Analytic Element Modeling of Transient Saltwater Interface Response In a Layered Freshwater Lens Aquifer

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Introduction

AnAqSim is a new (released August 2011) analytic element method (AEM) model that provides a broad range of capabilities including aquifer heterogeneity, multiple layers, transient simulation and the ability to solve for the location of a saltwater interface. In this study, an AnAqSim model was developed for a hypothetical site with realistic aquifer properties to demonstrate the use of the software for analyzing saltwater interface response to pumping for a variety of hydrogeologic conditions, well geometries, and pumping rates.

The notes below are not intended to provide a slide-by-slide narrative for the presentation, but are intended to supplement and clarify the information contained on several key slides.

Notes for Selected Slides

Slide 6 – While the ultimate goal is to develop a model like the one shown in the inset on Slide 6, with multiple geologic layers and a partially penetrating well, the modeling begins with a simple single-layer model for the freshwater lens. In other words, the well field domain with its multiple layers is not included in the initial model discussed in Slides 7 – 11. This single layer model was run first with recharge over the island aquifer and no pumping to calculate the position of saltwater interface (which forms the base of the freshwater lens aquifer). The same model was then run with a fully-penetrating well in the center of the island. Slide 11 shows the unrealistically large amount of upconing (saltwater interface rise of almost 100 feet) that results from this fully-penetrating representation of the pumping well.

Slide 12 – Water supply wells in freshwater lens aquifers are typically installed as shallow partially-penetrating wells to place the well screen at some distance above the saltwater interface. This reduces the amount of saltwater upconing that results for a given rate of pumping. In many instances, depending on the geologic setting or depositional environment, one or more lower permeability geologic layers may be identified at various depths in the aquifer between the shallow well screen and the deeper saltwater interface. The presence of a lower permeability layer also acts to reduce the amount of saltwater upconing that results for a given rate of pumping.

A three-layer domain was added to the AnAqSim model to represent a well field area in the center of the freshwater lens aquifer. Three simulations were performed:

> **Scenario 1:** Uniform geology, but with the well screen shortened from fully-penetrating (as it was in the initial simulation) to a depth of 50 feet below sea level so that it exists in Layer 1 only. The well pumps at a rate of 300,000 gallons per day.
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> **Scenario 2:** Same model as Scenario 1, but with a lower permeability layer assigned in Layer 2. (Note that the vertical hydraulic conductivity was reduced 30-fold from 30 feet/day to 0.1 feet/day.)
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> **Scenario 3:** Same model as in Scenario 2, but with pumping increased to 600,000 gallons per day.

Upconing Response Conclusions

Slide 16 – This comparison chart shows that the fully-penetrating well model greatly overpredicts the saltwater upconing that results from pumping of a typical shallow water supply well. Representation of the well as a partially-penetrating well in the model reduces calculated saltwater interface location beneath the well from -118 feet mean sea level (msl) to -184 feet msl. Introduction of a lower permeability layer beneath the well screen further reduces the calculated saltwater interface location from -184 feet msl to -196 feet msl. This interface location represents a rise of approximately 13 % of the distance from the non-pumping interface elevation (-215 feet msl) and the pumped interface elevation (-196 feet msl).

Previous analytical investigations of saltwater interface response to pumping have suggested that acceptable conditions may be achieved with a rise limited to no more than approximately 25 % to 30 % of the non-pumping well-screen-to-interface distance. Results for Scenario 3 indicate that, for this idealized model, the pumping rate can be increased from 300,000 gallons per day to 600,000 gallons per day which results in a calculated interface elevation of -176 feet msl; a rise of approximately 24 %.

Transient Freshwater Lens Interface Response

Slide 19 – To examine the time required for the interface to rise in the freshwater lens in response to pumping at a rate of 600,000 gallons per day, three scenarios were developed spanning a range of aquifer storage. It is important to realize that the rate of interface rise is strongly controlled by the porosity of the aquifer materials, and less by the confined or semi-confined storage coefficient in the model.

Upconing Response Conclusions

For a typical range of aquifer porosity values, e.g. a range from 35 to 50 %, the interface near the center of the lens (i.e. the deepest portion of the lens) will rise to a nearly steady condition in approximately 10 to 14 years. [See Slides 21 and 22 which show the hydraulic head decline in Layer 3 (the layer which contains the saltwater interface in the well field domain within the model) in response to pumping, and Slide 23 which shows an example of the interface rise in response to the head decline.]

Overall AnAqSim Model Conclusions

1. AnAqSim provides ease and accuracy of AEM plus anisotropy, layers, transient, etc.
2. Limited to small to moderate size problems
3. Saltwater interface solution is a valuable tool for exploring potential well field sites and examining aquifer parameter effects
4. AnAqSim SWI solve times are much quicker than density-dependent model simulations.

AnAqSim provides the ease of use and accuracy of an analytic element method (AEM) model. The design and implementation of a calculational grid or mesh is not required, and creating domains or representing boundaries is as easy as drawing a polygon line feature in the model space. Additionally, AnAqSim provides features that are not commonly found in other AEM models. These features include the ability to represent horizontal and vertical aquifer anisotropy; multiple subdomains within a model, including stacked subdomains that can represent multiple geologic layers; fully transient simulations; and the ability to solve for the location of a saltwater interface. Regarding the size and complexity of models that can be simulated using the software, as described in its documentation, AnAqSim is currently capable of solving a model with a limit of approximately 5,000 to 10,000 equations. This allows models of moderate complexity, making AnAqSim a useful tool for many practical engineering and environmental applications.

Because of its capability of solving for the location of a saltwater interface, as demonstrated by the test problems considered in this study, AnAqSim was found to be a valuable tool for exploring potential well field sites. A range of well screen depths and geologic conditions can be simulated. In addition, the effect of various hydraulic and hydrologic parameters (e.g. vertical hydraulic conductivity, aquifer storage, etc.) on saltwater interface rise in response to pumping can be examined.

Finally, one of the major advantages of exploratory saltwater interface analyses using AnAqSim is its speed of execution. Solution times for the various steady-state models were generally a few seconds to a few tens of seconds. Solution time to compute 20 time steps for the transient model required approximately 3 minutes. Similar simulations using a three-dimensional numerical density-dependent flow model can often take several days, depending on model complexity and grid resolution. This suggests that AnAqSim can be a valuable tool for initial exploration to quickly examine a range of scenarios. That information can then be used to guide decisions regarding a much reduced set of simulations to be performed using a more sophisticated, and time-consuming, numerical simulation technique as necessary.