Inverse Modeling Approach to Assess the Impacts of Climatic Change on the Water Resources Management of the Seyhan River Basin

Yoichi FUJIHARA[1], Slobodan P. SIMONOVIC[2], Fatih TOPALOGLU[3], Tsugihiro WATANABE[4] and Kenji TANAKA[5]

[1, 4]Research Institute for Humanity and Nature, 457-4 Kamigamo-motoyama, Kita-ku, Kyoto 603-8047, JAPAN

[2]University of Western Ontario, London, Ontario N6A 5B9, CANADA

[3]Cukurova University, Adana 01130, TURKEY

[5]Disaster Prevention Research Institute, Kyoto University, Gokasho, Uji 611-0011, JAPAN

e-mail:[1] fujihara@chikyu.ac.jp

1. Introduction

The potential impacts of climatic change on the water resources and hydrology have been received considerable attention from hydrologists during the last several years. Climate change impact is traditionally conducted using a top-down approach. In the top-down approach, outputs from Global Circulation Models (GCM) are statistically or dynamically downscaled to the river basin scale. The local climatic signal is then used as an input into a hydrologic model to assess the direct consequences in the basin.

Problems related to this approach arise from the incompatibility between GCM and river basin temporal and spatial scales. Serious effort is required to validate GCM outputs and the downscaling techniques. As a consequence, many river basin authorities are sceptical regarding the possible impacts of climate change.

This paper summarizes an attempt to improve the understanding of the processes leading to hydrologic hazards by implementing an inverse approach to the modeling of water resources risk and vulnerability to changing climatic conditions in the Seyhan River Basin, Turkey.

2. Method

2.1 Inverse Modeling Approach (IMA)

The inverse impact modeling approach is aimed at assessing the vulnerability of river basin hydrologic processes to climate forcing from a bottom-up perspective (**Figure 1**). The theoretical concepts of the approach are developed at the University of Western Ontario, Canada by Cunderlik and Simonovic (2004; 2005; 2006).The approach consists of the following four steps:

1. Critical hydrologic exposures, which may lead to local failures of water resource systems in a particular river basin, are identified. The identified critical hydrologic

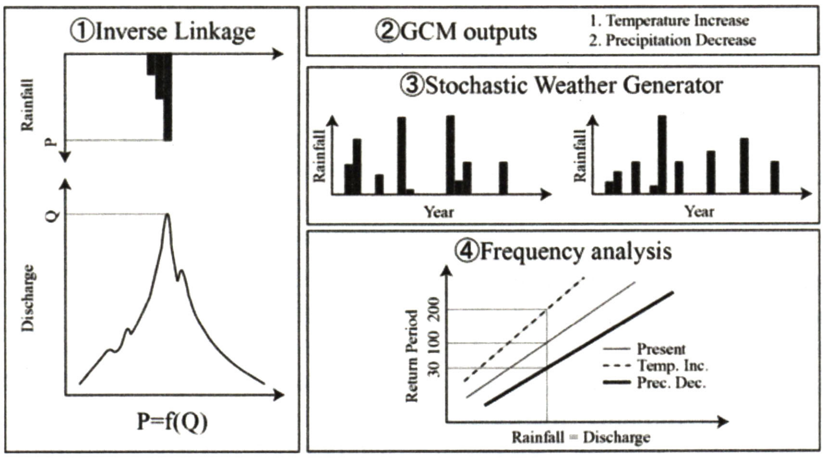

Figure 1 Inverse modeling approach (IMA)

exposures (such as floods and droughts) are transformed into corresponding critical meteorological conditions (e.g. extreme precipitation events, sudden warming, and prolonged dry spells). A hydrologic model is used to establish the inverse link between hydrologic and meteorological processes.

2. GCMs outputs (precipitation and temperature) are analyzed to investigate the future changes relative to present conditions. Some reliable future scenarios such as temperature increase and precipitation decrease are set up, and utilized in the next step instead of using GCMs outputs or downscaled data directly.

3. A stochastic weather generator (WG) is used to simulate the critical meteorological conditions under present and future climatic scenarios. The weather generator produces synthetic weather data that are statistically similar to the observed data. Since the focus is mainly on extreme hydrologic events, the generator reflects not only the mean conditions, but also the statistical properties of extreme meteorological events.

4. In the final stage, the frequency of critical meteorological events causing specific water resources risks is then assessed from the WG outputs.

The main advantages of the inverse approach over the traditional top-down approach are:

・ focus on specific existing water and potential water resource problems,

・ direct link with the end-user,

・ easy updating, when new and improved GCM outputs become available. The proposed approach would deal with critical hydrologic exposures that may lead to local failures of existing ecologic and socio-economic systems under current (or future) basin management practices. In this study, the focus will particularly be on rainfall-driven flood events, which are typical example of hydrologic exposures in most world climates.

2.2 K-nn approach and strategic resampling

Weather generator used in this study is based on the K-nn approach of Yates et al. (2003) as modified by Sharif and Burn (2004; 2006). It uses the Mahalanobis distance metric, which does not require explicit weighting of variables, and standardization of variables. The use of the covariance matrix in the Mahalanobis distance weights the variables with their covariance, which attributes less weight to strongly correlated variables. The algorithm samples the daily weather at the stations within a region simultaneously, and thus preserves the correlation structure between the stations and among variables. The bootstrap resampling retains non-Gaussian features in the probability density functions of the model variables. Finally, the approach can simulate inter-annual and intra-annual climate variability. Technical details of the approach are not repeated here as they are fully described in Yates et al. (2003).

The K-nn algorithm can be used to perform strategic resampling to derive new daily weather data with altered mean or variability. In the strategic resampling, new weather sequences are generated from the historical record based on prescribed conditioning criteria. For a given climatic variable regional periodical deviations are calculated for each year and for each period. A ranked list of years for a particular period can be then generated by sorting the years according to the magnitude of deviations of that period. An index is then assigned to each year in the ranked list based on the relative position of that year in the sorted list. Different years from the ranked list are then selected by means of a general integer function of the form (Yates et al., 2003):

$$f^i_{\Delta t} = Int(n(1 - x^{\gamma^i_{\Delta t}})) + 1 \qquad (1)$$

where $f^i_{\Delta t}$ is the index corresponding to year i and period Δt, x is a uniformly distributed random number, and $\gamma^i_{\Delta t}$ is the shape parameter that can be suitably adjusted to bias certain years over others. If the years in the ranked list are arranged such that the coldest year has an index of 1 and the warmest year has an index of n, then $\gamma^i_{\Delta t} > 1$ would create bias towards the selection of warmer years, $\gamma^i_{\Delta t} < 1$ would create bias towards selection of colder years, and $\gamma^i_{\Delta t} = 1$ would lead to no bias.

3. Study basin and hydrologic model

3.1 The Seyhan River Basin

The Seyhan River Basin (21,700 km^2) is within the range of 34.25E-37.0E and 36.5N-39.25N, and located in the south of Turkey (**Figure 2**). The Seyhan River heads in the Taurus Mountains and discharges into the Mediterranean Sea. The lower basin is dominated by the Mediterranean climate, and the middle and upper basin are influenced by the Continental climate.

The DMI precipitation and minimum and maximum temperature datasets covering between 1972 and 2002 are used to create areal precipitation and temperature using IDM (Inverse Distance Method).

3.2 Hydro-BEAM

The river discharge is simulated by a distributed hydrologic model (Hydro-BEAM; Hydrological river Basin Environment Assessment Model (Kojiri et al., 1998)). The simulation domain is an area of 2.75 degrees × 2.75 degrees (34.25E-37.0E and 36.5N-39.25N) with 5 minutes spatial resolution (33 × 33 grids). Gtopo30 is used as DEM, and the basin boundary and river information, which are created by Turkish collaborate researchers, are used to simulate hydrologic models. Based on ground truth and NDVI time series analysis, the land cover dataset of this study basin is improved and utilized in the numerical simulation.

The simulated hydrographs of the first and last 3 years are shown in **Figure 3** and **Figure 4**, respectively. The river discharge at station 1818 is quite well reproduced by Hydro-BEAM.

4. Results

4.1 Inverse link

The flood of March 1980 was the biggest flood and produced the biggest damage. Therefore, this flood is selected as the representative flood event in the Seyhan River Basin.

The synthetic precipitation data set is made to establish the relationship between the peak discharge and areal precipitation. In this study, the synthetic areal precipitation data (10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 mm/day) is created by multiplying the ratio between observed areal precipitation corresponding to flood event, and synthetic areal precipitation. Hydro-BEAM is run by each synthetic precipitation data set, and the relationship between the peak discharge and areal precipitation is shown in **Figure 5**. The inverse linkage is obtained as follows:

$$P = aQ^2 + bQ + c \qquad (2)$$

where P is the areal precipitation, Q is the peak discharge at station 1818, and a, b and c are parameters.

4.2 GCMs analysis

The GCMs used for this study are 4 state-of-the-art models (**Table 1**) that participated in the most recent phase of the Coupled Model Intercomparison Project (CMIP) and that provided the atmospheric dataset. From the atmospheric dataset, monthly precipitation and monthly mean temperature data under IPCC SRES A2 scenario are collected for each model. Two subset periods (present: 1961-1990 and future: 2070-2099) are set to investigate the temperature and precipitation changes.

The temperature changes of MRI-CGCM2 for the future period (2070-2099) relative to the present period (1961-1990) are shown in **Figure 6**. Although the magnitude of temperature rising and the area where temperature rising is large differ from model to model, all GCMs project the rising of annual temperature at all regions. Average

Table 1 GCMs used in this study

Institution	Model name
Meteorological Research Institute, Japan	MRI-CGCM2.3.2a
Hadley Centre for Climate Prediction, Meteorological Office, UK	HadCM3
Max Planck Institute for Meteorology, Germany	ECHAM5
Canadian Centre for Climate Modelling and Analysis, Canada	CCCMA-CGCM3.1

annual temperature changes for the GCMs grids which cover the Seyhan River Basin are in the range of +3 and +5 degrees C.

Precipitation changes of MRI-CGCM2 for the future period (2070-2099) relative to the present period (1961-1990) are shown in **Figure 7**. Although the magnitude of precipitation changes differ from model to model, it is extremely important to mention here that all GCMs project the decrease of annual precipitation in the Mediterranean region including Turkey. Average annual precipitation changes for the grids which cover the Seyhan River Basin are between -100 and -170 mm.

The increased temperature and decreased precipitation scenarios are set up according to GCMs analysis.

4.3 Results

Strategic resampling was carried out by k-NN to derive the driving data set corresponding to the scenarios (increased temperature and decreased precipitation). The basic statistics are shown in **Table 2**.

Since we selected March 1980 flood event induced by snow melting as representative flood, the precipitation within March is analyzed. The return periods for areal March precipitation are shown in **Figure 8**. The flood with the return period of 200-years under present condition will have about 400-years return period under the decreased precipitation conditions. On the other hand, the flood with the return period of 200-years under present condition will not change under the increased temperature conditions. In summary, under the decreased precipitation scenario the critical flood events may occur less frequently.

Table 2 The results of k-NN

	Prec. (mm)	Temp. (degreesC)
Present	680.2	10.0
Inc T	680.0	10.5
Dec P	607.0	9.9

5. References

Covey, C., K. M. AchutaRao, U. Cubasch, P. Jones, S. J. Lambert, M. E. Mann, T. J. Phillips and K. E. Taylor, 2003: An overview of results from the Coupled Model Intercomparison Project (CMIP), Global and Planetary Change, Vol.37, pp.103-133.

Cunderlik, J.M., and S.P. Simonovic, 2004: Inverse Modeling of Water Resources Risk and Vulnerability to Changing Climatic Conditions, Proceedings, 57th Canadian Water Resources Association Annual Congress: Water and climate change: Knowledge for better adaptation, CWRA.

Cunderlik, J., and S.P. Simonovic, 2005: Hydrologic Extremes in South-western Ontario under future climate projections, Journal of Hydrologic Sciences, 50(4), pp.631-654.

Cunderlik, J., and S.P. Simonovic, 2006: Inverse Flood Risk Modeling Under Changing Climatic Conditions, in print Hydrological Processes Journal.

Kojiri, T., A. Tokai and Y. Kinai, 1998: Assessment of River Basin Environment though Simulation with Water Quality and Quantity, Annuals of Disaster Prevention Research Institute, Kyoto University, No.41 B-2 pp.119-134.

Sharif, M, and D.H. Burn, 2004: Development And Application Of K-Nearest Neighbour Weather Generating Model, Proceedings, 57th Canadian Water Resources Association Annual Congress: Water and climate change: Knowledge for better adaptation, CWRA.

Sharif, M., and D.H. Burn, 2006: Simulating climate change scenarios using an improved k-nearest neighbor model, in print Journal of Hydrology.

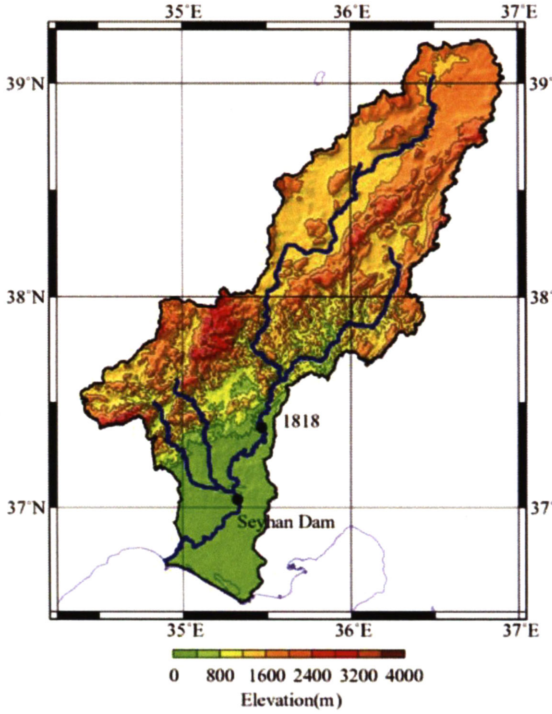

Figure 2 The Seyhan River basin

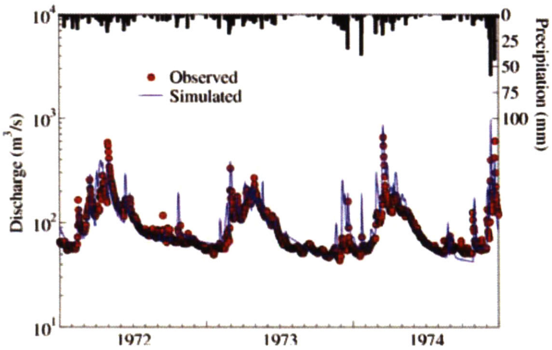

Figure 3 Simulated Hydrograph (1972-1974)

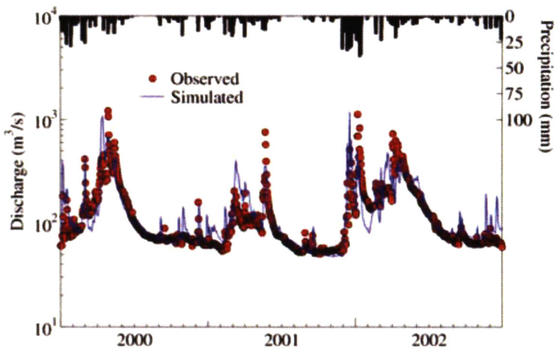

Figure 4 Simulated hydrograph (2000-2002)

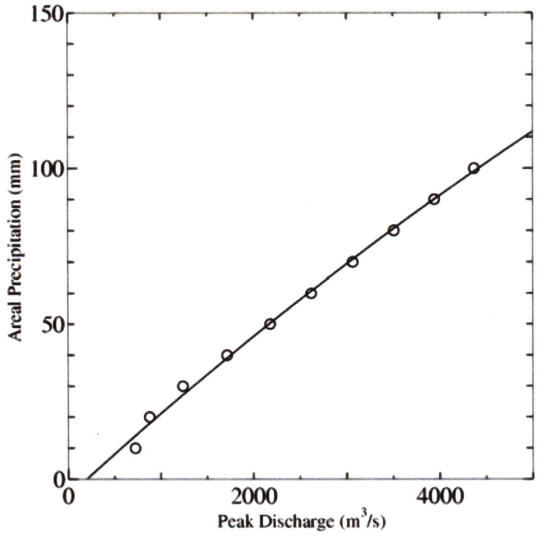

Figure 5 The relationship between the peakdischarge and areal precipitation

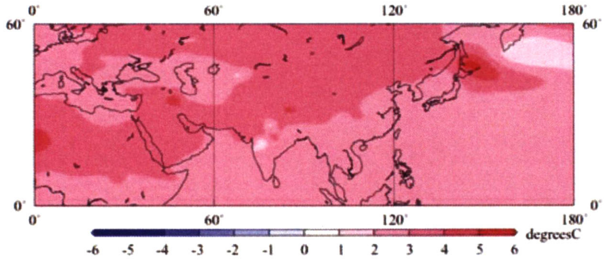

Figure 6 Temperature change

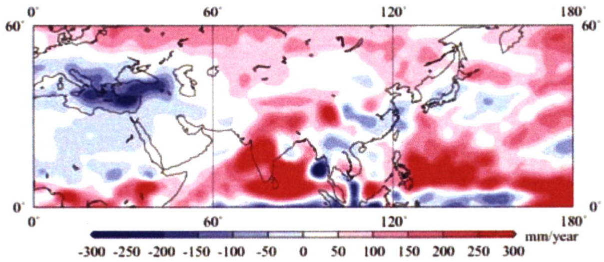

Figure 7 Precipitation change

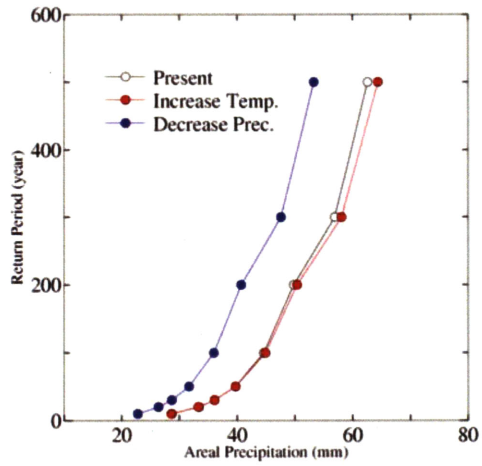

Figure 8 Return periods