*The International Conference on Environmentally Friendly Civil Engineering Construction and Materials*
*Manado, Indonesia, 13 – 14 November 2014*

EFCECM
2014

# WATER RESOURCES MANAGEMENT BY MODELING OF DAM OPERATION

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## ABSTRACT

The Arc-Geographic Information System interface of the SWAT2009 version was used to develop the SWAT model of Kase River Catchment. SWAT has a reservoir module, in which the reservoir is treated as an independent unit to be added in the corresponding sub basin.

Therefore, it is appropriate for simulating the influence of the hydrological cycle in a region with reservoirs, such as our study basin.

The catchment was divided into 23 sub-basins according to hydrologic stations, the position of dams, the water diversion point, and the discharge zones. The sub-basin threshold area was 500 ha. Kanjimbashi was selected as the outlet of the whole basin. The hydrologic response unit (HRU), which is a unique combination of soil and land use overlay in the sub- basins , is the minimum calculative smallest unit of hydrologic process. With a threshold value of 5% for land use and soil types, the total number of HRUs was 356.

By scenario analysis for controlled the minimum outflow rate from Hokuzan dam and Kase River dam, the water resources quantity improved and satisfied the demand water of 5 m3/s for preventing eutrophication at the creek network downstream area and also 18.6 m3/s for agriculture purpose after the implementation of water management operation of dams.

**KEYWORDS:** Water Resources Management, Dam Operation

## 1    INTRODUCTION

Dam design and operation typically focuses on its social functions, such as flood control, electricity generation, water supply, irrigation, and aquaculture (WCD 2000). Along with increased human activities in Kase River basin the demand of water have become more apparent in recent years.

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 Kase River dam with Hokuzan dam sequentially in this area in order to supply water needed especially for agriculture and water supply in Saga Prefecture.

In addition, there has been an open channel network, which is a creek network in Saga Plain. This network could enhancement a need of water for irrigation and also could store up the water when flood occurred. However after achievement of water supply facilities, the creek network was used only for irrigation or urban drainage and shortage of water discharge caused eutrophication of water by too much nutrient supply and polluted sediment settled down the channel. To improve this water environment of the creek network in the plain needs water quantity to some extent. The function of dam reservoir for restraining sediment transport including the nutrient causing the eutrophication in the downstream open channel is expected.

How the upstream dam reservoirs are utilized is directly or indirectly related to water quantity and quality in the downstream area.

For that reason, it is fairly essential to reflect on the integrated management of dam reservoir in this watershed. Managing the water resources in this area became an important topic in the integrated basin management to provide a new approach to water environment improvement.

This basin is very unique with high regulated since some water management such as the water diversion from downstream of Hokuzan dam to Ayunose was done in this area. A water demand for sufficiently quantity by 5 m3/s to prevent eutrophication at the creek network downstream, and a discharge of 18.6 m3/s for irrigation period are urgent issue to answer community needs.

The purpose of this study is to develop a water management tool of dams operation, at the basin scale, based on SWAT.
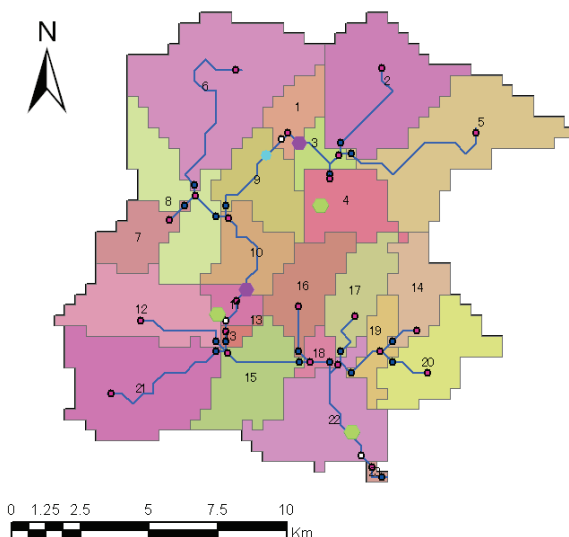


**Figure 1: Watershed delineation in the watershed with 2 dams, 3 precipitation stations**

**Table 2: Parameter used in the model calibration**

| Name | Definition | File Name |
|------|------------|-----------|
| CN2 | SCS moisture condition II curve number for pervious areas | .mgt |
| Sol_K | Saturated hydrolic conductivity of first layer | .sol |
| ESCO | Soil Evaporation compensation coefficient | .hru |
| Sol_AWC | Available water capacity of the soil layer | .sol |

## 2 METHODOLOGY

In order to develope the water management tools of dams operation, at the basin scale, it is necessary to recognize the problem that facing in this area, also the water management such as the diversion of water which done inside the watershed. Our research framework is that: Firstly, distributed hydrological and water quality model are developed including the diversion of water was setup and dam operation is considered, also the model parameters are calibrated in order to well simulated the process under current situation. Secondly, based on the calibrated model the management model of dams, which will be developed to reach objective. Finally the result of dam's management can be assessed.

ArcSWAT 2009 version of the SWAT model is used as a main tool in this study. SWAT is a basin or watershed scale model with strong physical mechanism. It has been widely applied in Canada and North America . In Japan, the SWAT has been applied to mountain area with enormous success (Supit et al. 2012).

It is demonstrated and agreed that SWAT is well established because of its flexibility and suitability for hydrological simulation in complex basins and water resources management. SWAT has a reservoir module, in which the reservoir is treated as an independent unit to be added in the corresponding subbasin. Therefore, it is appropriate for simulating the influence of the hydrological cycle in a region with reservoirs, such as our study basin.

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 hydrologic cycle of the SWAT model is based on the water balance equation, which considers the unsaturated zone and shallow aquifer above the impermeable layer as a unit.
The SWAT model uses the SCS curve number procedure to calculate the runoff volume. The volume of outflow calculated using one of four different methods: measured daily outflow, measured monthly outflow, average annual release rate for uncontrolled reservoir, controlled outflow with target release.

When measured monthly outflow (IRESCO = 1) is chosen as the method to calculate reservoir outflow, the user must provide a file with the average daily outflow rate for every month the reservoir is simulated in the watershed. The volume of outflow from the reservoir is then calculated using equation

$$V_{flowout} = 86400 \cdot q_{out}$$

When the average annual release rate (IRESCO = 0) is chosen as the method to calculate reservoir outflow, the reservoir releases water whenever the reservoir volume exceeds the principal spillway volume, $V_{pr}$.

### 2.1 Model Selection and improvement

The catchment was divided into 23 sub-basins according to hydrologic stations, the position of dams, the water diversion point, and the discharge zones. The sub-basin threshold area was 500 ha. Kanjimbashi was selected as the outlet of the whole basin. The hydrologic response unit (HRU), which is a unique combination of soil and land use overlay in the sub- basins (Neitsch et al.2002), is the minimum calculative smallest unit of hydrologic process. With a threshold value of 5% for land use and soil types, the total number of HRUs was 356 (Fig.1).

Moreover, water diversion that supply water in pipe to Ayunose in the catchment was added in the model as point source outlet and developed a data based on information from the water

use in this diversion. For run the first simulation Hokuzan dam and Kase River dam have no monitoring data, As a result, We selected the average annual release rate for uncontrolled reservoir method (IRESCO=0) in their control files (*.res), and modified the reservoir's design data including reservoir surface area (RES_ESA) and volume of water (RES_EVOL) as the water level reaches the emergency spillway and surface area of reservoir (RES_PSA), and volume of water (RES_PVOL) in their control files (*.res).

The further simulations were done by adjusting the minimum monthly outflow. As a result, We set the outflow simulation code to the measured monthly outflow (IRESCO = 1) in their control files (*.res), generate and added the minimum monthly outflow rate and read into SWAT for run the simulation.
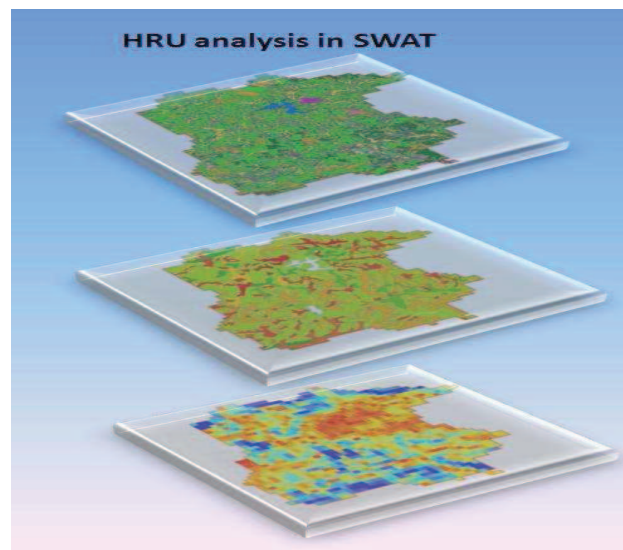


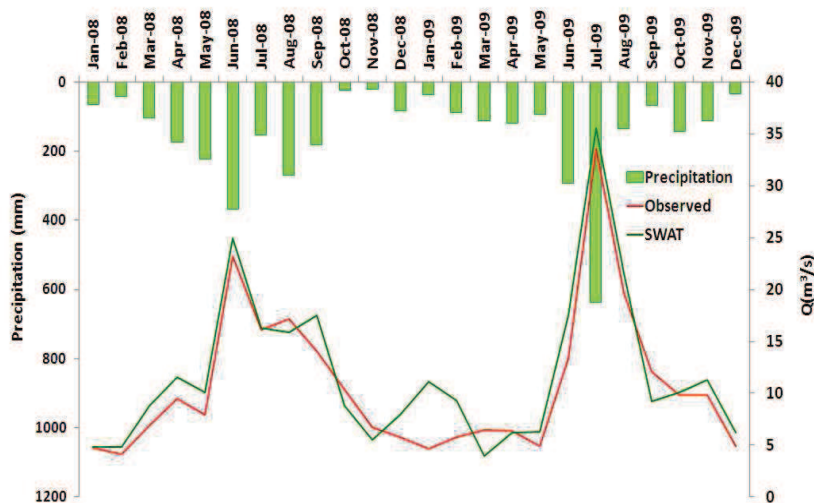**Figure 2: Hydrologic Response Unit analysis in SWAT**



**Figure 3: Observed and simulated discharge simulation**

# 3 RESULTS AND DISCUSSION

## 3.1 Model evaluation

Four sensitive parameters that may have a potential influence on river flow was selected (Table 1) (Arnold et al. 1998). The ranges of these parameters were obtained from the SWAT manual (Neitsch et al. 2002). The hydrologic parameters were calibrated to match the simulated and observed monthly flow data at Kanjinbashi outlet from 2008 to2009. Several evaluation indices, including correlation determination (R2), and Nash–Sutcliffe coefficient, were used to evaluate the model performance (Romanowicz et al.2005) (Fig. 4). For the runoff simulation, if the correlation coefficient and NSEC coefficient are ≤0.0, the model prediction is considered "unacceptable or poor."If the correlation coefficient and NSEC coefficient are 1.0, the model prediction is considered "perfect." Each of these categories followed the criteria used by Santhi et al. (2001). The result simulation show sufficient acceptable of the model with coefficient determination = 0.917, and Nash Sutcliffe =0.882.

## 3.2 Management dam operation

Currently the demand of water for preventing eutrophication at the open channel in downstream area is 5 m3/s, and a discharge over 18.6 m3/s in the irrigation period are the values that must be reach to meet the needs of community. The simulations were done by adjusting the minimum monthly outflow rate. Year 2008 and 2009 are selected to analyze the management operation of dams of the SWAT model. The management option of Hokuzan dam is as follows: minimum outflow rate by 5m3/s before the irrigation period, minimum outflow rate 19 m3/s in the irrigation period, and minimum outflow rate 5 m3/s after the irrigation period.

The management option of Kase River dam is as follows: minimum outflow rate by 5m3/s before the irrigation period, minimum outflow rate 19 m3/s in the irrigation period, and minimum outflow rate 5 m3/s after the irrigation period.

Conclusively, with the water discharge over 5 m3/s of dams before and after the irrigation period enhanced the fluvial fluidity and was useful to prevent the accumulation of pollutant or nutrient at the creek network, which would have decreased the water quality. Moreover, increasing water discharge during the irrigation period ensured the flood control safety during the flooding season and satisfied the demand for agriculture purpose.

The operation of dams involves always keeping them closed in the non flood season to store water for irrigation. The quantity of usable water resources is problem in Saga Plain since water demand 5 m3/s for preventing eutrophication at the creek network and 18.6 m3/s are more than available natural supply. During the flood season, however, Hokuzan dam usually open to discharge water for flood irrigation.

By the scenario for uncontrolled dam minimum outflow rate, the water resources quantity was not satisfied along the years. In January, February, July, August and September for 2008, and March, September for 2009, the stream flow not enough to meet the demand for downstream area, which need more supply water.

By scenario analysis for controlled the minimum outflow rate from Hokuzan dam and Kase River dam, the water resources quantity improved and satisfied the demand water of 5 m3/s for the creek network downstream area and also 18.6 m3/s for agriculture purpose after the implementation of water management operation of dams. The runoff increased in the non irrigation season to increase fluidity of rivers and improve water quality, while runoff will be reached in irrigation season to satisfy the demand for that time.
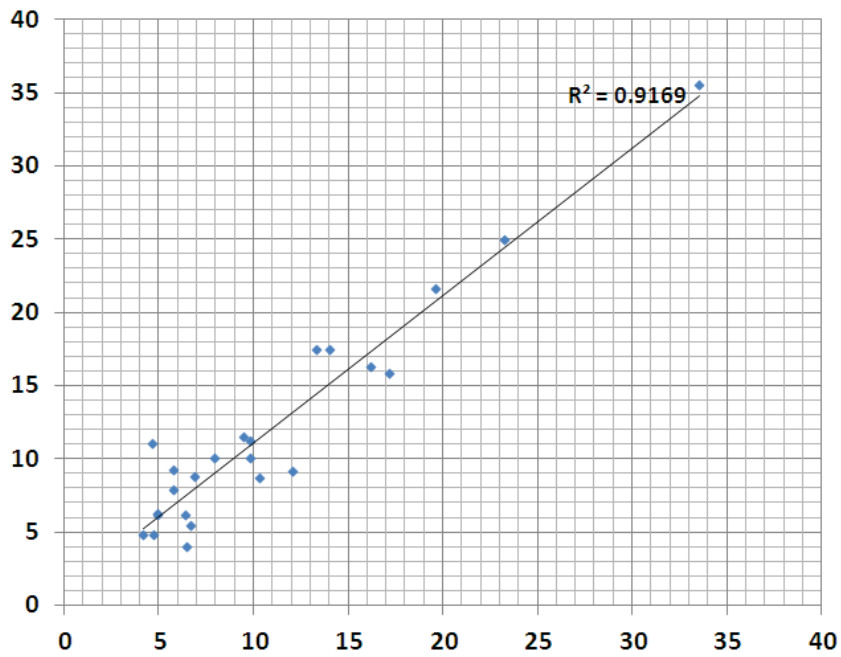
**Figure 4: performances of simulated and observed discharges in Kanjinbashi outlet**

Discharge (m$^3$/s)in Kanjimbashi for controlled dam

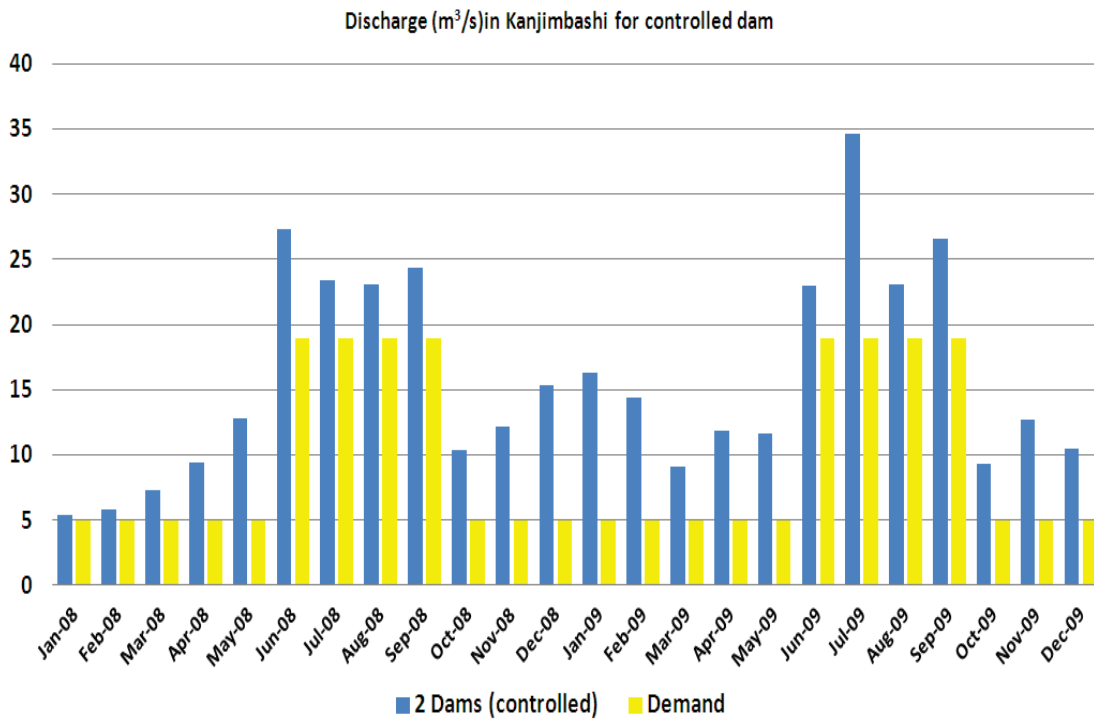

■ 2 Dams (controlled)   ■ Demand

**Figure 5: Monthly simulated runoff 2 dam (controlled) scenarios at Kanjinbashi outlet for 2008-2009**

## 4    CONCLUSIONS

Managing water resources is an important research topic   in    the    integrated basin management and will provide a new approach to water environment improvement. In  this study,  the  water  management operation of dams done with the SWAT  model. The simulation for managing water resources was done by adjusting the minimum outflow rate in reservoir module and read into SWAT.

By the scenario for uncontrolled dam minimum outflow rate, the water resources quantity was not satisfied along the years.

By scenario analysis for controlled the minimum outflow rate from Hokuzan dam and Kase River dam, the water resources quantity improved and satisfied the demand water of 5 m3/s for preventing eutrophication at the creek network downstream area and also 18.6 m3/s for agriculture purpose after the implementation of water management operation of dams.

Conclusively, with the water discharge over 5 m3/s of dams before and after  the irrigation periodenhanced the fluvial fluidity  and  was useful  to prevent the  accumulation of pollutant or nutrient at the creek network, which    would    have    decreased the water quality. Moreover, increasing  water  discharge  over 18.6 m3/s during  the irrigation period  ensured the flood  control safety during the flooding season and satisfied the demand for agriculture purpose.

The management of dam operation at the basin scale answers the demand of water for 5 m3/s for preventing eutrophication problem at the creek network downstream area and the discharge over 18.6 m3/s for irrigation, using the reservoir operation module of SWAT model.   It will purpose in Kase River Catchment in Saga, Japan.

Although this paper  still a preliminary study,  and  the  results  were  not  very satisfying due to  limitations     in  available observation data, this  model  provides     technical  support and reference for water  management operation of dams  and  will be  a very  useful  method for future integrated  basin improvement..

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