Assessing the Impact of Climate Change on the Water Resources of the Seyhan River Basin, Turkey

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1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report concluded that there was evidence that most of the warming observed over the last 50 years is attributable to human activities. With the expected build-up of greenhouse gases in the atmosphere, it is anticipated that the climate will continue to change throughout the 21^{st} century. Moreover, it is thought that global warming will have a significant impact on the hydrology and water resources of river basins.

Basins that have a large fraction of runoff driven by snowmelt, such as the Seyhan River Basin in Turkey, will be especially sensitive to global warming, because the temperature determines the fraction of precipitation that falls as snow and the timing of snowmelt. In this paper, the climate projected using two general circulation models (GCMs) under the Special Report on Emissions Scenarios (SRES) A2 emissions scenario was used to drive hydrologic models to assess the impact of climate change on the water resources of the Seyhan River Basin.

2. Study Basin

The Seyhan River Basin (21,700 km^2) is located in southern Turkey between 34.25-37.0°E and 36.5-39.25°N. The lower basin is dominated by the Mediterranean climate, while the middle and upper basins are influenced by the Continental climate.

The annual precipitation is about 700 mm in the coastal area, increases to approximately 1,000 mm at higher elevations, and decreases to about 400 mm in the northern area. The annual inflow at the Seyhan Dam ranges between 3.7 and 7.3 Gm^3 and averages 5.5 Gm^3. The Seyhan and Catalan Dams have storage capacities of 0.8 and 1.6 Gm^3, respectively. The stored water is used mainly for irrigation. According to the 1990 statistics, the amount of irrigation water used annually is about 1.4 Gm^3, and it is increasing annually (**Figure 1**). The amount of domestic water used annually is 0.1 Gm^3 according to the 2003 statistics.

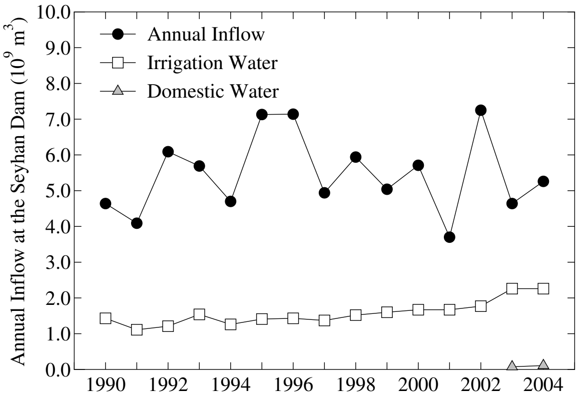
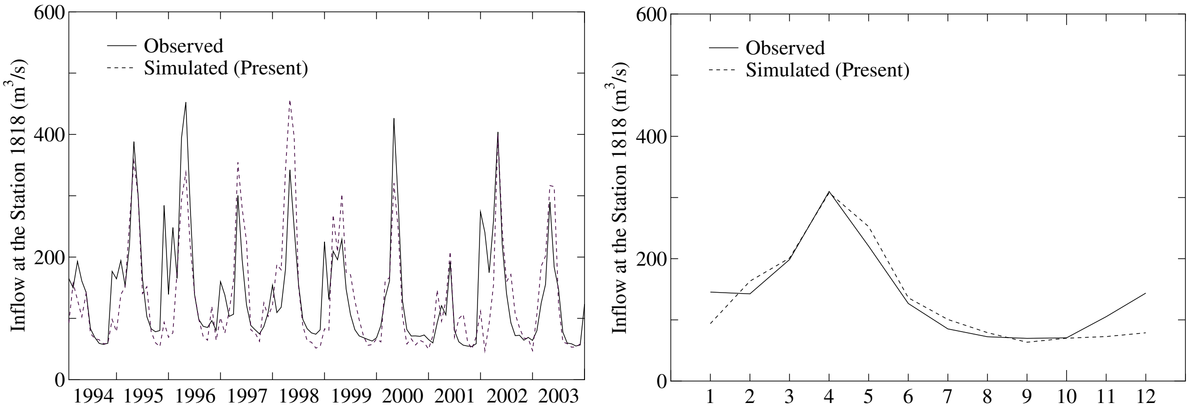


Fig.1 Annual inflow, irrigation water, and domestic water use at the Seyhan Dam.

3. Approach

3.1 Downscaling Method

The raw outputs of GCMs are inadequate for assessing the impact of climate change on the hydrology and water resources of river basins, because the temporal and spatial resolution of GCMs is too coarse compared to those of hydrologic models that are applied to river basins. This study applied a dynamic downscaling method called pseudo warming (Sato *et al.*, 2006) to connect the output of the raw GCMs and river basin hydrologic models.



(a) Monthly inflow (b) 10-year average monthly inflow

Fig.2 Simulated hydrograph at Station 1818.

The pseudo warming downscaling method is as follows. For the current climate simulation, the pseudo-warming method uses reanalysis data as a boundary forcing of the regional climate model (RCM). A specially created boundary condition, in which changes in meteorological variables projected in a GCM simulation are added to reanalysis data, is used to simulate global warming.

The GCMs used in this study were MRI-CGCM2 (Yukimoto *et al.*, 2001) and CCSR/NIES/FRCGC-MIROC (K-1 Model Developers, 2004) under SRES A2. The downscaled data covered two subset periods (the 10 years present and the 10 years future; Kimura *et al.*, 2007), and were used to drive hydrologic models to assess the impact of climate change on the water resources of the Seyhan River Basin.

3.2 Hydrologic Model

We used a land surface model (Simple Biosphere including Urban Canopy (SiBUC); Tanaka and Ikebuchi, 1994) to estimate the surface energy and water balance components. In addition, we used the stream flow rooting model of Hydro-BEAM (Kojiri *et al.*, 1998) to simulate river discharge and incorporated a reservoir model in this flow rooting model.

The region simulated was a 2.75 × 2.75° area (34.25-37.0°E and 36.5-39.25°N) with a 5-minute latitude-longitude spatial resolution (33 × 33 grids). The simulated hydrograph at station 1818 is shown in **Figure 2**. There were some discrepancies between the simulated and observed discharge. Nevertheless, since the input data were downscaled data, the hydrologic models reproduce the river discharge at station 1818. The annual inflow at the Seyhan Dam is shown in **Figure 3**. This figure shows that the simulated results agree with the observed data.

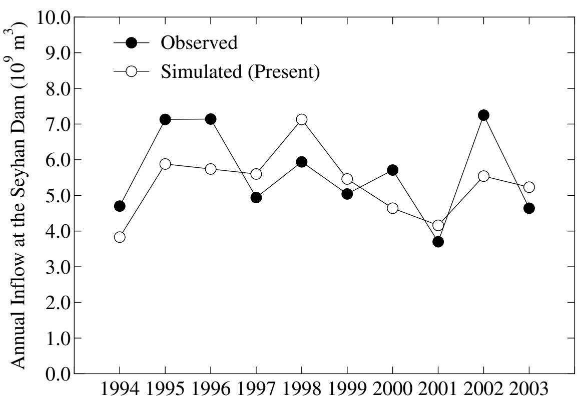
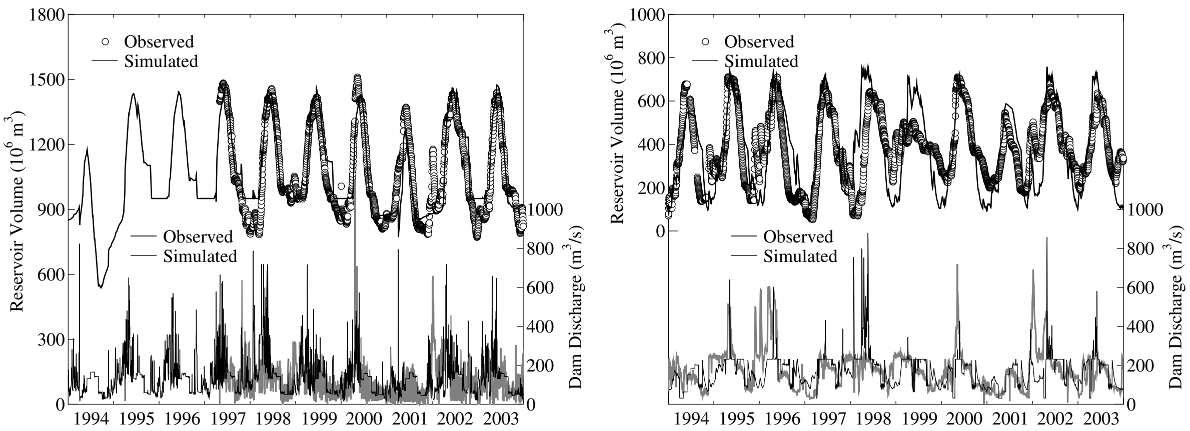


Fig.3 Annual inflow at the Seyhan Dam.

3.3 Reservoir Models

We developed reservoir models to simulate the reservoir operations of the Seyhan and Catalan Dams. We examined the historical record, including the inflow, water level, and dam discharge, and interviewed the dam operators about the actual operations. From these analyses, we used the following operational rule as a basic rule: water is stored to maintain a target operational water level and the demand water is released regardless of the level.

The simulated river discharge using the flow rooting model described in section 3.1 is input into the reservoir models. The target operational wa-



(a) Catalan Dam (b) Seyhan Dam

Fig.4 Simulated reservoir volume and discharge.

ter level is the average of historical operational records, and the demand water is the actual water withdrawal for irrigation and domestic use.

The simulated reservoir volume and dam discharge at the Seyhan and Catalan Dams are shown in **Figure 4**. The simulated volume and discharge agreed with the observed values. Although no results are shown in here, we found that the established reservoir models also reproduced the hydroelectric generation quite well. **Figure 5** shows the simulated inflows with and without the reservoir models. This figure clearly indicates that the reservoir models can reproduce the actual reservoir operations.

3.4 Land and Water Use Scenarios

The land and water use at the present period were the actual conditions in the Seyhan River Basin. For the future period, the following three scenarios were used:

(a) Future: The land and water use are the same as at present.

(b) Adaptation 1: The land and water use are under low investment conditions. The cropping pattern in the Lower Seyhan Irrigation Project (LSIP) simulated by Umetsu *et al.* (2007) is used to estimate the water demand. In addition, the effects of global warming on the irrigation water requirements are considered using the SiBUC simulation.

(c) Adaptation 2: The land and water use are un-

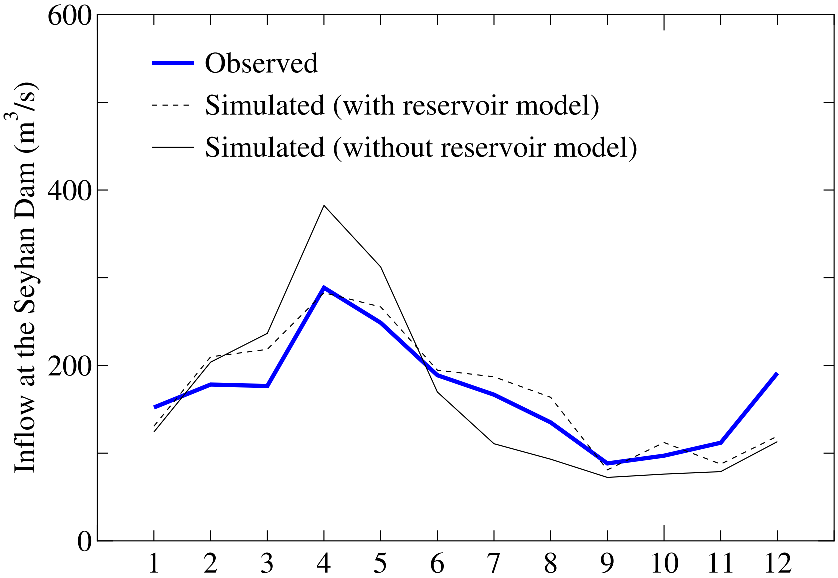


Fig.5 Simulated hydrograph at the Seyhan Dam.

der high investment conditions, in which 25% of the rain-fed winter wheat is converted to irrigated crop, and citrus is cultivated in this area. The cropping pattern in the LSIP simulated by Umetsu *et al.* (2007) is used as a future scenario to calculate the water demand. The effects of global warming on the irrigation water requirements are also considered using the SiBUC simulation.

4. Results

4.1 Temperature, Precipitation and Stream Flow Changes

The monthly mean temperatures are compared in **Figure 6**. The average annual temperature change for the Seyhan River Basin was +2.0°C in the Meteorological Research Institute GCM (MRI) and +2.7°C in the Center for Climate System Research GCM (CCSR). The monthly precipitation is compared in **Figure 7**. The average annual precipitation change for the Seyhan River Basin was -159 mm in MRI and -161 mm in CCSR. The decreases in precipitation in January, April, October, November, and December were greater than in the other months.

The monthly mean inflow at station 1818 is shown in **Figure 8**, which shows that the future inflow will decrease remarkably compared to the present. In addition, the decreases in the April, May, and June inflow are greater than in the other months, and the peak monthly inflow occurs earlier than at present.

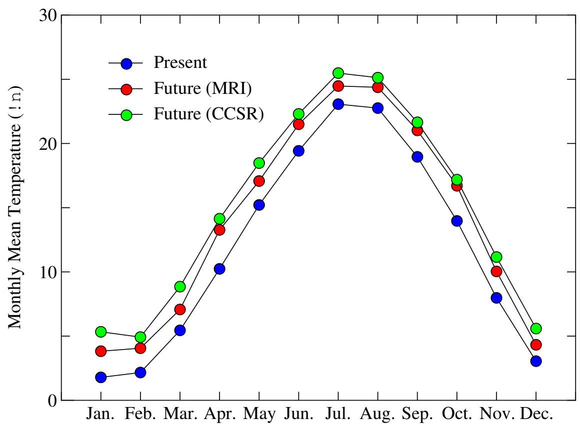


Fig.6 Temperature changes predicted under different models.

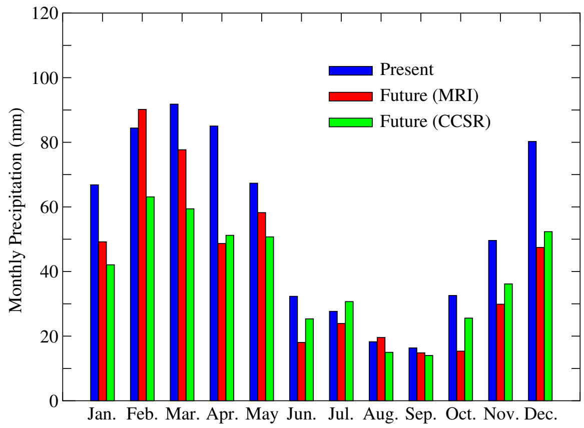


Fig.7 Precipitation changes predicted under different models.

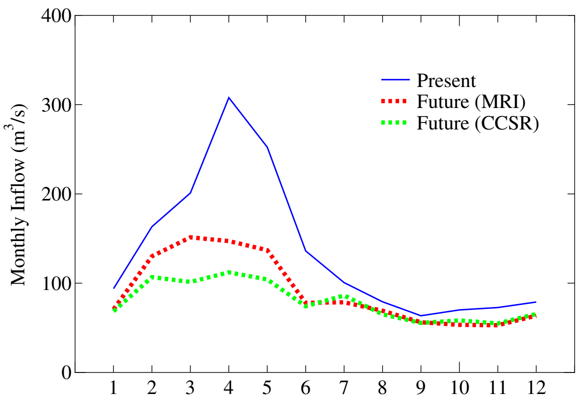


Fig.8 Stream flow changes predicted under different models.

4.2 Water Resources System Effects

The ratio of water withdrawal to discharge is shown in **Figure 9**. Many studies (*e.g.*, Alcamo *et al.*, 2003; Oki and Kanae, 2006) have reported that a region is considered highly water stressed if this index exceeds 0.4. The ratio is less than 0.4 at present, while it ranges from 0.4 to 0.7 in the future period, from 0.4 to 0.6 for Adaptation 1, and from 0.5 to 1.0 for Adaptation 2.

The reservoir volume at the Seyhan Dam is shown in **Figure 10**. The reservoir volume for the future and Adaptation 1 is less than at present, and in a few cases, the reservoir is empty. By contrast, in Adaptation 2, the reservoir is frequently empty.

The reliability of the dams is shown in **Figure 11**. The reliability (R) is defined using the following equation:

$$R = V_s / V_d \tag{1}$$

where V_s is the volume of water supplied, and V_d is the volume of water demanded. The index at

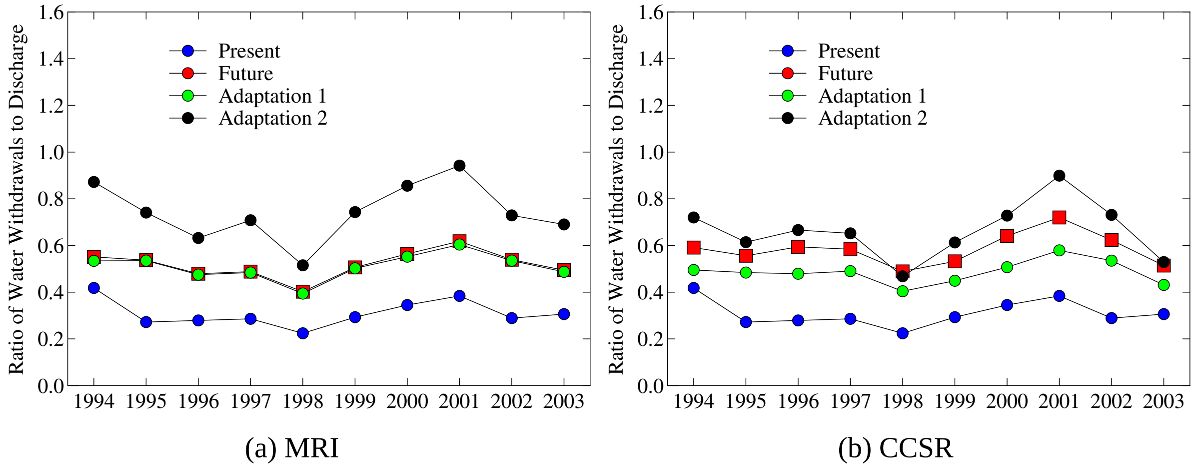


Fig.9 Ratio of water withdrawal to discharge.

present is usually 1. This indicates that the dams can supply the entire demand. The value in the future and for Adaptation 1 is always 1 in MRI and ranges from 1 to 0.95 in CCSR. By contrast, for Adaptation 2, the reliability is from 1 to 0.7 in MRI and CCSR.

These results lead to the following conclusions. Although the ratio of water withdrawal to discharge will increase due to the effects of global warming (decreased discharge), it is possible to supply the demand for water from the water resources system in the future case and Adaptation 1. By contrast, the effects of global warming and the increased demand for water in the upper basin will lead to water scarcity at the LSIP in Adaptation 2.

5. Conclusions

In this study, the climate projected using two GCMs under SRES A2 was used to drive hydrologic models to assess the impact of climate change on the water resources of the Seyhan River Basin. The results showed that:

1. Compared to the present, decreased precipitation will result in a considerably decreased inflow, in which the peak monthly inflow occurs earlier than at present;

2. The ratio of water withdrawal to discharge will increase due to the effects of global warming (decreased discharge), although it is possible to supply the demand for water based on the water resources system in the future and using Adaptation 1; and

3. The effects of global warming and the increased demand for water in the upper basin will lead to water scarcity at the LSIP in the case of Adaptation 2.

Acknowledgments

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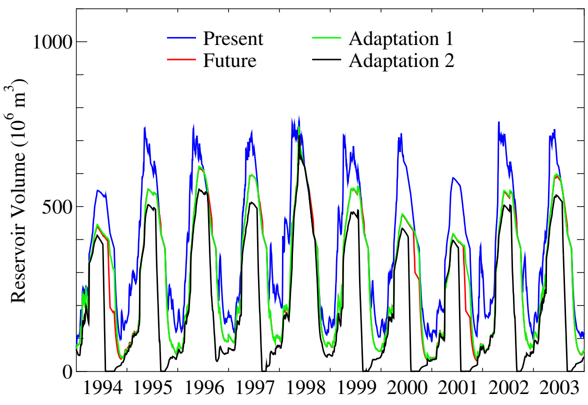
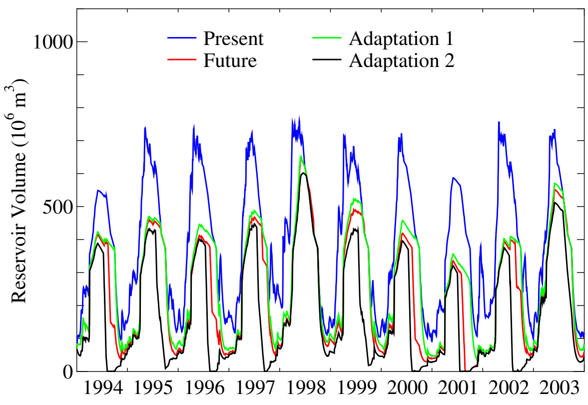
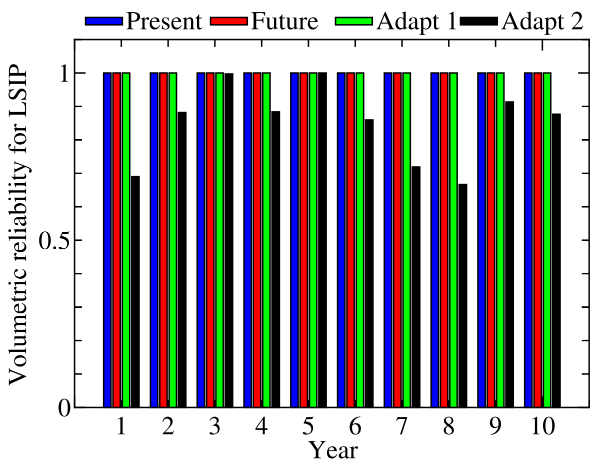


(a) MRI

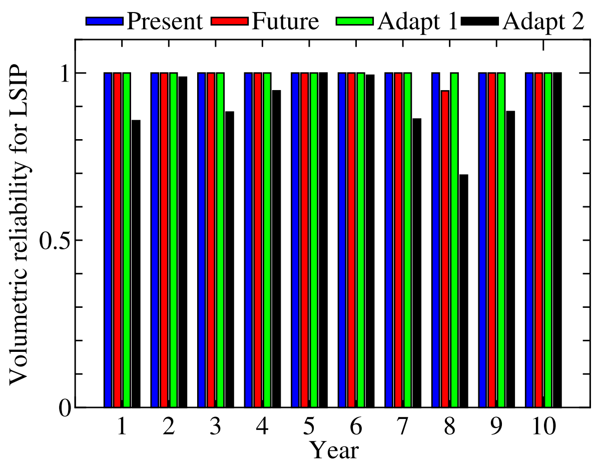


(b) CCSR

Fig.10 Reservoir changes.



(a) MRI



(b) CCSR

Fig.11 Reliability changes.

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