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Transient Groundwater Flow Modeling in Coastal Aquifer

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Abstract

Submarine groundwater discharge (SGD) and the interface between seawater and freshwater in an unconfined coastal aquifer was evaluated by numerical modeling. A two-dimensional vertical cross section of the aquifer was constructed. Coupled flow and salinity transport modeling were performed by using a numerical code FEFLOW. In this study, we investigated the changes in groundwater flow and salinity transport in coastal aquifer with hydraulic condition such as the magnitude of recharge flux, hydraulic conductivity. Especially, transient simulation considering tidal effect and seasonal change of recharge rate was simulated to compare the difference between quasi-steady state and transient state. Results show that SGD flux is in proportion to the recharge rate and hydraulic conductivity, and the interface between the seawater and the freshwater shows somewhat retreat toward the seaside as recharge flux increases. Considered tidal effect, SGD flux and flow directions are affected by continuous change of the sea level and the interface shows more dispersed pattern affected by velocity variation. The cases which represent variable daily recharge rate instead of annual average value also shows remarkably different result from the quasi-steady case, implying the importance of transient state simulation.

key word : transient groundwater modeling, coastal aquifer, FEFLOW.

1. Introduction

SGD is the outflux from the coastal aquifer to the sea driven by groundwater flux from the terrestrial origin and recirculated seawater flux by free convection due to density difference. SGD is one of main processes which transfers the contaminant and nutrient from the inland to the sea, thus has significant effect on the estuary environment and ecosystem.

Being difficult to notice its existence and the effect on estuary environment visibly, scientific interest to the SGD had not occurred until recently. Even though various investigations and studies have been performed to identify SGD for several years (Destouni and Prieto 2003; Smith 2004; Wilson 2005; Michael et al. 2005), many parts still exist that cannot explain scientifically. Especially, the studies of transient simulation considering time varying boundary condition have not been preformed enough.

Salinity distribution is the other factor which has the high potential effect on the estuary environment. As the main water resources in the coastal area, the groundwater and its quality are the critical problem because water with high salinity cannot be used for biological activity. So, it's important to understand the shape of interface between seawater and freshwater with various hydraulic condition and to control and expect its change considering time varying boundary condition.

In this study, we investigated the changes in SGD and interface shape with various hydraulic conditions by numerical modeling including transient simulation.

2. Method

Two dimensional cross section of an unconfined aquifer was employed for numerical modeling. Numerical code FEFLOW(Diersh 2005) was used for solving coupled equations of density-dependent flow and solute transport.

Figure 1 illustrates overall domain and its boundary condition. No flow boundary was specified to the left, right and bottom side of domain. Equivalent hydraulic head boundary was specified to the right part of top side and recharge flux boundary to the left part of top side. Between head and recharge boundary, 3-4m of seepage face was also applied. Three observation wells were installed to monitor continuous change of head and salinity distribution. Each well has five measurement points.

To examine how the SGD flux and interface change in relation to hydraulic condition, 10 cases which indicate different aquifer property, natural recharge effect and seawater fluctuation were tested. Table 1 illustrates hydraulic condition of each case. Annual precipitation rate was assumed to be 4mm/day. The cases that consider time varying boundary condition are case 8, 9, 10. In case 8, the model considered small tide effect. Tide amplitude and period are 25cm and 12hours respectively. In case 9, recharge rate was given as sine curve to represent the seasonal variation of natural recharge rate. The mean value, amplitude and period of sine curve are 0.0007, 1year, 0.0007, respectively. In case 10, daily averaged precipitation data of was used to show SGD flux variation based on real recharge rate variations. Figure 6 shows daily precipitation rate used in this modeling.

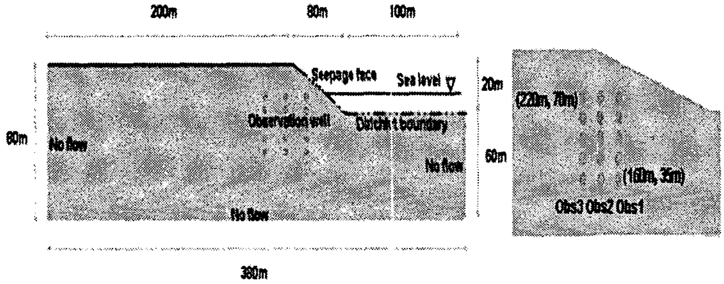

Fig 1. Schematic representation of domain and the location of observation wells

	K (10^{-4}m/s)	Recharge(m/day)	Feature
Case1	0.1	0.0007	17.5% of annual precipitation
Case2	0.1	0.001	25% of annual precipitation
Case3	0.1	0.0004	10% of annual precipitation
Case4	0.03	0.0007	
Case5	0.01	0.0007	
Case6	0.5	0.0007	
Case7	0.001	0.0007	
Case8	0.1	0.0007	Tide effect
Case9	0.1	0.0007	Recharge variation of sine curve
Case10	0.1	0.0007	Daily precipitation

Table 1. Simulation cases

3. Results

SGD

Under the condition that hydraulic properties except recharge rate are same, SGD flux shows the linear relation to the natural recharge rate(Fig 2.). Definitely, it is due to the increase of freshwater entering to the domain and this phenomenon was already investigated by Destouni and Preito(2003). The amount of recirculated seawater doesn't show critical difference. Change of hydraulic conductivity also affects the SGD. Figure 3 shows that under the condition of the same recharge rate, SGD flux is in proportion to the hydraulic conductivity, which leads to the change of recirculated seawater. The sensitivity of SGD flux to the hydraulic conductivity, however, is less than to the recharge rate.

In case 8, tide shows the significant effect on SGD. Under the neap tide condition, SGD flux magnitude increases compared to the case ignoring tidal effect. Under the spring tide condition total outflux is zero and finally, flow direction is reversed. Figure 4 illustrates the fluctuation of observed head in Obs1.

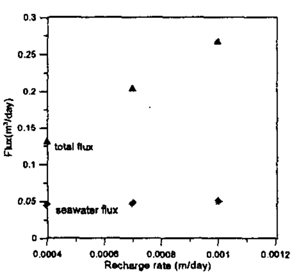

Fig 2. Recharge rate and SGD (K=0.1*10^{-4}m/sec)

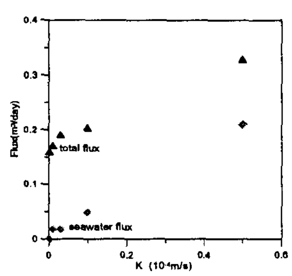

Fig 3. Hydraulic conductivity and SGD (R=0.7mm/day)

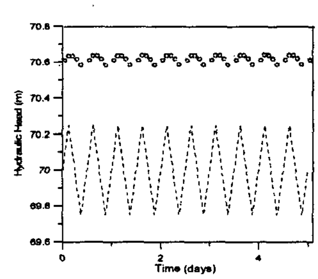

Fig 4. Tide effect(dashed line) and observed head(circle mark)

Seasonal recharge variation makes the SGD pattern more complicated. Figure 5 and Figure 6 illustrate SGD flux and recharge data in case 9 and 10, respectively. Considered seasonal change of recharge rate, SGD become quite different from the quasi-steady case showing fluctuating pattern of SGD flux driven by recharge rate variation was observed. Figure 6 illustrates the SGD flux pattern and recharge variation. The shapes of two graphs are similar but out of phase implying lag time exists. In case 10, Sudden increase of SGD driven by high rainfall event in September is also observed showing much shorter lag time than case 9.

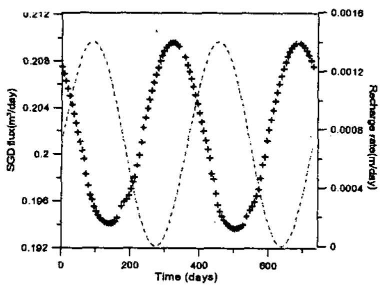

Fig 5. Recharge rate(dashed line) and SGD(cross mark) in case 9

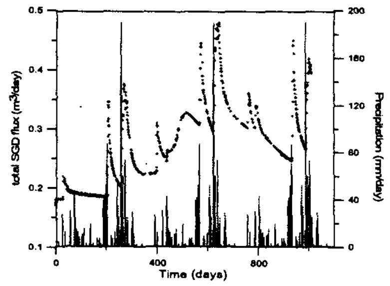

Fig 6. Precipitation rate and SGD

Interface between seawater and freshwater

As the recharge rate increase, the interface shows somewhat retreat toward the seaside. Raised the estimated head and position of water table, the interface goes down following the Ghybsen-Hertzberg relation, in quasi-steady simulation. Figure 7 (a), (b), shows this phenomenon well. Especially, salinity distribution shows that it is very sensitive to the change of hydraulic conductivity(Fig 7(c)). Decrease of hydraulic conductivity prevents the seawater from intruding to the aquifer and leads to the retreat of the interface.

In transient simulation, salinity distribution of the aquifer shows more dispersed pattern compared to the no tide condition. The continuous change of sea level leads to the variation of velocity vector of the groundwater, and eventually increases dispersion effect. Figure 7(d) shows the salinity distribution in case 8.

Under the simulation considering seasonal variation of recharge rate, more dispersed pattern of salinity distribution is also observed caused by continuous change of groundwater velocity. Case 10 also shows quite different result from case 9. In case 9, similar salinity distribution to case1 can be seen(Fig 7(e)), whereas interface in case 10 goes up for the first several years and then decreases suddenly. Eventually, interface between seawater and freshwater goes down(Fig 7(f)).

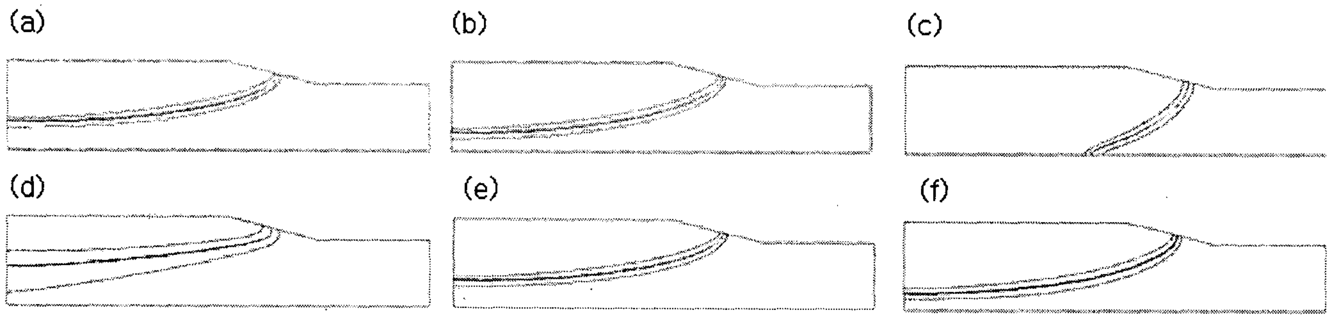

Fig 7 Salinity distribution. From the top, each line indicates contours of 1%, 50%, 99% of seawater salinity. (a) Case1 (b) Case2 (Case4 (d) Case8 (e) Case9 (f) Case10

4. Conclusion

SGD flux and interface between seawater and freshwater in coastal aquifer are affected by various hydraulic conditions in estuary such as recharge rate, hydraulic conductivity, tide effect and the seasonal recharge variation. Especially, SGD flux is in proportion to the total recharge flux and hydraulic conductivity. This phenomenon can lead to site specific SGD flux magnitude and different shapes of interface. In transient state simulation considering time varying hydraulic condition, the results show different patterns of SGD flux and salinity distribution from the steady state simulation.

5. References

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6. Acknowledgements

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