THE IMPACT OF WATER PROJECTS ON RIVER HYDROLOGY

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ABSTRACT

Water project construction such as dams is one of the major activities in basin development and utilization. The reservoirs are usually located in the headstream with large storage capacity for main function of water storage, water supply and flood control. The impact of water projects on river hydrology, surrounding environment and ecology are important topics in river basin management and environmental protection.

Through this research, the model has shown to be able to simulate the hydrological process in Kase River basin. The existences of Hokuzan dam reservoir and Kase River dam reservoir in this area resulted in reductions in annual and peak stream flow rates in the watershed because of the storage of dams. Wide surface areas of reservoirs can evaporate higher than natural channels. These dams seem to result in decrease of average annual discharge by 3.68 % from only Hokuzan dam scenario, and decrease 4.49 % from the no dam scenario.

A developed management tool for water resources seems to be a new approach to water environment improvement in Kase River basin. Integrated water management of Kase River basin including management of multiple dam's reservoir shows possibility for satisfaction of water quantity demand both in the irrigation period and non irrigation period. This integrated water management also gives feasibility for water supply to prevent eutrophication at the creek network downstream.

This research will be a useful step for the future integrated basin management and expected as the foundation for the sustainable development of Saga City in the future.

Keywords: Water project, river hydrology

INTRODUCTION

Kase River Basin in Saga Prefecture is currently facing a large scale environmental change. A new multi-purpose Kase River Dam has been constructed sequentially with an agricultural dam already built in the previous by MAFF (Ministry of Agriculture, Forestry and Fisheries) Japan. Forest and agricultural areas have been changed from artificial coniferous forest and rice field to water area.

Estimating the impact of water resources project such as dam to hydrological flow is one of the most important topics in a river basin management. (Yang et al. 2008; Horne et al. 2004). A study of the impact of water projects is important for river basin management and environmental protection (Nislow et al. 2002, Bartholow et al. 2004)

The resultant hydrological alterations caused by reservoirs may include changes in flood frequency and magnitude, reduction in overall flow, increased or decreased summer base flows, and altered timing of releases, with a consequently wide range in effects on riverine ecology (Petts 1984).

The SWAT model has been used to estimate the effects of dam reservoirs on annual and peak stream flow rates in Kase River, Japan. The watershed area is set up 197.735 km^2 that accounts for 54% of the entire area of the Kase River Basin. The model was calibrated and validated for stream discharge data from 2008-2009 by using Nash-Sutcliffe to model performed evaluation. Simulated data from the model for the period 2008 - 2009 were used in order to investigate the response of stream flow to dam reservoir in Kase River basin. Using sensitivity analysis dominant parameters affecting water flow, the four most sensitive parameters of flow were selected and adjusted. The results of this study enhance the understanding of strea m flow consequences of dam reservoirs associated with impoundment, while these estimates could aid a decision maker to optimize water supply and demand and further water quality management in this basin.

METHODS AND MATERIAL

ArcSWAT 2009 version of the SWAT model is used as a main tool in this study. This version integrates the newest version of Soil and Water Assessment Tool. The SWAT is a river basin or watershed, scale model

developed to predict the impact of land management practices on water, sediment, and agriculture chemical yields in large, complex watersheds with varying soil, land use, and management conditions over long periods of time (Arnold et.all 1998). This model was chosen because it was physically based and computationally efficient (Neitsch, 2002). The SWAT model uses the SCS curve number procedure to calculate the runoff volume under
different soil types and land uses
The peak runoff rate is the maximum runoff flow rate that occurs with a given rainfall event. The peak runoff rate is an indicator of the erosive power of a storm and is used to predict sediment loss. SWAT calculates the peak runoff rate with a modified rational method.
In Japan, the SWAT has been applied to mountain area with enormous success (Somura et al.2009).

Study area and model input data

Kase River Basin is located in the center part of Saga Prefecture. This basin consists of 3 cities including Saga City. The population in the basin about 130,000 people mostly concentrated on the inside and the downstream part. The basin has wide variety of land use while MLIT (Ministry of Land, Infrastructure and Transportation) Japan due to National Comprehensive Water Resources Plans was added a new multi-purpose dam in this area in order to supply water needed especially for agriculture and water supply in Saga Prefecture.
Kase River flows through Saga Plain and pours into the Ariake Sea. The length of Kase River is about 57 km, with catchment area about 368 km^2 . Kase River dam construction is started in December 1992 with the surface area of the reservoir 270 ha, and has started a first impounding in October 2010.
The SWAT was set up for the basin upstream area of 197.74 km^2 that accounts for 54% ofthe entire area of the Kase River basin in Japan. Figure 1 shows the watershed was automatically delineated and divided by SWAT into 23 sub watersheds where Hokuzan dam had constructed and Kase dam have been impounded. The DEM was taken from Nippon-III 50 m grid elevation of digital map, land use map in 2007 obtained from the Ministry of Land Infrastructure and Transportation Japan, and detailed soil map was clipped from National Land Survey Division, Land and Water Bureau of MLIT`s website and used as the GIS input data for the model simulation. Figure 2 and Figure 3 respectively show the land use and soil map of the study area. Hourly observed weather data (temperature, humidity, solar radiation) from Saga Meteorological Observatory were applied in order to calculate the potential evapotranspiration (PET) using Penman-Monteith`s method. Daily observed discharge data were taken by the Ministry of Land Infrastructure and Transportation (M LIT) (2008-2009) for the analysis.

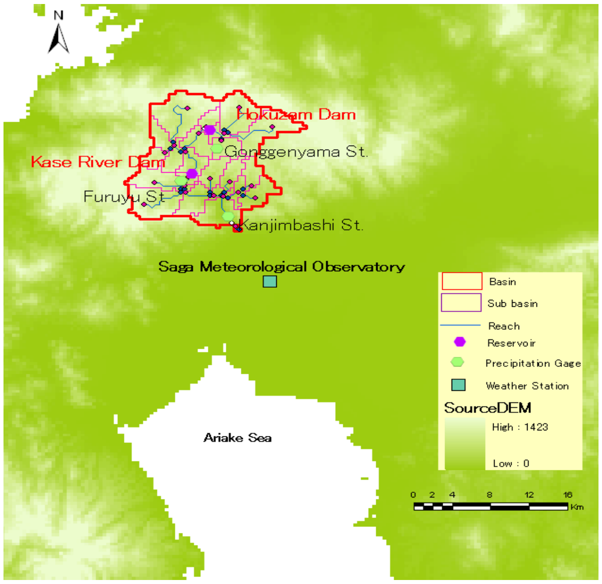

Figure 1. Watershed delineation in the watershed with 2 dams, 3 precipitation stations and Saga me teorological observatory

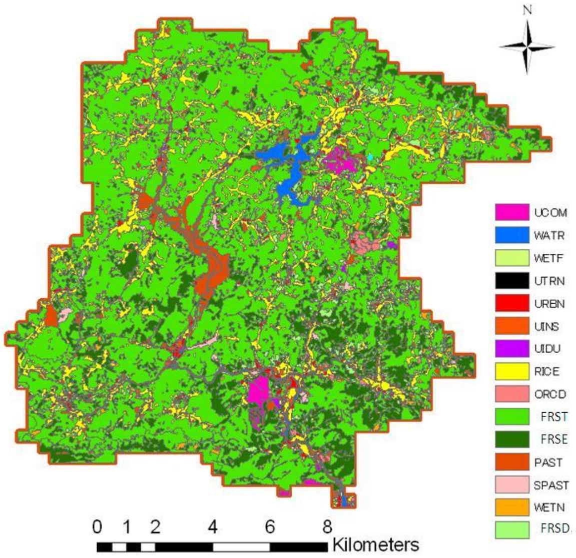

Figure 2 . Land use map of study area

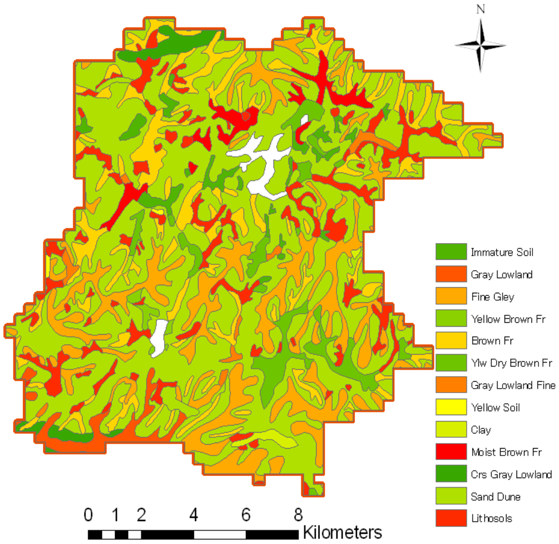

Figure 3. Soil map of study area

Model Calibration and validation

Calibration and validation were performed since the model accuracies within a watershed are requisite for a semi-distributed model such as the SWAT. Due to available data, a period from January 2008 to December 2008 was used for the calibration and the stream flows in 2009 at the Kanjinbashi stations located just in the downstream of the new dam were applied for validation. Prior to calibration, 4 most sensitive parameters: CN2, GWQMN, Alpha_BF, and Sol_AWC, were selected and adjusted manually based on previous SWAT research in Japan mountains area. Table 1 gives the range over which each parameter was varied and a more complete definition of the parameters. Figure 4 shows the calibration and validation result for flow at the watershed during 2008~2009. Although there were some discrepancies between the observations and simulations, overall the simulated daily flows coordinated well with the observed flows (R^2=0.917 and Nash-Sutcliffe (1970) NSI=0.882). The R^2 value is a marker of strength from the correlation between the observed and simulated values. The NSI value is commonly used in modeling figures and marks how closely the simulated versus observed data points resembles the 1:1 line. The ranges of NSI value is between minus infinity and one. Values that are less than or closely to zero for R^2 and NSI, marks model performance is poor and unacceptable, and values equals to one indicates the model prediction is perfect. Our simulations perform sufficiently acceptable of the model

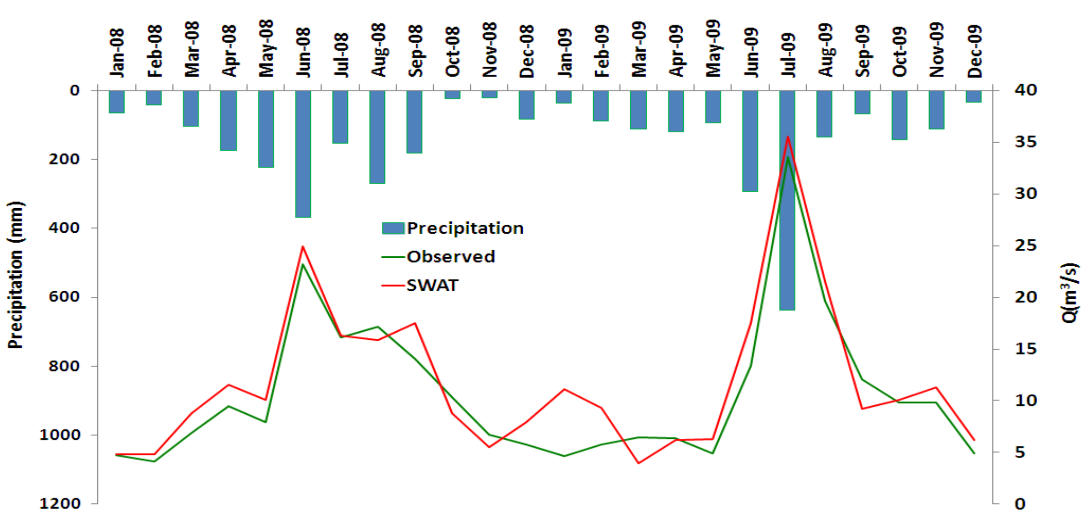

Figure 4. Simulated and observed discharges in Kanjinbashi outlet (calibration: 2008, validation: 2009)

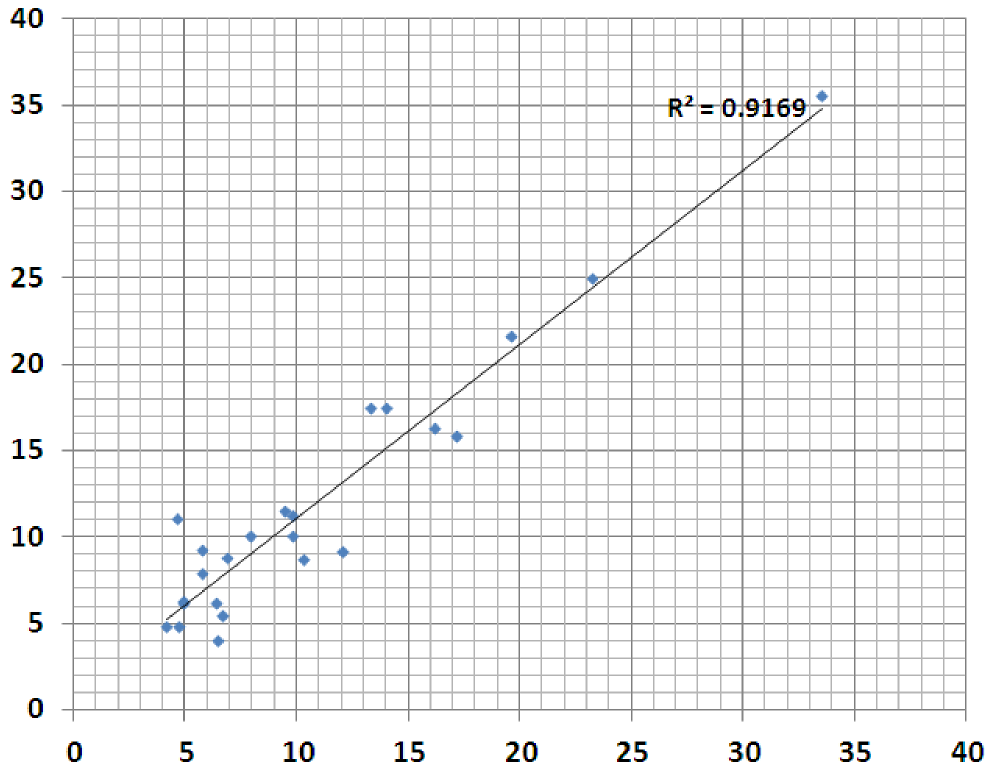

Figure 5. Model performances of simulated and observed discharges in Kanjinbashi outlet

Dam scenarios

To describe effects on annual and peak stream basin discharge from various presented dam reservoir, scenarios were run, using the calibrated model. The set of scenarios tested the impact of the existence or nonexistence of reservoirs in the watersheds. The scenarios were carried out with Hokuzan dam but no Kase River dam , with both Hokuzan dam and Kase dam, and with all the dams in watershed disappeared or no dams.

The Hokuzan dam operates on a temporal schedule, according to the agricultural management of watershed. In the wet/rainy period, the reservoir collects water and the water level increases. In the irrigation period of tenth of June to tenth of October or when the discharge water volume reaches to 15 m^3/s at Kawakami water head, the water in the dam is released to meet the demand of agricultural resources in the Saga Plain at the lower reach.

According on the available data and the necessary inputs of the SWAT, the following characteristic indicators of the dam were set up: the surface area of reservoir when filled to the emergency spillway, surface area of reservoir when filled to the principal spillway, volume of water held in reservoir when filled to the emergency spillway, and volume of water held in the reservoir when filled to the principal spillway.

Table 1 . Description of dams in Kase river basin

Dam	Hokuzan dam	Kase River dam
Service Date	1957	2010
Height(m)	59.3	97
Dam Volume (m^3)	145,000	1,220,000
Eff. Capacity (m^3)	22,000,000	68,000,000
Storing Water Area(ha)	200	270
Catchment area(ha)	5,463	12,840

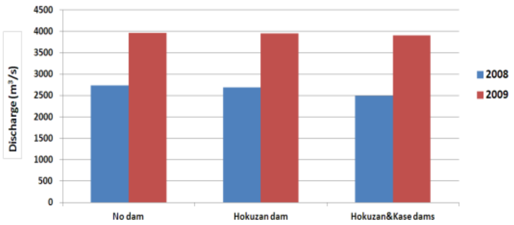

Figure 6. Simulation of annual discharge of the Kase River basin at Kanjinbashi outlet under the scenarios

RESULTS AND DISCUSSION

Effect of dam reservoirs on annual stream flow

As predictable, the presence of dam reservoirs resulted in reductions in annual flow in the watershed. The results also showed that the existence of Hokuzan dam reservoir and Kase River dam reservoir in the watershed caused greater reductions in stream flow than did the only Hokuzan dam reservoir.

These dams seem to, result in decrease of average annual discharge by 3.68% from the only Hokuzan dam scenario, and a decrease of 4.49 % from the disappeared dam scenario. Figure 5 show annual discharge of Kase River basin for 2008-2009 at Kanijnbashi outlet under the scenarios. In 2008, the annual discharge decrease from 2738.9 m^3/s when no dam in the watershed, became lower at 2691.7 m^3/s when only added the Hokuzan dam, and 2494.9 m^3/s when all dams appear. The outcome show in 2009, the annual discharge also became lower from 3964.3 m^3/s (no dam) to 3955.2 m^3/s (only Hokuzan dam) and 3907.02 m^3/s (Hokuzan dam and Kase dam).

The decrease of stream discharge from this alteration may be attributed to the fact that dams that divert water to offstream uses such as irrigation and urban uses (multi-purpose), especially out of basin diversions, will reduce the total downstream flow (Collier et al, 1995). Excessive dams and floodgate operations have change dramatically the flow regimes and shift peaking time (J. Xia, et al. 2005). In addition, reservoir area has a higher rate of water loss by large evaporation than natural stream does. Wide surface areas of reservoirs can evaporate higher than natural channels. Average monthly evapotranspiration rates from Hokuzan dam area is 36.01 mm, larger than 17.34 mm in Kanjimbashi area.

These effects on decrease of streamflow by increased number of dams in the watershed are particularly strong in the wet period from June to July, because precipitation is abundant in the wet period and temperatures are high enough to support high evaporation. Therefore, the stream flow rates in June decreased from 22.085 m^3/s when there is no dam scenario to 21.24 m^3/s for only Hokuzan dam existence and 18.46 m^3/s for Kase River dam and Hokuzan dam existences. Decreases in discharge also occur in the periods after the wet period. The quite lower decrease in discharge in the August period resulting from hot temperatures in this month. In August, stream flow rates decrease from 18.89 m^3/s when no dam scenario, to 18.75 m^3/s for only Hokuzan dam scenario and 17.32 m^3/s when all the dams appear. Also in September a decrease from 13.56 m^3/s (no dam), to 13.35 m^3/s and 13.05 m^3/s when Hokuzan dam was constructed and all the dams appear respectively. In dry period the effect not obvious. In February stream flow rates decrease from average 7.2 m^3/s (no dam) to 7.05 m^3/s and 6.63 m^3/s in only 1 dam and 2 dams exist scenarios respectively

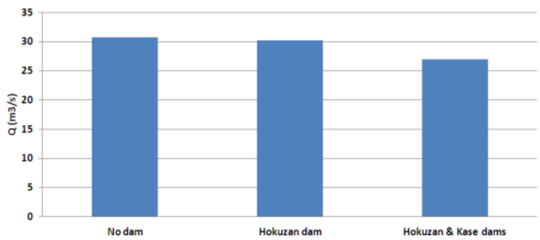

Figure 7. Change in average annual peak flow rate in Kanjinbashi

Effect of dam reservoirs on peak stream flow

Figure 7 shows the average annual peak flow rates at Kanjinbashi outlet, under the presence-absence scenarios. In this figure shows changes of annual peak flow in different existence-absence dam in Kanjinbashi point which is the outlet of watershed model. In each group, annual peak discharges from three scenarios are shown. From Figure 8, I have found differences in watershed peak flow in Kanjinbashi among the scenarios. In 2008-2009 average annual peak flow for no dam scenario is 30.72 m3/s, while for Hokuzan dam only scenario and Hokuzan dam with Kase dam scenario are 30.245 m3/s and 26.93 m3/s respectively.A decrease of Kanjinbashi peak flow indicate that the effect of dam construction is seen in the lowering peak flow at downstream of watershed. Peak flow rates in Kanjinbashi decreased by 1.57% when the Hokuzan dam and Kase River dam were removed from the Hokuzan dam only condition. In Kanjibashi outlet, a change of annual peak flow rate decreased by 10.94 % due to scenario 2.

CONCLUSIONS

The constructions of a dam reservoir will have consequences on the nature of environment. The existences of Hokuzan dam reservoir and Kase River dam reservoir in this area resulted in reductions in annual and peak stream flow rates in the watershed because of the storage of dams. Wide surface areas of reservoirs can evaporate higher than natural channels.

Dam reservoirs in Kase River basin have changed the stream flow regimes. These dams seem to, result in decrease of average annual discharge by 3.68 % from only Hokuzan dam scenario, and decrease 4.49 % from the disappeared dam scenario. Dams in Kase River basin also have changed the peak flow rates based on results at the Kanjinbashi which is the outlet of watershed model. Peak flow rates in 2008-2009 decrease by 10.49 % when Hokuzan dam and Kase dam were added from only Hokuzan dam scenario and a decrease of 1.57 % when Hokuzan dam was added from no dam condition.

The effects on decrease of annual stream flow are larger in the wet period from June to July and in dry period such as February the effect are not obvious.

The SWAT model successfully passed the scenarios exercises considering annual and peak stream flow rates outputs. Result shows the simulations perform sufficiently acceptable of the model with coefficient determination = 0.917 and Nash Sutcliffe = 0.882.

However, further research is required in order to confirm the clarifying of the model with respect to dam construction impacts on water quality in the basin. A key objective of this study was to calibrate and validate the SWAT model for running the scenarios to better understand the influence of impoundments over the stream hydrology.

Considering this research, the result model is able to use for making a first preliminary assessment of the prospective impacts of dams reservoir in Kase river basin. The results in this study show a test of the sensitivity of hydrology to an exacting feature of the ecosystem dynamics. Nevertheless, this is a first step which provides a move toward into how basin responds to dam reservoir associated with impoundment and will be more accommodating when analyzing relations between dam reservoir, water quality and hydrology.

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