MULTIPLE DAM RESERVOIR OPERATION FOR WTER RESOURCES MANAGEMENT UNDER CLIMATE CHANGE

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ABSTRACT

For a climate change impact analysis on the Tone River Basin, Japan, a distributed hydrologic model was composed and dam reservoir operation rules were evaluated using an object-oriented hydrologic modeling system. The upper part of the Tone River (8772.2 km^2) is the main water source of the metropolitan Tokyo, and the upstream of the basin is in snow-dominated regions with 7 multi-purpose dam reservoirs. According to the simulation results, seasonal pattern of the future dam inflow will be largely changed due to the shifted snowmelt season and its amount. Using the current dam reservoir operation rules, it was able to control the outflow as the current release pattern, and successfully meet the current water demand at the upstream of the basin. However, at the downstream of the subject basin, more frequent failure of water supply was found in the future. Revising the reservoir operation rules is necessary to provide stable water supply under the changed river flow regimes of future.

1 INTRODUCTION

In areas dominated by snow, seasonal variations in water resources due to climate change become more apparent. A warmer world means less snowfall in winter and earlier snow melting in spring, shifting much surface runoff to earlier seasons (Mote et al., 2005; Dettinger et al., 2004). Adam et al. (2009) showed that decreased snowpack produces decreases in warm season runoff in many mid to high latitude areas according to their global scale investigation. The magnitude of the climate change impact depends on the characteristics of the river basin (e.g. Nijssen et al., 2001), and thus there have been many regionalized climate change impact study so far.

Future water supply conditions, especially for fresh water, are difficult to assess not only because of uncertain changes in climate condition but also because of rapid and uncertain changes in society (Vorosmarty et al., 2000). As the urban population increases, fresh water must be drawn increasingly from distant watersheds as local surface and groundwater sources cease to meet water demand for water or become depleted or polluted. Obtaining additional water resources invariably requires time to prepare required equipments and facilities, and rapidly changing climatic and environmental conditions demand that urban and national water supply conditions be monitored regularly and comprehensively.

Heavily populated Tokyo Metropolitan should not be an exception. Despite Japan's abundant average annual precipitation of 1,690 mm/year (MLIT, 2007), that is over twice the global average of 807 mm/year, the water supply's seasonal nature and Japan's high population density prevent the water supply from being sustainable. The main objective of this study is to assess the possible climate change impact on the Tone River basin using the output of a super-high resolution atmospheric model having 20-km spatial resolution and 1-hr time resolution.

2 MODEL DESCRIPTION

2.1 MRI-AM20km

In 2007, Japan's Ministry of Education, Culture, Sports, Science, and Technology (MEXT) launched the Innovative Program of Climate Change Projection for the 21st Century (Kaku-shin21), and has developed MRI-AM20km, a very-high- resolution atmospheric model having 20-km spatial and 1-hour temporal resolution (Kitho et al., 2009). Due to the spatial scale of frontal rain bands and the difficulty of simulating physical tropical cyclone behavior using conventional GCMs, a high-spatial-resolution model was required to simulate extreme precipitation more accurately and to project trends based on climate change. Through several test simulations, MRI-AM20km showed advantages in simulating orographic rainfall and frontal rain bands (Mizuta et al., 2006; Kitoh and Kusunoki, 2007).

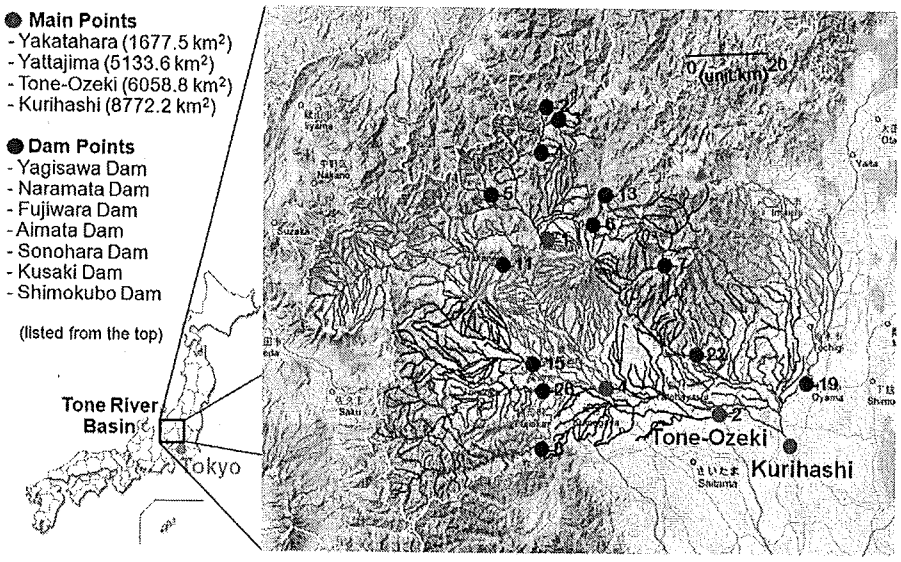
MRI-AM20km uses the HadISST1 dataset (Rayner et al., 2003) as observed monthly mean climatologic sea surface temperature (SST) for a boundary condition of controlled simulation. SST projected for simulation was estimated from the ensemble mean of GCM simulation output under the A1B emission scenario (Nakicenovic et al., 2000) from the model output of the Coupled Model Inter-comparison Project Phase 3 (CMIP3). The ensemble mean of SST for MRI-AM20km projection simulation was additionally composed with an annual variation of the current HadISST1 SST to make the estimation more realistic. Refer to Mizuta et al. (2006) and Kitoh and Kusunoki (2007) for details on MRI-AM20km and Kusunoki and Mizuta (2008) for simulation environment details.

Hydrologic data from the MRI-AM20km are mainly rainfall, snowfall, evaporation and transpiration values that are for the distributed hydrologic model input data for long-term simulations. The model provides present (1979-2003) and future (2075-2099) climate scenarios, and these two data sets were analyzed to investigate whether there will be any considerable changes in water resource.

2.2 Distributed Hydrologic Model

To investigate the hydrologic impacts of climate change on the Tone River basin (see Figure 1), a distributed hydrologic model was composed with an object-oriented hydrologic modeling system, OHyMoS (Takasao et al. 1996; Ichikawa et al. 2000). OHyMoS enables user to easily build any complex hydrologic system by connecting a number of element models, such as catchment rainfall-runoff simulation model, channel routing model, dam reservoir operating simulation model. One of the main elements for the rainfall-runoff simulation is kinematic wave model of Takasao and Shiiba (1988) and Tachikawa et al. (2004). The kinematic wave model utilized in the OHyMoS is for overland flow and channel routing simulation as well. Dam element model is also included in the system to simulate dam reservoir operation with decision making processes of the dam operator.

The developed hydrologic model was calibrated manually using the observed data of rain-fall and daily inflow into each sub-basin in the Tone River basin using the summer season (July~ October) data of five years (1994~1998). The rainfall data was prepared using the AMeDAS data, and a monthly uniform evaporation amount was estimated from the observed data. There are five parameters to be optimized in the model and they are roughness coefficient n, soil depths ds, dc, hydraulic conductivities ka and kc, which determine the velocity of saturated and unsaturated subsurface flow, respectively.



Figue 1. Basin map of the Tone River Basin, upper Kurihashi gauging station (8,772km^2)

2.3 Dam Reservoir Operation Model

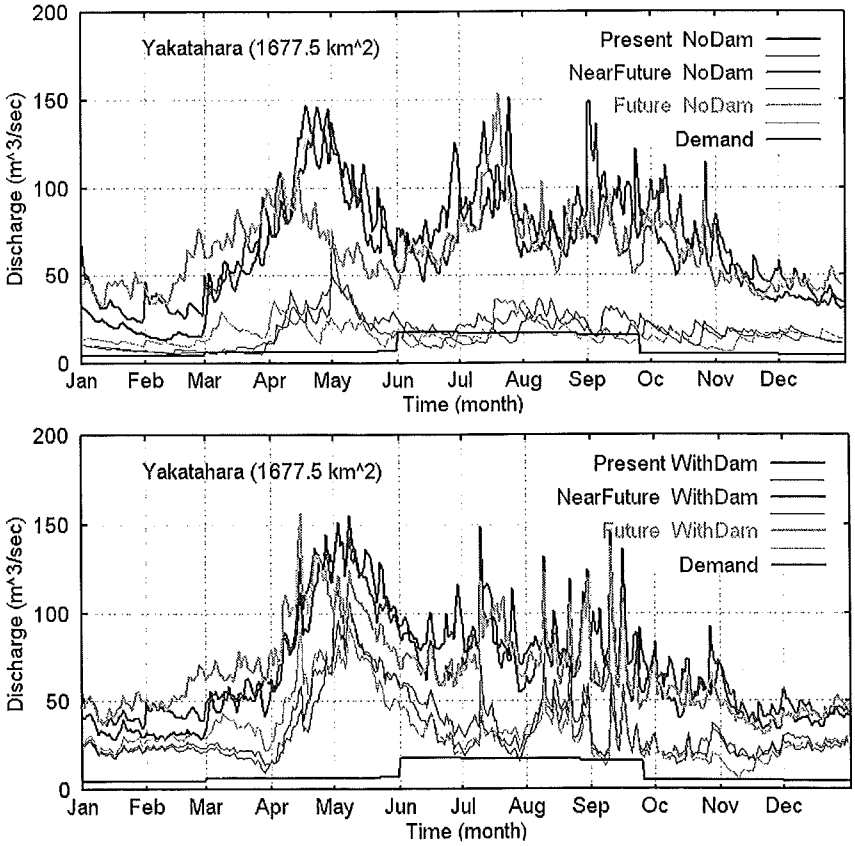
There are 7 dam reservoirs to control water resource in the basin, and every reservoir has an optimized operation rule to maximize its own function. This dam reservoir operation function is also considered in the developed hydrologic model. To understand the dam reservoir operating pattern, observed daily water level, inflow and outflow of ten years (1994~2003) were prepared from the dam database of the Ministry of Land, Infrastructure and Transport (MLIT), Japan.

In this study, a simple but very effective dam reservoir operation model was adopted, which is mainly for long-term reservoir operations focusing on water resources management. The main rules in this reservoir operation is to reproduce the given dam outflow, which is the averaged historical outflow. This 10-year of average outflow becomes the standard outflow in the reservoir operation model of this study.

The regulation rules to reproduce the given outflow are as follow: (1) if water level is between the minimum water line and the surcharge water line, store the inflow and release the target outflow, (2) if water level reaches to the surcharge water line, release the target outflow and inflow as well, (3) if water level is lower than the minimum water line, no outflow is allowed until the water level is getting higher than the minimum water line, and (4) the relationship of the water level and the reservoir volume is following the H-V relationship of the subject dam. In the previous study (Kim et al., 2009) testing this dam reservoir operating simulation showed effective application of this method in-to the study to check the long-term water resources management.

3 RESULTS AND DISCUSSION

With the same method to the Yagisawa Dam reservoir operation modelling by Kim et al (2009), the other dam reservoirs' operation was also carried out. The simulation results present successful water release control for the most dam reservoirs. Even though the dam inflow seasonal pattern would be changed largely due to the shifted snowmelt season and amount, through the proper reservoir operation it is able to control the reservoir outflow same to the current outflow pattern. In other word, reproducing current dam release pattern is able to realize even in the future. In this case, however, the water level regulations should be revised, and the shortage of the reservoir water in summer season should be carefully considered.



Figue 2. Simulated annual discharge pattern of present, near future and future without dam reservoir operations (left) and with the dam reservoir operations (right) at the Yakatahara station.

The effect of the controlled dam outflow was also checked at the downstream of the dam reservoirs. First of all, the annual discharge pattern at the Yakatahara gauging station was evaluated and presented in Figure 2. From the Figure , it is able to see the changed flow pattern of future was regulated through the designed dam reservoir operation, and the future flow pattern get close to the present flow pattern at the Yakatahara station (1677.5 km^2). From the simulation result that does not

consider dam reservoir operations, it was able to see that the annual runoff pattern at the Yakatahara will be changed in the future especially in spring season (February to May) mainly due to the shifted snowmelt season. This shifted snowmelt river flow, however, was able to be delayed and can be closed to the current runoff pattern as shown in the hydrograph of Figure 2 (down). This means that the current water usage pattern can be sustained up to certain level even under the changed climate condition of future.

4 SUMMARY

This study shows comprehensive hydrologic impact analysis on the Tone River basin under climate change condition using the MRI-AM20KM output and rainfall-runoff simulation through a distributed hydrologic model. The impact of climate change on the Tone River basin water resource should be viewed as a complex interaction between the natural systems. In the previous study (Kim et al., 2010), simulated discharge was evaluated using the observed river discharge data of each sub-basin in the study area. Simulations including dam reservoir operation present successful water release control for the most dam reservoirs. Even though the dam inflow seasonal pattern would be largely changed due to the shifted snowmelt season and amount, through the proper reservoir operation it is able to control the reservoir outflow same to the current outflow pat-tern even in the future. In this case, however, the water level regulations should be revised, and the shortage of the reservoir water in summer season should be carefully considered.

Water usage pattern in the future would not be the same to the current one. Many social factors, such as population, agricultural and industrial conditions, and land usage type would be changed in the future. Because of these changed social factors in the future, desirable water demand would be different to the current one. To investigate climate change impact on the water resources more comprehensively, it is necessary to consider these kinds of possible social factors changes and reliable water demand scenarios in the subject basin.

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