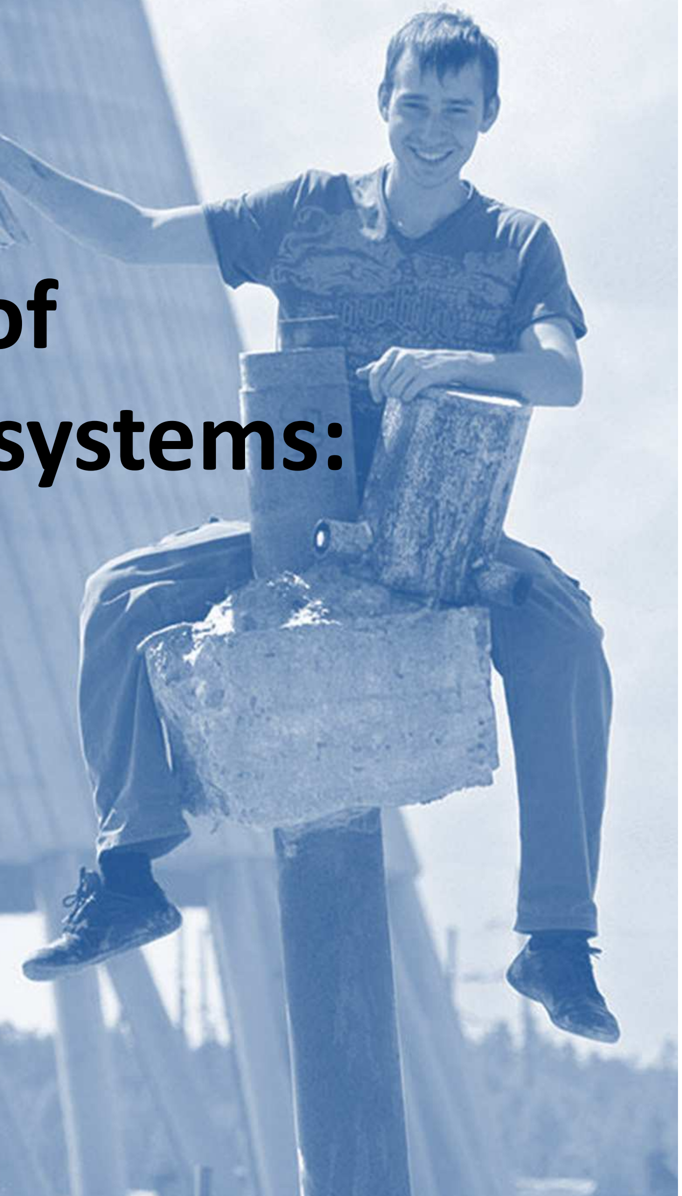
IAH AUSTRALIA

WA chapter monthly talk
Wednesday, 17-th of September 2014

Analytical modelling of groundwater wells and well systems: how to get it right?



Anastasia Boronina[1], Leonid Sindalovskiy[2]
Anton Nikulenkov[3]

[1]Independent Hydrogeologist, Perth WA
[2]Principal Research Scientist, Institute of Environmental Geosciences, Russian Academy of Sciences
[3]Senior Research Scientist, Institute of Environmental Geosciences, Russian Academy of Sciences

Contact: Anastasia.Boronina@pangeawater.com.au
tel: 0478 633 429

Why talk about pump tests interpretation?

Often this is the only data available for water supply and dewatering

Obtaining aquifer test data is expensive and time-consuming

- n x 10,000 – n x 100,000 AUD – average test cost
- Weeks of planning, drilling and testing in the field.

But..

Interpretation time – hours. We attempt to do it quickly and save money

Better interpretation – more reliable groundwater predictions!

IAH 2013 International Congress paper: Todd Hamilton and Milo Simonic "Reducing uncertainty in test pumping analysis"

Outline

- Common pitfalls in pump test interpretations and case studies
- Analytical method for well systems design
- MODFE and RADFLOW numerical codes for solving 2D axis-symmetrical numerical flow models

Software

Aqtesolv 4.5

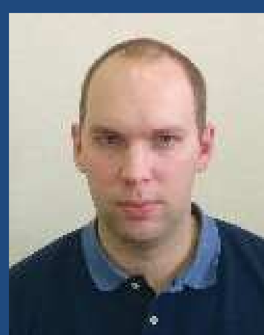
HydroSOLVE, Inc, http://www.aqtesolv.com/

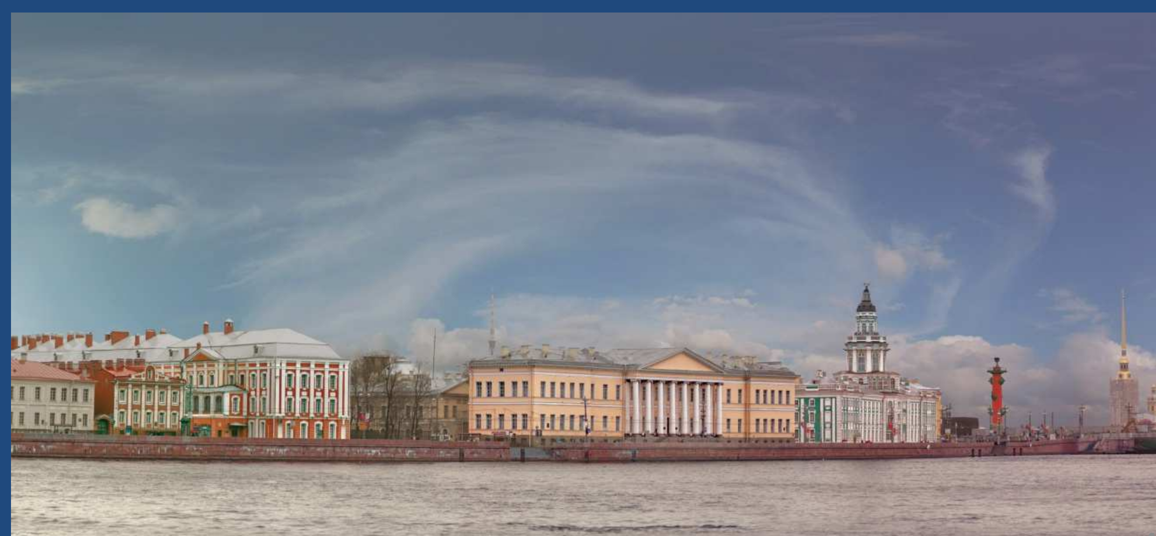
Feflow 6.1

DGI-WASY GMbH, www.feflow.com

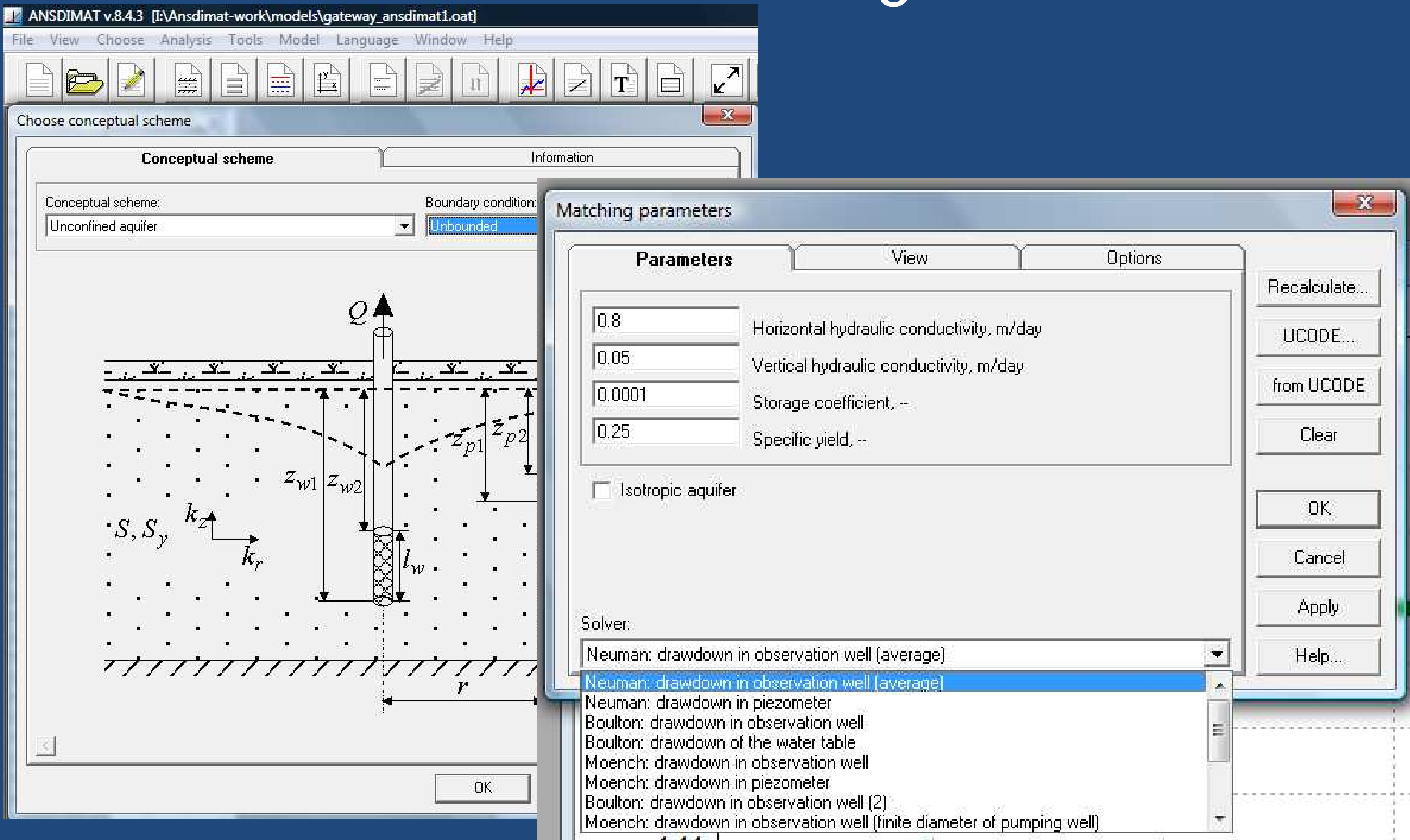
Ansdimat 8.5

Institute of Environmental Geosciences of the Russian Academy of Sciences, http://www.ansdimat.com/





ANSDIMAT – pump test interpretation by curve-matching

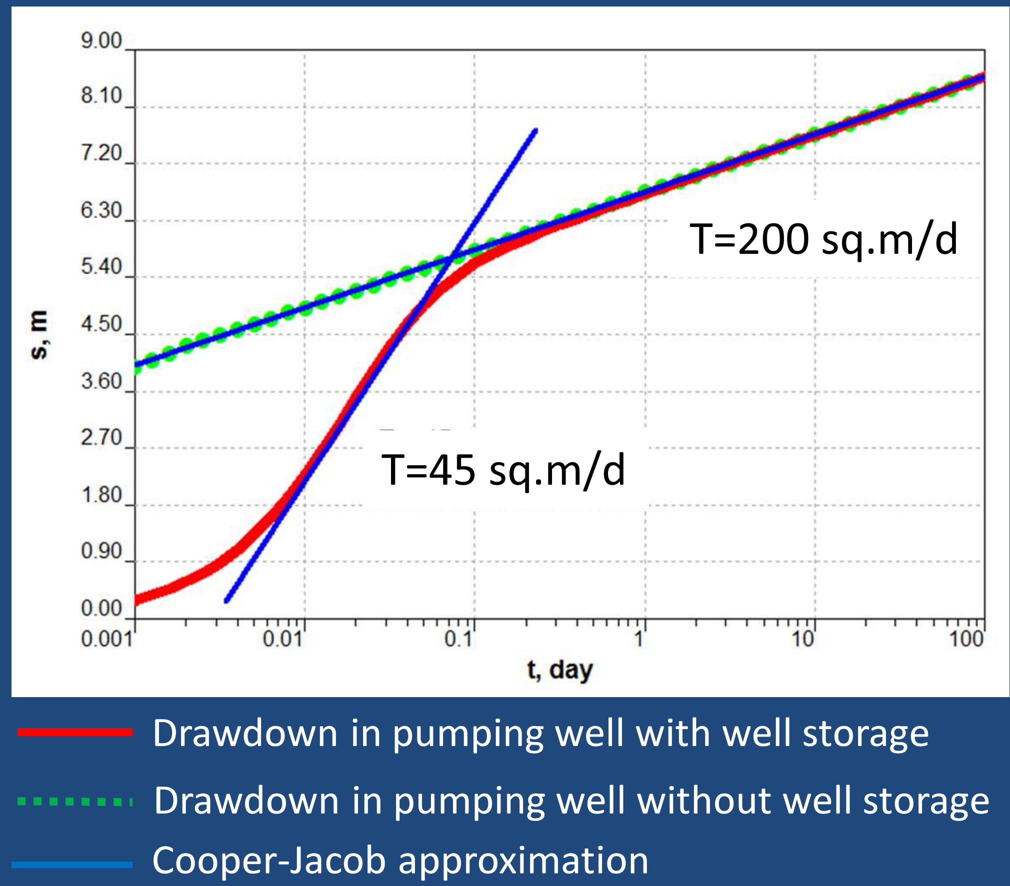


ANSDIMAT users

ANDISMAT is officially registered and included in the Russian State Register of computer codes. Certificate #2009614366

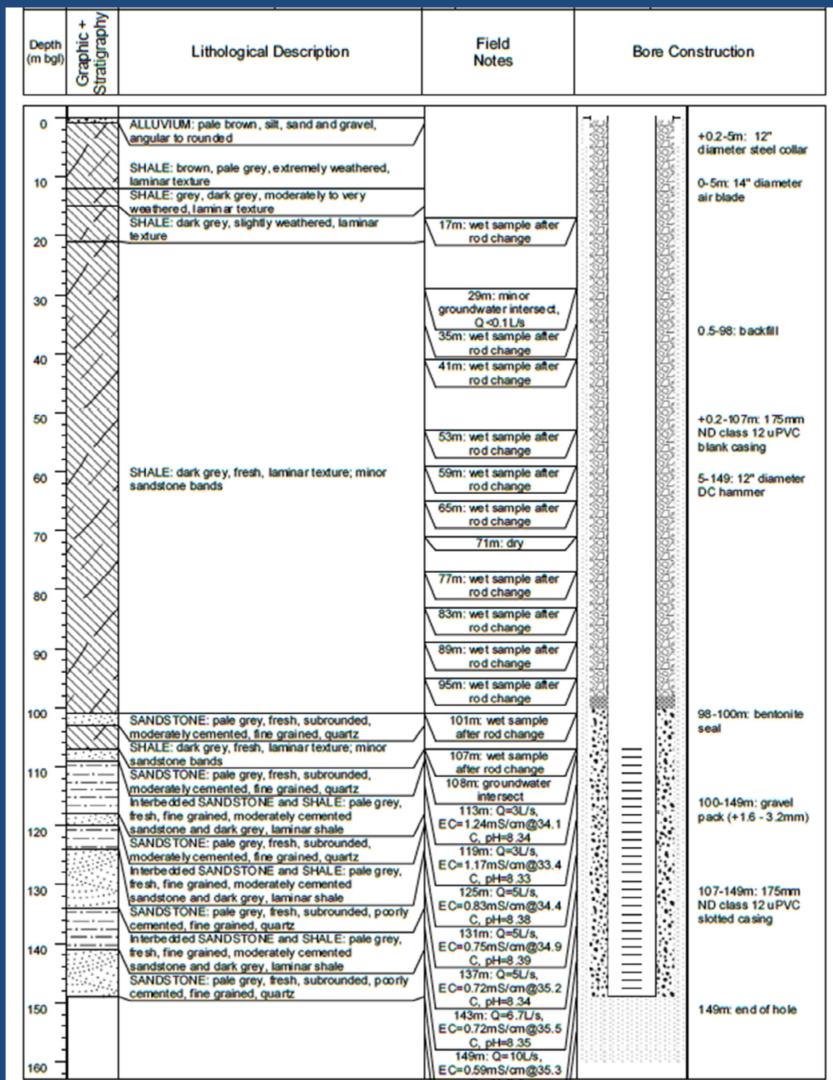
Common pitfalls in pump test interpretation by analytical models

- Interpreting unconfined aquifer response by "confined" analytical solution for a wrong time-drawdown interval
- Not accounting for well storage
- Interpreting skin-effect as an aquifer response



Short-time pump tests – high risk of errors !!

Example 1 – Fitzroy River Catchment Test borehole for water supply



Profile:

0-100 m bgl – confining or semi-confining shale

100-150 m bgl – Poole Sandstone

Poole sandstone – a high yielding aquifer, good water quality (TDS < 1 g/L). It is believed to have a thickness of around 250 m

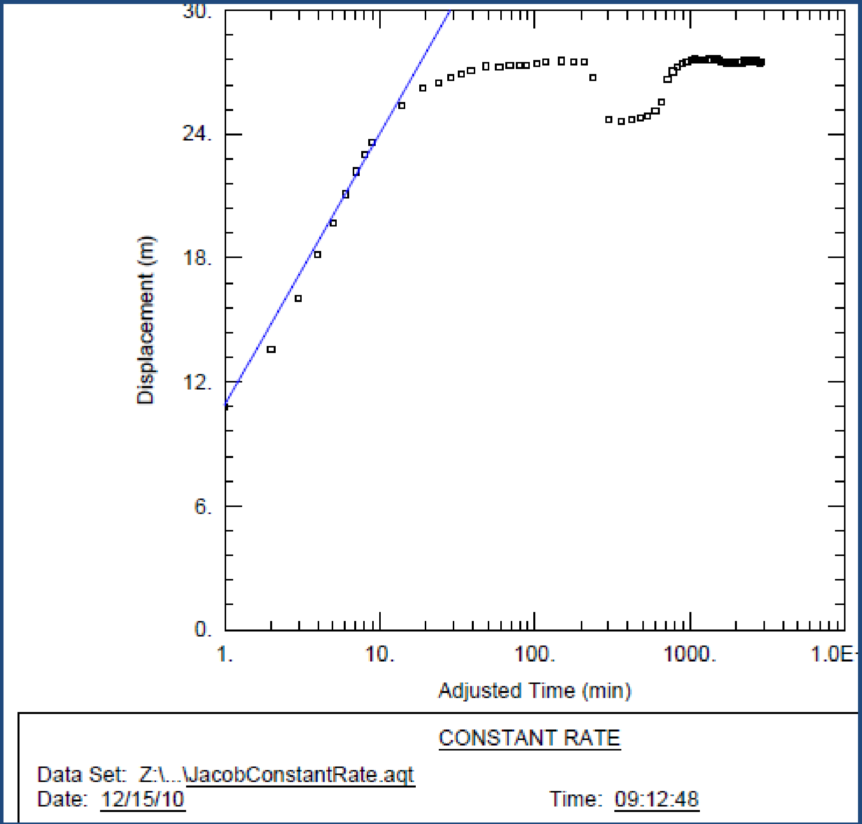
Borehole:

Total depth – 150 m

Screen interval – 100-150 m bgl

48-hour constant rate pump test. Pumping rates were recorded at hourly intervals

Example 1 – original interpretation



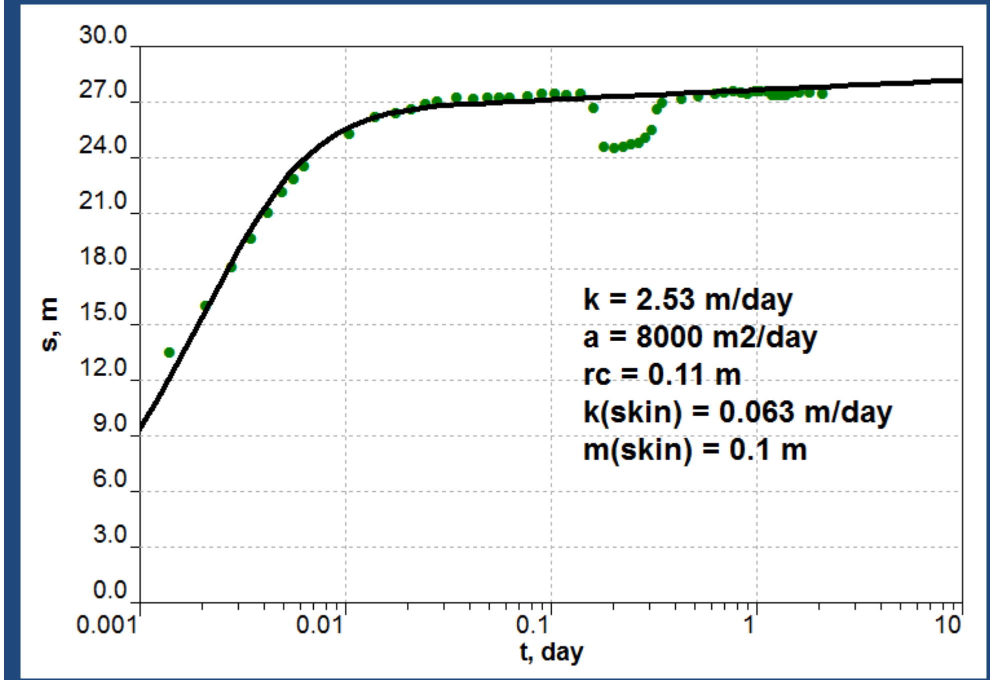
K=0.14 m/d or less (depending on assumed effective thickness).

The value is based on the first interval that reflects well bore storage and skin-effect, but not the aquifer!

Table 7: Summary of Aquifer Properties

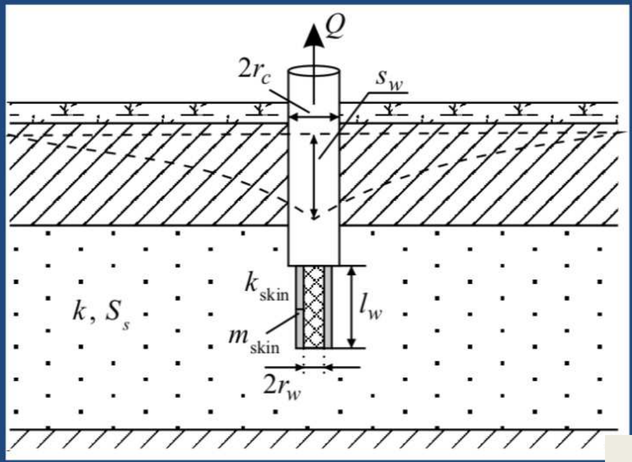
Test Type	Transmissivity (m^2/d)	Aquifer Thickness (m)	Hydraulic Conductivity (m/d)	Method
Constant Rate	6.034	42	0.14	Cooper-Jacob (1946)
Recovery	10.53	42	0.25	Theis (1935)

Example 1 – corrected interpretation



Conceptual scheme

partially penetrating well in a thick confined aquifer, Well-bore storage and skin-effect



Well-bore storage parameter: $W_D = \frac{r_c^2}{2r_w^2 S_s l_w}$

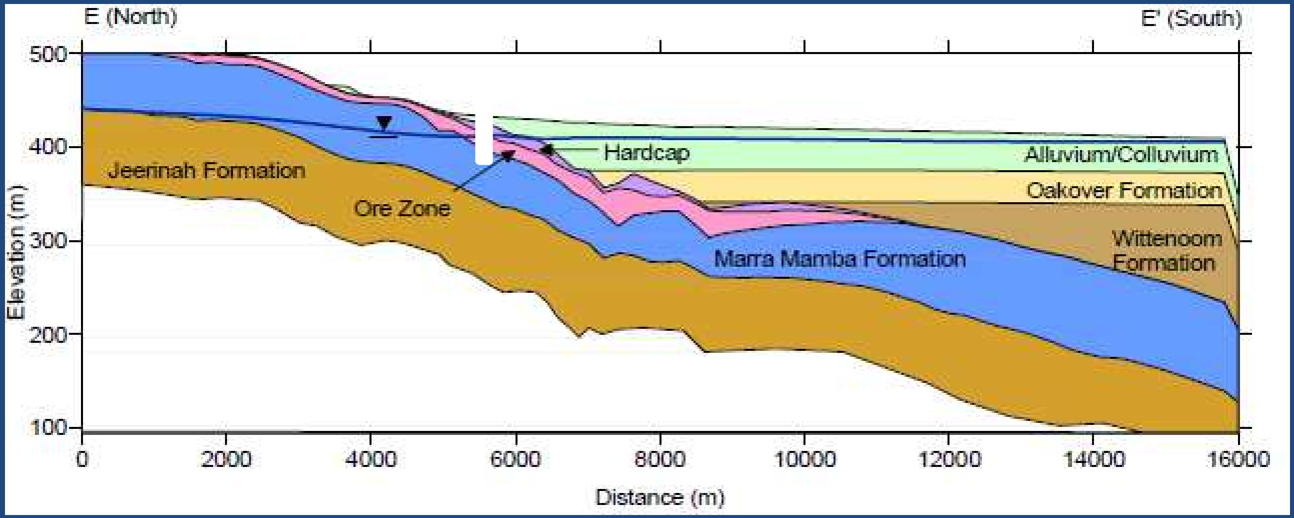
$$s_w = \frac{Q}{4\pi k_r m} f\left(t, r_w, r_c, m, l_w, L_{Tw}, k_r, k_z, a_r, k_{\text{skin}}, m_{\text{skin}}\right)$$

Well-bore skin parameter: $W_{\text{skin}} = \frac{k m_{\text{skin}}}{r_w k_{\text{skin}}}$

Algorithm WTAQ3 (Moench, 1997):

Moench A.F. Flow to a well of finite diameter in a homogeneous, anisotropic water table aquifer // Water Resources Research. 1997. Vol. 33, N 6. P. 1397–1407.

Example 2 – Pilbara
Test pumping for mine dewatering



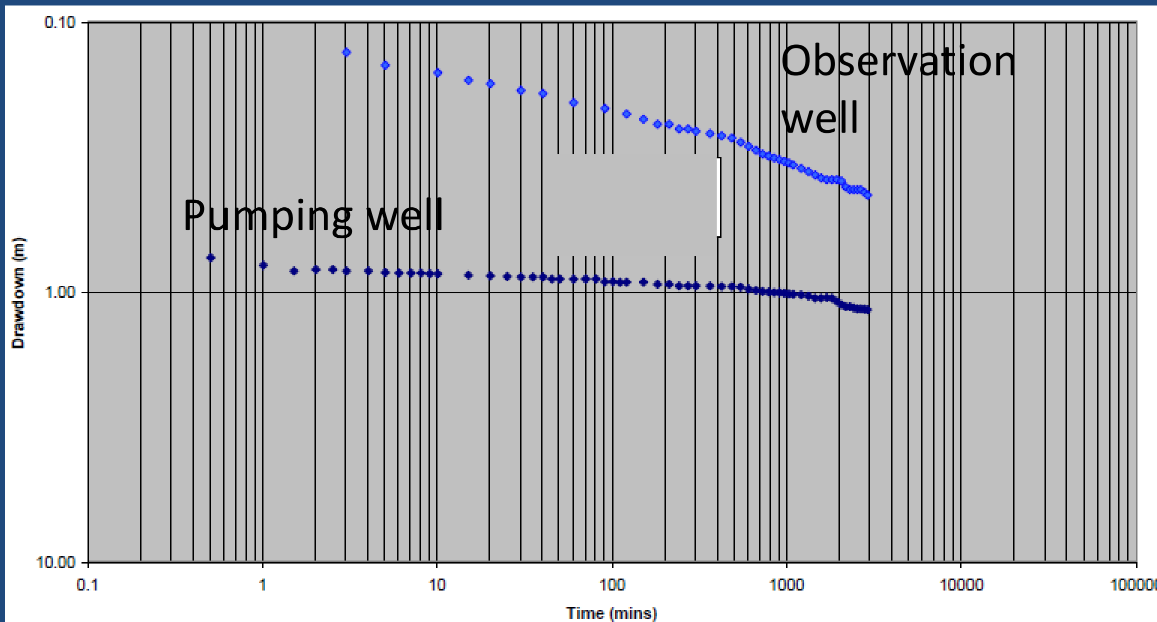
Unconfined aquifer

Profile:

- Alluvium
- Ore Zone (aquifer)
- BIF

Well	Distance from Test Well, m	Total Depth, m	Slotted Interval, m bgl	Lithology
Pumping Well	-	45	12-45	Alluvium, Hardcap, Ore Zone & BIF
Obs Well	15.2	32	20-32	Alluvium, Hardcap, Ore Zone

Example 2 – original interpretation



124 m/d for early time and 38 m/d for late time.

The same results for pumping and observation wells

"Early time data may represent the aquifer while the late time data may represent the underlying shales"

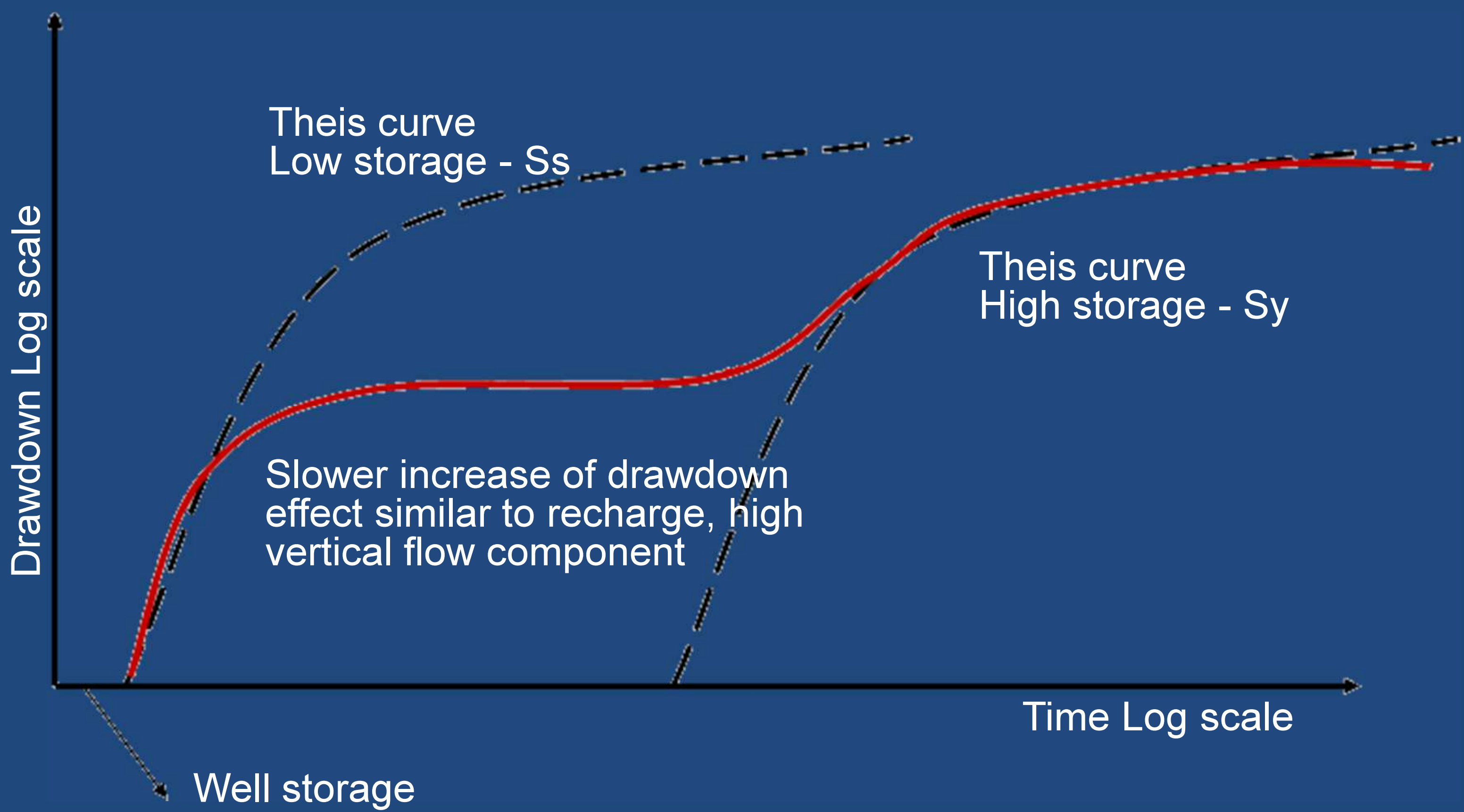
Test Well	Observation Well	Constant Rate Test Transmissivity (m^2/d)	Recovery Test Transmissivity (m^2/d)	Storativity Estimate
		-[a]	-[a]	-[a]
CB471T	Pumping	4,090 (early); 1,240 (late)	5,450	-
	Obs	4,020 (early); 1,190 (late) *Theis* 3,910 (early) 1,130 (late) *Cooper-Jacob*	-	6.06×10^{-4} (early); 1.79×10^{-1} (late) *Theis* 6.14×10^{-4}(early); 1.95×10^{-1} (late) *Cooper-Jacob*

Note: a. Insufficient drawdown induced in observation well to enable analysis

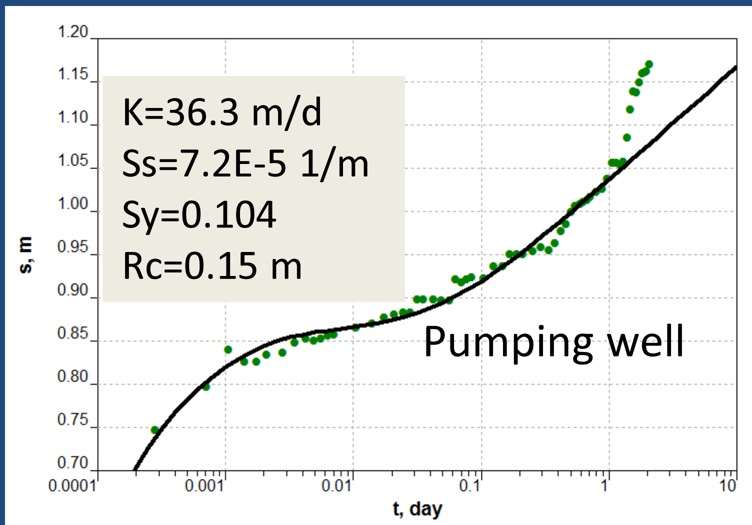
The test pumping analysis confirms the heterogeneity of both the alluvium and mineralised Marra Mamba, but does not provide reasonable estimates of regional hydraulic properties. Actual values used in the numerical modelling are described in Section 6.

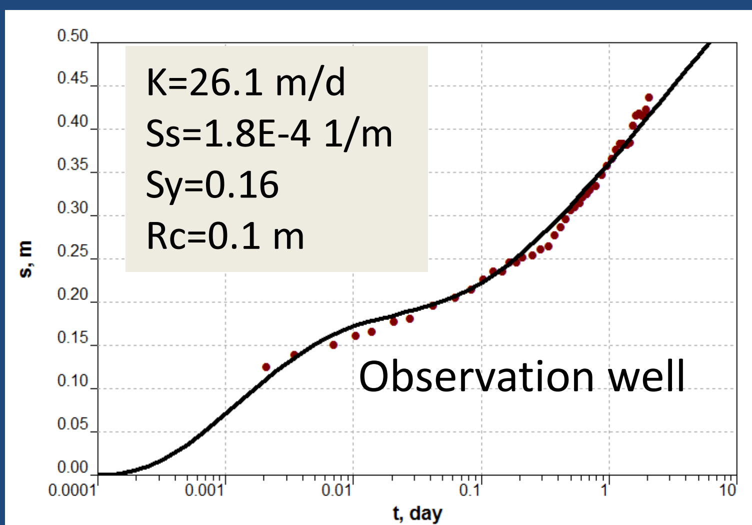
Conclusion:
The aquifer is highly heterogeneous. Because of this, the test results are not applicable, so the model used different values

Unconfined aquifer – three stages of drawdown



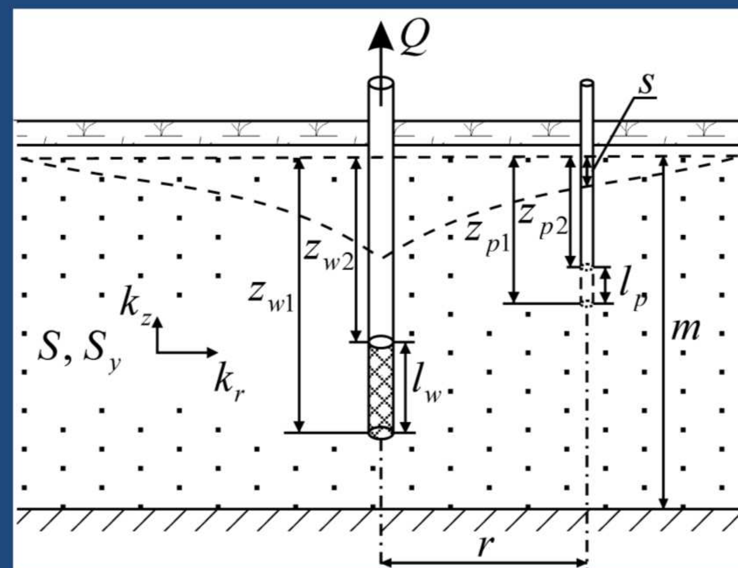
Example 2 – corrected interpretation





Conceptual scheme

partially penetrating well in an unconfined aquifer



Algorithm: Moench (1997):

Kh = 26 m/d - 36 m/d, rather homogeneous aquifer, though lower-permeability zone or boundary may be present at distance

Marra Mamba heterogeneity

Is it really so high?

Or may be just an artefact of interpretation?

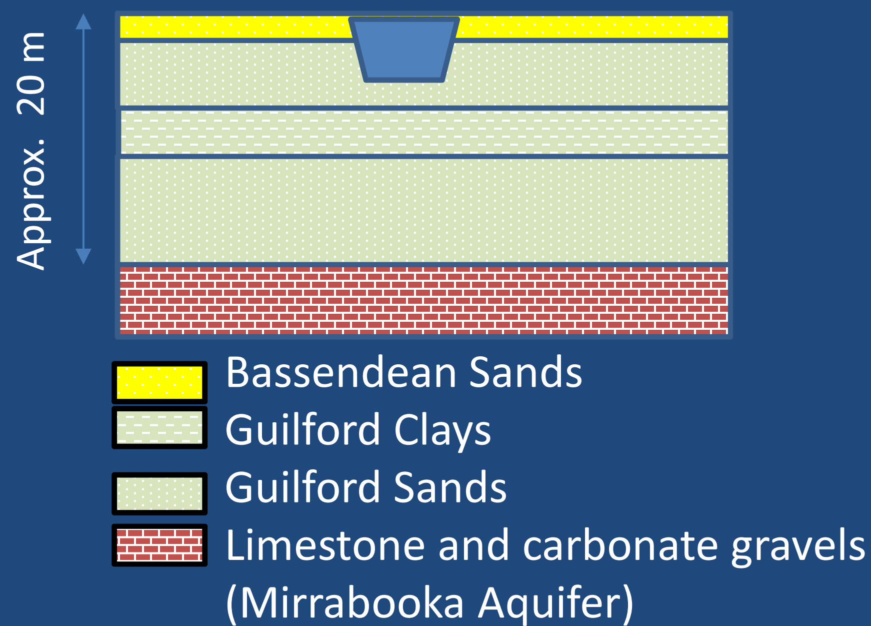
Table 6 – Aquifer Test Results (by Aquifer)

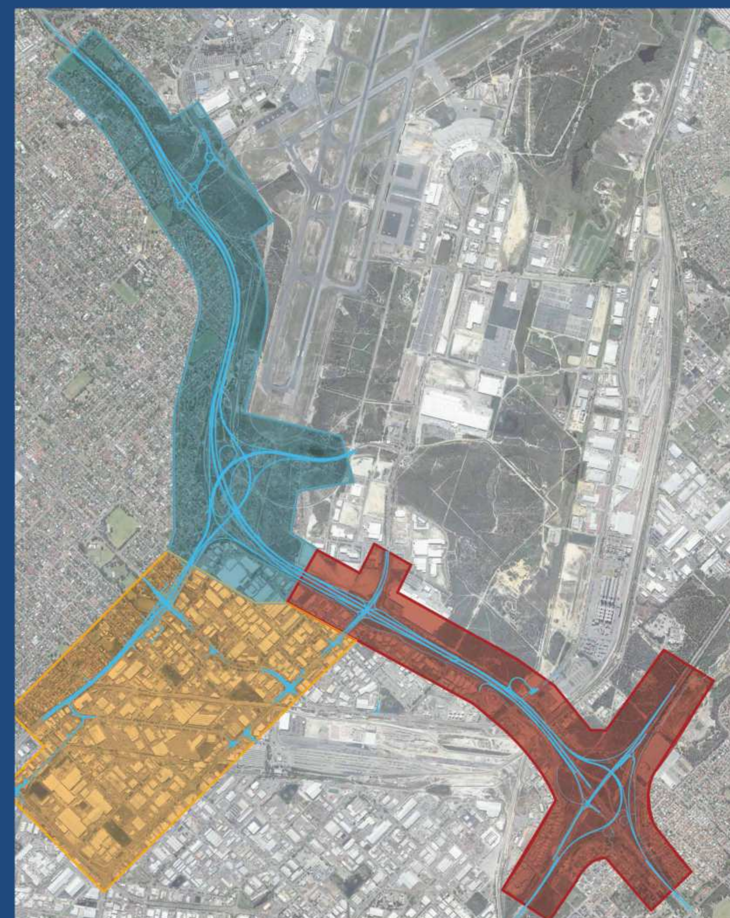
Aquifer	T[1]		K[2]		S[3]		No. of Tests
	Range	Avg.	Range	Avg.	Range	Avg.	
Tertiary Detritals	59–210	135	4.2–5.3	4.8	1.3×10^{-3} – 4.2×10^{-4}	8.6×10^{-4}	2
Oakover Fmn.	3460–5505	4483	115–167	141	3.3×10^{-3} – 4.4×10^{-4}	7.87×10^{-3}	2
Mineralised Marra Mamba Fmn.	1520–6955	4046	11- 311	226	3.3×10^{-5} – 7.9×10^{-3}	5.01×10^{-3}	3
Non-mineralised Marra Mamba Fmn.	18–773	287	1.7–32	13	-	1.7×10^{-3}	3
Marra Mamba Fmn. (all[4])	222–5797	2358	11–386	100	1.4×10^{-4} – 7.7×10^{-3}	2.03×10^{-3}	14

1 Transmissivity (m^2/day)
2 Hydraulic Conductivity (m/day)
3 Aquifer Storativity (dimensionless) (not assessed where no monitoring bore data are available)
4 All includes both the mineralised and non mineralised Marra Mamba. However, the bore may not screen the entire non-mineralised sequence.

FMG, 2010. Hydrogeological Assessment for the Christmas Creek Water Management Scheme (http://www.fmgl.com.au/community/Environment/Approval_Publications/Christmas_Creek_WMS)

Case study 3 – Gateway WA Pump testing for dewatering

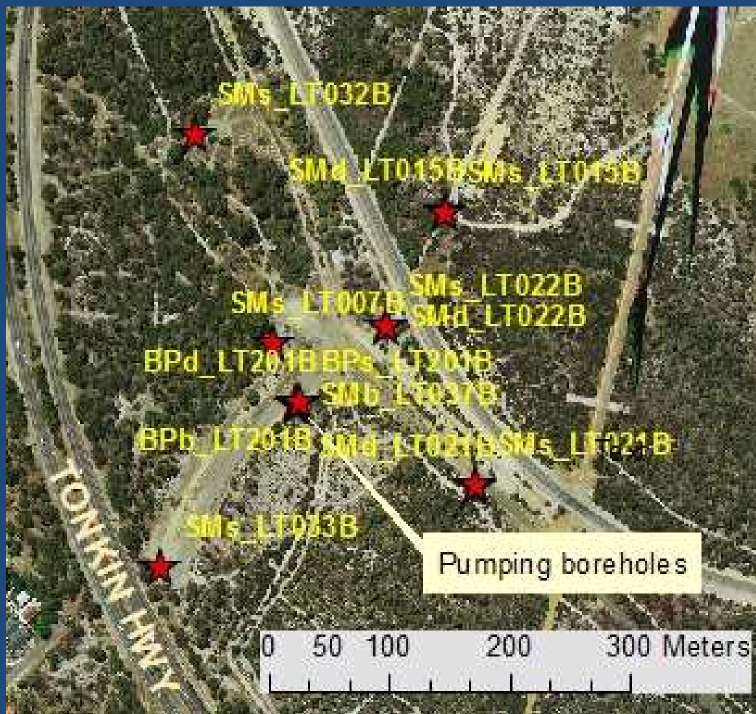


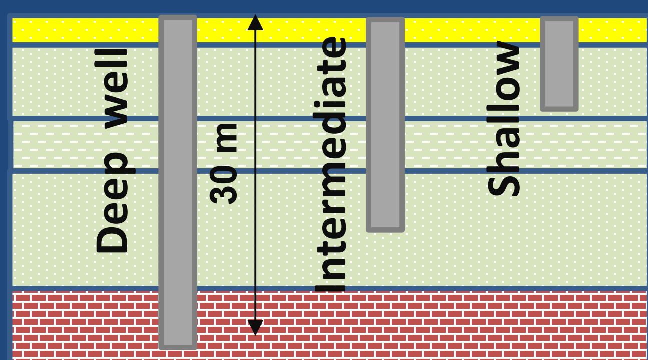


- 2-3 m drawdown for some sites
- High yielding aquifer at 20 m bgl
- Up to 6 months of dewatering is required

We acknowledge MRWA for opportunity to conduct this study and present the results

Case study 3 – Gateway WA
Pump test settings

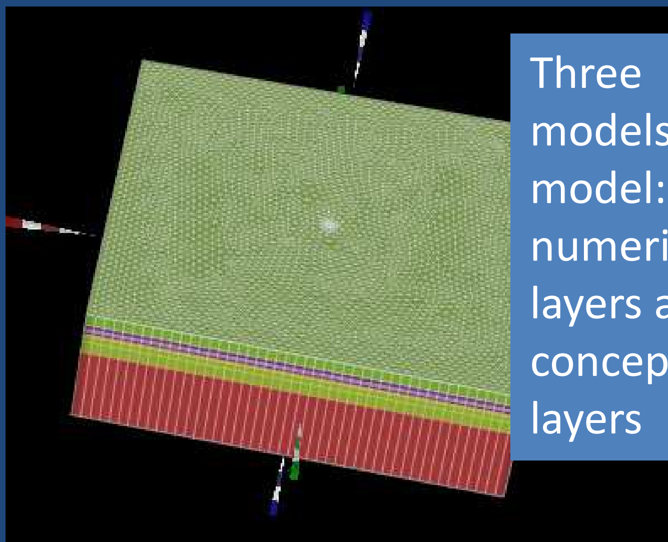




- Three pumping wells – shallow (10.5 mbgl), intermediate (15.5 mbgl) and deep (30 mbgl);
- Average pumping rates: 6 L/s (deep), 3 L/s (intermediate) and 1.3 L/s (shallow);
- 48 hour pump tests + recovery;
- 11 monitoring wells at distances 2–200 m;
- Screen lengths: 3 m (monitoring wells); 6m, 6m and 12m (pumping wells);
- Screen intervals: all horizons;
- Pressure transducers in all pumping and observation boreholes; digital flowmeters

Case study 3 – original interpretation

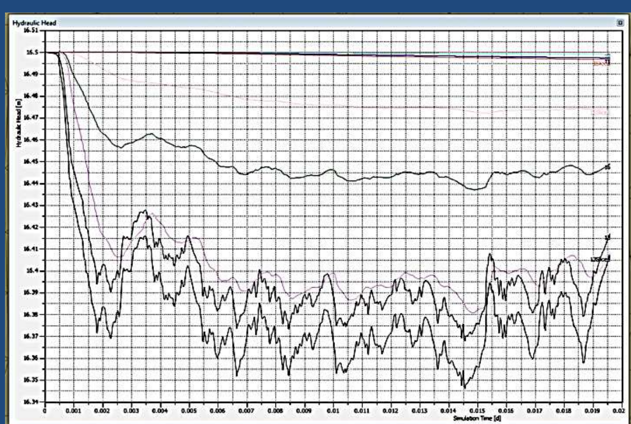
FEFLOW model



Three models. Each model: 13 numerical layers and 4 conceptual layers

CHALLENGES

- Non-uniquiness
- Requirements for fine vertical discretisation to accommodate various screen and pumping intervals
- Numerical oscillations
- Results are sensitive to numerical parameters (residual water depths, slice location etc.)
- Not sensitive to Sy and K of Mirrabooka
- Sensitivity analysis is subjective



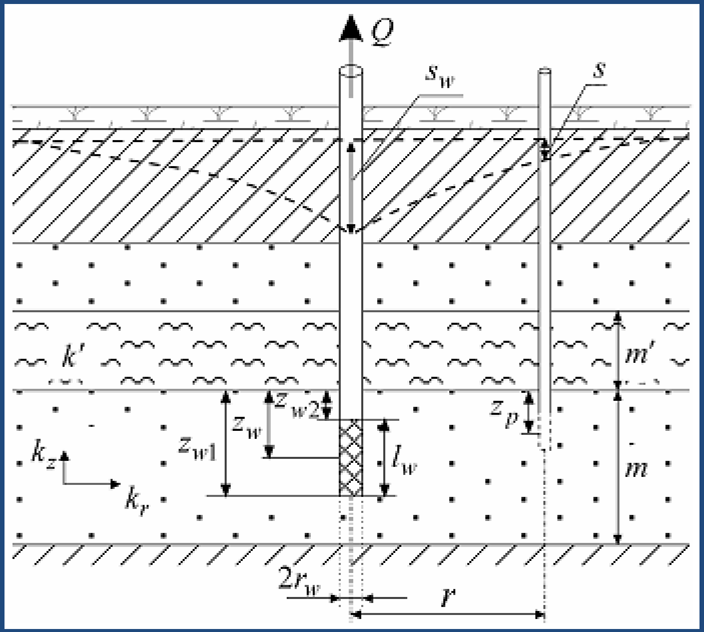
Shallow well: example of oscillations

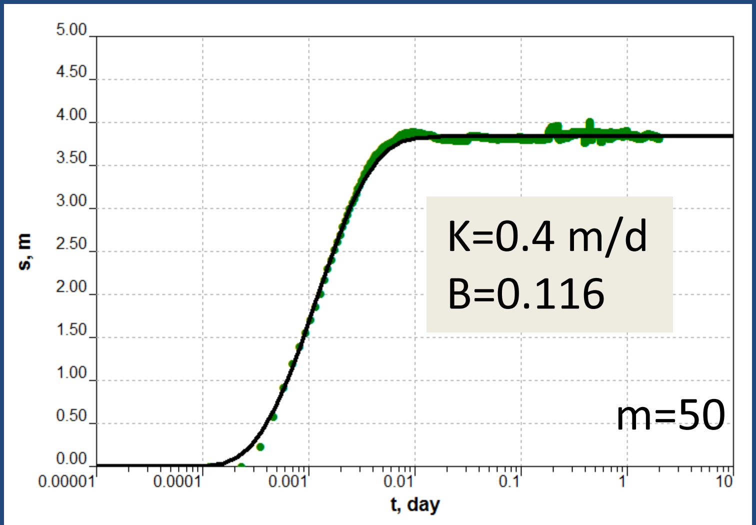
RESULTS

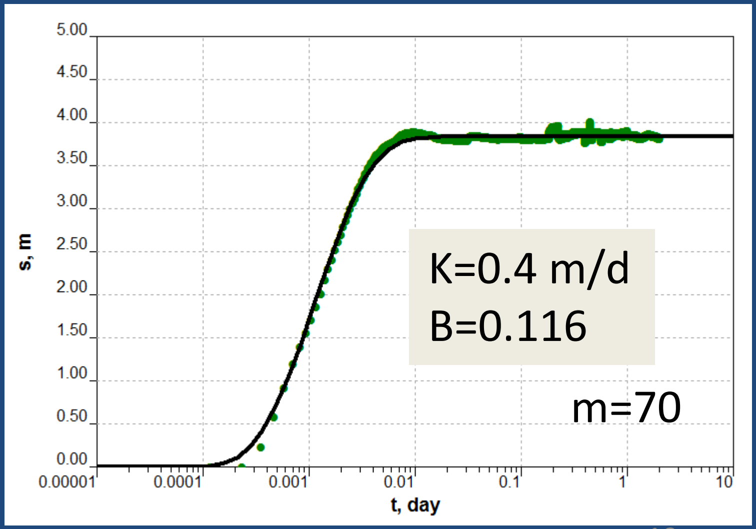
Description	K horizontal		K vertical		Sy
	Best fit	Acceptable fit	Best fit	Acceptable fit	range
Upper sands (Bassendean and GF formations)	7	5-15	1.75	1.8-3.5	0.1-0.3
Sands with silt and clay	1	0.5-1	0.15	0.15-0.3	0.1-0.3
Lower sands of Guildford formation	5.2	5.2-10.4	2	1-4	0.1-0.3
(Mirrabooka Aquifer)	20	15-20	7.5	5-10	0.1-0.3

Case study 3 – corrected interpretation, shallow pumping well

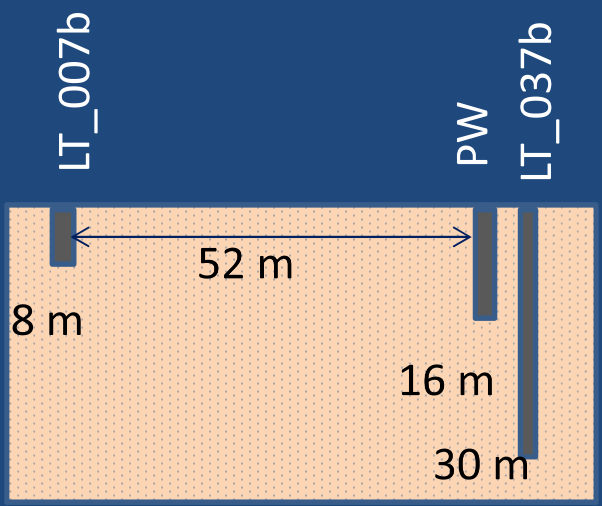
Conceptual scheme
partially penetrating well in an unconfined leaky aquifer (Hantush solution)

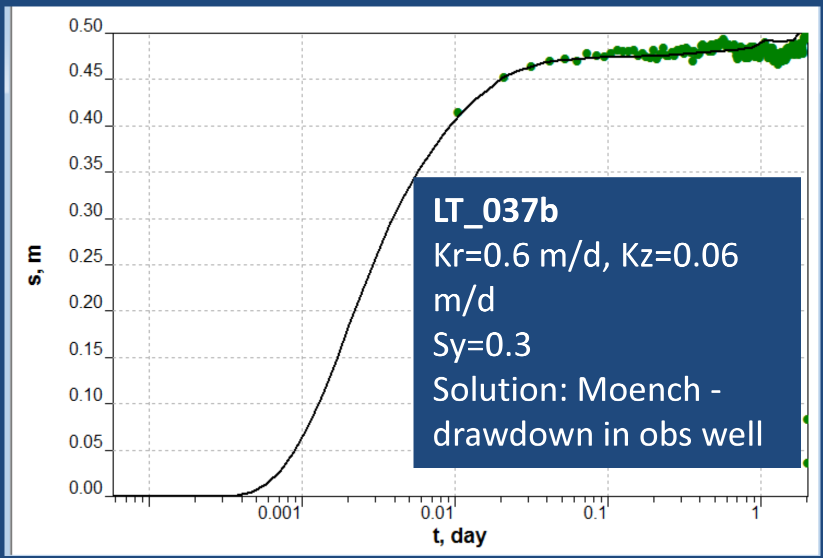


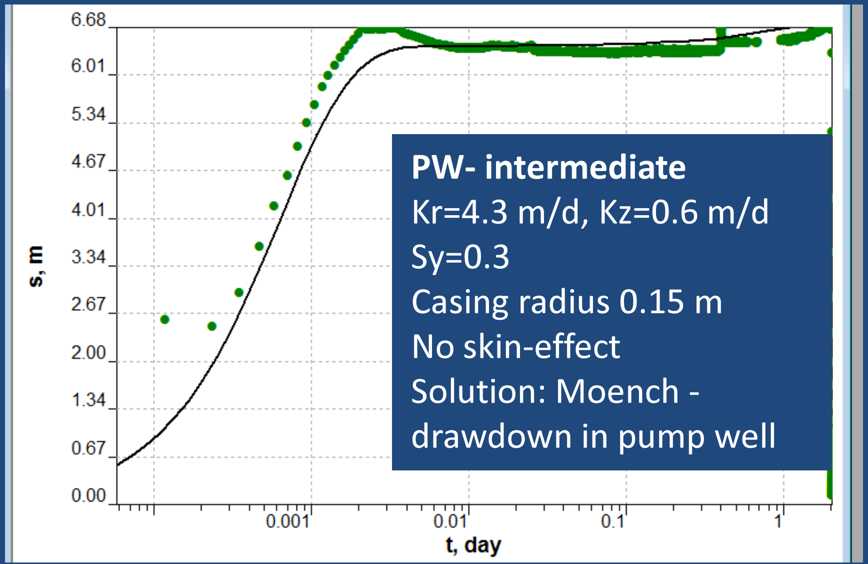


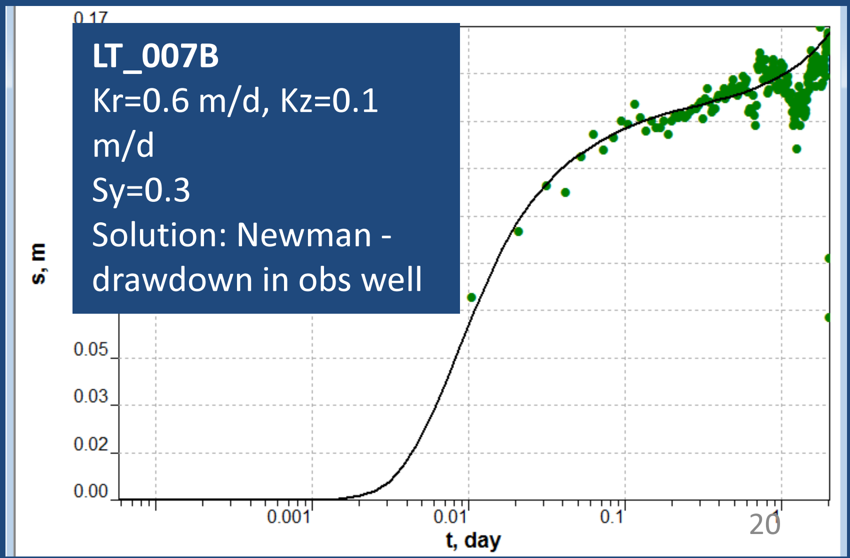


Case study 3 – corrected interpretation, intermediate pumping well

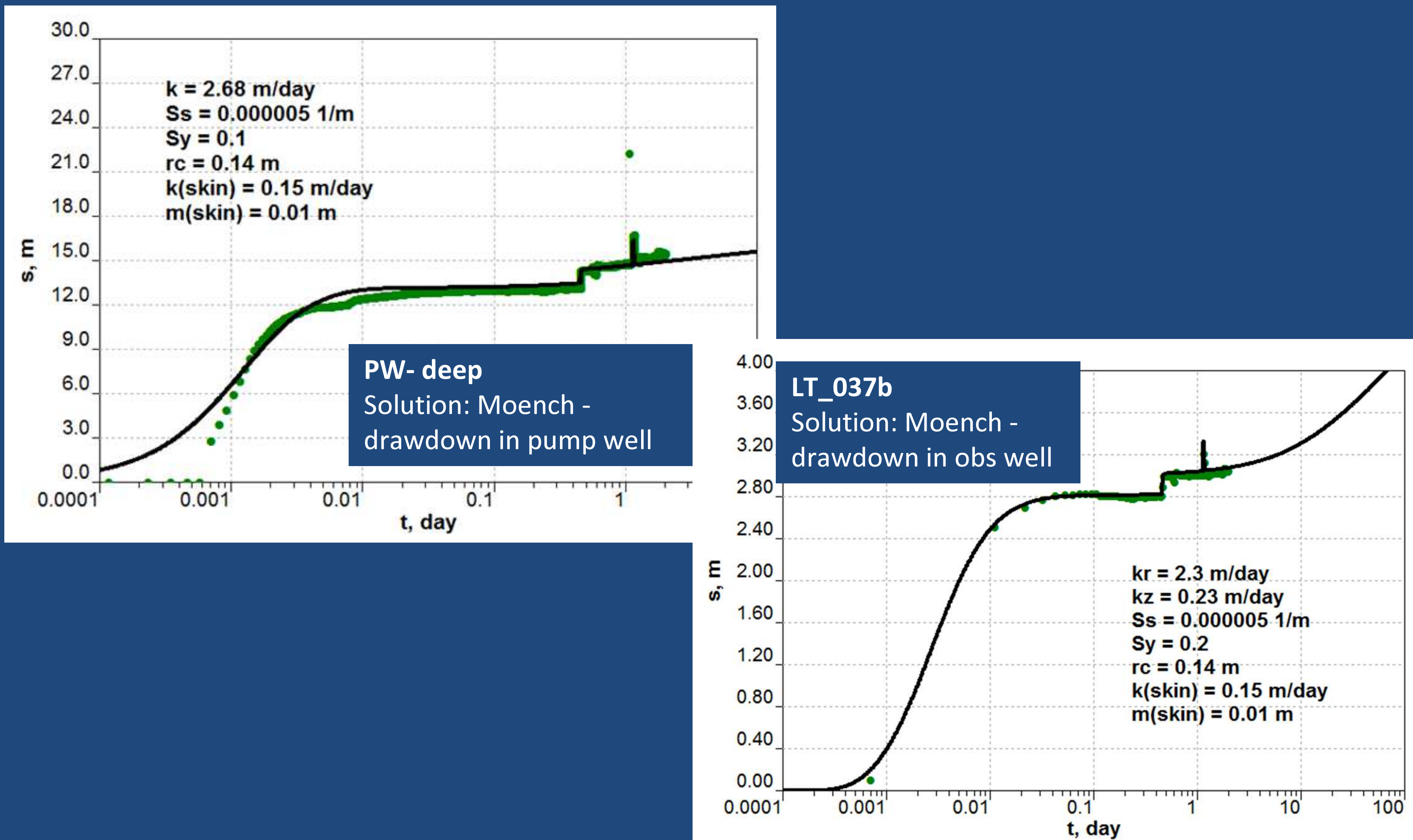








Case study 3 – corrected interpretation, deep pumping well

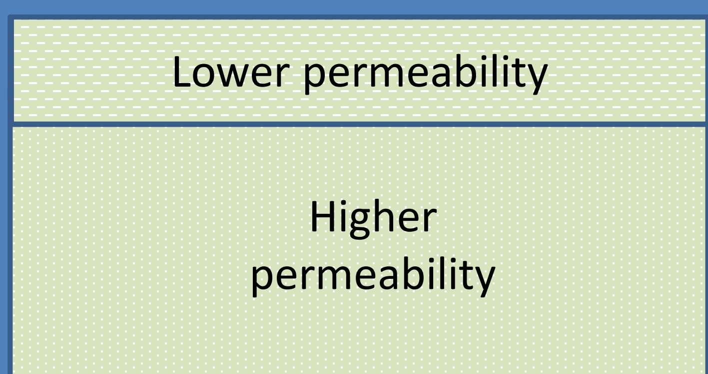


Case study 3 – corrected results and updated profile

Original Results

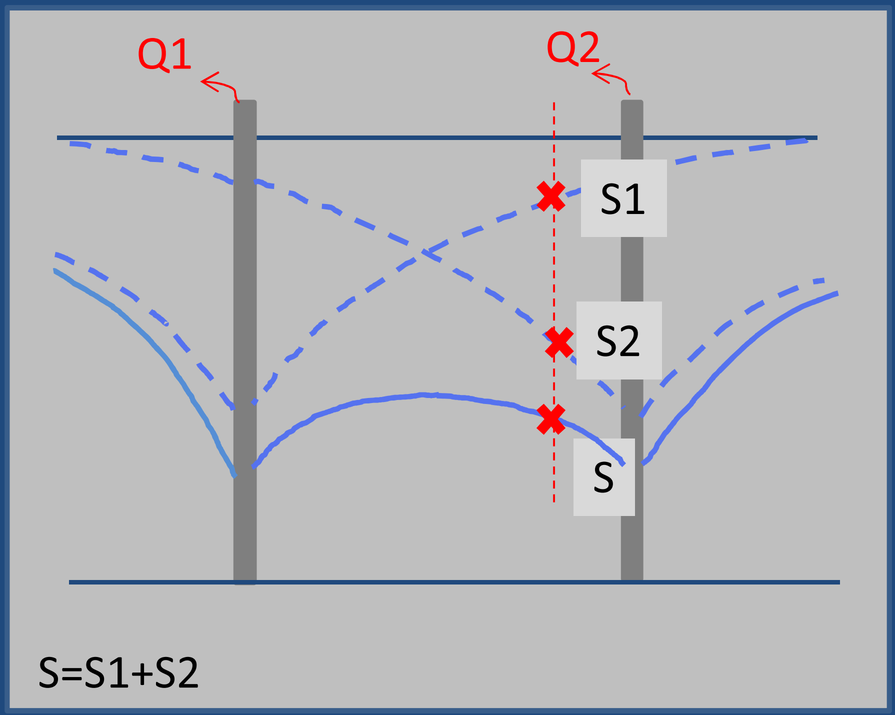
Description	K horizontal		K vertical		Sy
	Best fit	**Acceptable**	**Best fit**	**Acceptable**	**Acceptable**
Upper sands (Bassendean and GF formations)	7	5-15	1.75	1.8-3.5	0.1-0.3
Sands with silt and clay	1	0.5-1	0.15	0.15-0.3	0.1-0.3
Lower sands of Guildford formation	5.2	5.2-10.4	2	1-4	0.1-0.3
(Mirrabooka Aquifer)	20	15-20	7.5	5-10	0.1-0.3

Updated Results



- Upper Sands and Clays – 0.4 m/d
- Lower sands - up to 4 m/d, Sy is between 0.1 and 0.3
- Anisotropy coefficient is up to 10 (not important)
- Mirrabooka aquifer has K similar to that of lower sands

Analytical models for well system design. Principle of Superposition



Software

- EXCEL,
- EXCEL+ any pump test interpretation software,
- WINFLOW*,
- AMWELLS

Standard numerical codes are not modelling drawdown in pumping wells correctly because:

- Grid/element size is not suitable
- Equations for well hydraulics, skin-effect, well and screen diameters etc. are not included

*http://www.scisoftware.com/products/winflow_overview/

Open pit dewatering - wellfield design in EXCEL (gold deposit in CAF)

Superposition formula:

$$s = \frac{1}{T}\sum_{i=1}^{n} Q_i f_i$$

s – drawdown at any well or at any other point
T – transmissivity;
Q - pumping rate of a single well;
fi - a function that depends on boundary conditions and well parameters

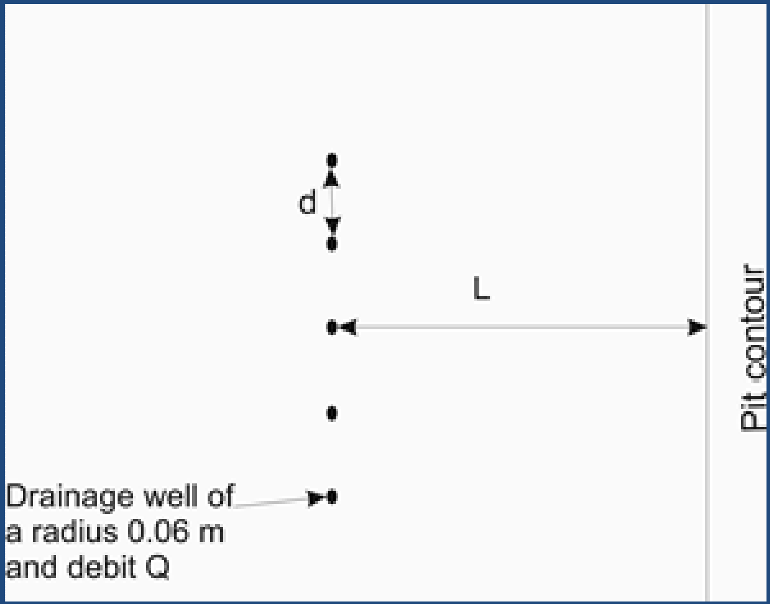
A linear pit boundary, a linear contour of dewatering wells and a linear contour of recharge at a distance *R* from a drainage line:

$$f_i = 0.367 \times \lg\left(\frac{R}{r}\right)$$

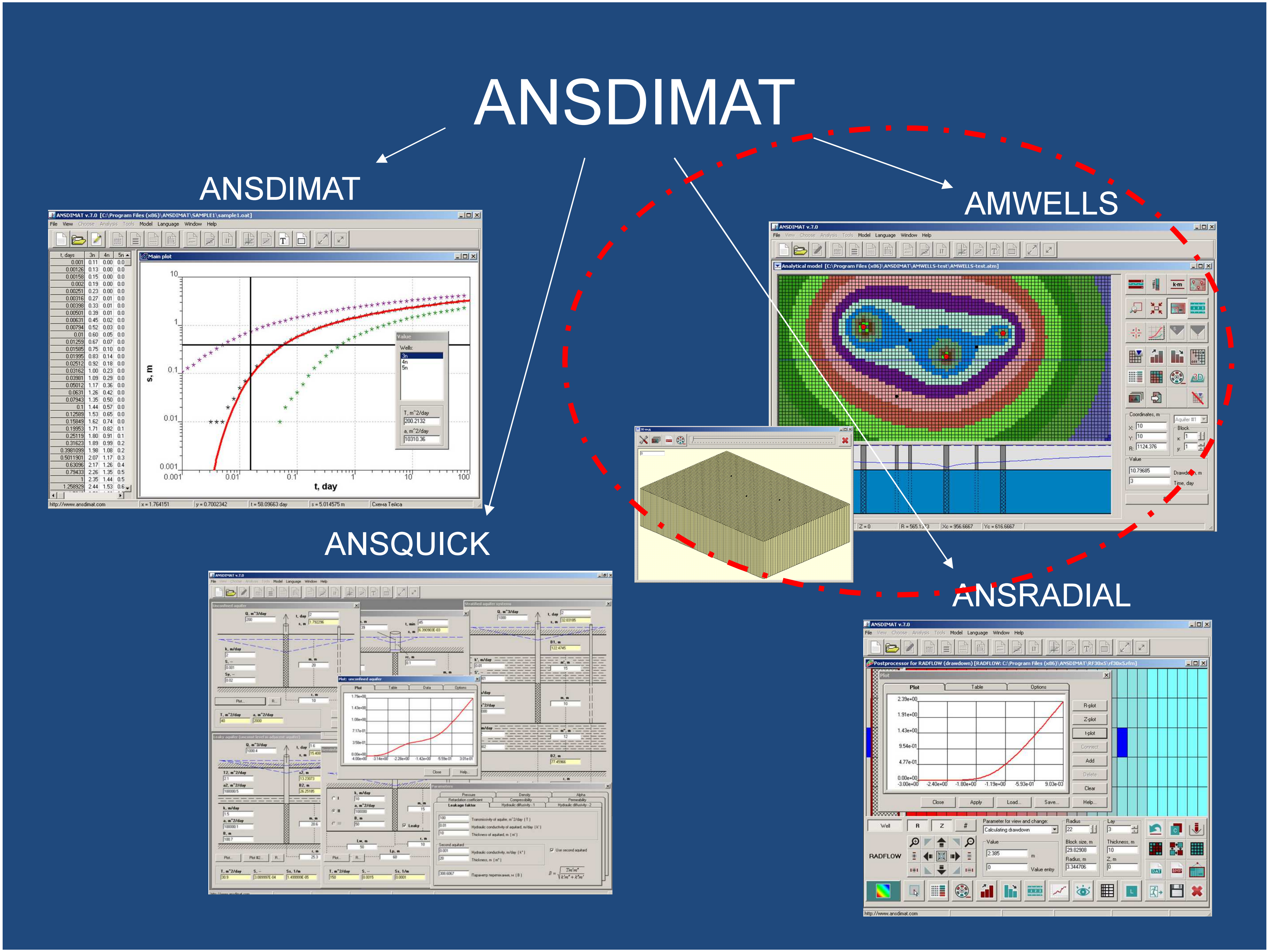
r – distance from a pumping well
R - *Radius of Influence*

$$R = 1.5\sqrt{\frac{T \times t}{S}}$$

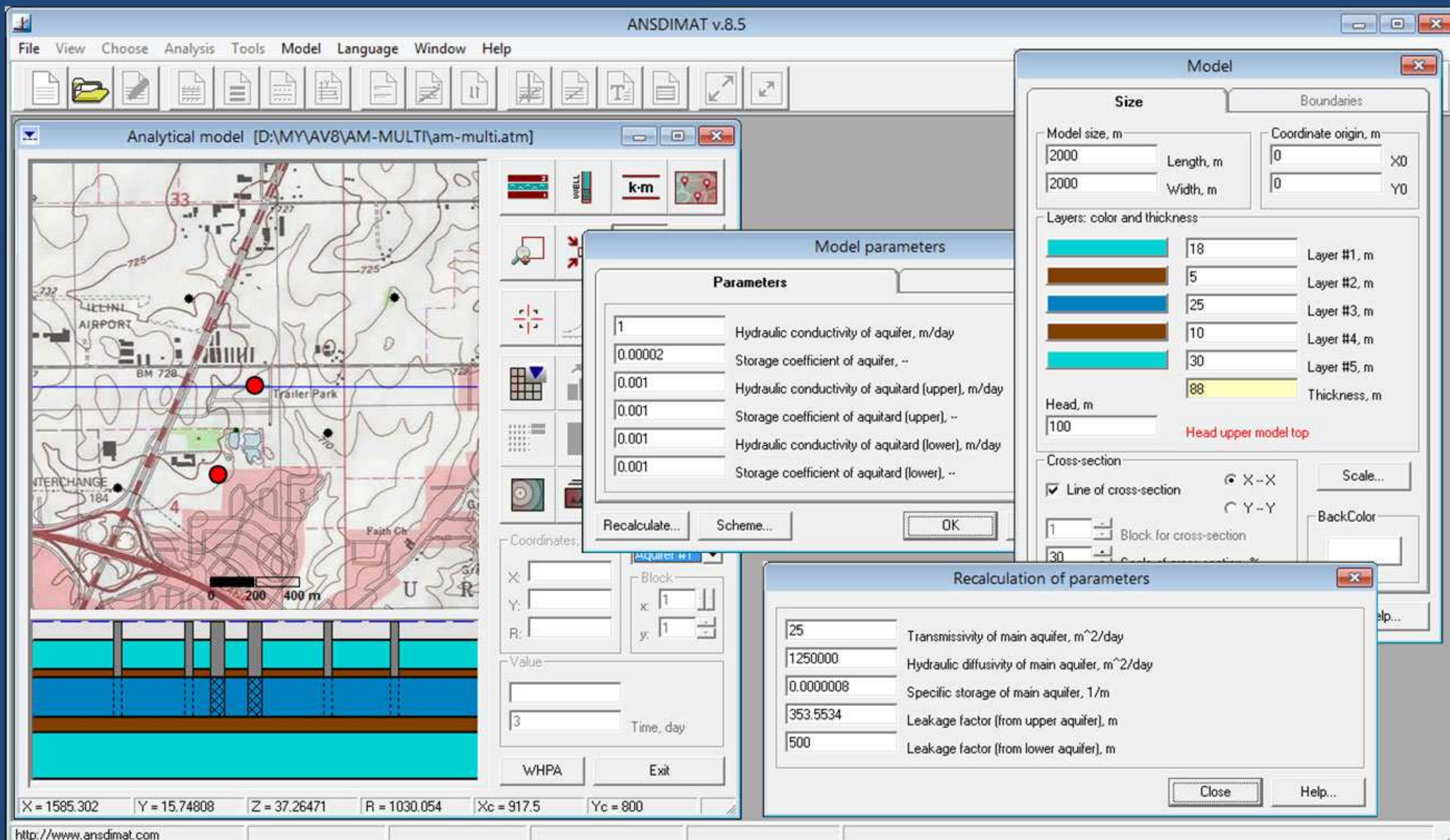
S – storage coefficient;
t – time from the beginning of pumping



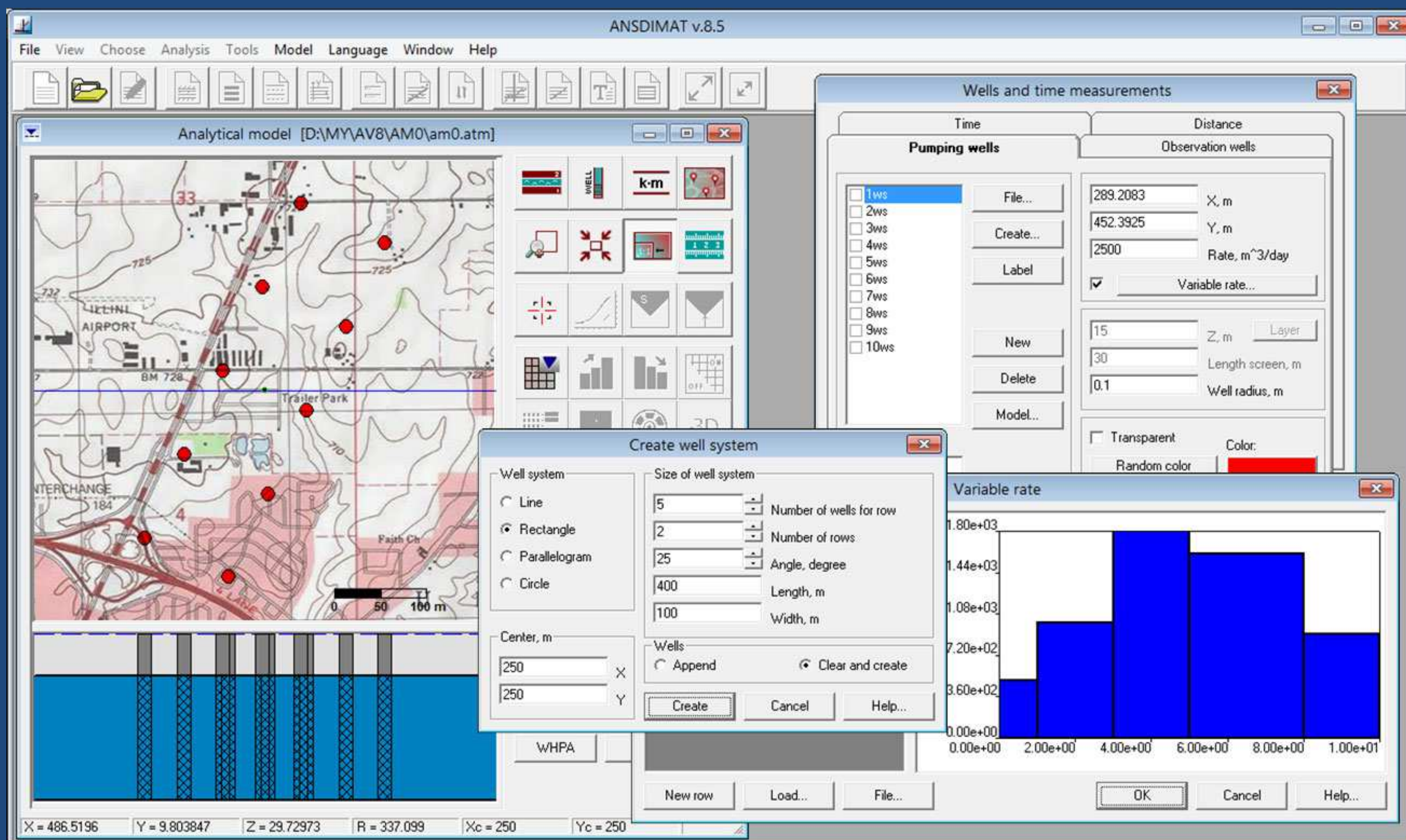
Results: drawdown at a pit contour and inside each well for a specific Q. Helps to decide on number of boreholes and distances between them


ANSDIMAT
ANSDIMAT
ANSQUICK
AMWELLS
ANSRADIAL

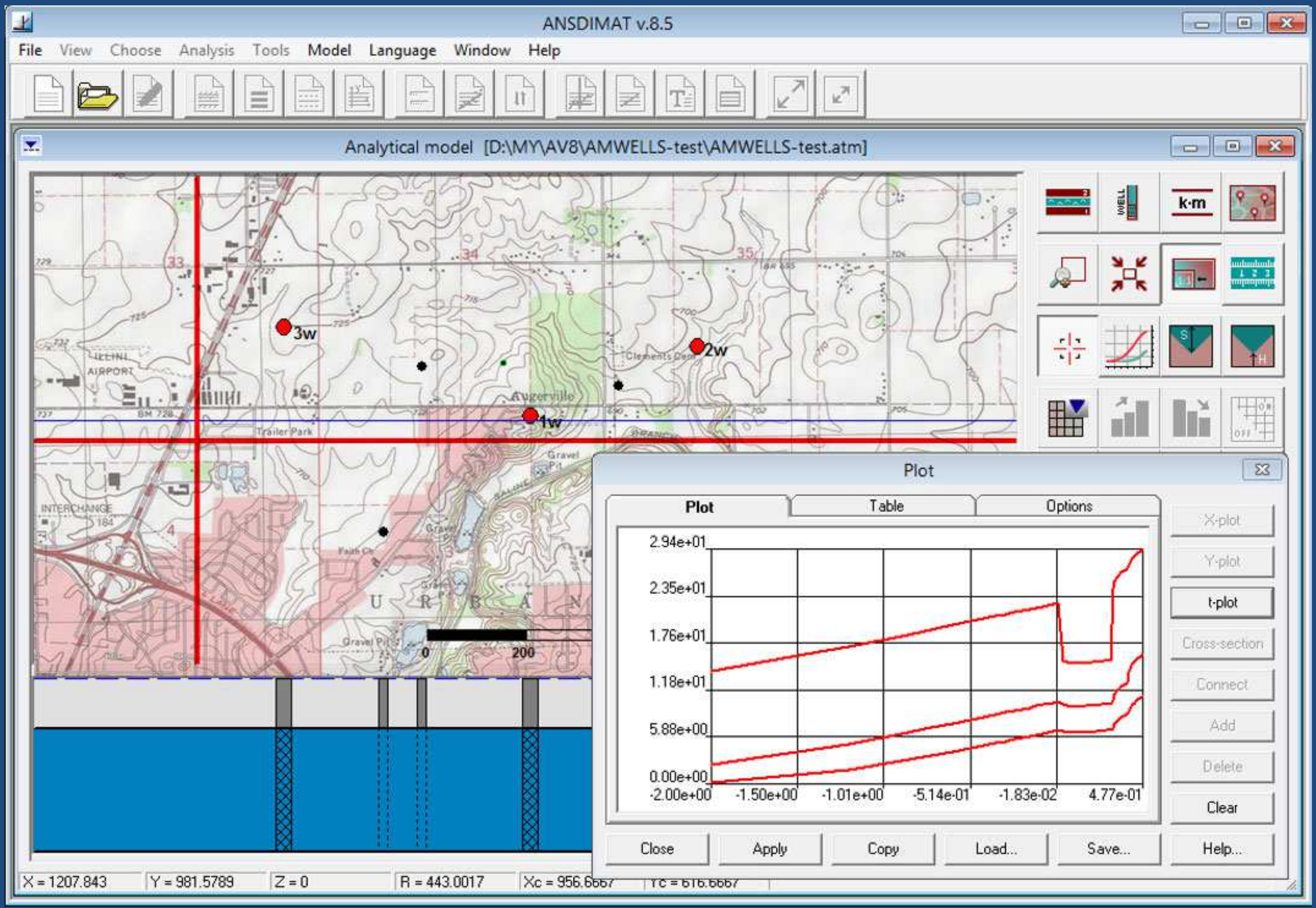
AMWELLS:
Model geometry, well locations



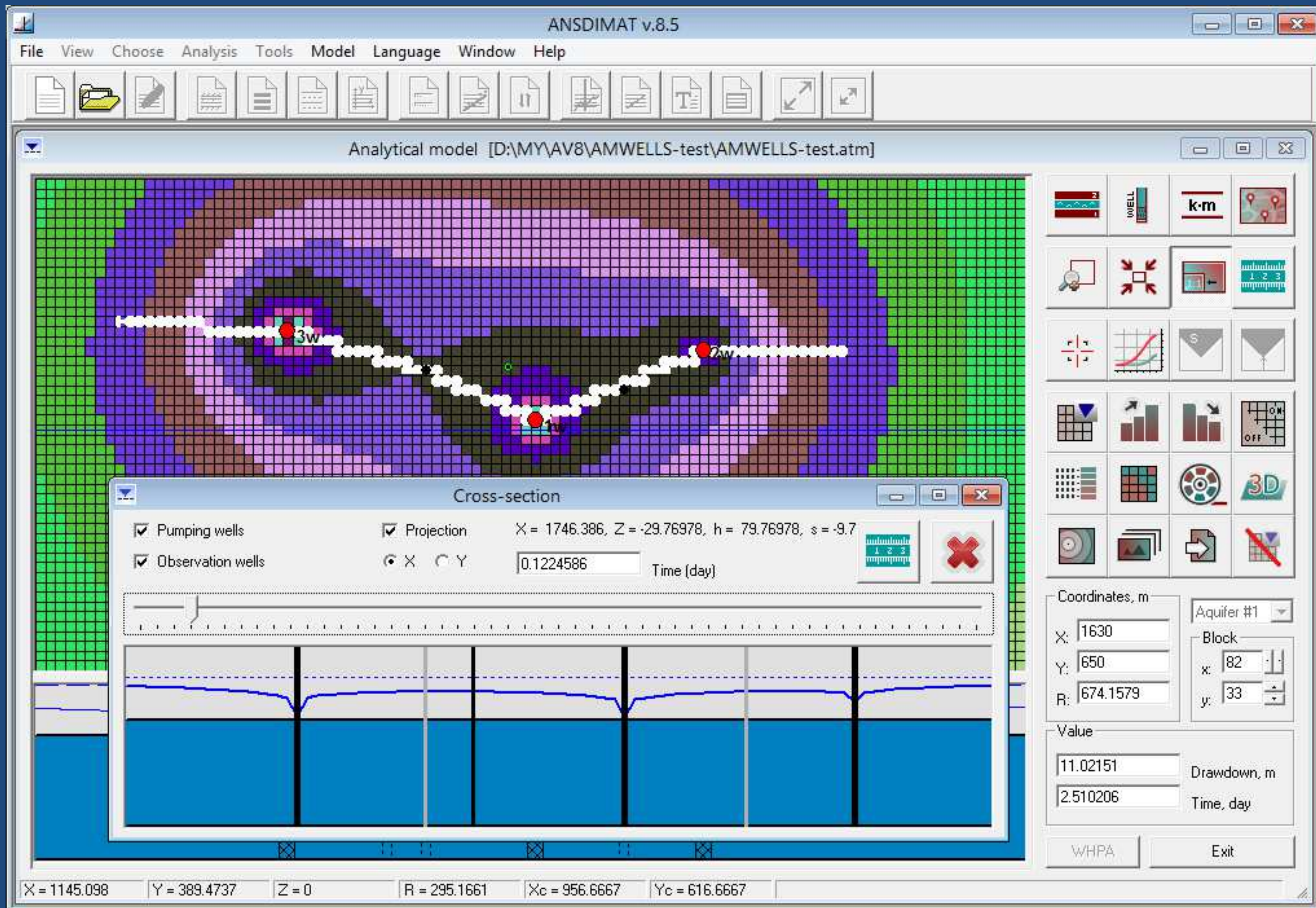
AMWELLS:
Input of well systems – choice of layouts



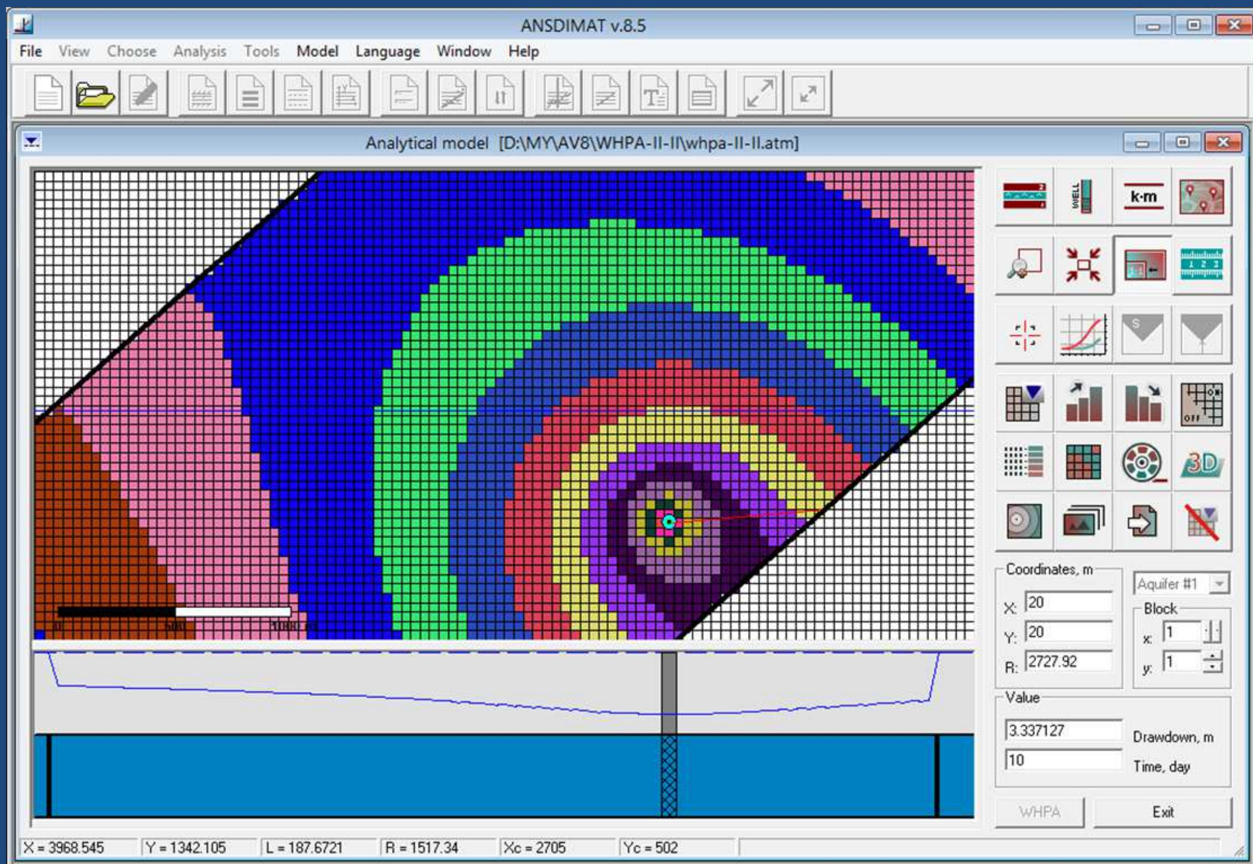
AMWELLS: Calculation of drawdown in each well



AMWELLS: Piezometric maps and hydrogeological cross-sections

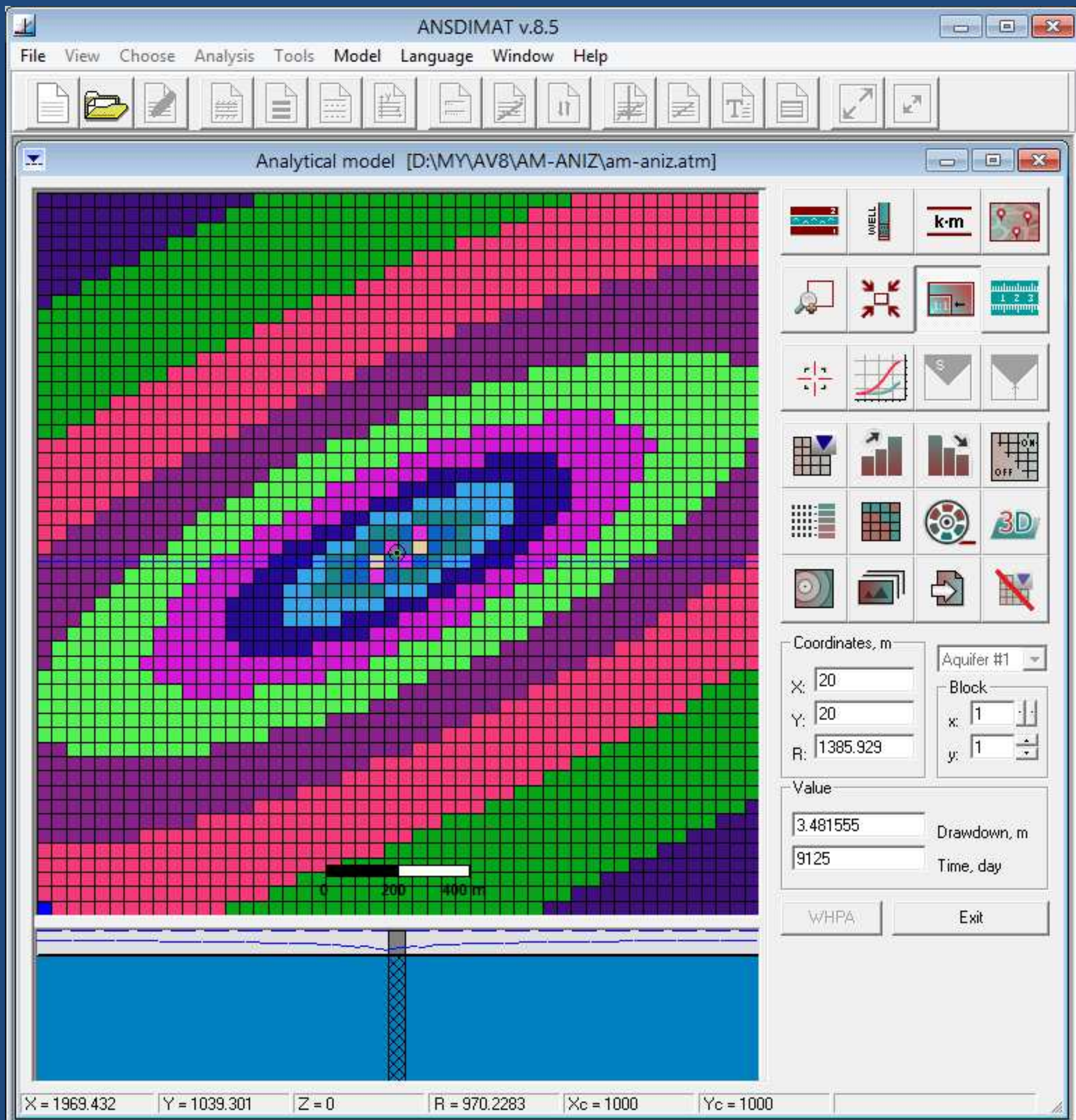


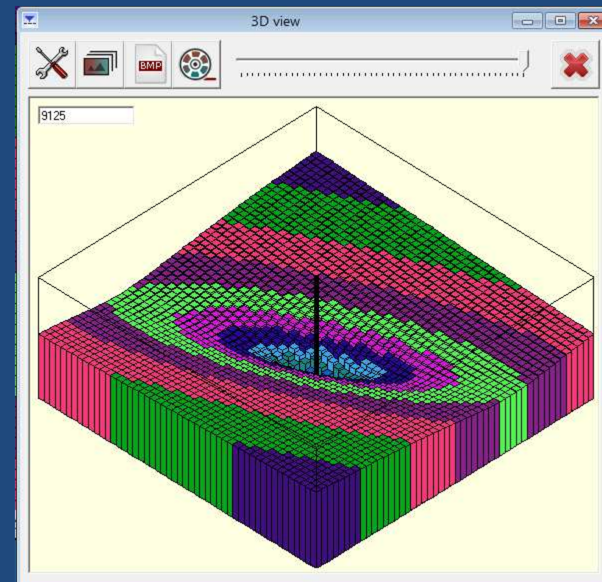
AMWELLS:
Hydrodynamic boundaries

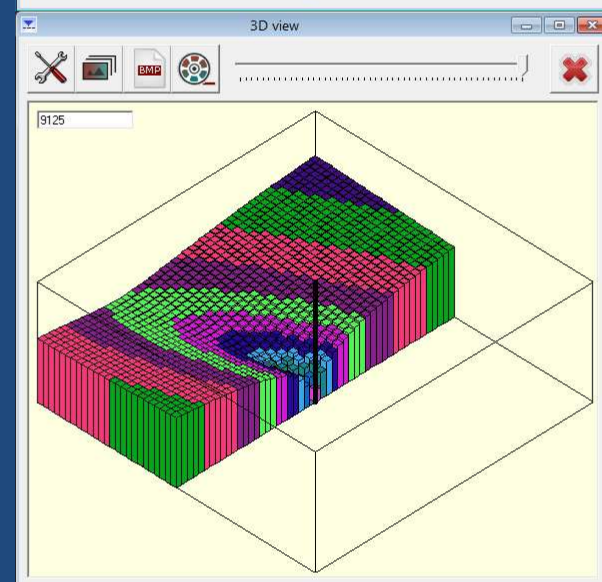


Choice of Dirichlet, Neumann or Cauchy boundaries (straight line boundaries only)

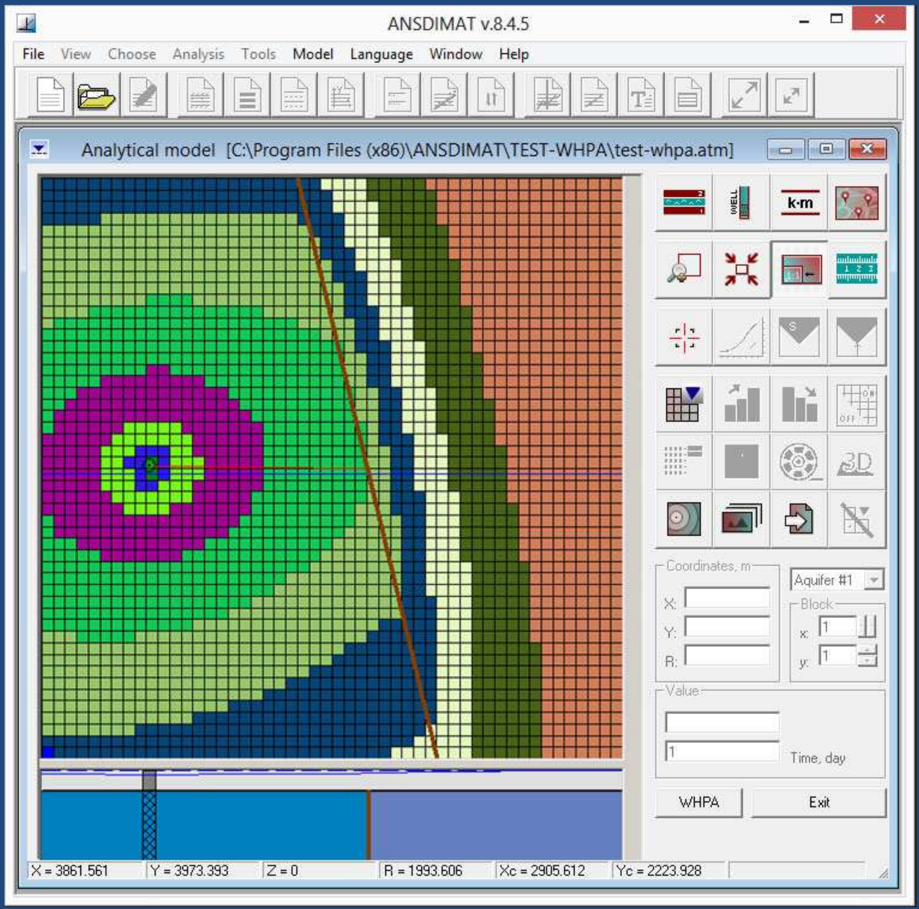
AMWELLS: Anisotropy

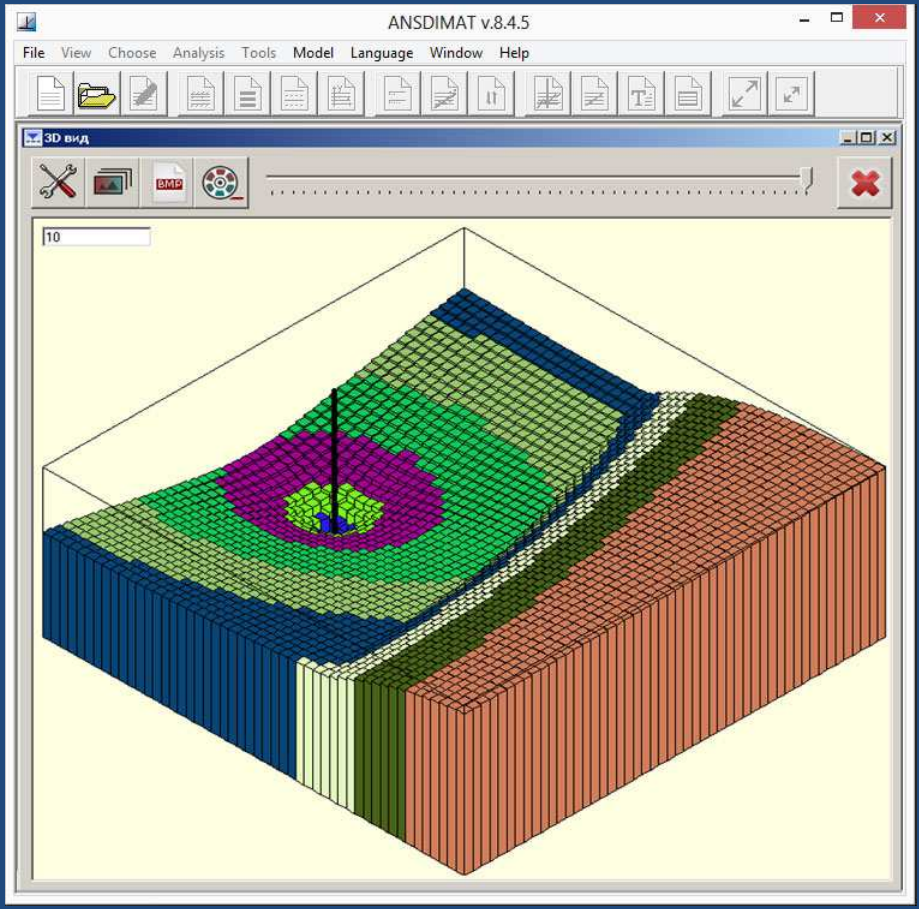




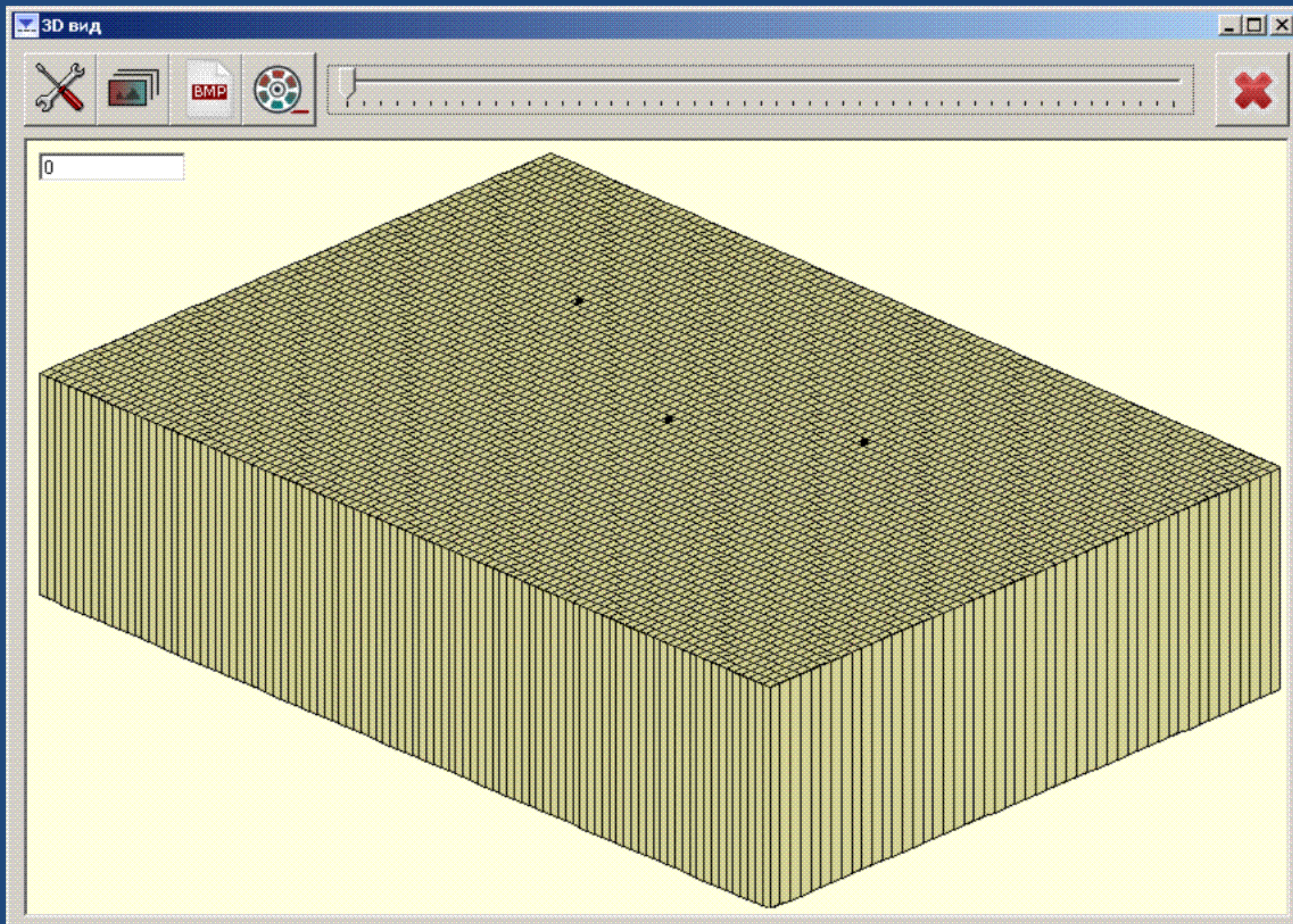


AMWELLS: Heterogeneity

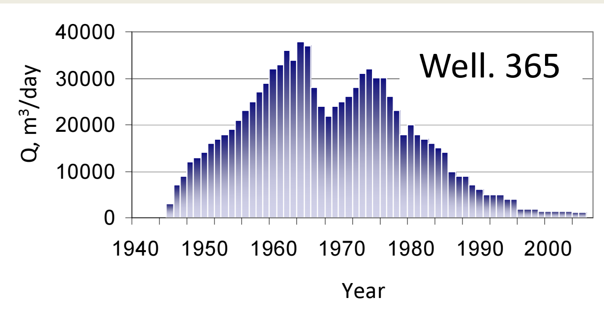


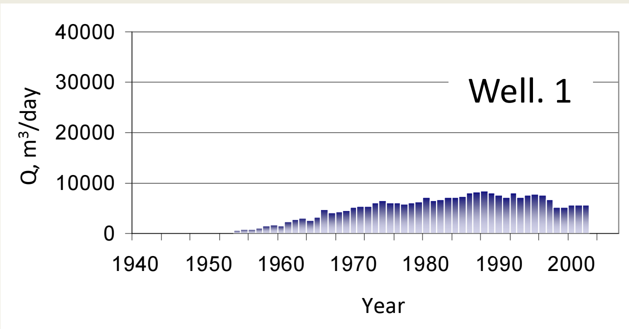


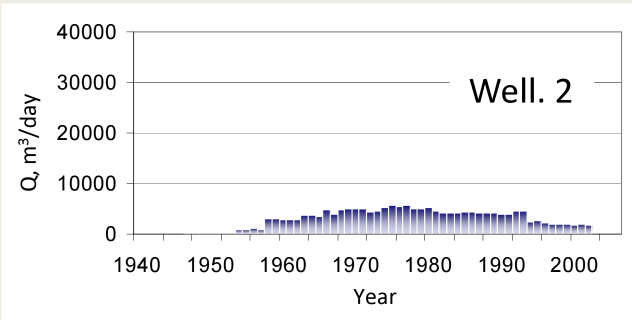
AMWELLS: 3D animation movie

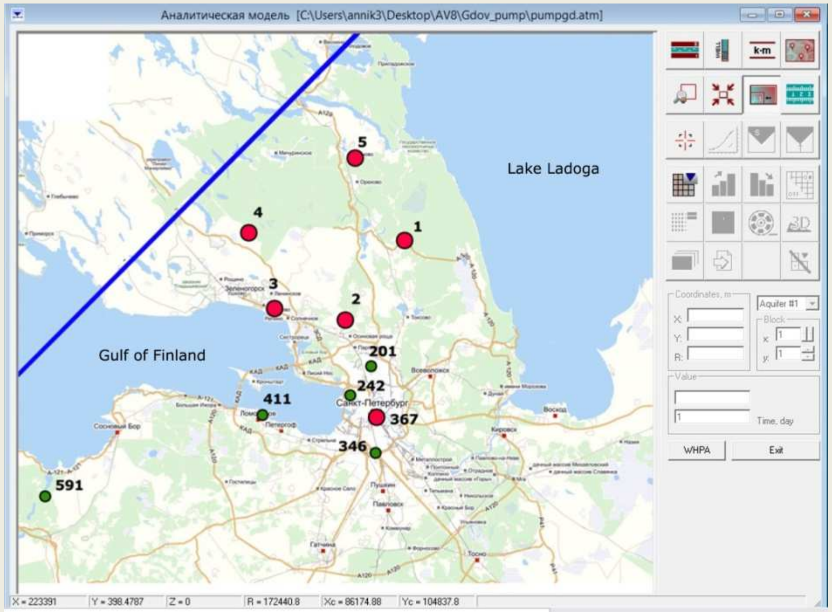


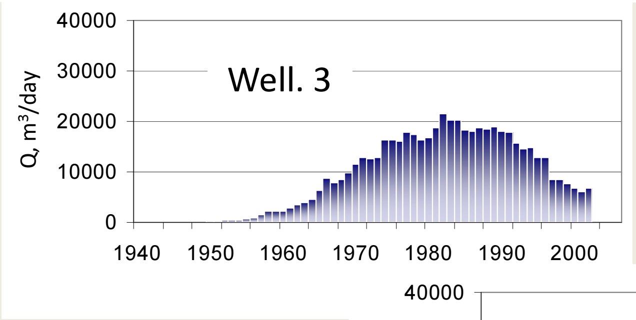
Case study 4: Water supply borefield Leningrad – St-Petersburg, 1946–2006

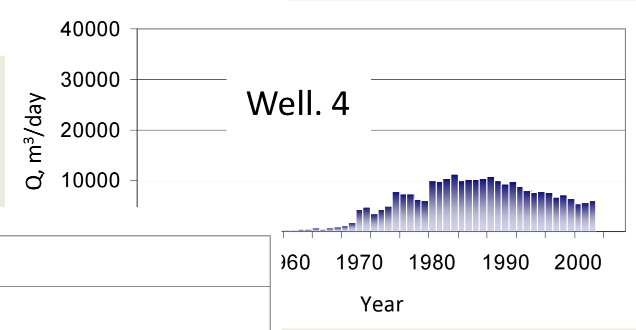


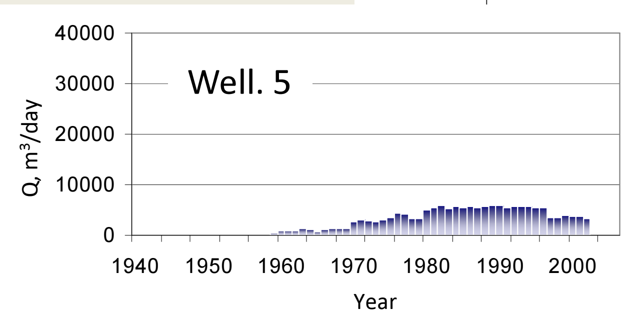




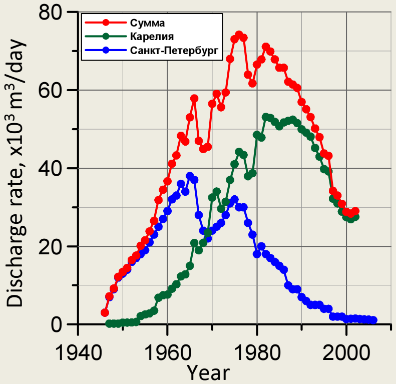


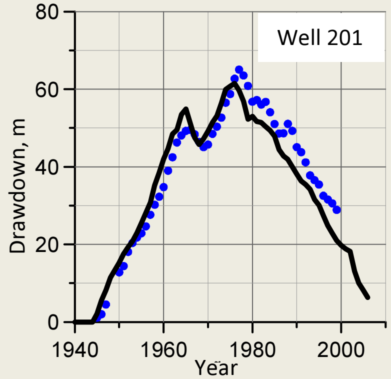


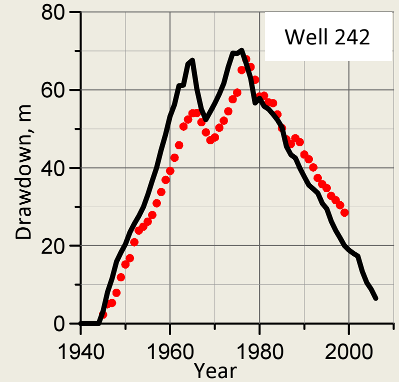


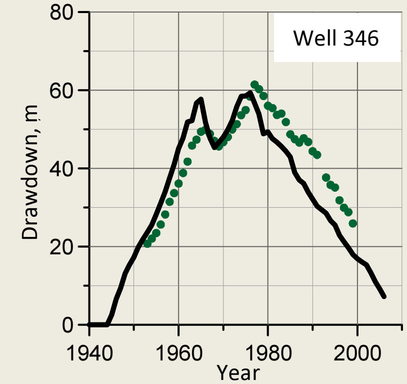


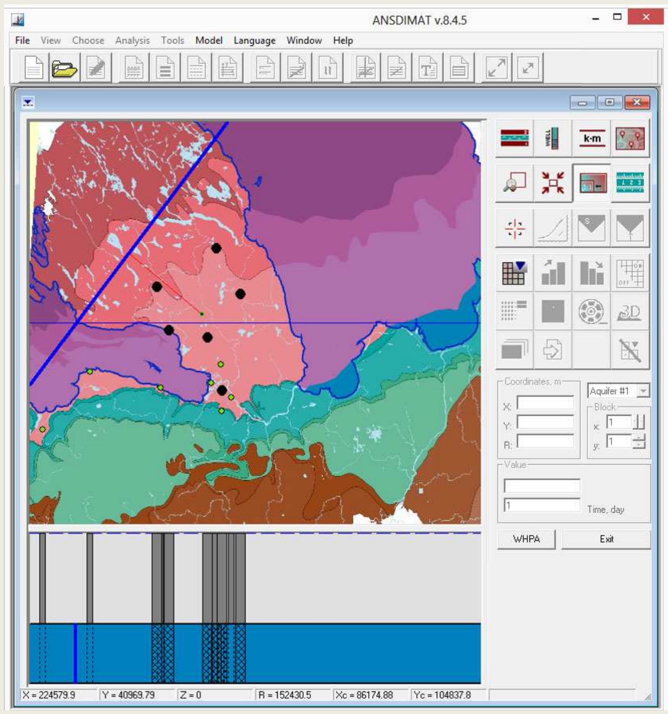
Case study 4: model calibration and predicted drawdowns, 1946–2006

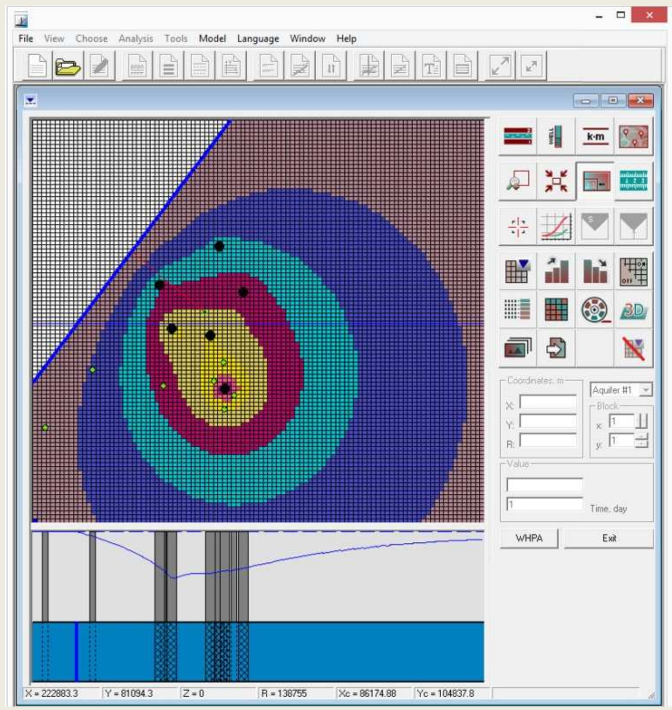


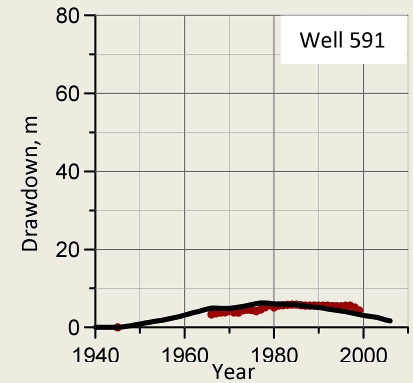


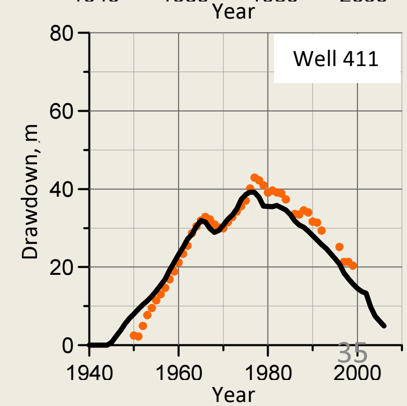




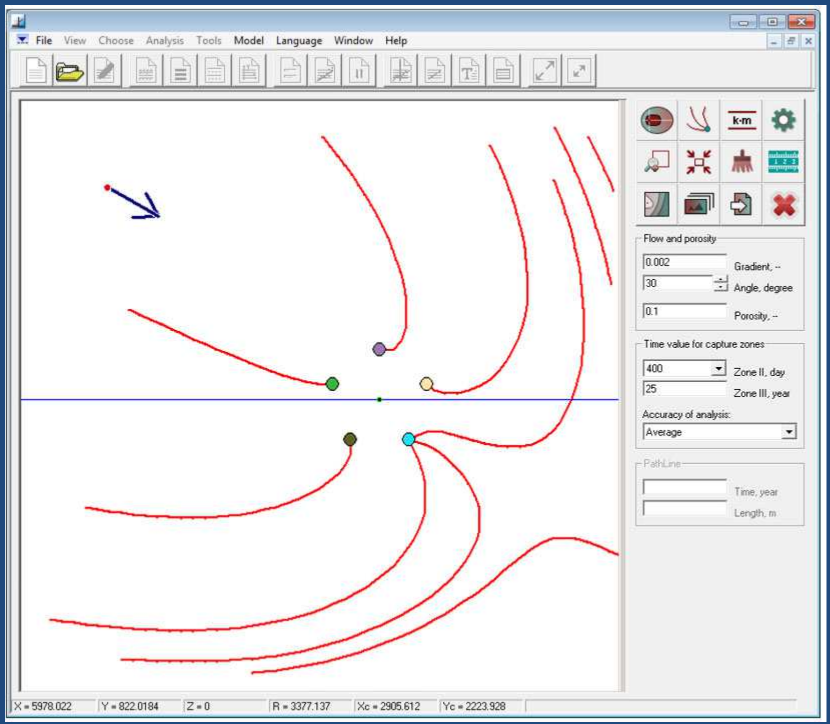


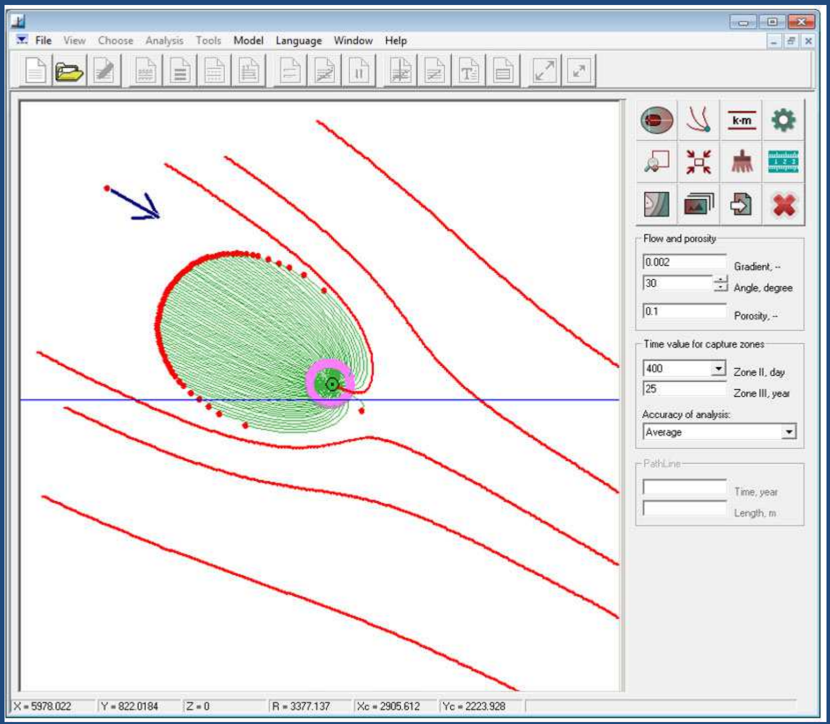




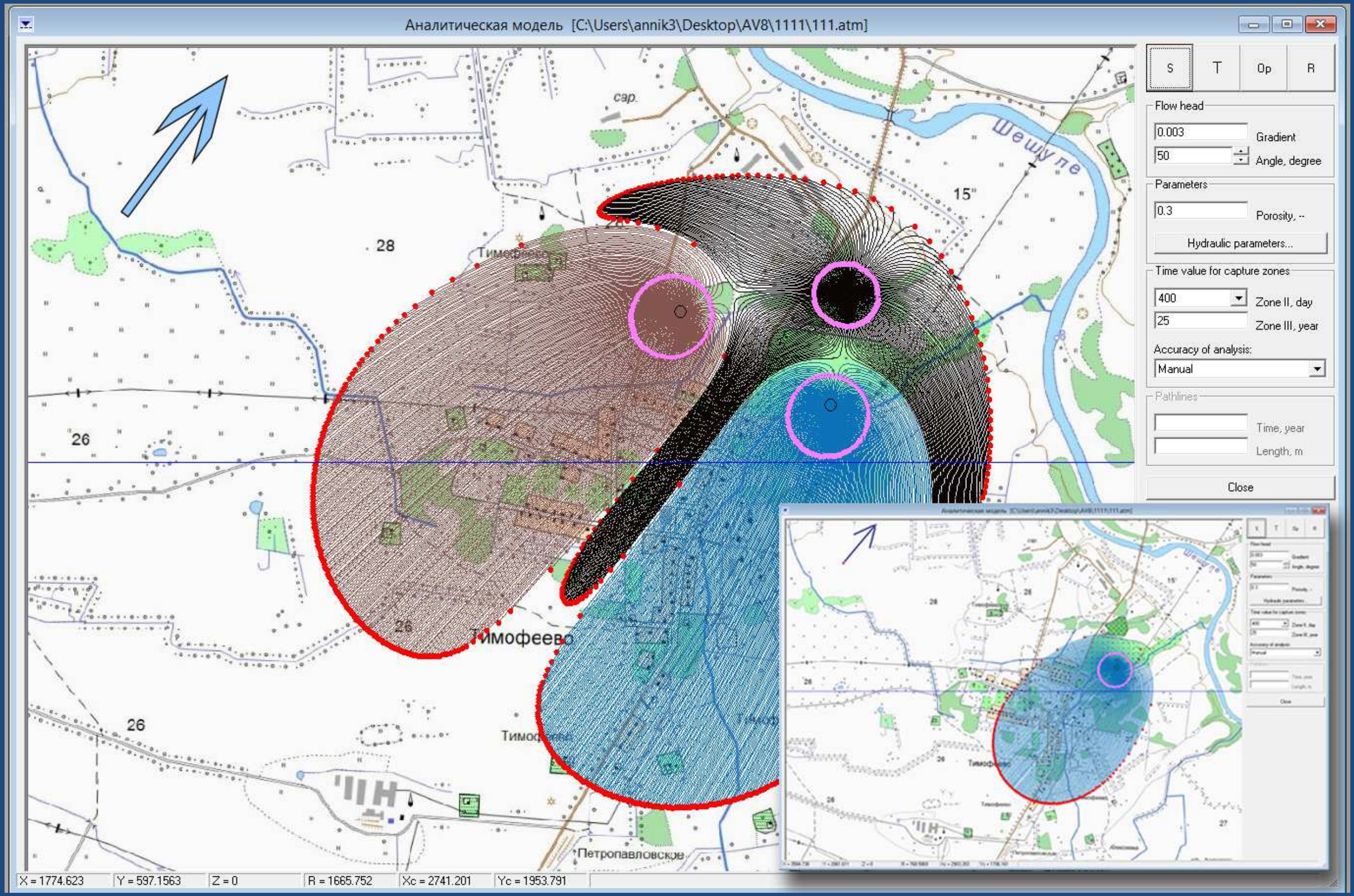


Particle tracking

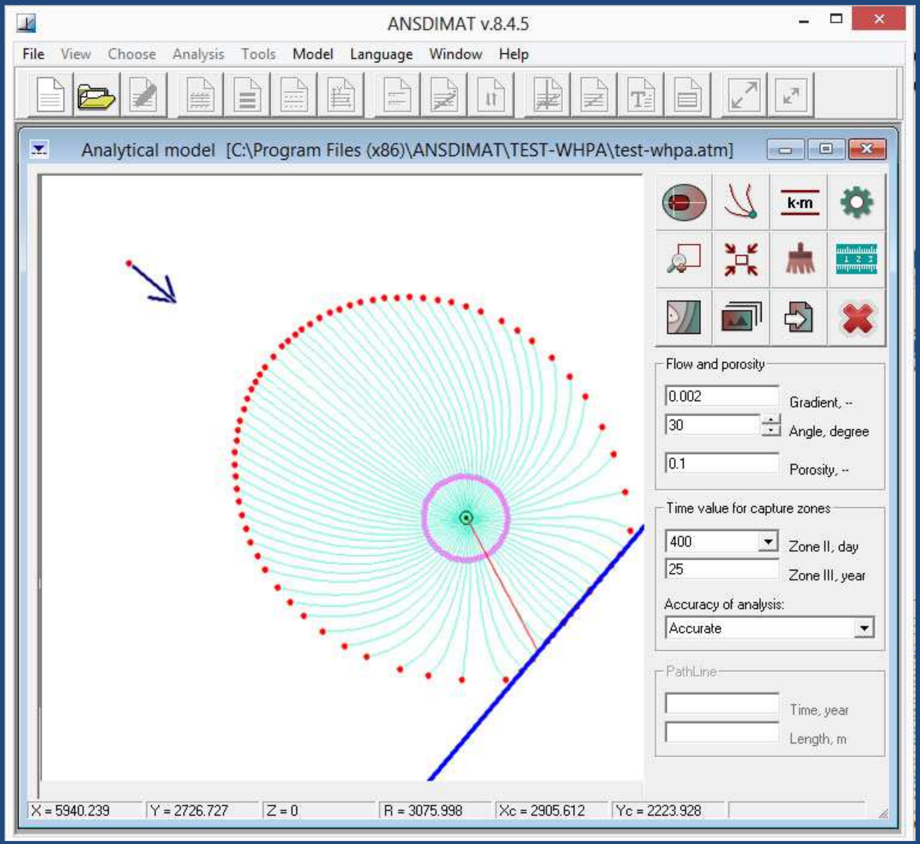


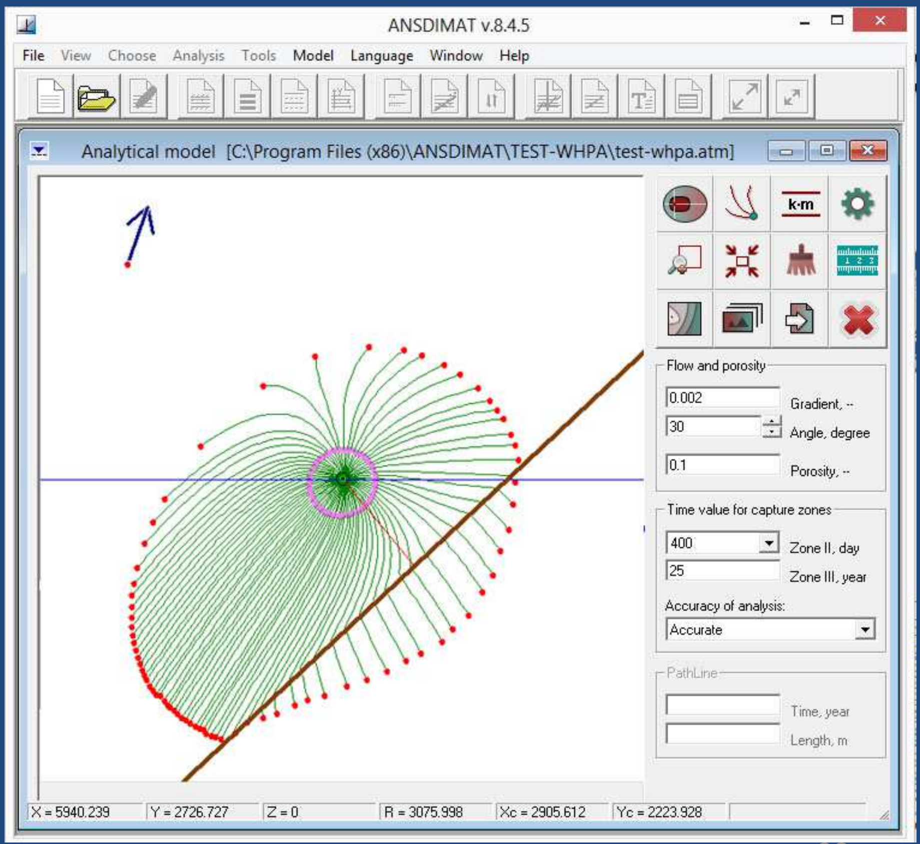


Well catchments (wellhead protection areas)

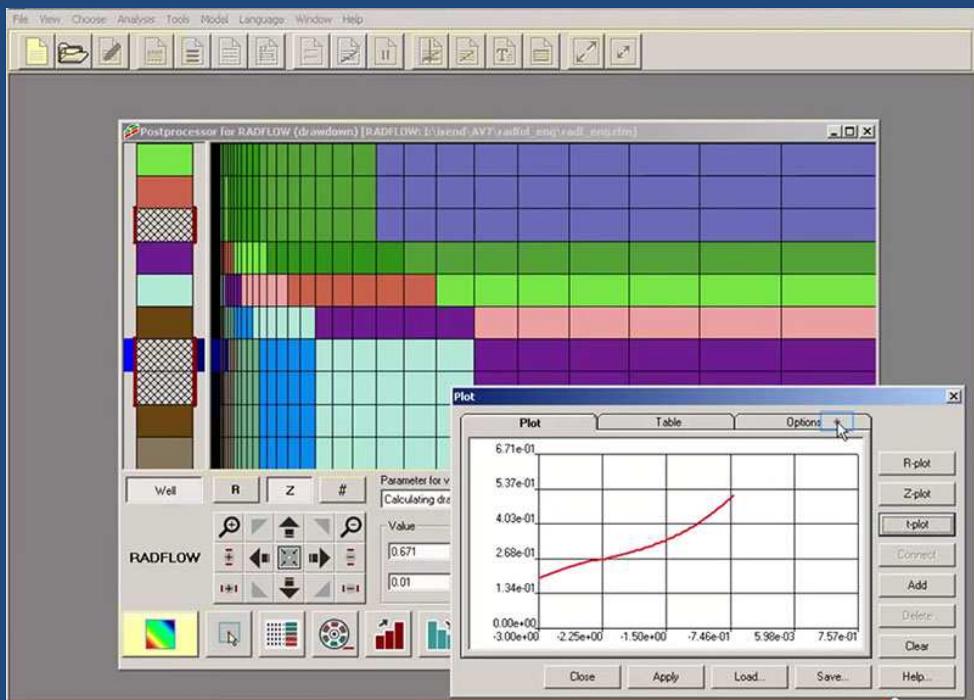


Impact of boundaries and heterogeneity on well catchments





ANSRADIAL - finite-difference simulator of axisymmetric groundwater flow



…when hydrogeological conditions are too complex to be modelled analytically.

Typical applications:

aquifer tests with simultaneous pumping from different horizons in multi-layer aquifers

Pre- and postprocessor for 2-D numerical modelling codes:

- MODFE (USGS)
- RADFLOW (G.S. Johnson, D.M. Cosgrove, Idaho Water Resources Research Institute).

Thank you for attention!

http://www.ansdimat.com/