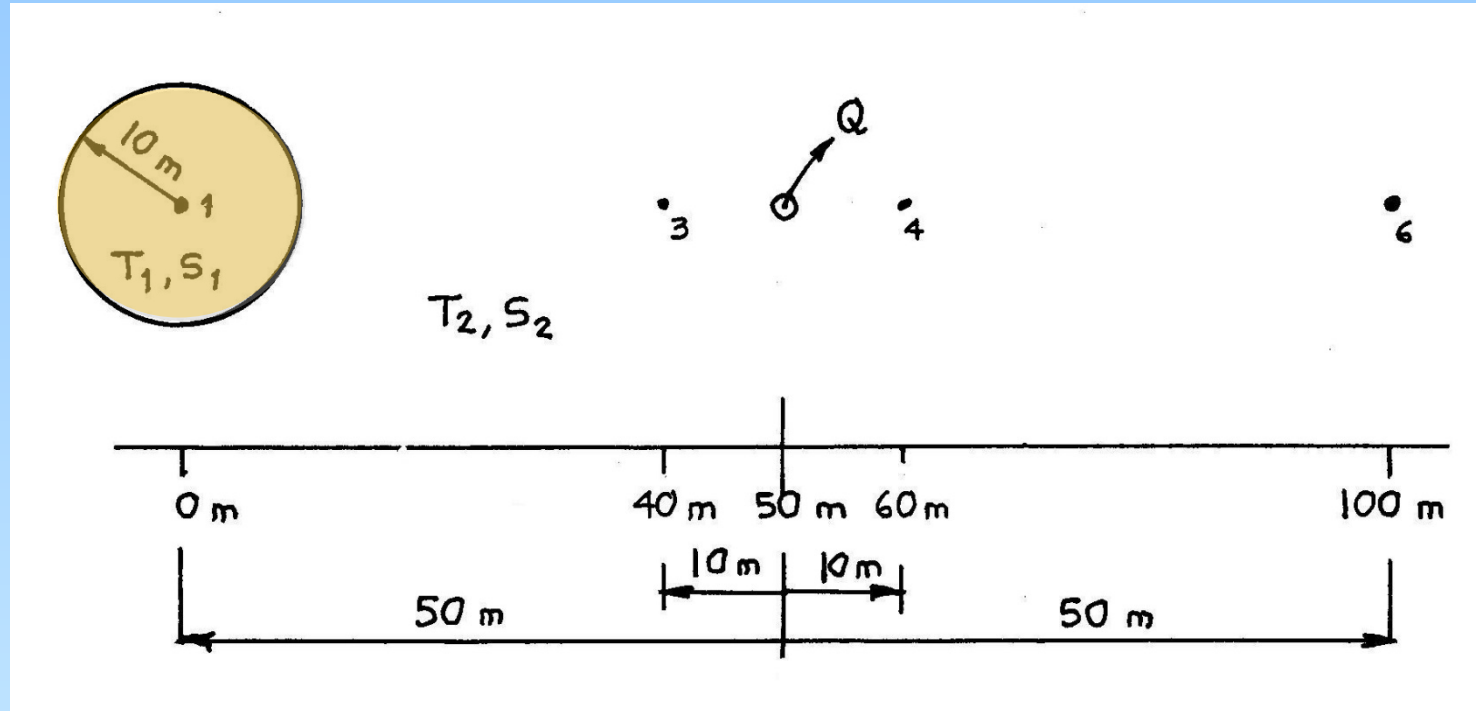
Semilog composite plot



Cooper-Jacob analysis



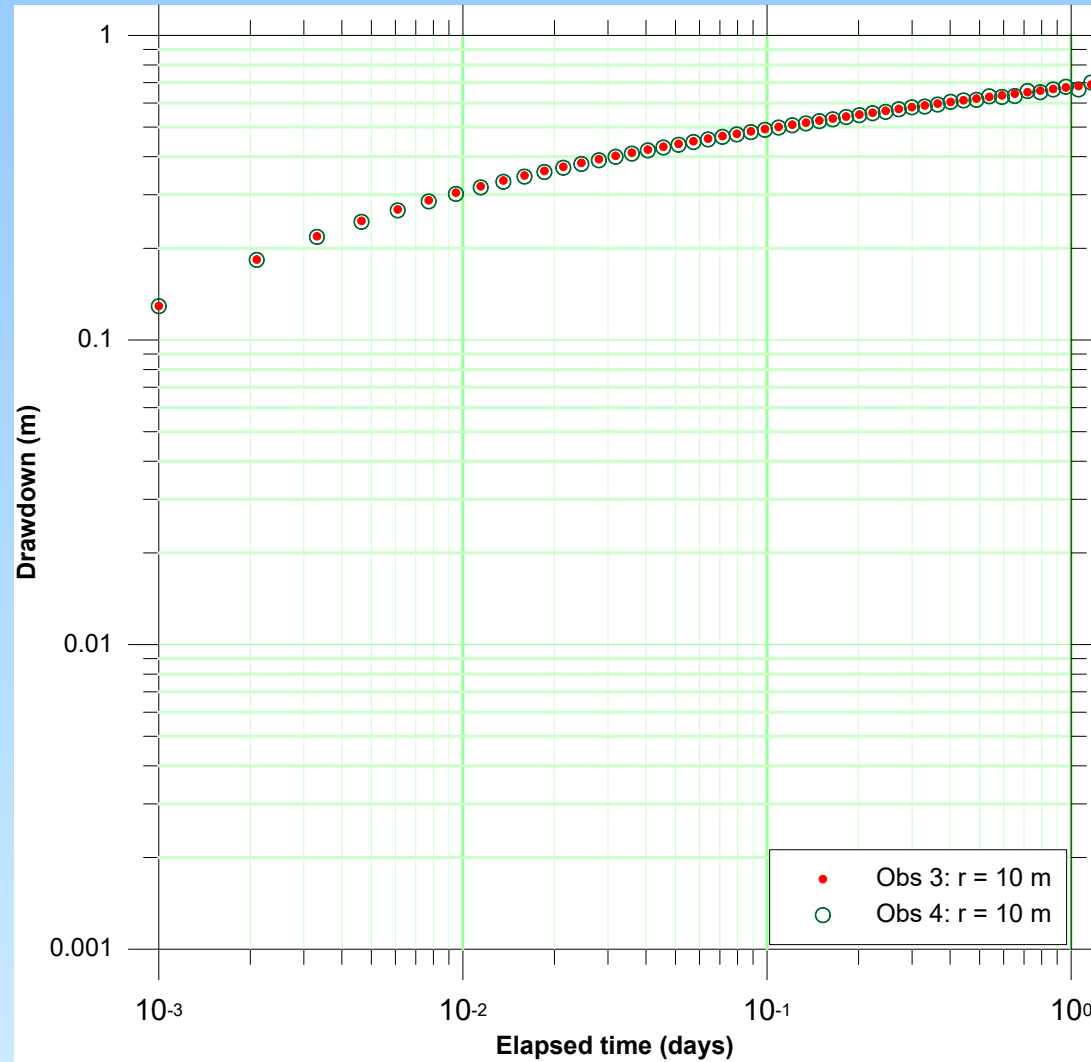
Pod problem #2



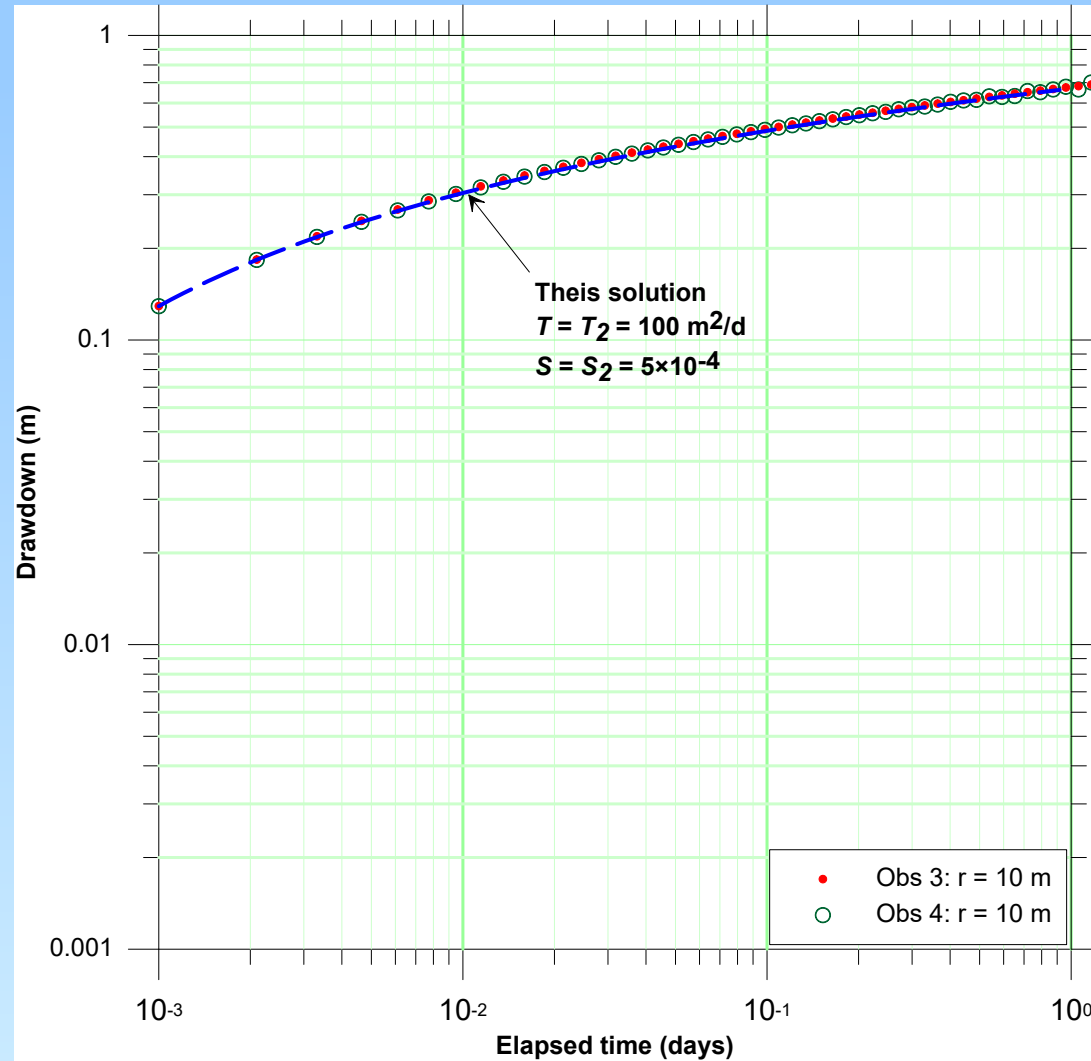
$T_2 = 100 \text{ m}^2/\text{d}$ [formation]

$T_1 = 0.1 \text{ m}^2/\text{d}$ [pod containing Obs. Well #1]

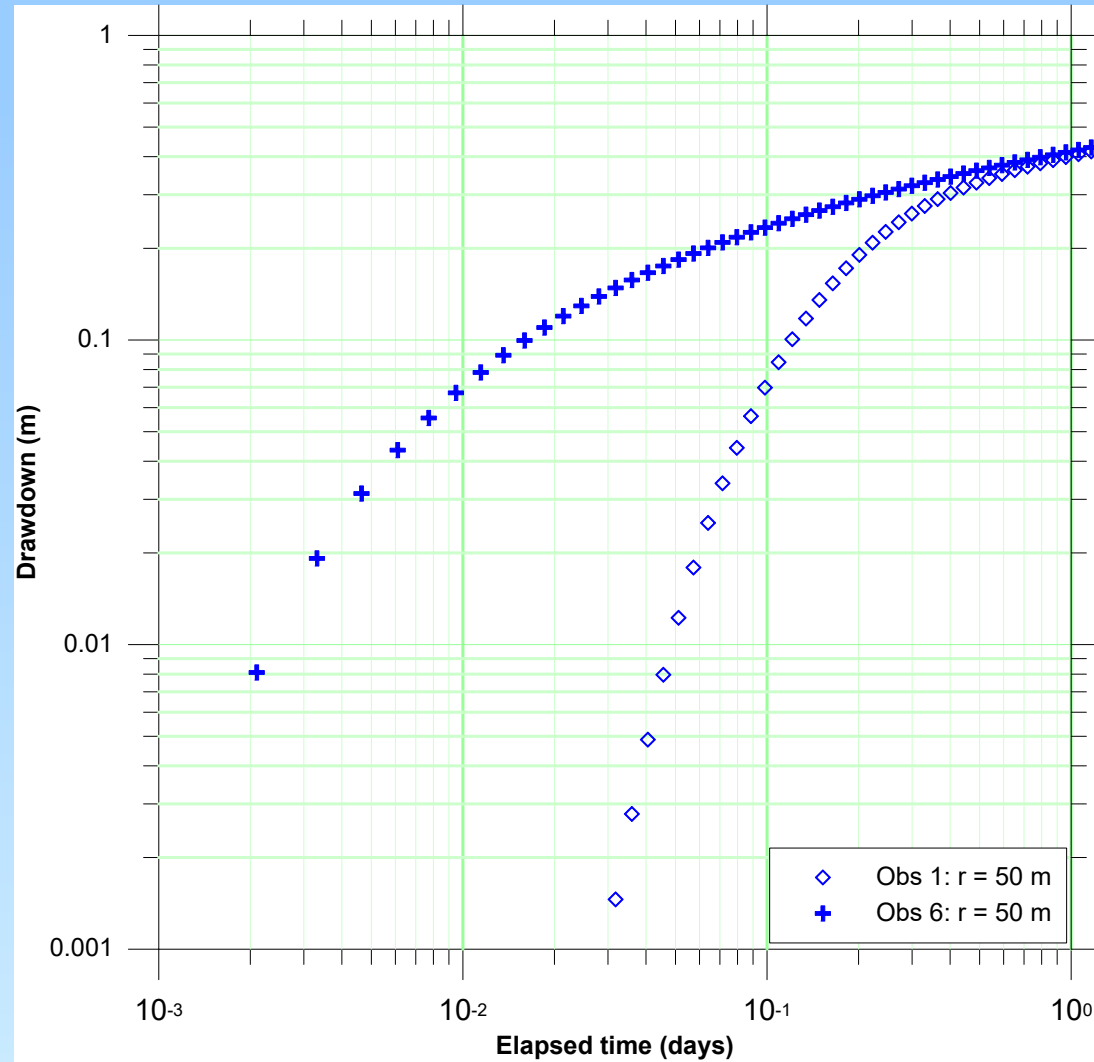
Observation wells at $r = 10$ m



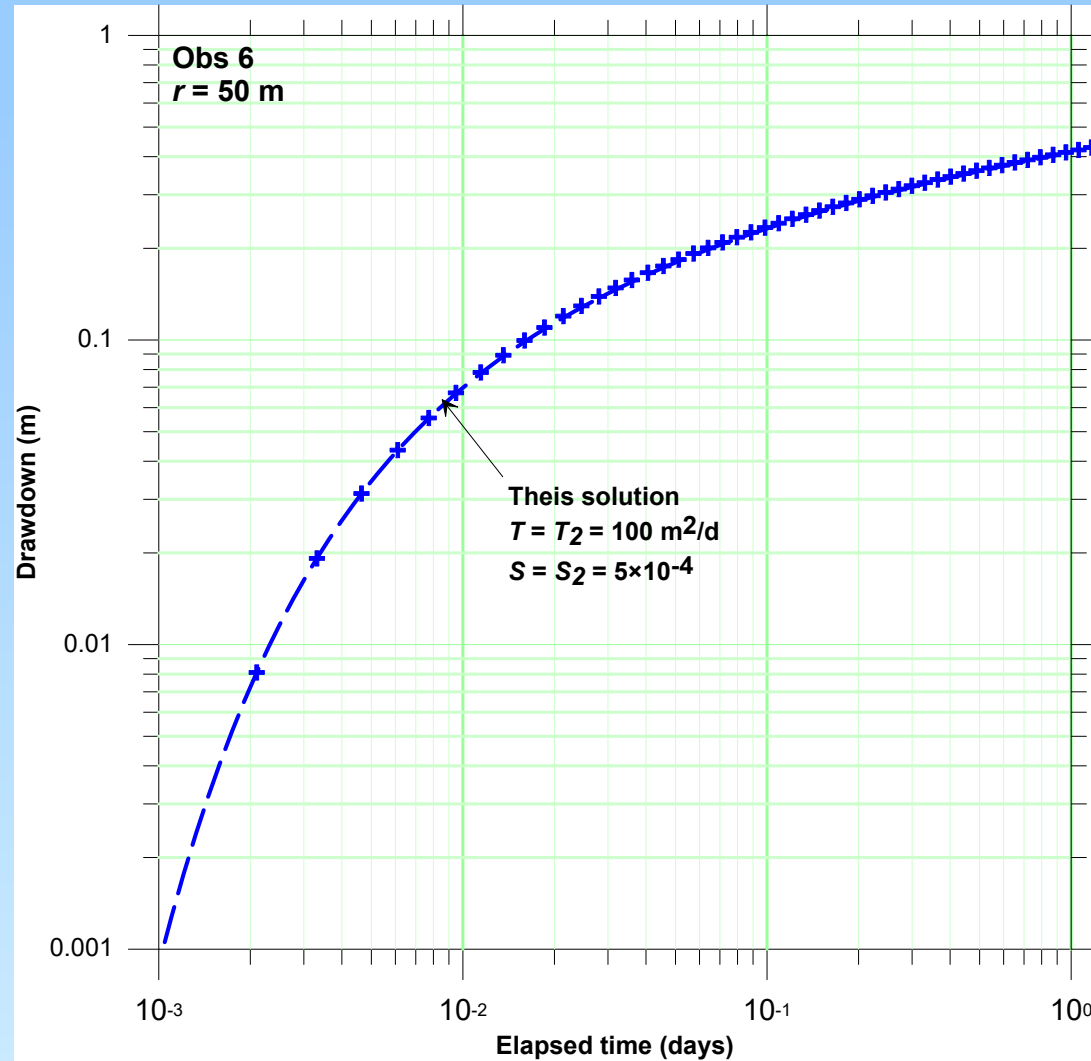
Match to observation wells at $r = 10$ m



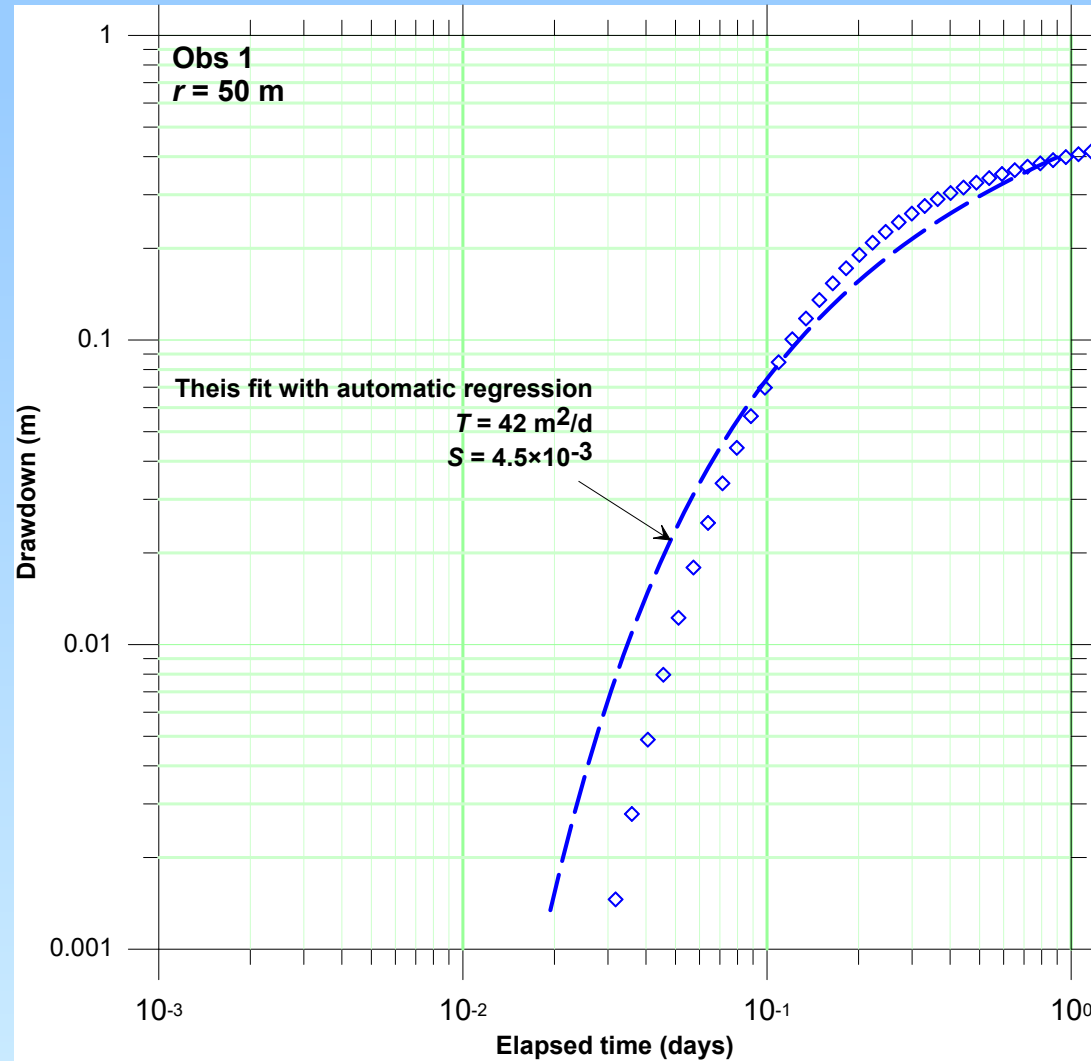
Observation wells at $r = 50$ m



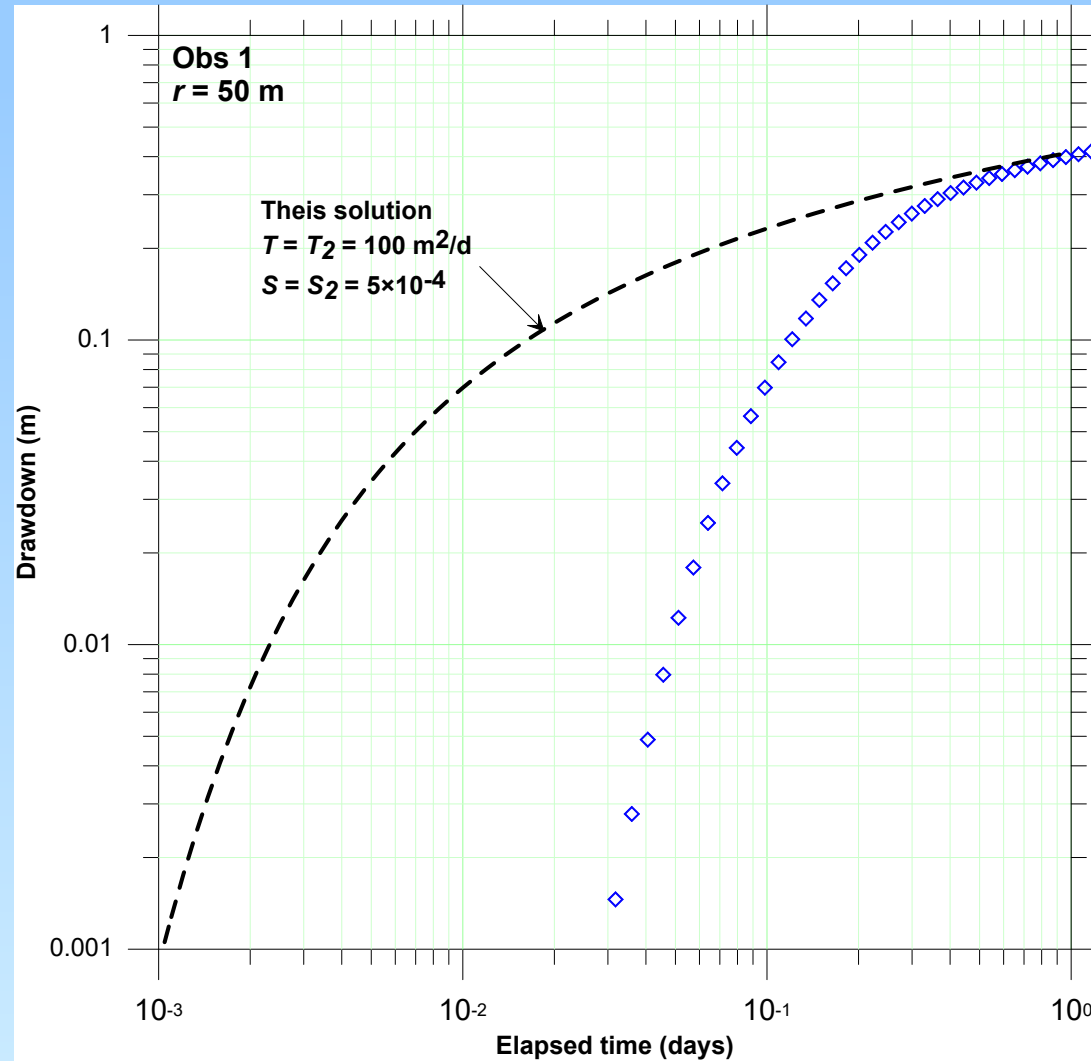
Match to observation well Obs 6



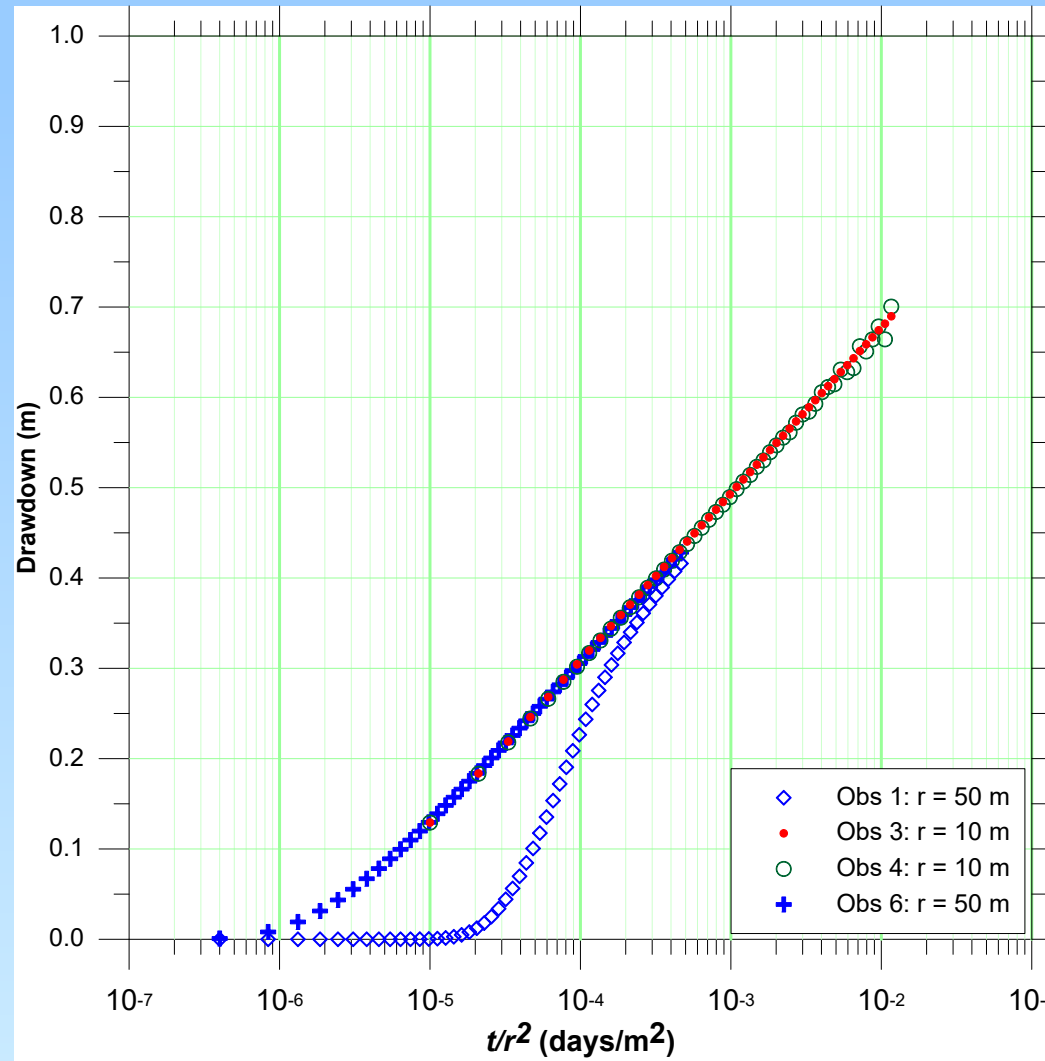
Match to observation well Obs 1



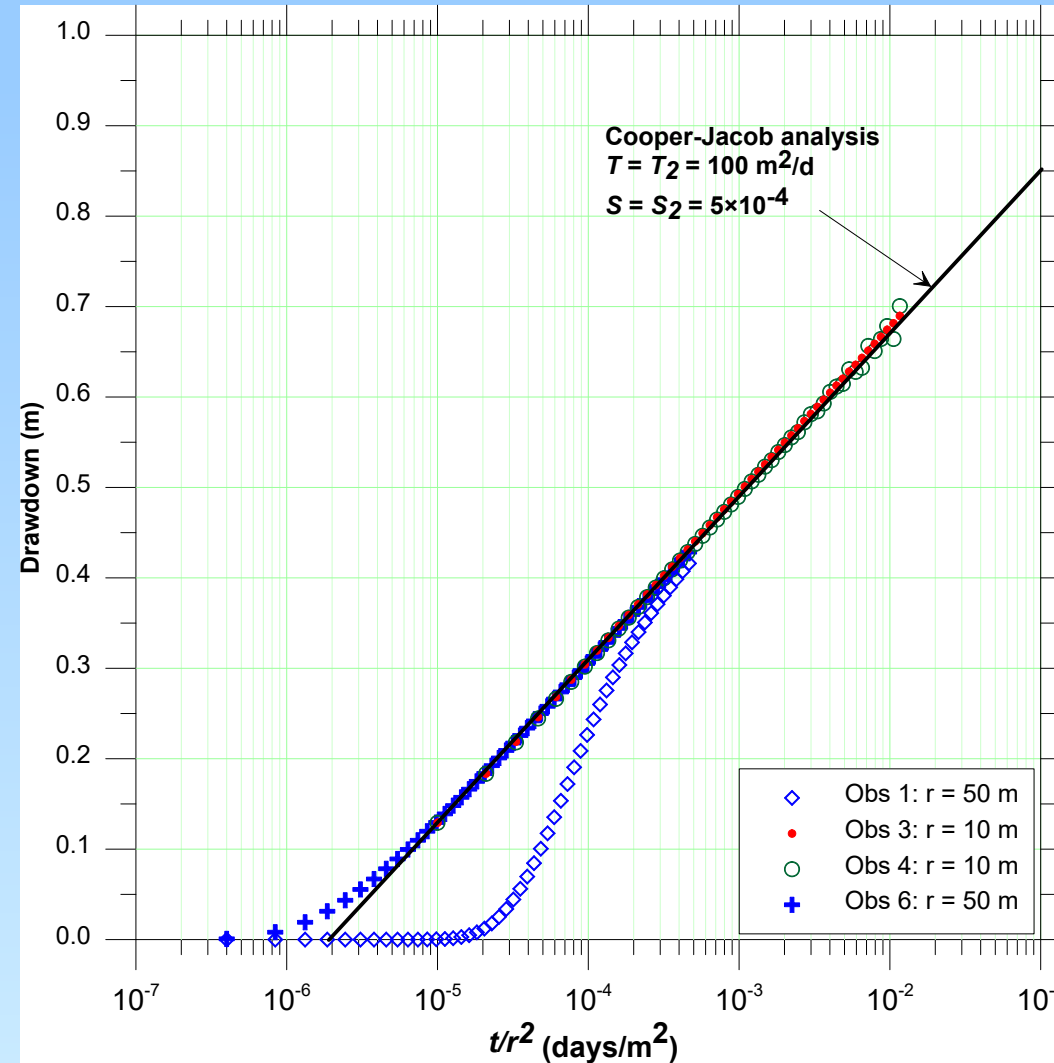
Obs 1: Theis model, formation properties



Semilog composite plot



Cooper-Jacob analysis



Conceptual model #2

Pumping tests in aquifers with discrete zones

Tentative conclusion

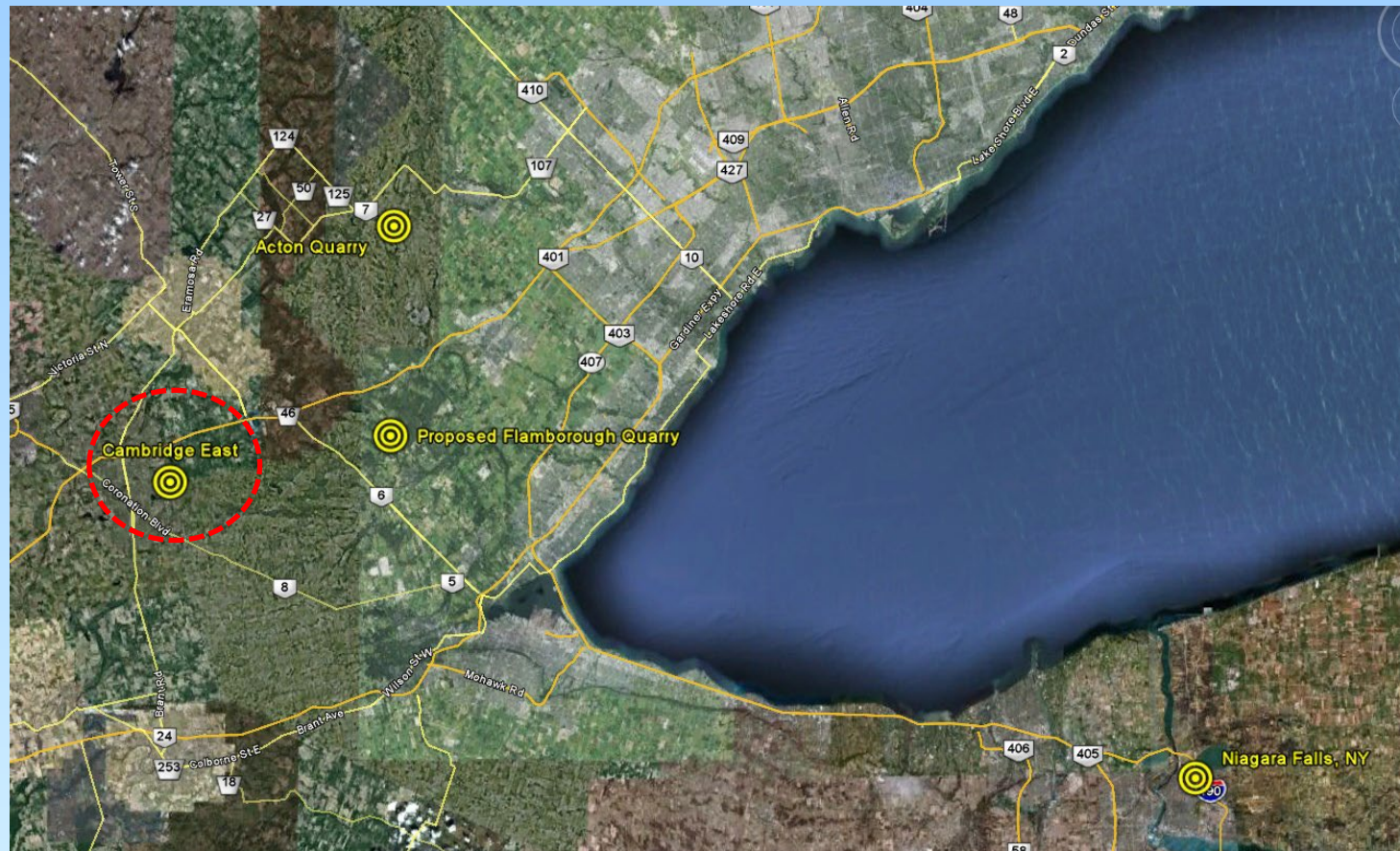
In aquifers that contain distinct zones it may be possible to take advantage of the strengths of the Cooper-Jacob composite analysis to identify the portion of the response that is representative of bulk-average radial flow, and to estimate a representative transmissivity from that portion of the data.

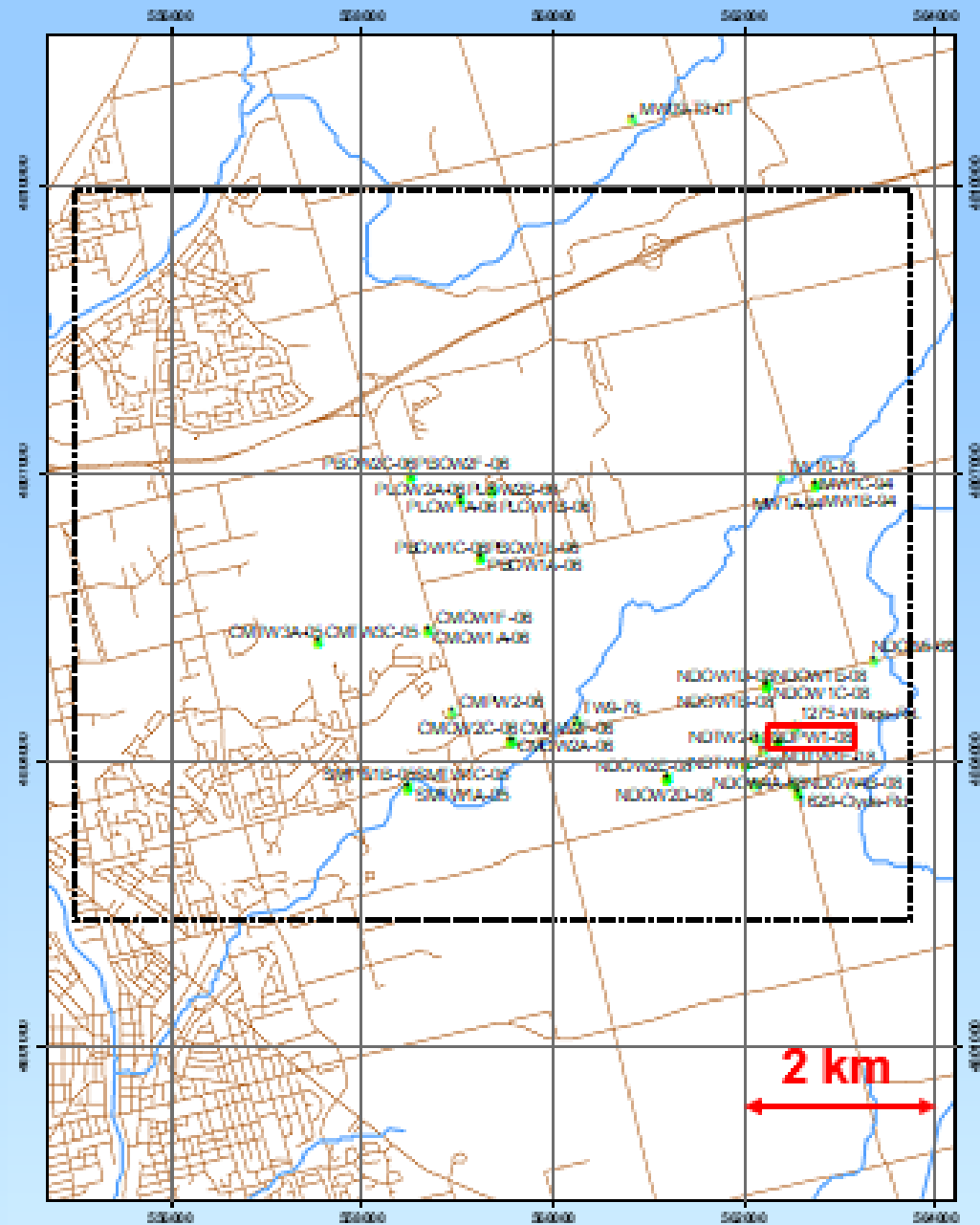
Take home points

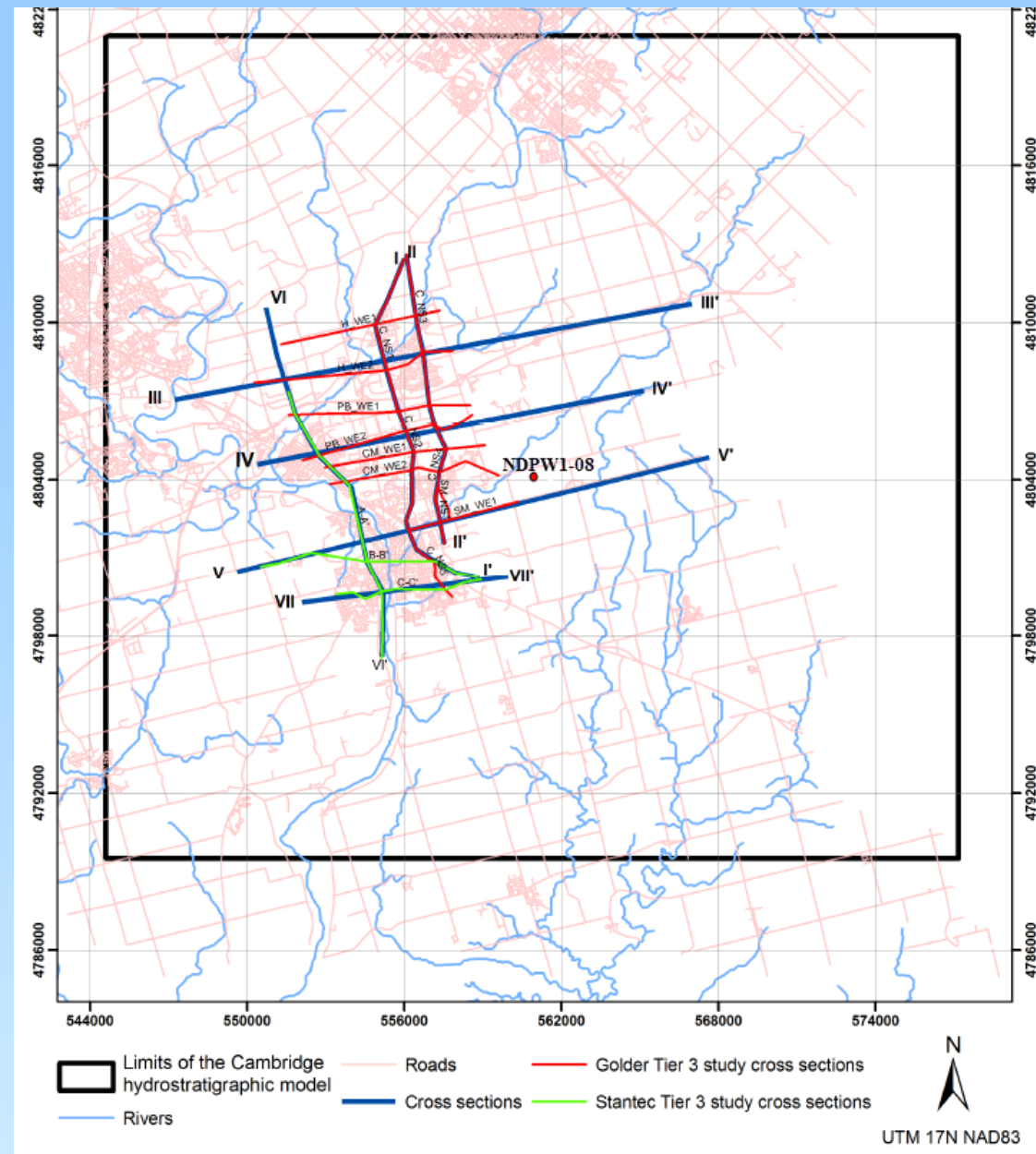
- Real aquifers are heterogeneous, but models of pumping tests are generally founded on the assumption of *homogeneity*.
- The composite plot is the appropriate starting point for the interpretation of pumping tests with multiple observation wells in heterogeneous aquifers.
- The composite plotting approach directs analysts to the recognition of the effects of heterogeneity and to the estimation of a bulk-average transmissivity.

Case study: NDPW1-08

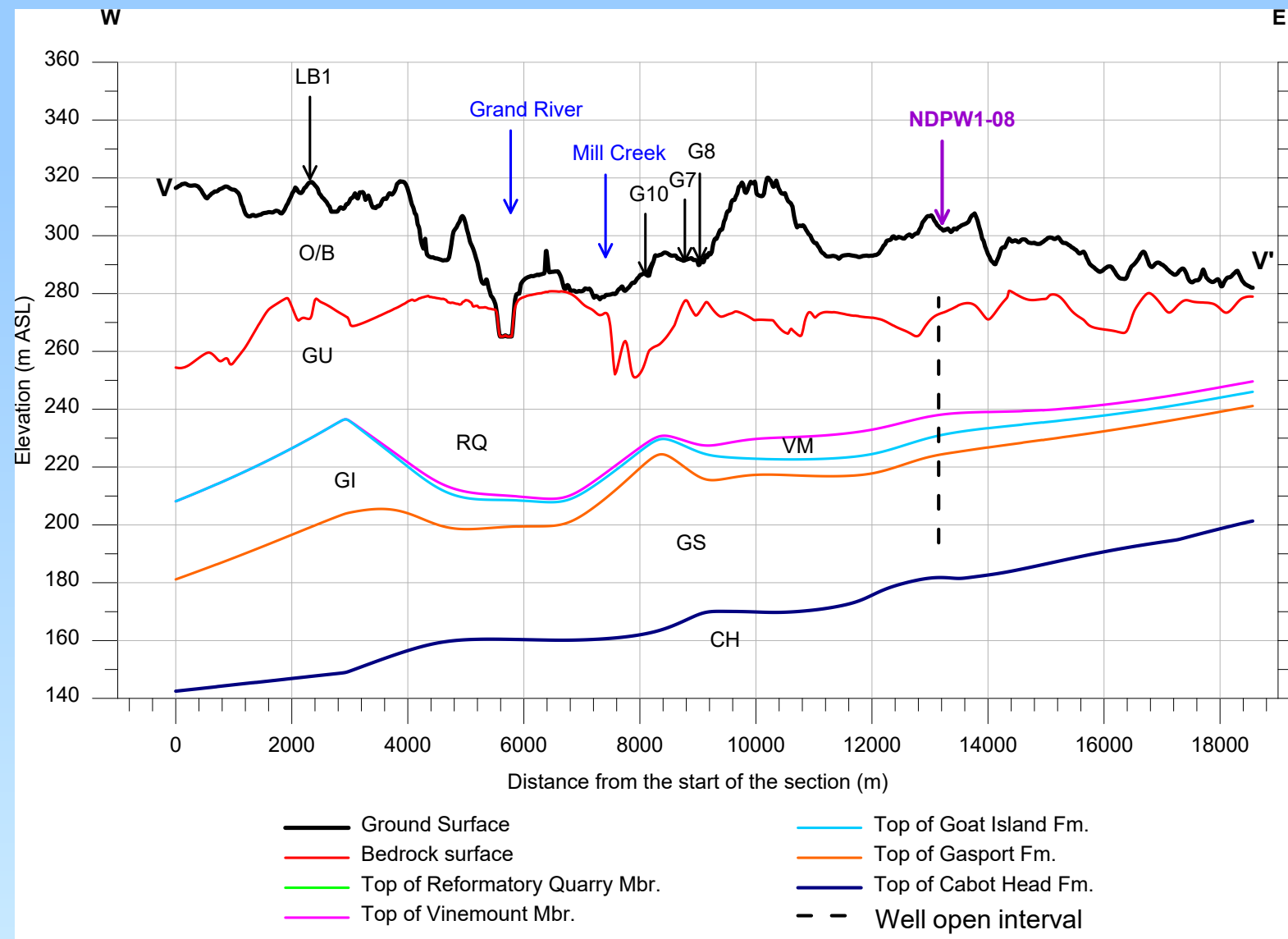
Testing of potential new municipal production well Cambridge, Ontario



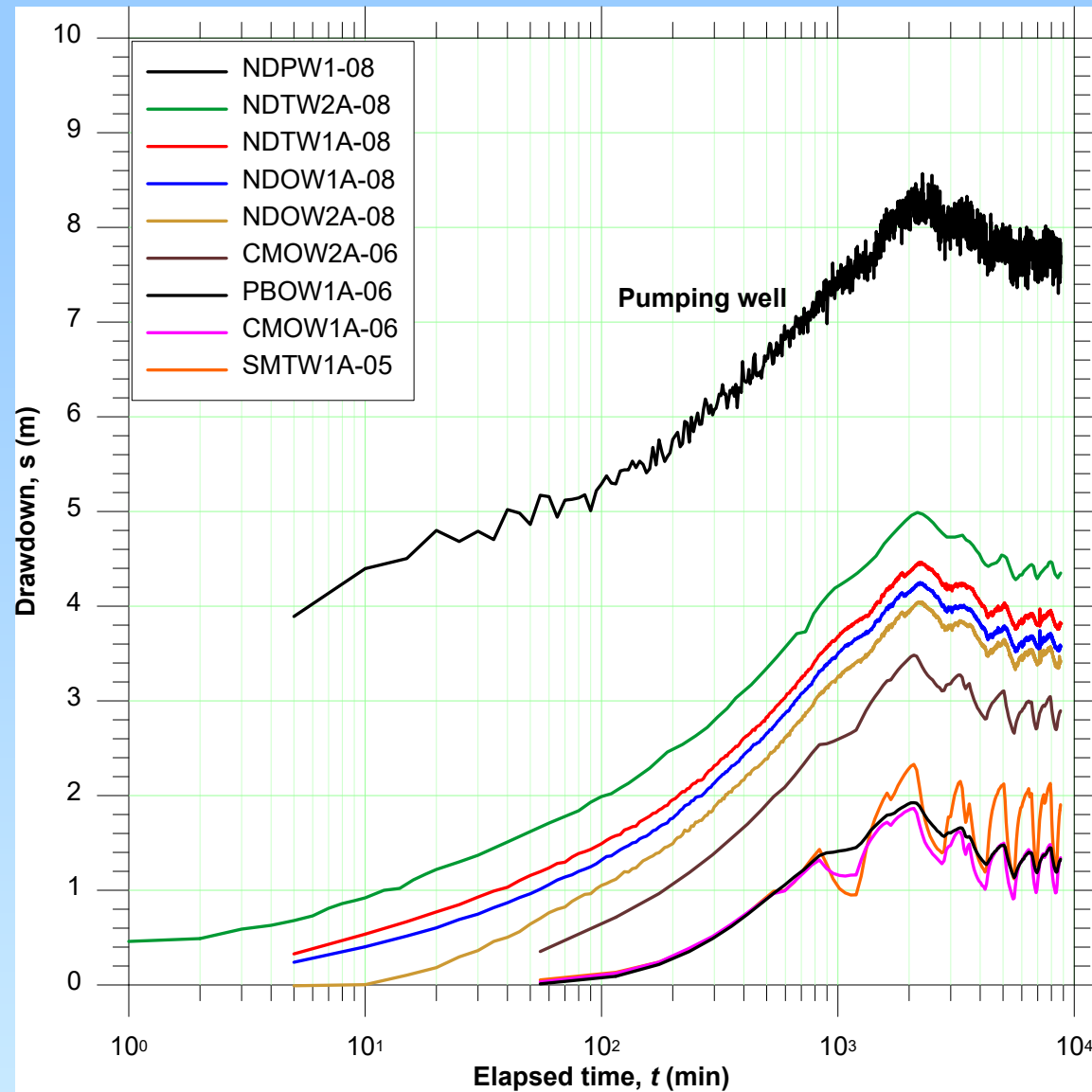




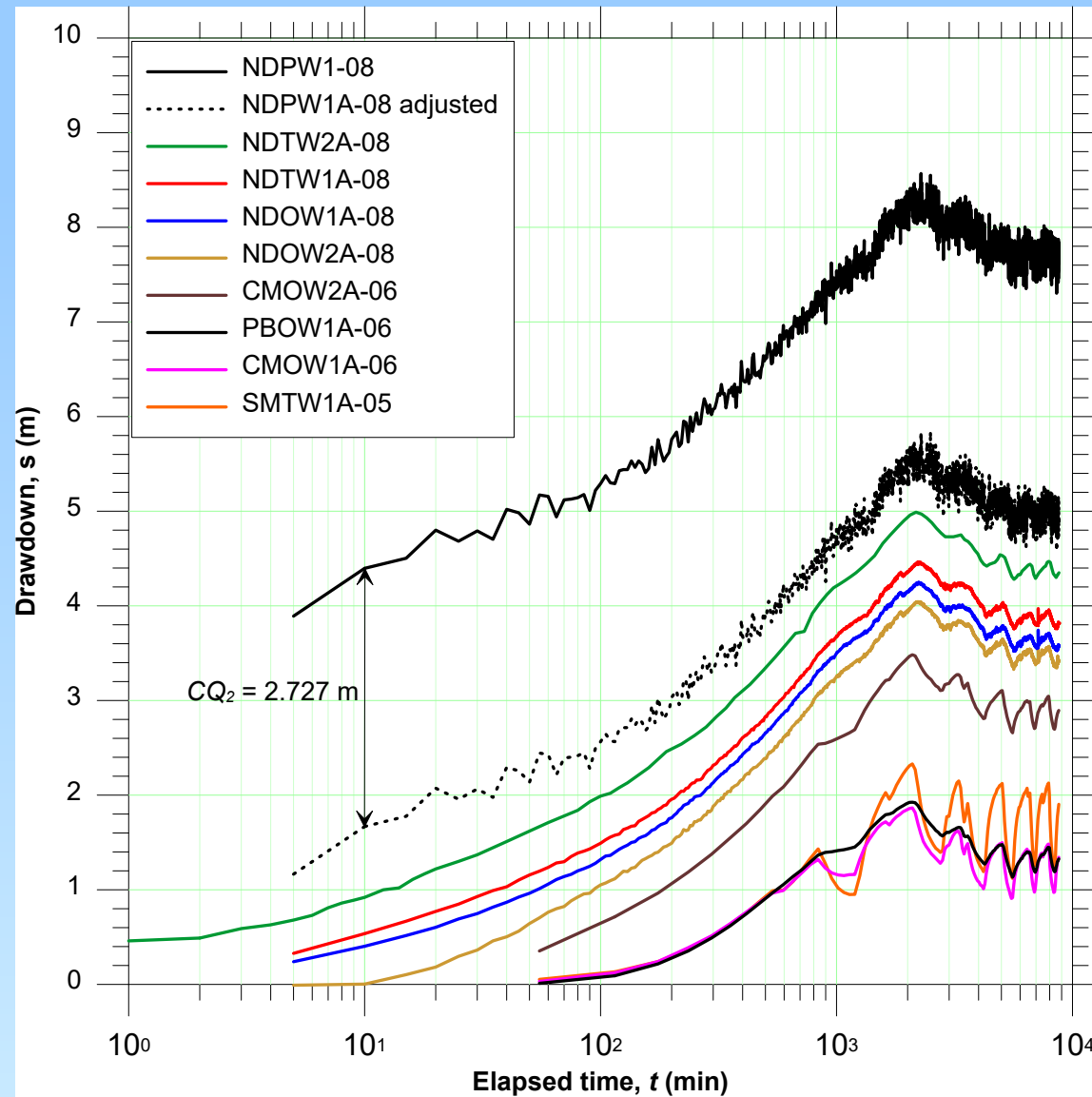
Stratigraphy



Time-drawdown plots

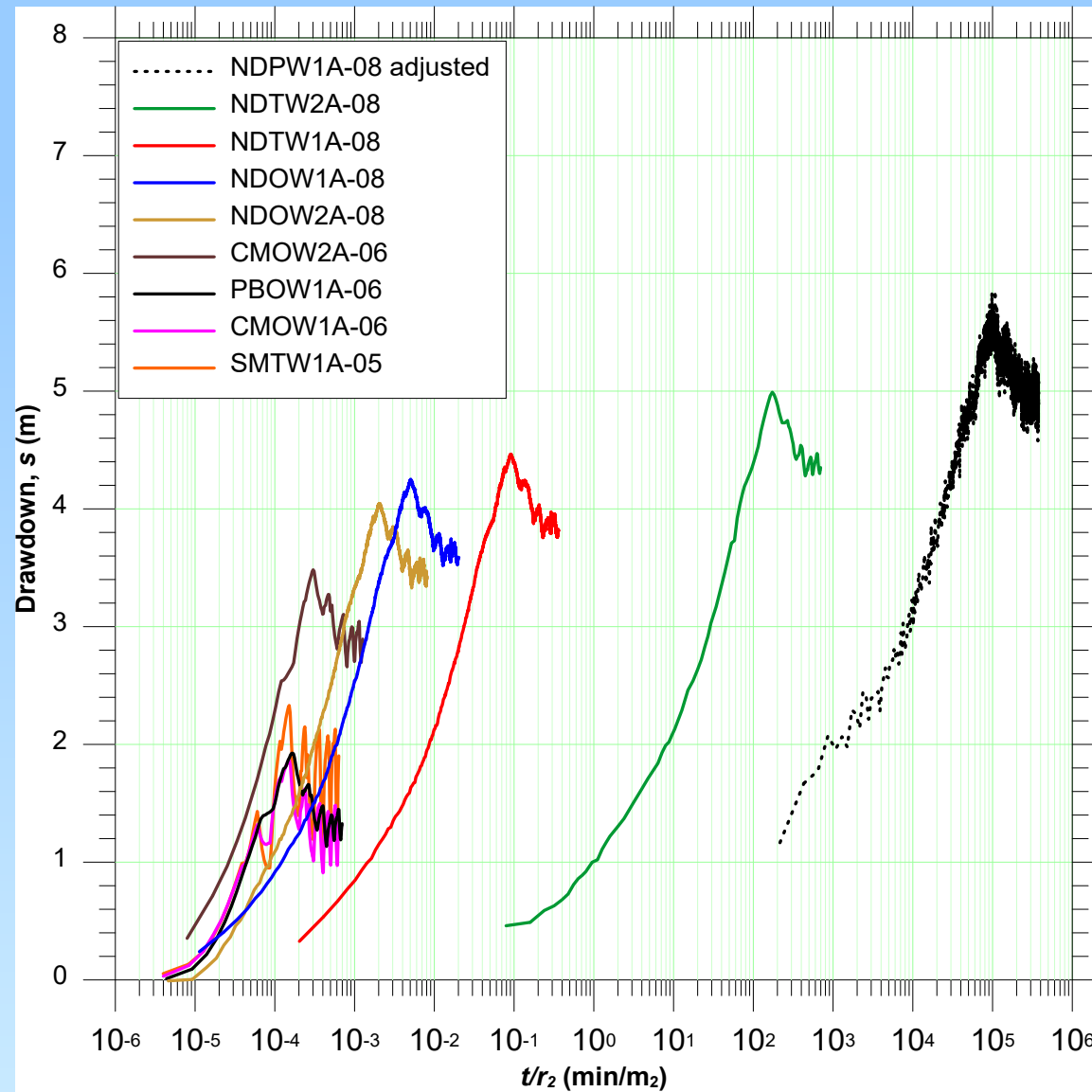


Time-drawdown plots (2)

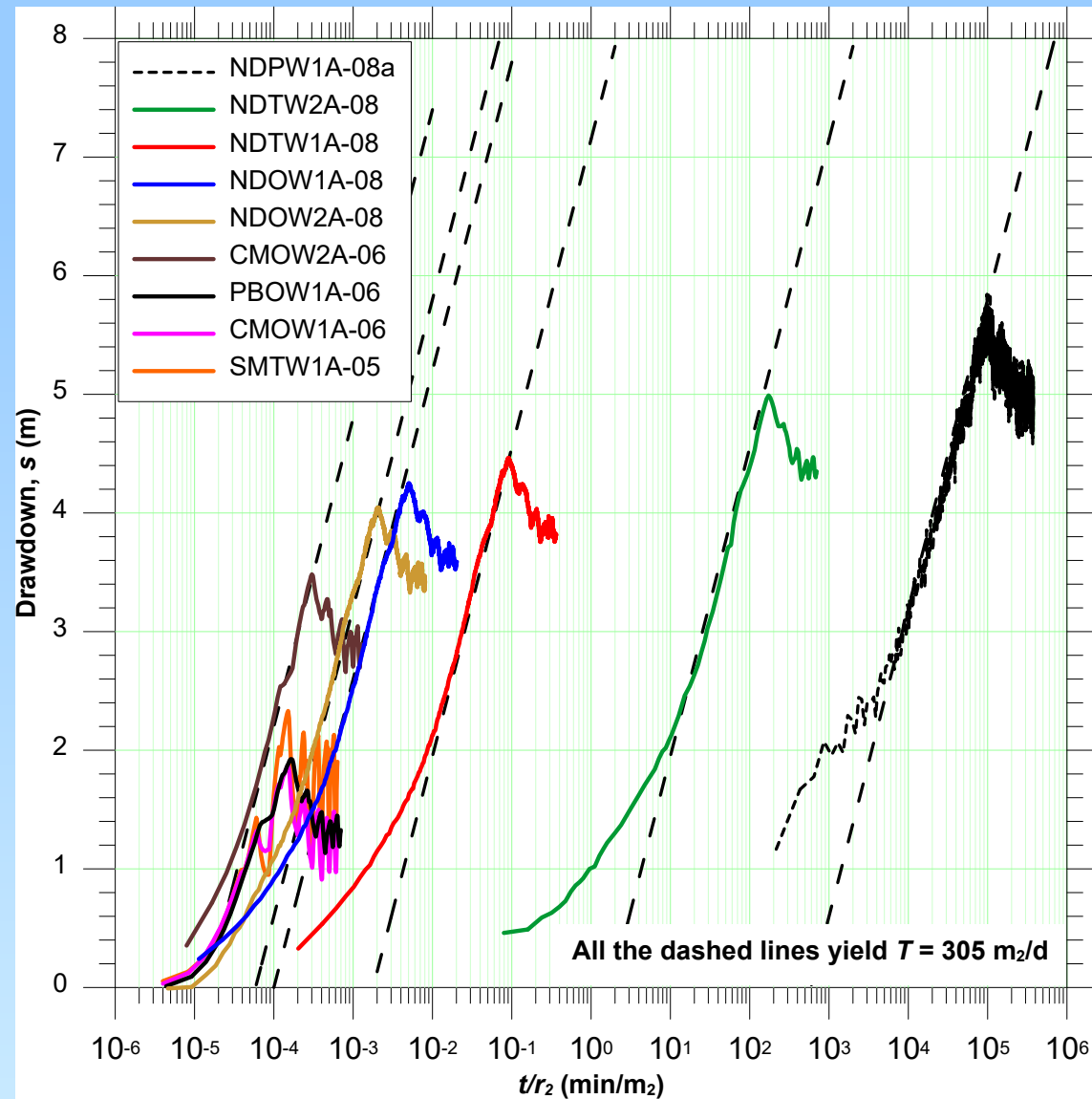


Pumping well drawdowns adjusted for nonlinear well losses with the results of a step test.

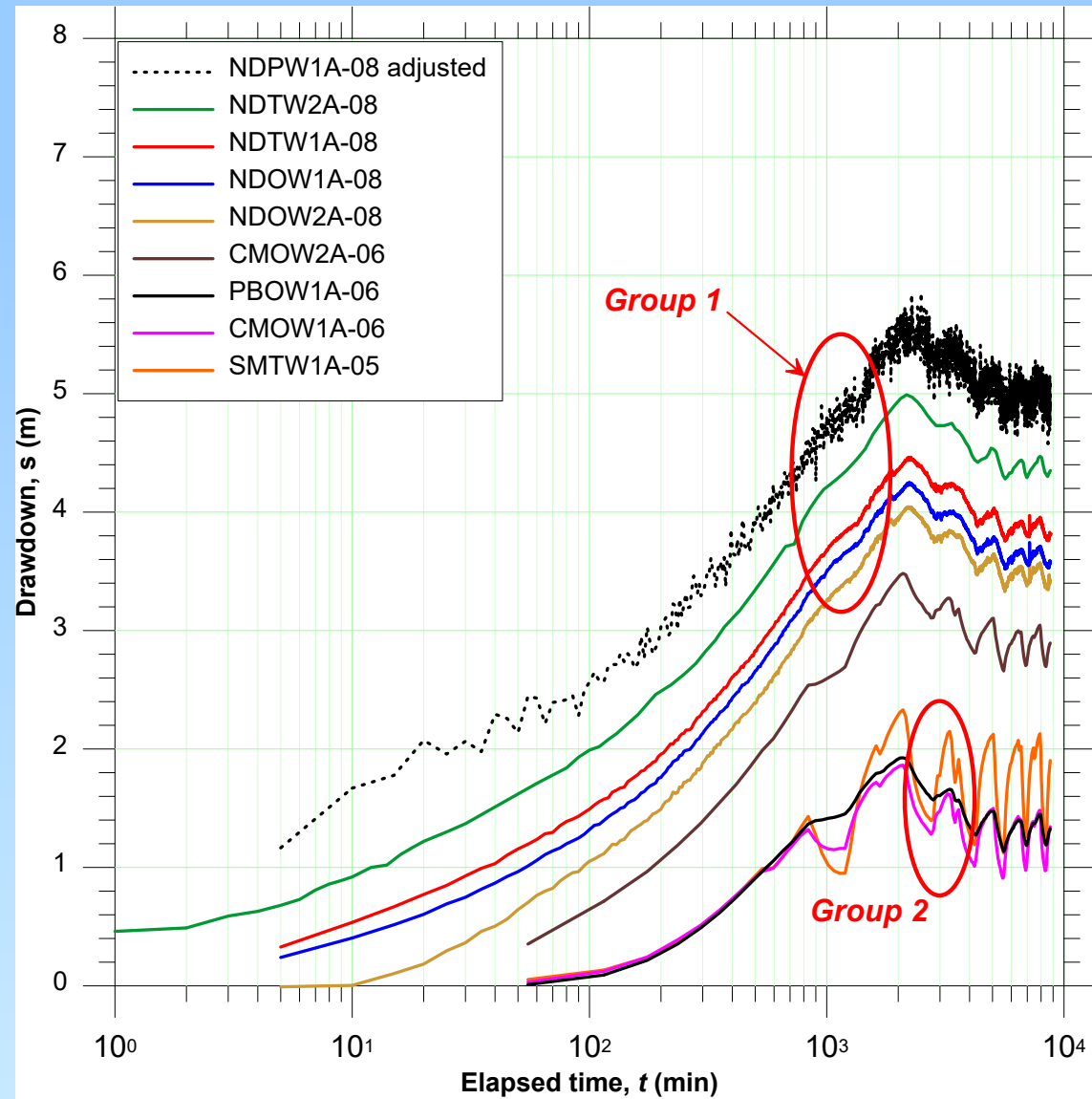
Composite plot



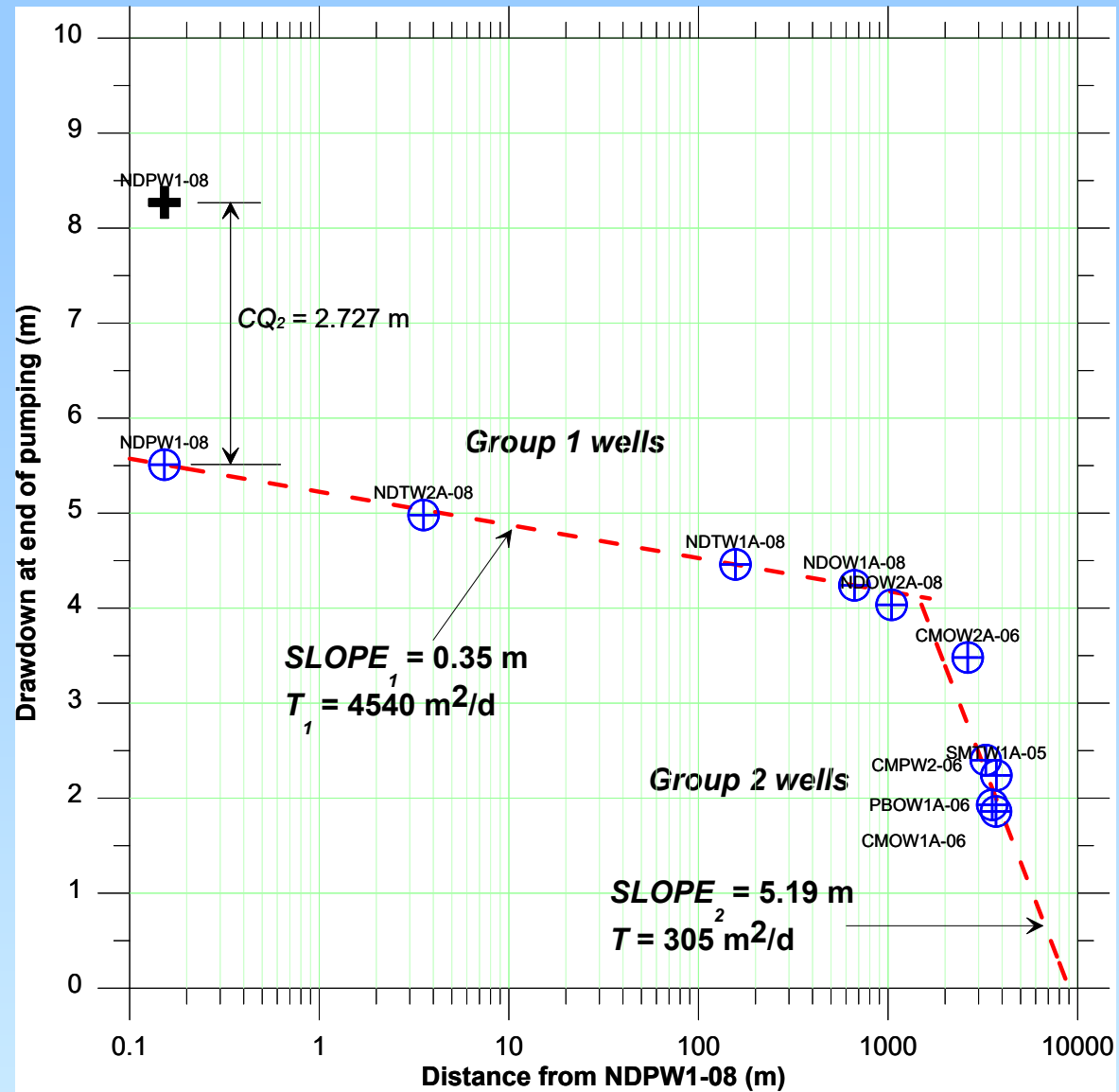
CJSL analysis on the composite plot



Further diagnosis...

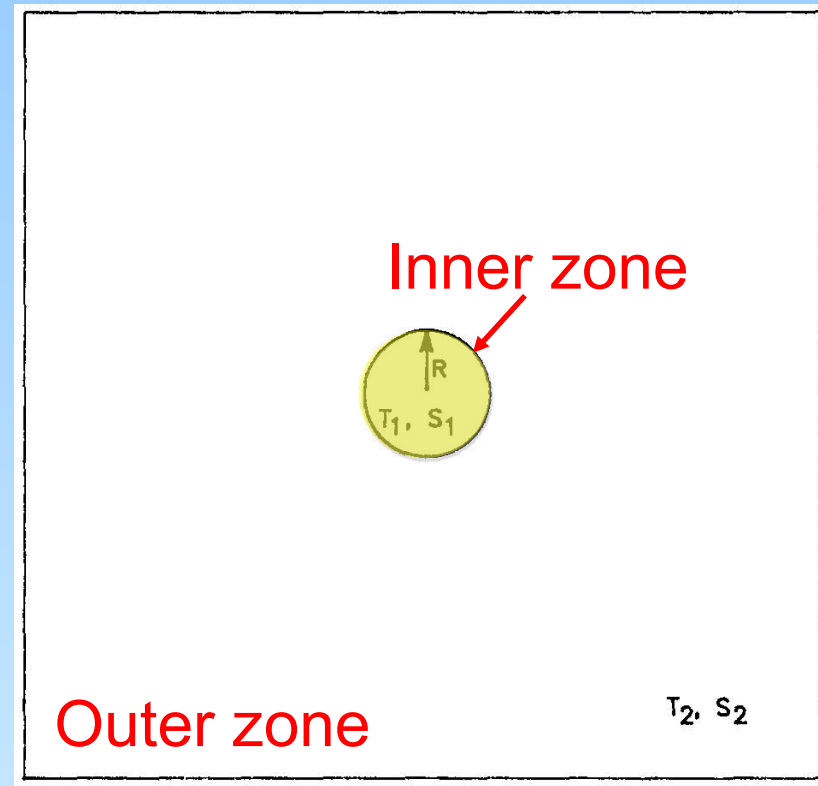


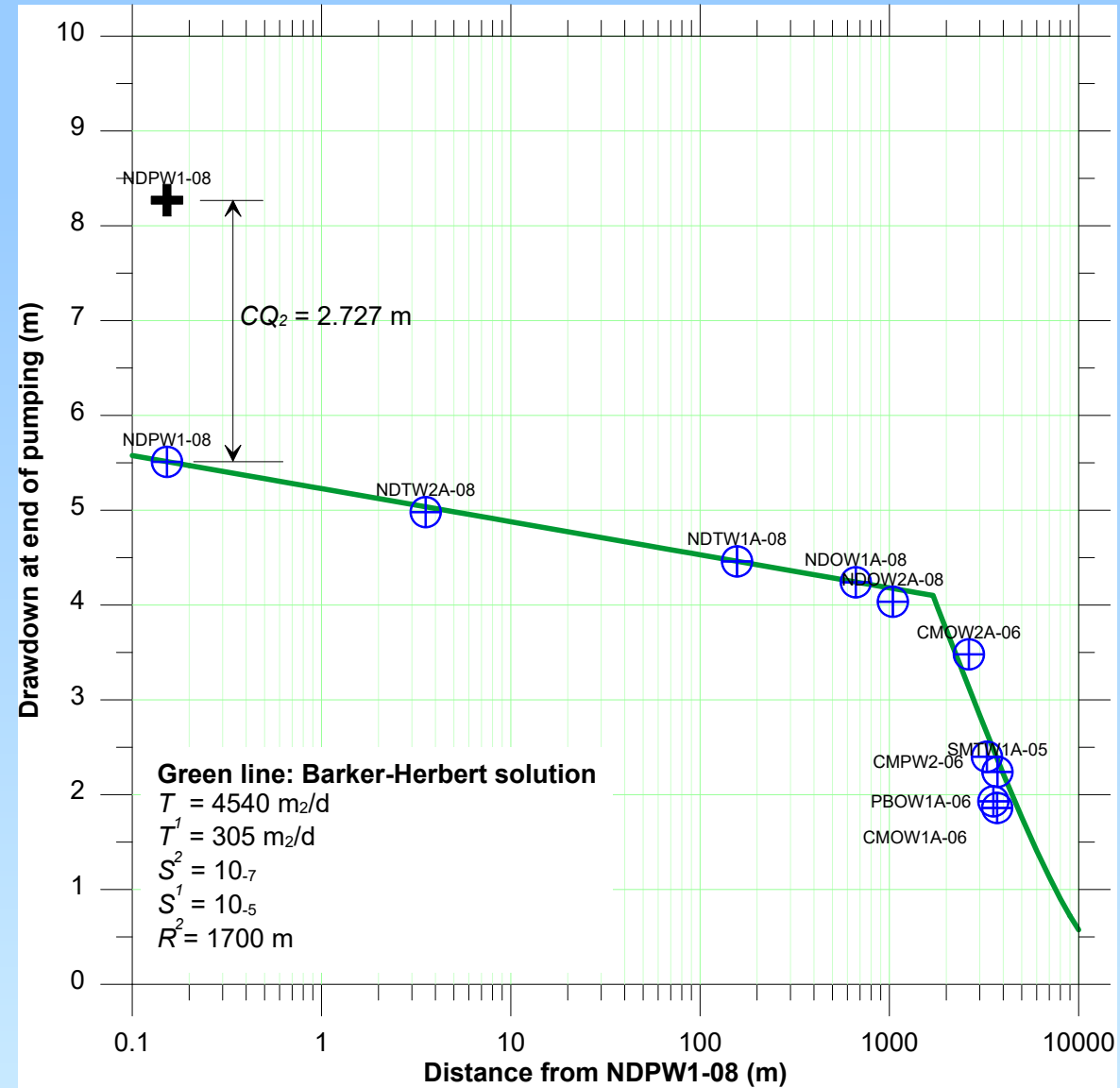
Distance-drawdown plot at maximum drawdowns

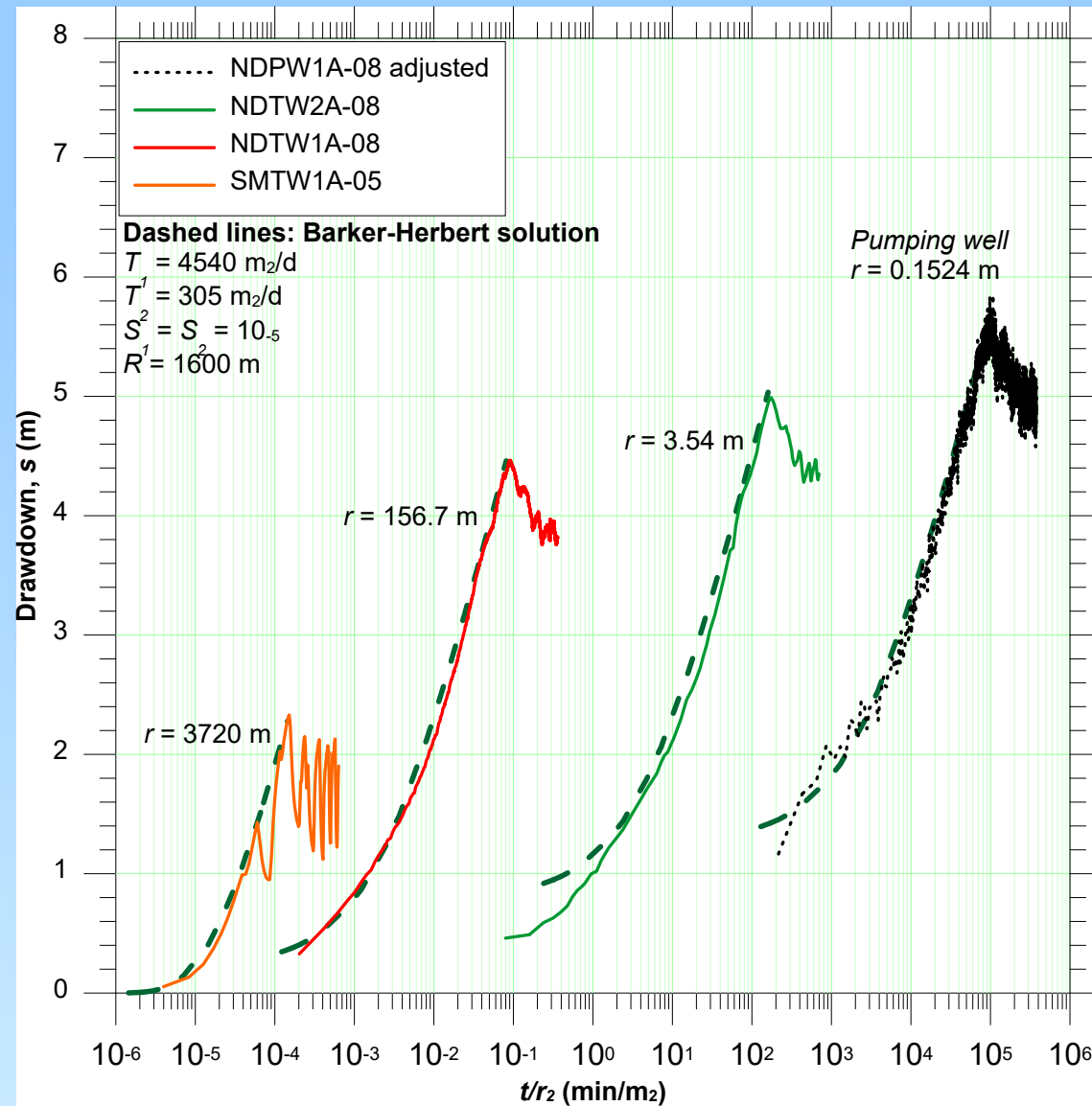


Barker and Herbert (1982) model

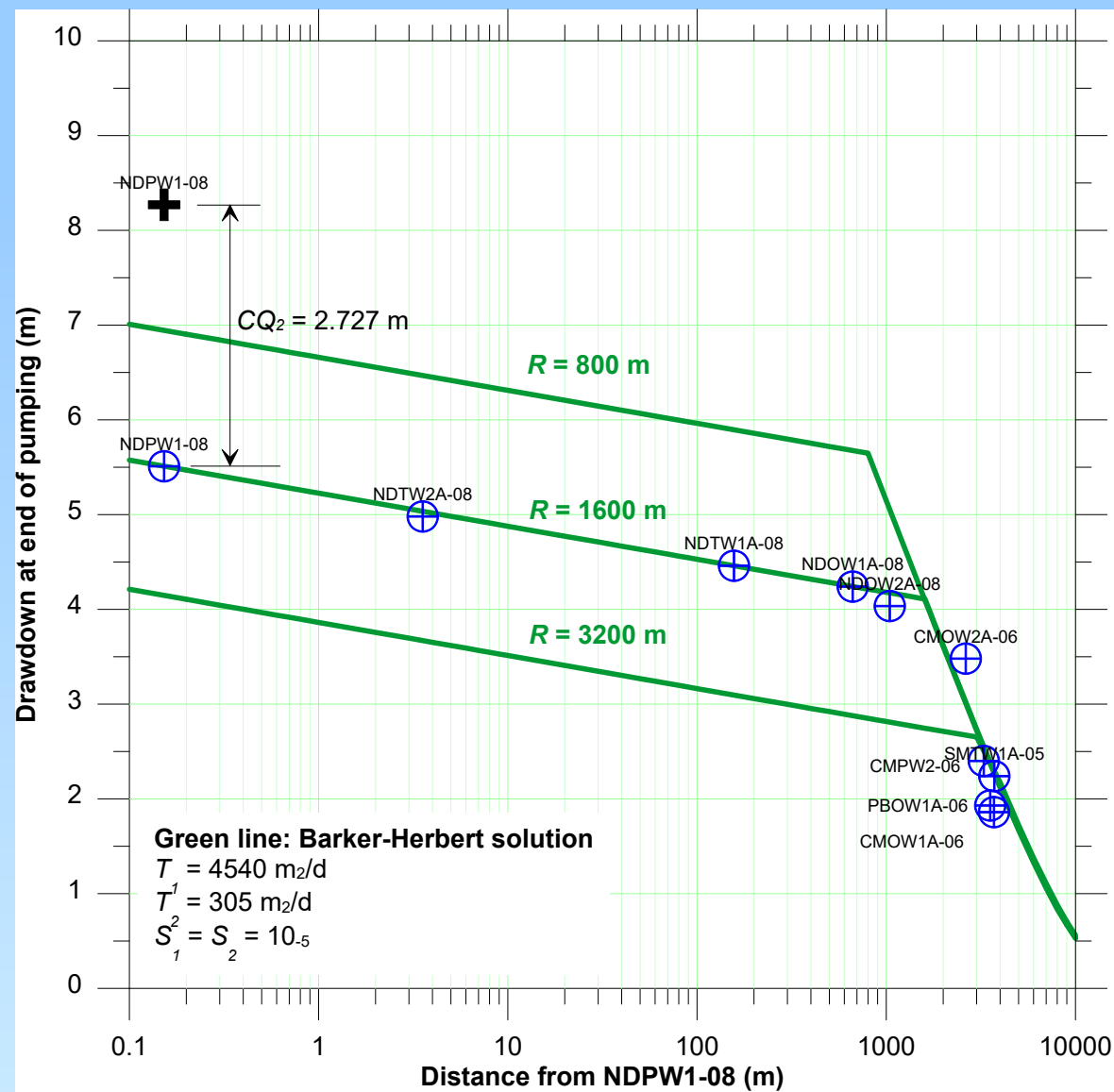
[Predecessor to the Butler and Liu (1993) pod model]



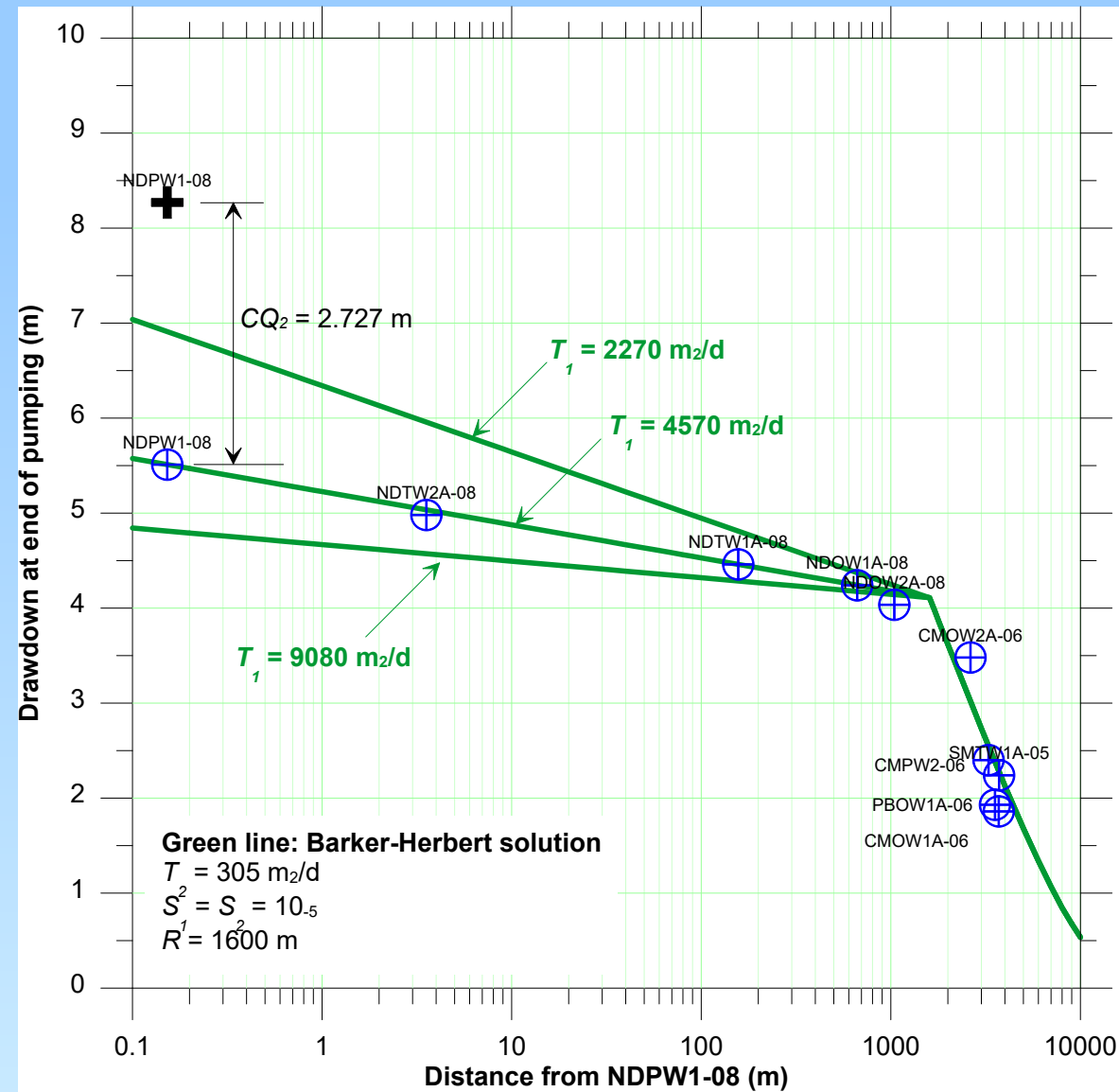




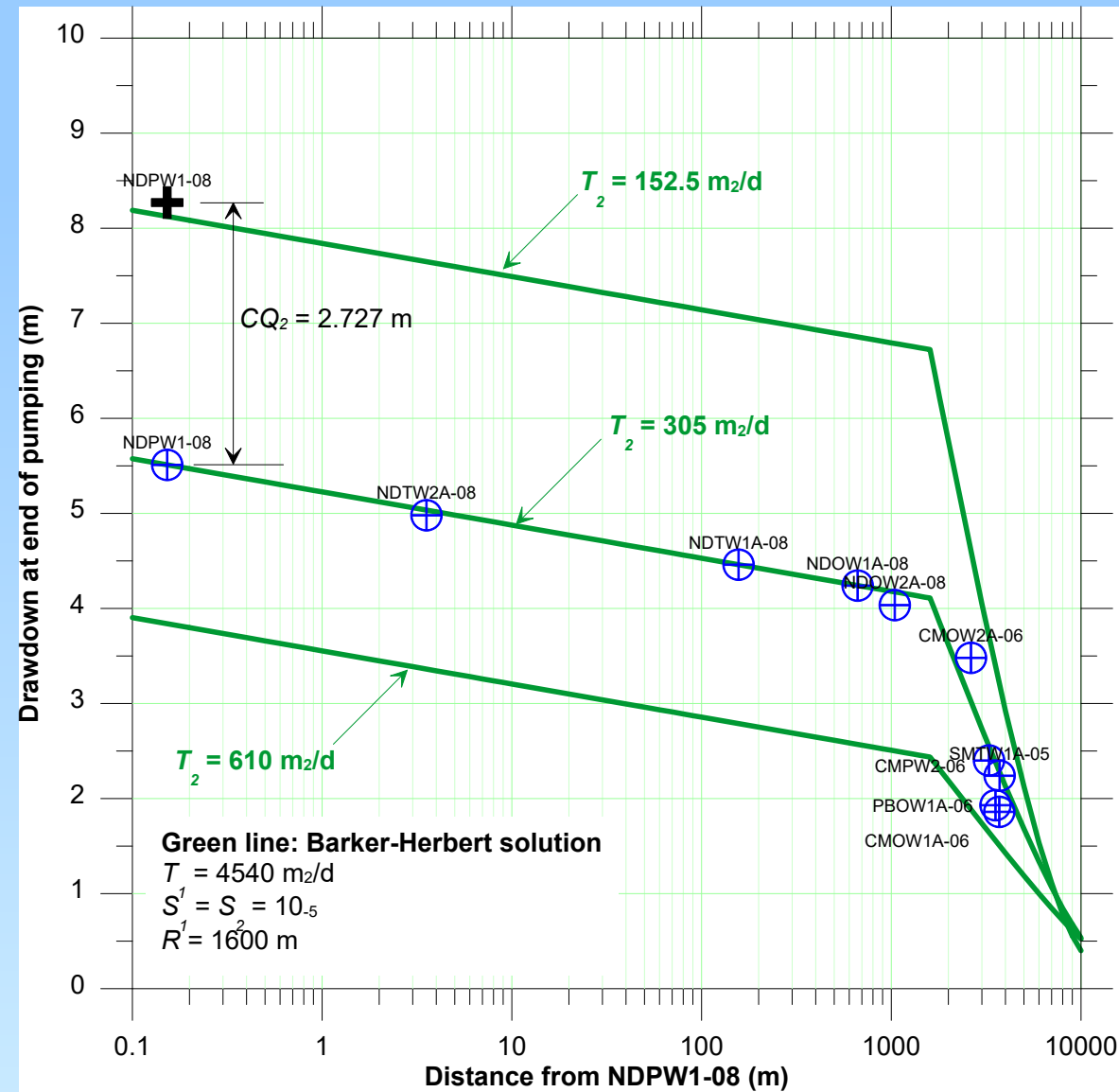
Sensitivity w.r.t. size of inner zone (R)



Sensitivity w.r.t. T of inner zone (T_1)



Sensitivity w.r.t. T of outer zone (T_2)

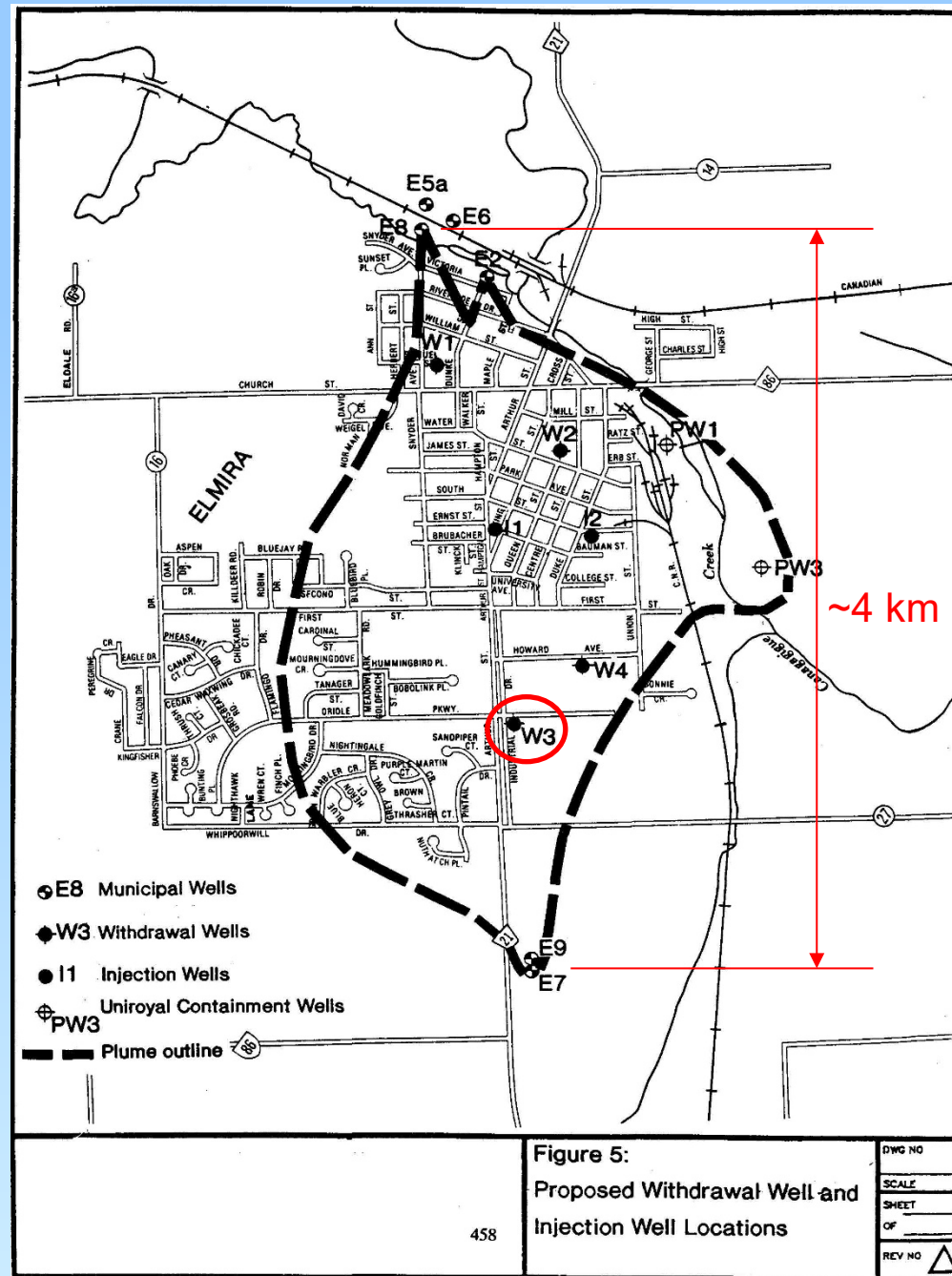


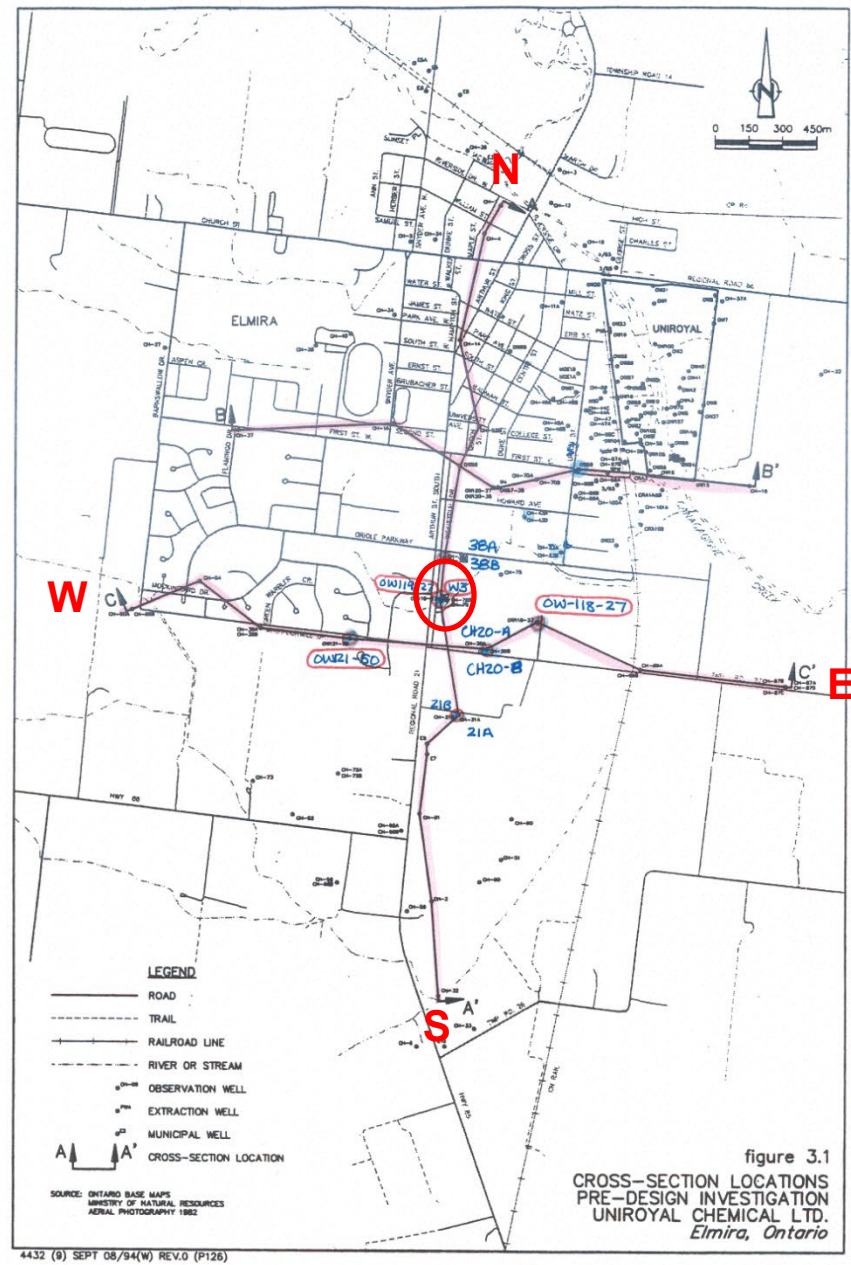
Take-home points

1. My analysis is not the answer. *However*, the Barker-Herbert two-zone conception is the simplest possible model that matches all of the available data.
2. Distance-drawdown never lies.

$$Q = T \times 2\pi r \times \frac{\partial h}{\partial r} = T \times 2\pi \times \frac{1}{2.303} \frac{\Delta h}{\Delta(\log\{r\})}$$

Case Study:
W3 Pumping Test
Elmira, Ontario





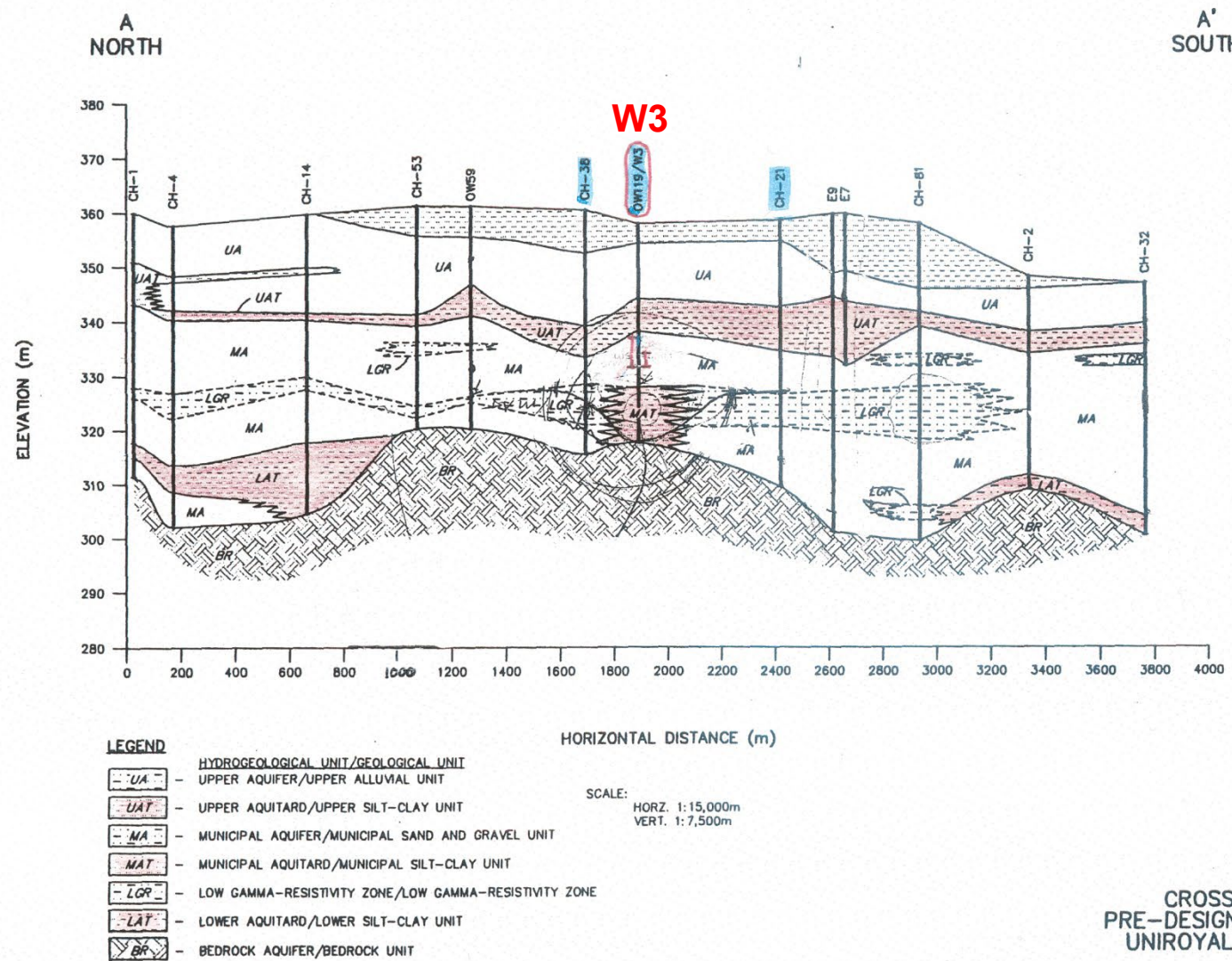
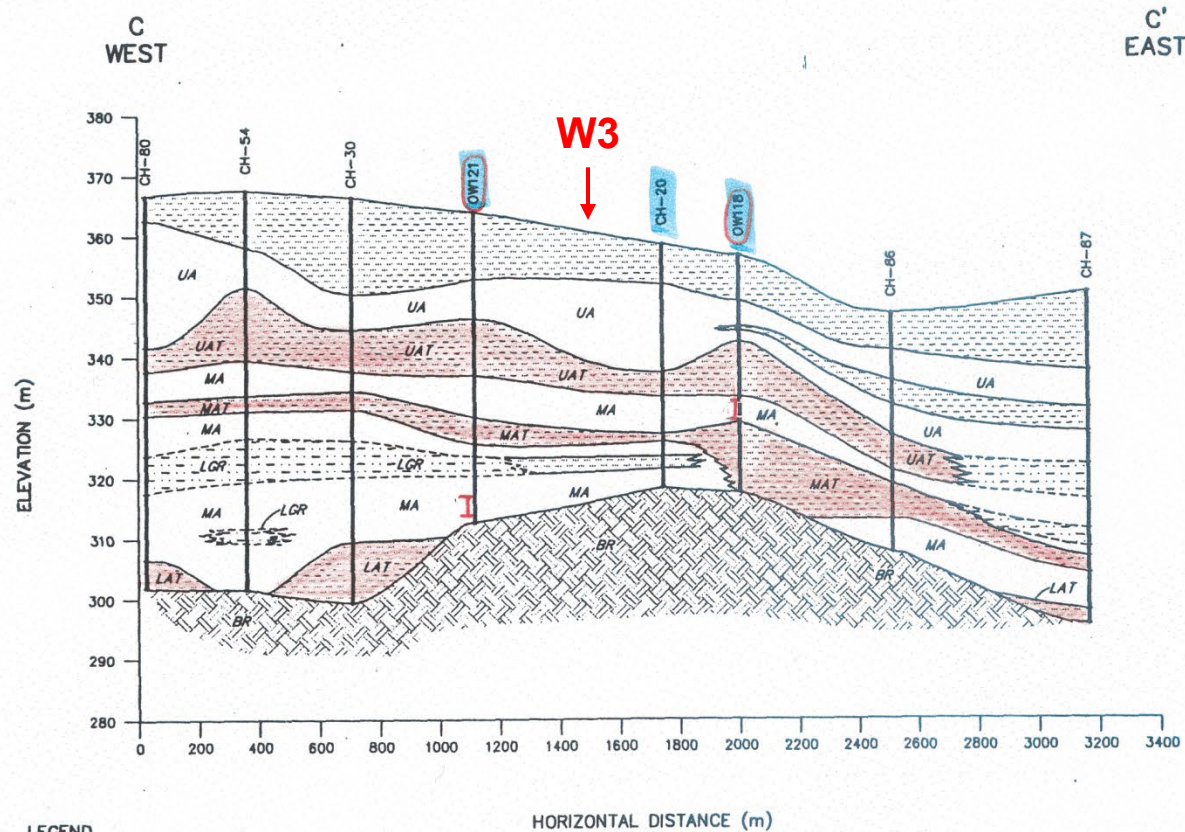


figure 3.2
 CROSS-SECTION A-A'
 PRE-DESIGN INVESTIGATION
 UNIROYAL CHEMICAL LTD.
 Elmira, Ontario



LEGEND

HYDROGEOLOGICAL UNIT/GEOLOGICAL UNIT	
UA	UPPER AQUIFER/UPPER ALLUVIAL UNIT
UAT	UPPER AQUITARD/UPPER SILT-CLAY UNIT
MA	MUNICIPAL AQUIFER/MUNICIPAL SAND AND GRAVEL UNIT
MAT	MUNICIPAL AQUITARD/MUNICIPAL SILT-CLAY UNIT
LGR	LOW GAMMA-RESISTIVITY ZONE/LOW GAMMA-RESISTIVITY ZONE
LAT	LOWER AQUITARD/LOWER SILT-CLAY UNIT
BR	BEDROCK AQUIFER/BEDROCK UNIT

SCALE:
 HORZ. 1:15,000m
 VERT. 1:7,500m

figure 3.4
 CROSS-SECTION C-C'
 PRE-DESIGN INVESTIGATION
 UNIROYAL CHEMICAL LTD.
 Elmira, Ontario

Reporting

**SUMMARY OF TRANSMISSIVITY RESULTS, W3 PUMPING TEST
PRE-DESIGN INVESTIGATION
UNIROYAL CHEMICAL LTD.
ELMIRA, ONTARIO**

Location	Distance to Pumped Well (metres)	Drawdown at 23 Hours (metres)	Drawdown Results		Recovery Results		Geometric Mean (m ² /min)
			(m ² /min)	(m ² /day)	(m ² /min)	(m ² /day)	
W3	0.127	1.26	0.5371	7.73E+02	1.0380	1.49E+03	7.47E-01
CH78B (1)	3	0.53	1.1360	1.64E+03	0.9562	1.38E+03	1.04E+00
OW119-27 (1)	35	0.71	0.9637	1.39E+03	0.9707	1.40E+03	9.67E-01
CH38A	210	0.36	0.9665	1.39E+03	0.9503	1.37E+03	9.58E-01
CH38B	210	0.24	1.7900	2.58E+03	1.7390	2.50E+03	1.76E+00
CH20B	240	0.07	3.8680	5.57E+03	6.4610	9.30E+03	5.00E+00
CH75A	290	0.37	0.6343	9.13E+02	0.5222	7.52E+02	5.76E-01
CH75B	290	0.43	0.7488	1.08E+03	0.6304	9.08E+02	6.87E-01
OW118-27	400	0.09	3.1000	4.46E+03	1.9540	2.81E+03	2.46E+00
OW121-50	450	0.17	2.0580	2.96E+03	1.9890	2.86E+03	2.02E+00
CH43A	490	0.25	0.9151	1.32E+03	0.8451	1.22E+03	8.79E-01
CH21A	545	0.06	4.5790	6.59E+03	2.3010	3.31E+03	3.25E+00
CH21B	545	0.05	11.1100	1.60E+04	7.6270	1.10E+04	9.21E+00
CH23B	575	0.30	1.1180	1.61E+03	0.9304	1.34E+03	1.02E+00
OW56-26	900	0.34	2.0380	2.93E+03	0.4996	7.19E+02	1.01E+00

Geometric Average of all Results: 1.47E+00

Notes:

- (1) The transmissivity value calculated from drawdown results has been corrected for partial penetration of the aquifer by the observation and pumping wells.
The pumping test was conducted at 150 lgpm (0.66 m³/min) on July 20-21, 1994.
All transmissivities were obtained using the Theis method in AQTESOLV except the drawdown test for W3 which was analysed with the Cooper- Jacob method in AQTESOLV.

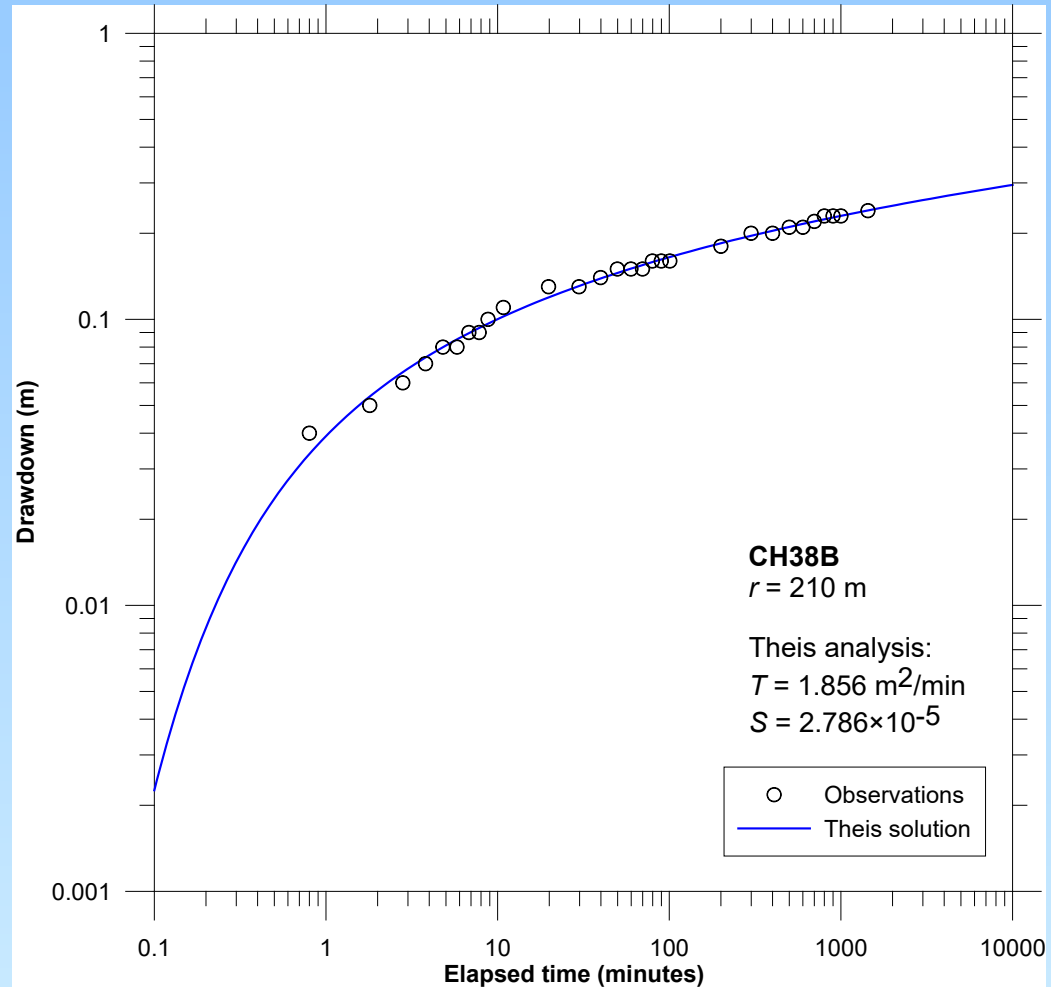
m²/min metres squared per minute

m²/day metres squared per day

Analysis approach:

Example individual analysis

- 15 observation wells
- 15 matches with the Theis solution



Q1. Is the reporting appropriate?

TABLE 3.2

SUMMARY OF TRANSMISSIVITY RESULTS, W3 PUMPING TEST
PRE-DESIGN INVESTIGATION
UNIROYAL CHEMICAL LTD.
ELMIRA, ONTARIO

Location	Distance to Pumped Well (metres)	Drawdown at 23 Hours (metres)	Drawdown Results		Recovery Results		Geometric Mean (m ² /min)
			(m ² /min)	(m ² /day)	(m ² /min)	(m ² /day)	
W3	0.127	1.26	0.5371	7.73E+02	1.0380	1.49E+03	7.47E-01
CH78B (1)	3	0.53	1.1360	1.64E+03	0.9562	1.38E+03	1.04E+00
OW119-27 (1)	35	0.71	0.9637	1.39E+03	0.9707	1.40E+03	9.67E-01
CH38A	210	0.36	0.9665	1.39E+03	0.9503	1.37E+03	9.58E-01
CH38B	210	0.24	1.7900	2.58E+03	1.7390	2.50E+03	1.76E+00
CH20B	240	0.07	3.8680	5.57E+03	6.4610	9.30E+03	5.00E+00
CH75A	290	0.37	0.6343	9.13E+02	0.5222	7.52E+02	5.76E-01
CH75B	290	0.43	0.7488	1.08E+03	0.6304	9.08E+02	6.87E-01
OW118-27	400	0.09	3.1000	4.46E+03	1.9540	2.81E+03	2.46E+00
OW121-50	450	0.17	2.0580	2.96E+03	1.9890	2.86E+03	2.02E+00
CH43A	490	0.25	0.9151	1.32E+03	0.8451	1.22E+03	8.79E-01
CH21A	545	0.06	4.5790	6.59E+03	2.3010	3.31E+03	3.25E+00
CH21B	545	0.05	11.1100	1.60E+04	7.6270	1.10E+04	9.21E+00
CH23B	575	0.30	1.1180	1.61E+03	0.9304	1.34E+03	1.02E+00
OW56-26	900	0.34	2.0380	2.93E+03	0.4996	7.19E+02	1.01E+00
Geometric Average of all Results:							1.47E+00

Notes:

- (1) The transmissivity value calculated from drawdown results has been corrected for partial penetration of the aquifer by the observation and pumping wells.
The pumping test was conducted at 150 l/gpm (0.66 m³/min) on July 20-21, 1994.
All transmissivities were obtained using the Theis method in AQTESOLV except the drawdown test for W3 which was analysed with the Cooper- Jacob method in AQTESOLV.

m²/min metres squared per minute
m²/day metres squared per day

Q2. Are the analyses conceptually sound?

TABLE 3.2

SUMMARY OF TRANSMISSIVITY RESULTS, W3 PUMPING TEST
PRE-DESIGN INVESTIGATION
UNIROYAL CHEMICAL LTD.
ELMIRA, ONTARIO

Location	Distance to Pumped Well (metres)	Drawdown at 23 Hours (metres)	Drawdown Results		Recovery Results		Geometric Mean (m ² /min)
			(m ² /min)	(m ² /day)	(m ² /min)	(m ² /day)	
W3	0.127	1.26	0.5371	7.73E+02	1.0380	1.49E+03	7.47E-01
CH78B (1)	3	0.53	1.1360	1.64E+03	0.9562	1.38E+03	1.04E+00
OW119-27 (1)	35	0.71	0.9637	1.39E+03	0.9707	1.40E+03	9.67E-01
CH38A	210	0.36	0.9665	1.39E+03	0.9503	1.37E+03	9.58E-01
CH38B	210	0.24	1.7900	2.58E+03	1.7390	2.50E+03	1.76E+00
CH20B	240	0.07	3.8680	5.57E+03	6.4610	9.30E+03	5.00E+00
CH75A	290	0.37	0.6343	9.13E+02	0.5222	7.52E+02	5.76E-01
CH75B	290	0.43	0.7488	1.08E+03	0.6304	9.08E+02	6.87E-01
OW118-27	400	0.09	3.1000	4.46E+03	1.9540	2.81E+03	2.46E+00
OW121-50	450	0.17	2.0580	2.96E+03	1.9890	2.86E+03	2.02E+00
CH43A	490	0.25	0.9151	1.32E+03	0.8451	1.22E+03	8.79E-01
CH21A	545	0.06	4.5790	6.59E+03	2.3010	3.31E+03	3.25E+00
CH21B	545	0.05	11.1100	1.60E+04	7.6270	1.10E+04	9.21E+00
CH23B	575	0.30	1.1180	1.61E+03	0.9304	1.34E+03	1.02E+00
OW56-26	900	0.34	2.0380	2.93E+03	0.4996	7.19E+02	1.01E+00

Geometric Average of all Results: 1.47E+00

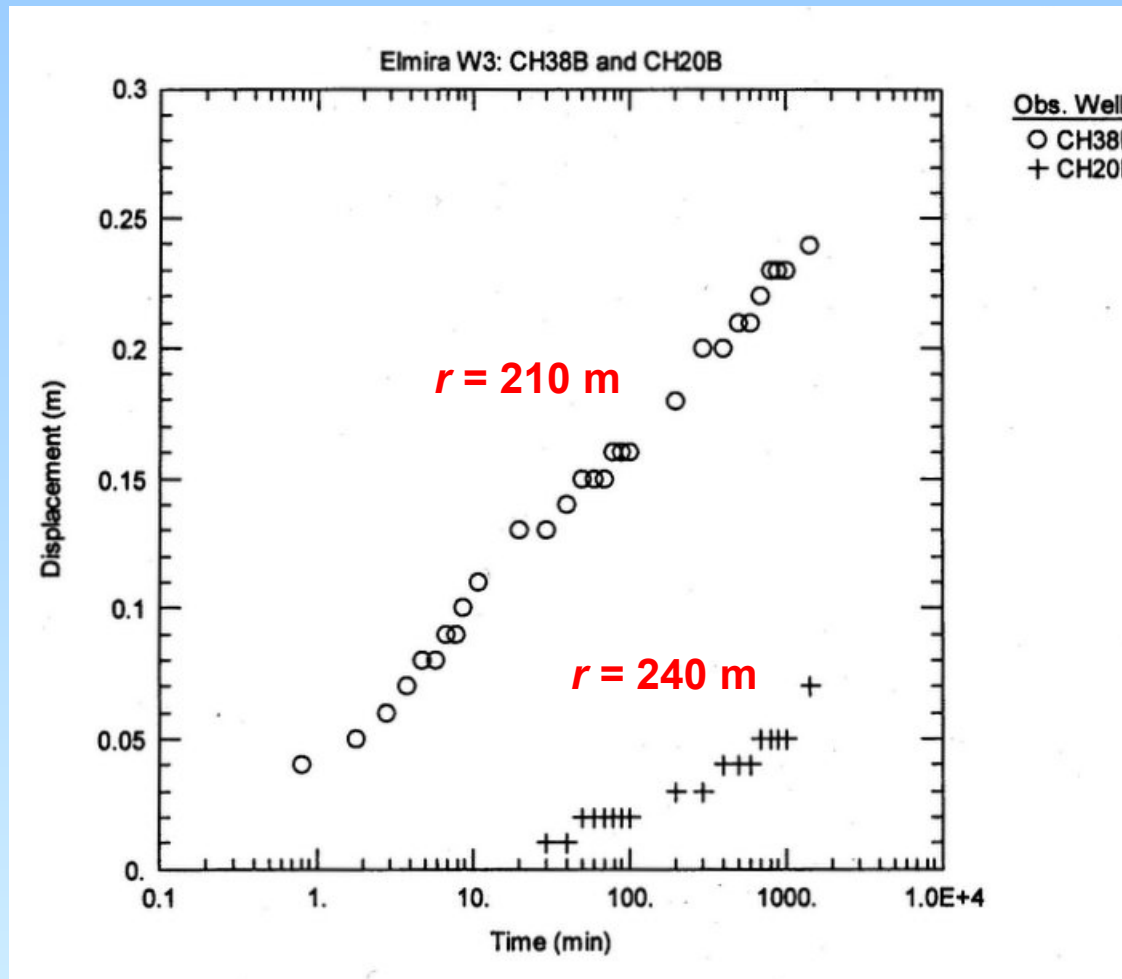
Notes:

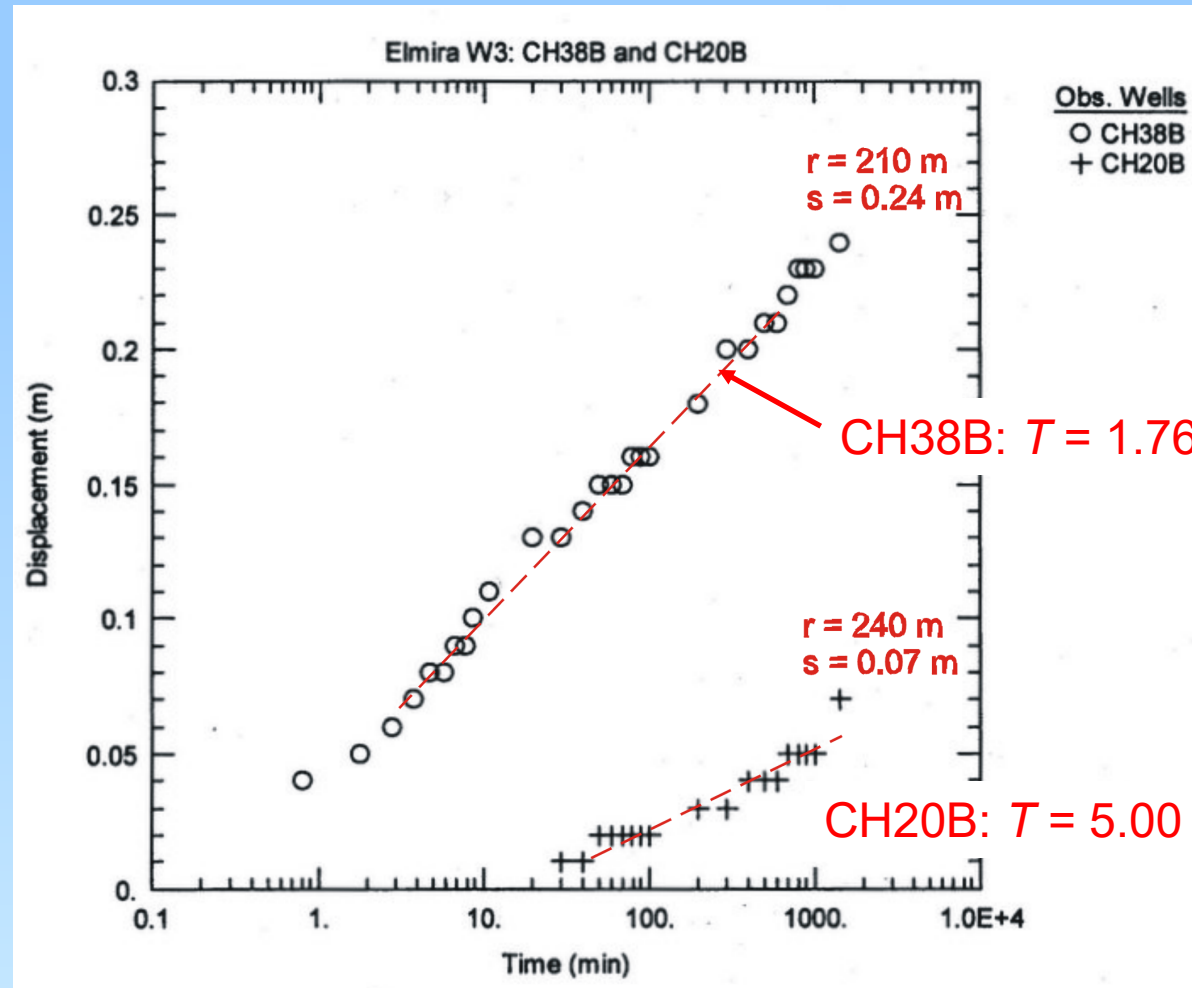
- (1) The transmissivity value calculated from drawdown results has been corrected for partial penetration of the aquifer by the observation and pumping wells.
The pumping test was conducted at 150 lpm (0.66 m³/min) on July 20-21, 1994.
All transmissivities were obtained using the Theis method in AQTESOLV except the drawdown test for W3 which was analysed with the Cooper- Jacob method in AQTESOLV.

m²/min metres squared per minute
m²/day metres squared per day

Q3. Are the interpretations reliable?

Might the interpretations of individual drawdown records provide reliable (perhaps not general, but local) transmissivity estimates?

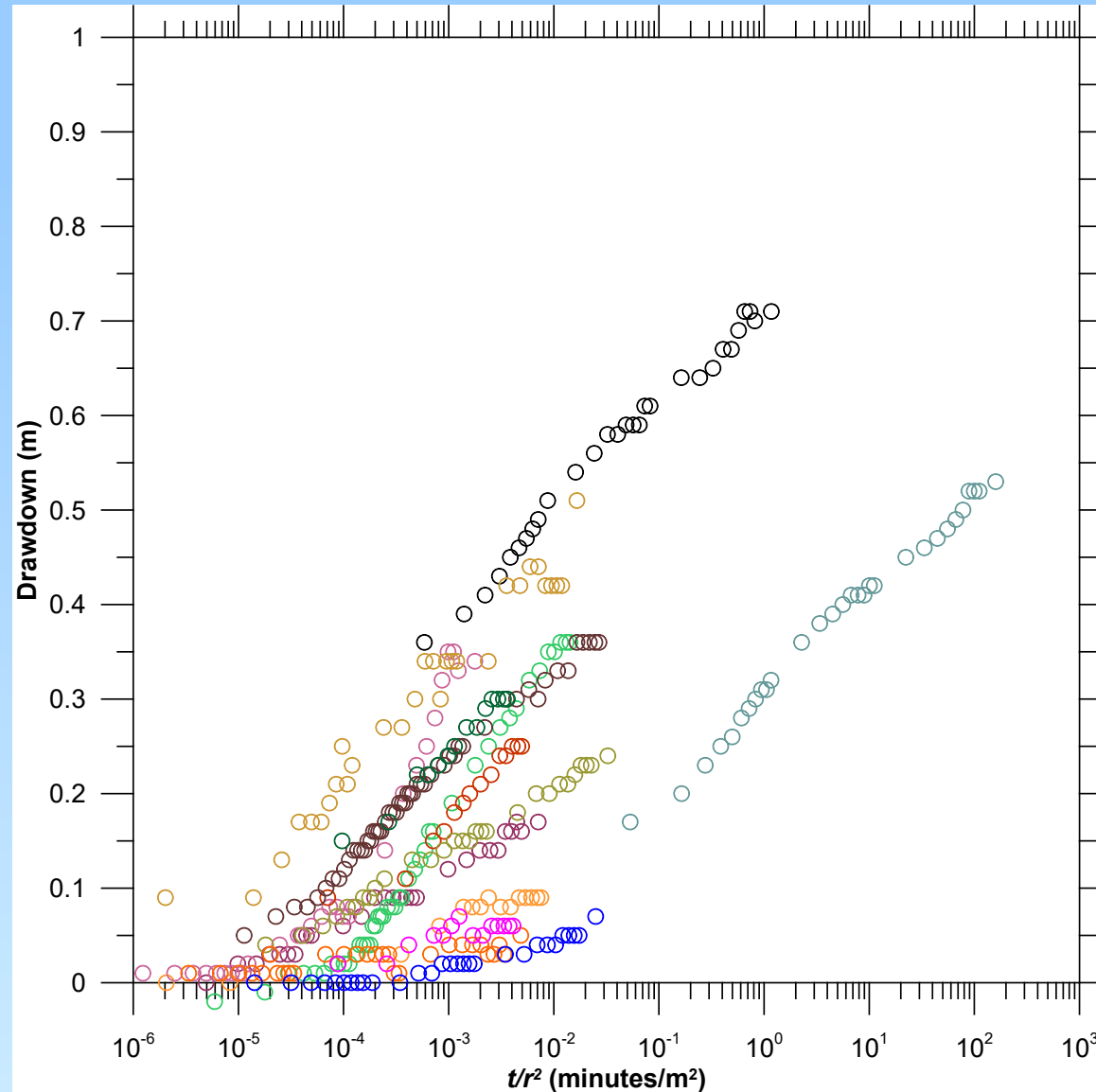




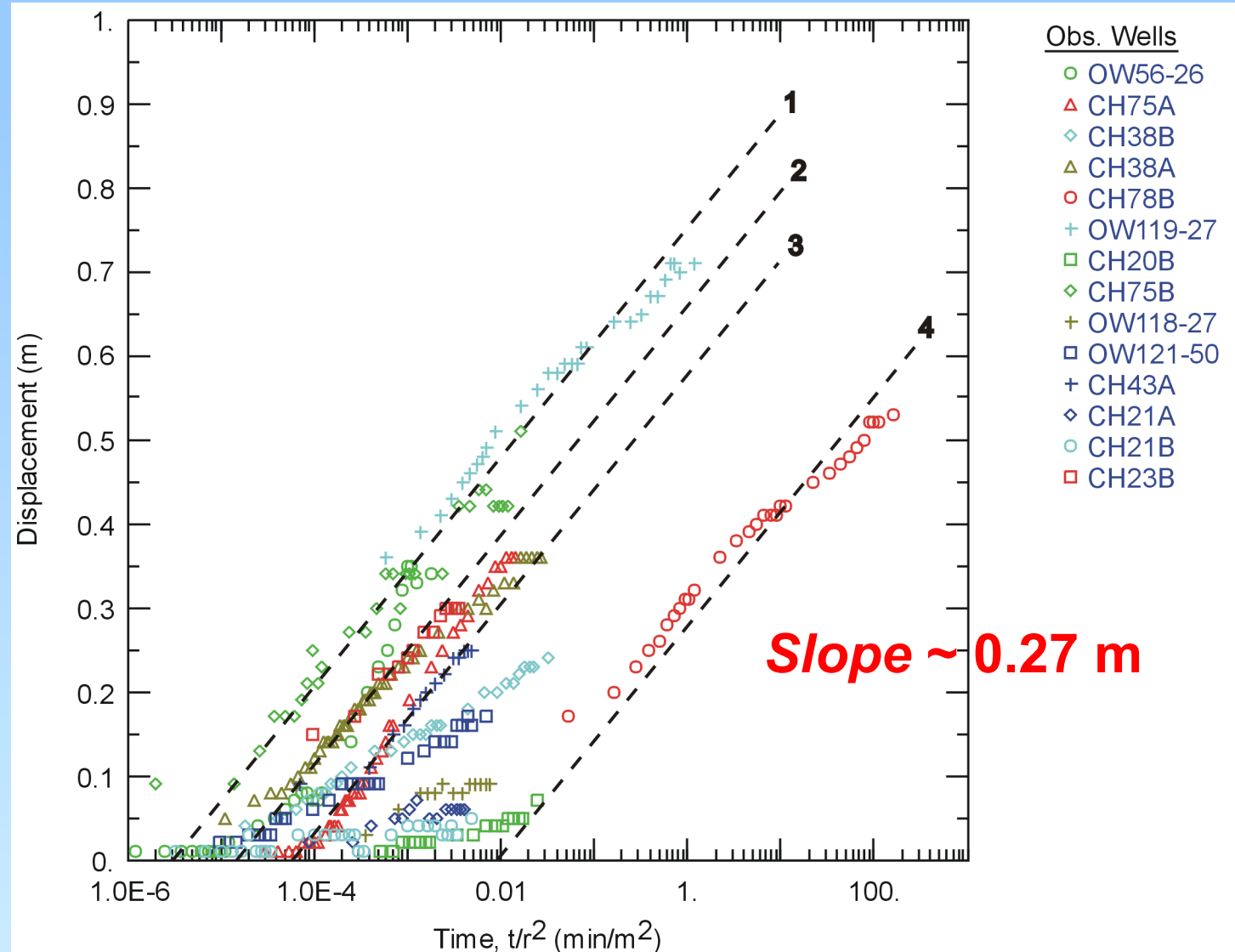
Q4. Do the analyses have any diagnostic value?

- Does the table of reported values shed any light on the subsurface structure?
- Does the table of reported values provide any insight into the representative large-scale transmissivity?
- Does the table of reported values help identify outliers?

Alternative Interpretation: Composite plot



Interpretation: CJSL Analysis



Estimation of transmissivity

SLOPE 1, 2, 3 and 4 $\cong 0.27$ m/log cycle t/r^2

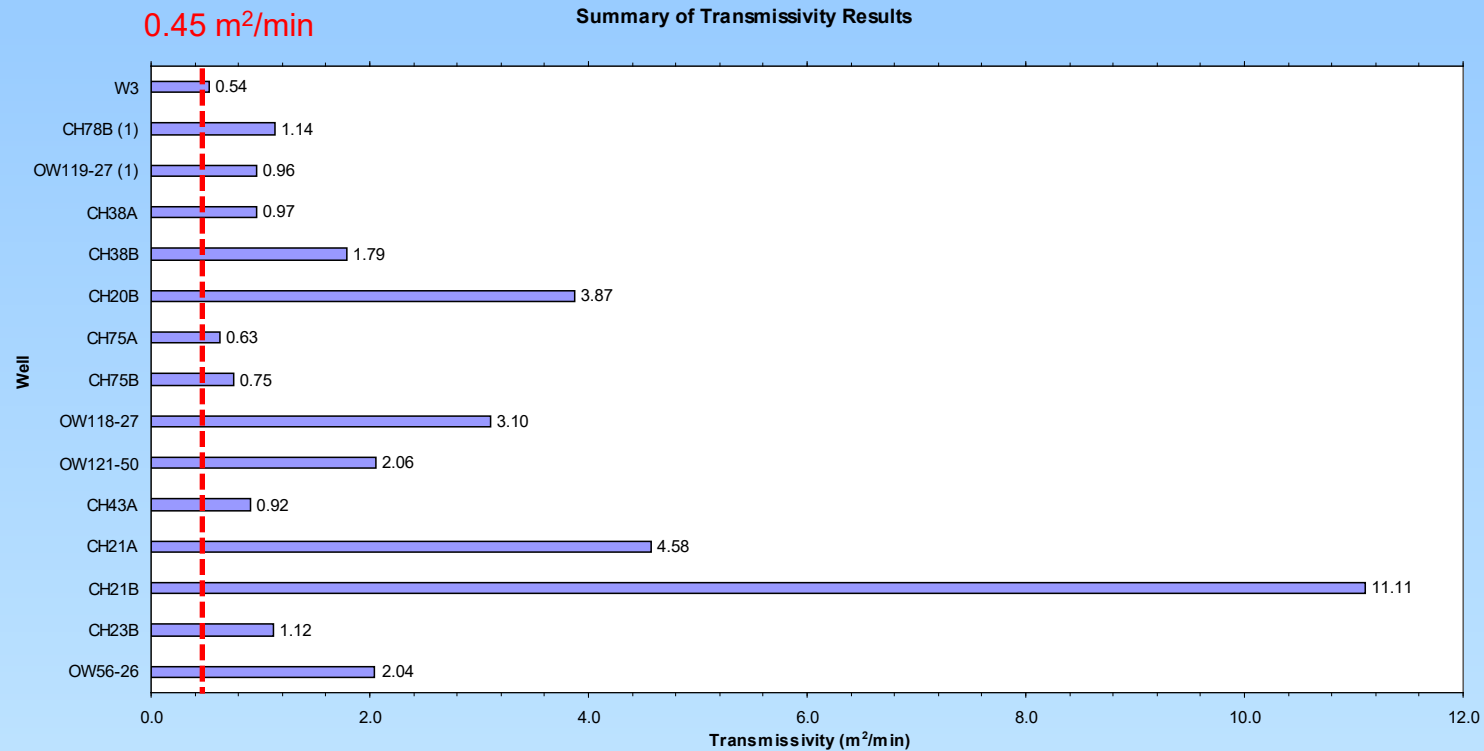
Average pumping rate: $Q = 150$ gpm ($= 0.66$ m³/min)

$$T = 2.3026 \frac{Q}{4\pi} \frac{1}{\Delta s}$$

$$\cong 2.3026 \frac{(0.66 \text{ m}^3/\text{min})}{4\pi} \frac{1}{(0.27 \text{ m})}$$

$$= 0.45 \text{ m}^2/\text{min}$$

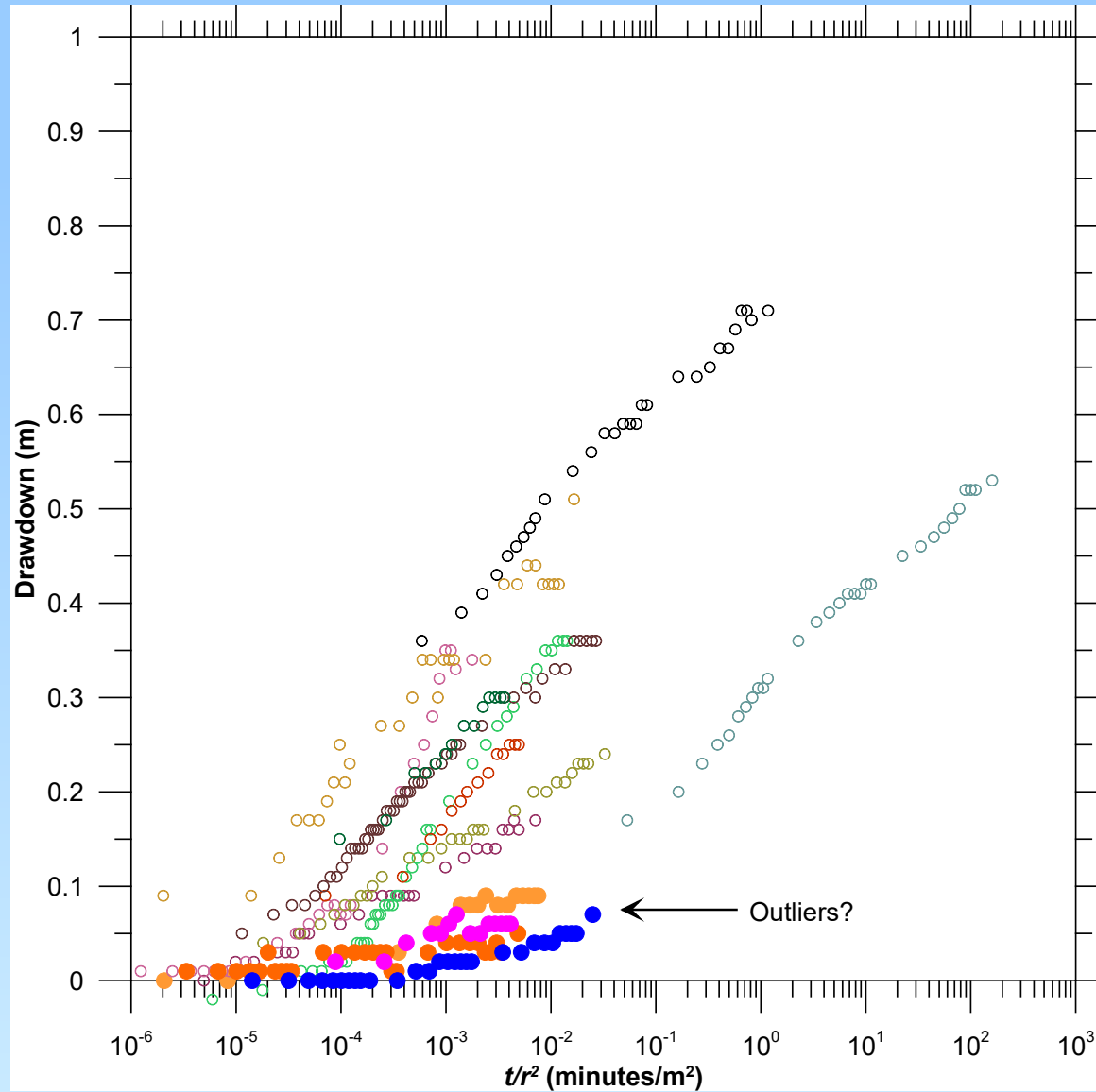
Original analysis: $T = 0.5$ to $11.1 \text{ m}^2/\text{min}$



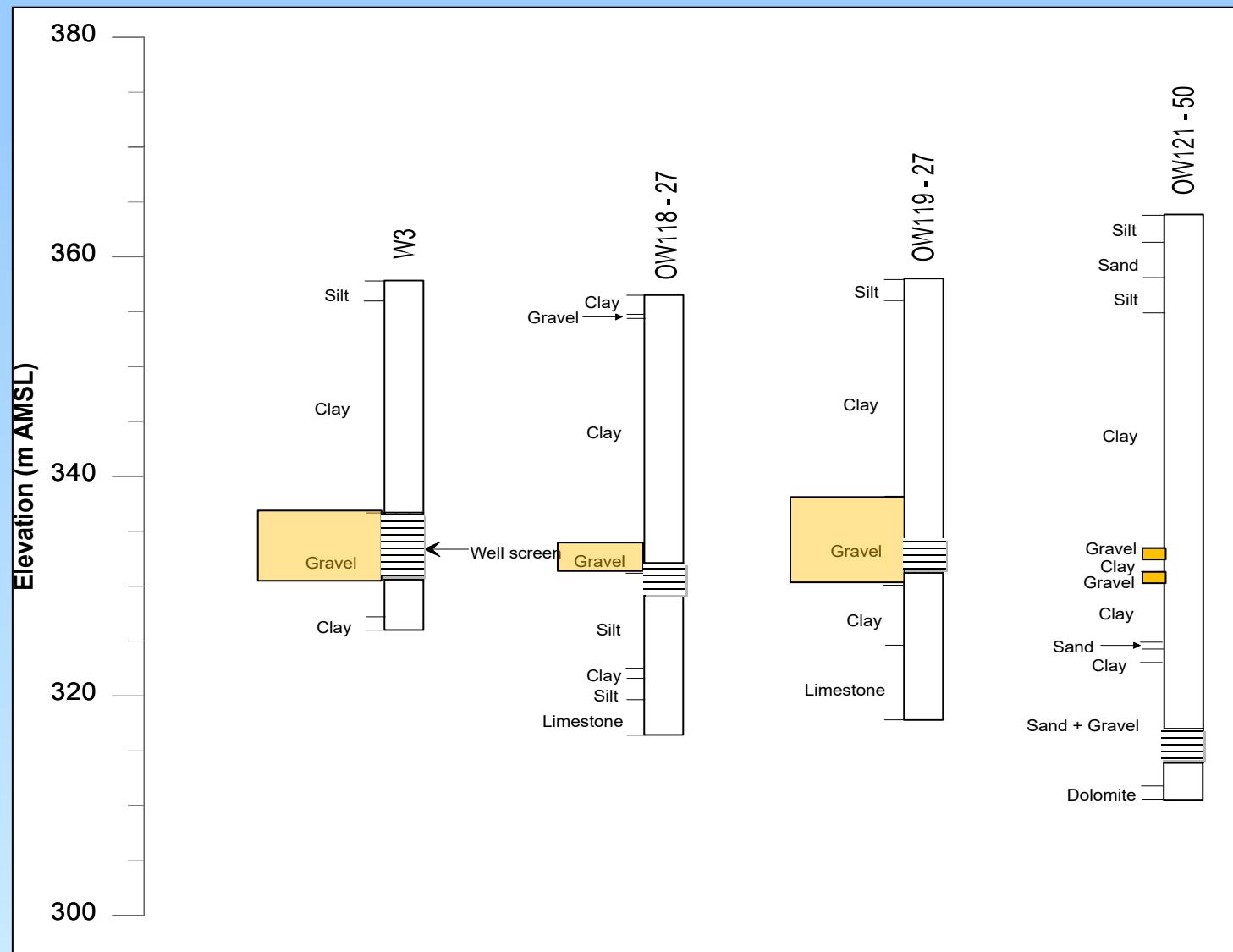
Cooper-Jacob composite analysis: $T = 0.45 \text{ m}^2/\text{min}$

Outliers?

Outliers?



Further analysis?

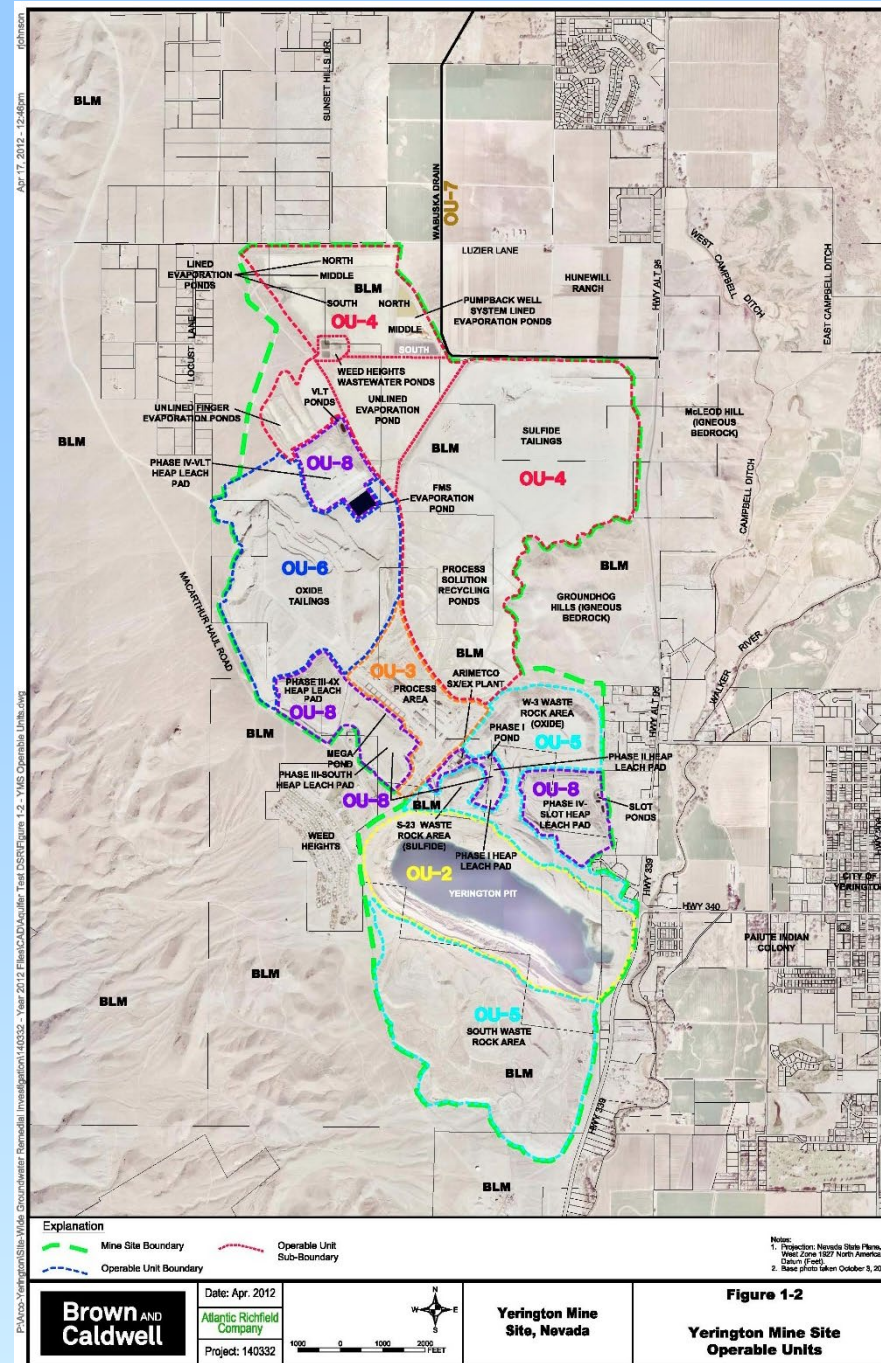


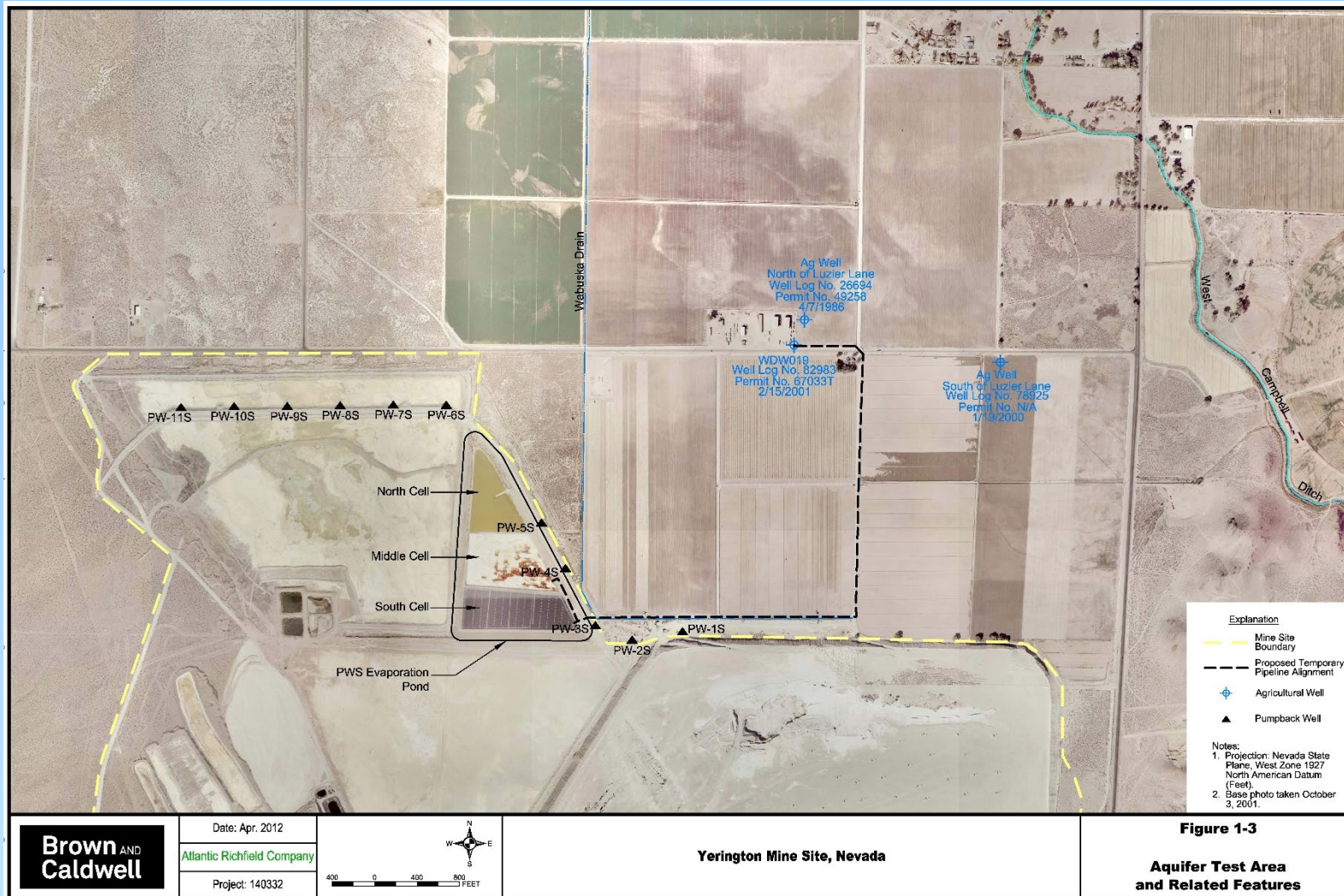
Take-home points

1. Careful how you report your results.
2. Assembling a table with a wide range of transmissivity estimates obtained from matching the data with a solution that assumes aquifer homogeneity is not helpful to anyone.

Case Study:

Yerington Mine Site, Nevada





- More than 90 instrumented monitoring wells
- Pumping test > \$1M

Table 7.1 Estimated Aquifer Properties										
Well ID	Zone	Theis Method		Theis Recovery	Cooper-Jacob		Walton		Hantush	
		Transmissivity	Storativity	Transmissivity	Transmissivity	Storativity	Transmissivity	Storativity	Transmissivity	Storativity
BW-1S	Shallow	172	8.62E-01	2,002	1,436	8.52E+00	1,723	5.60E-03	574	1.40E-05
BW-4S	Shallow	25,852	1.45E-01	3,223	11,490	2.44E-01	215,434	1.03E-03	10,054	4.14E-03
BW-9S	Shallow	574	2.87E-02	NA	16,313	2.87E+00	32,828	1.14E-03	718	8.41E-06
BW-25S	Shallow	13,405	1.53E+00	9,788	9,176	2.71E+00	13,405	1.00E-03	5,745	4.04E-04
BW-29S	Shallow	4,787	7.18E-01	4,719	4,404	7.47E-01	4,787	4.85E-04	3,830	4.02E-04
BW-44S	Shallow	2,872	9.57E-02	4,129	2,447	1.24E-01	2,872	6.84E-05	517	1.09E-06
BW-60S	Shallow	10,341	2.76E+00	1,673	7,773	6.48E+00	10,054	1.70E-03	7,181	1.52E-03
BW-61S	Shallow	5,107	2.04E+00	9,438	3,886	2.98E+00	5,745	1.34E-02	5,745	1.49E-03
BW-64S	Shallow	574	1.44E-01	247	1,519	2.92E-01	5,027	1.41E-03	8,617	1.48E-03
BW-65S	Shallow	9,575	2.55E+00	88,088	11,011	1.94E+00	11,490	1.80E-03	2,872	3.15E-04
BW-66S	Shallow	7,660	1.07E+00	16,313	9,305	1.12E+00	646	6.87E-05	1,532	6.51E-06
BW-2I	Intermediate	3,447	1.21E+00	3,571	5,683	4.85E-01	2,681	8.89E-04	4,596	1.74E-04
BW-3I	Intermediate	40,214	4.02E+00	18,100	41,617	2.65E+00	34,469	2.12E-03	17,235	1.06E-03
BW-4I	Intermediate	34,469	2.76E-01	6,445	22,980	4.89E-01	11,490	4.51E-04	4,924	1.88E-04
BW-9I	Intermediate	3,830	5.11E+00	11,342	7,201	3.28E+00	22,980	2.50E-02	2,298	2.50E-03
BW-27I	Intermediate	48,257	2.57E+00	9,438	56,628	4.75E+00	3,447	1.28E-03	30,639	1.71E-03
BW-29I	Intermediate	2,553	1.02E+00	3,303	3,524	5.63E-01	1,915	4.32E-04	2,553	5.75E-04
BW-32I	Intermediate	10,213	4.54E+00	8,258	20,328	1.68E+00	10,054	2.46E-03	2,298	5.06E-04
BW-37I	Intermediate	1,838	3.68E-01	4,332	3,109	2.72E-01	1,149	1.99E-04	383	1.99E-03
BW-65I	Intermediate	6,566	1.13E+00	33,033	7,550	9.40E-01	4,596	5.45E-04	2,681	2.82E-04
BW-1D1	Deep 1	6,894	1.84E-02	5,663	3,020	6.21E-01	6,894	4.20E-04	6,032	7.71E-05
BW-2D1	Deep 1	3,939	8.75E-01	5,724	5,873	5.24E-01	3,830	7.32E-02	306	6.50E-05
BW-3D1	Deep 1	13,788	1.65E+00	10,363	17,424	1.06E+00	6,894	5.20E-04	2,758	7.44E-05
BW-4D1	Deep 1	57,449	2.87E+00	41,726	35,235	8.19E-01	60,321	1.19E-03	45,959	9.49E-04
BW-25D1	Deep 1	114,898	2.04E+01	12,584	12,485	1.98E+00	10,341	1.62E-03	4,596	6.90E-04
BW-29D1	Deep 1	574	1.38E-01	777	695	7.06E-02	383	7.41E-05	511	9.22E-05
BW-30D1	Deep 1	29,545	3.15E+00	22,651	53,749	2.27E+00	29,545	2.11E-03	34,469	2.47E-03

Table 7.1 Estimated Aquifer Properties										
Well ID	Zone	Theis Method		Theis Recovery	Cooper-Jacob		Walton		Hantush	
		Transmissivity	Storativity	Transmissivity	Transmissivity	Storativity	Transmissivity	Storativity	Transmissivity	Storativity
BW-37D1	Deep 1	6,894	8.27E-01	14,032	10,786	6.31E-01	6,128	5.91E-04	3,939	1.95E-04
BW-60D1	Deep 1	948	1.01E-01	20,071	18,437	1.22E+00	13,788	1.22E-03	12,064	1.02E-03
BW-61D1	Deep 1	12,064	1.69E+00	12,387	14,414	1.43E+00	12,064	1.18E-03	6,894	7.74E-04
BW-64D1	Deep 1	7,660	5.11E+00	NA	10,935	3.72E+00	965	1.67E-03	6,128	2.74E-03
BW-65D1	Deep 1	9,192	1.84E+00	7,079	10,786	1.26E+00	9,651	1.28E-03	9,651	1.28E-03
BW-66D1	Deep 1	4,924	5.91E+00	4,664	10,099	4.89E+00	2,585	2.83E-03	1,149	8.09E-04
BW-67D1	Deep 1	43,087	7.66E+00	52,853	39,640	4.37E+00	34,469	4.25E-03	8,273	8.74E-04
LEP-MW-2D1	Deep 1	43,087	7.66E+00	52,853	39,640	4.37E+00	34,469	4.25E-03	8,273	8.74E-04
BW-1D2	Deep 2	3,447	3.06E-01	5,663	4,285	6.38E-01	2,758	3.36E-04	2,068	2.70E-04
BW-9D2	Deep 2	6,894	1.84E+00	6,662	7,207	9.22E-01	3,830	8.17E-04	38,299	7.26E-03
BW-11D2	Deep 2	12,409	1.42E+00	8,809	12,997	8.70E-01	5,515	7.15E-04	2,068	5.36E-05
BW-25D2	Deep 2	4,309	6.89E-01	3,821	3,604	8.53E-01	1,970	6.91E-04	1,609	2.01E-04
BW-31D2	Deep 2	11,490	1.97E+00	4,173	18,545	1.34E+00	620	8.16E-05	103,408	1.36E-02
BW-32D2	Deep 2	5,515	8.82E-01	8,345	9,552	6.91E-01	5,170	6.33E-04	5,170	6.33E-04
BW-44D2	Deep 2	34,469	1.15E+00	49,550	29,363	1.49E+00	34,469	8.20E-04	6,204	1.31E-05
BW-64D2	Deep 2	4,309	1.15E+00	NA	1,586	1.43E+00	394	5.26E-05	3,064	8.18E-04
MW-5D2	Deep 2	15,511	7.24E-01	10,035	16,346	5.38E-01	15,320	5.07E-04	43,087	6.66E-04
BW-1D3	Deep 3	7,660	2.30E+00	7,550	8,131	2.09E+00	7,879	1.44E-03	3,677	5.04E-04
BW-2D3	Deep 3	10,341	1.55E+00	9,495	9,113	4.85E-01	45,959	5.80E-03	4,826	5.08E-04
BW-27D3a	Deep 3	5,170	9.31E-01	7,641	7,207	6.73E-01	3,939	5.45E-04	3,217	1.58E-04
BW-27D3b	Deep 3	4,596	3.06E+00	NA	3,303	1.95E+00	3,447	1.66E-03	4,596	1.38E-03
BW-29D3	Deep 3	5,909	7.09E-01	5,663	5,873	4.48E-01	6,204	4.67E-04	483	3.81E-05
BW-61D3	Deep 3	6,894	9.19E-01	6,607	5,663	8.25E-01	6,128	5.49E-04	2,758	1.92E-04
W5DB-D3	Deep 3	7,660	8.75E-01	9,466	9,581	6.31E-01	6,894	5.31E-04	13,788	1.06E-03
W4CB-2D4	Deep 4	7,660	4.60E-01	7,948	8,237	3.70E-01	68,939	3.31E-03	5,170	2.90E-04
BW-1D5	Deep 5	7,660	2.30E+00	7,207	8,131	2.51E+00	7,660	1.75E-03	3,677	5.04E-04
BW-32D5	Deep 5	8,617	1.21E+00	13,788	13,213	8.20E-01	4,136	5.91E-04	6,894	7.04E-04

Table 7.1 Estimated Aquifer Properties										
Well ID	Zone	Theis Method		Theis Recovery	Cooper-Jacob		Walton		Hantush	
		Transmissivity	Storativity	Transmissivity	Transmissivity	Storativity	Transmissivity	Storativity	Transmissivity	Storativity
BW-65D5	Deep 5	6,894	9.65E+00	10,750	7,047	8.18E-01	5,515	5.47E-04	2,206	1.00E-04
BW-66D5	Deep 5	7,660	8.17E-01	9,466	8,131	8.90E-01	5,170	5.88E-04	7,660	5.88E-04
BW-11B	Bedrock	657	1.88E-01	1,739	979	1.35E-01	919	2.86E-04	574	1.34E-04
BW-36B	Bedrock	1,915	1.15E-01	8,580	2,202	9.46E-02	718	7.17E-05	574	2.58E-05
BW-37B	Bedrock	1,293	1.48E-01	1,247	1,592	1.24E-01	574	1.11E-04	574	4.27E-05
BW-64B	Bedrock	957	3.83E-01	2,166	1,555	3.16E-01	574	2.31E-04	191	2.31E-03
MW-5B	Bedrock	479	3.83E-02	304	413	2.30E-02	259	1.90E-05	345	1.90E-05

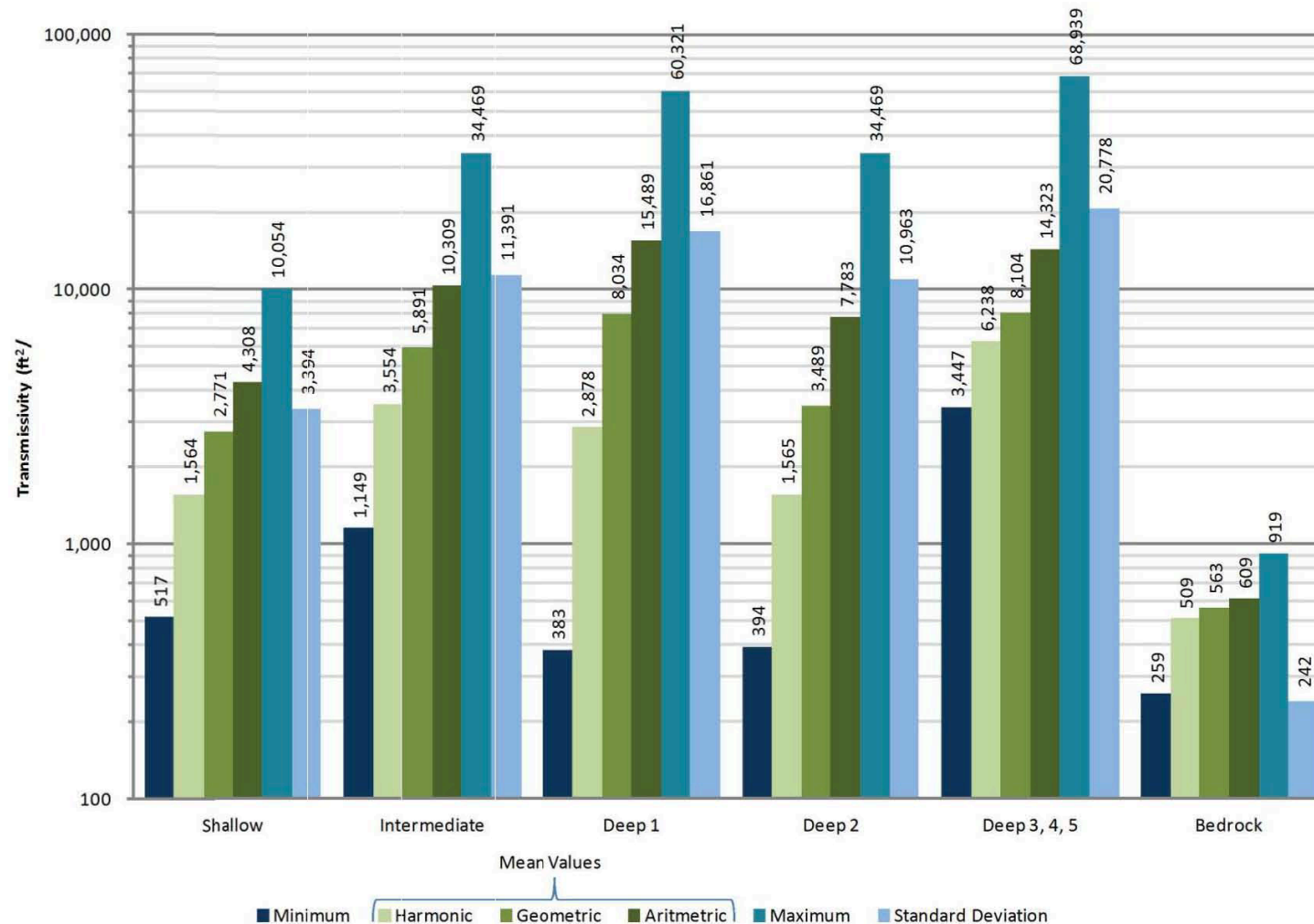
Transmissivity values provided in ft²/d, Storativity is unitless

Table 7-2. Statistical Measures for Aquifer Hydraulic Properties

Zone	Geometric Mean		Arithmetic Mean		Harmonic Mean		Minimum		Maximum		Standard Deviation	
	Transmissivity	Storativity	Transmissivity	Storativity	Transmissivity	Storativity	Transmissivity	Storativity	Transmissivity	Storativity	Transmissivity	Storativity
Shallow	2,771	1.45E-04	4,308	2.52E-03	1,564	3.04E-04	517	6.84E-05	10,054	1.34E-02	3,394	3.92E-03
Intermediate	5,891	1.14E-03	10,309	3.71E-03	3,554	6.33E-04	1,149	1.99E-04	34,469	2.50E-02	11,391	8.03E-03
Deep 1	8,034	1.50E-03	15,489	6.42E-03	2,878	5.93E-04	383	7.41E-05	60,321	7.32E-02	16,861	1.85E-02
Deep 2	3,489	3.77E-04	7,783	5.17E-04	1,565	2.09E-04	394	5.26E-05	34,469	8.20E-04	10,963	2.96E-04
Deep 3	7,562	1.12E-03	12,259	1.74E-03	5,900	8.26E-04	3,447	4.67E-04	45,959	5.80E-03	16,589	2.05E-03
Deep 4 ¹	68,939	3.31E-03	68,939	3.31E-03	68,939	3.31E-03	68,939	3.31E-03	68,939	3.31E-03	NA	NA
Deep 5	5,482	7.59E-04	5,620	8.69E-04	5,354	6.91E-04	4,136	5.47E-04	7,660	1.75E-03	1,480	5.87E-04
Deep 3, 4, 5	8,104	1.01E-03	14,323	1.48E-03	6,238	7.87E-04	3,447	4.67E-04	68,939	5.80E-03	20,778	1.60E-03
Bedrock	563	9.99E-05	609	1.44E-04	509	5.99E-05	259	1.90E-05	919	2.86E-04	242	1.11E-04

Transmissivity values provided in ft²/d, Storativity is unitless

1 Only one monitor well in the Deep 4 zone, no statistical data



**Brown AND
Caldwell**

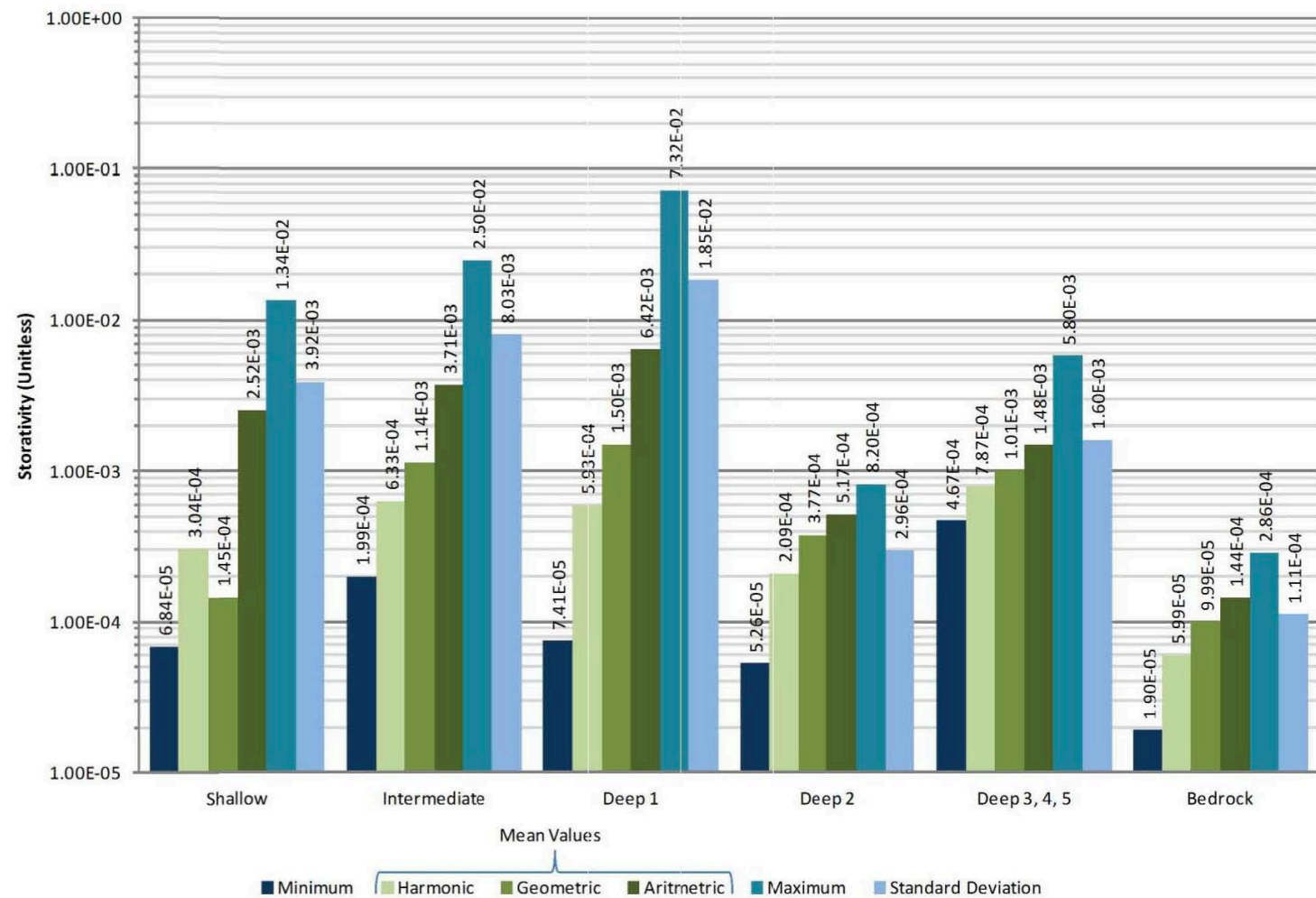
Date: Apr. 2012

Atlantic Richfield
Company

Project: 140332

**Yerington Mine
Site, Nevada**

Figure 7-1
**Statistical Measures
of Transmissivity**



**Brown AND
Caldwell**

Date: Apr. 2012

Atlantic Richfield
Company

Project: 140332

**Yerington Mine
Site, Nevada**

**Figure 7-2
Statistical Measures
of Storativity**