Assessment of vulnerability of water resources system to climate change

Hydrology and Water Resources Sub-Group

1. Introduction

Response of water resources systems in the Seyhan River Basin will be investigated by numerical models developed for surface and groundwater systems separately. Different kind of numerical models are developed and applied for surface water and ground water system both by Turkish and Japanese team, respectively. Basically, the Turkish team and the Japanese team act in parallel in the development of their numerical models. But all models are physically-based distributed multi-layer type. Thus, the data requirement for the model parameters and boundary conditions are basically same, and these common dataset will be constructed and shared by both Turkish and Japanese side.

2. Turkish hydrology group

2.1 Vulnerability of water system

In order to establish strategies to cope with the expected problems about water resources, it is essential first to define the problem in terms of vulnerability of water resources to climate change. This requires a thorough understanding of the type and extent of the relationship between climate and water resources system which are connected through the hydrological cycle. Water resources system is constitute of two main part: hydrology (dynamic part) and the geological configuration (static part).

Following the definition by IPCC, the term "vulnerability" is used to define the "extent to which the water resources system is susceptible to sustaining damage from climate change".

2.2 Technical approach and methodology

The three-phase approach is employed in the study of vulnerability of water resources to climate change. The first phase is devoted to definition of the present status. The second phase is the assessment of the vulnerability of the system to climate change. The third phase is devoted to prediction of the response of the water resources system to the given climate change scenario. **Fig.1** shows the summarized flowchart of this approach. Phase-1 is represented by the construction of the "conceptual model". Transfer of the conceptual model to an appropriate mathematical model is the method applied to achieve phase-2.

The hydrological/hydrogeological struc- ture of water resources system should be evaluated in terms of their role in capturing and storing capability of the precipitation. Recharge mechanism is thus of major importance. The relative residence or turn- over time of the water resources is important in assessing the impact of change in recharge regime. Keeping in mind that each watershed has its own unique hydro-geological structure, parameters making the system more vulnerable may differ for each different system. Therefore, an accurate impact assessment necessitates analyses of parameters for their vulnerability to climate change for each system. This is achieved by construction of a conceptual model which is then transferred to mathematical model of the water resources system. Once the mathematical model is calibrated for the prevailing conditions, it is possible to test every parameter for its response to change in water resources.

2.3 Hydrogeological conceptualization of Seyhan Basin

The Seyhan River Basin, having an area of 23172.8km^2, was first divided into two major parts, according to the water resources types. The area downstream of the Seyhan dam is a large coastal alluvial plain while the upstream constitutes one of the largest hydrological basins in Turkey. The basin extends from the Mediterranean Sea coast in the south to the foothills of the Erciyes Mountain in Central Anatolia (**see Fig.2**).

The plain, constituting the groundwater resources is almost flat while the upstream part is mountainous exhibiting steep topography. Hot and dry summers and temperate and rainy winters characterize the plain, while cold and snowy winters are typical in the northern-upstream part.

The Seyhan Dam located at the northern edge of Adana city can be regarded as the approximate divide between the ground- water system and the surface water system. The groundwater system occurs in the alluvial plain extending from the Seyhan Dam site to the Mediterranean in the south. The plain is composed of alluvium deposited mainly in deltaic and fluvial environments. The surface area of the plain is 2211.9km^2 corresponding to about 10% of the total area of the basin. Owing to the heterogeneity that is evident from boreholes, the groundwater reservoir is constituted by more than one aquifer separated by less permeable layers. On the other hand, because the lithological layer covering the upper aquifer is not homogeneous, the aquifer is confined in some areas. The general hydrogeological structure is depicted on a cross-section in **Fig.3.** The hydrogeological behavior of the boundary between the groundwater system and the sea is not clear and should be defined. The EC and chemical composition of the groundwater of different depths imply at least three hydro-chemically separate units.

The surface water resources in the Seyhan River Basin originate from the runoff of the hydrologic cycle. This potential depends to great extent upon the physio- graphical and meteorological conditions of the basin. In addition to the type and spatial and temporal distribution of precipitation, vegetation, land-use, soil type, underlying lithology, slope, and basin characteristics (such as area, shape, drainage patterns and density etc.) controls the occurrence of the runoff and storage capacity of the basin.

In the higher elevations of the basin, the precipitation falls in the form of snow. In addition to its contribution to the runoff, the importance of the snowmelt stems from the fact that karst groundwater system contributes in significant amounts to the streamflow through numerous huge karstic springs. The karstic groundwater systems (aquifers) are recharged by the snowmelt as well as rainfall.

2.4 Plausible impacts of climate change

As far as the groundwater system in the plain is concerned, two major factors seem to play essential role in assessing the impact of climate change: the boundary conditions of the aquifer and the mechanism of recharge. The upper boundary of the aquifer is made of pervious and impervious units in different parts. As regard to the connection with the sea, groundwater flow into sea does not occur all along the coastline because impervious lithologies may form barriers in some sections. Lithological variation with depth may also affect the sea water intrusion at different layers of the aquifer. Therefore, it is of vital importance to characterize the boundary conditions along the sea coast to be able to assess the effect of sea level rise. The actual recharge of the aquifer seems to be by infiltration from direct precipitation and by seepage from the basin where it flows over permeable units. However, the hydrogeological behavior of the northern boundary of the plain is not clear yet.

The surface water resources in the basin are fed by three major sources: direct runoff, snowmelt, and karstic springs. Owing to the areal extent and the morphology of the basin, the hydrological behavior of the basin is dependent largely on the snowmelt and the karstic discharges. Although karstic aquifers are more vulnerable to climate change than granular aquifers, in Seyhan basin, the karstic aquifers has large storage and long residence time so that it should compensate to a certain extent the change in frequency of precipitation. However, the change in precipitation type, from snow to rain, will alter the flow regime of the river and will adversely affect the recharge of karstic aquifer.

3. Japanese surface hydrology group

3.1 Basin Characteristics

The start point of the surface hydrology group was to define a physical boundary of the target basin. Once the basin boundary is defined, other basin characteristics (soil type, vegetation, topography, etc.) can be extracted from the global dataset and local detailed information. Since planned target resolution of the hydrological model is 1km, **Gtopo30** is selected as basic DEM. **HYDRO1k** is also utilized to characterize the location of the boundary and river channel. Boundary of the Seyhan River Basin is defined as **Fig.4** (catchment area is about 24625km^2), and it mostly coincides with that was produced by Turkish hydrology group. As for the small inconsistency, we need to discuss more and reproduce a common dataset.

3.2 Analysis of surface meteorological data

All the available DMI meteorological data from 1971 to 2002 have been checked and analyzed. **Table 1** is a summary of available data within and near the Seyhan River Basin. Based on this information, it is possible to create gridded meteorological dataset to some extent. Although 44 stations data are listed, only ten stations are located within the basin. It is not enough to capture the realistic distribution of precipitation in such a large (more than 20000km^2) and highly mountainous (altitude range is more than 3000m) area. Thus, there is a need for collecting more precipitation data even though they are stored as printed data.

Table 1 List of available DMI stations

Meteorological element	number
Precipitation (daily)	44
Air Temperature (hourly)	18
T_{max}, T_{min} (daily)	31
RH_{max}, RH_{min} (daily)	20
Wind, SW_{down}, P_{surf}…(daily)	20

domain: E34.0-E37.0, N36.5-N39.5

3.3 Up-grading of the hydrological model

Hydrological model (HydroBEAM) was expanded to 3D-HydroBEAM which can dynamically link the surface runoff, subsurface flow, and groundwater flow (see **Fig.5**). Reservoir operation model that can decide the release based on its own and others' storage has also been implemented in 3D-HydroBEAM.

3.4 Preliminary analysis of the impact of climate change on basin water balance

The first product of RCM was provided from **Climate sub-group**. Preliminary simulation forced by this dataset was executed to start the discussion about the application of projected climate change information. Unfortunately, this first product does not cover the whole Seyhan Basin. Then, 2degree x 2degree area (E34.5-36.5, N36-N38) is selected as simulation domain. In order to estimate energy and water balance as accurately as possible, and to evaluate the impacts of climate change on water resources in this semi-arid region realistically, SiBUC land surface model is run with irrigation scheme activated. As for the details of the experimental design and results, please refer to the personal research report (Tanaka and Kojiri, in this volume).

4. Japanese ground-water group

4.1 Introduction

It is expected that the global warming will impact on hydrological environment, irrigation system, plant growth, and agricultural economy. The purpose of this study is to predict changes of soil and groundwater environment on Seyhan river delta due to the global warming. We developed a saturated-unsaturated, density- dependent flow model for sea water intrusion, SIFEC (Salt-water Intrusion by Finite Elements and Characteristics)$^{1)}$. And SIFEC will be applied to simulate hydraulic conditions of Seyhan river delta.

4.2 Feature of SIFEC

Within a non-deformable porous media, the governing equation for flow of non-compressive fluids with variable density is given by

$$\nabla \cdot K_f \left(\nabla h_f + \frac{\rho}{\rho_f} \nabla y \right) = C_s \frac{\partial \rho}{\partial t} \tag{1}$$

where ρ、ρ_f are the density of fluid and fresh water, K_f、h_f are the hydraulic conductivity and the pressure head in terms of fresh water, and y is the upward vertical coordinate. The governing equation for transport of conservative mass is given by

$$\nabla \cdot D \nabla C - \mathbf{v} \cdot \nabla C = \frac{\partial C}{\partial t} \tag{2}$$

where D is the dispersion coefficient, C is the concentration of salt, and $\mathbf{v}$ is the fluid flow velocity vector.

SIFEC used a finite element method to solve the fluid flow equation and a characteristics finite element method to solve mass transport equation.

SIFEC adopted single-step reverse particle tracking with quadratic interpolation scheme for interpolating concentration in solving transport equation.

4.3 Model design

We created 2D finite element mesh, based on geological profile of Seyhan Delta as shown in **Fig.6**. The boundary conditions for the fluid flow are shown in **Fig.7**. At the seaside(NH3 - NH4), the hillside(NH5 - NPOIN) and lagoon(NH6 - NH7), fixed head boundary is set up. At the surface between the hillside and lagoon(NH1 - NH2), h=0 is given when seepage occurs. At the bottom of model and the dune between lagoon and sea, no flow boundary is set up. The boundary conditions for mass transport are shown in **Fig.7**. At the seaside(NC1 - NC2), the hillside(NC5 - NPOIN) and lagoon(NC3 - NC4), fixed concentration boundary is set up. But NC1 and NC3 changes the position according to seepage. The values shown in **Table 2** will be used for this simulation.

Table 2 Parameter for 2D model

Parameter		*Value*	*Unit*
Water level			
(hillside)	H_f	*15.0*	*(m)*
(lagoon)	H_l	*0.0*	*(m)*
(seaside)	H_s	*0.0*	*(m)*
Density			
(fresh)	ρ_f	*1.000*	*(g/cm^3)*
(lagoon)	ρ_l	*1.037*	*(g/cm^3)*
(sea)	ρ_s	*1.031*	*(g/cm^3)*
Saturated hydraulic conductivity			
clay	K_s	*0.432*	*(m/d)*
sand,gravel,congromaridge	K_s	*4.32*	*(m/d)*
Porosity	*ne*	*0.47*	-
Residual water content		*0.17*	-
α		*0.5*	*(1/m)*
β		*1.5*	-
Dispersivity			
longitudial	*al*	*10.0*	*(m)*
transversive	*at*	*1.0*	*(m)*

4.4 Plan of simulation

It is expected that the role of the lagoon which has high-concentration salt water on the groundwater flow system of the Seyhan delta will be clear from this simulation. Then, impact of sea-level rise due to the global warming will be examined.

Moreover, infiltration rate is important for grasping present groundwater environment and future prediction. The information about the weather and soil moisture, which were obtained by the primary run of the climate model, will be arranged and used for surface boundary of the groundwater model.

5. References

K. Fujinawa, K. Masuoka, T. Nagano, T. Watanabe: Numerical Simulation Modeling for Salt-Water Intrusion in Predicting Impacts of Sea-Level Rise on areas below Sea-Level, (in contribution)

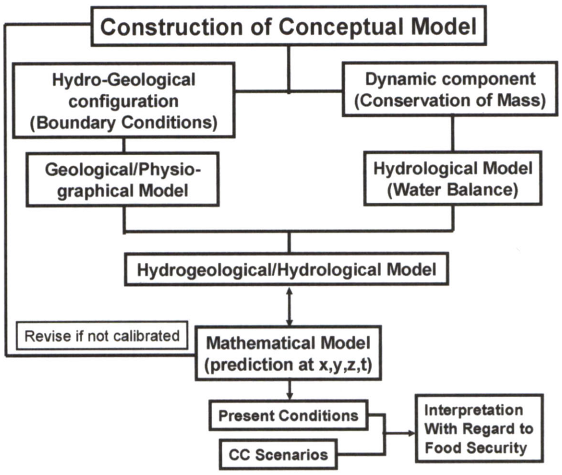

Fig.1 Methodology applied in the study of assessment of vulnerability of water resources system to climate change

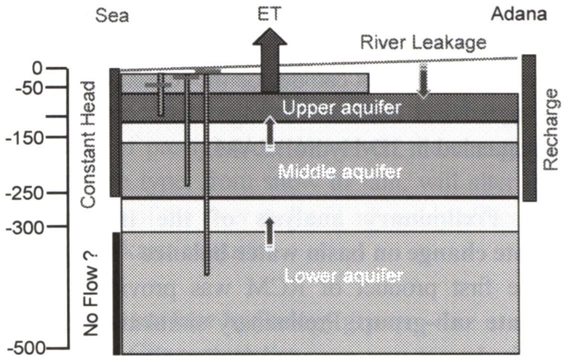

Fig.3 Simplified geological cross-section of the Adana plain conceptualizing the hydrogeological structure

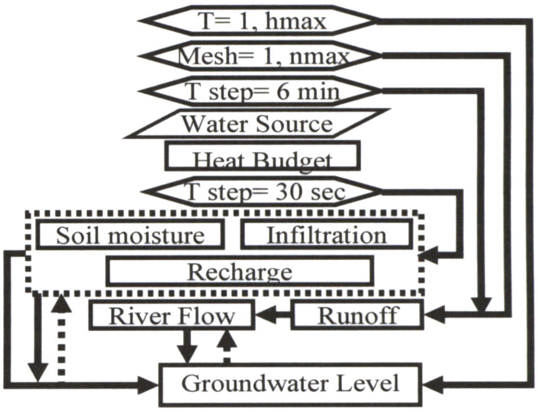

Fig.5 3D-HydroBEAM main algorithm

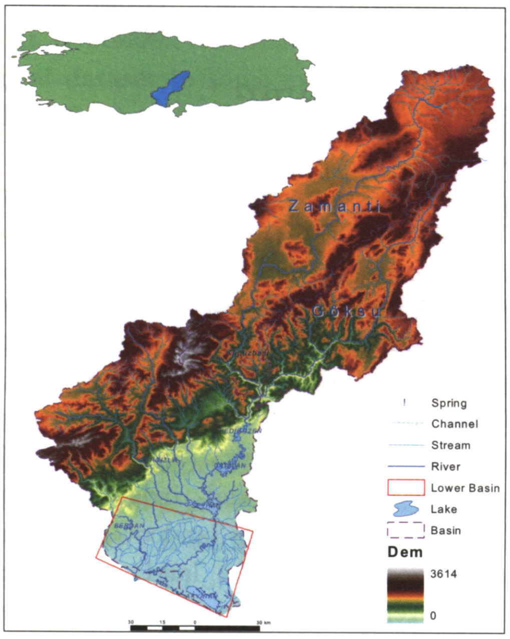

Fig.2 Structure of the Seyhan River Basin

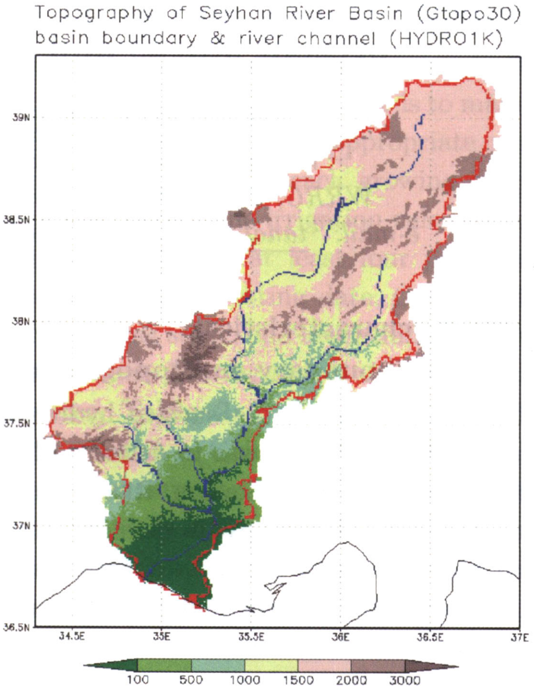

Fig.4 Basin boundary and topography of the Seyhan River Basin

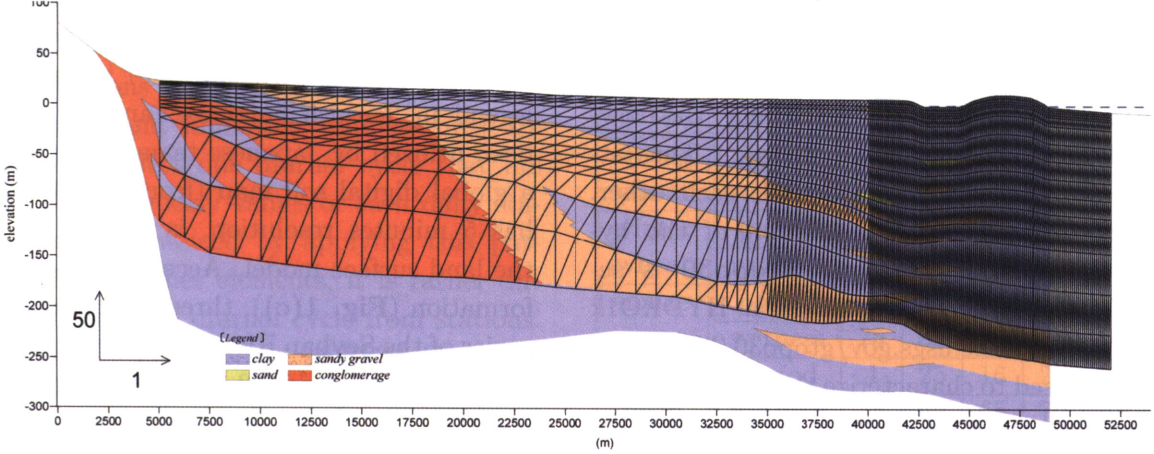

Fig.6 Two dimensional finite element mesh, based on geological profile of Seyhan Delta

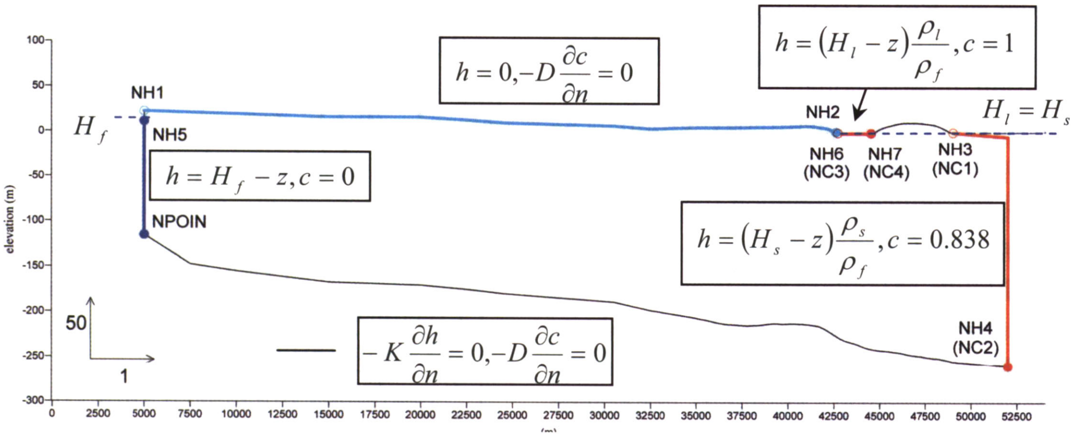

Fig.7 Boundary condition