SENSITIVITY OF THE KEUM RIVER BASIN TO CLIMATE CHANGE

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Abstract: This study reports an examination of the sensitivity of water resources in the Keum River basin to climate change. Assuming a doubling in CO_2 concentrations, a cooperative study provided four climate change scenarios for this study, which have been translated into temperature and precipitation scenarios on a basin scale. The study utilized these temperature and precipitation data for each climate change scenario as inputs to the NWS-PC model to generate the corresponding streamflow scenario over the Keum River basin. A reservoir simulation model for the Dae-Chung Dam in the Keum River basin has been developed with an object-oriented simulation environment, STELLA. For each streamflow scenario, the performance of the reservoir was assessed in terms of reliability, resiliency, and vulnerability. Although the simulation results are heavily dependent on the choice of the climate change scenarios, the following conclusions can be clearly concluded: (1) the future streamflow over the Dae-Chung Dam tends to decease during the dry period, which seriously increases competitive water use issues and (2) flood control issues predominate under the $2CO_2$-High case.

Key Words: global warming, climate change scenario, sensitivity analysis, the Keum River basin

1. INTRODUCTION

During the last two decades, the issue of global warming has been the subject of intense political and scientific debate. Recently, however, a general consensus has developed that the global concentration of greenhouse gases has increased, which, in turn, has led to an increase in global average temperature, as assessed by the Intergovernmental Panel on Climate Change (IPCC) in 1996. Of the potential effects of global warming, the implications for water resources are among the most important to society (Lettenmaier et al., 1999). Most of the developed countries have launched their own projects to investigate the climatic sensitivities of not only their hydrology but also the performance of their water resources systems. Seo et al. (2000) and Kim et al. (2000) summarized the ongoing climate change assessment studies and projects for water resources throughout the world and reviewed the current state of modeling techniques for hydrology and water resources which are associated with climate change.

The objective of this paper, therefore, is to examine the potential effects of climate change on a multipurpose reservoir system in Korea where only a limited number of climate change assessment studies have been performed to date. The methodology used in this paper follows a modeling procedure which is in general use in many climate change assessment studies, which (1) generates a climate change scenario on a global scale, using a general circulation model (GCM) under the assumption of a doubling in CO_2 concentrations (denoted $2CO_2$), (2) translates the global-scale climate change scenario into a basin-scale scenario of precipitation and temperature, (3) generates a streamflow scenario by inputting the precipitation and temperature data into a hydrologic model, and (4) finally evaluates the performance of the water resources system under consideration, using a water resources management model under the altered streamflow scenario.

2. THE STUDY SITE AND ITS OPERATIONAL CHARACTERISTICS

Completed in 1981, Dae-Chung Dam is located approximately 150 km upstream from the mouth of the Keum River, which flows in a westerly direction for 401 km, draining 9810 km^2 area of South Korea (Fig. 1). As a multipurpose dam, the Dae-Chung Dam is operated mainly for flood control, water supply (e.g. municipal and industrial use, agricultural use, and downstream flow requirement), and energy

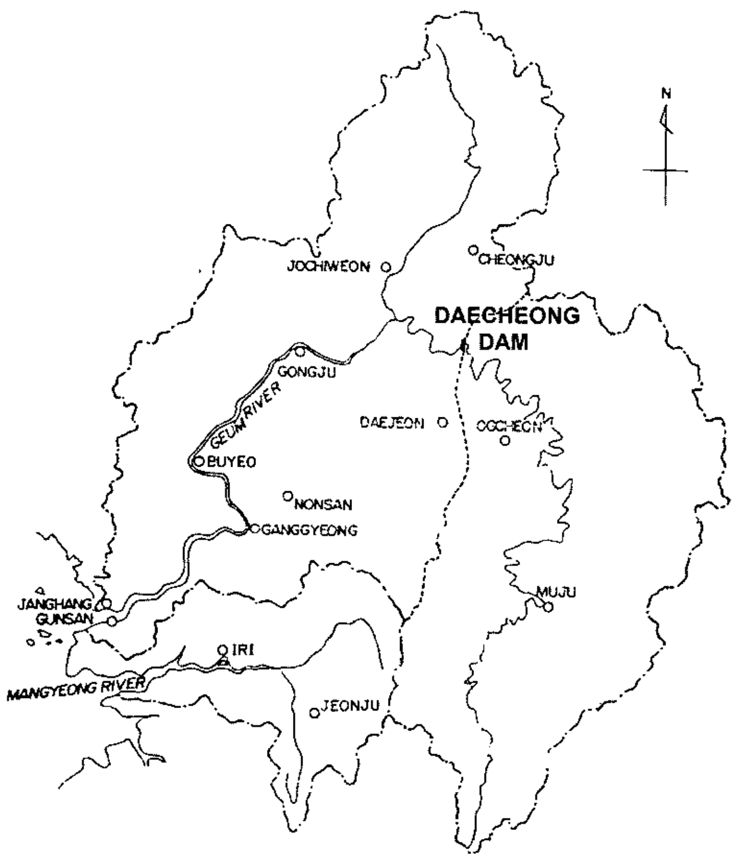

Fig. 1. Location Map of the Dae-Chung Dam in Korea

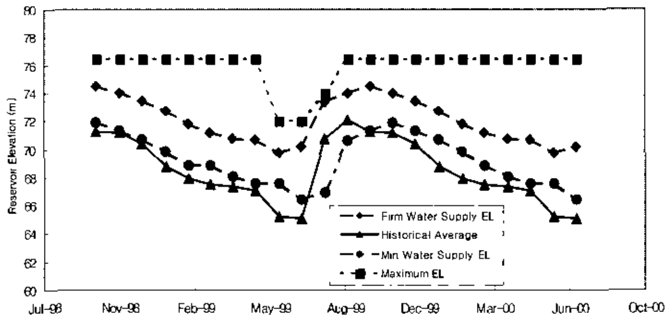

Fig. 2. Monthly Rule Curves for the Dae-Chung Dam

Table 1. Monthly Firm Water Supplies for the Dae-Chung Dam

Objectives / Month	Municipal Requirement	Agricultural Requirement	Total
1	41.2	0.0	41.2
2	41.2	0.0	41.2
3	41.2	0.0	41.2
4	41.2	1.1	42.3
5	41.2	4.8	46.0
6	42.2	47.6	88.8
7	41.2	30.4	71.6
8	41.2	26.5	67.7
9	41.2	22.6	63.8
10	41.2	0	41.2
11	41.2	0	41.2
12	41.2	0	41.2
Average (CMS)	41.2	11.0	52.5
Average (MCM)	1300.0	349.0	1649.0

generation. The monthly operating policy for the Dae-Chung Dam is based on three rule curves: maximum elevation, firm water supply elevation, and minimum water supply elevation (Fig. 2). The maximum elevation is set constant during non-flood months but varies for the flood control purpose during flood months, i.e. July, August, and September. The firm water supply elevation is established in order to guarantee a reliable water supply during the 2-year period from July of a given year and as well as to at least guarantee the minimum elevation in June at the end of the 2-year period, assuming that the dam receives a series of 20-year low flows during the same period. The minimum water supply elevation is established using the same rationale as the firm water supply except that the former is based on 1-year period while the latter is on a 2-year period. Monthly values of the firm water supply are reported in Table 1. A monthly release rule can be constructed based on the location of the actual elevation compared to these three rule curves; (1) The storage that exceeds the maximum elevation escapes through the spillway; (2) If the actual elevation is between the maximum elevation and the firm water supply elevation, then the reservoir releases water, in order to maximize energy generation; (3) If the actual elevation is between the firm and the minimum water supply elevations, then the reservoir first release water to meet the firm water supply and the storage that exceeds the minimum water supply elevation is then additionally released to maximize the energy generation if such additional storage is available; (4) If the actual elevation is below the minimum, then the reservoir first releases sufficient water for the municipal and industrial usefollowed by the agricultural use. The minimum flow is not required at downstream of the Dae-Chung Dam.

3. GENERATION OF STREAMFLOW SCENARIOS

As described in Section 1, generating a streamflow scenario requires downscaling a global-scale climate change scenario to a basin-scale scenario for precipitation and temperature data and then inputting these data to a hydrologic model. The input data of the basin-scale precipitation and temperature for the Dae-Chung Dam basin were provided by a cooperative study which have been conducted in conjunction with this study. The cooperative study utilized GCM results for the Korean Peninsula, produced by the KAIST (1995) and Kang (1993). The KAIST study reported

approximately a -5 ~ 13% increase in the annual precipitation and -30 ~ 50% increase in the monthly precipitation while Kang reported a minimum of 2.7°C and a maximum of 4.7°C in the seasonal temperature. The GCM results of both studies were based on five GCM models as listed Tables 2 and 3 and thus the cooperative study considered the maximum, average, and minimum of such five GCM results as the $2CO_2$-High, $2CO_2$-Average, and $2CO_2$-Low scenarios, respectively, for each month. In addition to these three climate change scenarios, the cooperative study also considered the 'Base' scenario where the present level of CO_2 concentration is assumed to be maintained throughout the simulation period. From each of the global-scale scenarios, a basin-scale scenario with respect to precipitation and temperature has been simulated using an approach similar to that proposed by Richardson (1981). For details, see

Table 2. Monthly Precipitation Change (%) Generated From Various GCMs for the Korean Peninsula Under $2CO_2$ (KAIST, 1995)

GCM / Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual
GFDL-R30	+10	+10	0	+10	0	-10	0	+20	+70	+20	+20	+30	+13
CCC	-30	-40	-10	0	0	+20	+20	0	+50	+40	-30	-30	+4
GISS	0	+10	+10	+20	+40	-30	-10	+20	+20	0	-10	+20	+6
UKMO	0	+10	-20	+30	-20	-20	+50	-20	+20	-10	-10	+10	-1
GFDL	0	-10	+10	-10	+20	-20	+10	0	-10	-20	0	0	-6
Mean (Min-Max)	-4 (-30-+10)	-4 (-40-+10)	-2 (-20-+10)	+10 (-10-+30)	+8 (-20-+40)	-12 (-30-+20)	+14 (-10-+50)	+4 (-20-+20)	+30 (-10-+70)	+6 (-20-+40)	-6 (-30-+20)	+6 (-30-+30)	+3 (-6-+13)

Table 3. Monthly Temperature Change (°C) Generated From Various GCMs for the Korean Peninsula Under $2CO_2$ (Kang, 1993)

GCM \ Season	Spring	Summer	Fall	Winter	Annual
CCC	4.2	4.5	3.7	3.1	3.9
GISS	3.5	3.5	3.0	2.7	3.2
UI	4.3	4.4	4.9	4.7	4.6
GFDL	4.8	3.6	4.3	4.7	4.3
Mean (Min-Max)	4.2 (3.5-4.8)	4.0 (3.5-4.5)	4.0 (3.0-4.9)	3.8 (2.7-4.7)	4.0 (3.2-4.6)

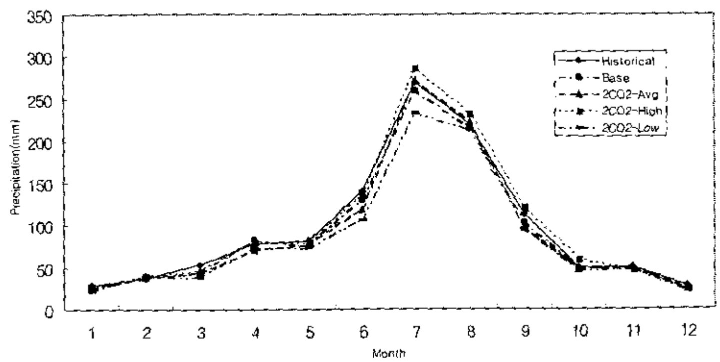

Fig. 3. Monthly Precipitation Scenarios for the Dae-Chung Dam Basin Under $2CO_2$

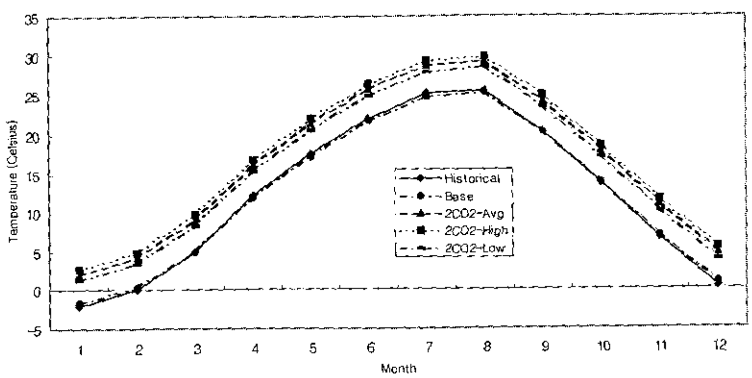

Fig. 4. Monthly Temperature Scenarios for Dae-Chung Dam Basin Under $2CO_2$

Yoo et al. (2000). As the results of the cooperative study, daily precipitation and temperature data for a 100 year period are available at 11 precipitation and 3 temperature gauge stations, respectively, over the Dae-Chung Dam basin. Figs. 3 and 4 show the values for monthly precipitation and temperature for the Dae-Chung Dam basin, aggregated from the corresponding daily data. As expected, the Base scenario correlates well with the historical series in both figures. In other words, the historical series confirms the reliability of the basin-scale simulation. Note that the historical and the Base scenarios for temperature are consistently lower than all the other $2CO_2$ scenarios in Fig. 4 while the rank of the five temperature scenarios varies from month to month in Fig. 3. Such an inconsistency in the basin-scale precipitation change also has been reported for 6 US river basin studies performed, as reported by Lettenmaier et al. (1999).

To generate the streamflow scenarios, this study employs the NWS-PC model as a hydrologic model. The NWS-PC, a PC version of NWSRFS (National Weather Service River Forecasting System) developed by National Weather Service, consists of soil moisture and flow routing components. The soil moisture component uses the SAC-SMA (Sacramento Soil Moisture Account) model and the flow routing component uses the kinematic wave and Muskingum methods in the HEC-1 model. The input data are the average precipitation calculated by the Thiessen method, over 11 precipitation gage stations, the average temperature over 3 meteorological gage stations, and the average evaporation estimated by the Penman method as the input data to the model.

The modeling basin area covers the Dae-Chung Dam, Ok-Chun, and Yong-Darm, which is divided into 3 SAC-SMA groups, 11 runoff sub-basins and 2 channel routing zones. Using such input data and the geographical configuration, the NWS-PC model runs for 100 years to simulate the daily streamflow data under the prescribed climate change scenarios. Table 4 and Figs. 5 show the resultant monthly streamflow scenarios for the Dae-Chung Dam basin. Although the annual means of the historical and the Base scenarios are similar in Table 4, the monthly pattern of two scenarios are quite different in some periods (Fig. 5). This seems to be due to the fact that the historical

Table 4. Monthly Streamflow Scenarios (MCM) for the Dae-Chung Dam Basin Under $2CO_2$

Month \ Scenarios	Base	$2CO_2$-Avg	$2CO_2$-High	$2CO_2$-Low	Historical
1	52.69	44.22	45.95	45.43	38.00
2	68.87	72.76	70.70	65.73	68.52
3	116.52	78.18	70.97	70.52	58.51
4	133.27	172.77	151.66	120.07	134.20
5	146.06	134.17	132.24	125.79	119.98
6	176.19	295.59	292.27	244.19	199.77
7	724.83	744.70	818.76	776.80	644.62
8	625.45	656.18	716.31	673.72	620.63
9	353.70	318.84	375.18	281.64	281.17
10	99.97	125.34	166.73	112.59	112.46
11	74.73	105.06	98.04	100.77	86.44
12	63.39	42.66	48.66	47.82	45.84
Average Annual Sum	2790.47	2665.06	2987.45	2410.15	2635.68

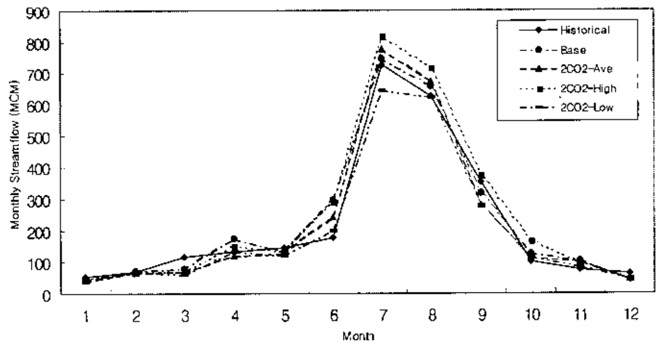

Fig. 5. Monthly Streamflow Scenarios (MCM) for the Dae-Chung Dam Basin Under $2CO_2$

streamflow series is the average of only an 18-year period of observations while the other scenarios are based on a 100-year simulation period. Although the Base case simulation cannot be verified with the historical series, this study assumes that the Base scenario of streamflow is used as a baseline. Table 4 and Figure 5 show that the Base scenario is greater than or compatible with the $2CO_2$-High in all months except for the period from July to October. In other words, under a $2CO_2$ condition, the future streamflow tends to decrease in the dry season, which can seriously threaten our water supply system. During the flood season, however, the differences between the scenarios are large, especially in July, so the future remains relatively unpredictable.

4. THE SENSITIVITY OF THE DAE-CHUNG DAM OPERATIONS

The performance of a water resources system can be evaluated in two types of system performance metrics (Lettenmaier et al., 1999): absolute and relative metrics. In this study, energy generation is evaluated in absolute metrics while the other objectives are evaluated in relative metrics. Relative metrics are represented by reliability, resiliency, and vulnerability which has been proposed by Hashimoto et al. (1982). Reliability is defined as the percentage of time that the system operates without failure, i.e. the number of successful periods divided by the total number of simulation periods. Resiliency is defined as the ability of the system to recover from a failure, i.e. total time in a failure mode divided by the number of times the system went into failure. Vulnerability is defined as the average magnitude of the failures.

In this study, a simulation model is developed using an object-oriented simulation environment, called STELLA (Fig. 6). Object oriented environments are not based on traditional procedural coding such as in FORTRAN, but rather are based upon the graphical manipulation of objects or icons that have specific characteristics and can perform specific functions (Palmer et al., 1993). Among several object-oriented softwares, STELLA offers a particularly elegant environment when it applies to complex systems using four basic icons: stocks, flows, converters, and connectors. These basic icons can be used to represent water resource components such as reservoirs, rivers, economic impacts, or functional relationships (Palmer et al., 1993).

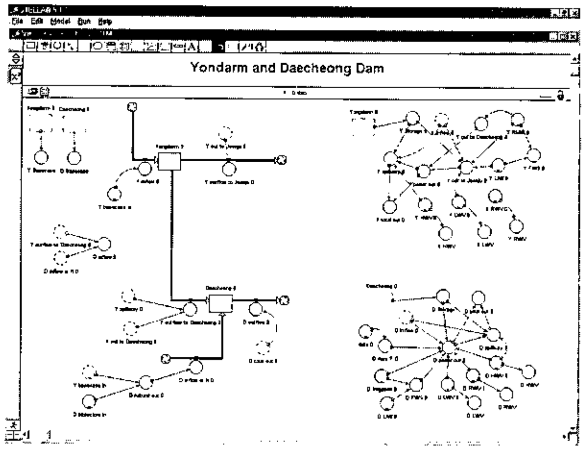

Fig. 6. Overview of the STELLA Simulation Model for the Dae-Chung Dam

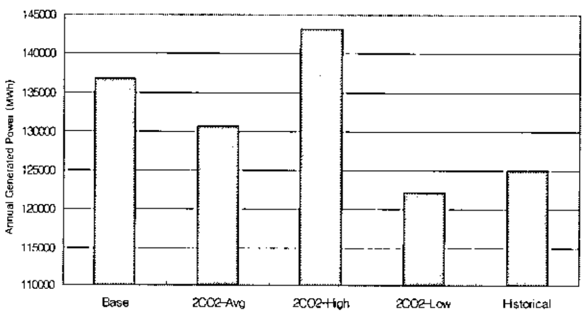

Fig. 7. Annual Average Energy Generation from the Dae-Chung Dam Under $2CO_2$

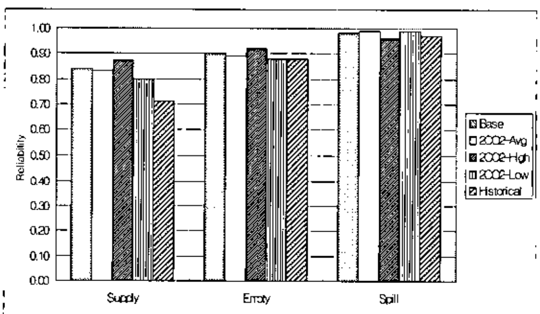

Fig.8 . Reliability at the Dae-Chung Dam Under $2CO_2$

Assuming that the current operating rule for the Dae-Chung Dam (as described in Section 2) remains the same under the $2CO_2$ conditions, the simulation model runs for 100 years and calculates the performance metrics for each of the four streamflow scenarios as well as for the historical series.

Fig. 7 compares energy generation while Figs. 8, 9, and 10 present figures on reliability, resiliency, and vulnerability, respectively. In these

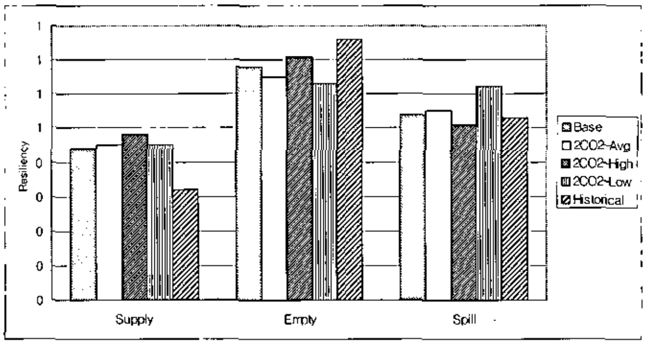

Fig. 9. Resiliency at the Dae-Chung Dam Under $2CO_2$

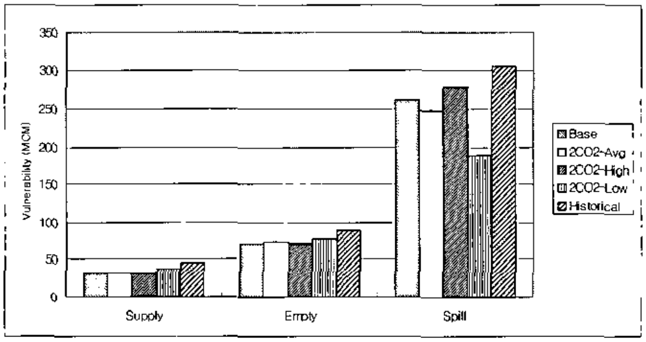

Fig. 10. Vulnerability at the Dae-Chung Dam Under $2CO_2$

figures, the 'Supply' represents the objective for meeting the firm water supply, the 'Empty' for meeting the minimum water supply elevation, and the 'Spill' for maintaining the maximum elevation. The maximum elevation and the minimum water supply elevation are shown in Fig. 2.

As emphasized previously, the $2CO_2$ cases should be compared with the Base case rather than the historical case because the historical is based on only an 18-year record. On the whole, the $2CO_2$-High case performs better for the 'Supply' and 'Empty' objectives than the Base case while the $2CO_2$-High case performs worse for the 'Spill' objective than the Base case. This is because the $2CO_2$-High is the wettest scenario among the climate change scenarios, as shown Table 4 and Fig. 5. In other words, an increased water availability improves the water supply and hydropower generation but results in increased flood potential due to higher reservoir elevations throughout the year at the Dae-Chung Dam. Figs. 8, 9, and 10 also show the reliability is the least sensitive to the scenario choice among the three relative performance metrics.

5. CONCLUSIONS

This study reports an examinations of the sensitivity of water resources in the Keum River basin to climate change, emphasizing water management issues. Although the simulation results are heavily dependent on the choice of the climate change scenarios, the following conclusions can be clearly concluded: (1) the future streamflow over the Dae-Chung Dam tends to decease during the dry period, which seriously increases competitive water use issues and (2) flood control issues predominate under the $2CO_2$-High case.

It must be emphasized that these assessments are preliminary. Since such a long-term streamflow projection is highly dependent on the quality of GCM simulations and downscaling techniques, these preliminary results should be updated as better modeling techniques and new observations concerning the global warming appear. Even if water resource planners and managers cannot alter their current planning and operating policies in the near future, they should gear adaptation strategies towards the development of techniques to incorporate climate change uncertainty into long-term planning and management.

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