Storage Estimation of Irrigation Reservoir Using BROOK90-R Hydrological Model

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Abstract**—**This study has developed the BROOK90-R hydrological model. The model is modified the BROOK90 to estimate storage of irrigation reservoir take into account the behavior of floodgate manager. The BROOK90-R shows a significantly high efficiency during irrigated season. However, the model had a low efficiency during non-irrigated season. Despite the limitation of simulation, the model can be used to estimate the storage of irrigation reservoir which will be operated by a farmer.

Keywords**—** BROOK90-R, Irrigation reservoir, Water balance, Storage estimation.

I. INTRODUCTION

THE irrigation reservoirs can be used for various purposes such as water supply, flood control, and recreation. Recently, the construction and operation of reservoir has focusing on a method for mitigation of drought in small watershed located in mountain area [1]. That region is vulnerable to extreme low flow occur due to the low storage capacities of the groundwater bodies [5], [12]. The storage of irrigation reservoir is an important basic data to developing the proactive strategies to mitigate the drought.

Inter-annual variation of the storage can be obtained from long-term monitoring, but it has a limitation in terms of time and cost. Therefore, hydrological model has been used for the storage estimation. The hydrological model is helpful to represent the physical processes in the back sub-watershed and reservoir. In previous studies, the long-term rainfall-runoff models such as the Soil and Water Assessment Tool (SWAT), Semi-distributed Land Use-based Runoff Processes (SLURP), Streamflow Synthesis and Reservoir Regulation (SSAR), and Catchment hydrologic cycle Assessment Tool (CAT) were often used [3], [6], [7].

In the hydrological model, the water balance for a reservoir is composed of the volume of water entering the water body, the volume of water flowing out of the water body, precipitation falling on the water body, the water lost from the water body by evaporation and seepage. The storage of a particular date is calculated by using these components. The amount flowing out is determined by an operation rule of reservoir. Simulation or optimization method such as linear programming or dynamic programming has been employed as a rule [15].

However, the amount flowing out of many small irrigation reservoirs is usually determined by experimental operation of floodgate manager. The manager generally is a person of local farmers for each reservoir. Their operating rules could be modeled by the interviews with them. This study focused on modifying BROOK90 hydrological model (here-after BROOK90-R) to consider behavior of floodgate manager for storage estimation of irrigation reservoir and evaluating the model performance.

II. METHODS AND MATERIALS

A. *Concept of BROOK90-R*

The BROOK90 is a physically-based, deterministic and process-oriented, parameter hydrological model [2]. It is a one-dimensional model designed to study the processes of daily evaporation and soil water movement, with provision for streamflow generation by different flow paths. This model allows the leaf area index (LAI) to vary throughout the year, despite it being a lumped hydrological model. This model uses relative LAI between 0 and 1. The value is an array of ten pairs of DOY (day of the year). The relative LAI is a multiplier of the maximum LAI. However, this model without a parameter relates to artificial irrigation system such as an agricultural reservoir. A detailed description of the model used by [4].

BROOK90-R is modified the BROOK90 4.4.e [4] by adding a reservoir module in this study. The Fig. 1 shows the conceptual structure of BROOK90-R.

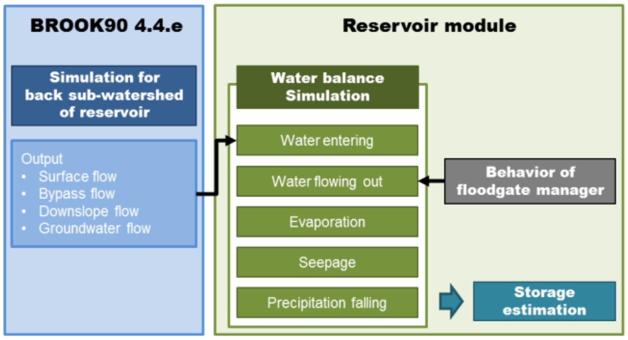

Fig. 1 The conceptual structure of the BROOK90-R

In the reservoir module, water balance of reservoir is defined (following [14]) by

$$V = V_y + V_i - V_o + V_p - V_e - V_s) \qquad (1)$$

where V is the volume of water in the impoundment at the end of the day (m^3), V_y is the volume of water stored in the water

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body at the beginning of the day (m^3), V_i is the volume of water entering the water body during the day (m^3), V_o is the volume of water flowing out of the water body during the day (m^3), V_p is the volume of precipitation falling on the water body during the day (m^3), V_e is the volume of water removed from the water body by evaporation during the day (m^3), and V_s is the volume of water lost from the water body by seepage (m^3).

The volume of water entering is sum of surface flow, bypass flow, downslope flow, and groundwater flow. The volume of evaporation from the water body calculated by the equation [9]:

$$E_p = \frac{\Delta(R_n - S) + \gamma E_a}{\Delta + \gamma} \tag{2}$$

$$E_a = f(u_2)(e_s - e_a) = c(a + bu_2)(e_s - e_a) \tag{3}$$

$$f(u_2) = c(a + bu_2) \tag{4}$$

where E_p is the evaporation from the water body (mm/d), Δ is the slope of the saturation vapor pressure-temperature curve (mb/^{o}C), S is the soil heat flux, R_n is the net irradiance (mm/d), γ is the psychrometric constant (mb/^{o}C), E_a is an atmosphere drying power function which represents the capacity of the atmosphere to transport water vapor (mm/d), u_2 is the wind speed at a height of 2 meters above the surface (m/s), e_s is the saturated vapor pressure of air, as is found inside plant stoma (mb), e_a is vapor pressure of free air (mb), (e_s - e_a) is the vapor pressure deficit (mb), a=0.5, b=0.54 and c=0.26 are Penman's experimental constants [8].

The volume of water flowing out of the water body is calculated by six parameters related with the behavior of floodgate manager in terms of withdrawal as shown in Table 1. The daily flowing out volume calculate by *MXV* times *RAT*. The manager opens the floodgate at a constant rate (*RAT*) during from *SOD* to *EOD*. However, if the *CLS* satisfied the specific condition, the manager closes the floodgate and the *RAT* is zero.

These parameters were composed by an interview with the floodgate manager of Deoksan Reservoir. The flood gates of Deoksan usually open from April 12 (102 DOY) to September 30 (273 DOY). The parameter values were applied to Yangak reservoir. MXV was used as a fitting parameter in the study.

TABLE I
THE PARAMETERS RELATED WITH THE BEHAVIOR OF FLOODGATE MANAGER

Parameter	Description	Value	
		Deoksan	Yangak
MXV (m^3/d)	Maximum daily withdrawal though floodgate	18,000	32,000
RAT (%)	Opening rate of floodgate	100	100
SOD (DOY)	The day to start flowing out	102	102
EOD (DOY)	The day to end flowing out	273	273
CLS (%)	Storage condition to closing floodgate	60	60

DOY = Day of the year, it is a number between 1 and 365

The effect of soil heat flux (S) can be ignored when daily mean or monthly mean climate data used in the calculation [10]. R_n is calculated by equation of [13].

B. Study area

The study areas are Deoksan and Yangak irrigation reservoirs. These study areas are located in the central mountainous region of the South Korea (Fig. 2). The Deoksan reservoir was constructed in 1981 and the original design storage capacity was 1,591,000 m^3. The Yangak reservoir was constructed in 1991 and the original design storage capacity was 3,280,000 m^3. The back sub-watershed areas of the Deoksan and Yangak reservoirs are 9.3 km^2 and 13.1 km^2, respectively.

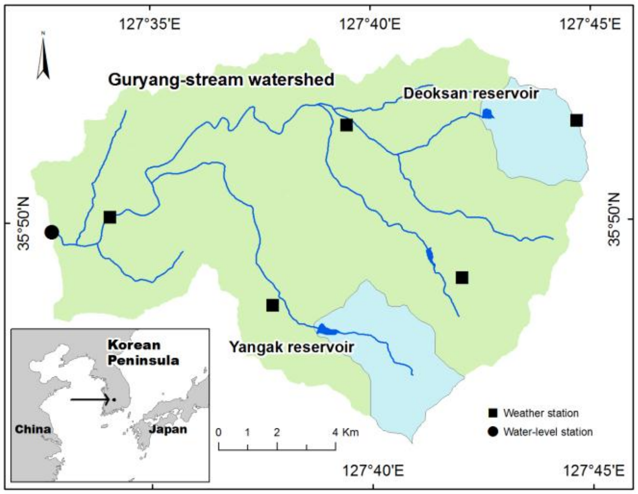

Fig. 2 The Study area

C. Data

The daily discharge records needed for calibration of hydrological model are not available in this study area. To solve the problem, this study calibrated the model using discharge data from the higher order watershed which is Guryang-stream watershed. The calibrated input data in Guryang-stream watershed are applied to the two study watersheds.

Seven years (from 2000 to 2007) of historical weather data was obtained from the Korean Meteorological Administration. The flow data was obtained from the WAMIS (http://www.wamis.go.kr). The data of the year 2000 was used to initialize the model. The soil and canopy parameter of the model were derived from the national land-use map 2001 and national digital soil map.

Four years of historical flow data covering the period from 2001 to 2004 are used for model calibration, while the next three years of data from 2005 to 2007 are used for model validation.

D. Evaluation of the model

In Guryang-stream watershed, Nash-Sutcliffe efficiency [11] was employed to evaluate the model performance. The storages of the reservoirs estimated using BROOK90-R compared with the measured values by the Korean Rural Community Corporation.

III. RESULTS

The overall model performances were good in the Guryang watershed. Fig. 3 shows measured and simulated daily discharge during the validation period (2005 to 2007). The simulated daily discharge was comparable with the measured values over the entire simulation period and the Nash-Sutcliffe efficiency was 0.78. However, the simulation efficiency is likely to vary depending on the season. The Nash-Sutcliffe efficiency was 0.77 in the wet season (June to September), while it was close to zero in the dry season (October to May).

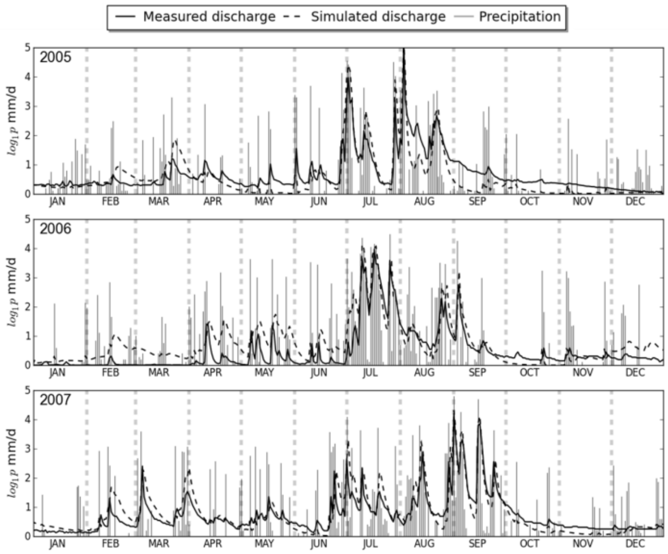

Fig. 3 Measured and simulated daily discharge (2005~2007).

The measured annual mean discharge of the Guryang watershed was 718.5 mm/yr, while the simulated discharge was 945.6 mm/yr in the validation period (Table II). The model was overestimated the discharge both in the wet and dry seasons. The simulated discharge was approximately 131% of the measured discharge.

The annual mean discharge was simulated by 866.4 mm/yr in the Deoksan watershed. The annual mean discharge was simulated by 837.4 mm/yr in the Yangak watershed.

TABLE II
ANNUAL MEAN WATER BALANCE IN THE STUDY AREAS FROM 2005 TO 2007

Component	Guryang watershed	Deoksan watershed	Yangak watershed
Precipitation (mm/yr)	1475.1	1660.5	1588.4
Measured discharge (mm/yr)	718.5	-	-
Dry season	114.5	-	-
Wet season	604.0	-	-
Simulated discharge (mm/yr)	945.6	866.4	837.4
Dry season	170.1	125.1	120.4
Wet season	775.4	741.3	717.0

TABLE III
DAILY MEAN STORAGE OF THE RESERVOIRS FROM 2001 TO 2007

Component	Deoksan reservoir	Yangak reservoir
Annual		
Measured daily mean (%)	80.4	88.3
Simulated daily mean (%)	84.4	86.6
Irrigated season (Apr. to Sep.)		
Measured daily mean (%)	81.6	88.8
Simulated daily mean (%)	85.3	86.1
None-irrigated season (Oct. to Mar.)		
Measured daily mean (%)	79.2	87.9
Simulated daily mean (%)	83.4	87.1

The water balances in the two reservoirs was simulated by BROOK90-R. As shown in Table III, the simulated storages were overall higher than the measured values in the Deoksan reservoir. On the other hand, the simulated values were lower in the Yangak reservoir. Fig. 4 shows the measured and simulated daily mean storage from 2001 to 2007. Changes of the two lines are similar to each other, and the overall R^2 in the Deoksan and Yangak were 0.62 and 0.38, respectively.

However the simulated storage rate is increased, while the measured value decreases in August. In addition, systematic errors are observed in the Yangak reservoir. This means that the behavior of the floodgate manager of Yangak could be different in the Doeksan. Future studies will require addressing these issues. For example, it is necessary to study in more detailed classification of the behavior of the floodgate manager.

Despite the limitation of simulation, the BROOK90-R could be used to estimate the storage of irrigation reservoir.

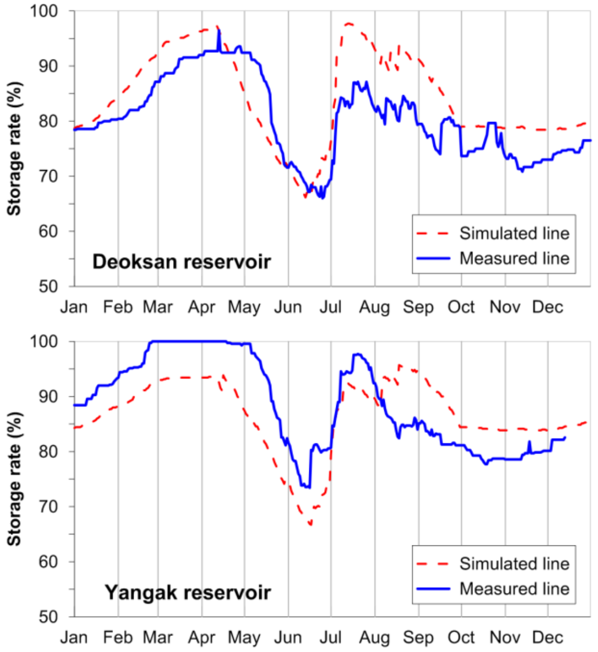

Fig. 4 Daily mean storages of reservoirs from 2001 to 2007.

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REFERENCES

[1] B. Tomas, J. Steidl, O. Dietrich, and G. Lischeid, "Measures to sustain seasonal minimum runoff in small catchments in the mid-latitudes: A review," *Journal of Hydrology*, vol. 408, pp. 296-307, October 2011 http://dx.doi.org/10.1016/j.jhydrol.2011.07.045

[2] C. A. Federer, C. Vörösmarty, and B. Fekete, "Intercomparison of methods for calculating potential evaporation in regional and global water balance models," *Water Resource Research*, vol. 32, pp. 2315–2321, July 1996.
http://dx.doi.org/10.1029/96WR00801

[3] C. H. Jang, H. J. Kim, and J. T. Kim, "Prediction of Reservoir Water Level using CAT," *Journal of the Korean Society of Agricultural Engineers*, vol. 54, no. 1, pp. 27-38, January 2012
http://dx.doi.org/10.5389/KSAE.2012.54.1.027

[4] C.A. Federer, C. Vörösmarty, and B. Fekete, "Sensitivity of annual evaporation to soil and root properties in two models of contrasting complexity," *Journal of Hydrometeorology*, vol. 4, pp. 1276-1290, December 2003.
http://dx.doi.org/10.1175/1525-7541(2003)004<1276:SOAETS>2.0.CO;2

[5] D. Niehoff, U. Fritsch, and A. Bronstert, "Land-use impacts on storm–runoff generation: scenarios of land-use change and simulation of hydrological response in a meso-scale catchment in SW-Germany," *Journal of Hydrology*, vol. 267, pp. 80–93, October 2002
http://dx.doi.org/10.1016/S0022-1694(02)00142-7

[6] G. W. Kite, "Modeling the mekong : hydrological simulation for environmental impact studies," *Journal of Hydrology*, vol. 253, pp. 1-13, November 2001
http://dx.doi.org/10.1016/S0022-1694(01)00396-1

[7] H. Kwon, J. H. Lee, Y. K. Lee, J. W. Lee, S. W. Jung, and J. Kim, "Seasonal variations of evapotranspiration observed in a mixed forest in the Seolmacheon catchment," *Korean Journal of Agricultural and Forest Meteorology*, vol. 11, pp. 39-47, February 2009
http://dx.doi.org/10.5532/KJAFM.2009.11.1.039

[8] H. L. Penman, "Natural evaporation from open water, bare soil and grass," Proc. Roy. Soc. London, vol. A193, pp. 120-146, April 198.

[9] J. D. Valiantzas, "Simplified versions for the Penman evaporation equation using routine weather data," *Journal of Hydrology*, vol. 331, pp. 690-702, December 2006
http://dx.doi.org/10.1098/rspa.1948.0037.

[10] J. E. Nash, and J. V. Sutcliffe, "River flow forecasting through conceptual models. Part I a discussion of principles," *Journal of Hydrology*, vol. 10, pp. 282~290, April 1970.

[11] J. F. Exbrayat, N. R. Viney, J. Seibert, S. Wrede, H.-G. Frede, and L. Breuer, "Ensemble modelling of nitrogen fluxes: data fusion for a Swedish meso-scale catchment," *Hydrol. Earth Syst. Sci.*, vol. 14, no. 12, pp. 2383–2397, December 2010
http://dx.doi.org/10.1016/0022-1694(70)90255-6

[12] R. G. Allen, L. S. Pereira, D. Raes, and M. Smith, "Crop evapotranspiration-guidelines for computing crop water requirements," *FAO Irrigation and Drainage Paper*, vol. 56, pp. 2-15, 1998
http://dx.doi.org/10.5194/hess-14-2383-2010

[13] S. L. Neitsch, J. G. Arnold, J. R. Kiniry, and J. R. Williams, *Soil and Water Assessment Tool Theoretical Documentation*. Temple, Texas, 2005, pp. 430-432.

[14] J. K. Choi, J. G. Son, J. W. Koo, and Y. J. Kim, "Storage Estimation of Irrigation Reservoir by Water Balance Analysis," *Journal of Korean Society Of Rural Planning*, vol. 9, no. 4, pp. 1-7, December 2003.

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