Pumping Test Analyses in an Aquifer with Fresh Water/Salt Water Interface

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ABSTRACT

In order to analyze pumping test data in a fresh water aquifer with a laterally encroaching or underlying salt water zone, methods typically employed for fresh water aquifers may not produce accurate estimates of aquifer parameters because they fail to account for the change in aquifer geometry and distribution of heads caused by movement of the salt water interface in response to pumping. This paper presents a methodology to analyze pumping test data in coastal aquifers using the SEAWAT density-dependent flow and transport numerical code. Comparisons of the hydraulic conductivity and vertical anisotropy estimates obtained from pumping test data using a classical method (Hantush-Jacob) and a numerical groundwater flow model which does not account for changes in salt water density (MODFLOW) with values obtained using the more sophisticated SEAWAT model suggest that standard methods may overestimate horizontal hydraulic conductivity and underestimate vertical anisotropy of the aquifer.

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INTRODUCTION

Obtaining accurate estimates of aquifer parameters is of paramount importance for proper management of groundwater resources. A single well pumping test is one of the standard procedures for estimating hydraulic properties of aquifer systems, such as transmissivity and storativity. Commonly, hydraulic conductivity and vertical anisotropy are estimated from measured pumping test drawdowns. Pumping test analysis in a coastal aquifer with an adjacent or underlying salt water zone should be evaluated as a flow problem in which not only movement of the water table but also of the salt water interface may change the thickness of the aquifer in the vicinity of the pumping well, and thus the results of the test. In addition, it is often necessary to make corrections to measured groundwater elevations to account for salt water density fluctuations with depth and time. Thus, in a coastal aquifer setting it may be necessary to apply techniques beyond the standard groundwater modeling methods to produce more accurate estimates of the hydraulic conductivity and vertical anisotropy using salt water transport modeling as described in the sections below.

STUDY AREA

We consider for our analysis data from an aquifer test in the Pamet Flow Cell, a fresh water lens aquifer on Cape Cod, Massachusetts (Figure 1). The glacial sediments of Lower Cape Cod were deposited in a lacustrine deltaic system by meltwaters from the Cape Cod Bay and South Channel glacial lobes that occupied the area 15,000 years ago. These glacial sediments consist predominantly of sand with some gravel and few silt or clay deposits (Masterson 2004; Andrew Miller personal communication 2007), and extend to depths of up to 900 ft below sea level, where they contact the underlying crystalline bedrock (Masterson 2004). There is sufficient contrast in the hydrostratigraphy of these deposits that they generally should not be characterized as homogeneous for the purpose of modeling movement of the salt water interface (e.g. upconing beneath a pumping well).

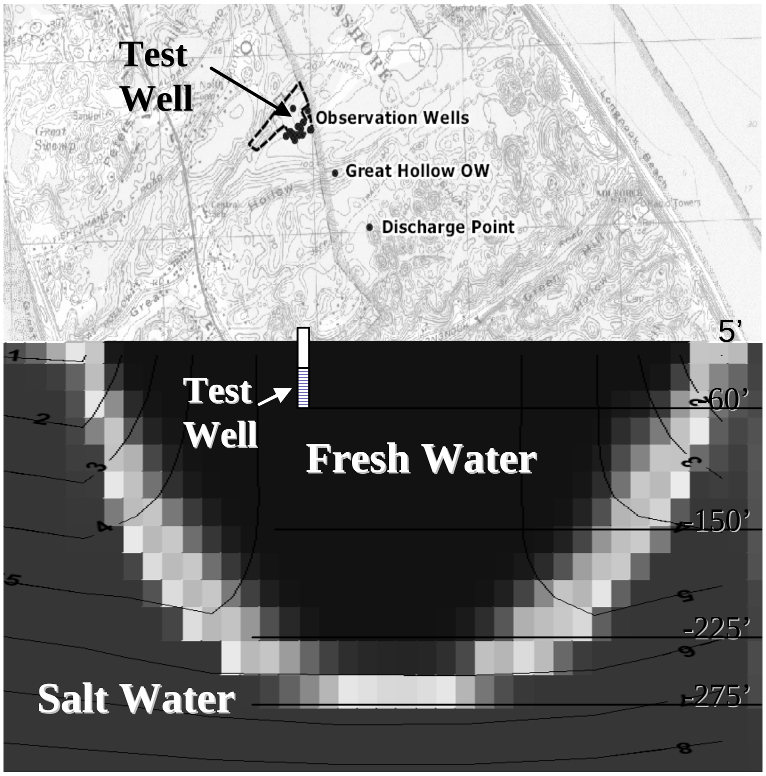

Figure 1 Site Map

A ten-day aquifer test was performed using a set of monitoring wells, installed in the shallow (at about -60 feet amsl), intermediate (at about -150 feet amsl) and deep (at about -250 feet amsl) zones. The water level elevation at the proposed supply well location is at about 5 feet amsl, which implies that the thickness of the fresh water lens in the area is about 200 feet. During the ten-day pumping test the pumping rate was maintained at 500 gpm (0.72 MGD), producing drawdown of about 20 feet at the pumping well which is screened from -30 to -60 feet amsl; up to 4.5 feet at the monitoring wells in the shallow zone; about 1 feet at the intermediate wells; and about 0.2 feet at the deep wells after a fresh water head correction was applied.

HYDRAULIC CONDUCTIVITY ESTIMATES

Hydraulic conductivity and anisotropy estimates for the well cluster data set using classical analytical methods for leaky confined aquifers (Hantush-Jacob) and simple numerical models (MODFLOW) estimated horizontal hydraulic conductivities of 150 to 300 feet/day for the area, and a horizontal to vertical hydraulic conductivity anisotropy range of 2:1 to 10:1. MODFLOW simulations also performed for the same area, using a box model that accounted for recharge and heterogeneity, estimated horizontal hydraulic conductivities of about 100 ft/day and a horizontal to vertical hydraulic conductivity anisotropy range of 10:1 to 30:1. This model does not account for the upconing of the salt water interface caused by pumping. Further improvements on the estimated horizontal and vertical hydraulic conductivities can be made by accounting for the moving interface.

The USGS SEAWAT calibrated numerical transient groundwater flow model (Masterson 2004) prepared for Lower Cape Cod, Massachusetts (LCape) was used to assist in the analysis of the pumping test data at the site. The model can account for the moving interface caused by pumping. The model offers the advantage of being readily available from the USGS, but carries a penalty of extended computational time as it contains three other flow cells in addition to the Pamet Lens (PametL) flow cell of interest. From the USGS SEAWAT LCape regional model, telescopic mesh refinement (TMR) was applied to extract a smaller computational grid that covers only the extent of the Pamet flow lens in order to significantly decrease model execution time. The resulting model grid was refined to increase modeling accuracy. The refined, SEAWAT PametL model uses the same coastal boundaries and initial conditions as the original USGS LCape SEAWAT regional model. Boundaries on the north and south ends of the flow cell along which the LCape model was cut to create the PametL model have been set as constant head and constant concentration boundaries using values taken from corresponding locations in the USGS LCape SEAWAT regional model.

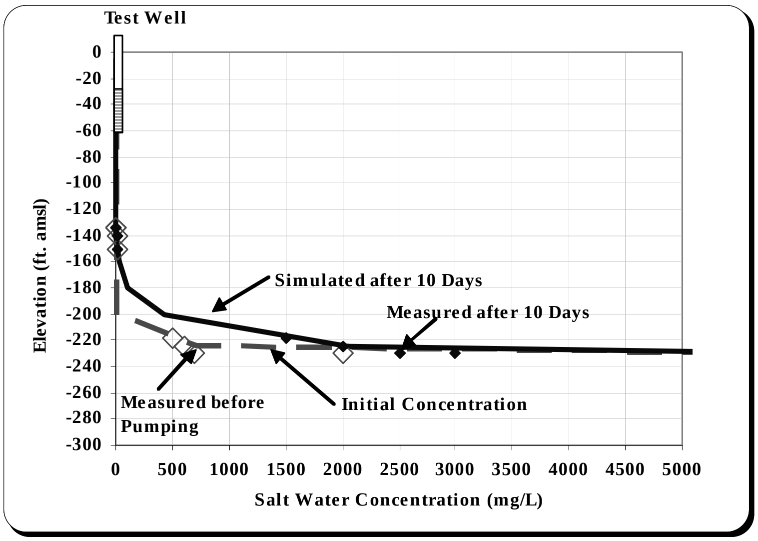

Figure 2 Measured and Simulated Results

Figure 2 shows the observed and the simulated salt water concentration vs. elevation curves obtained using the SEAWAT PametL numerical model simulations. The ten-day aquifer pumping test data was used to calibrate the SEAWAT PametL proposed numerical model, and will be used to estimate the safe yield pumping rate. The horizontal and vertical hydraulic conductivities estimated through the calibration of the PametL model yielded reasonable matches between the observed and simulated transient drawdown and salt water concentration distributions. The calibrated PametL model exhibited a lower horizontal hydraulic conductivity (ranging from 200 feet/day in the shallow layers to 10 feet/day in the deeper layers of the model) and a higher vertical anisotropy (ranging from 30:1 in the shallow layers to 1000:1 in the deeper layers of the model) than the preliminary hydraulic conductivity estimates determined using the classical analyses of pumping test data.

Using a salt water numerical model well calibrated to both, measured drawdown and salt water concentrations, improves the horizontal and vertical hydraulic conductivities estimates. Accurate estimates of these parameters are of paramount importance in determining safe yield, and maximum upconing caused by pumping (Ma et al., 1997; van Dam, 1999). Nelson et al. (*this conference*) shows that, by accounting for vertical anisotropy in the aquifer zone between the well and the interface, the predicted impacts to the pumping well from upconing may be greatly reduced, and wellfield safety yield estimates maybe increased.

DISCUSSION AND CONCLUSIONS

For a site situated in a coastal aquifer, application of a classical analytical technique, a standard numerical flow model, and a salt water flow and transport numerical model produced different estimates of hydraulic conductivity and vertical anisotropy. The differences are attributed to the salt water model’s capability to account for changes in heads caused by pumping, changes in groundwater density and groundwater density distribution, and changing boundary conditions (moving salt water interface) during pumping. The classical analytical and numerical models do not account for the above mentioned changes in fitting the aquifer test data, and therefore overestimate horizontal hydraulic conductivity and underestimate vertical anisotropy.

A ten-day pumping test in which drawdown and specific conductance is measured at multiple cluster wells is beneficial for calibrating the salt water numerical models needed to be used to evaluate safe yield pumping rates. Thus, when conducting pumping tests in coastal aquifer studies, it is important to measure not only the drawdown at cluster wells, but also the changes in the salt water interface induced by pumping. If, in addition to calibrating to heads, the model is calibrated to concentration and to changing boundaries (upconing) a better estimate of horizontal and vertical hydraulic conductivities can be obtained.

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