Application of a long-term runoff simulation model for the construction of a River Flow Management System

Seung Jin Maeng
Chungbuk National University, Cheongju-si, Korea
maeng@cbnu.ac.kr

Ji Hoon Shim
Chungbuk National University, Cheongju-si, Korea

Ji Hye Jeong
Chungbuk National University, Cheongju-si, Korea

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Long-term runoff, Runoff simulation, SSARR, Parameter, Sensibility analysis

ABSTRACT
A river flow management system was constructed as part of the 4 great rivers project for comprehensive water management in a watershed unit connected to a dam and a watercourse. In this system, to estimate the dam inflow and outflow of sub-basins, the long-term runoff simulation model, which has already been developed, was improved for the river system of Han River, Nakdong River, Geum River, and Seomjin River. In the case of Youngsang River and 8 rivers watersheds, a long-term runoff simulation model was developed for the applicable watersheds. To develop a daily long-term runoff model, the SSARR (Streamflow Synthesis and Reservoir Regulation) model, which the Korea Water Resources Corporation frequently applied, was ultimately selected as a based model since it is considered suitable for the purpose of the project. A stream diagram was drawn up for the standardized unit basin, targeting each watershed, and a P-card of SSARR was constituted for simulation. The input data of the SSARR model were divided into physical parameters, hydrological meteorological parameters, and internal processing parameters for construction. In addition, the constructed input data were stored in a DB within the developed River Flow Management System so that they can be operated with a seamless interface when the model is used. A sensibility analysis was carried out that targeted the representative middle region of the Han River watershed to analyze the sensitivity of the SSARR model. The results of the sensibility analysis showed that among the parameters related to rainfall-runoff, greater sensitivity is shown in the parameter that separates the surface flow from the subsurface flow and the runoff rate according to the soil moisture levels in the case of the flood season and the drawdown period. In the case of the drawdown period, the regression groundwater accounted for a large proportion, and a relatively high degree of sensitivity appeared in the detention storage time of the surface flow, subsurface flow, ground water, and regression ground water. The parameters were calibrated through a comparative analysis between the runoff simulated using the SSARR model and the runoff at the major points of the 5 great rivers and the 8 watercourses measured from October 1, 2007 to June 30, 2008 based on the total amount of the annual runoff. In addition, the 5 rivers and 8 watercourses were verified using the calibrated parameters from October 1, 2008 to June 30, 2009.

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1. INSTRUCTIONS

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In May 1999, the Han River watershed integrated dam operation rule (Article 5, Principle of integrated dam operation, clause 2: The integrated dam operation should be operated with a scientific operating system that considers the status of the water demand, power line, discharge, inflow, storage of each dam, and the hydrology status within the Han River watershed) was enacted upon instructions (No. 242) of the Ministry of Construction and Transportation. In addition, an academic research for a coordinated multi-reservoir operating model was carried out as a 21C frontier project from 2001 to 2011, and the Nakdong River and Han River watersheds real-time reservoir operation system was established by the Korea Water Resources Corporation in 2004 and 2007. It is expected that if a small dam was constructed through the implementation of the 4 great rivers project in 2008, the small dam would be efficiently operated and managed with the developed River Flow Management System.

A river flow management system will be constructed as part of the 4 great rivers project for comprehensive water management in a watershed unit connected to a dam and a watercourse. In this system, to estimate the dam inflow and outflow of sub-basins, the long-term runoff simulation model, which has already been developed, will be improved for the river system of Han River, Nakdong River, Geum River, and Seomjin River. In the case of Youngsang River and 8 rivers watersheds, a long-term runoff simulation model will be developed for the applicable watersheds.

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2. RAINFALL-RUNOFF MODEL DESCRIPTION

2.1. Hydrological Model

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In hydrological cycle, streamflow is the most important hydrological amount in terms of water utilization and control. In conducting water resources management, it is crucial to develop and establish techniques to determine runoff amount from basic data on triggering runoff in channels.

Since most of channels are equipped with runoff gauging stations, runoff amounts are measured, but these do not provide the exact runoff amount measurement data as engineers in water resources management want to get for target points to develop and manage water resources, thus posing problems. Moreover, in establishing plans on the appropriate management and preservation of land and water resources, runoff amount changes should be forecast according to hydrological condition changes.

To meet these needs, mathematical techniques such as hydrological synthesis and hydrological simulation have continued to be developed, and such techniques have materialized into hydrological models.

Model is a term opposed to prototype, and is meant to represent the expression of real-world natural phenomena or behaviors, and such behaviors are expressed in terms of mathematical equations - a universal model in the field of today's natural sciences. Unit hydrograph, based on hydrology, is one of the most widely used hydrological models.

The use of hydrological models allows one to calculate channel runoff amounts and understand scientific explanation on runoff phenomenon in basins.

Hydrological models consist of physical laws representing hydrological cycle and experiential elements. Physical laws applied to the Figure 1 sketchy hydrological cycle include law of mass conservation, law of energy conservation, and law of momentum conservation, and recently, to analyze the evapotranspiration phenomenon in basins more accurately, thermodynamic theory was introduced. Components of hydrological cycle that should be generally included in hydrological models are rainfall and interception, evapotranspiration, infiltration, overland and channel runoff, interflow and behavior of soil moisture, and percolation and baseflow.

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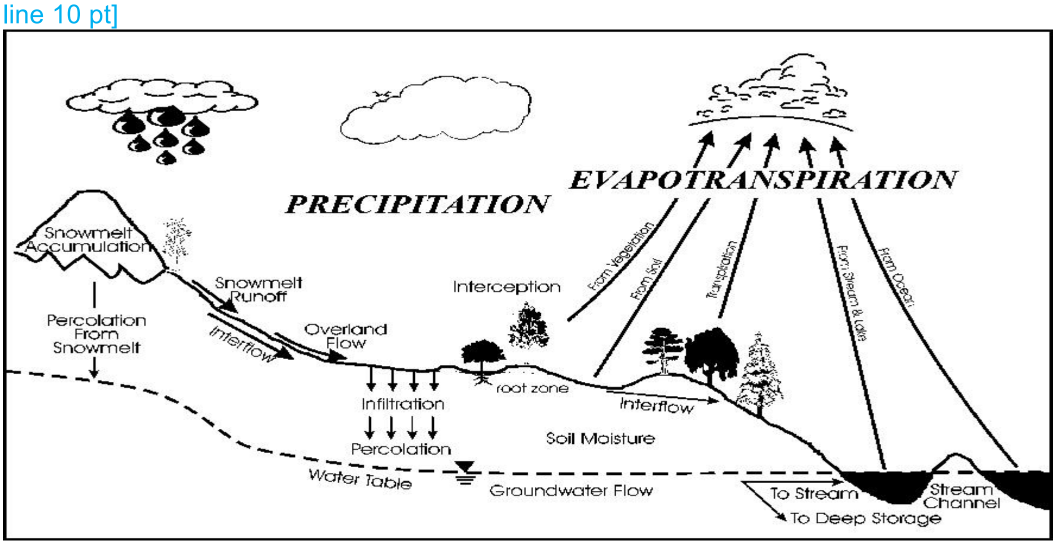

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Figure 1. Diagram of Hydrological Cycle

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This manual describes theoretical background and input/output statements of the RRFS (Rainfall-Runoff Forecasting System) base model, SSARR (Streamflow Synthesis and Reservoir Regulation Model, US Army Corps of Engineers, 1987), and then overall simulation system of RRFS.

2.2. SSARR Model

Developed in 1956 by U.S. Army Corps of Engineers, the SSARR model is a comprehensive model for mathematical hydrological simulation necessary for planning, designing and operation of hydraulic facilities, and has continued to be updated until recently. SSARR consists of basin, river system, and reservoir regulation models.

The basin model, as shown in Figure 2, is designed to simulate rainfall-runoff, snow cover, and snow melting in basins by simulating the hydrological cycle of up to channel inlets through interception, evapotranspiration, infiltration, soil moisture, baseflow and overland runoff. The river system model and reservoir regulation model are designed to use channel routing and simulate runoff in various river sections upstream and downstream in natural conditions and through reservoir regulation. In particular, the channel routing includes a simulation of backwater influences in reservoirs and tidal compartments, river diversion, and embankment overflow.

Simulation time intervals range from 0.1 hour to 24 hours, and they can be selected according to user's purposes, basin characteristics such as basin size and response time, and availability of hydrological meteorological data, thus offering a wide range of use. Thus, the SSARR model can be categorized into deterministic, lumped, and continuous runoff models.

The deterministic model, the SSARR model, as mentioned above, is fit for comparatively large basins, and includes a simulation of rainfalls and snowfalls. Thus, the SSARR model has been used to simulate and evaluate long-term runoffs in rivers and basins, as well as forecast flood runoffs in basins and rivers.

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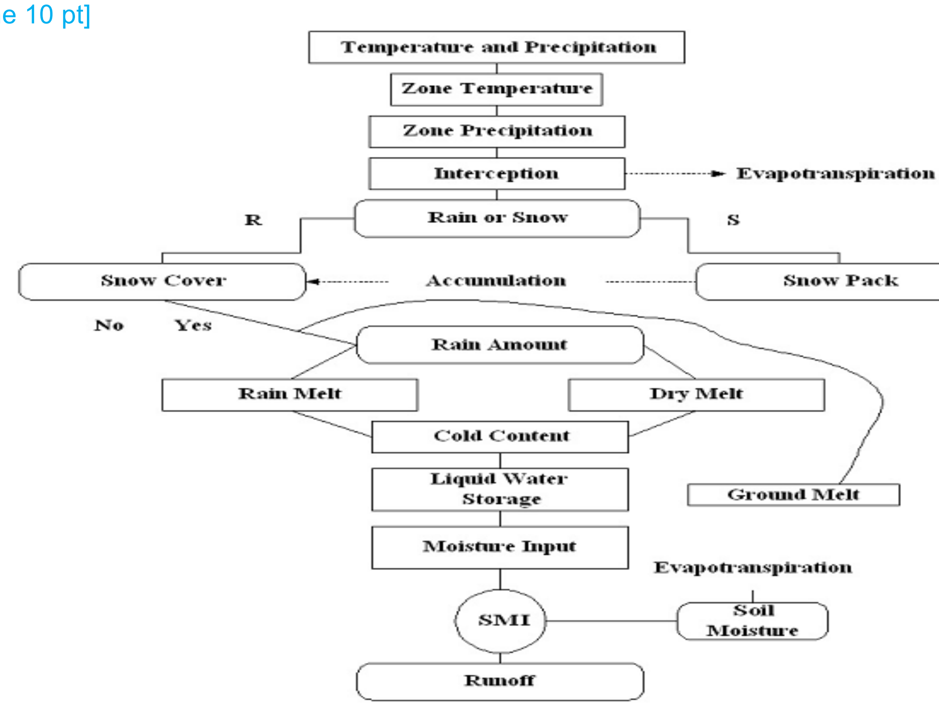

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Figure 2. Basin Model's Simulated Flow Diagram of SSARR Model

As mentioned above, the SSARR model was developed by U.S. Corps of Engineers to plan the Columbia River water resources in the northeast of the USA. Afterwards, this model continued to be improved, helped by U.S. National Weather Service and power company Bonneville Power Administration, and has since been applied to forecasting flood runoffs in large U.S. rivers and water management work. This model was also applied to international rivers such as the Mekong River located in Cambodia.

The SSARR model, in Korea, was applied in 2001 jointly by Korea Water Resources Corporation (KOWACO) and Seoul National University to improve the coordinated optimum operation system in multi-dams in the Nakdong River basin.

3. RESULTS AND DISCUSSION

3.1. Review of the Effects of the New River Facilities

In this project, the long-term runoff simulation model for the river facilities to be established under the 4 great rivers project, which targets the Han River, Nakdong River, Geum River, Seomjin River, and Youngsang watersheds, was improved, and a long-term runoff simulation model for the 8 rivers was developed.

For the Thiessen coefficients and rainfall observatory selected for each watershed, the same ones used in the TANK model, a long-term runoff model developed by the Korea Institute of Construction Technology was used; and in the case of the classification of the sub-basins of a standardized unit

basin, the same one decided upon by the Korea Institute of Construction Technology was also used.
As an analytical point to figure out the runoff characteristics of watersheds, the point of the dam and the small dam to be constructed was selected.

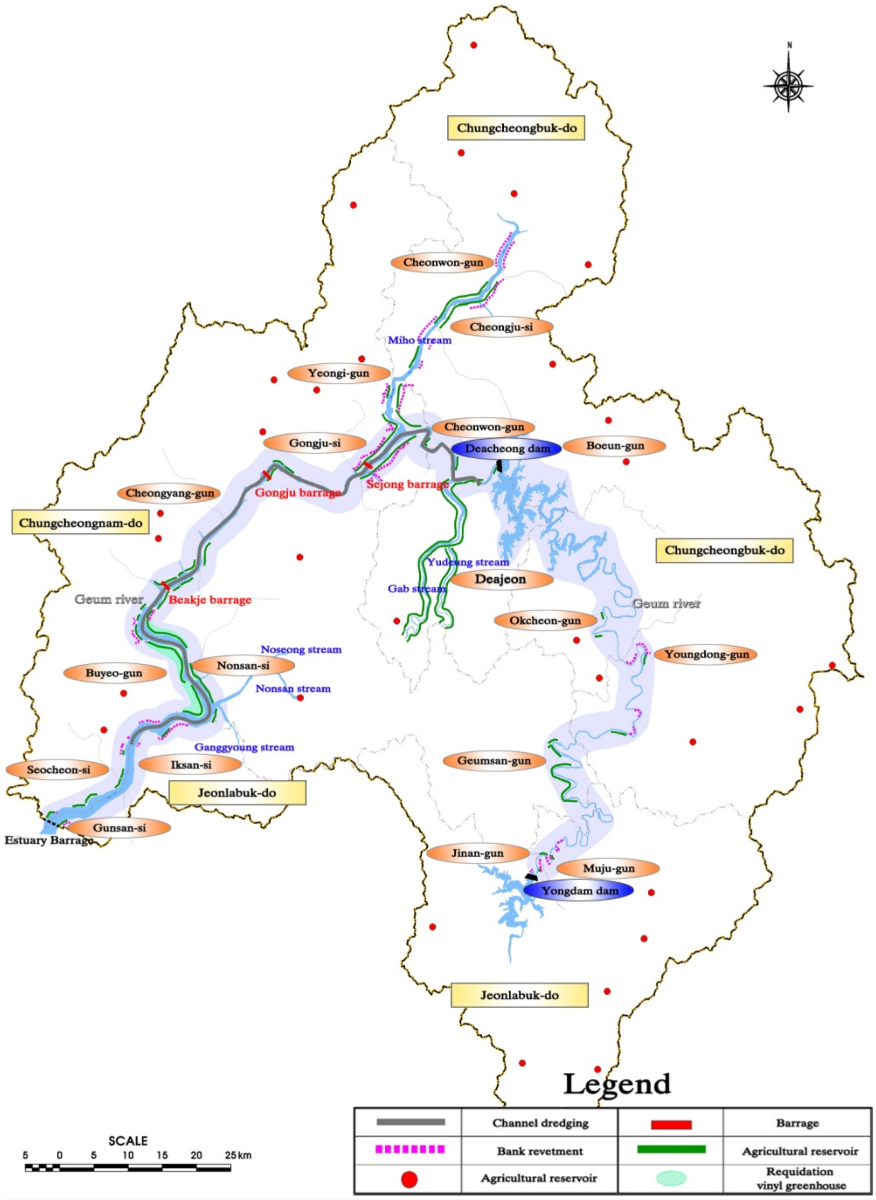

Figure 3. Map of Geum river project

3.2. Improvement and Development of the Daily Runoff Model

To develop a daily long-term runoff model, the SSARR (Streamflow Synthesis and Reservoir Regulation) model, which the Korea Water Resources Corporation frequently applied, was ultimately selected as a based model since it is considered suitable for the purpose of the project.
A stream diagram was drawn up for the standardized unit basin, targeting each watershed, and a P-card of SSARR was constituted for simulation.
The input data of the SSARR model were divided into physical parameters, hydrological meteorological parameters, and internal processing parameters for construction. In addition, the constructed input data were stored in a DB within the developed River Flow Management System so that they can be operated with a seamless interface when the model is used.
A sensibility analysis was carried out that targeted the representative middle region of the Han River watershed to analyze the sensitivity of the SSARR model. The results of the sensibility analysis showed that among the parameters related to rainfall-runoff, greater sensitivity is shown in the

parameter that separates the surface flow from the subsurface flow and the runoff rate according to the soil moisture levels in the case of the flood season and the drawdown period. In the case of the drawdown period, the regression groundwater accounted for a large proportion, and a relatively high degree of sensitivity appeared in the detention storage time of the surface flow, subsurface flow, ground water, and regression ground water.

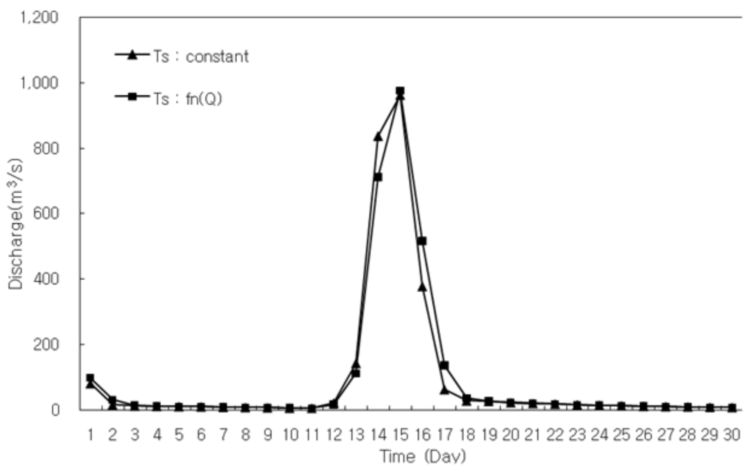

Figure 4. Sensitivity for surface storage time as a function of flow

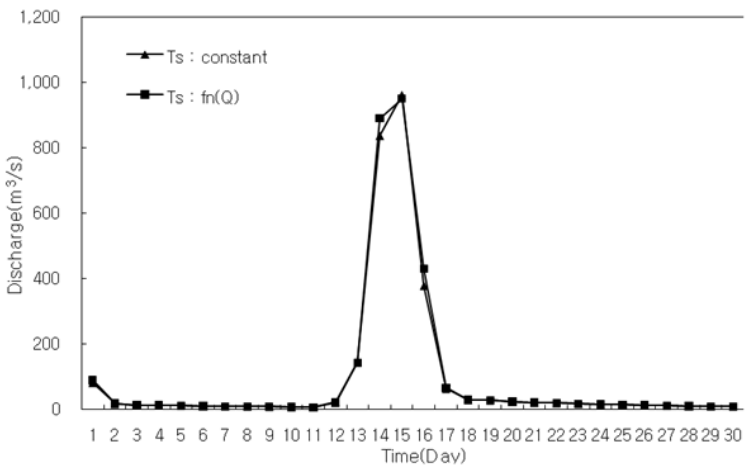

Figure 5. Sensitivity for baseflow storage time as a function of flow

The parameters were calibrated through a comparative analysis between the runoff simulated using the SSARR model and the runoff at the major points of the 5 great rivers and the 8 watercourses measured from October 1, 2007 to June 30, 2008 based on the total amount of the annual runoff. In addition, the 5 rivers and 8 watercourses were verified using the calibrated parameters from October 1, 2008 to June 30, 2009.

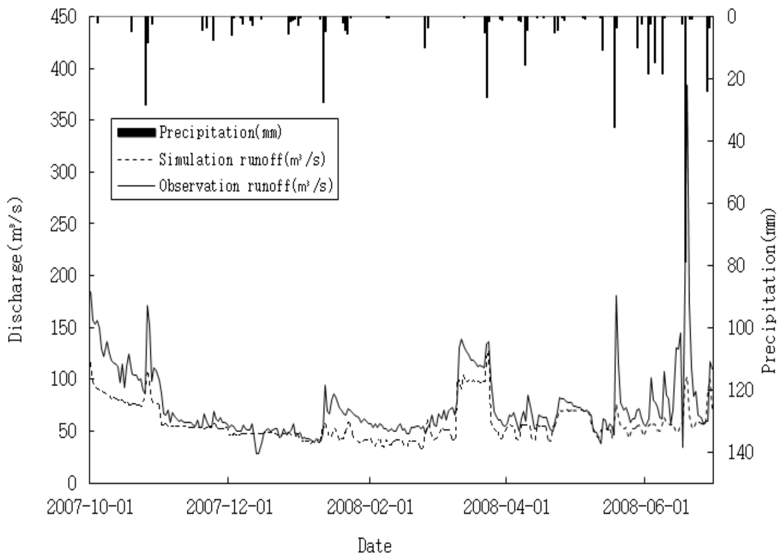

Figure 6. Runoff curve before calibration at Gongju

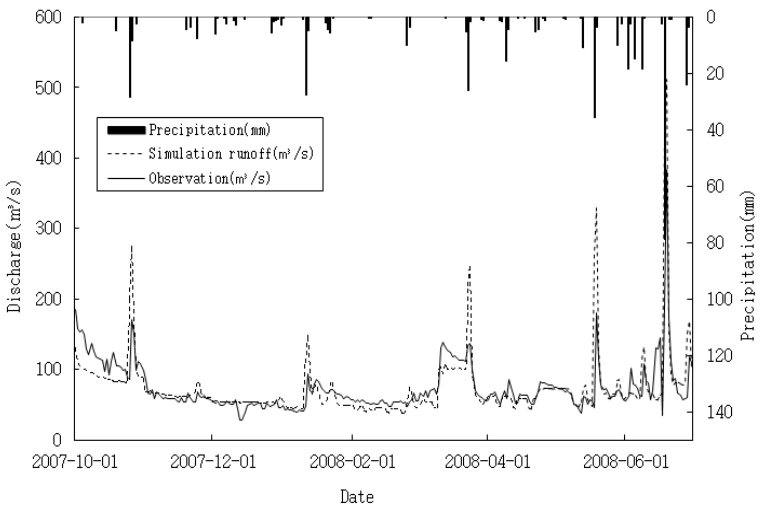

Figure 7. Runoff curve after calibration at Gongju

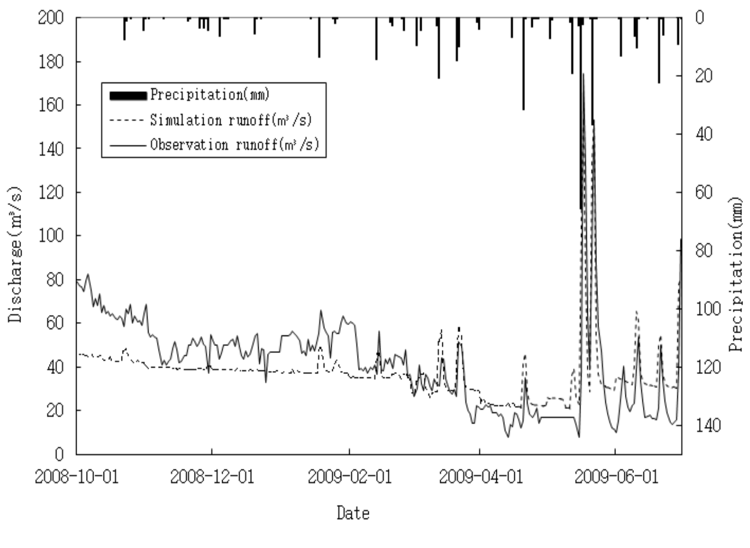

Figure 8. Verification of model at Gongju

3.3. Verification and Review of the Performativity of the Developed Model

Schematic procedures to use the long-term runoff model mounted on the River Flow Management System were presented, and the simulated runoff within the system was standardized so that it could be estimated in the 5 rivers and 8 watercourses using the same methods. In addition, a cross-linked system between the models was constructed so that the simulated runoff estimated by the long-term runoff model could be used as input data for the linked operation model for the dam and the small dam.

4. CONCLUSION

This study used the SSARR model to create the runoff model as an accompanying procedure for joint operation of dams required to effectively secure and manage water resources from the 5 rivers and 8 watercourses.

We selected the SSARR model as base model that can reflect the current status of water use and physical characteristics of upper dams in the 5 rivers and 8 watercourses. We classified the object, the 5 rivers and 8 watercourses, into so many areas; collected precipitation data and basic hydrological data; calculated the size ratio of areas in the 5 rivers and 8 watercourses; and made use of them as input data of the SSARR model.

The results of this study will be used as basic future data and technology for optimized water management of the 5 rivers and 8 watercourses.

AKCNOWLEDGEMENT

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