A numerical assessment of large screened wells on flow fields and solute distribution

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‘Monitoring Wells are instruments that are there to tell you lies’

John Williams

The problem

Long screens often used in groundwater studies

Good for ideal, Theis type 2D aquifers

Largely replaced with short screens and multi level monitoring systems recently

However, still present in many sites

Potential for shortcutting and communicating different aquifers largely understood, but

- How bad is the problem at contaminated sites?
- What sorts of flow rates can go through monitoring wells under typical conditions?
- Is it that bad really? Where and what driving forces and factors are at play?

Objectives

To illustrate and quantify the effects of long screened monitoring wells on flow fields and contaminant distribution

To try to quantify flows through monitoring wells under typical hypothetical scenarios

To illustrate the problem on a real site

Methodology

Used modeling techniques (Modflow / MT3D) to simulate typical (and some more extreme) scenarios

- Wells simulated as High K zone
- Compared results with Multi-Node Well (MNW) package (Halford & Hanson, 2002)

Theoretical Scenarios

- Single layered aquifers
  - High K; varying gradients
- 3-Layer system (aquifer-aquitard-aquifer)
  - Varied K and head differences in Aquifers
  - Plotted Q_{well} versus ΔH (Head Difference in aquifers)
  - Plotted Q_{well} versus $K_{aquifers}$

Practical Application

- Real site; multiple aquifer/aquitard layers; significant Head differences across layers
- Estimated Q_{well} using MNW and high K approach to quantify flows through the well

Theoretical Cases

3D Modflow models

Case1: Single Aquifer

- Single aquifer, K=1E-2cm/s;
- Varying horizontal hydraulic gradient
- Varying screen lengths

Case 2: 3-Layer system aquifer/aquitard/aquifer

- Varying vertical hydraulic gradient (head differences between aquifers)
- Varying K values in top/bottom aquifers
- Varying Monitoring well Diameter (2”; 4”)

Theoretical Case 1: Single Aquifer

$K_{aquifer}$ = 1E-2 cm/s

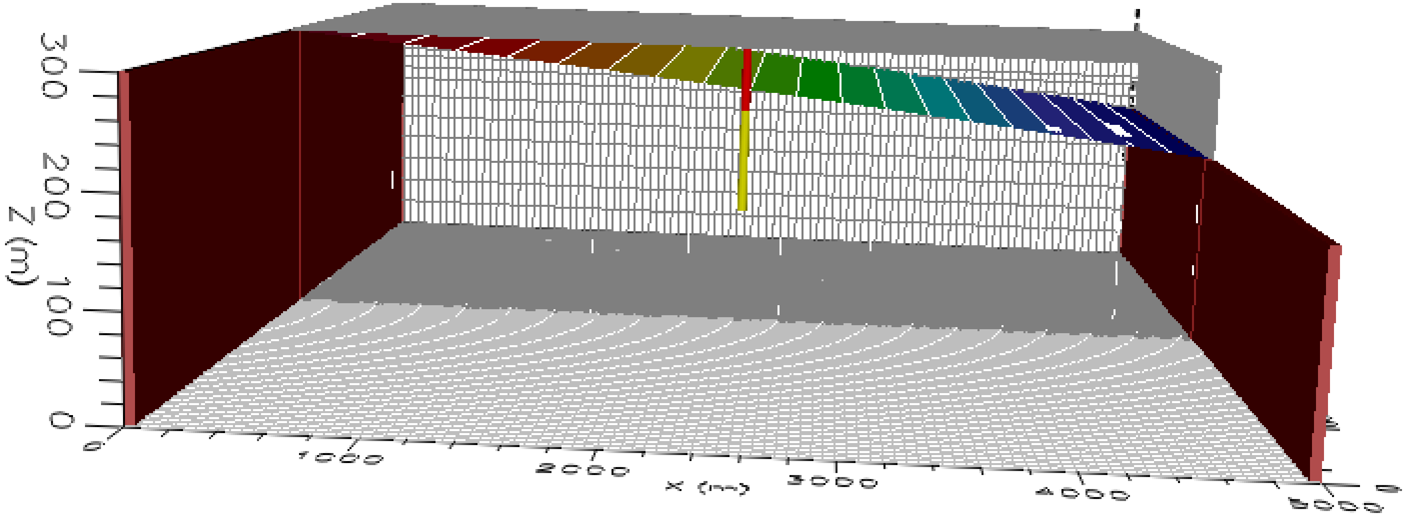
Varied horizontal gradient :

- 0.001
- 0.01
- 0.05

Varied screen length:

- 50m
- 100m

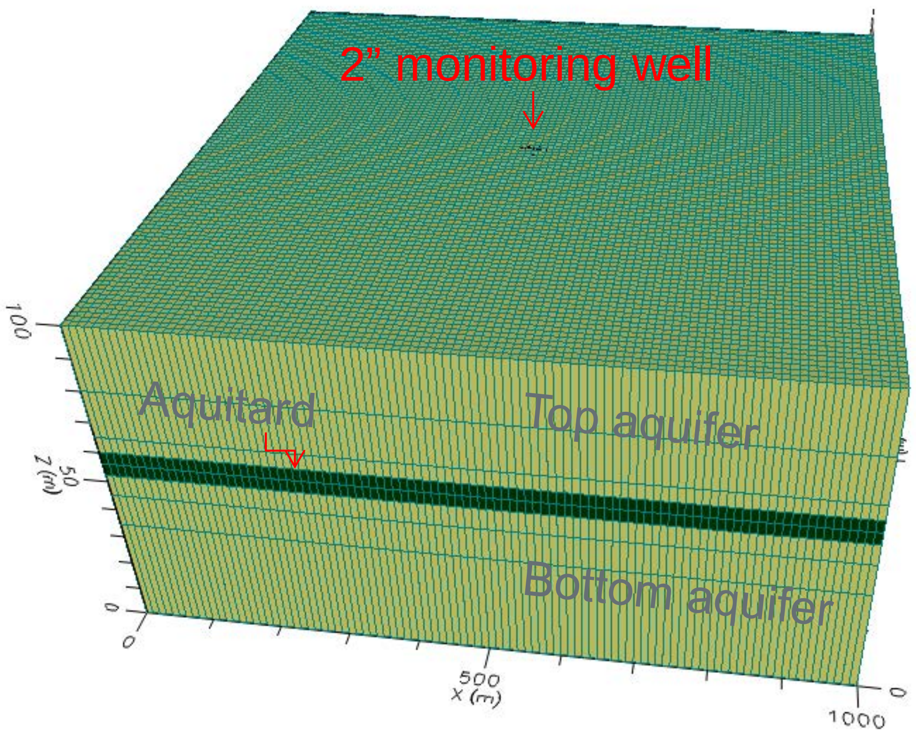
Well simulated with MNW

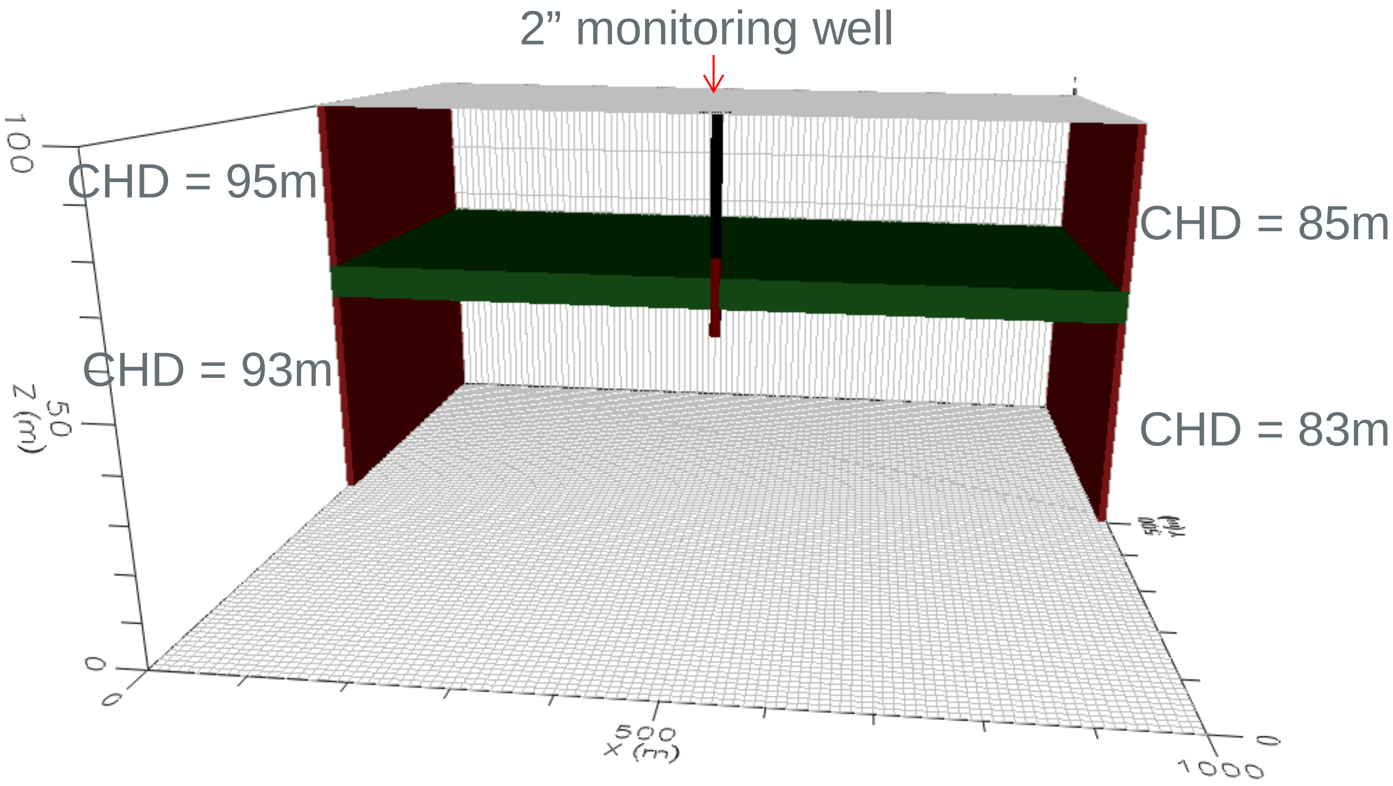


Theoretical Case 2: 3-Layer System

3-Layer system (Aquifer/Aquitard/Aquifer)

Varying $K_{aquifer}$ and ΔH between aquifers (e.g. 2m head difference)



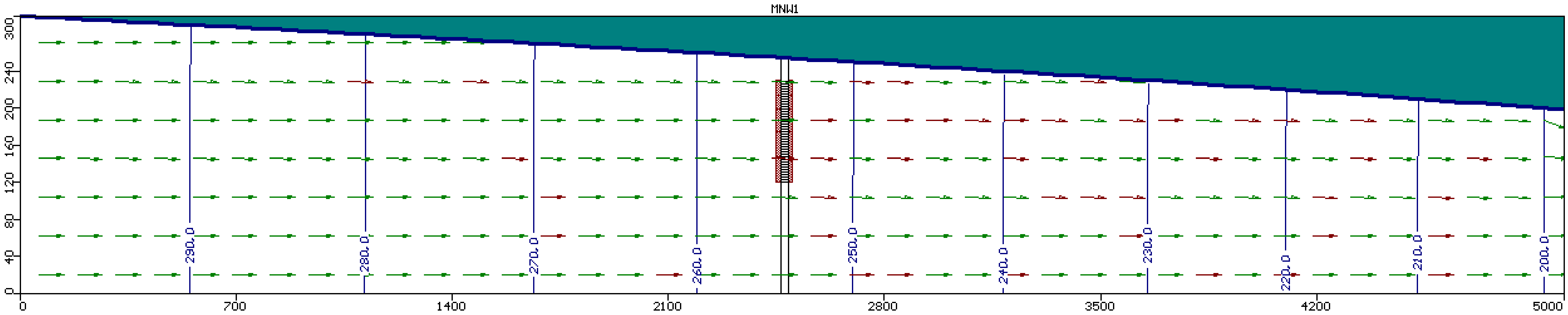


Results – Case 1: Single aquifer

Flows through monitoring wells very small (<1e-3 gpm) in all cases

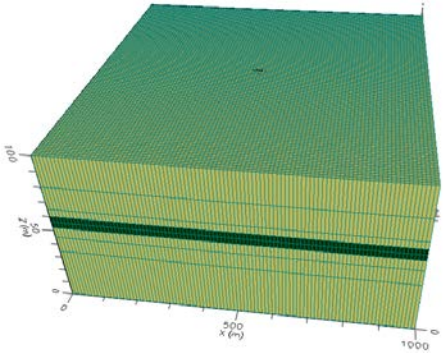
Flows increase with increasing screen lengths, however still very small

Increasing horizontal gradients increase flows, also modestly

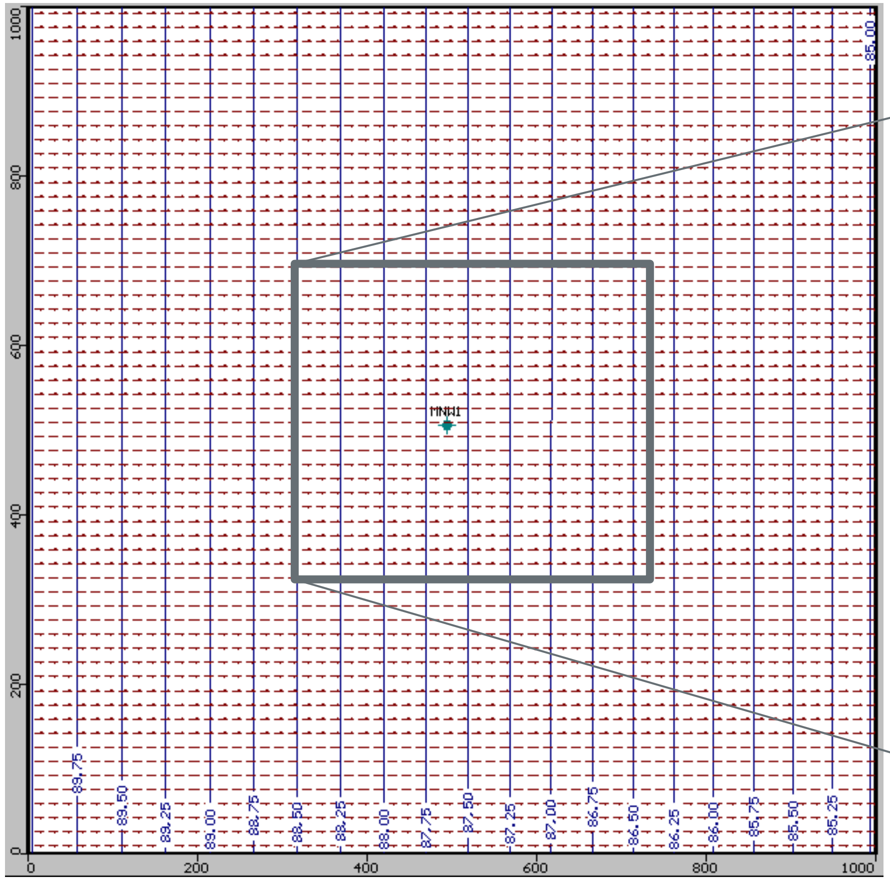


Results – Case 2: 3-Layer Case

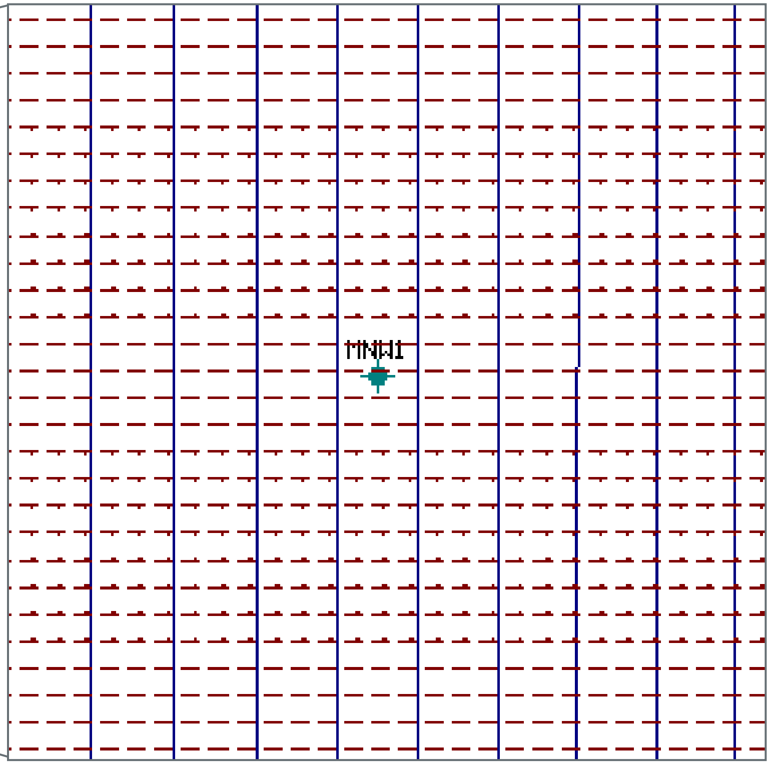
ΔH=2m, No Well



GW Head Contours and flow vectors



Plan View

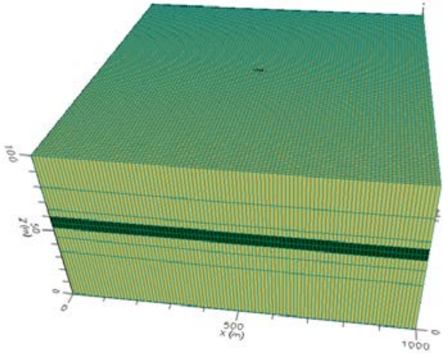


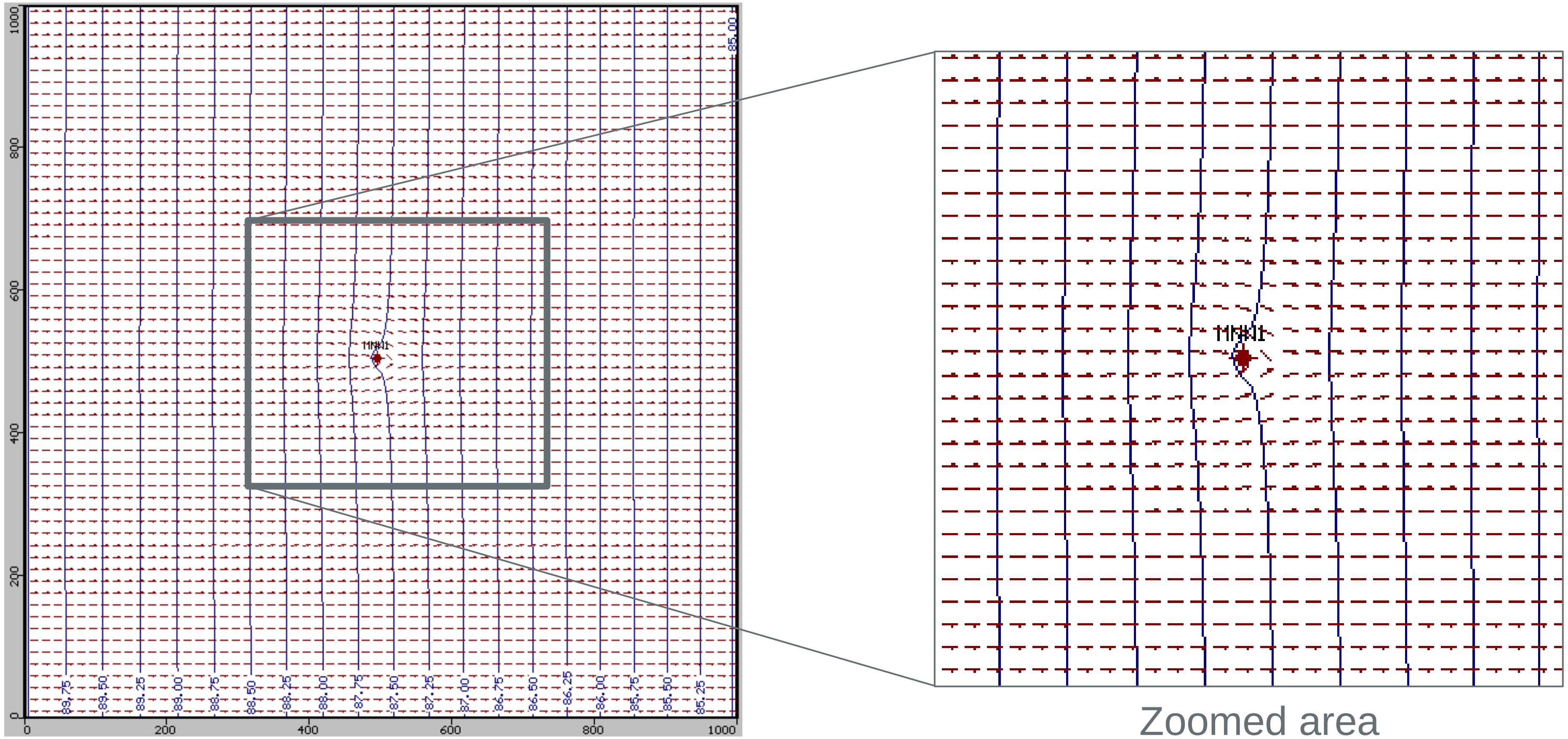
Zoomed area

Results – Case 2: 3-Layer Case

ΔH=2m, 2" Monitoring Well

GW Head Contours and flow vectors





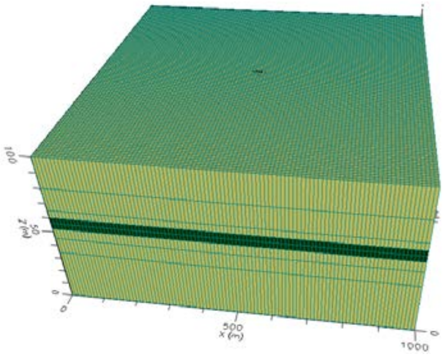
Plan View

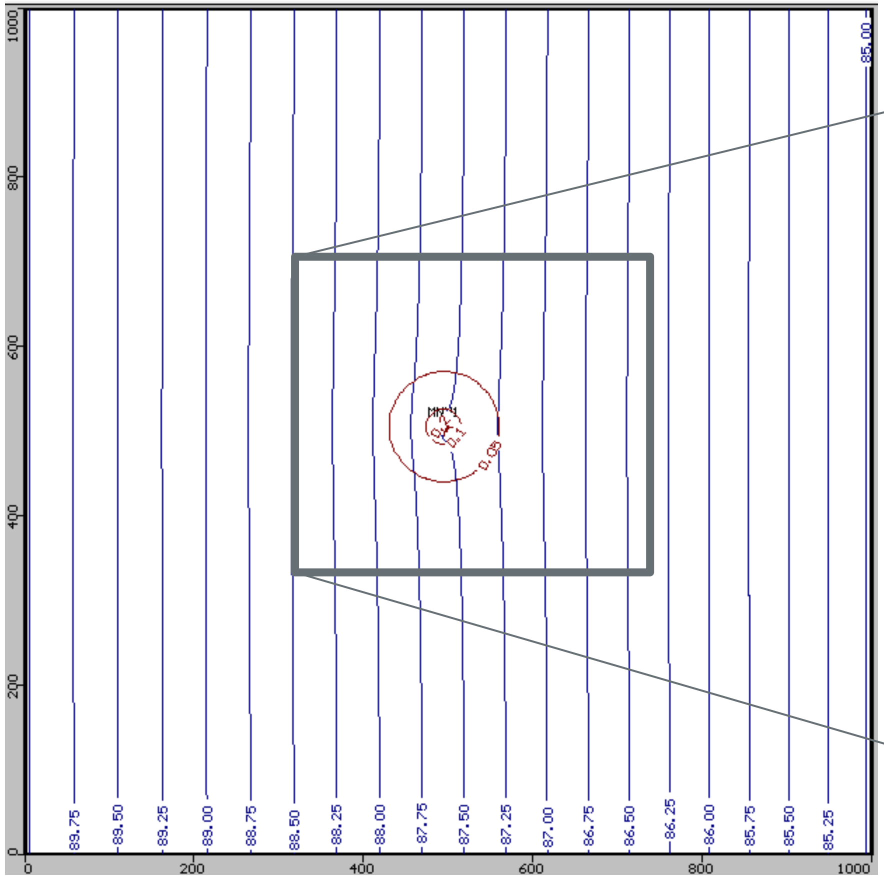
Zoomed area

Results – Case 2: 3-Layer Case

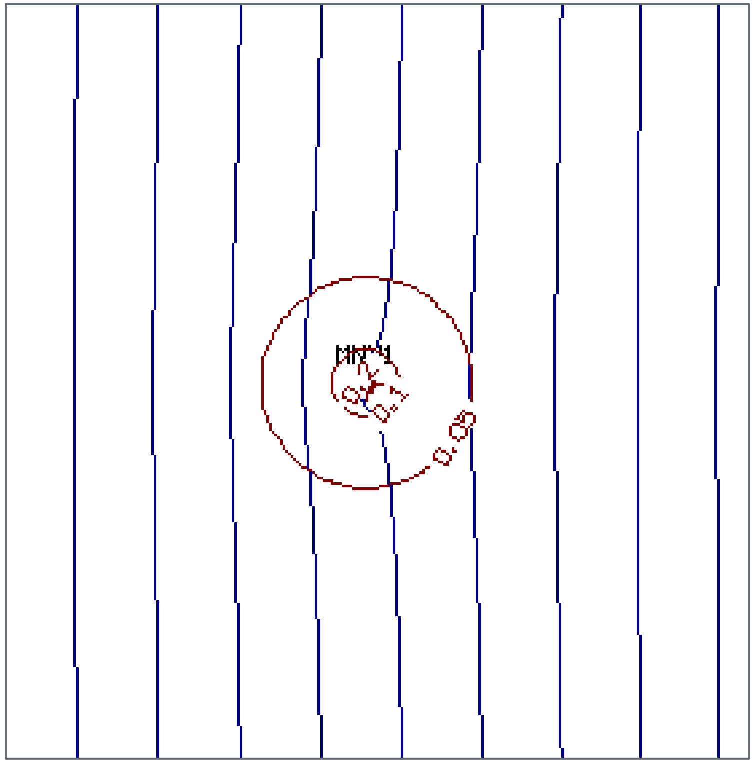
ΔH=2m, 2” Monitoring Well

GW Head and Drawdown Contours





Plan View



Zoomed area

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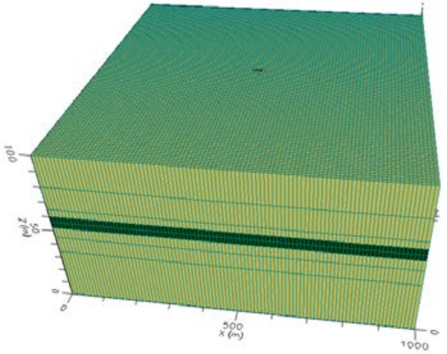
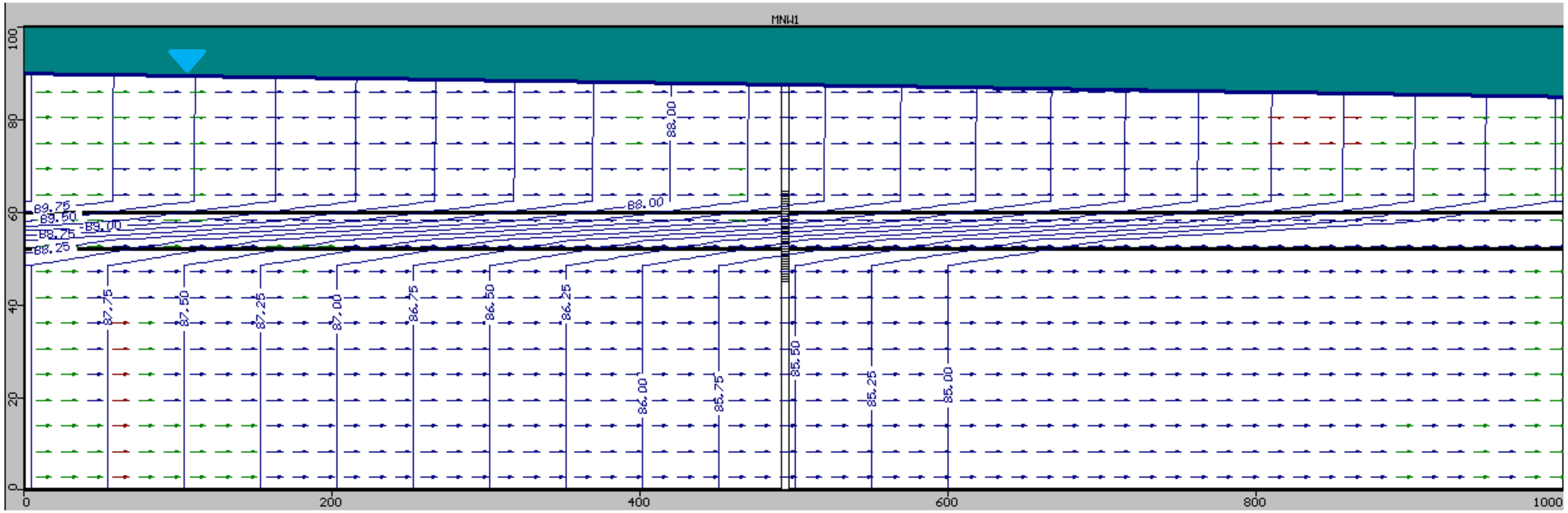
Results – Case 2: 3-Layer Case

ΔH=2m, No Well, Cross-Section View (Head/Flow)





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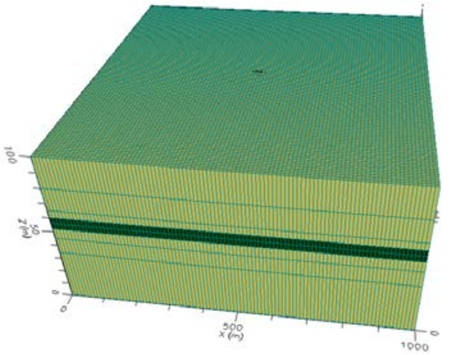
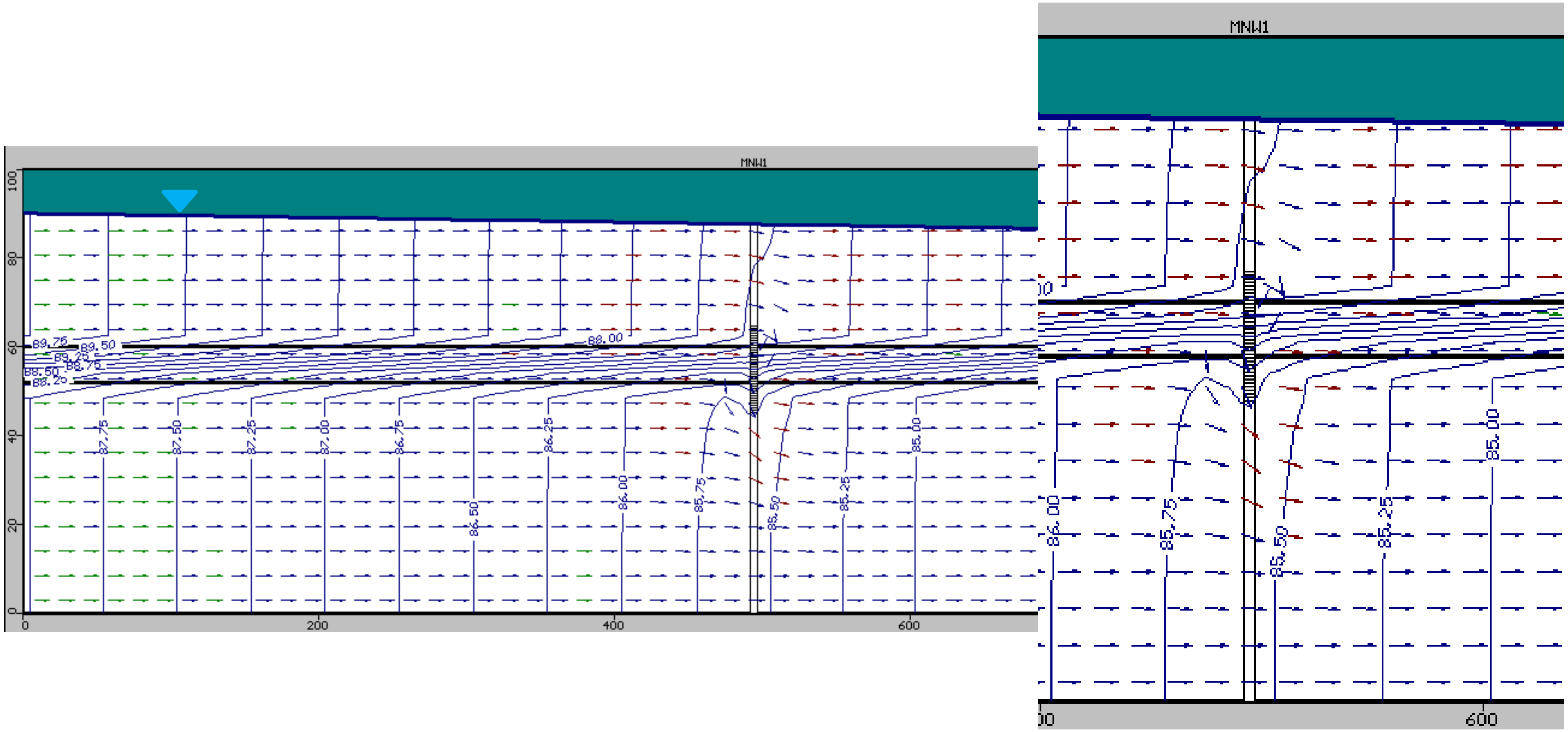
Results – Case 2: 3-Layer Case

ΔH=2m, 2” Well, Cross-Section View (Head/Flow)

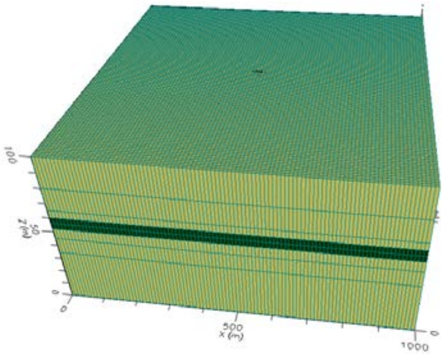


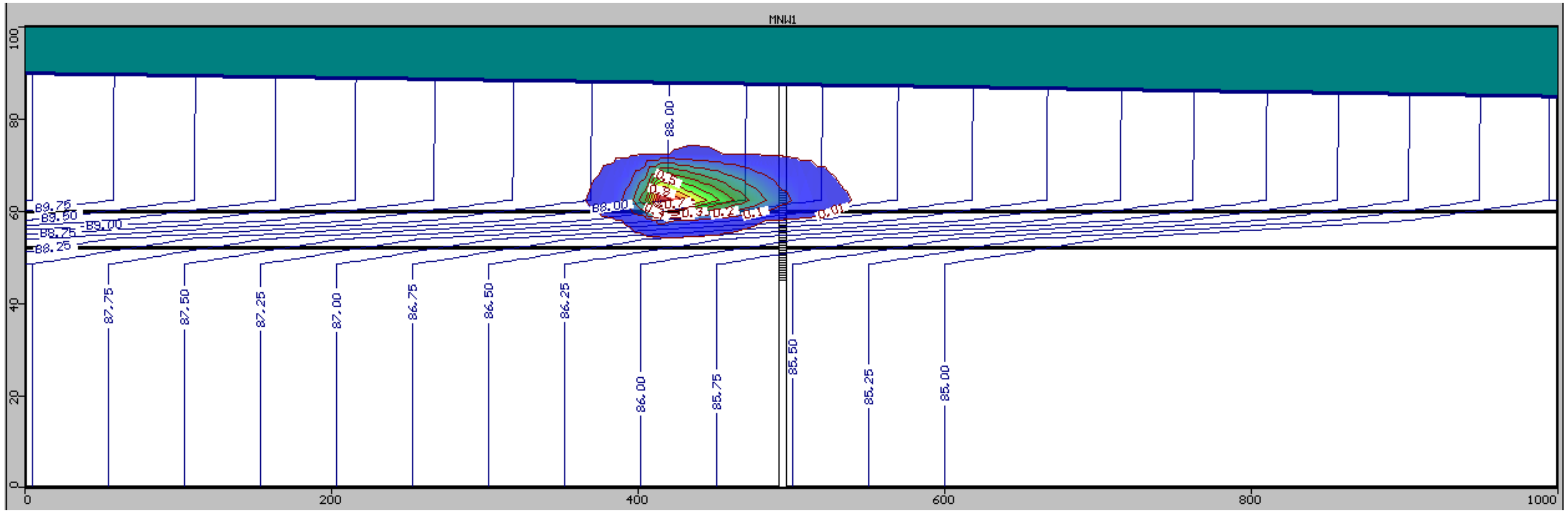


Results – Case 2: 3-Layer Case

ΔH=2m, No Well, Cross-Section View (Plume)

Plume does not cross aquitard





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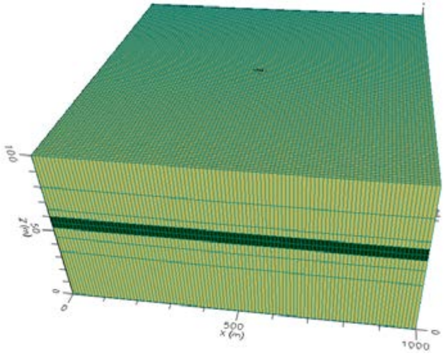
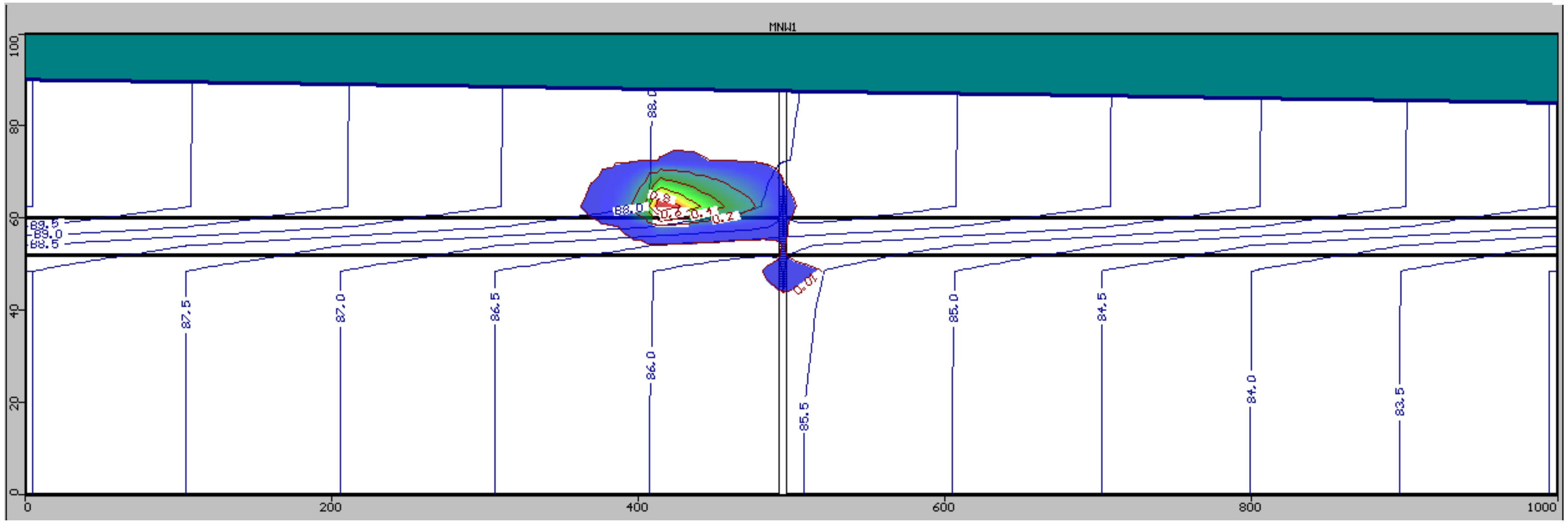
Results – Case 2: 3-Layer Case

ΔH=2m, 2” Well, Cross-Section View (Plume)

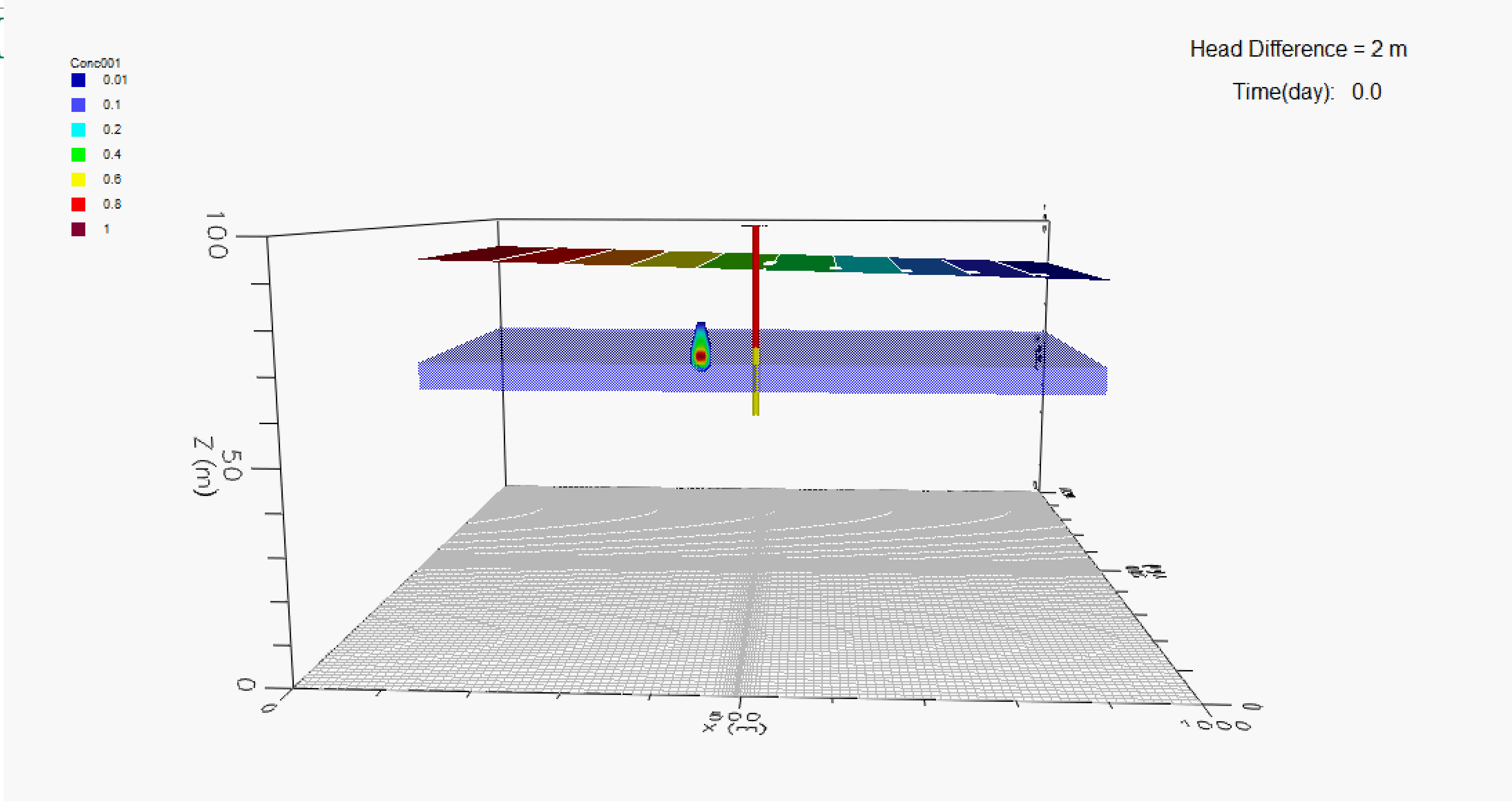
Cross-connection through monitoring well



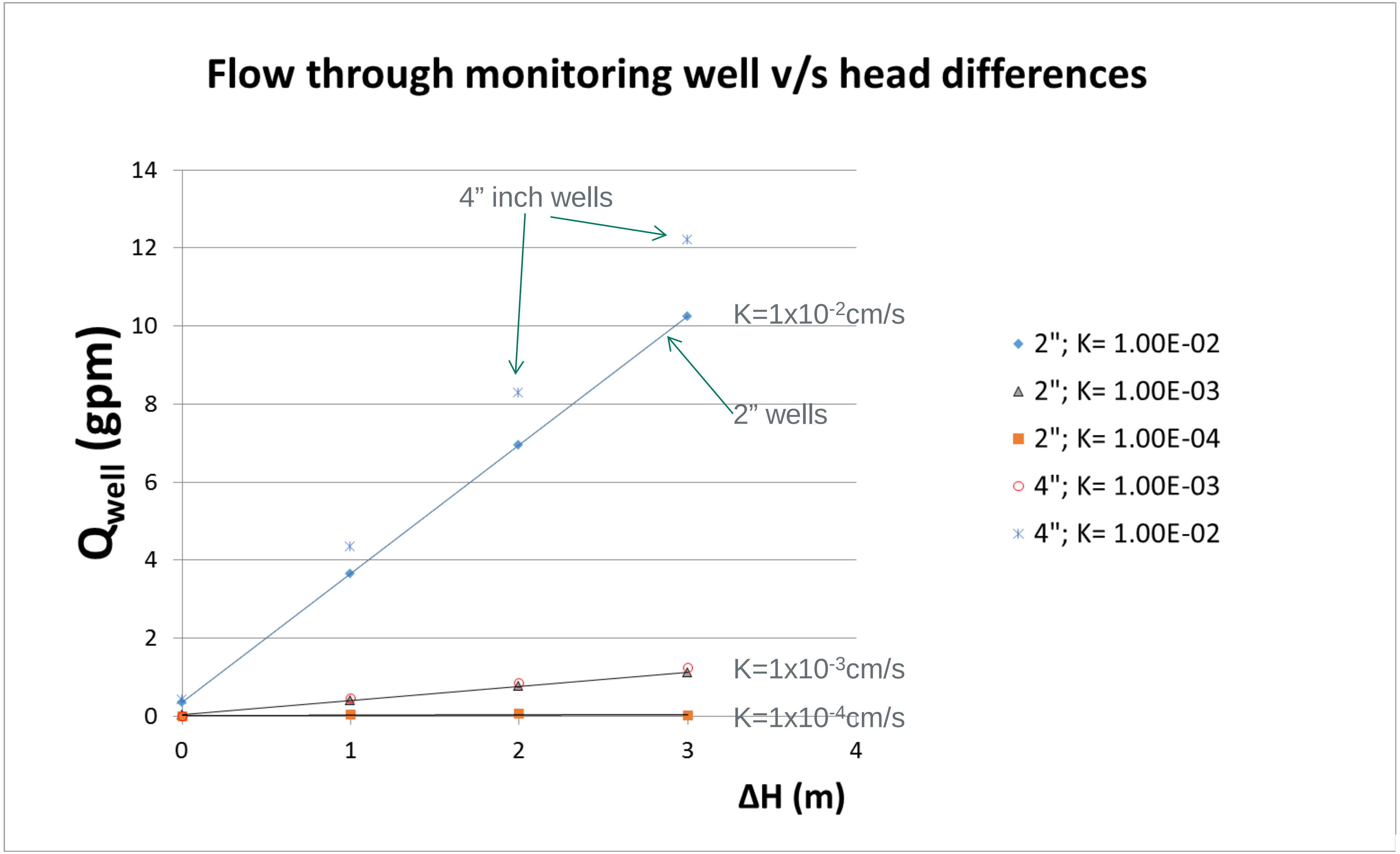


Results – Case 2: 3-Layer Case

ΔH



Simulation Results – Monitoring Well Flows



Summary – Single layered and Layered aquifer cases

Flows through long screened wells within single aquifers are negligible under typical horizontal hydraulic gradients (<0.001gpm)

In layered aquifer-aquitard aquifers, flows can be substantial depending on K and head differences

- Driving force is head difference across aquifers (vertical gradient)
- Flows increase linearly with increasing head difference and Hydraulic conductivity (Darcy's Law)

Long screened wells may significantly distort groundwater flow fields and cross communicate different aquifers, affecting groundwater contours, as well as concentration distribution, in particular in areas with:

- Moderate to high Ks
- Large head differences (recharge/discharge areas, close to pumping wells)

Case Study: Real Site Conditions

Let's see what happens in a real case:

- Multi-layered system composed of fractured variably-lithified sandstones and clay/shale
- Over 700 monitoring wells installed to characterize and monitor the site, screened based on geologic sequences (lithostratigraphy).
- Recent high resolution methods used to refine understanding of site and define hydrogeologic units (HGUs)
- Strong downward gradients (Head difference of 8-9 meters over ~50 m depth)
- Delineation of HGUs identified confining layers occurring within supposed aquifer unit of lithostratiphically based CSM
- Older wells screened through lithostratigraphically defined units, thus cross communicating previously isolated layers (HGUs).

The Geology

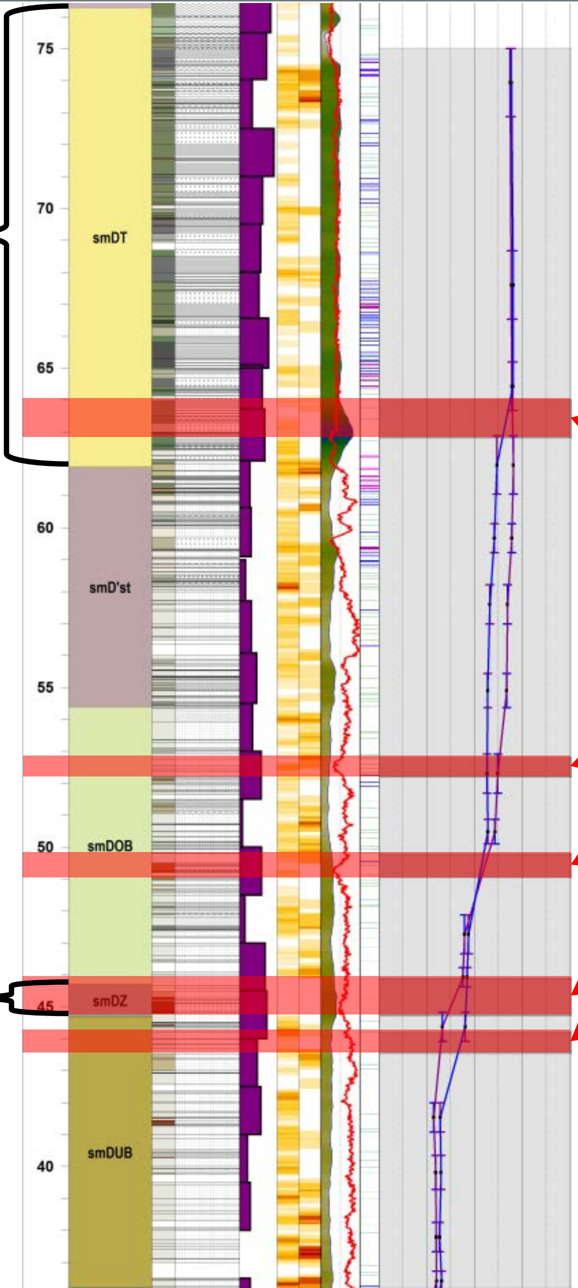
Variably-lithified sequence of fractured, Triassic, interbedded clay/shale and sand/sandstone of fluvio-lacustrine origin.

Evolution of Lithostratigraphically Based Framework

1980s		<1993		2010	
Fill	Aquifer 1	Fill	Aquifer 1	Fill	Aquifer 1
smH	Aquifer 2	smH	Aquifer 2	smH	Aquifer 2
smDT	Aquitard	smDT	Aquitard	smDT	Aquitard
smD’s	Aquifer 3	smD’st	Aquifer 3.1	smD’st	Aquifer 3.1
		smD’s	Aquifer 3.2	smDOB	Aquifer 3.2o
				smDZ	Aquitard
				smDUB	Aquifer 3.2u
smVA’ts	Aquitard	smVA’ts	Aquitard	smVA’ts	Aquitard
smVA’s	Aquifer 4	smVA’s	Aquifer 4	smVA’s	Aquifer 4

Comparison of Lithostratigraphic vs. Hydrogeologic Framework

Lithostratigraphic Aquitard Units 2010



Aquitard HGUs 2014

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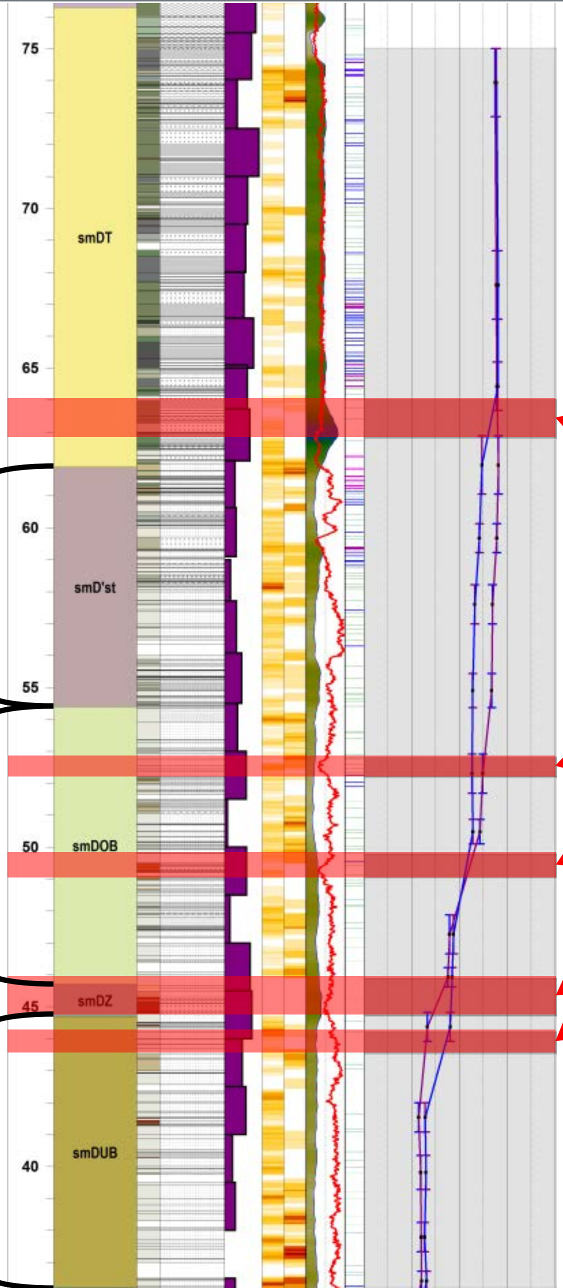
Comparison of Lithostratigraphic vs. Hydrogeologic Framework

Where did wells get screened in Post-2010?

Lithostratigraphic Aquifer 3.1

Lithostratigraphic Aquifer 3.2u

Lithostratigraphic Aquifer 3.2o



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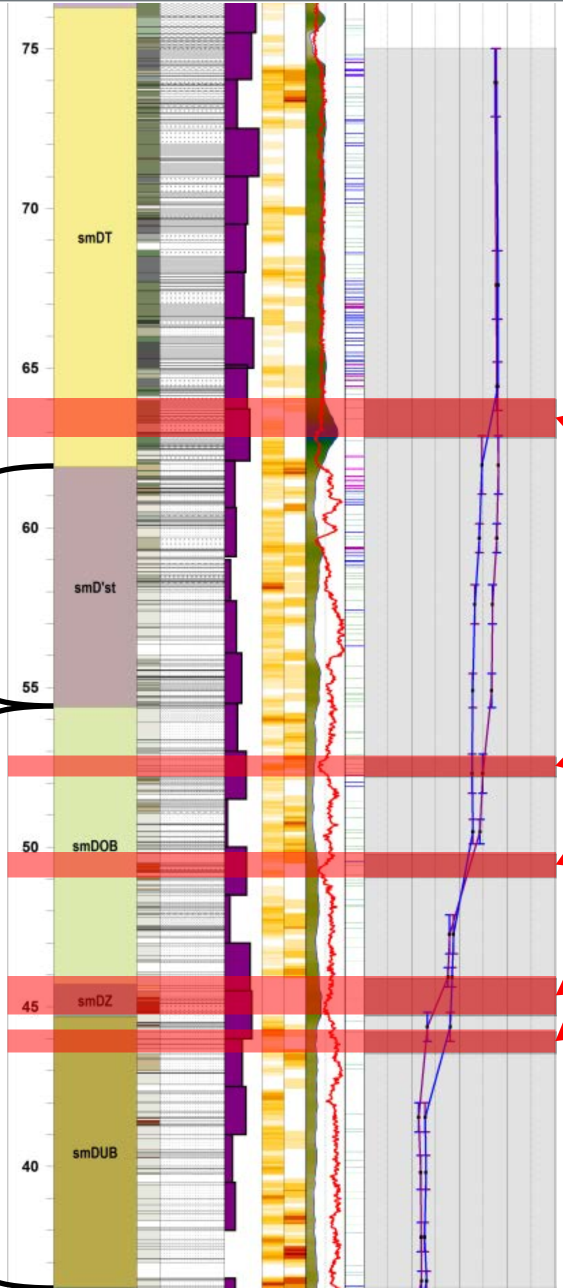
Comparison of Lithostratigraphic vs. Hydrogeologic Framework

Where did wells get screened in 1990s-2000s?

Lithostratigraphic Aquifer 3.1

Lithostratigraphic Aquifer 3.2



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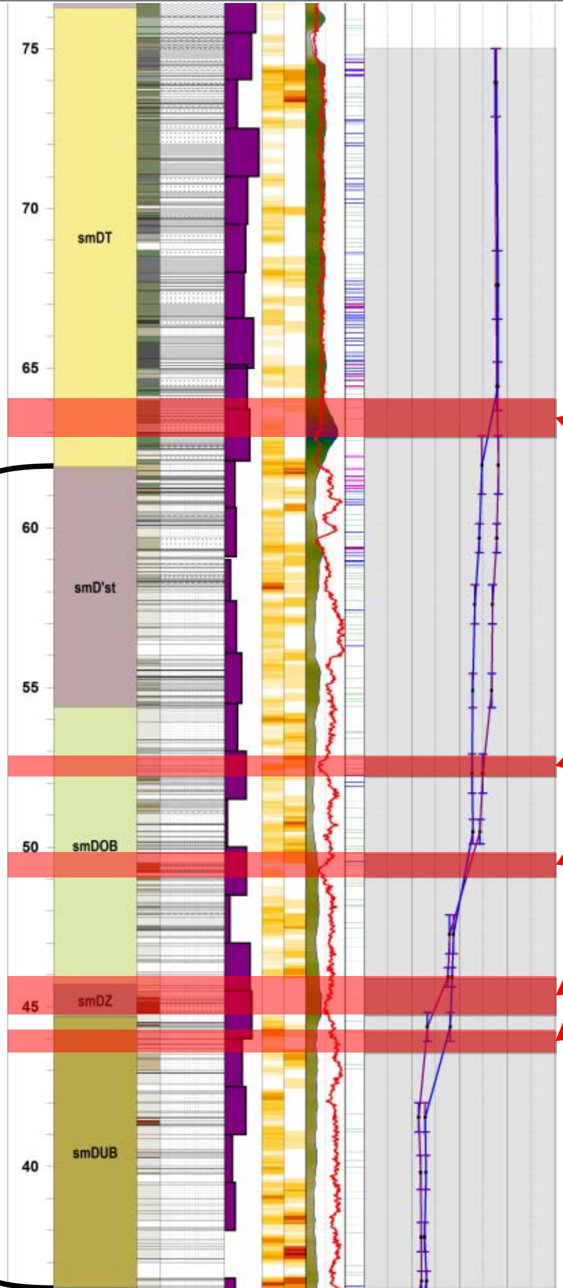
Comparison of Lithostratigraphic vs. Hydrogeologic Framework

Where did wells get screened in 1980s?

Lithostratigraphic Aquifer 3 1980s

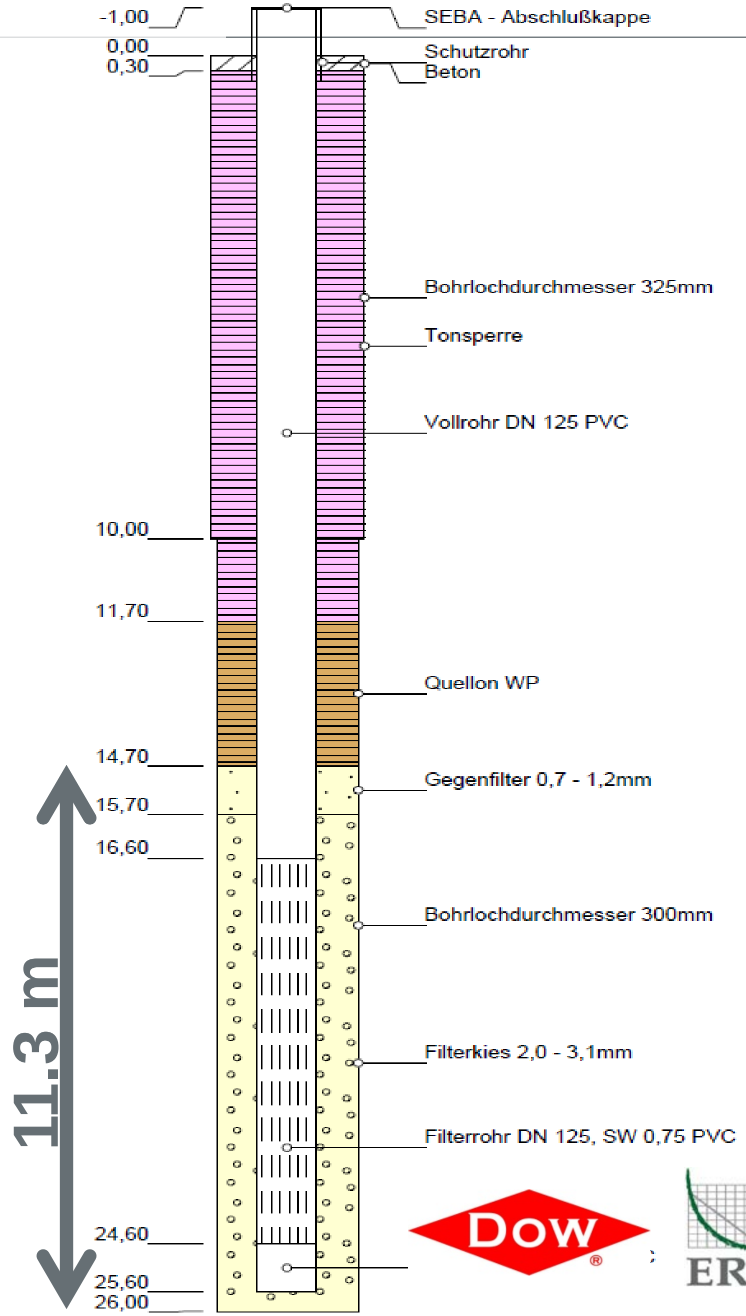


Aquitard HGUs 2014

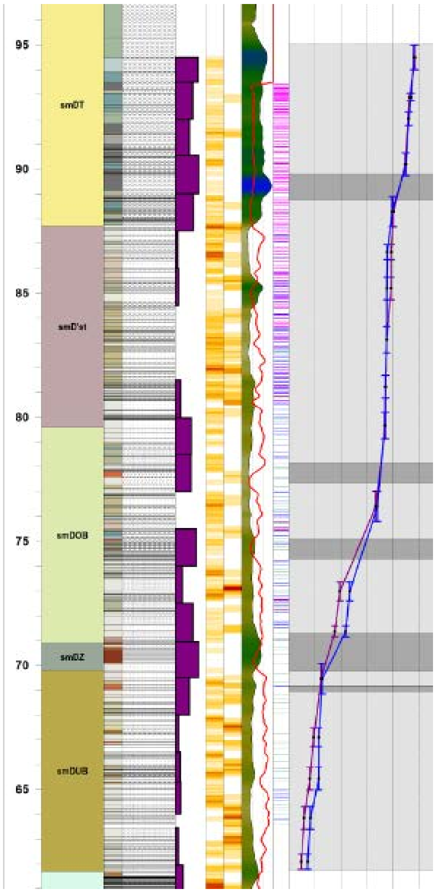
>700 Conventional Wells

- Screened based on lithostratigraphic units
- Some span several HGUs due to evolution of stratigraphic framework
- Average screen length ~8m
- Typically 125mm (~5”) wells in 300mm (~12”) Boreholes

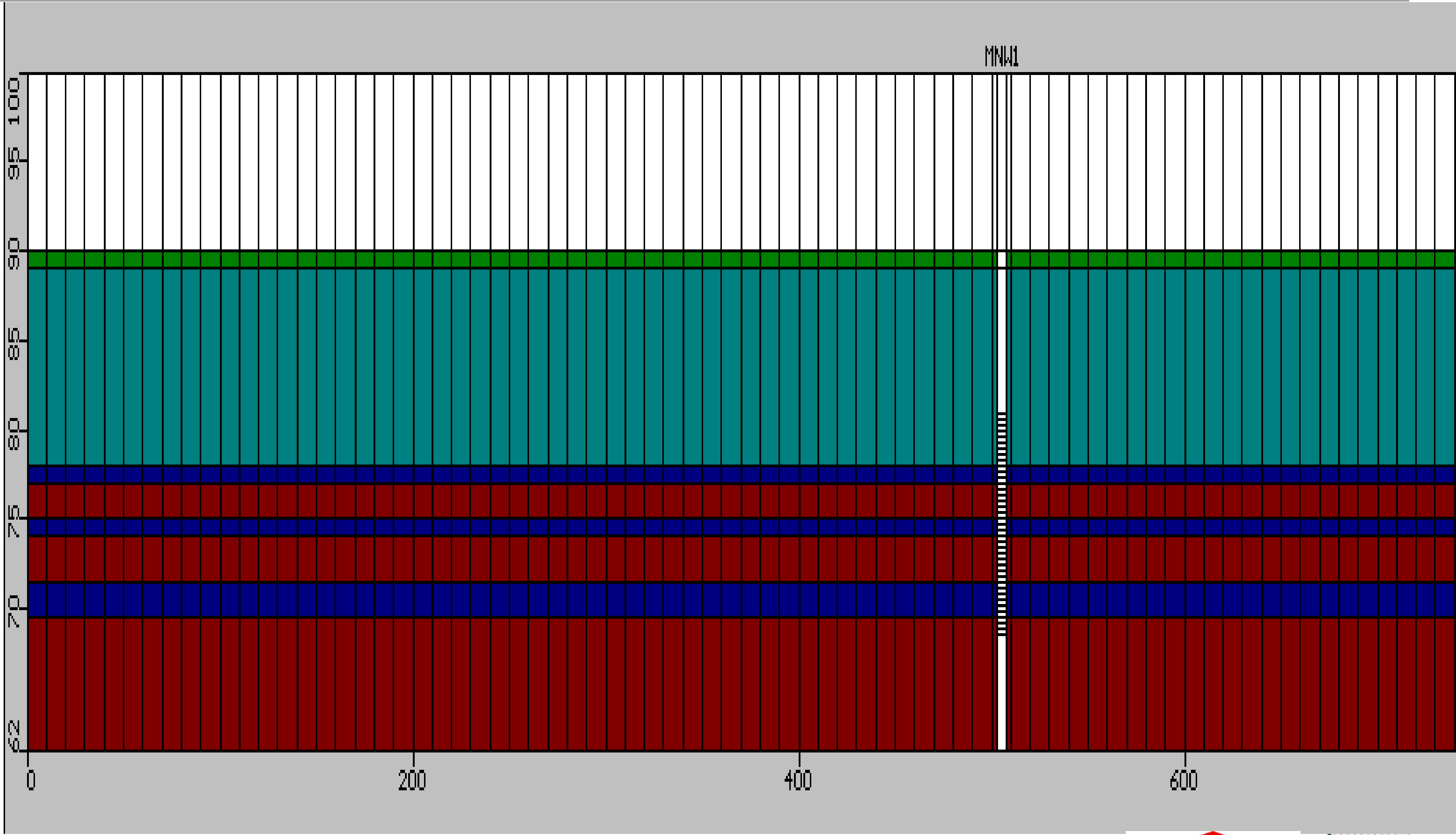
Well Completion Example: Well 7776



Hydraulic Conductivity and Heads profile

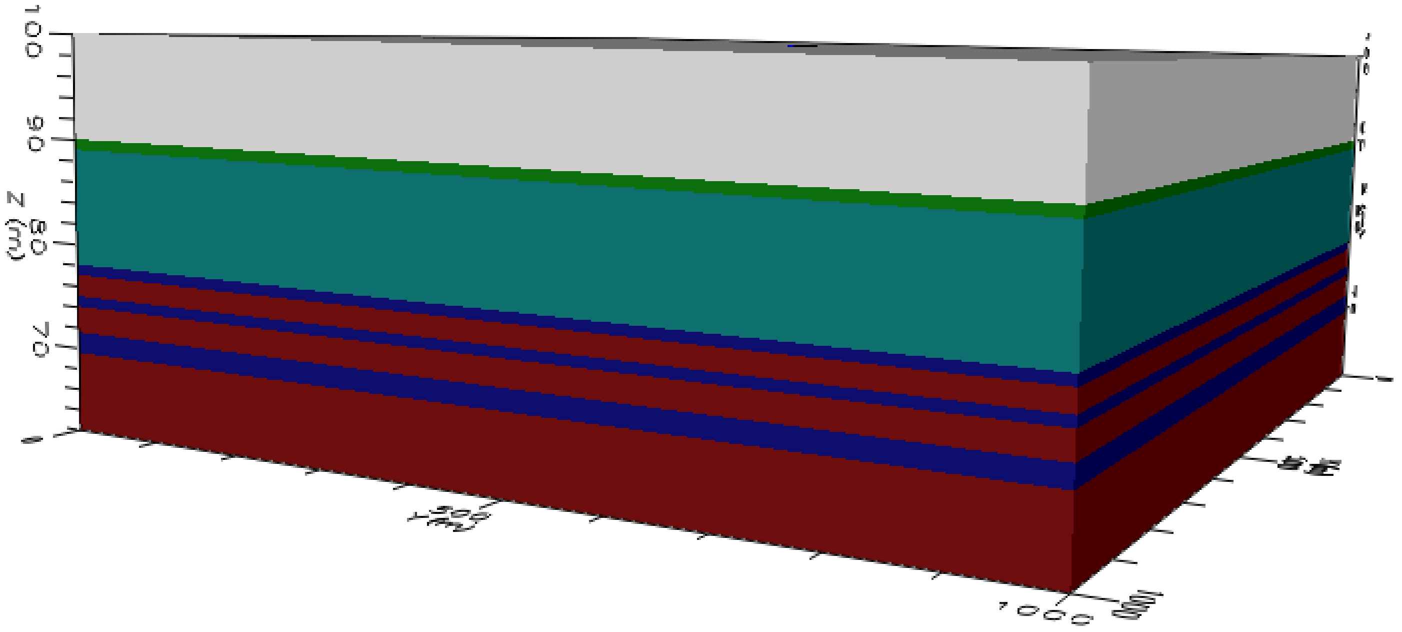


(Stuetzle, 2014)



Hydraulic Conductivity distribution in the model

K_H values based on pumping test data (IHU and MUEG, 2008)
K_V values based on triaxial testing (MUEG and IHU, 1998)

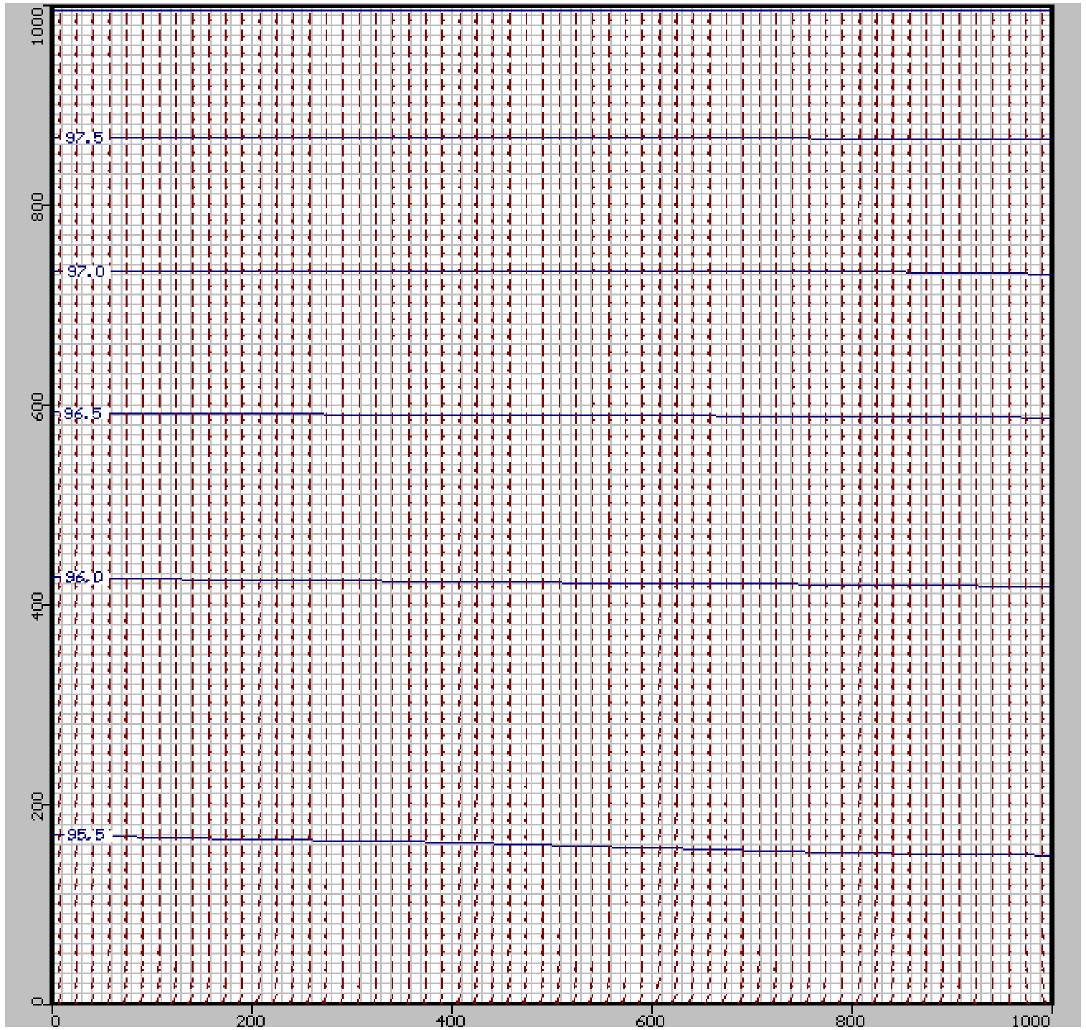


Color	Kx	Ky	Kz
...	0.00016	0.00016	1.6E-7
...	1E-7	1E-7	1E-8
...	1E-8	1E-8	1E-9
...	0.0016	0.0016	3.35E-6
...	0.0017	0.0017	2.15E-7

Effects on flows – plan view – Water Table

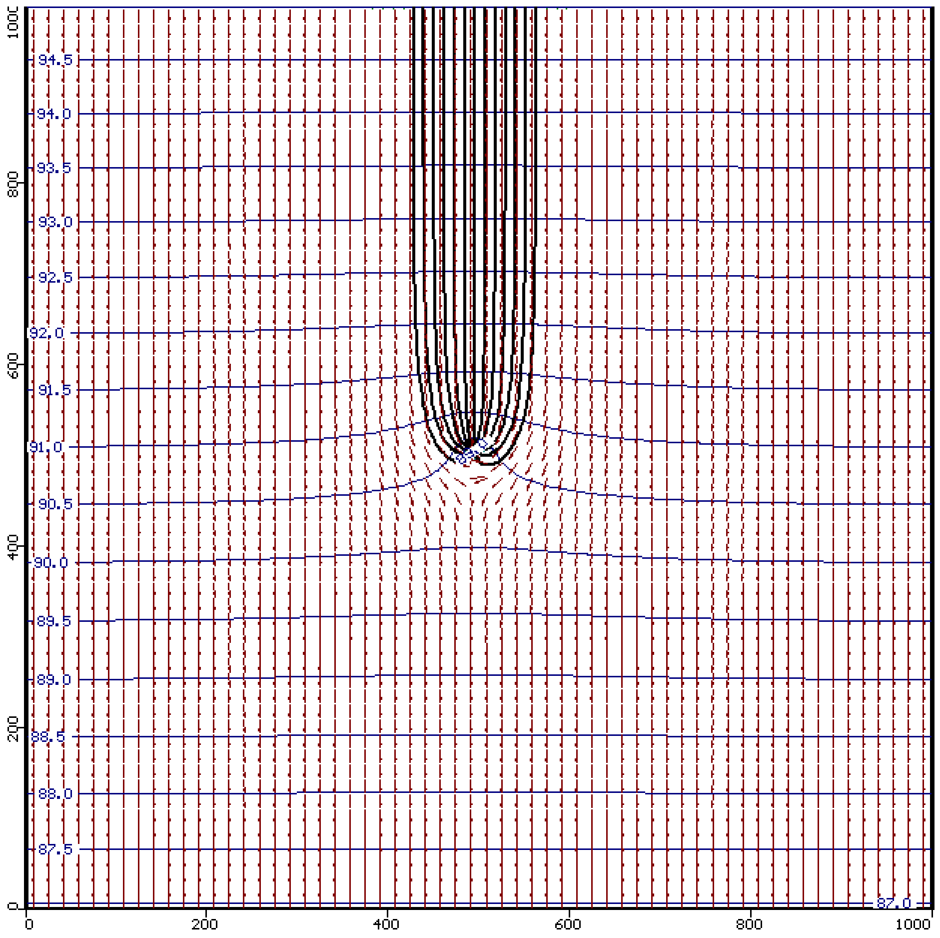
No clear effects from the monitoring well in the water table

Looking good, but…

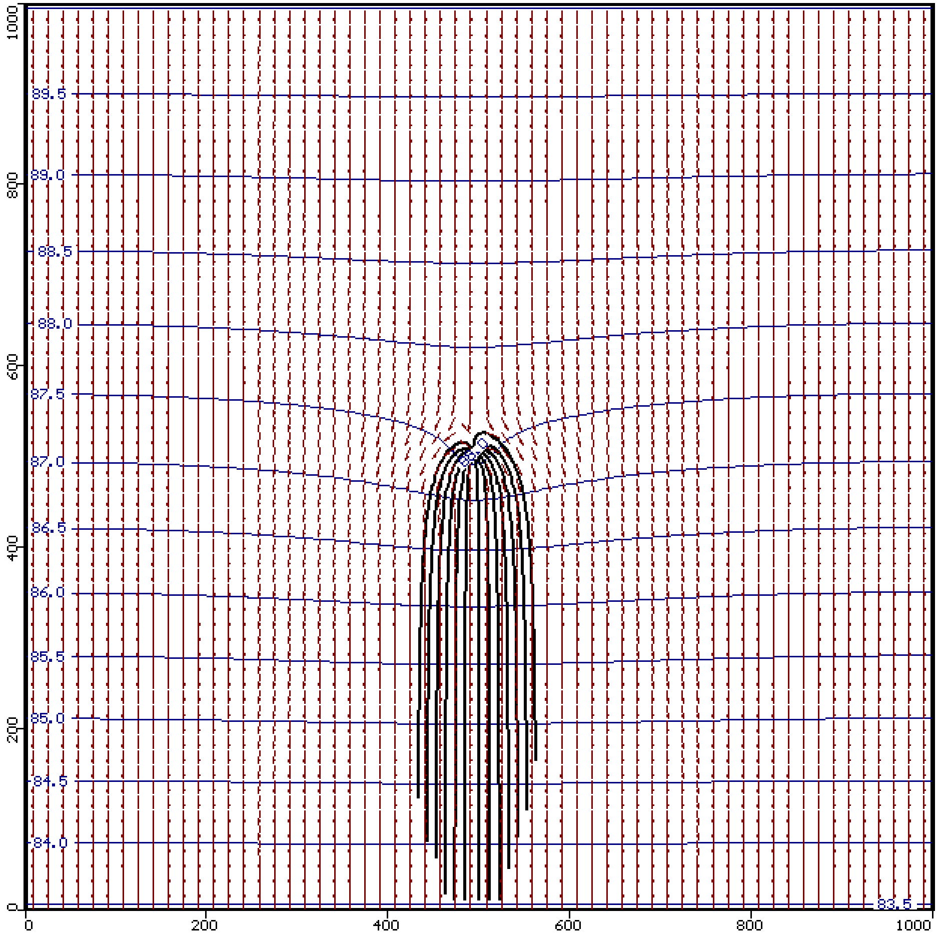


Effects on flows – plan view

Top of Screen

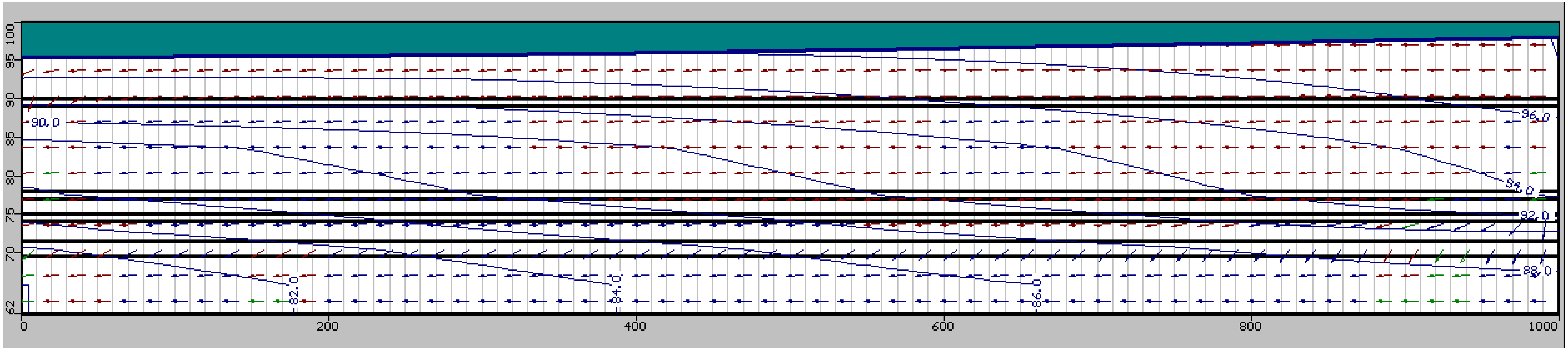


Bottom of screen



Effect on Flows: Cross Section

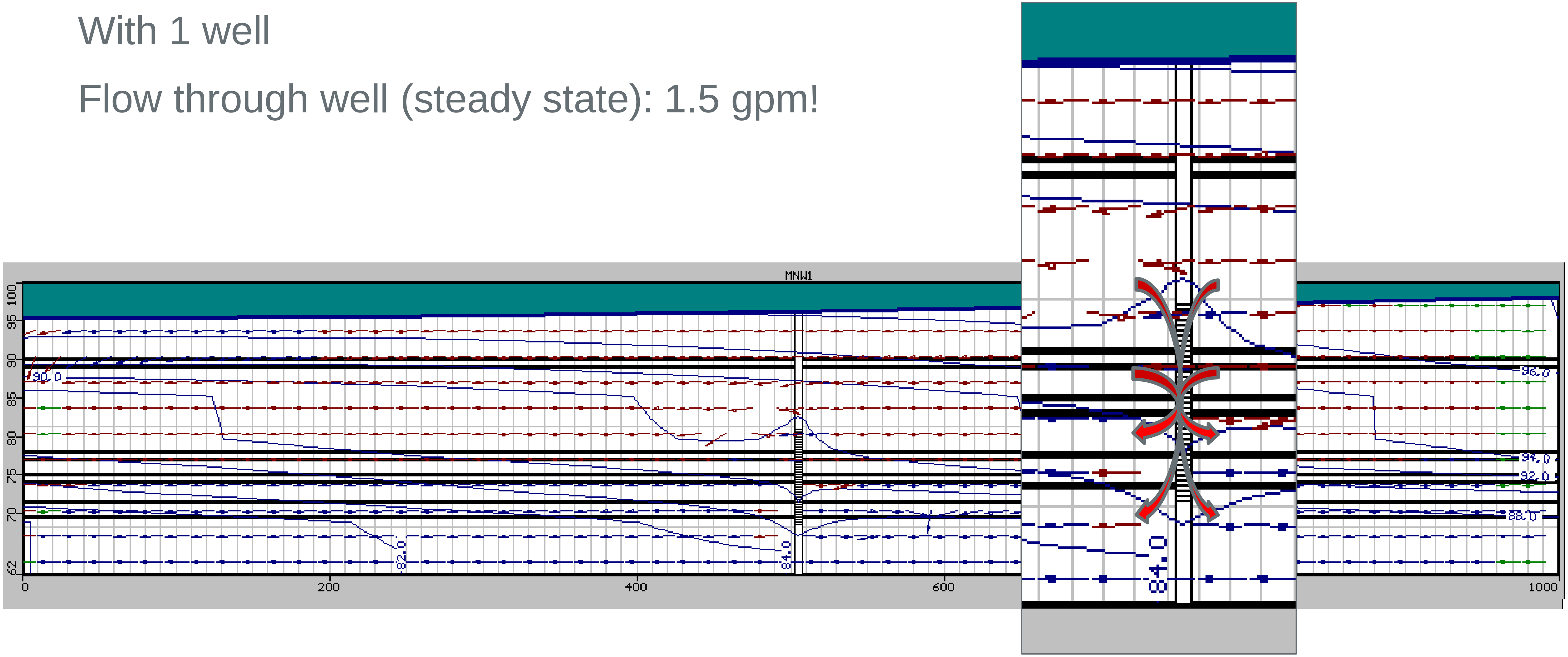
No well



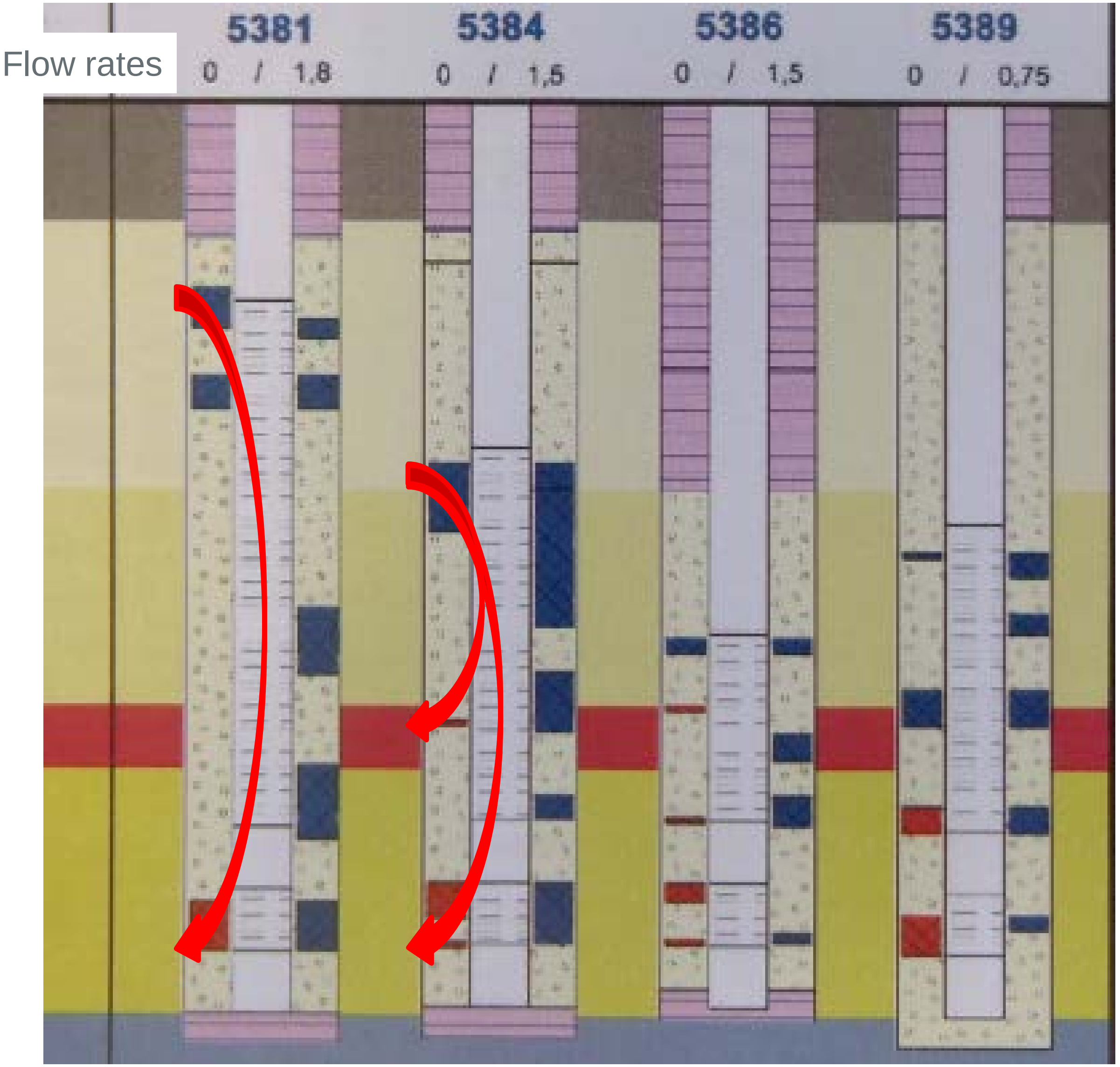
Effect on Flows: Cross Section

With 1 well

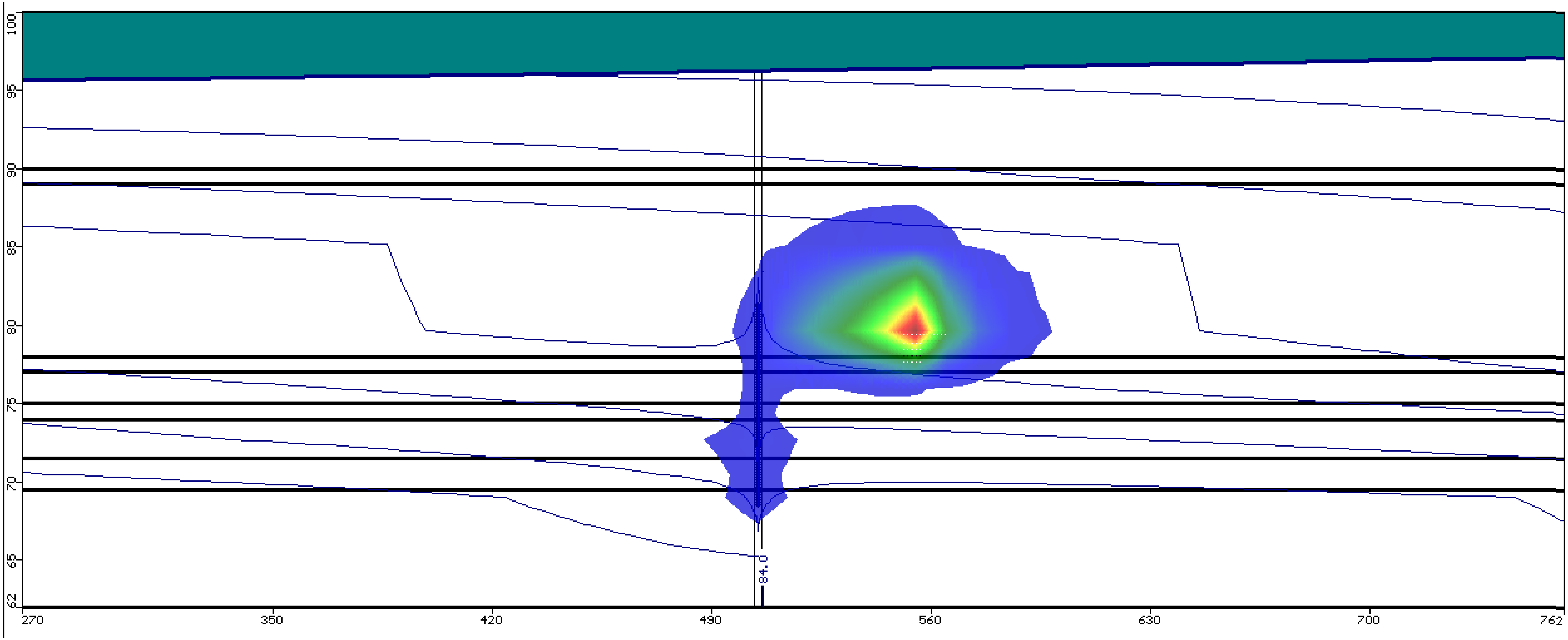
Flow through well (steady state): 1.5 gpm!



Flowmeter data confirms it!

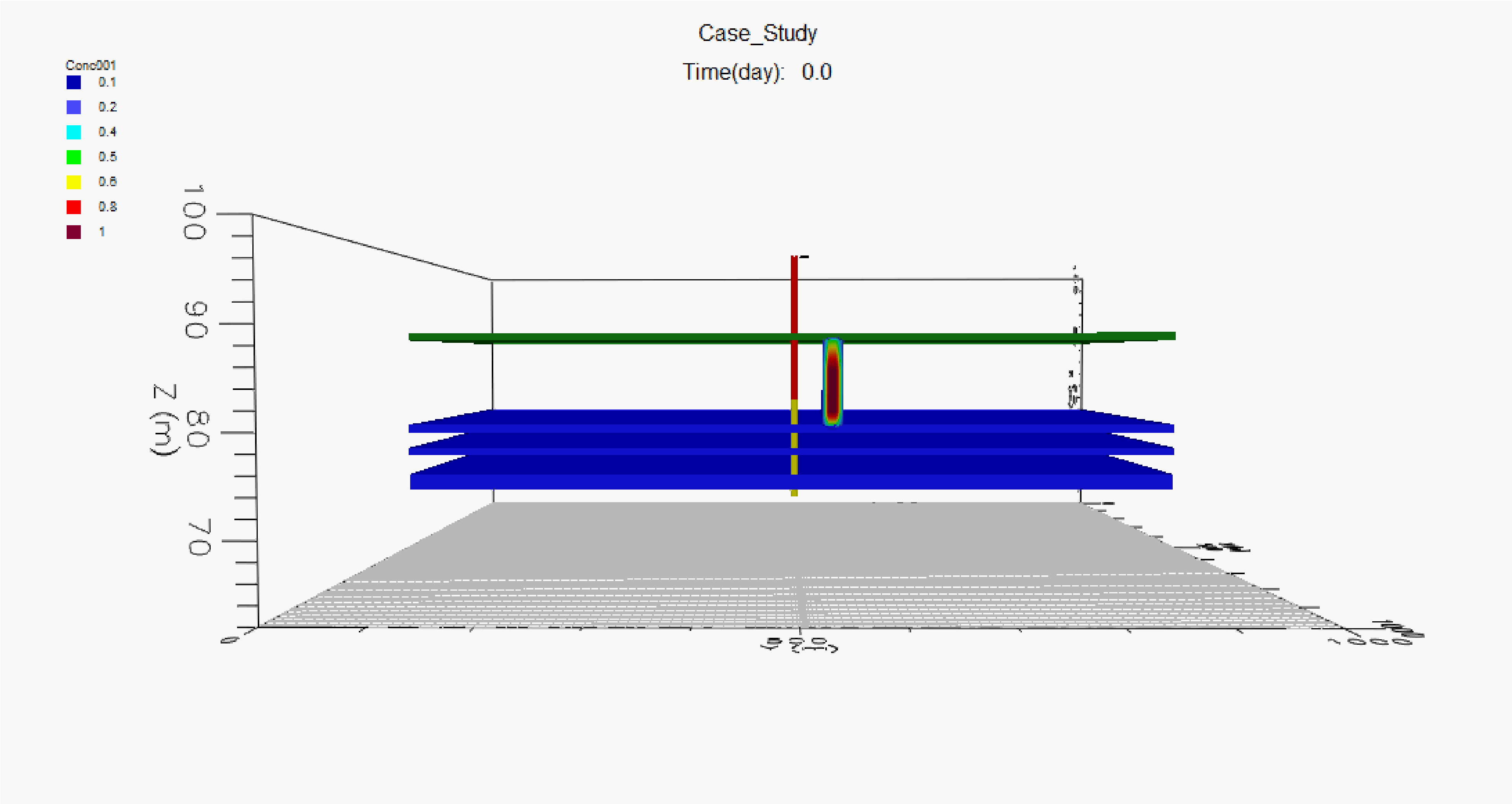


(Synwoldt, 2012)



100
95
90
85
80
75
70
65
62
84.0
270
350
420
490
560
630
700
762

Animation



What happens with multiple wells?

Do rates scale up linearly to the entire site?

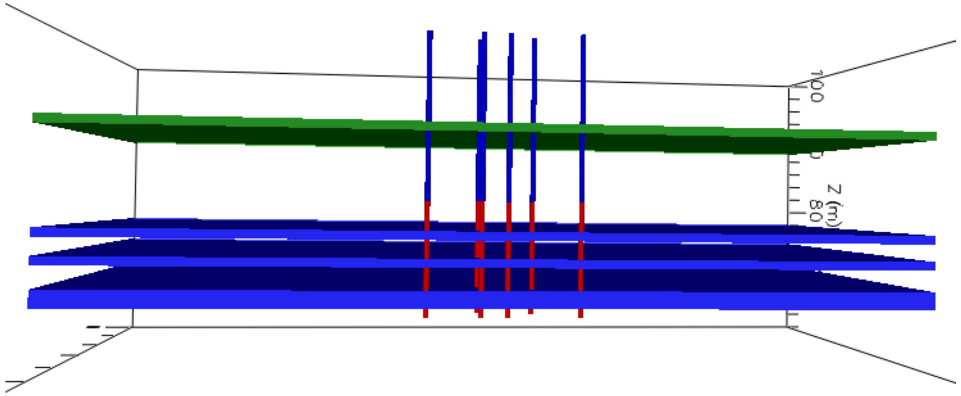
- How do flows and gradients change in various layers?
- How does this impact contaminant distribution?

Hard to know… this is a simplified model only…

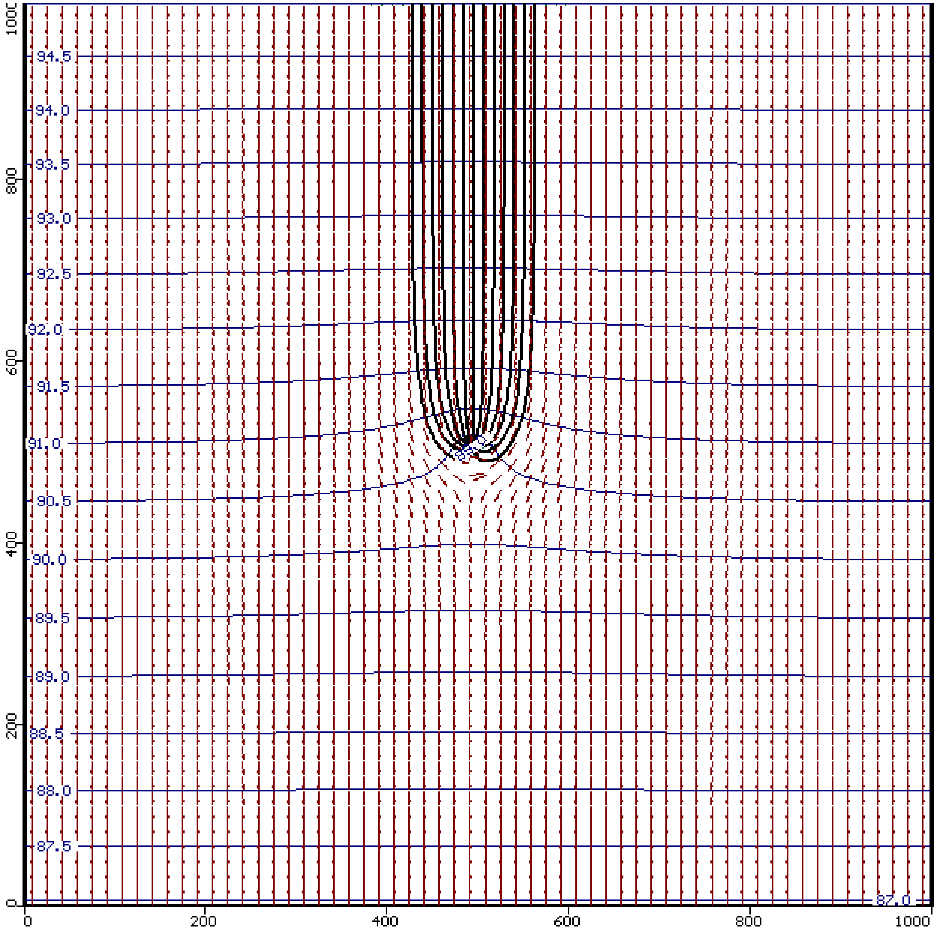
Ran 1 simulation using the same well design distributed across the model

- The site has many more wells placed in different depths

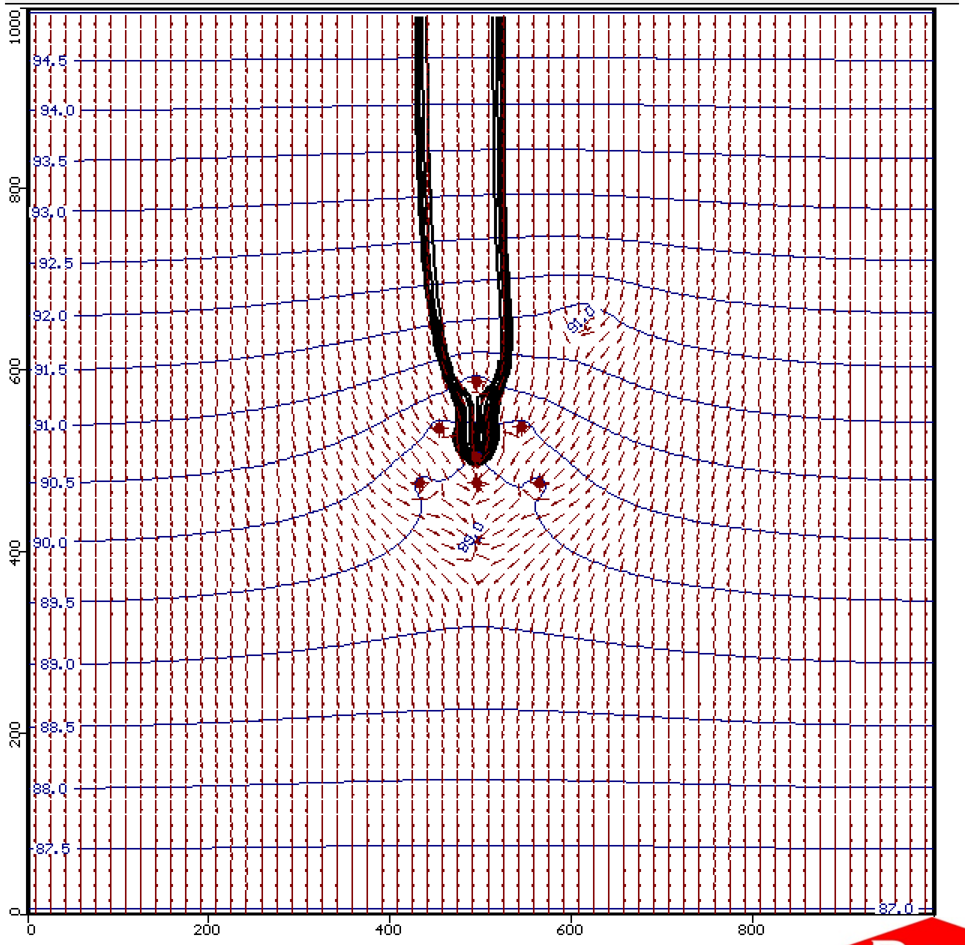
Let’s see the results!



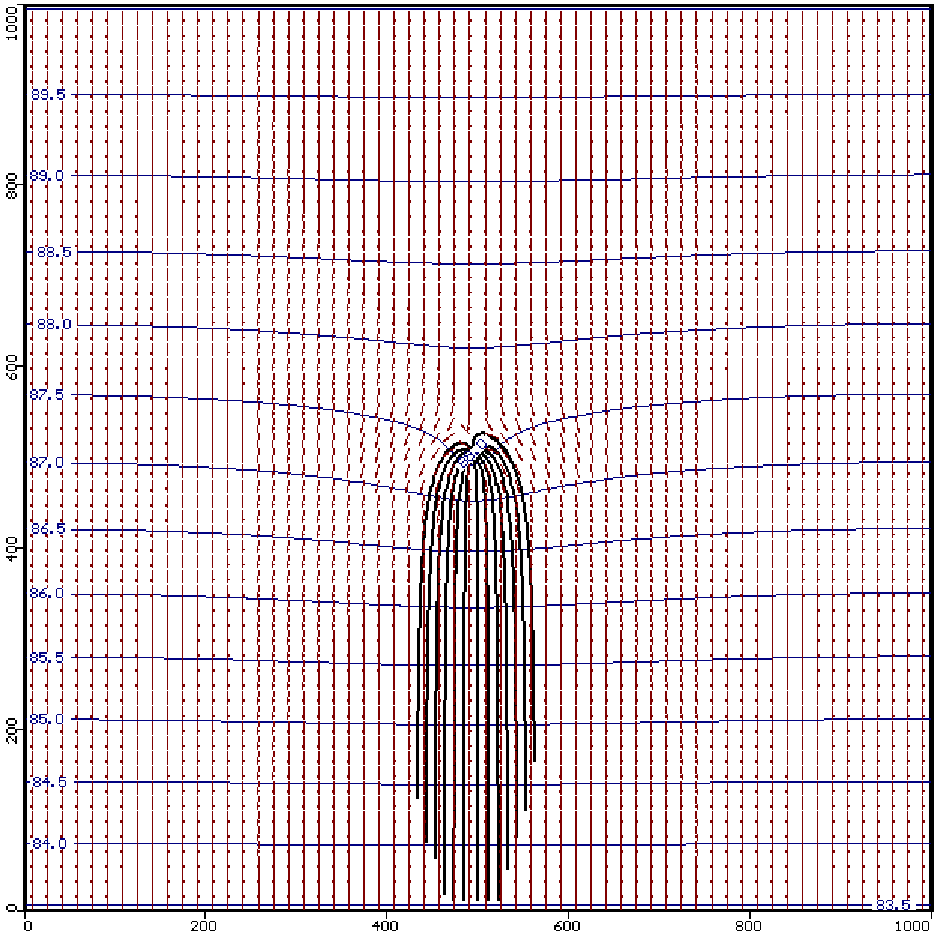
Top of screens, single well



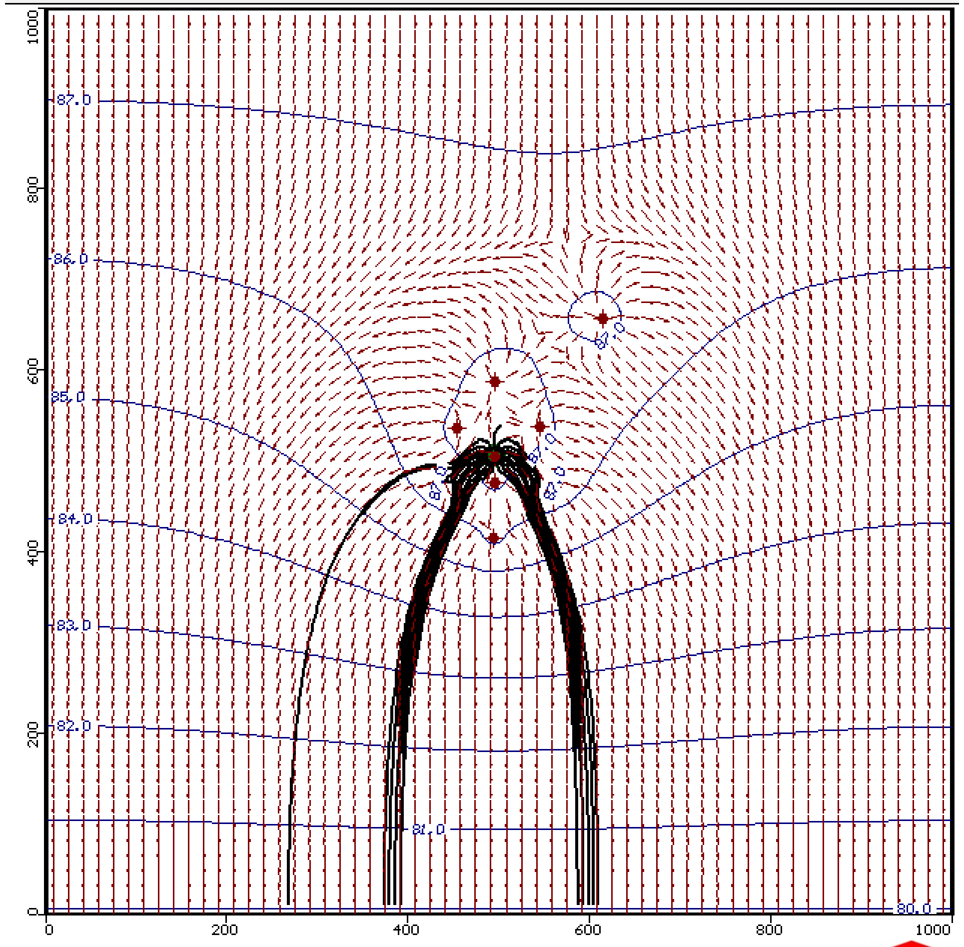
Top of screen, 7 wells



Bottom of screen, 1 well

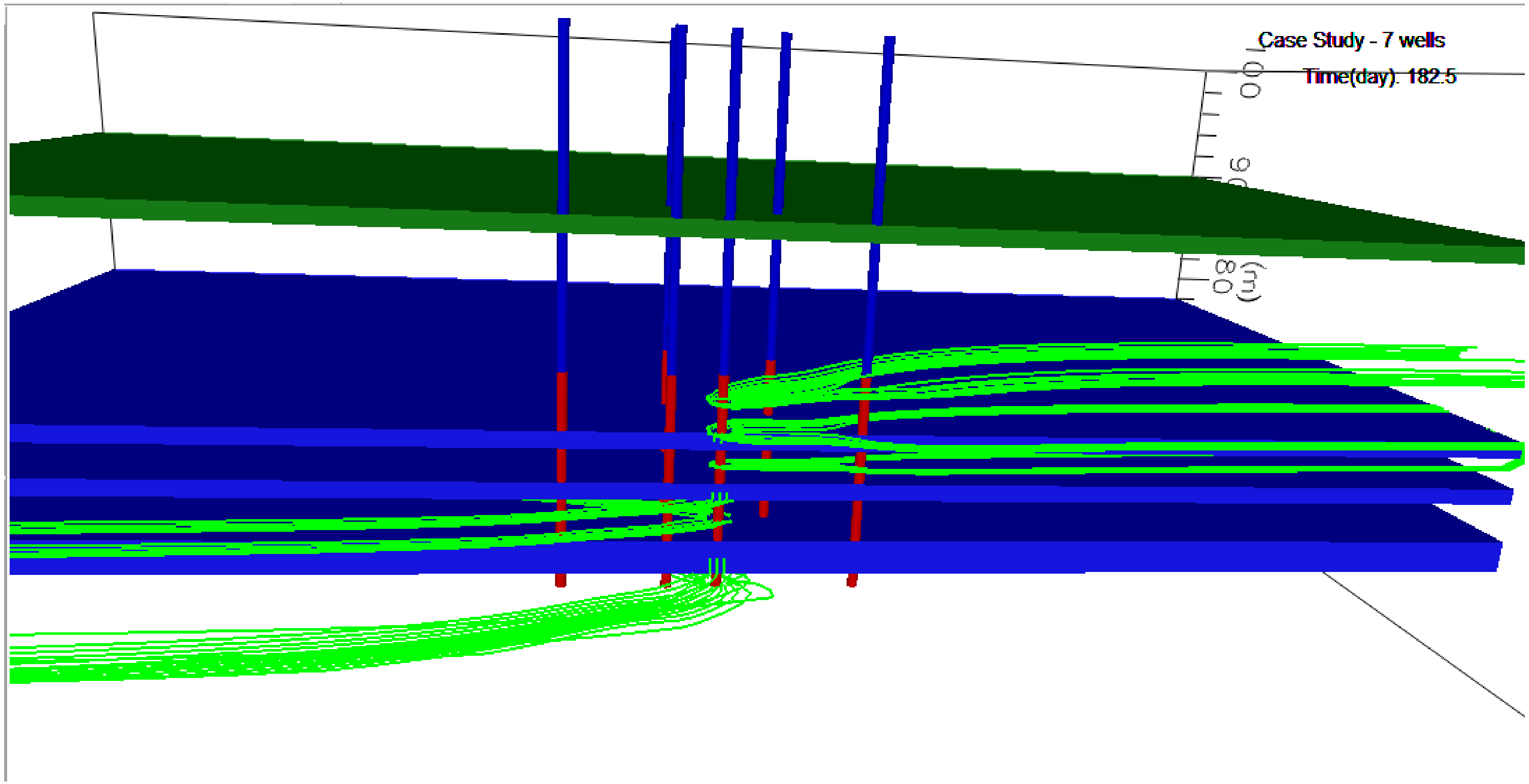


Bottom of screen, 7 wells

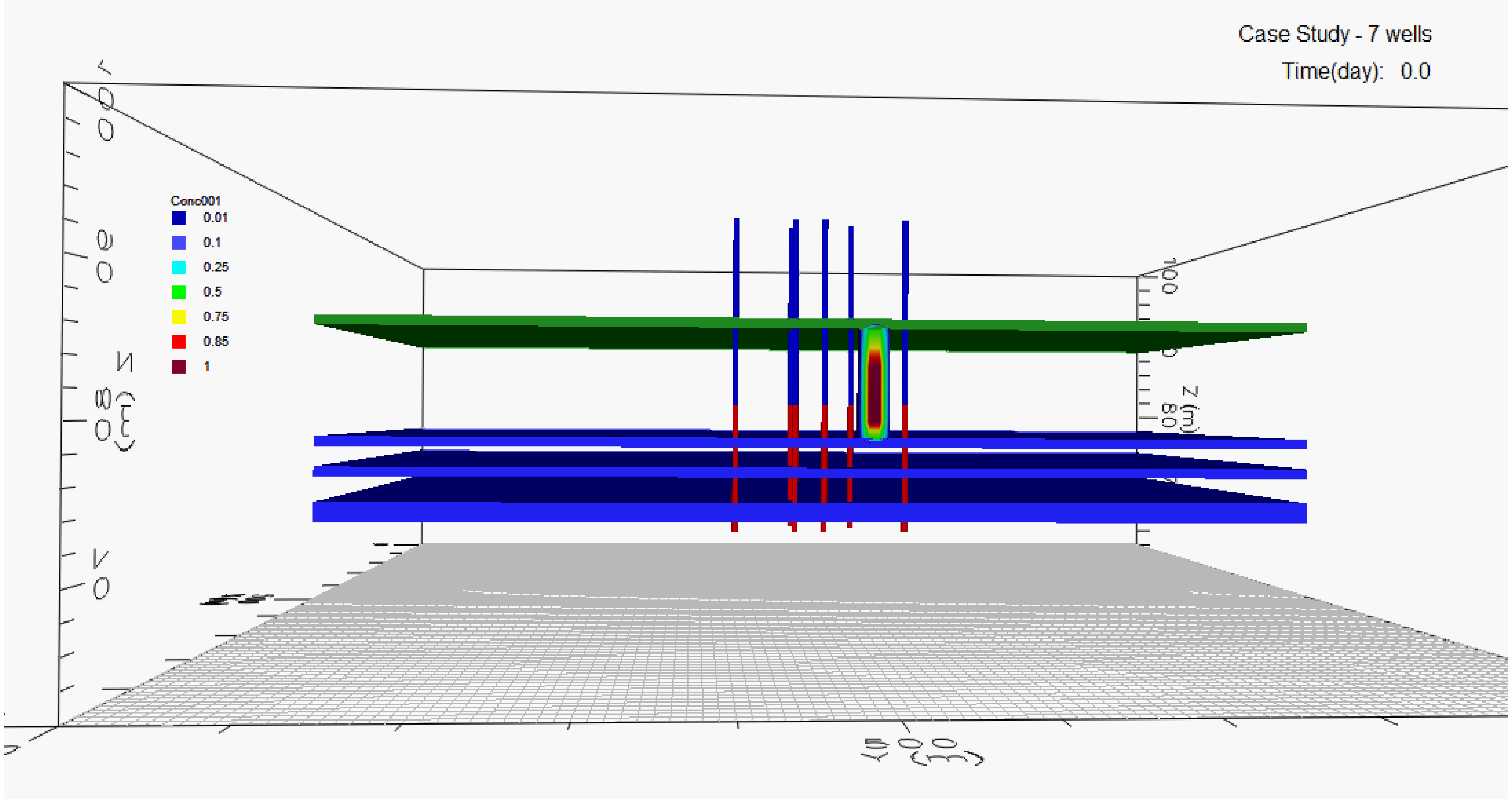


Pathlines – 3D view multiple wells

Flow per well:
~1.1gpm



Plume 3D view – multiple wells



Conclusions – Case Study

Downward flows through long screened wells can be significant, in the order of a few gpm per well. Multiple

With over 700 wells in place, many of them long screened wells, the potential for cross connection can be significant, if K is high and head differences across aquitards are important (>1m).

Proper definition of aquitard position in space is critical

- Geophysical logging and multi-level monitoring wells help identify such layers, and guide future well design

Sites with large screened wells will distort ambient flow conditions, groundwater contours and vertical gradients. This should be recognized during data interpretation, remedial design and modeling efforts.

References: Pending

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