JOURNAL OF THE KOREAN SOCIETY OF AGRICULTURAL ENGINEERS DEC. 2004, pp.71-80

JOURNAL OF THE KOREAN SOCIETY OF AGRICULTURAL ENGINEERS, Vol. 46, No. 7

A System for Estimating Daily Paddy Irrigation Water Requirements in Simulating Daily Streamflow

Noh, Jaekyoung*

Abstract

A system for estimating daily paddy irrigation water requirements was developed to simulate daily stream flows that reflect various upstream and downstream return flows from river basin. Evapotranspiration in paddy fields was estimated using the modified Penman equation. Daily irrigation water requirements of paddy fields were calculated by multiplying the paddy area and the daily decrease in ponding depth. The system was constructed almost completely using images, grids, etc. in Visual Basic 6.0. The developed model was verified in the Damyang dam, and was used to estimate daily paddy irrigation water requirements at 12 small watersheds in Geum river basin for 20 years, from 1983 to 2002, covering paddy field areas of 3,332~26,422 ha. The results on the runoff analysis on the inflow to the Daecheong multi-purpose dam with various return flows were satisfactory. They were reasonable compared to the scenario where return flows were not considered.

Keywords : water supply capacity, reservoir inflow, water balance, water demand

I. Introduction

Covering an area of 11,267 ㎢, the paddy fields occupy 11.3% of the total land area in South Korea, which is 99,601 ㎢. Given the large water storage capability of paddy fields, irrigation water to paddy areas also largely affects runoffs in watersheds. Therefore, irrigation water to paddy areas must be estimated and applied to simulate stream flows that will be suitable for runoffs in the Korean peninsula.

The status of upstream and downstream stream flows is the basic and kernel element in operating an integrated and effective real-time water management system. Stream flows at one point along a river add natural flows to the results that correspond to return flows from upstream agricultural, domestic, and industrial waters.

Irrigation water requirements largely vary compared with those of domestic and industrial waters. Runoff models, such as the tank model (Lee et al., 2003), SSARR model (KOWACO, 1996), DAWAST model (Noh, 1991), TPHM

* Department of Rural Infrastructure Engineering, Chungnam National University
* Corresponding author. Tel.: +82-42-821-5796
Fax: +82-42-822-5796
E-mail address: jknoh@cnu.ac.kr

(Kim, 2001), and SWAT model (Kim et al, 2003), have been applied to Korean watersheds. These models are difficult to simulate natural flows since each simulates a runoff, not considering return flows from various water demands.

The objective of this study is to construct an easy and user-friendly system to estimate the irrigation water requirements of paddy fields to provide estimated paddy irrigation water data in simulating runoff considering return flows which is principal element in real-time integrated water management system operated in river boundary scale.

Ⅱ. Design of the System

Irrigation water requirements of paddy fields are estimated to consider evapotranspiration, infiltration, and effective rainfall. The rate of evapotranspiration is affected by meteorological conditions, such as duration of sunshine, temperature, humidity, and wind speed. Infiltration is determined by factors such as soil properties, types and groundwater level. The amount of water used in cultivating rice and in managing hydraulic facilities are also considered. Paddy water requirements are calculated to consider values obtained by multiplying the paddy area, adding decreasing ponding depth and subtracting effective rainfall and taking into account additional various losses.

Evapotranspiration is estimated using the modified Penman equation of Doorenbos and Pruitt (FAO, 1977). The Penman equation (1) is used mainly in irrigation scheduling because daily evapotranspiration is estimated by meteorological data.

$$ET_O = C\ [W \cdot Rn + (1-W) \cdot f(u) \cdot (e_a - e_d)] \quad (1)$$

where ETo represents the potential evapotranspiration (mm/day), W the weighing coefficient on temperature, Rn the net solar radiation (mm/day), f(u) the function of wind speed, $(e_a - e_d)$ the difference between saturation vapor pressure and mean vapor pressure at average air temperature, and C the coordinating factor according to meteorological conditions.

The irrigation water requirements of rice in paddy fields are estimated using Equation (2):

$$Req(t) = ET(t) + I - Re(t) \cdots\cdots\cdots\cdots (2)$$

where Req is the irrigation water requirements of paddy fields, ET the evapotranspiration, I the infiltration, Re the effective rainfall, and subscript t the day.

Irrigation water requirements of paddy fields are estimated on a daily basis by ponding depth and effective rainfall. Ponding depths in paddy fields are calculated using the water balance equation (3). Effective rainfall is calculated using Equation (4).

$$D(t) = D(t-1) + Re(t) + Req(t) - U(t) \cdots\cdots (3)$$

$$Re(t) = D(t) - D(t-1) - Req(t) + U(t) \cdots\cdots (4)$$

where D is the ponding depth in paddy fields, Re the effective rainfall, Req the irrigation water requirement, and U the water consumption out of actual evapotranspiration and infiltration. Subscript t denotes time.

The cultivation of transplanting rice is composed of seed plot period, number of transplanting days, and main plot period. The seed plot period is approximately 45 days, whereas the

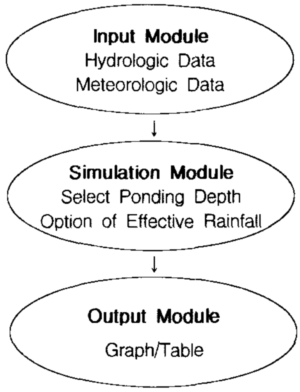

Fig. 1 Schematic diagram for the system's design

duration of transplanting rice is 15 to 20 days. The period of cultivating rice is from the first 10 days in April to the second 10 days in September, including the seed plot period.

A system for estimating the irrigation water requirements of paddy fields was designed to use only one form in Visual Basic Version 6.0. The system was composed of input, simulation, and output modules as shown in Fig. 1. The input module was designed to treat daily hydrologic and meteorological data. The simulation module was designed to select ponding depth and to decide whether effective rainfall should be included. The output module was designed to consist of superposing the PictureBox Control for graphs and the FlexGrid Control for tables.

Ⅲ. Development of System

The system was constructed to enable practitioners to use their PC's to estimate the irrigation water requirements of paddy fields. Input, simulation, and output modules were constructed in only one form, using Visual Basic Version 6.0. Menus, command buttons, and labels in the system were written in Korean to provide Korean hydrological engineers with easy and user-friendly instructions. Various controls in the frame were on the left side of the form to manipulate input, simulation, and output data. The picture box and grid controls were superposed at the center of the form to show outputs in graphs or tables.

The data entered in the input frame include the watershed area, latitude, longitude, first day of irrigation, paddy area, infiltration, water consumption ratios on the use of hydraulic facilities, and cultivation management. The initial action taken involved selecting the option of 60 mm and 80 mm ponding depth in the simulation frame, to select whether or not to consider effective rainfall, to choose the option of observed and simulated pan evaporation, and to push the command button to start estimating paddy irrigation water requirements daily. Results in the output frame include graphs for year-round and one-year daily paddy estimated irrigation water requirements, tables for daily and yearly estimated results, rainfall, evaporation, evapotranspiration, ponding depth, water consumption, etc.

Fig. 2 shows the system and an example of estimated daily paddy irrigation water requirements. The graph above tallies daily rainfall, evaporation, evapotranspiration, ponding depth, and paddy water requirements. Fig. 3 shows the daily rainfall, evaporation, evapotranspiration, ponding depth, and paddy irrigation water requirements covering the period under study. Fig. 4 shows the table expressing daily rainfall, evaporation, evapotranspiration, ponding depth, and paddy irrigation water requirements.

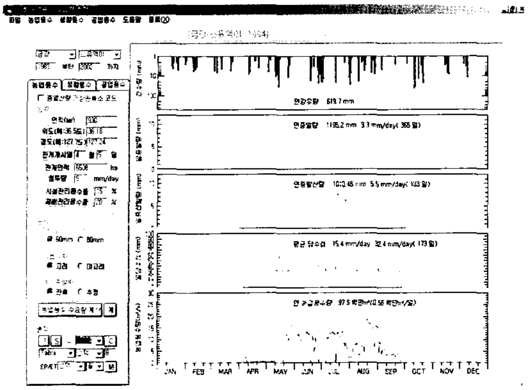

Fig. 2 Example of simulated daily paddy irrigation water requirements

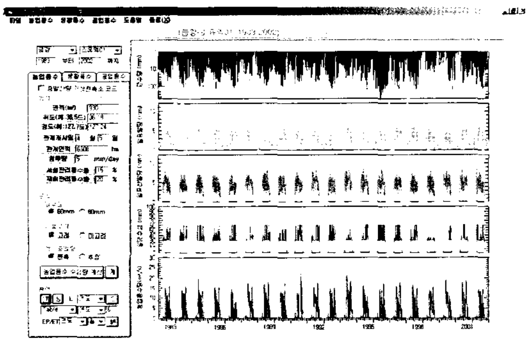

Fig. 3 Example of simulated long-term daily paddy irrigation water requirements

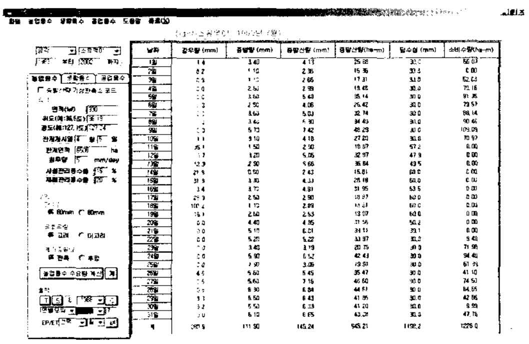

Fig. 4 Table of simulated daily paddy irrigation water requirements

Ⅳ. Verification of System

The developed system is used to estimate irrigation water requirements in a large paddy irrigation districts on a daily basis. Estimated paddy irrigation water requirements is applied to calculate return flows for simulating runoffs in a small watersheds in integrated real-time water management system. But water use data from a large paddy irrigation districts are not available. Therefore developed system will be verified by comparing observed reservoir storages with simulated reservoir storages. Paddy irrigation water will be supplied from agricultural reservoir.

1. Study Area

The Damyang dam was selected to verify a system for estimating irrigation water requirements in a large paddy irrigation districts. This reservoir was constructed in 1976, is situated at latitude of 35°22′24″ and longitude of 127°0′5 0″ in Jeonnam province in Korea, has irrigated area of 5,011 ha, effective capacity of 64.8 Mm^3, and watershed area of 65.6 km^2. Fig. 5 shows watershed of this reservoir.

The relationships between elevation and water surface area, storage volume were shown in Fig. 6. Full water level is 119.5 m above sea water level, and dead water level is 80.0 m.

Land uses within the watershed of the Damyang dam are consisted of forest areas of 85%, paddy areas of 10%, and residential areas of 5%.

Meteorologic data of temperature, humidity, sunshine duration, and wind velocity in the Gwangju meteorologic station were used on a

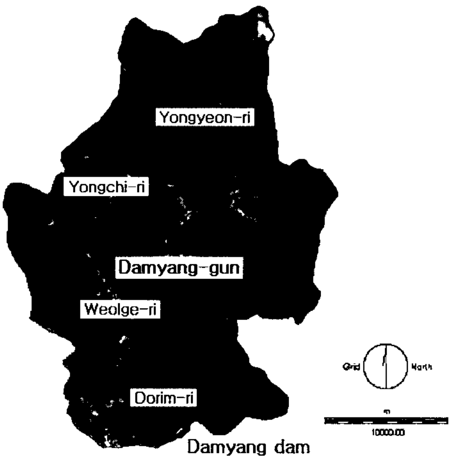

Fig. 5 Watershed of the Damyang dam

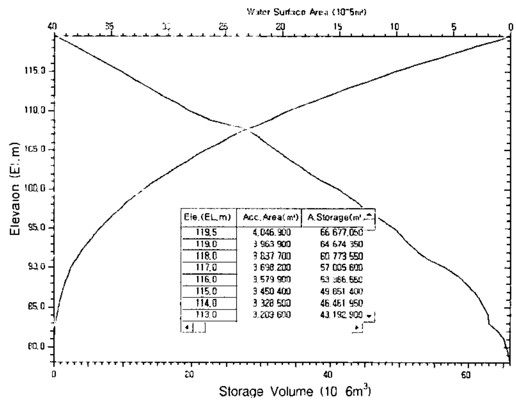

Fig. 6 Area-capacity curve of the Damyang dam

daily basis. But evaporation has not observed after 1991, that in the Mokpo station was used. And rainfall and operation data of the Damyang dam were used.

2. Calibration

Water storage volumes in agricultural reservoir are balanced by equation (5). Water are used only in storages between full water level and dead water level. If water is over full water level, overflows happen. And if water is below dead water level, water supply will be zero. Inflow to reservoir was simulated by the DAWAST model. Water demands are paddy irrigation water requirements which is estimated by the developed system. Outflows are stream minimum flows to be used to maintain water quality in streams in a appropriate level. Objective functions of minimizing storage errors were selected as shown in equation (6), (7) to parameterize inflow model (Noh, 2000). Simulation results are evaluated through Nash-Sutcliffe model efficiencies and equal lines.

$$Ss(t+1) = Ss(t) + I(t) - E(t) - D(t) - O(t) \cdots\cdots (5)$$

where Ss denotes reservoir water storages, I inflow to reservoir, E water surface evaporation, D water demand, O outflow, t time interval of daily basis.

$$\text{Min Se} = \Sigma(So-Ss) \cdots\cdots (6)$$

$$\text{Min Se} = \Sigma(So-Ss)^2 \cdots\cdots (7)$$

where Se denotes reservoir water storage error, So observed water storage, Ss simulated water storage.

The DAWAST model's parameters were determined as UMAX is 343 mm, LMAX 29 mm, FC 127 mm, CP 0.0216, and CE 0.0080 by the Simplex optimization method as shown in Fig. 7. UMAX denotes maximum water depth in unsatuated soil profile, LMAX maximum water depth in satuated soil profile, FC field capacity, CP coefficient of deep percolation, and CE coefficient of evapotranspiration in wateshed.

In calibration year of 1999, daily inflow to the Damyang dam was simulated as shown in Fig. 8 in which rainfall of 1,324 mm produced runoff of

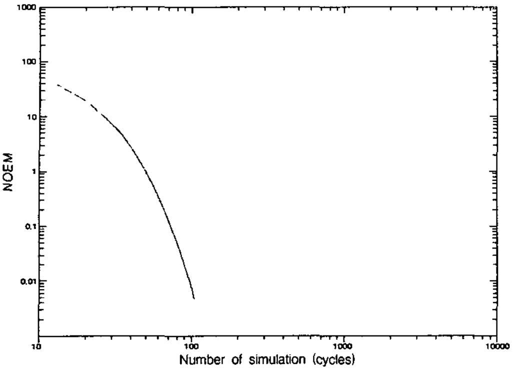

Fig. 7 Paramater optimization of the DAWAST model using objective function with minimization of reservoir storage error

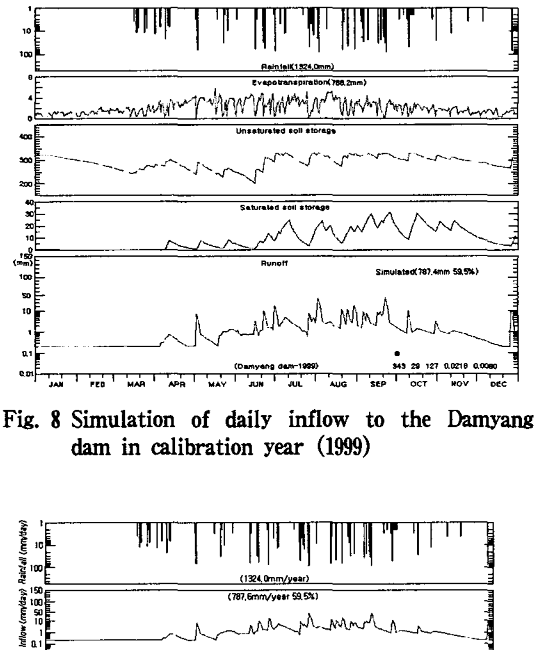

Fig. 8 Simulation of daily inflow to the Damyang dam in calibration year (1999)

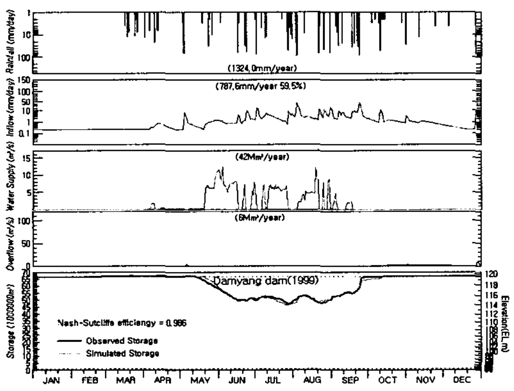

Fig. 9 Comparison of the observed storage and the simulated in the Damyang dam for calibration year (1999)

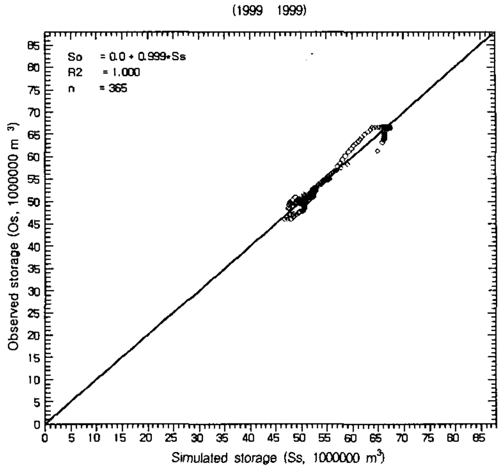

Fig. 10 Equal line comparison of the observed storage and the simulated in the Damyang dam for calibration year (1999)

787.4 mm for one year. And the observed storage and the simulated storage in the Damyang dam were very closely fitted to in Fig. 9 in which Nash-Schcliffe's model efficiency was shown to 0.986 very highly. Equal line between the observed storage and the simulated storage was very closely to 45° line.

3. Verification

Verification year was selected to 1999. Daily inflow to the Damyang dam was simulated as shown in Fig. 11 in which rainfall of 1,098.1 mm produced runoff of 546.1 mm for one year. And the observed storage and the simulated storage in the Damyang dam were very closely fitted to in Fig. 12 in which Nash-Schcliffe's model efficiency was shown to 0.951 very highly. Equal line between the observed storage and the simulated storage was very closely to 45° line.

Therefore the developed system was decided to be able to estimate daily paddy irrigation water requirements on a reasonable level.

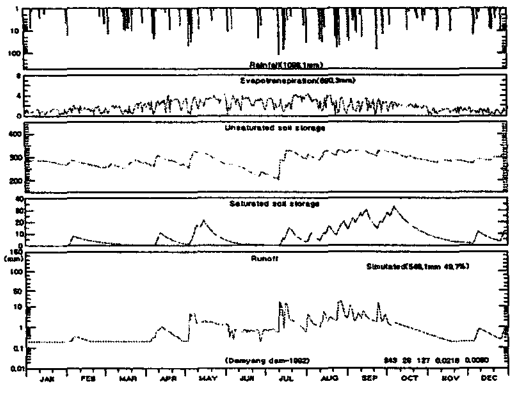

Fig. 11 Simulation of daily inflow to the Damyang dam in verification year (1992)

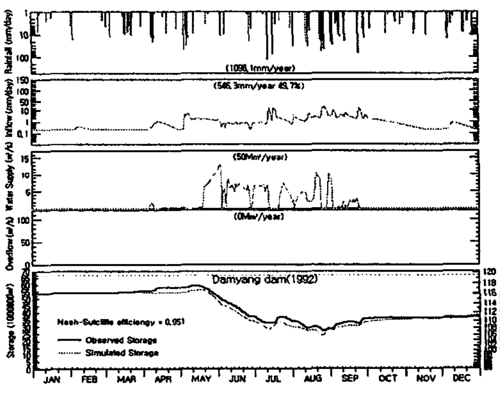

Fig. 12 Comparison of the observed storage and the simulated in the Damyang dam for verification year (1992)

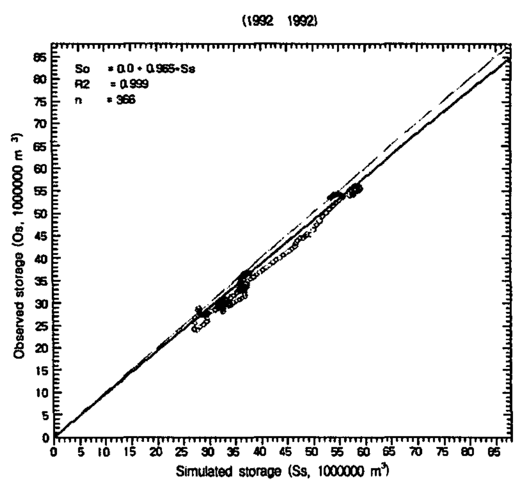

Fig. 13 Equal line comparison of the observed storage and the simulated in the Damyang dam for verification year (1992)

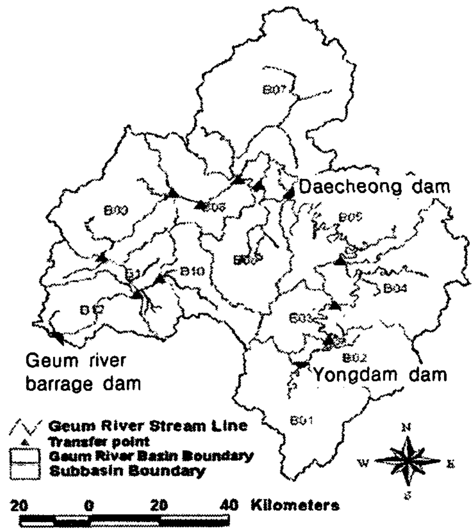

Fig. 14 12 sub watersheds in the Geum river basin

V. Application of System

1. Study Area

The developed system was applied to 12 sub-watersheds of the Geum river basin to estimate daily paddy irrigation water requirements that will be used to simulate runoff. Fig. 14 shows 12 sub-watersheds of the Geum river basin. The Geum River, which flows into the Yellow Sea from the middle part of the Korean peninsula, is 401 km long with basin area of 9,805 ㎢, which is equivalent to 10% land area of this country. As shown in Fig. 14, the Daecheong multi-purpose dam is situated in the middle stream of the Geum River and the Yongdam multi-purpose dam is in the upstream, whereas the Geum River estuarine barrage is in the river estuary.

2. Estimating Paddy Irrigation Water Requirements

Using the developed system, daily paddy irrigation water requirements were estimated in 12 sub- watersheds of the Geum river basin for the last 20 years, from 1983 to 2002. Effective rainfall was considered, ponding depth was set at 60 mm, infiltration depth was 5 mm, ratio of canal system water requirement was at 15 %, and ratio of lot management water requirement was at 20 %. Fig. 15 shows an example of estimating daily paddy irrigation water requirements wherein rainfall was 1,289.2 mm, pan evaporation 939.6 mm (2.6 mm/day), evapotranspiration 830.7 mm (4.5 mm/day), mean ponding depth 36.5 mm, and paddy water requirements 66.7 Mm³ for a period of one year. The annual average for the last 20 years, from 1983 to 2002, of the 12 sub watersheds included annual paddy irrigation water requirements ranging from 37.22 Mm³ to 294.54 Mm³ as shown in Table 1.

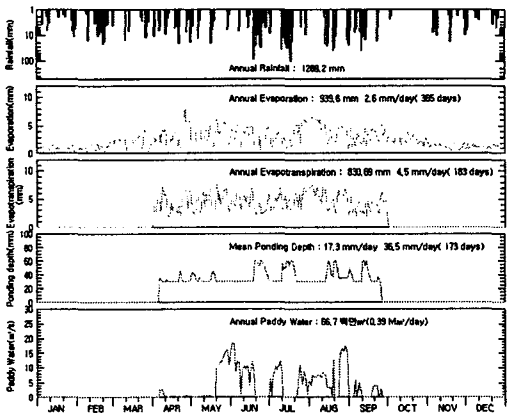

Fig. 15 Example of estimating daily paddy irrigation water requirements

Using this developed system, paddy irrigation water requirements will be estimated recursively until the runoff analysis reflecting water demands shows reasonable results.

3. Application of Paddy Water Values to the Runoff Analysis

The runoff analysis that considered return flows from water demands was found to be using inflows to the Daecheong multi-purpose dam. Using this analysis, the viability of the developed system was validated. Fig. 16 shows water demands within the watershed of the Daecheong multi-purpose dam, wherein paddy water requirements were estimated using this developed system and considering the domestic and industrial water demands that were based on the survey data of water consumption. The parameter optimization of the DAWAST model was calibrated using the Simplex method attached to

Table 1 Annual mean paddy irrigation water requirements in sub watersheds of the Geum river basin

item	sub 1	sub 2	sub 3	sub 4	sub 5	sub 6	sub 7	sub 8	sub 9	sub 10	sub 11	sub 12
watershed area (ha)	92,908	62,623	38,841	107,249	122,217	76,951	185,430	34,358	121,070	47,190	56,273	53,316
paddy field area (ha)	6,508	3,332	3,528	4,573	11,693	8,430	26,422	4,839	18,068	9,751	13,293	13,975
annual paddy water (Mm³)	73.16	37.22	39.56	51.04	129.65	93.51	294.53	52.16	201.41	110.69	151.94	161.24

the model system (Noh, 1999). Fig. 16 shows an example of simulating daily inflows using the

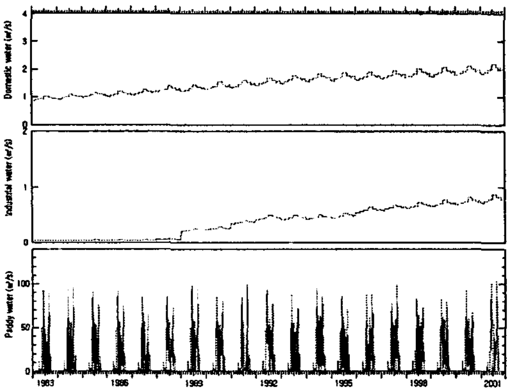

Fig. 16 Daily water demands within the Daecheong dam watershed

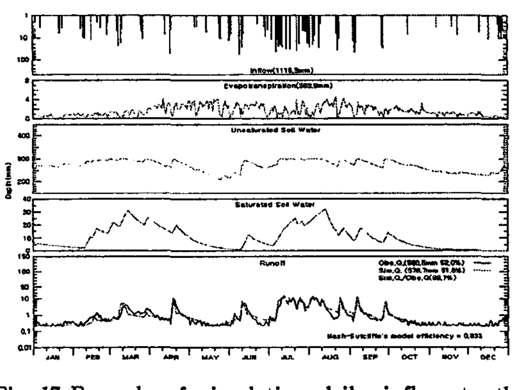

Fig. 17 Example of simulating daily inflow to the Daecheong multipurpose dam with return flows as considered in the DAWAST model

DAWAST model, considering return flows from various water demands (Noh *et al.*, 2003). The rates of return flows were applied to 35% for paddy water irrigation requirements and 65% for domestic and industrial water demands. The ratio of simulated inflow to observed inflow was highly reasonable at 99.7%. The annual average from 1983 to 2001 indicated that the ratio of simulated inflow to observed inflow was at 97.8%, compared to 90.9% in the runoff analysis without considering return flows as shown in Table 2. Therefore, the runoff analysis with return flows was confirmed to be superior to the one that did not consider return flows.

V. Conclusions

A system for estimating daily paddy irrigation water requirements was developed to enable hydrological practitioners to come up with easy and user-friendly runoff analyses.

The developed system was verified from analyzing the variation of water storage volumes in the Damyang dam on a daily basis, and was applied to the Geum river basin, where paddy irrigation water requirements were estimated on a daily basis. With paddy irrigation water require-

Table 2 Comparison of monthly inflows by the DAWAST model with and w/o return flows (mm) (1983~2001)

item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	year	Rq (%)	Sim/Obs (%)
OP	29.4	36.0	49.5	64.6	76.2	165.3	270.9	231.8	136.0	54.8	45.4	24.7	1184.6		
OQ	13.1	17.7	29.9	33.9	31.6	62.2	176.9	141.5	97.4	30.1	17.8	15.2	667.3	56.3	
EQ1	9.4	13.0	18.7	27.3	28.2	67.8	179.8	147.2	100.2	31.5	14.6	14.7	652.6	55.1	97.8
EQ2	8.6	12.1	17.5	26.3	27.3	57.9	171.4	137.0	91.1	29.7	14.1	13.8	606.8	51.2	90.9

remarks) OP: rainfall, OQ: observed inflow, EQ1: simulated inflow with considering return flows,
EQ2: simulated inflow w/o considering return flows, Rq: ratio of inflow to rainfall,
Sim/Obs: ratio of yearly simulated inflow to observed inflow

ments estimated from the developed system, the runoff analysis was complemented by the inflow to the Daecheong multi-purpose dam that considered return flows. Results were satisfactory compared to those that did not consider return flows.

Using this developed system, a practical water balance analysis is expected to be realized in sub watersheds.

Acknowledgement

This research was supported by a grant (code number 1-6-1) from Sustainable Water Resources Research Center of the 21st Century Frontier R/D Program.

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