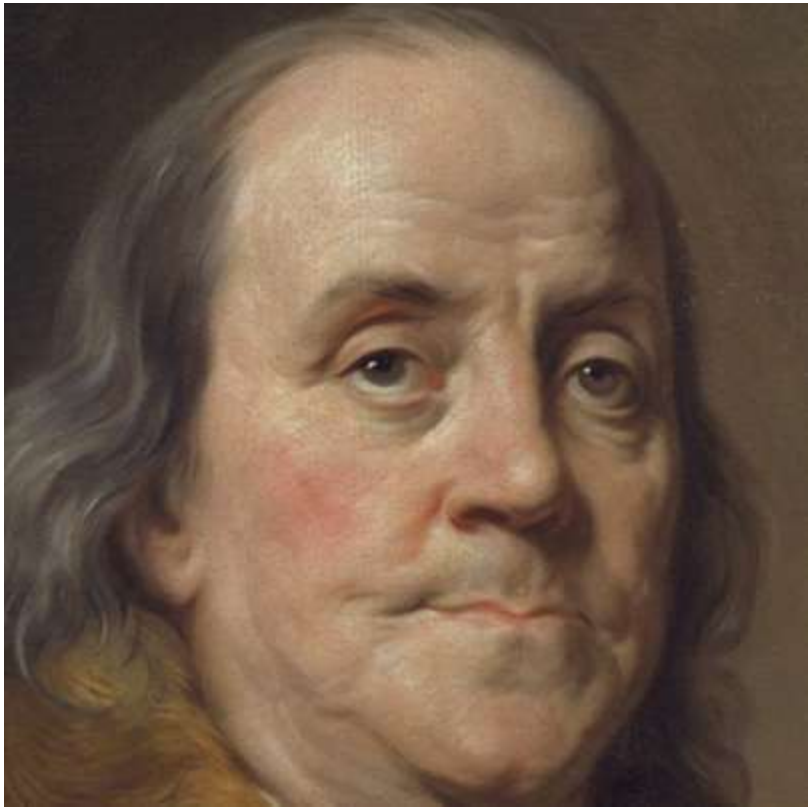
NORAD supported project in MRRD covering
Capacity Building and Institutional Cooperation in the
field of Hydrogeology for Faryab Province
Afghanistan

Hydrogeology Course 1.11.2
Practical Pumping Test Interpretation

By Andreas de Jong
October 2015

NORPLAN



"When the well's dry,
we know the worth of water."
Benjamin Franklin (1706 - 1790)

PURPOSE OF THIS COURSE

The purpose of this course is to practise:

1. Interpretation of pumping test data, using the Faryab pumping test carried out by the project.
2. Aquifer sustainability estimations.
3. Writing a pumping test report.

KEY REFERENCES & Resources

Kruseman & de Ridder, (1994), Analysis and Evaluation of Pumping Test Data; ILRI publication 47.
Available online: http://www.hydrology.nl/key-publications/93-analysis-and-evaluation-of-pumping-test-data-1970.html

Glenn M. Duffield, Aquifer Testing Reference List:
http://www.aqtesolv.com/aquifer-tests/aquifer-testing-references.htm

Hydrogeological Toolbox: www.geosearch.co.uk

Carlos Molano Web Site:
https://sites.google.com/a/hidrogeocol.com.co/carlos_molano

Tentative Course Schedule

Day	Date	Activity
1	Sunday 25/10/15	Opening & Introduction Practical: Interpretation of Faryab pumping Tests
2	Monday 26/10/15	Practical: Sustainable Yield Calculations Practical: Pumping Test Report

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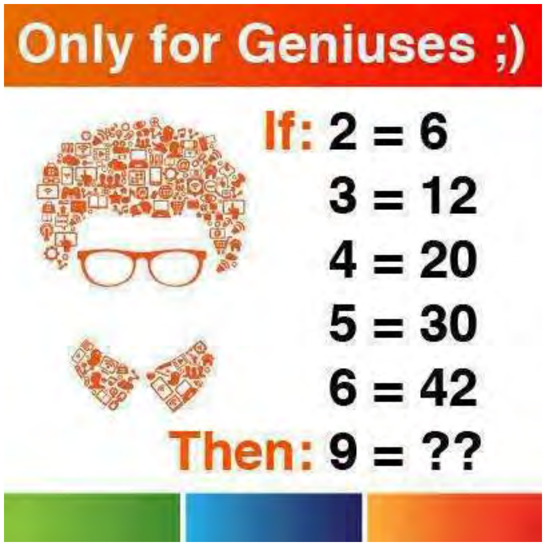
What you will need for this course (1)



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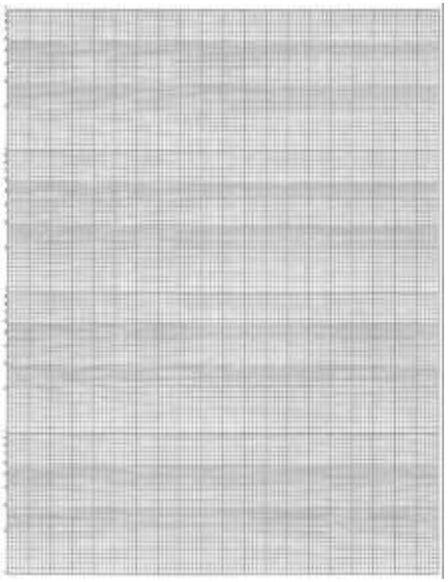

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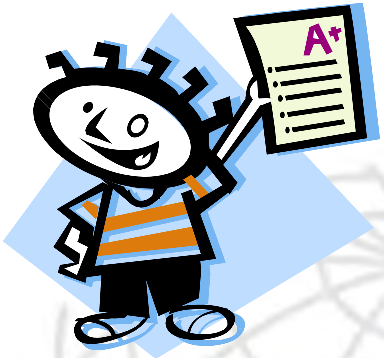

What you will need for this course (2)

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TOPICS TO BE COVERED

1. Well performance tests / Step tests
2. Constant Rate Pumping Test
3. Recovery Test
4. Calculating the “Safe Yield” of a Well

PART 1 – Well Performance Tests

1. Hantush – Bierschenk Method
2. Rorabough Method

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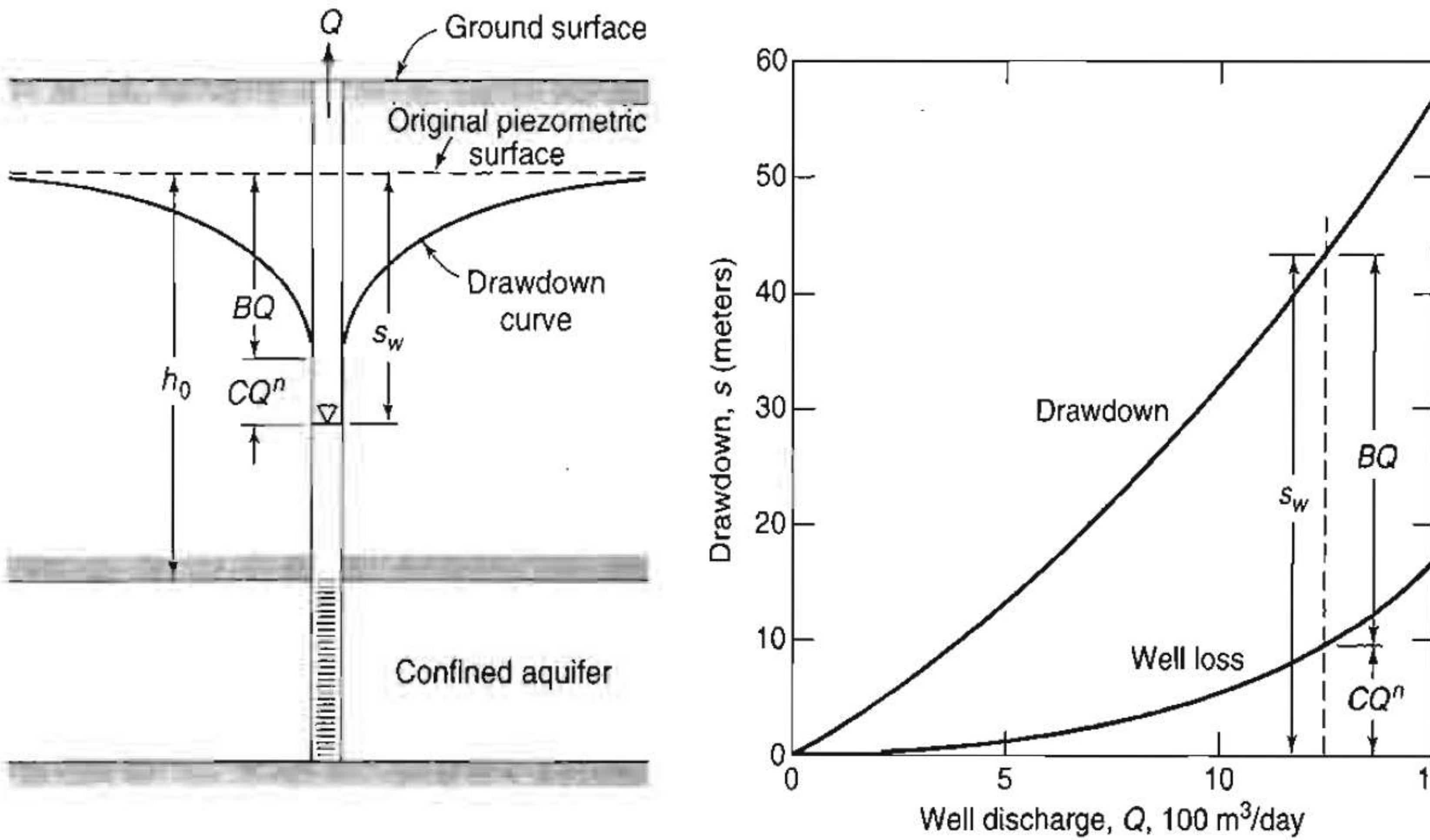
Aquifer & Well Loss Components of Drawdown



Source: Todd, 2005; Groundwater Hydrology 3rd Ed.

Aquifer & Well Loss Components of Drawdown

Jakob's equation (1947) $s_w = B(r_{ew}, t)Q + CQ^2$

$B(r_{ew}, t) = B_{1(r_w,t)} + B_2$

$B_{1(r_w,t)}$= linear aquifer loss coefficient

B_2 = linear well loss coefficient

C = non-linear well loss coefficient

r_{ew}= effective radius of the well

r_w= actual radius of the well

t= pumping

Aquifer & Well Loss Components of Drawdown

$$s_w = BQ + CQ^n$$

Assuming n= 2,

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

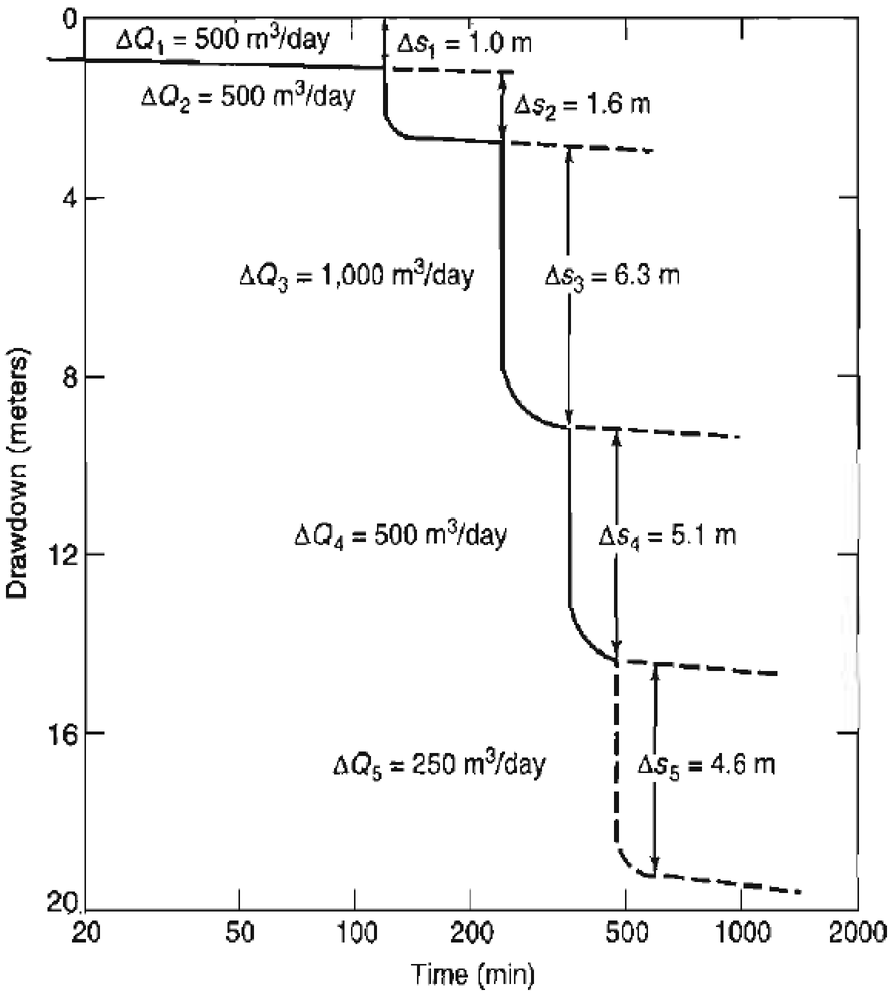
Table 5.11.1 Relation of Well Loss Coefficient to Well Condition (after Walton[10])

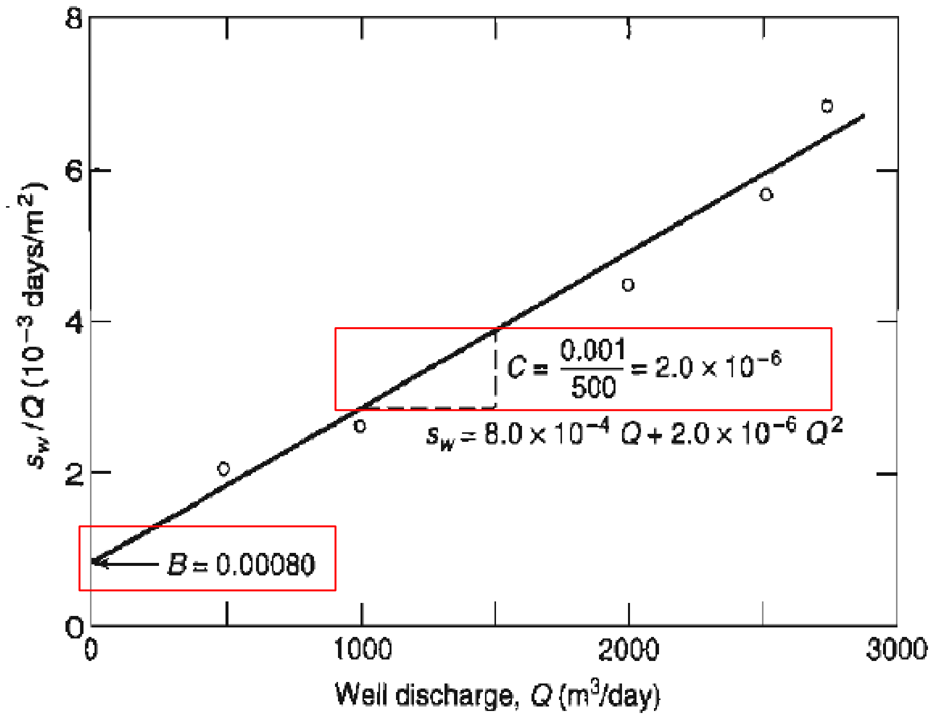
Well loss coefficient C (min^2/m^5)	Well condition
< 0.5	Properly designed and developed
0.5 to 1.0	Mild deterioration or clogging
1.0 to 4.0	Severe deterioration or clogging
> 4.0	Difficult to restore well to original capacity

Source: Todd, 2005; Groundwater Hydrology 3rd Ed.

Step-drawdown Test or "Step Test" Analysis

Hantush – Bierschenk Method





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

Source: Todd, 2005; Groundwater Hydrology 3rd Ed.

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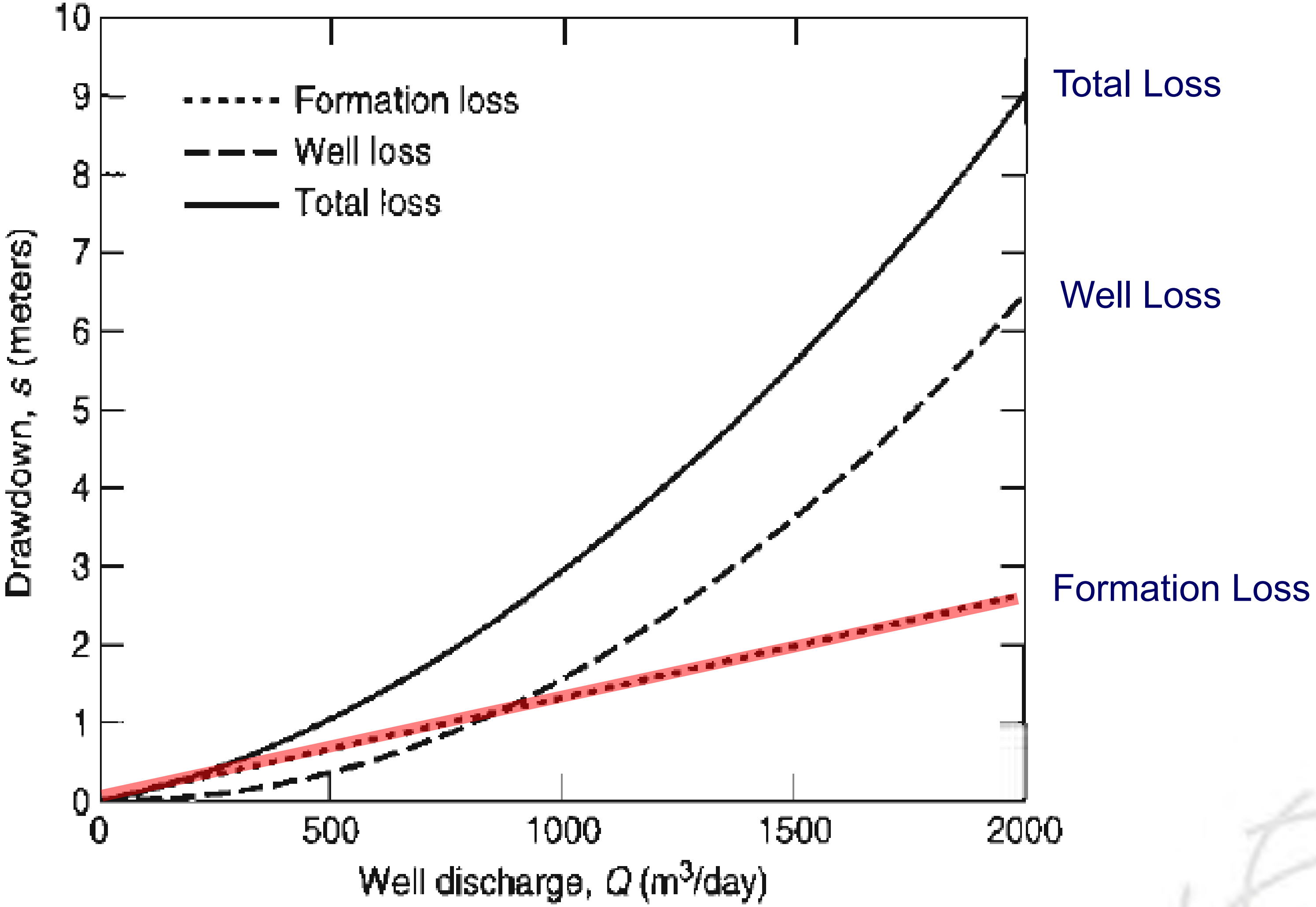
Well & Formation Losses



Source: Todd, 2005; Groundwater Hydrology 3rd Ed.

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Well Performance Tests

Well Efficiency

$$E_w = \left\{ \frac{B_1 Q}{(B_1 + B_2)Q + CQ^P} \right\} \times 100\%$$

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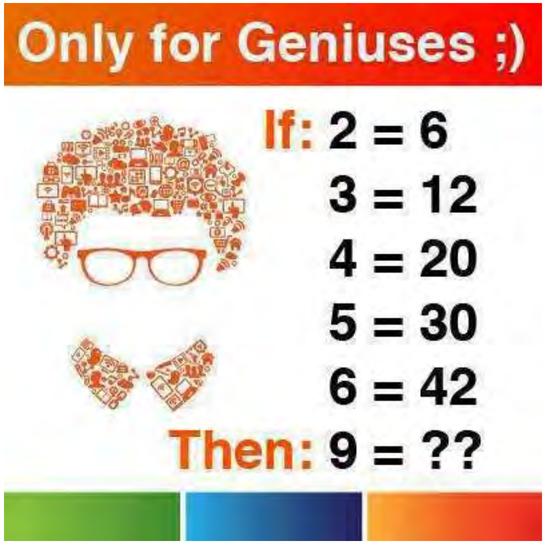
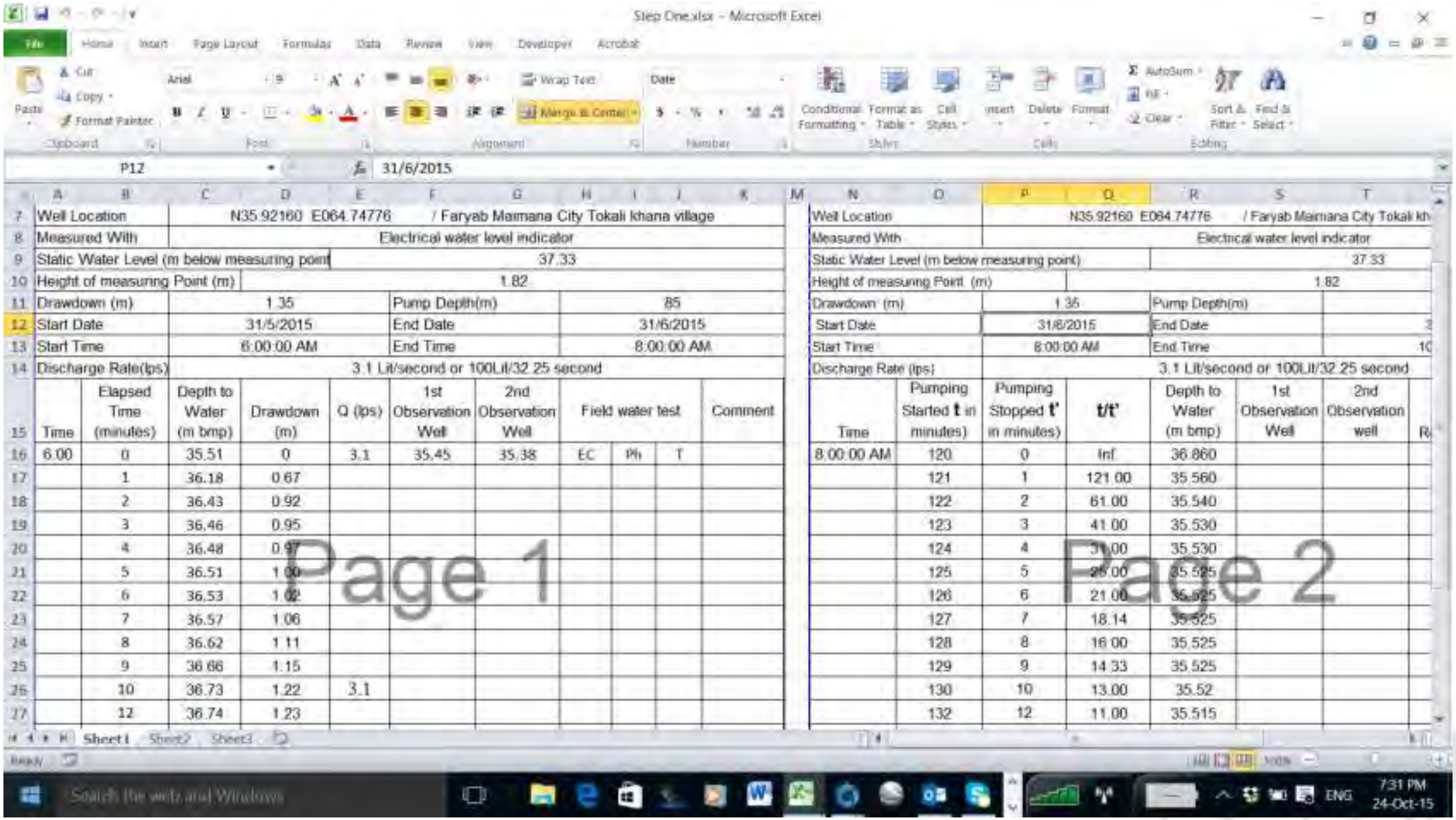
Step Test Practical



Step Test Practical (1)

Tasks: Import the Excel Data into a usable format.



Step One.xlsx - Microsoft Excel

P12 31/6/2015

Well Location	N35.92160 E064.74776 / Faryab Maimana City Tokali khana village									
Measured With	Electrical water level indicator									
Static Water Level (m below measuring point	37.33									
Height of measuring Point (m)	1.82									
Drawdown (m)	1.35			Pump Depth(m)	85					
Start Date	31/5/2015			End Date	31/6/2015					
Start Time	6:00:00 AM			End Time	8:00:00 AM					
Discharge Rate(lps)	3.1 Lit/second or 100Lit/32.25 second									
Time	Elapsed Time (minutes)	Depth to Water (m bmp)	Drawdown (m)	Q (lps)	1st Observation Well	2nd Observation Well	Field water test			Comment
6.00	0	35.51	0	3.1	35.45	35.38	EC	Ph	T	
	1	36.18	0.67							
	2	36.43	0.92							
	3	36.46	0.95							
	4	36.48	0.97							
	5	36.51	1.00							
	6	36.53	1.02							
	7	36.57	1.06							
	8	36.62	1.11							
	9	36.66	1.15							
	10	36.73	1.22	3.1						
	12	36.74	1.23							

Page 1

Well Location	N35.92160 E064.74776 / Faryab Maimana City Tokali kh					
Measured With	Electrical water level indicator					
Static Water Level (m below measuring point)			37.33			
Height of measuring Point (m)		1.82				
Drawdown (m)	1.35		Pump Depth(m)			
Start Date	31/6/2015		End Date		3	
Start Time	8:00:00 AM		End Time		10	
Discharge Rate (lps)	3.1 Lit/second or 100Lit/32.25 second					
Time	Pumping Started **t** in minutes)	Pumping Stopped **t'** in minutes)	**t/t'**	Depth to Water (m bmp)	1st Observation Well	2nd Observation well
8:00:00 AM	120	0	Inf	36.860		
	121	1	121.00	35.560		
	122	2	61.00	35.540		
	123	3	41.00	35.530		
	124	4	31.00	35.530		
	125	5	25.00	35.525		
	126	6	21.00	35.525		
	127	7	18.14	35.525		
	128	8	16.00	35.525		
	129	9	14.33	35.525		
	130	10	13.00	35.52		
	132	12	11.00	35.515		

Page 2

Sheet1 Sheet2 Sheet3

Next time please use the FIELD SHEETS PROVIDED!!!!!!

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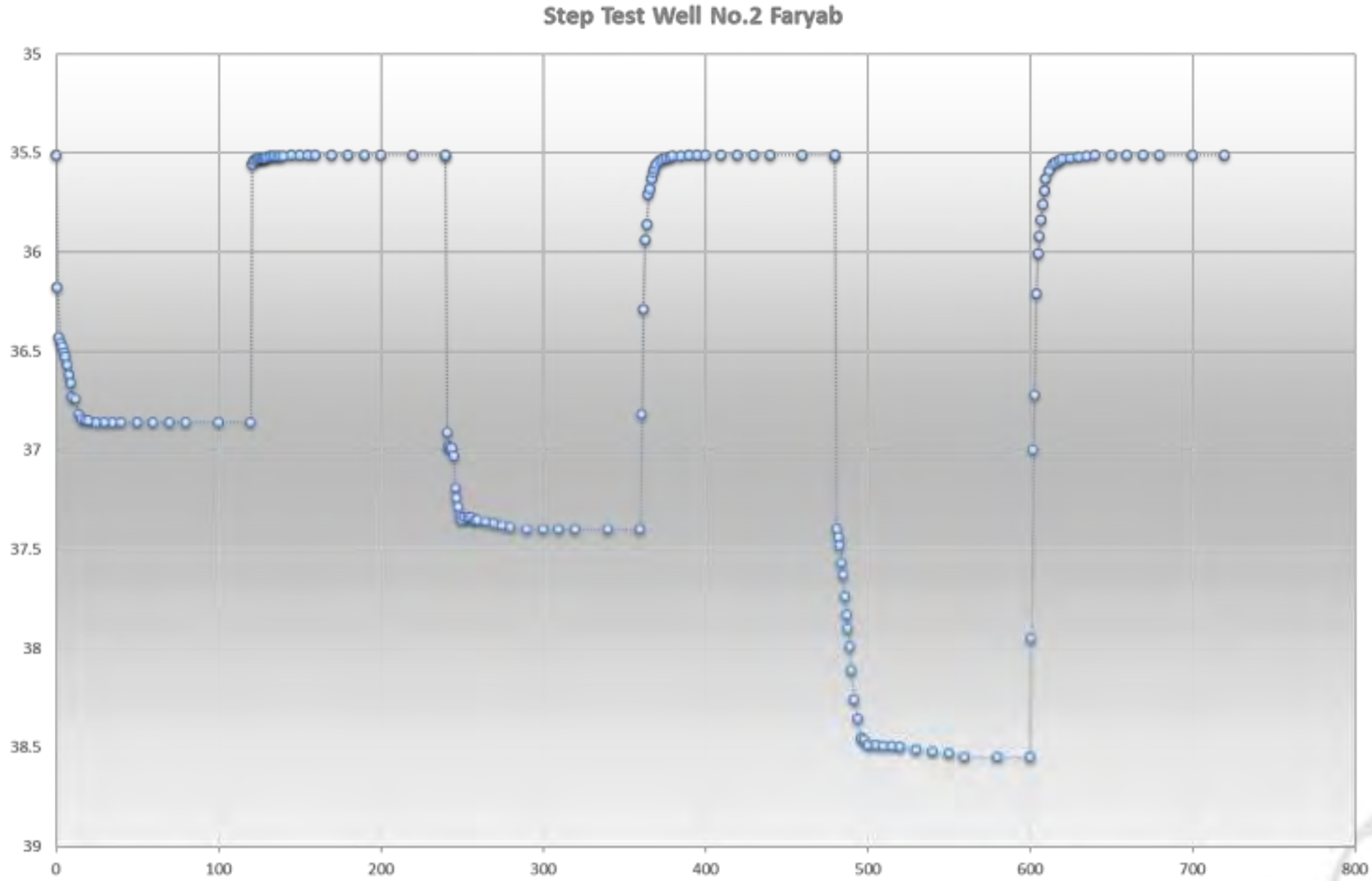
Step Test Practical (2)

Tasks: Plot the data and have a look at it



It is USUAL to do at least 4 steps.
There is NO NEED for a full recovery after all steps.

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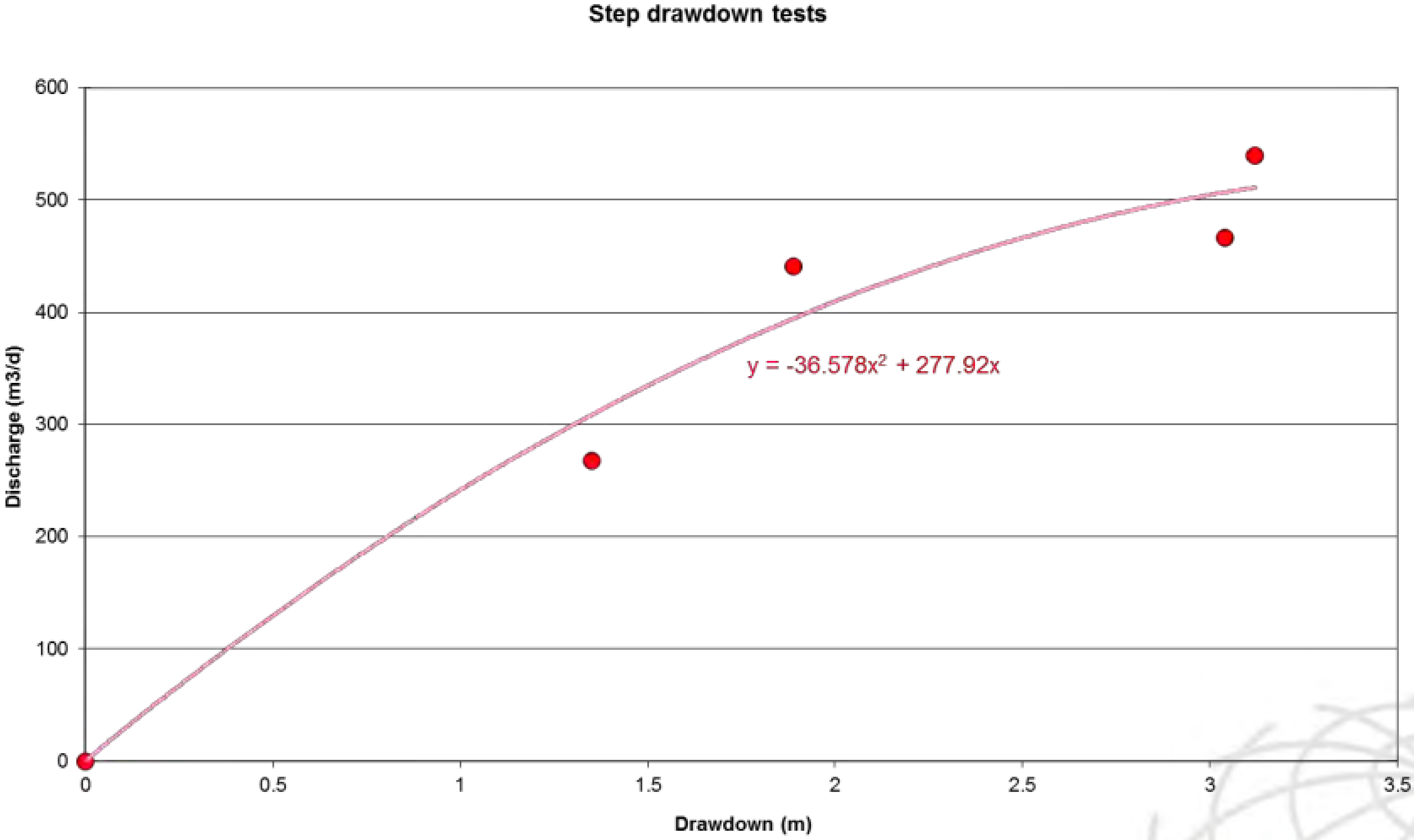
Step Test Practical (2)

Tasks: Plot the data and have a look at it



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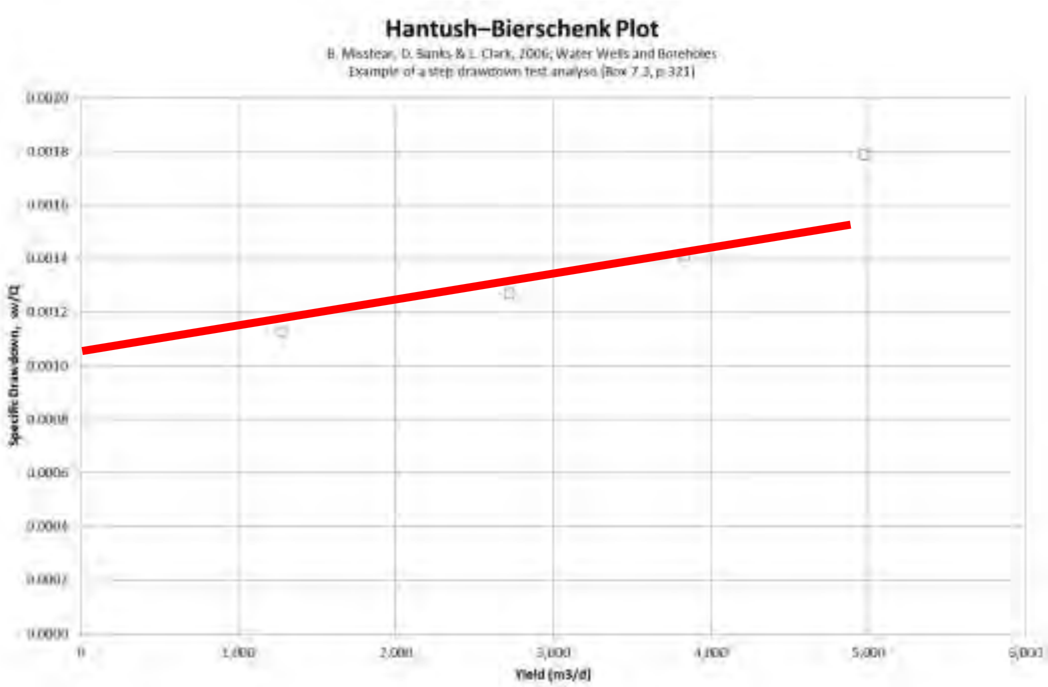
Step Test Practical (3)

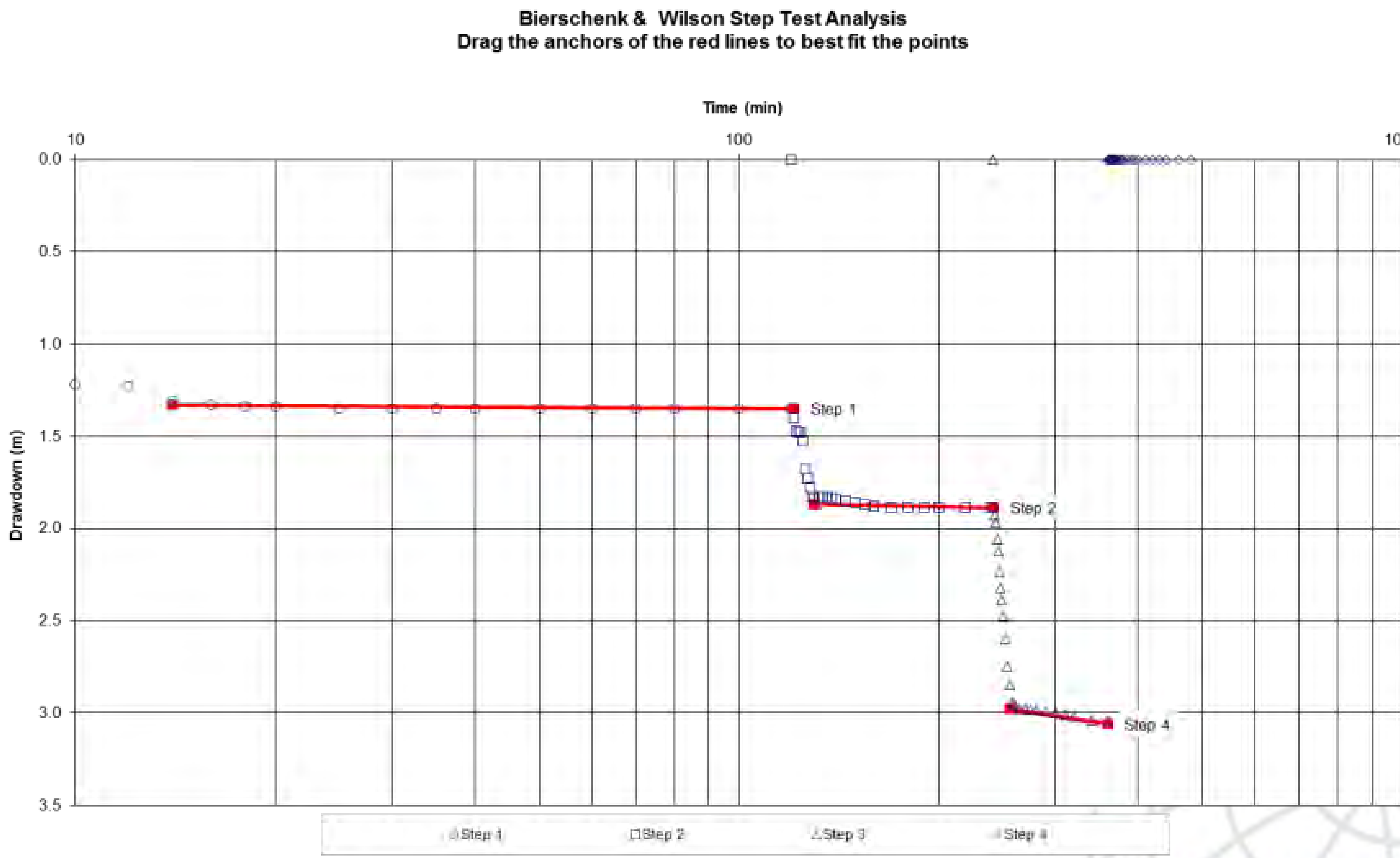
Tasks:

Use MS Excel to analyse this data, using the Hantush–Bierschenk method.

1) Calculate B, C & Well efficiency for each step.
2) Plot drawdown, well & formation losses v. Discharge
3) Estimate the transmissivity using the Logan approximation.



Step Test Practical (4) – Step Test XL V1.0



Source: www.geosearch.co.uk

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TOPICS TO BE COVERED

1. Well performance tests / Step tests
2. Constant Rate Pumping Test
3. Recovery Test
4. Calculating the “Safe Yield” of a Well

PART 2 – Constant Rate Pumping Test

1. Unsteady State Flow
   - Cooper & Jakob's Straight Line Method
   - Newman Method (unconfined aquifers)

2. Steady State Flow
   - Dupuit Method (unconfined aquifers)

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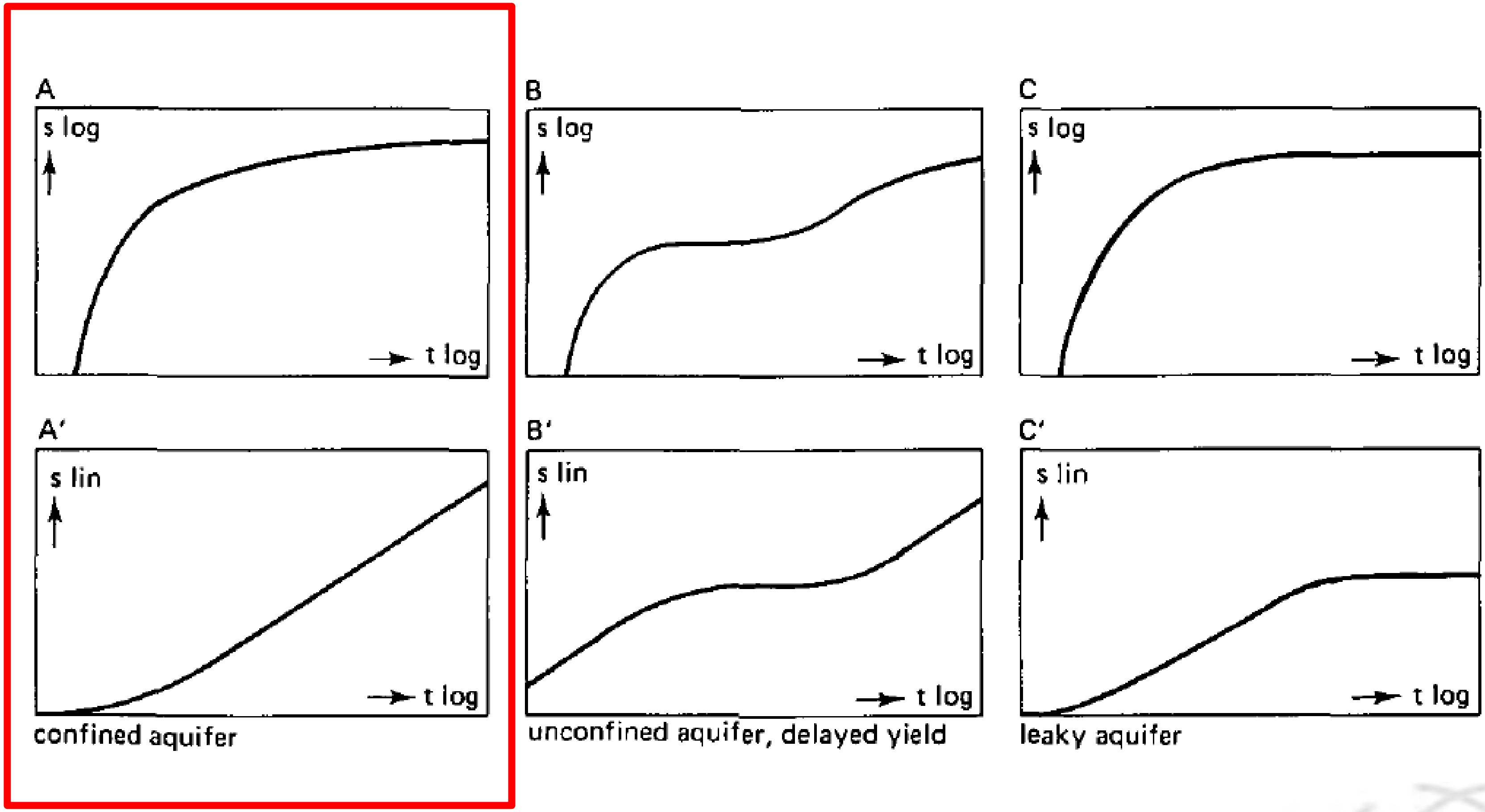
Data Interpretation – unconsolidated aquifers



Source: Kruseman & de Ridder, (1994), Analysis and Evaluation of Pumping Test Data; ILRI publication 47.

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Confined Aquifers: Unsteady-State Flow

Theis' equation (1935)

$$s = \frac{Q}{4\pi T}\int_u^\infty \frac{e^{-y}dy}{y} = \frac{Q}{4\pi T} W(u)$$

s = the drawdown in m measured in a piezometer at a distance r in m from the well.
Q = the constant well discharge in m^3/d
T = the transmissivity of the aquifer in m^2/d
S = the dimensionless aquifer storativity
t = the time in days since pumping started
u = $r^2S/4Tt$
W(u) = $-0.5772 - \ln u + u - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} - \frac{u^4}{4.4!}$ = well function

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Confined Aquifers: Unsteady-State Flow

Theis' equation $$s = \frac{Q}{4\pi T} W(u)$$

$$T = \frac{Q}{4\pi s} W(u)$$

$$S = \frac{4Ttu}{r^2} = \frac{4T(t/r^2)}{1/u}$$

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Confined Aquifers: Unsteady-State Flow

Cooper & Jakob's equation (1946)

$$s = \frac{2.3Q}{4\pi T} log \frac{2.25Tt}{r^2 S}$$

s = the drawdown in m measured in a piezometer at a distance r in m from the well.
Q = the constant well discharge in m^3/d
T = the transmissivity of the aquifer in m^2/d
S = the dimensionless aquifer storativity
t = the time in days since pumping started

OK for small values of u (u<0.01) = later time and greater distances from the pumping well.

Confined Aquifers: Unsteady-State Flow

Cooper & Jakob's equation

$$s = \frac{2.3Q}{4\pi T} log \frac{2.25Tt}{r^2 S}$$

when r is constant

$$T = \frac{2.30Q}{4\pi\Delta s} \qquad S = \frac{2.25Tt_0}{r^2}$$

when t is constant

$$T = \frac{2.30Q}{2\pi\Delta s} \qquad S = \frac{2.25Tt}{{r_0}^2}$$

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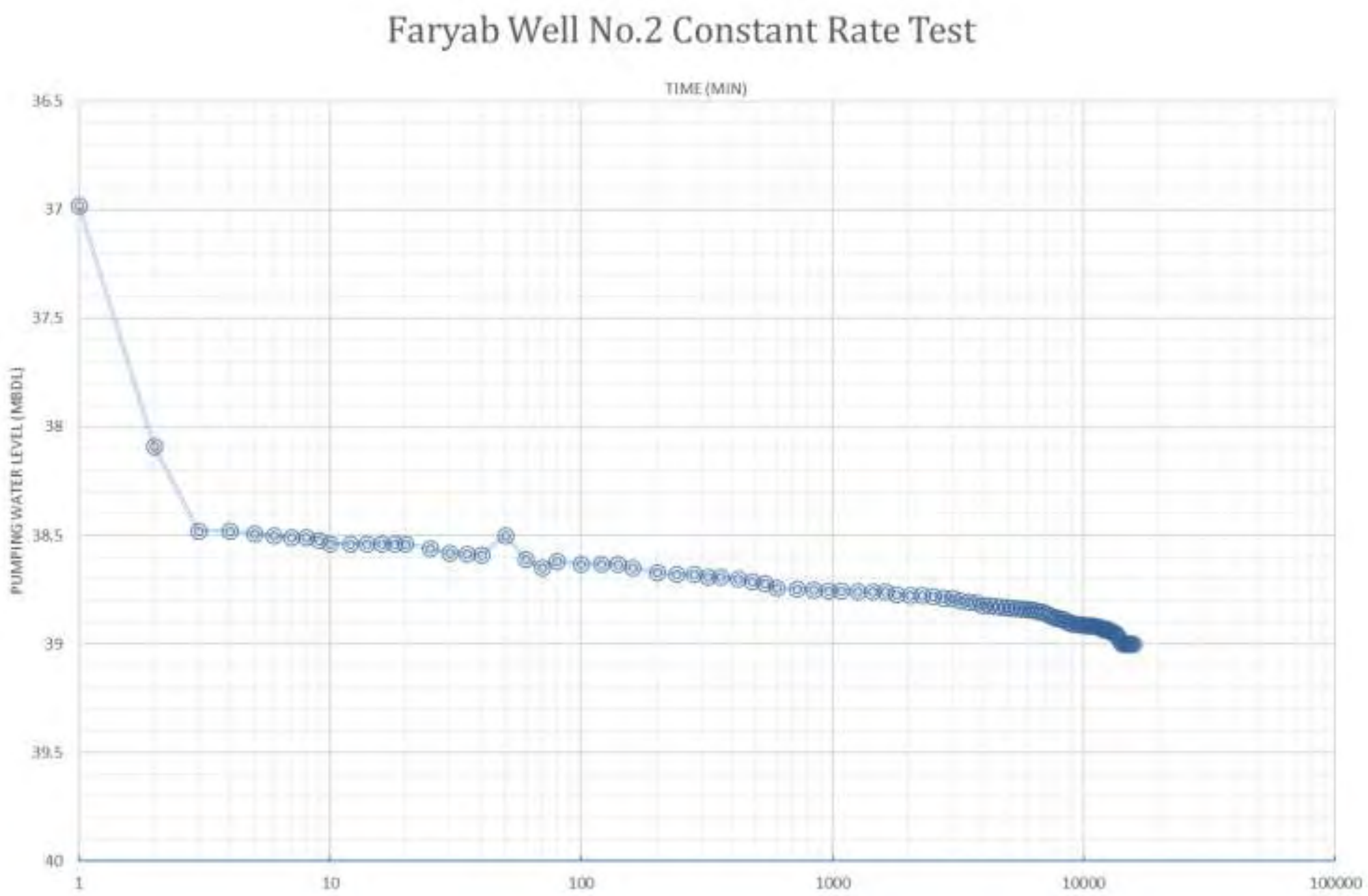
Constant Rate Pumping Test (1)

Tasks: Import the Excel Data & plot it in Excel.



Is it confined, leaky confined or unconfined?

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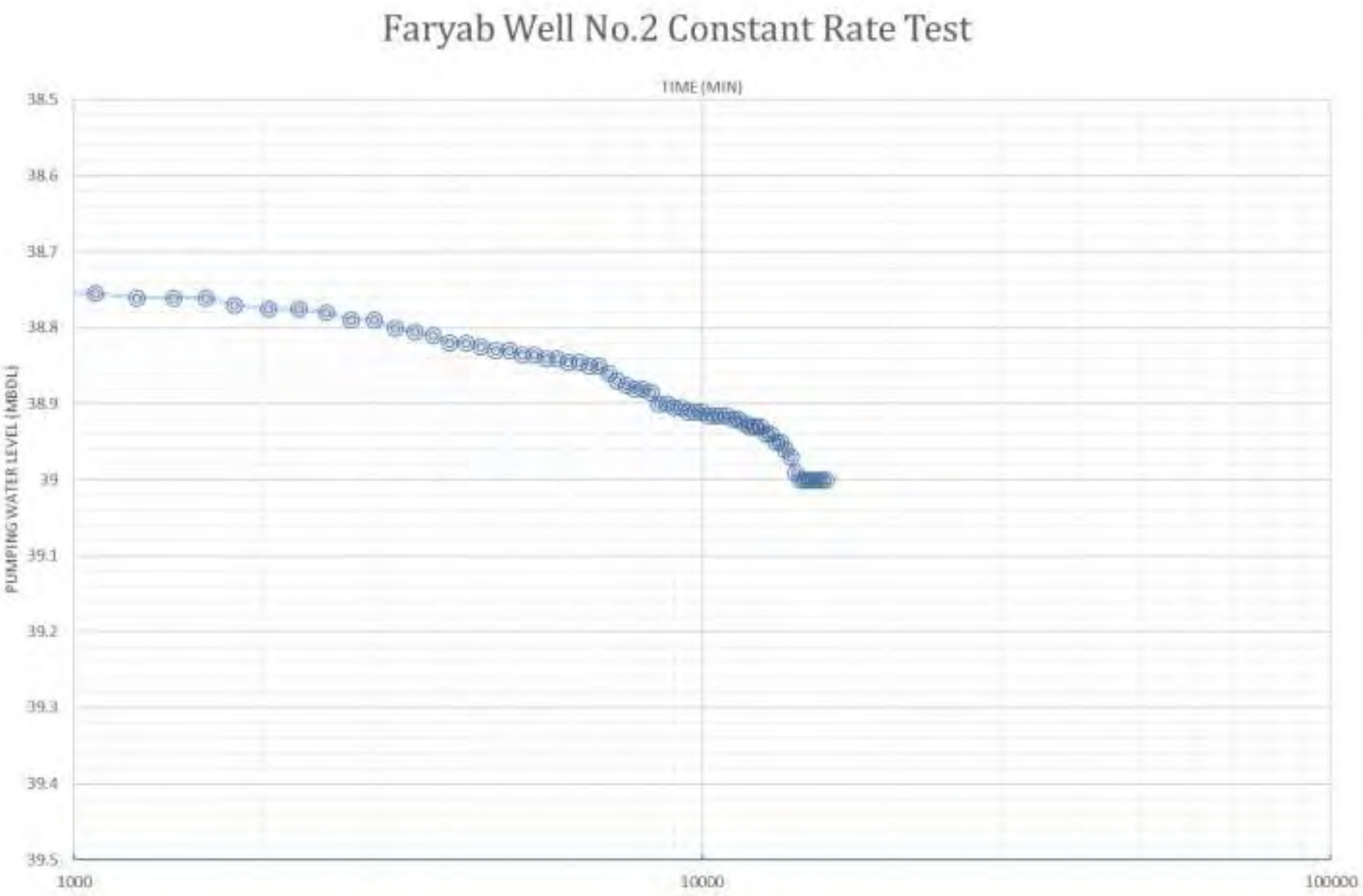
Constant Rate Pumping Test (1)

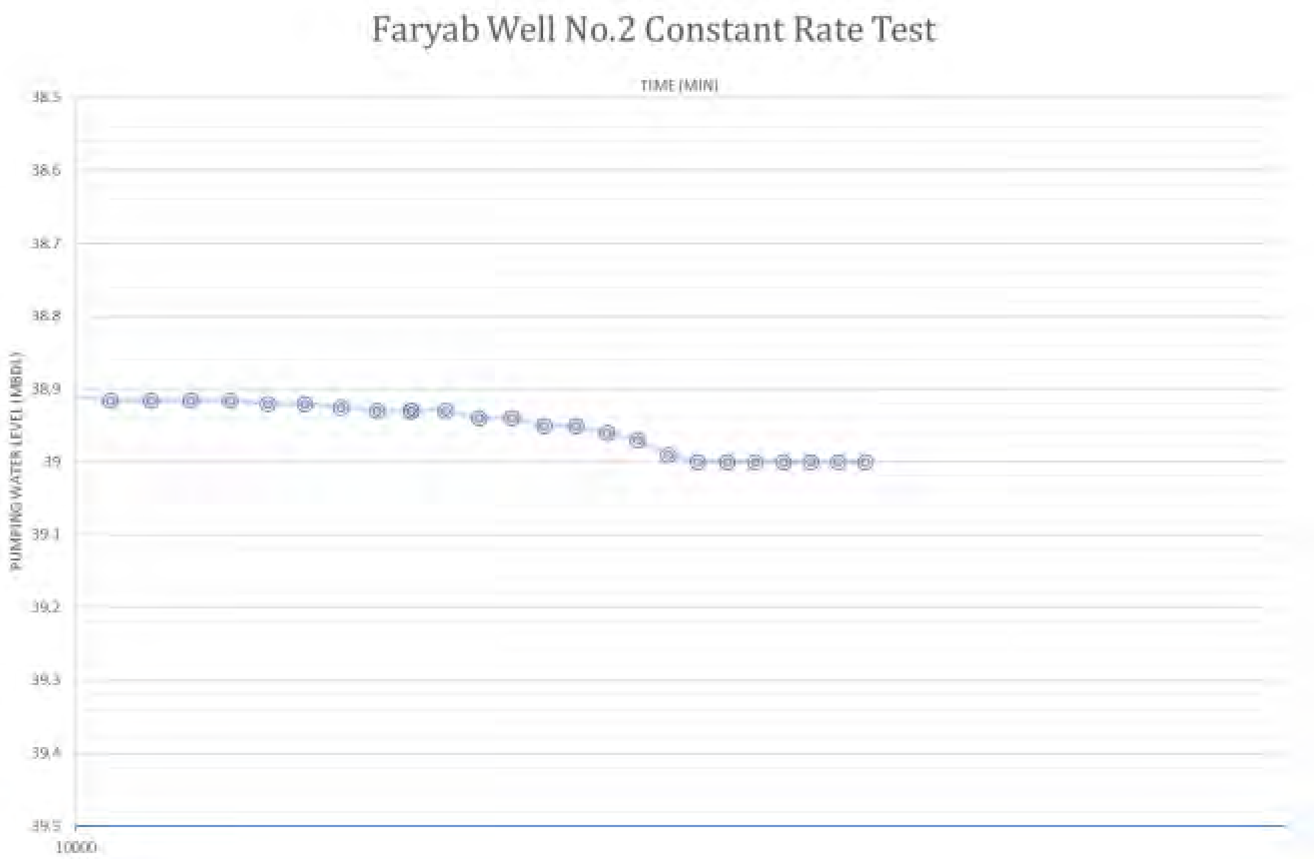
Tasks: Import the Excel Data & plot it in Excel.



What is happening with the late data?

Constant Rate Pumping Test (1)

Tasks: Import the Excel Data & plot it in Excel.



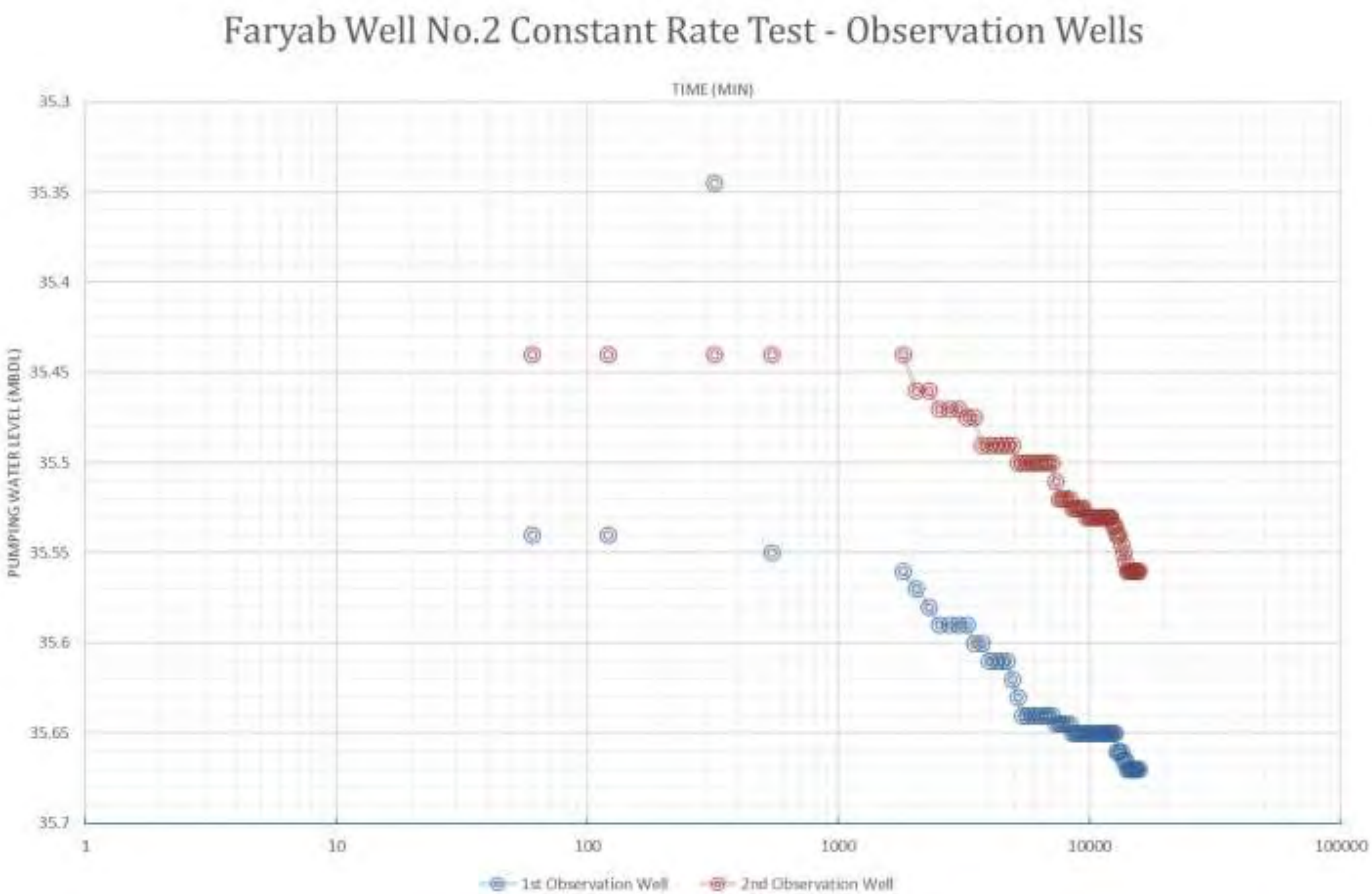
And the very late data – do you think it is real?

Constant Rate Pumping Test (1)

Tasks: Calculate the Transmissivity using the Cooper-Jacob straight line approximation.

Unconfined Aquifers: Non Steady-State Practical

Tasks: Calculate the Transmissivity and Storativity using the Cooper-Jacob straight line approximation.



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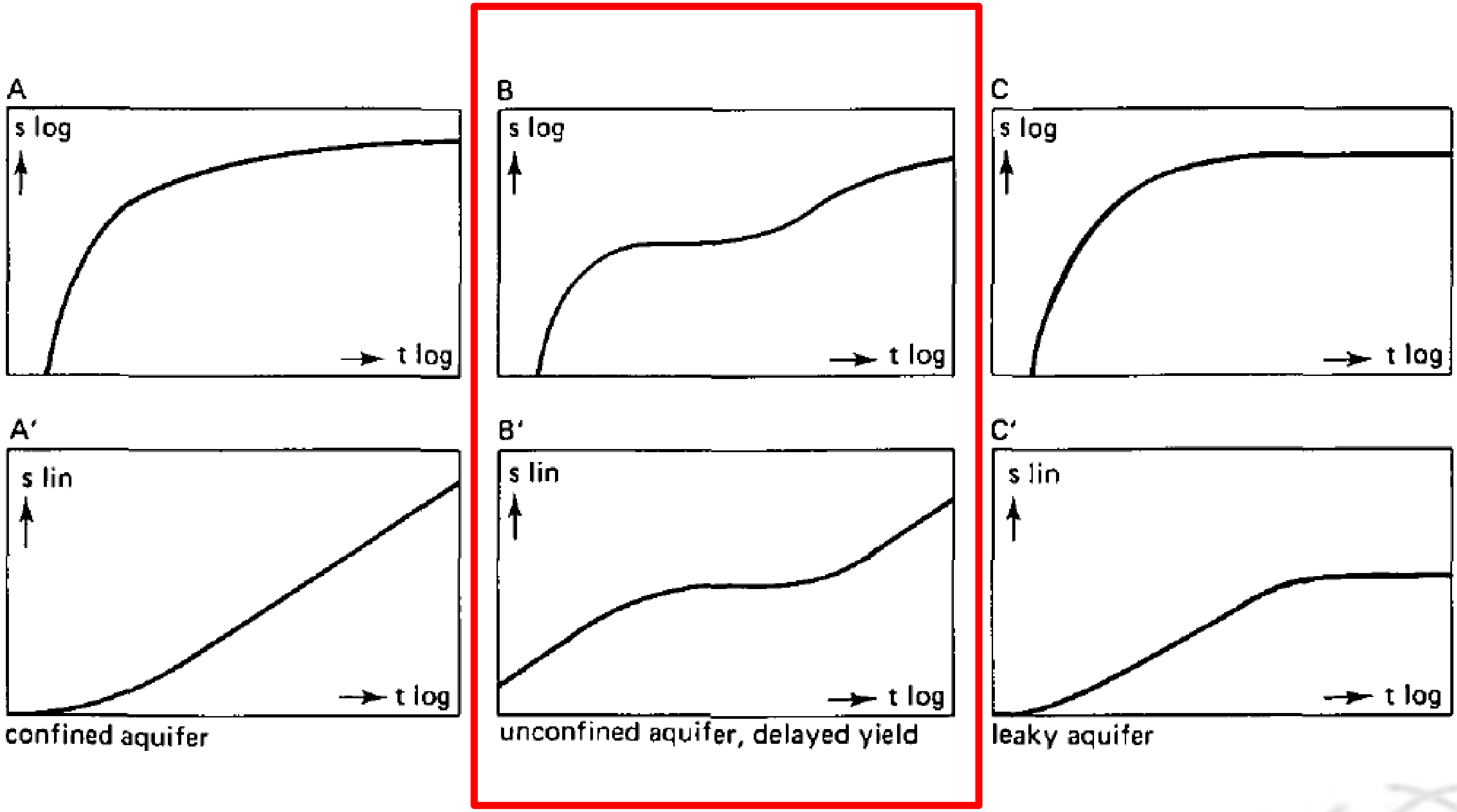
PART 2 – Constant Rate Pumping Test

1. Unsteady State Flow
   - Cooper & Jakob's Straight Line Method
   - Newman Method (unconfined aquifers)

2. Steady State Flow
   - Dupuit Method (unconfined aquifers)

Data Interpretation – unconsolidated aquifers



Source: Kruseman & de Ridder, (1994), Analysis and Evaluation of Pumping Test Data; ILRI publication 47.

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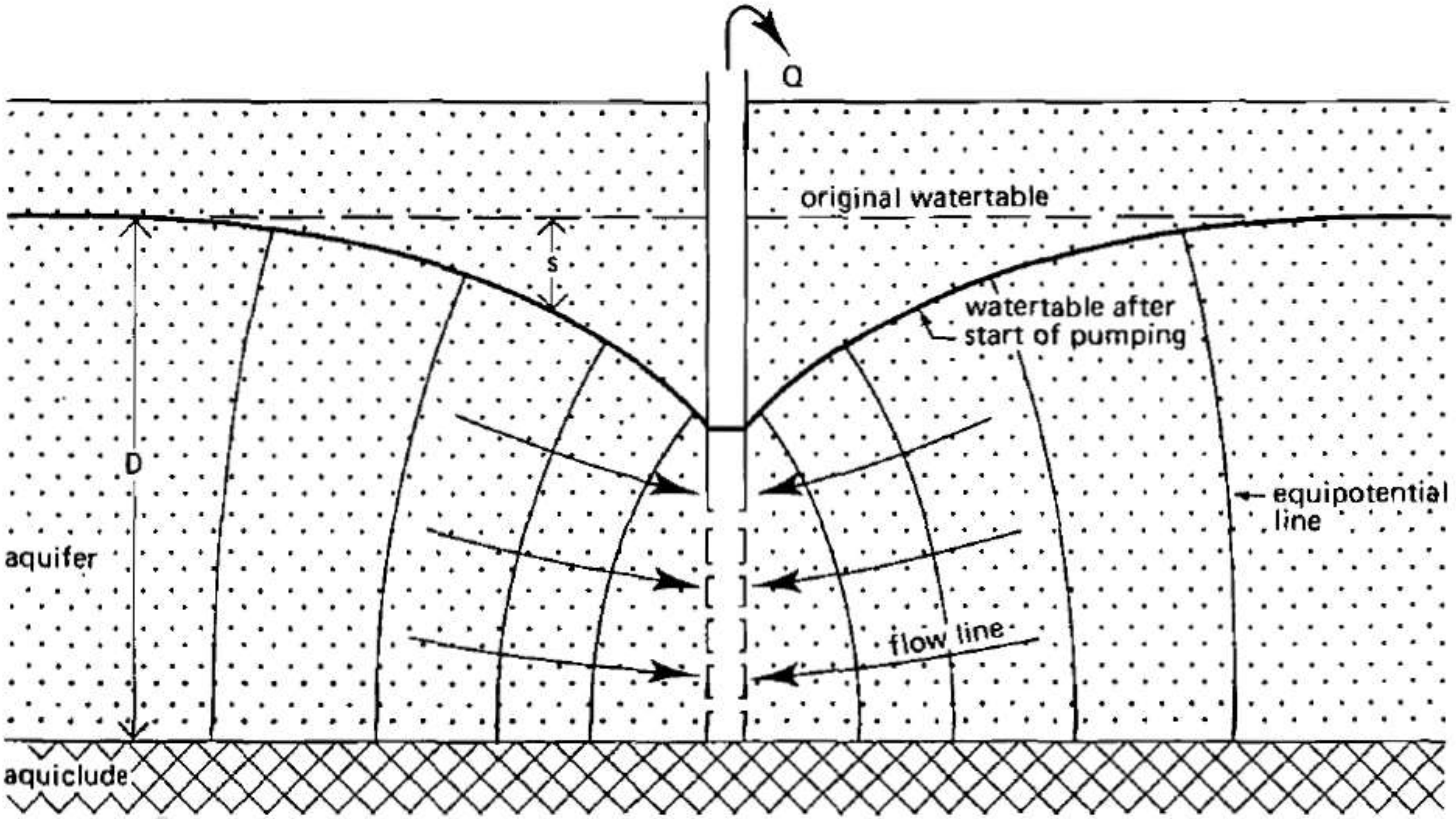
Cross Section of an Unconfined Aquifer



Source: Kruseman & de Ridder, (1994), Analysis and Evaluation of Pumping Test Data; ILRI publication 47.

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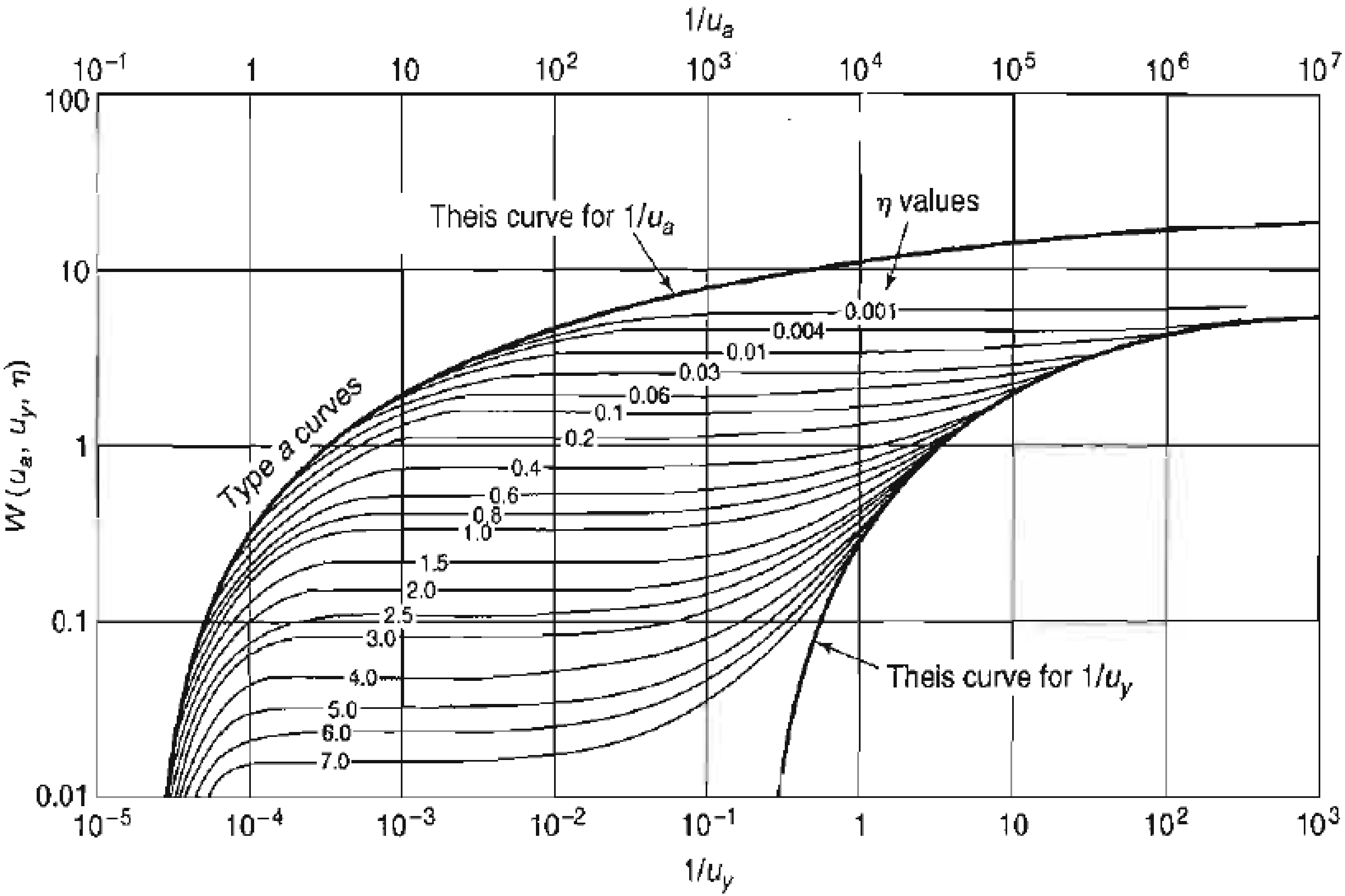
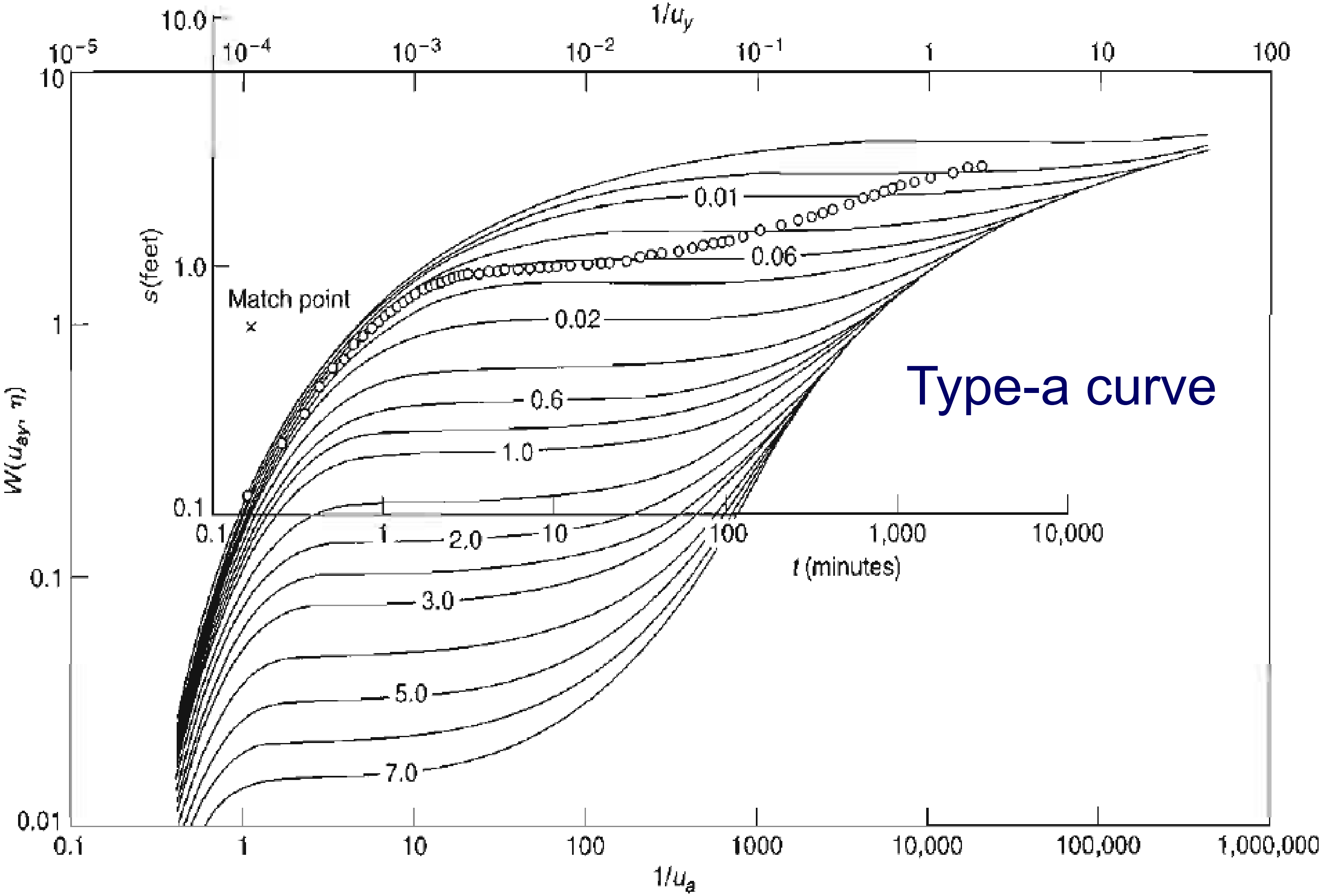
Unconfined Aquifer: Neuman Type curves



Source: Todd, 2005; Groundwater Hydrology 3rd Ed.

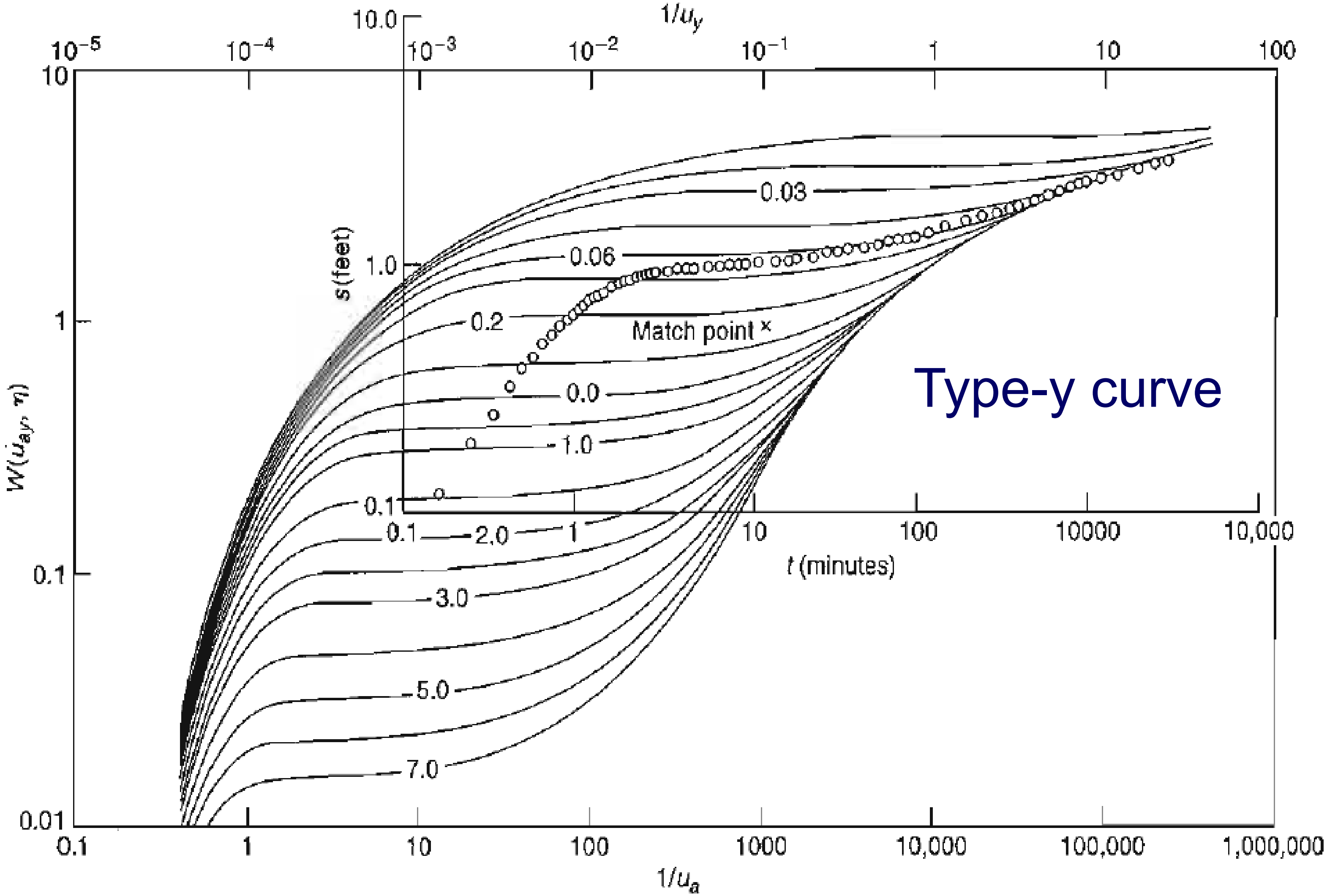
Unconfined Aquifer: Neuman Type curves



Type-a curve

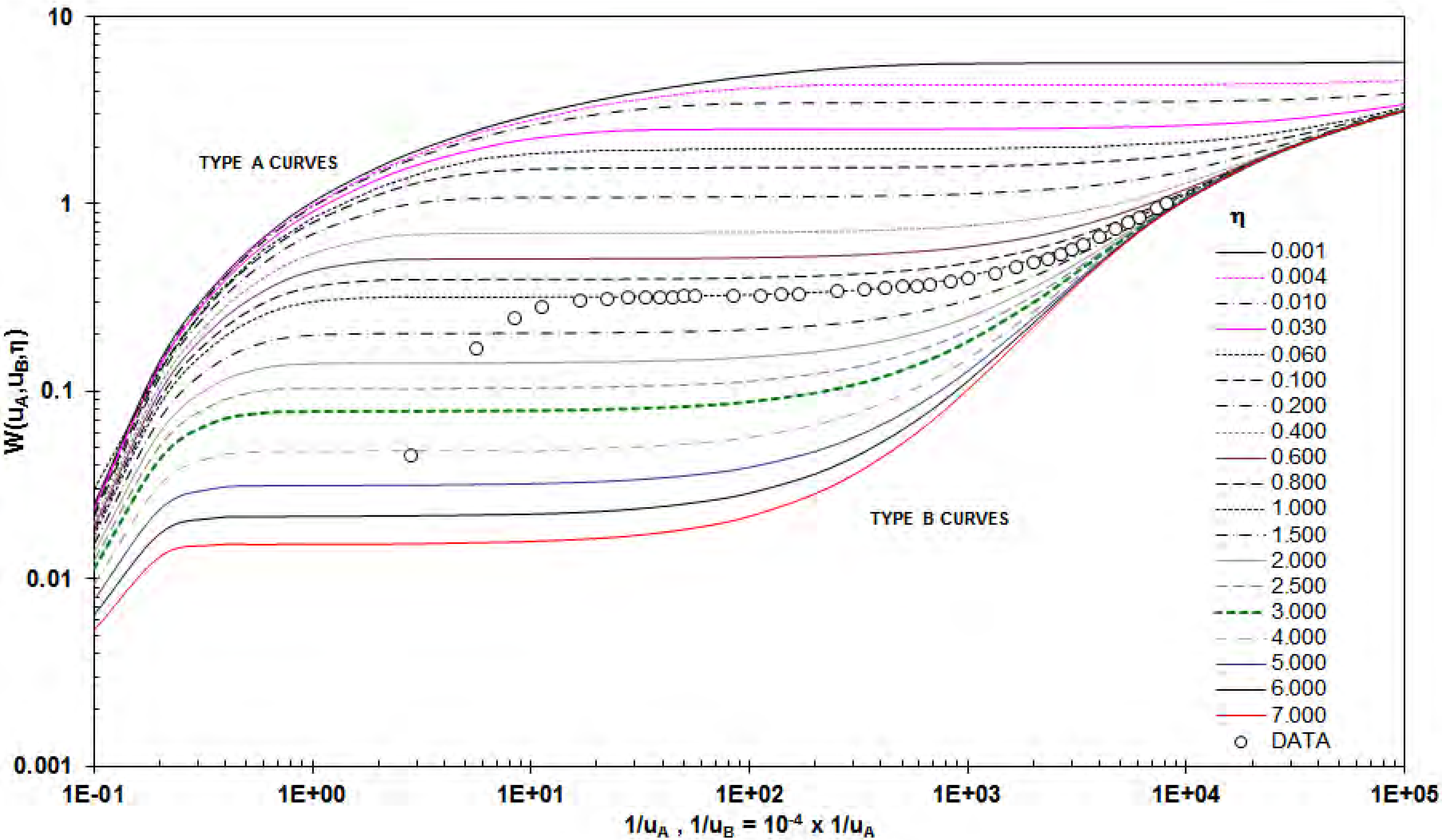
Source: Todd, 2005; Groundwater Hydrology 3[rd] Ed.

Unconfined Aquifer: Neuman Type curves



Source: Todd, 2005; Groundwater Hydrology 3rd Ed.

MS Excel based Neuman Type curves



Source: https://sites.google.com/a/hidrogeocol.com.co/carlos_molano/

Key Assumptions: Unconfined Aquifers (1)

1. The aquifer is unconfined;

2. The aquifer has a seemingly infinite areal extent;

3. The aquifer is homogeneous and of uniform thickness over the area influenced by the test;

Key Assumptions: Unconfined Aquifers (2)

4. Prior to pumping, the watertable is horizontal over the area that will be influenced by the test;

5. The aquifer is pumped at a constant discharge rate;

6. The well penetrates the entire aquifer and thus receives water from the entire saturated thickness of the aquifer.

Unconfined Aquifers: Non Steady-State Flow

Newman's equation (1972)

$$s = \frac{Q}{4\pi T} W(u_A, u_B, \beta)$$

For early time data:

$$s = \frac{Q}{4\pi T} W(u_A, \beta)$$

$$u_A = \frac{r^2 S_A}{4Tt}$$

S_A = volume of water instantaneously released from storage per unit surface area per unit decline in head (= elastic early time storativity)

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Unconfined Aquifers: Non Steady-State Flow

For late time data:

$$s = \frac{Q}{4\pi T} W(u_B, \beta)$$

$$u_B = \frac{r^2 S_y}{4Tt}$$

S_y = volume of water released from storage per unit surface area per unit decline of the water table (= specific yield released by dewatering of the aquifer)

Unconfined Aquifers: Non Steady-State Flow

Neuman's parameter $$\beta = \frac{r^2 K_v}{D^2 K_h}$$

K_v = hydraulic conductivity for vertical flow, in m/d
K_h = hydraulic conductivity for horizontal flow, in m/d

For isotropic aquifers, $K_v = K_h$ and $\beta = r^2/D$

Additional Assumptions: Neuman (1)

1. The aquifer is isotropic or anisotropic;

2. The flow to the well is in an unsteady state;

3. The influence of the unsaturated zone upon the drawdown in the aquifer is negligible;

4. $S_y/S_A > 10$;

Additional Assumptions: Neuman (2)

5. An observation well screened over its entire length penetrates the full thickness of the aquifer;

6. The diameters of the pumped and observation wells are small, i.e. storage in them can be neglected.

If drawdown > 5% of saturated aquifer thickness, apply the Jacob correction:

$$s' = s - \left(\frac{s^2}{2D}\right)$$

s' = corrected drawdown
s = observed drawdown
D = original aquifer thickness

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Unconfined Aquifers: Unsteady-State Flow

Newman's equation (1972)

$$s = \frac{Q}{4\pi T} W(u_A, u_B, \beta)$$

$$T = \frac{Q}{4\pi s} W(u_A, \beta)$$

$$S_A = \frac{4Ttu_A}{r^2}$$

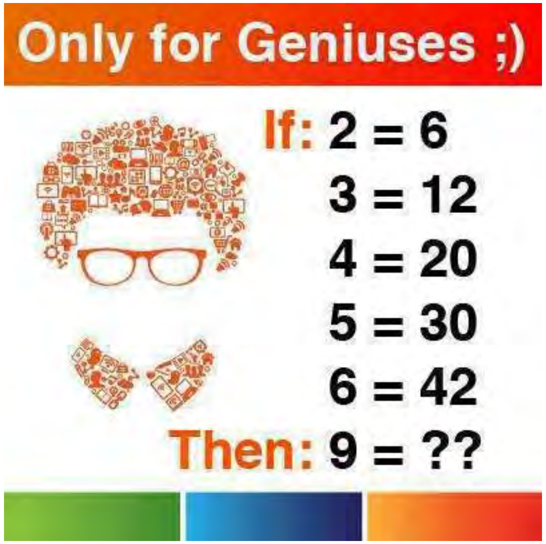
$$T = \frac{Q}{4\pi s} W(u_B, \beta)$$

$$S_y = \frac{4Ttu_B}{r^2}$$

$$K_h = \frac{T}{D}$$

$$K_v = \frac{\beta D^2 K_h}{r^2}$$

Unconfined Aquifers – Unsteady State Practical



PART 2 – Constant Rate Pumping Test

1. Unsteady State Flow
   - Cooper & Jakob's Straight Line Method
   - Newman Method (unconfined aquifers)

2. Steady State Flow
   - Dupuit Method (unconfined aquifers)

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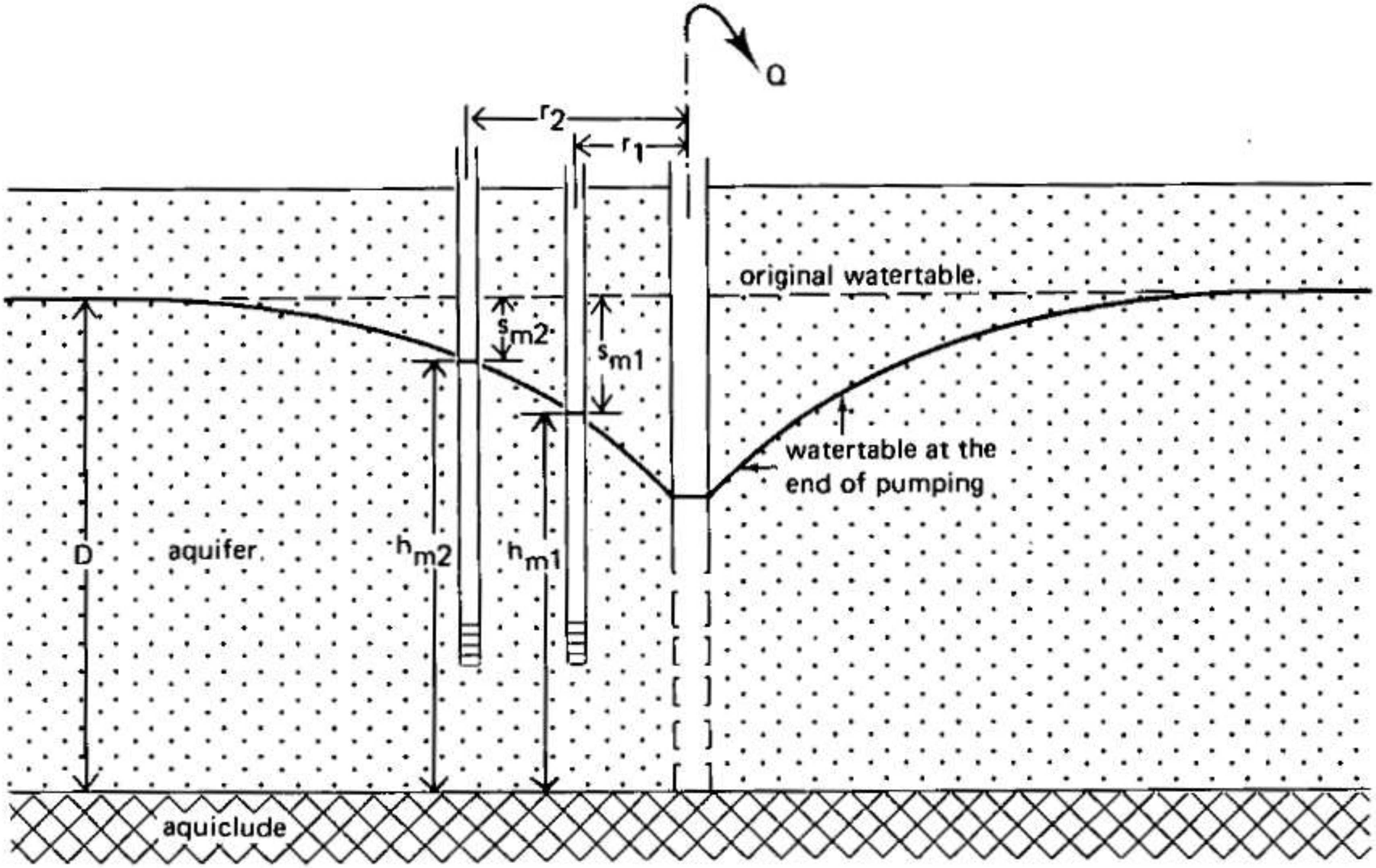
Unconfined Aquifers: Steady-State Flow



Source: Kruseman & de Ridder, (1994), Analysis and Evaluation of Pumping Test Data; ILRI publication 47.

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Unconfined Aquifers: Steady-State Flow

Dupuit's equation

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

$$Q = \pi K \frac{2\pi T\left({s_1}' - {s_2}'\right)}{2.30\, log(r_2/r_1)}$$

Dupuit's equation = Thiem's equation for a confined aquifer

Additional Assumptions: Dupuit

1. The aquifer is isotropic;

2. The flow to the well is in steady state;

3. The Dupuit (1863) assumptions are satisfied, i.e.:
   - The velocity of flow is proportional to the tangent of the hydraulic gradient instead of the sine as it is in reality;
   - The flow is horizontal and uniform everywhere in a vertical section through the axis of the well.

Additional Considerations: Dupuit

1. Does not accurately describe drawdown near the well due to strong curvature of water table.

2. Approximate steady state will be reached only after a long pumping time.

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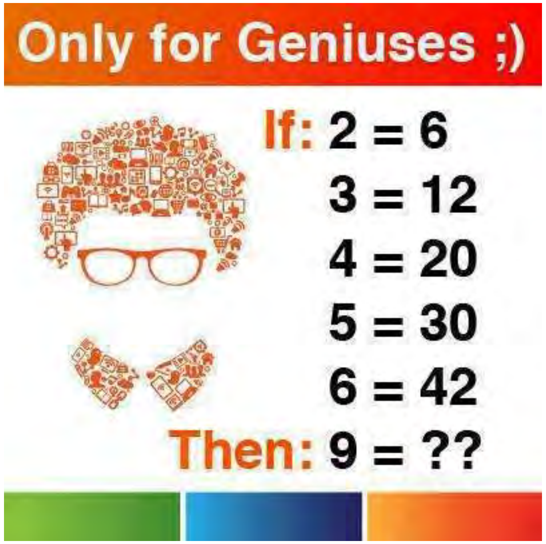
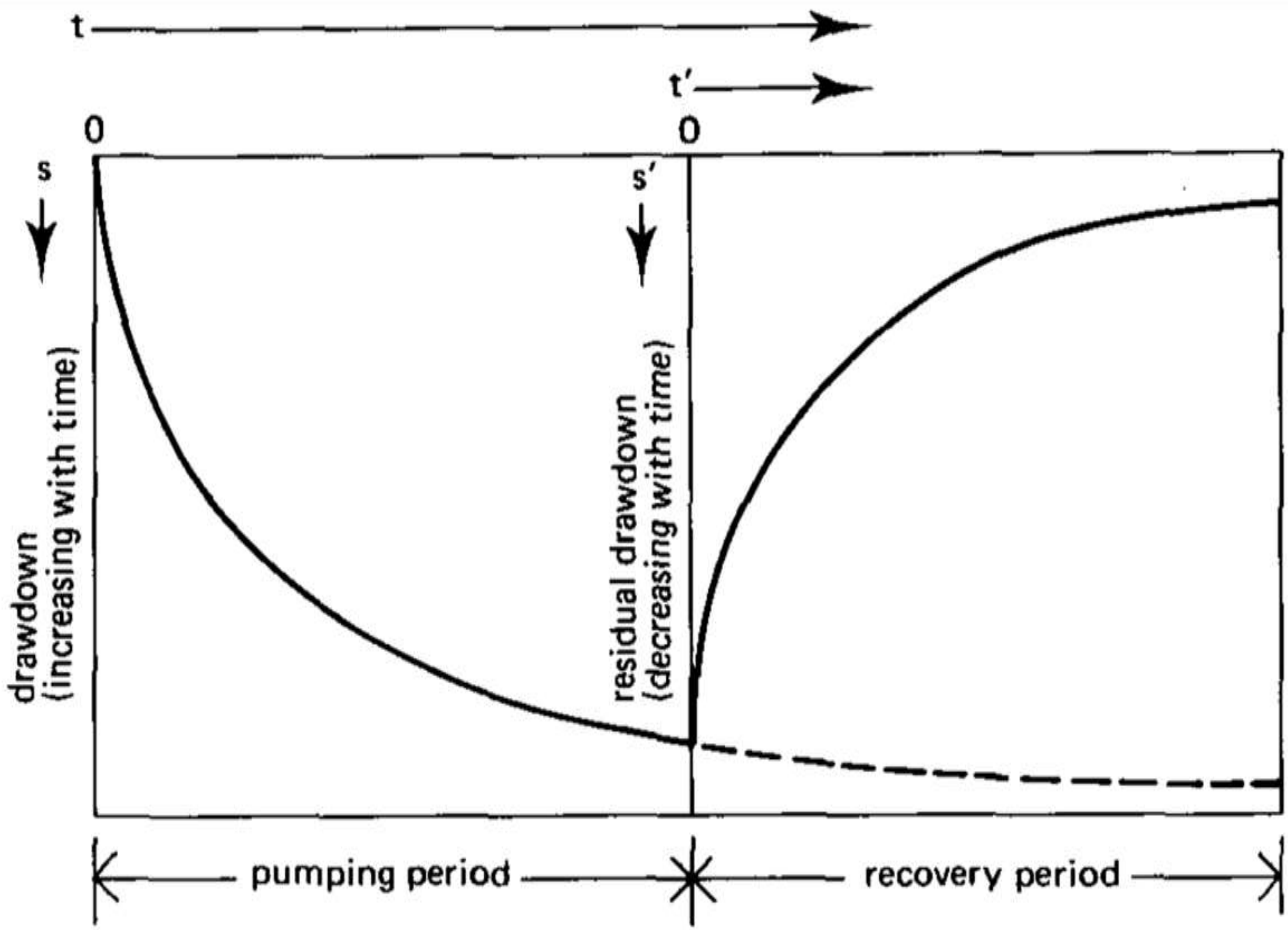
Unconfined Aquifers – Steady State Practical



TOPICS TO BE COVERED

1. Well performance tests / Step tests
2. Constant Rate Pumping Test
3. Recovery Test
4. Calculating the “Safe Yield” of a Well

PART 3 – Recovery Tests



Source: Kruseman & de Ridder, (1994), Analysis and Evaluation of Pumping Test Data; ILRI publication 47.

Recovery Tests

Residual drawdown, *s'* is the rise in water levels once the pump is shut down after a pumping test. This is known as the recovery period.

You should always measure the residual drawdowns during the recovery period, as an independent & low cost check on the pumping test data.

Recovery Tests

Theis' equation (1935)

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

$$u = \frac{r^2 S}{4Tt} \qquad u' = \frac{r^2 S'}{4Tt'}$$

when u' <0.01

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

Recovery Tests

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

s'	= the residual drawdown in m
r	= distance in m from well to piezometer
T	= the transmissivity of the aquifer in m^2/d
S'	= the storativity during recovery, dimensionless
S	= the storativity during pumping, dimensionless
t	= the time in days since the start of pumping
t'	= the time in days since the cessation of pumping
Q	= the rate of recharge = rate of discharge in m^3/d

Recovery Tests

When S' & S are constant & equal and T is constant:

$$s' = \frac{2.3Q}{4\pi T} log \frac{t}{t'}$$

$$\Delta s' = \frac{2.3Q}{4\pi T} \qquad T = \frac{2.3Q}{4\pi \Delta s'}$$

$\Delta s'$ is the residual drawdown difference per log cycle of t/t’ when you plot s’ versus t/t’ on semi-log paper.

Key Assumptions: Theis Recovery Method

1. The flow to the well is in unsteady state

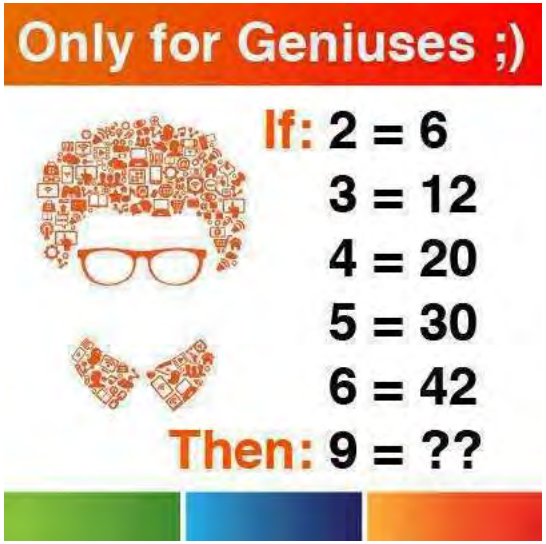
2. $u < 0.01$ i.e. the pumping time $t > (25\ r^2 S/T)$

3. $u' < 0.01$ i.e. $t' > (25\ r^2 S/T)$

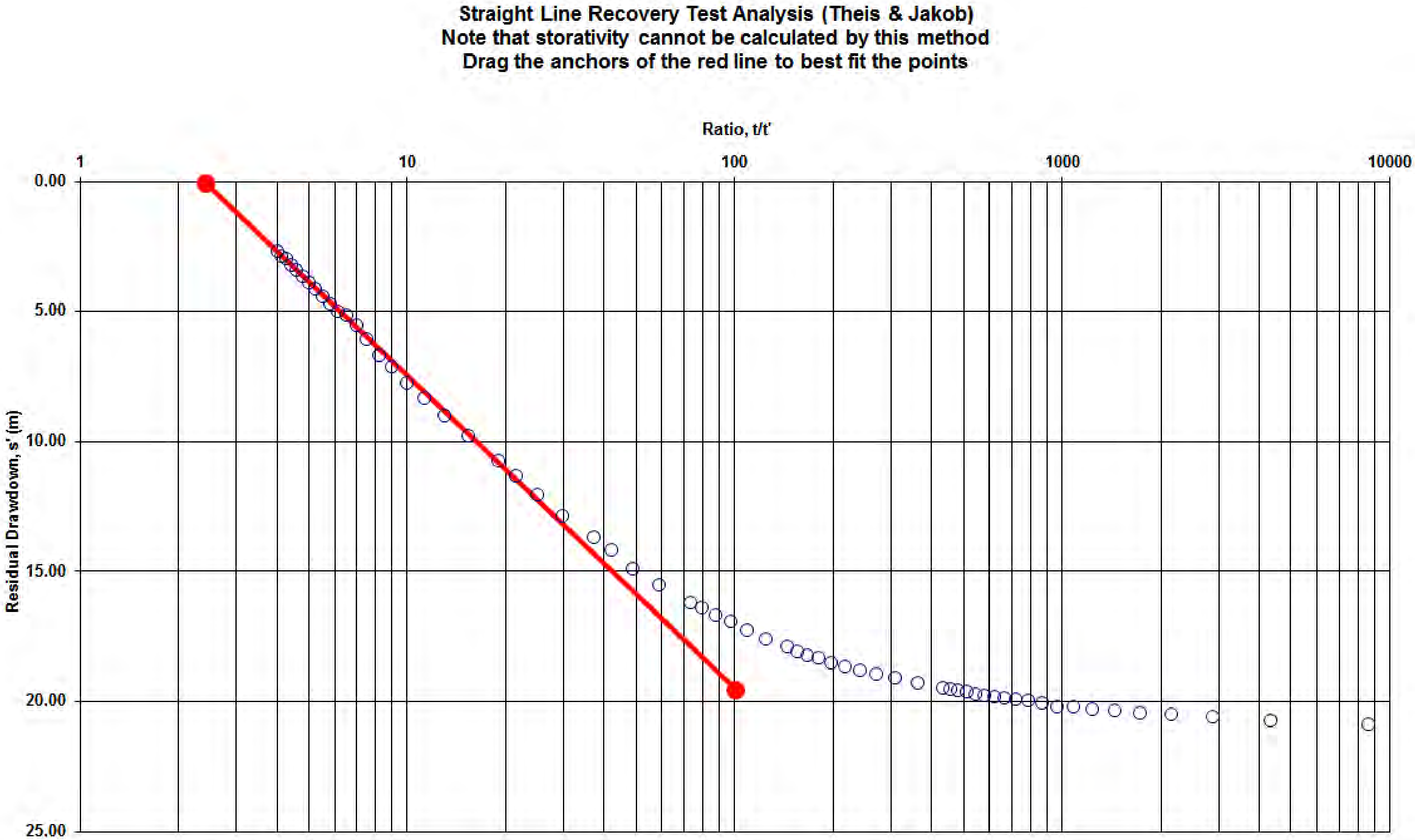
The Theis recovery method can be used in:

- unconfined aquifers for late time recovery date.
- partial penetration wells that have been pumped long enough

Recovery Test Practical



Recovery Tests: Theis-Jakob Recovery XL V1.0



Source: www.geosearch.co.uk

TOPICS TO BE COVERED

1. Well performance tests / Step tests
2. Constant Rate Pumping Test
3. Recovery Test
4. Calculating the “Safe Yield” of a Well

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PART 4 – Calculating the "Safe Yield" of a Well

1. "Safe Yield" is a dangerous term to use, but pump setting depths & estimated sustainable yields must be estimated for all wells.
2. Water levels in a water supply well will drop continuously until discharge is balanced by groundwater recharge. This may only happen once a year during the rainy season.
3. We need to know the well efficiency, T, S, recharge rates & recharge area of the well for the calculations.

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Example – Ghana: Safe Yield XL V1.3

A custom built spreadsheet for estimating the sustainable yield of wells for small towns water supply. It includes the effects of intermittent pumping & a water balance check. Available online: www.geosearch.co.uk

Source: www.geosearch.co.uk

SafeYield XL V1.0 – Data Entry Sheet

A Borehole

Estimated Maximum Sustainable Well Yield Calculation

Pumping Test & Borehole Parameters			
Q	500	l/min	Constant rate pumping test yield
	30.0	**m^3/h**	
	720	**m^3/d**	
$t_{pumptest}$	4,320	minutes	Pumping test duration
	3	**days**	
r	8.5	inch	Effective well diameter
	0.10795	**m**	Effective well radius
swl	9.2	m	Static water level below datum before pumping test
s	21.93	m	Drawdown at end of pumping test
Δs	6.64	m	Change in drawdown over one log cycle of time
pwl_{max}	35	m	Maximum allowable pumping water level below datum
$\Delta s_{seasonal}$	3	m	Estimated seasonal water level decline
s_{max}	**22.8**	**m**	Maximum allowable drawdown
T	56	m^2/d	Transmissivity calculated from pumping test data
S_{min}	0.005		Minimum likely storativity
S_{max}	0.03		Maximum likely storativity
$E_{steptest}$	0.75		Well efficiency estimated from step test
E_{min}	**0.73**		Well efficiency estimated from Transmissivity & minimum likely Storativity
E_{max}	**0.65**		Well efficiency estimated from Transmissivity & maximum likely Storativity
E_{min}	**0.73**		Well Efficiency used for calculations. E = 1 if calculated E > 1
E_{max}	**0.65**		Well Efficiency used for calculations. E = 1 if calculated E > 1
t	300	d	Length of hydrological year without recharge - the time between two rainy seasons

Source: www.geosearch.co.uk

SafeYield XL V1.0 – Estimating Qmax @ 24h/day

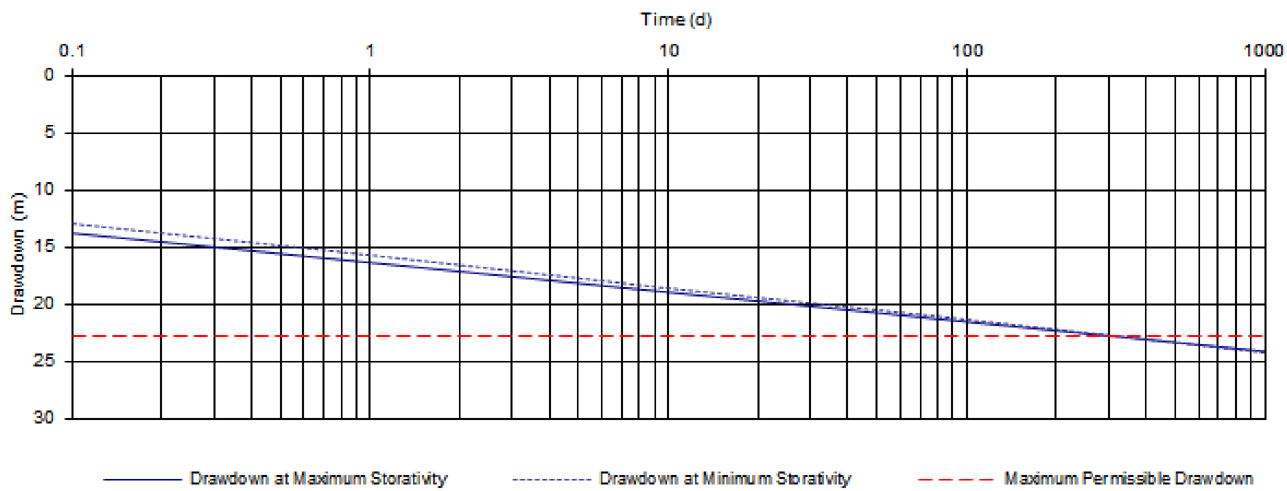
$$Q_{max} = \frac{E \cdot s_{max} \cdot T}{0.183 \log (2.25\, Tt / r^2 S)}$$

The sustainable yield formula is based on the Modified Nonequilibrium Equation, Cooper & Jakob (1946)

Estimated Maximum Sustainable Well Yield at Continuous 24/24 Hour Pumping										
Qmax	Q_{max} (1a)		Q_{max} (1b)		Q_{max} (2a)		Q_{max} (2b)		Lowest Q_{max}	
S	0.005		0.03		0.005		0.03		0.03	
E	0.75		0.75		0.73		0.65		0.647376385	
24/24 h Pumping Cycle	594 m^3/d	24.7 m^3/h	651 m^3/d	27.1 m^3/h	579 m^3/d	24.1 m^3/h	562 m^3/d	23.4 m^3/h	562 m^3/d	23.4 m^3/h

Note that these estimates are very theoretical and that all production wells should be monitored regularly

Predicted Drawdown at Estimated Maximum Sustainable Yield



SafeYield XL V1.0 – Estimating Qmax @ 8-16h/day

$$Q_{max} = \frac{E \cdot 0.228 \cdot s_{max} \cdot T}{t_1 \log((t_2 - 1 + t_1)/ t_1) + \log(2.25\, T t_1 / (r^2 S))}$$

The sustainable yield formula for intermittent pumping is based on the Modified Nonequilibrium Equation, Cooper & Jakob (1946) and the imaginary well procedure outlined in "Groundwater & Wells" Driscoll, 1986.

Estimated Maximum Sustainable Well Yields at Intermittent Pumping Rates

	Q_{max} (1a)		Q_{max} (1b)		Q_{max} (2a)		Q_{max} (2b)		Lowest Q_{max}	
S	0.005		0.03		0.005		0.03		-	
E	0.75		0.75		0.73		0.65		-	
Daily Pumping Cycle (hrs)	Q_{max} (1a) m^3/h	Volume (1a) m^3/d	Q_{max} (1b) m^3/h	Volume (1b) m^3/d	Q_{max} (2a) m^3/h	Volume (2a) m^3/d	Q_{max} (2b) m^3/h	Volume (2b) m^3/d	Lowest Q_{max} m^3/h	Lowest Volume m^3/d
8	31.9	255	36.0	288	31.1	249	31.1	249	31.1	249
9	31.2	281	35.1	316	30.4	274	30.3	273	30.3	273
10	30.6	306	34.3	343	29.8	298	29.6	296	29.6	296
11	30.0	330	33.5	369	29.2	321	29.0	319	29.0	319
12	29.4	353	32.9	394	28.7	344	28.4	340	28.4	340
13	28.9	376	32.2	419	28.2	366	27.8	362	27.8	362
14	28.4	398	31.6	443	27.7	388	27.3	382	27.3	382
15	28.0	420	31.1	466	27.3	409	26.8	402	26.8	402
16	27.5	441	30.5	489	26.8	429	26.4	422	26.4	422

Note that these estimates are very theoretical and that all production wells should be monitored regularly.
It is unwise to select a pumping rate that exceeds those used during the pumping tests, without further tests.

Source: www.geosearch.co.uk

SafeYield XL V1.0 – Testing Different Scenarios

$$s = \frac{0.183\,Q}{E\,.T}\left[t_1 \log\left((t_2 - 1 + t_1)/t_1\right) + \log\left(2.25\,Tt_1 / (r^2 S)\right)\right]$$

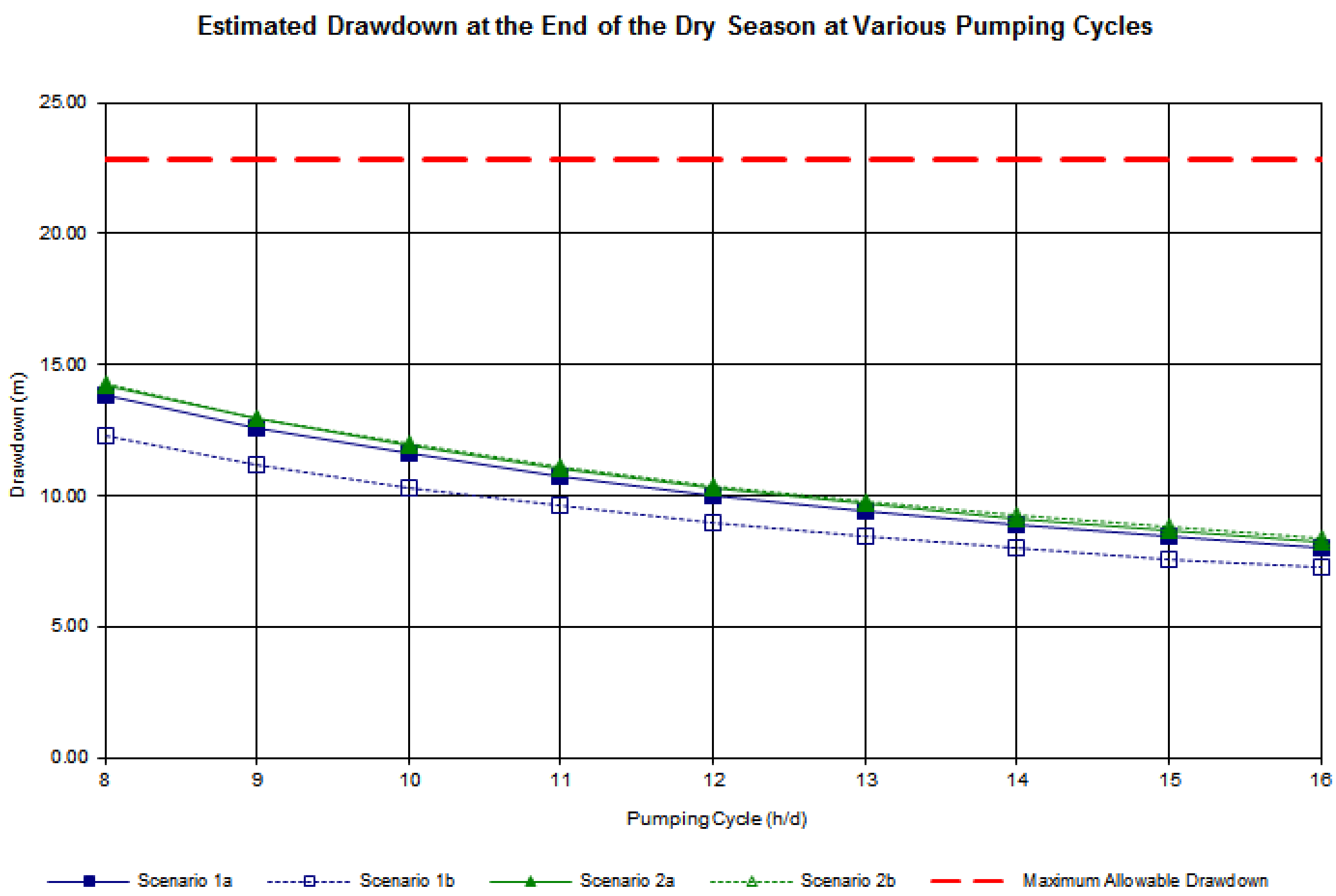
The formula for estimated drawdown due to intermittent pumping is based on the imaginary well procedure outlined in "Groundwater & Wells", Driscoll, 1986.

Estimated Drawdown at Intermittent Pumping Rates						
		Scenario	1a	1b	2a	2b
		Storativity (S)	0.005	0.03	0.005	0.03
		Well Efficiency (E)	0.75	0.75	0.73	0.65
Max. Yield (m3/d)	Daily Pumping Cycle (hrs)	Q_{abs} m^3/h	Estimated Drawdown (m) at end of Dry Season	Estimated Drawdown (m) at end of Dry Season	Estimated Drawdown (m) at end of Dry Season	Estimated Drawdown (m) at end of Dry Season
155.0	8	19.4	13.9	12.3	14.2	14.2
	9	17.2	12.6	11.2	12.9	13.0
	10	15.5	11.6	10.3	11.9	12.0
	11	14.1	10.7	9.6	11.0	11.1
	12	12.9	10.0	9.0	10.3	10.4
	13	11.9	9.4	8.4	9.7	9.8
	14	11.1	8.9	8.0	9.1	9.3
	15	10.3	8.4	7.6	8.7	8.8
	16	9.7	8.0	7.2	8.2	8.4

Note that these estimates are very theoretical and that all production wells should be monitored regularly

Source: www.geosearch.co.uk

SafeYield XL V1.0 – Testing Different Scenarios



Max. Yield (m3/d) = 155

Note that drawdown cannot exceed the maximum allowable drawdown, s_{max}

Source: www.geosearch.co.uk

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SafeYield XL V1.0 – Effects on Other Wells

$$s = \frac{0.183\,Q}{T} \cdot \text{Log} \frac{2.25Tt}{r^2 S}$$

The formula for estimated drawdown due to pumping in a well is described by the Modified Nonequilibrium Equation, Cooper Jakob, 1946.

Estimated Drawdown with Distance from the Pumping Well			
Scenario		1	2
Storativity (S)		0.005	0.03
Abstraction Rate (m3/d)		155.00	155.00
Location	Distance from Pumping Well (m)	Estimated Drawdown (m) at end of Dry Season	Estimated Drawdown (m) at end of Dry Season
-	10.0	2.47	2.08
-	25.0	2.07	1.67
-	50.0	1.76	1.37
-	75.0	1.58	1.19
-	100.0	1.46	1.06
-	150.0	1.28	0.89
A borehole	245.0	1.06	0.67
A borehole	285.0	1.00	0.60
A borehole	332.0	0.93	0.54

Note that these estimates are very theoretical and that all production wells should be monitored regularly

Source: www.geosearch.co.uk

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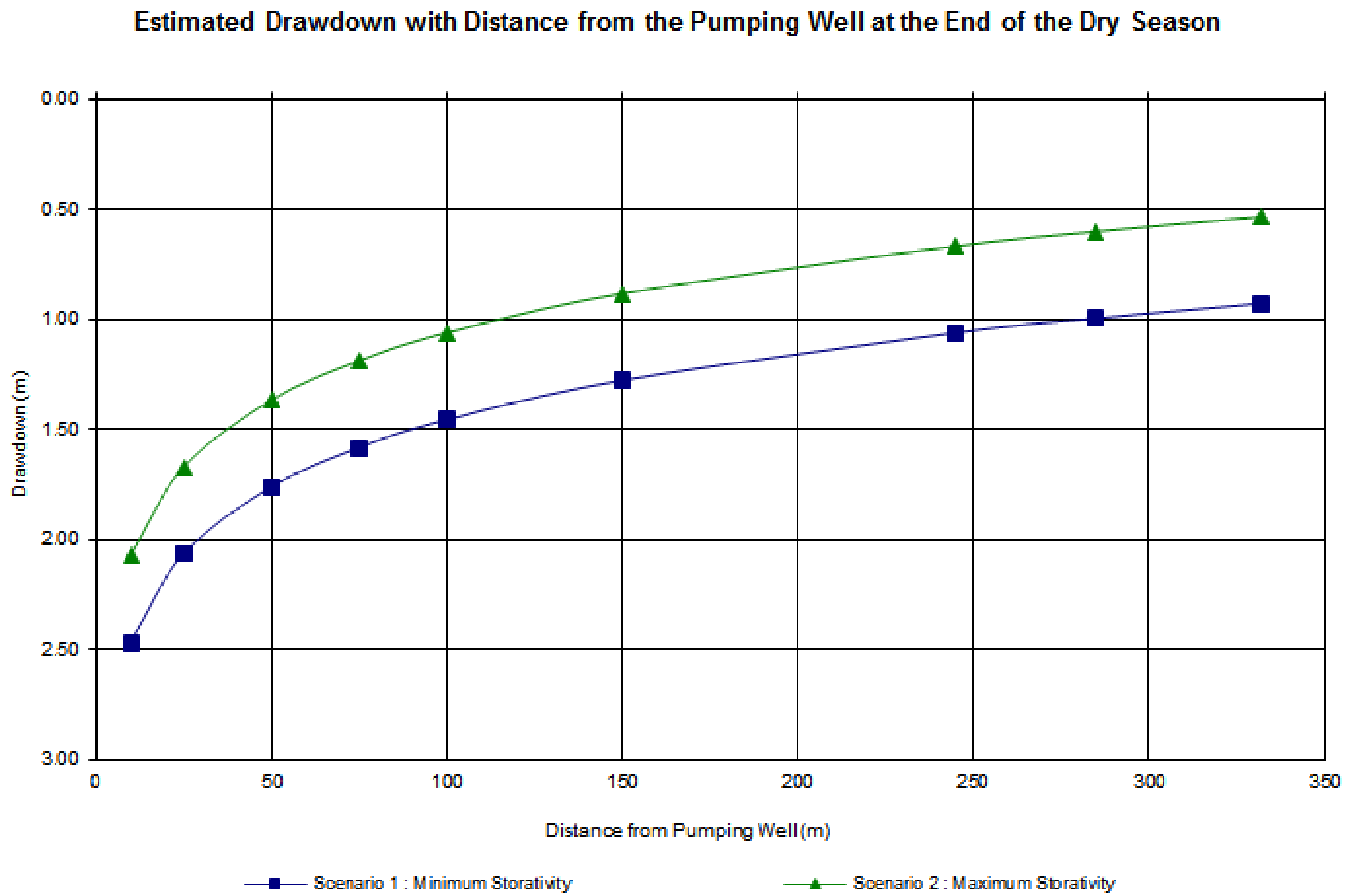
SafeYield XL V1.0 – Effects on Other Wells



Abstraction Rate in Well = 155 m3/d

Note that drawdown will be affected by both recharge and barrier boundaries

Source: www.geosearch.co.uk

SafeYield XL V1.0 – Water Balance Check

Water Balance Check

The sustainability of a borehole depends not only on the hydraulic characteristics of the borehole and the aquifer. Pumping the borehole will change the water balance of the area, and it is important to establish the theoretical impact the borehole will have on this. It is wrong to assume that the borehole can pump the entire groundwater aspect of the water budget. This is known as the *'water budget myth'*. The approach adopted here is to estimate what the theoretical required catchment area is, assuming various recharge rates, and to compare this with the theoretical recharge rate required for the actual catchment area. This approach could be called the *'recharge area myth'*. Only long term monitoring of water levels will show if groundwater abstraction exceeds the 'safe yield'.

Water Balance Check : Recharge Area & Aquifer Storage Capacity			
Daily pumping cycle		Continuous Pumping	Intermittent Pumping
Abstraction Rate (m3/d)		562.2	155.0
Abstraction Rate (m3/year)		205,208	56,575
Annual groundwater recharge (mm/year)		Catchment area required to sustain borehole yield (Km2)	Catchment area required to sustain borehole yield (Km2)
Lowest likely	2	102.60	28.29
Most likely	20	10.26	2.83
Highest likely	200	1.03	0.28
Actual catchment area estimated from GIS (Km2)		8.5	
Annual groundwater recharge required to sustain borehole yield (mm)		24.14	6.66
Aquifer storage capacity required to sustain borehole yield (m3/m2)		0.0241	0.0067

Source: www.geo[illegible]

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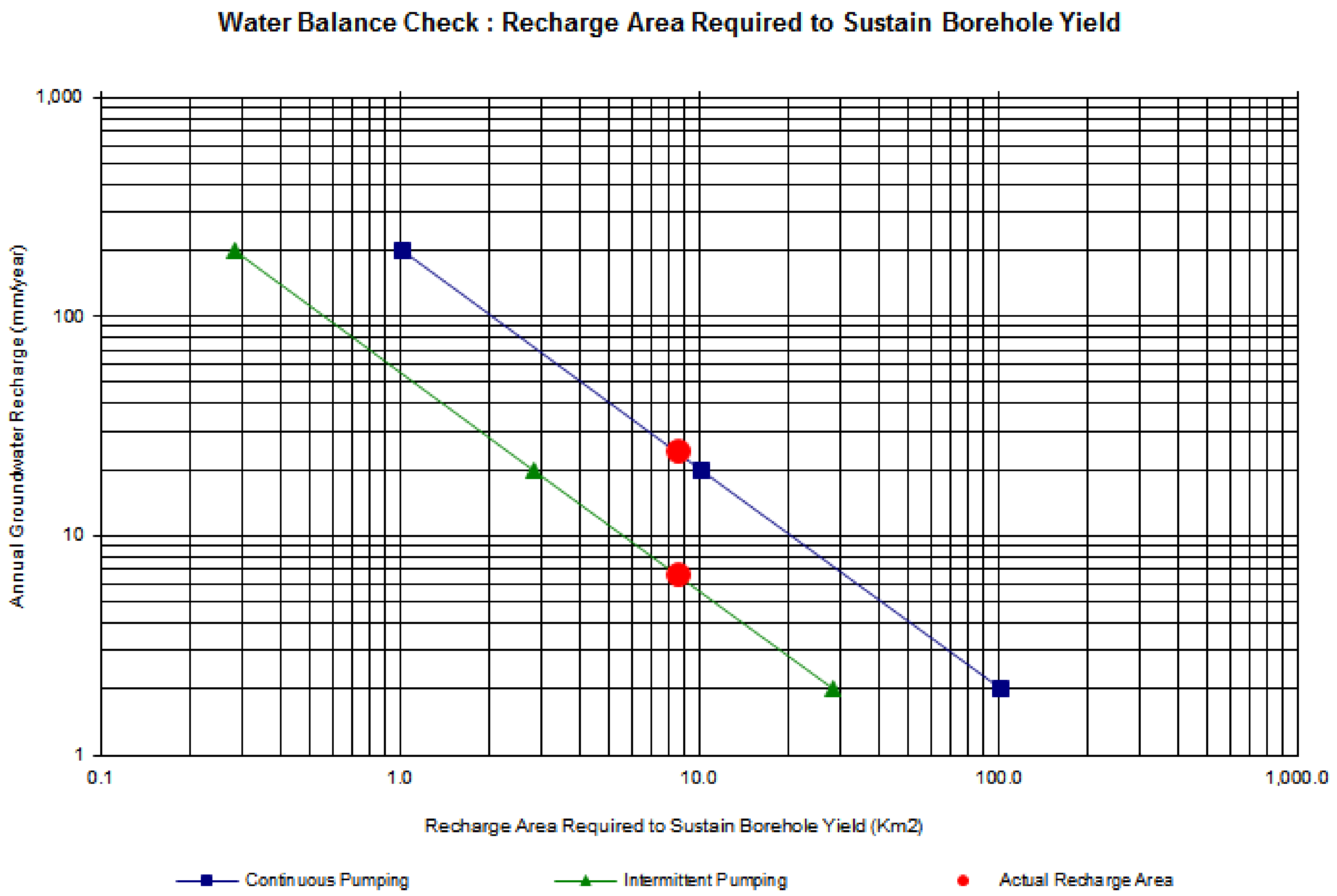
SafeYield XL V1.0 – Water Balance Check



Source: www.geosearch.co.uk

Thank you

for your attention!

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