II－41 NUMERICAL MODELING OF SALTWATER－FRESHWATER INTERFACE

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1. INTRODUCTION

The prediction of the behavior of the coastal aquifers under different saltwater and freshwater flow conditions is very important and it becomes necessary in designing and planning of groundwater systems in coastal areas. Since groundwater systems in coastal areas are in contact with saline water, the quantitative understanding of the patterns of movement between freshwater and saltwater, and the factors that influence these processes, are important to manage the coastal groundwater resources.

The objectives of this study are to model the freshwater saltwater interface in coastal aquifer and to study the major geo-hydrological factors affecting the movement of the fresh water- saltwater interface.

2. METHOD OF APPROACH

The studies involving the movement of fresh groundwater and saltwater in coastal aquifer systems are classically studied using two different approaches: sharp interface method and disperse interface method. It is assumed, for the purpose of analysis, that the two fluids are separated by a sharp interface and the sharp interface model couples the freshwater and saltwater flow based on the continuity of flux and pressure. For freshwater and seawater regions, the principal groundwater flow equations can be simplified to the following system of differential equations. To solve the above equations, there was a necessity of a numerical technique. A two-dimensional numerical finite difference method can be used to discretize the coupled, non linear, partial differential equations. Since the Strongly Implicit Procedure (Remson et al, 1971) is much faster than the other methods, it was used as a numerical technique.

$$\frac{\partial}{\partial x}\left[K_{fx}\left(h^f-h^i\right)\frac{\partial h^f}{\partial x}\right]+\frac{\partial}{\partial y}\left[K_{fy}\left(h^f-h^i\right)\frac{\partial h^f}{\partial y}\right]+q_f=S_f\frac{\partial h^f}{\partial t}-\theta\left[(1+\delta)\frac{\partial h^s}{\partial t}-\delta\frac{\partial h^f}{\partial t}\right]+\alpha\theta\frac{\partial h^f}{\partial t} \quad (1)$$

$$\frac{\partial}{\partial x}\left[K_{sx}\left(h^i-z^b\right)\frac{\partial h^s}{\partial x}\right]+\frac{\partial}{\partial y}\left[K_{sy}\left(h^i-z^b\right)\frac{\partial h^s}{\partial y}\right]+q_s=S_s\frac{\partial h^s}{\partial t}-\theta\left[(1+\delta)\frac{\partial h^s}{\partial t}-\delta\frac{\partial h^f}{\partial t}\right] \quad (2)$$

The location of the interface is given by:

$$h^i=\frac{\rho_s}{\rho_s-\rho_f}h^s-\frac{\rho_f}{\rho_s-\rho_f}h^f \quad \Rightarrow \quad h^i=(1+\delta)h^s-\delta h^f \quad (3)$$

Where, ρ_f and ρ_s are specific weight in fresh and salt water respectively, h^f and h^s are piezometric heads of freshwater and saltwater regions. q_f and q_s are flow rate in fresh and salt water respectively. K_f and K_s are hydraulic conductivity in fresh and salt water regions. S_f and S_s are storage coefficient in fresh and salt water regions. θ is the porosity of the aquifer media. α =1 for unconfined aquifer and α =0 for confined aquifer.

3. STUDY AREA

The coupled freshwater-saltwater flow model has been implemented to investigate the effects of storage characteristics and the effect of hydraulic conductivity on the behavior of the freshwater-saltwater interface dynamics. The case study used an unconfined aquifer with 2 km long and 2 km width, in the southern coastal aquifer in Sri Lanka. The southern coastal aquifer mainly consists of dune sand and alluvium with permeable sandy aquifer and it provides a thin lens of fresh groundwater along the coastal area. The hydraulic conductivity varies from 12m/day at the upper part to 75m/day in alluvium deposits near river beds.

4. RESULTS AND DISCUSSION

The average groundwater recharge was estimated as 0.218 mm/day and it was used for the calibration process. For this study, the field data observation has been carried out in the study area and the change in salinity with depth (vertical profile of groundwater salinity) was measured.

For the simulation process, a sensitivity analysis had to do prior to calibration process to understand the effect of each factor on the location of freshwater-saltwater interface. The effect of the specific storage was evaluated by increasing the storage coefficient by orders of magnitude. It shows that the system responds in almost same manner for different storage coefficient values because most of the water to fulfill the changes in storage is coming from the freshwater flow rather than elastic storage.

To investigate the effect of porosity on the behavior of the interface, porosity was changed between 0.1 and 0.4. The change in the porosity does not lead to change in the position of the interface, but it changes the time period to achieve the steady state of the interface. Reduction in porosity accelerates the interface and it drives the system to steady state over a shorter time period (Figure 01).

The main factor affecting the change in the position of freshwater-saltwater interface is hydraulic conductivity. The hydraulic conductivity was changed over the range of the estimated hydraulic conductivity values in the study area as shown in figure 02. Since the changes in hydraulic conductivity has quite an impact on the steady position of the interface and the effects of other factors are negligible, the model was calibrated by adjusting hydraulic conductivity values to match the steady state interface location with the field observations at two observation wells (figure 03).

It is important to understand the effect of varying recharge on the movement of the interface. The calibrated model has been used to simulate the interface with the changes in groundwater recharge. Since the actual recharge defers seasonally the simulation runs were conducted with recharge values of 0.15, 0.2, 0.25, 0.3mm/day. The effect of recharge in saltwater freshwater interface dynamics is depicted in figure 04. The results show that higher recharge can reduce saltwater intrusion effectively.

5. SUMMARY

The calibration shows the change in storage characteristics is not affecting the location of interface, but the change in porosity affected the time scale to become the system to steady state. Hydraulic conductivity is the main factor affecting the interface location. When hydraulic conductivity is decreased interface is lowered, and the interface is upcoming with the increments of hydraulic conductivity. The simulation highlights the effect of groundwater recharge on seawater intrusions. High recharge rate in the aquifer can reduce the seawater intrusion effectively.

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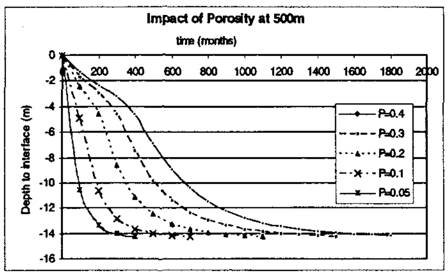

Figure 01. Effect of Porosity on the steady interface

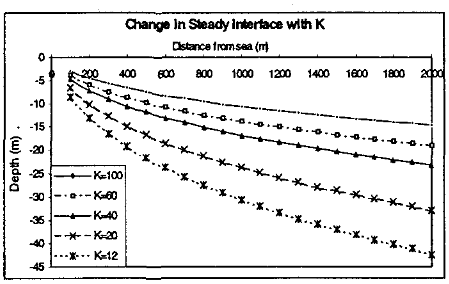

Figure 02. Change in steady interface with K

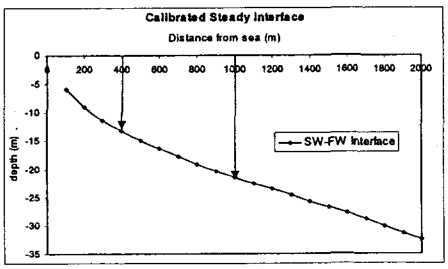

Figure 03. Simulated steady interface.

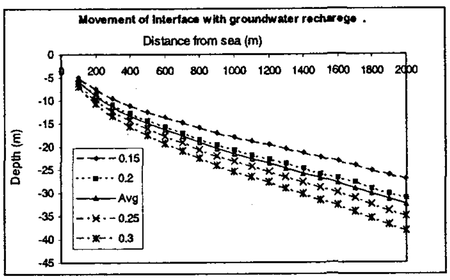

Figure 04. Effect of recharge on the interface