Impacts of Sea-Level Rise on Subsurface Water Environment in the Lower Seyhan River Basin

—Calibrated and Projected Results—

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1. Introduction

According to IPCC, global warming is expected to cause sea-level rise and abnormal weather, which in turn affects natural phenomena such as salt water intrusion in coastal aquifers, groundwater flow, salt transport by groundwater or irrigation practice, etc. The Cukurova plain, Turkey, is an important agricultural area expanding in the Seyhan River Delta along the Mediterranean.

Fig.1 shows a procedure for projecting impacts of sea-level rise on subsurface water environment. The core of numerical simulation is a newly developed 2D saltwater intrusion model, SIFEC (Salt-water Intrusion by Finite Elements and Characteristics), which is based on coupling of the Galerkin-finite element method for saturated-unsaturated, density-dependent flow and the method of characteristics for mass transport.

The high performance of SIFEC in terms of accuracy has already been proved (Fujinawa et al, 2005) and its applicability is also shown by an example applied to problems of salt-water intrusion into coastal aquifers in small islands (Tomigashi and Fujinawa, submitted for publication).

Provided with future changes in precipitation, evapotranspiration, river

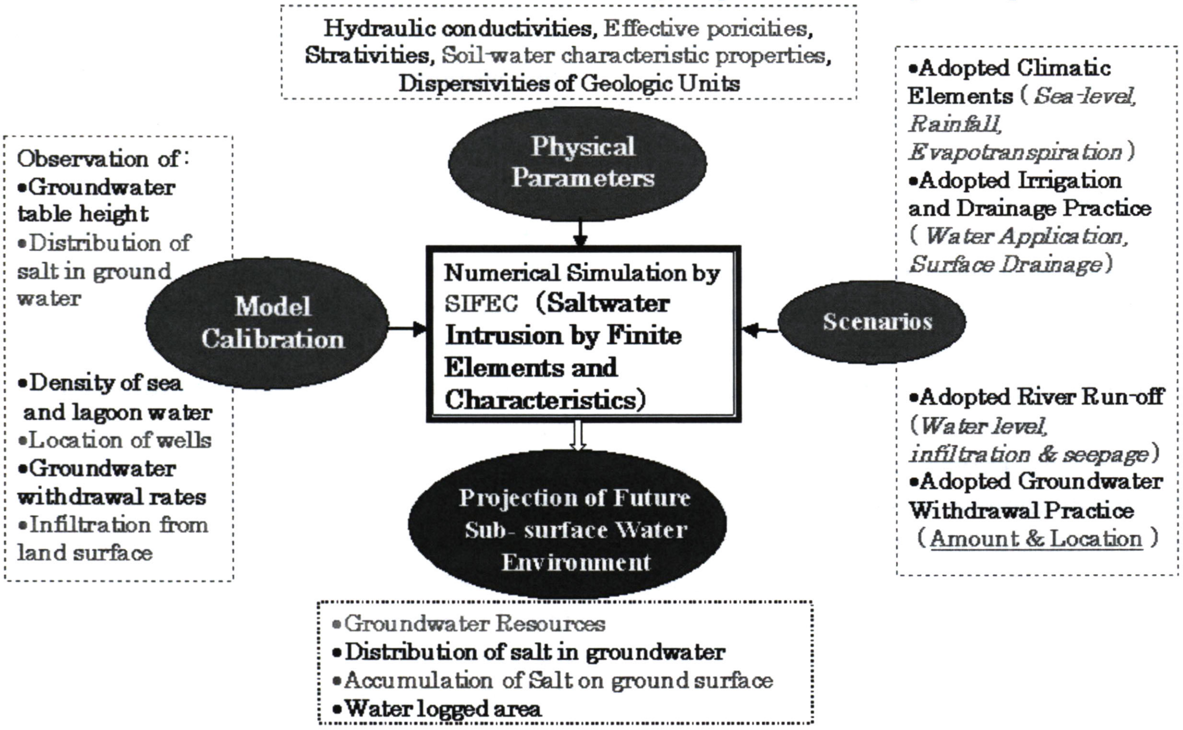


Fig.1 Procedure for Projecting the Impacts of Sea-Level Rise

discharge, etc, SIFEC can be applied to assess impacts of climate change on groundwater flow, saltwater intrusion, water logging, and salt accumulation on land surface.

A physical model to describe the above mentioned phenomena was first constructed taking into consideration geologic and geographic properties of the Lower Sayhan River Basin (LSRB).

The model is then calibrated by using estimated hydrogeologic parameters such as hydraulic conductivities, specific yields, soil-moisture characteristics, longitudinal and transverse dispersivities, together with observed salinity distribution in the aquifer, estimated rate and distribution of recharge, and withdrawal so that the calculated and the observed groundwater table coincide.

The model was then run under several scenarios with respect to sea-level rise this time. Other runs for scenarios with respect to recharge rate and groundwater withdraw rate will be followed soon. The results of future projection of water environment related to groundwater systems in LSRB are discussed in this report.

2. Preparation of Input Data

Construction of a mathematical model that represents actual groundwater systems of any regions in concern requires a variety of data. Structures of geologic units is one of the most important and has already been reported in the former publications of this series. A mathematical model further requires a set of physical parameters such as hydraulic conductivity, effective porosity, strativity, soil water characteristic properties, and longitudinal and transverse dispersivity. The geologic units of LSRB is consisted of four types of formations; namely, aquifer, sand dune clayey layer, and basal layer. The hydrogeologic properties of these layers are given in Table 1.

Hydraulic Conductivity (m/day)	**Aquifer : 86.00** **Sand Dune : 34.50** **Clayey Layer : 0.22** **Base : 0.04**
Effective Porocity	**All Layer : 0.22**
Longitudinal Dispersivity (m)	**All Layer : 30.0**
AT/AL	**1/10 (=3.0)**

Table 1 Hydrogeologic Properties of Geologic Units

Boundary Conditions for GW Flow Eq.
Fresh water on the left side=18.7(m)
Sea water on the right side =0.0(m)
Lagoon water=0.0(m)

Boundary Conditions for Mass Trans. Eq.
Fresh water on the left side= 1.002(g/cm^3)
Sea water on the right side =1.030(g/cm^3)
Lagoon water=1.030(g/cm^3)

Table 2 Boundary conditions

Boundary conditions are settled by observing groundwater table height, salinity of groundwater, sea water and/or lagoon water together with infiltration rate along the periphery of solution domain. Table 2 shows those conditions used for the calibration run.

By using monthly data of precipitation, irrigation, evapo-transpiration calculated using the Thornthwaite method, daily average recharge rate was determined as 1.5mm/day for irrigated area, 0.71mm/day for non-irrigated area north of the Akyatan lagoon, and 0.36mm/day for dune area.

Initial distribution of salinity in shallow groundwater was determined by referring to soil and groundwater salinity data provided by S. Donma at DSI. It is assumed that initial salinity of shallow groundwater decreases gradually downward upto 50 m deep from mean sea level, and the rest of the regional groundwater has constant EC of 0.02 S/m. Furthermore, a sharp interface is also assumed between salt and fresh

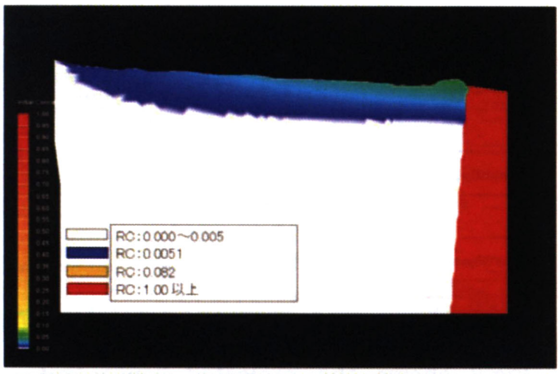
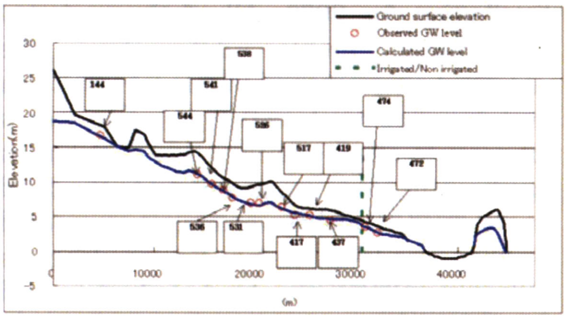


Fig.2 Initial concentration distribution of salinity relative to Mediterranean Sea



Max Error: 0.40m at well no.417

Fig.3 Comparison between Observed and Calculated Groundwater Table

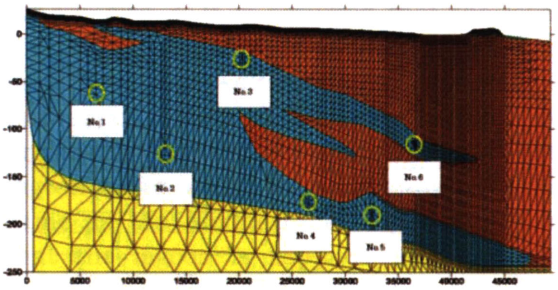
groundwater, which locates with slightly inclined straight line from vertical direction. Fig.2 shows the initial distribution of relative concentration.

3. Calibrated Results

While those data are utilized as input data, the model outputs in terms of piezometric head and salt concentration are compared with those of observed values. Calibration runs are usually repeated until both results coincide to a satisfactory degree. Fig.3 shows a comparison between observed and calculated groundwater table. The maximum error was detected to be 0.4 m at well no.417.

Fig.4 illustrates discretized finite elements together with location of well screens. Groundwater withdraw rates described below the figure were values inversely identified so as for the discrepancy between the observed and calculated hydraulic head to be minimized.

Accumulation of salt on land surface can be evaluated from seepage rate that is calculated as outward groundwater flux, and its concentration.



No.1=No.2=9.50(m^3/day), No.3=19.09(m^3/day), No.4=9.21(m^3/day)
No.5=5.77(m^3/day), No.6=1.26(m^3/day)

Fig.4 Finite Element Mesh and Location of Well Screens

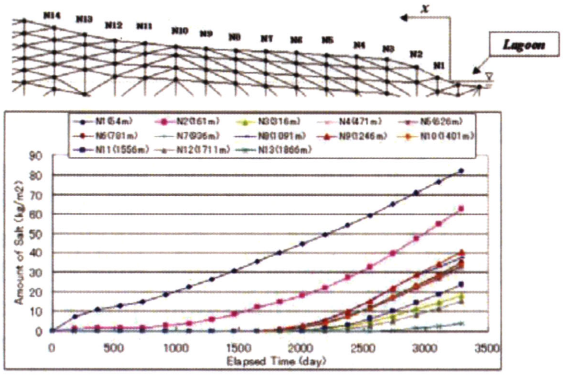


Fig.5 Accumulation of salt on land surface carried by groundwater seepage

Fig.5 shows temporal accumulation of salt on land surface at nodal points close to the lagoon where seepage face is formed. The area with accumulated salt is restricted only as far as 1,866m from the shore of the lagoon. Maximum amount of salt accumulated after the simulated period of 9 years is about 80 kg/m^2.

Water level of the lagoon was maintained to be the same level as the Mediterranean since both water is connected via a narrow stream. However, condensation of the lagoon water is taking place due to seepage of saline groundwater and evaporation from the water surface.

Observation of the salinity distribution of the Akyatan lagoon revealed that mean EC of deep part is 10.0 S/m and that of shallow part is 7.8 S/m, while that of the Mediterranean is 5.8 S/m. Concentration of the lagoon water can also be calculated using seepage rate and the mass of salt carried by seepage flow. Fig.6 shows temporal changes in concentration of the lagoon water. Its concentration gradually increases from the initial concentration (EC=5.8 S/m) , which is

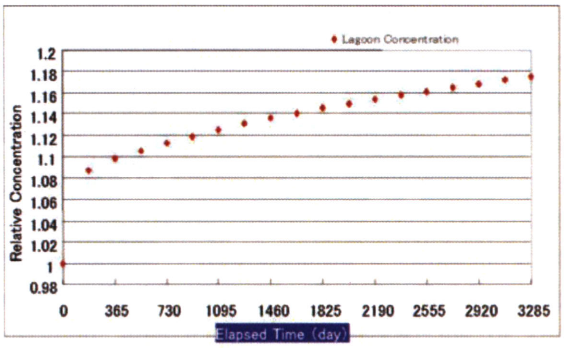


Fig.6 Changes in Concentration of Lagoon Water

the same as the Mediterranean, to the current observed concentration of the Akyatan lagoon (EC=6.8 S/m).

4. Some Projected Results

Followed by the calibration process, the fixed model are then run for various scenarios based on adopted climatic elements, irrigation and drainage practice, river run-off, and groundwater withdrawal practice to obtain future projection of groundwater situation, salinity of groundwater, accumulation of salt on land surface, water logging, etc.

The possible factors for the scenarios can be consisted of see level rise, recharge rate, and pumping rate. Combination of these factors make up scenarios as shown in Fig.7.

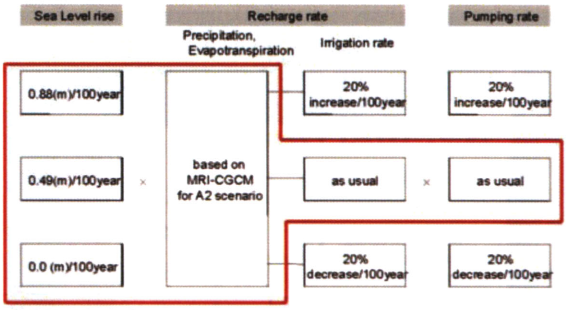


Fig.7 Scenarios for Projecting Impacts of Global Warming on Subsurface Water Environment

Fig.8 shows the projected concentration distribution for 2070. All of the projected concentration profiles differ from the calibrated concentration profile for 2005. Sea level rise of as much as 0.88 m/ century does not seem to affect concentration distribution significantly. However, according to the third report of IPCC, global warming is considered to keep sea-level rising for as long as millennium. Thus, this kind of short ranged simulation may not be enough to evaluate its real devastating characteristics.

Fig. 9 shows distribution of velocity vectors for scenario 1 and 3, both of which do no differ so much either.

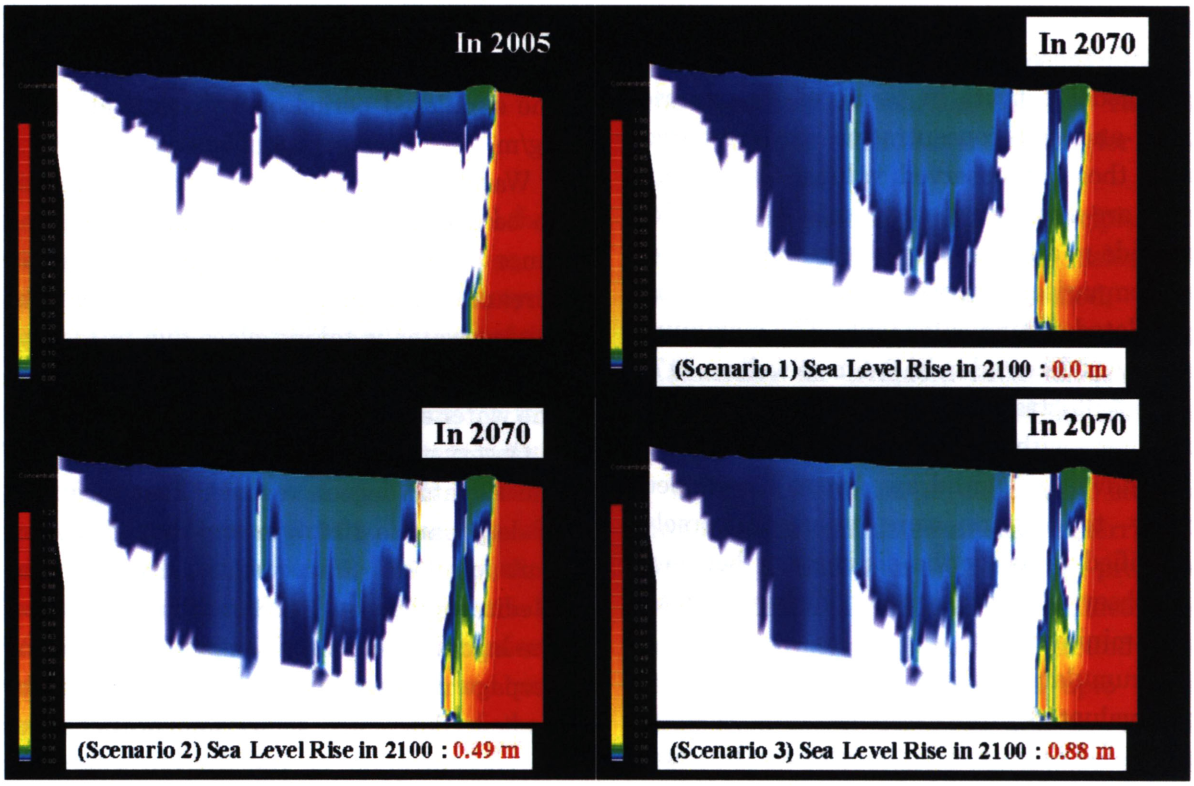
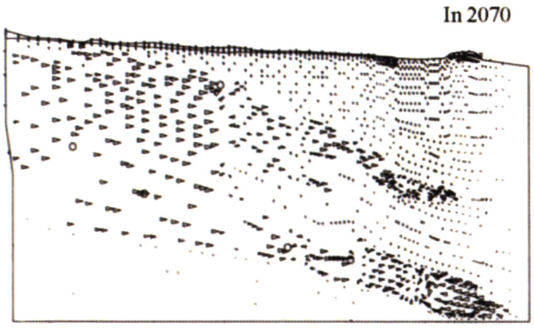
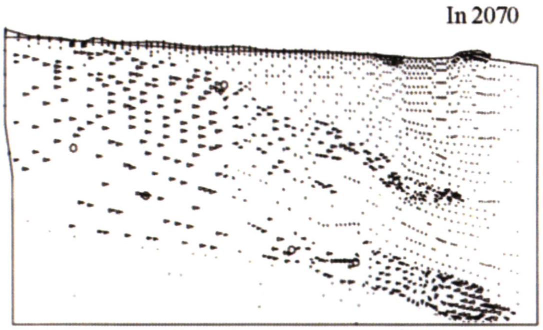


Fig.8 Projected Concentration for Three Types of Scenarios



(Scenario 1) Sea Level Rise in 2100: 0.0 m **O Well Screen**
Inflow Across Mountain-side Boundary into LSRB: 1631.6 m³/year/m



(Scenario 3) Sea Level Rise in 2100: 0.88m **O Well Screen**
Inflow Across Mountain-side Boundary into LSRB: 1596.73m³/year/m

Fig.9 Velocity Vectors for Scenario 1 and 3

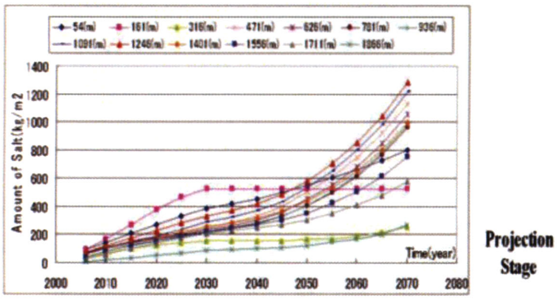


Fig.10 Projected Accumulation of Salt on Land Surface

Compared with scenario 1, the amount of inflow rate across mountain-side boundary for scenario 3 slightly reduces due the reduction in hydraulic gradient, accompanied by sea-level rise,.

Groundwater table height for scenario 3 is not affected to a measurable degree compared with scenario 1 either, since recharge rate and pumping rate remain the same rate as in 2005.

Fig.10 shows the projected accumulation of salt on land surface for scenario 3. The amount of accumulated salt increased drastically compared to the calibration run. Thus, drainage practice is strongly recommended in the future to minimize the impacts of salt accumulation on land surface.

Fig.11 shows the projected temporal changes in concentration of the lagoon water for scenario 3. It is assumed that the level the Mediterranean rises as much as 0.572 m in 2070 and its salt concentration remains unchanged throughout the period of projection. Furthermore, the level of the lagoon water is also assumed to remain the same as the Mediterranean, which means that the lagoon is supplied with the sea water via stream. Fig.11 suggests that salt supplied by seepage groundwater containing salt and evaporation of water from the lagoon surface is not enough to increase the concentration of the lagoon water due to supply of sea water with constant salinity.

5. References

(1) K. Fujinawa, K. Masuoka, T. Nagano, T. Watanabe, (2004): Numerical simulation modeling for salt-water intrusion in predicting impacts of sea-level rise on areas below sea-level, *Journal of Environmental Systems and Engineering, Japan Society of Civil Engineers*, No.790/VII-35,pp.35-48.

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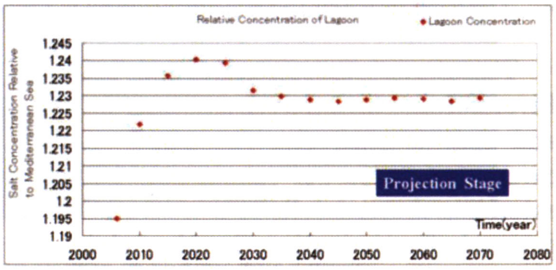

Fig.11 Projected Changes in Relative Concentration of Lagoon Water for Scenario 3