**Homework 10 Figures**

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**The Challenge**

1. Compare the impact of pumping on the single layer model vs the multilayer model. What physical explanation do you have for the differences?

A picture containing chart

Description automatically generatedThe layered model has a low-K layer between the well screen depth and the surface. This restricts most of the impact of pumping to the bottom semi-confined layer and the head distribution at the surface is undiminished. In contrast, the single layer model experiences drawdown increasing the head gradient across the entire single-layer domain. Figure 1 shows that the head profile of the single layer model is less extreme, which reflects that it is drawing from the entire domain instead of a single, thin layer.

Figure 1 Head transect of the single layer model, and the top and bottom of 3 layer model

1. Repeat the three layer simulations putting the well in each layer (i.e. once in the bottom once in the middle and once in the top) provide plots and discussions comparing and contrasting your simulations. Provide at least one plot where you have all of your runs in the same figure.

The middle layer of the three-layered model has low hydraulic conductivity, K = .0001 m/day, in the vertical and horizontal directions. The top and bottom layers of the model have Kvert=.1 m/day and KHoriz=1 m/day. Placing the well in the top or bottom layers would be comparable except for middle layer acting as a confining unit. Pumping from the lowest layer (Fig. 2A) has little impact at the surface until considerably downgradient (physically, x-axis) where the heads equalize. Pumping from the topmost layer (Fig. 2C) similarly increases the head gradient at the pumping location first, then equalizes with distance from the well. Pumping from the bottom layer creates a larger head gradient because it is drawing the 500 m3/day volume from a smaller area. Placing the well in the middle low-K layer (Fig. 2B) immediately drains the model. Pumping from a low-K zone is impractical and will limit the efficiency of the well.

Chart, bar chart, histogram

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Figure 2 Cross-section of well locations in three layer model. 3A pumping well in bottom layer, 3B pumping well in middle layer inoperable due to low K inclusion, 3C pumping well in top layer

The head transects in Figure 3 provide a simpler perspective for comparison. The blue lines represent the head profiles of the topmost layer for the scenarios of pumping from the top and pumping from the bottom of the domain. Notice how the top profile is unchanged when pumping occurs at the bottom of the domain below the low-K layer. The green-dotted line highlights how pumping from a smaller, confined area (bottom layer) can drastically increase head gradients.

Chart

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Figure 3 Head transects for three layers for each scenario of pumpin from the top layer and pumping from the bottom. The case of pumping from the middle layer was excluded.

1. Change the properties of your three layer model so that it matches the 1 layer model (but still has 3 layers) put the pump in the bottom layer and compare and contrast with your one layer solution. How does your answer to this challenge compare with your answer to the first?

In this case the vertical and horizontal hydraulic conductivities are constant throughout the domain. However, pumping from a single thin layer as opposed to a layer the size of the domain restricts the flux and is reflected in the more localized head gradients (Figure 4)

Chart, bar chart, histogram

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Figure 4 A three layer model with the same K\_horiz and K\_vert as the single layer still has a unique head distribution due to the well pumping from the bottom of the layered domain.

1. Modify the topography of your domain so that it is no longer sloping left to right (you can make it a valley or have it sloping the other way, whatever you want). Re-run you 1 and 3 layer solutions and explain any differences you do or don't see.

I started with an experiment to see how the model would respond to an abrupt change in elevation below the constant head boundary. It was not very useful, but I encountered something interesting: the model seems to hold a ‘memory’ of those top elevation values even after I reset the original elevation file. I am still working on this.

Chart, histogram

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Figure My experiment drops the top elevation below our constant head boundary. This would imply a confined aquifer and does not make sense for this run.

## Glossary Questions

1. Layers: Why do we want multiple layers in our groundwater models? Compare and contrast the different approaches to vertical discretization (briefly describe different approaches and discuss their strengths and weaknesses).

Adding model layers is a way to represent real subsurface geologic units and groundwater flow properties’ distribution. Strengths and weaknesses exist in the tradeoff between complexity, computational expense, and what the available data can actually support. Simple vertical discretization requires less data and run time, but simplification also affects the model’s usefulness and may add bias.

1. Discretization: What are the pros and cons of adding more layers to a model? Are there considerations for vertical discretization that are different from horizontal discretization?

In simple language, adding more layers to a model increases complexity and uncertainty if the data are insufficient to support additional layers. Vertical discretization requires additional considerations than horizontal alone, such as whether to distort model cells to conform to thickness. This is not a concern for horizontal discretization.

1. Stream Aquifer Exchange: How is water exchanged between a stream and an underlying aquifer? Include the following concepts: (dis)connected streams; streambed hydraulic conductivity; boundary condition type; and coupled models.

Stream-aquifer exchange can happen in many different ways, or not at all, which has made it challenging to gain legal recognition of their relation. Gaining streams receive contributions from a shallow water table near the surface; losing streams are fed by other sources such as snowmelt and runoff and experience loss through infiltration along the length of the course. The infiltration loss is determined by the streambed hydraulic conductivity. Coupled models attempt to capture the interaction between surface and subsurface systems, for instance GSFLOW.