JOURNAL OF THE KOREAN SOCIETY OF AGRICULTURAL ENGINEERS DEC. 2003, pp.1-10

JOURNAL OF THE KOREAN SOCIETY OF AGRICULTURAL ENGINEERS, Vol. 45, No. 7

Development of a Hydrologic System for Simulating Daily Water Storage in an Estuary Reservoir

Noh, Jaekyoung*

Abstract

In order to analyze the water supply capacity in an estuary reservoir, a system composed of daily water balance model and daily inflow model was developed. The agricultural water demands to paddy fields, domestic water demands to residential areas, and industrial water demands to industrial complexes were considered in this daily water balance model. Likewise, the outflow volume through sluice gates and inside the water level at the start of the outflow was initially conditioned to simulate estuary reservoir storage. The DAWAST model (Noh, 1991) was selected to simulate daily estuary reservoir inflow, wherein return flows from agricultural, domestic, and industrial water were included to simulate runoff. Using this system, the water supply capacity in the Geum River estuary reservoir was analyzed.

Keywords : Water supply capacity, Reservoir inflow, Water balance, Water demand

I. Introduction

Estuary reservoirs were constructed in three of the five largest Korean rivers: the Nakdong River, the Geum River, and the Yeongsan River. These estuary reservoirs were constructed to supply water, to alleviate inundation damages from floods, and to control damages from sea-water. The operation of an estuary reservoir is different from reservoirs situated in upstream basins because of the large amount of inflows, low water depths, and small storage capacities. To discharge a large volume of inflows to the sea, sluice gates were normally opened once every two or three days and two times a day during flooding. Therefore, water supplies in estuary reservoirs were limited compared to the up-stream dams. If the water level in an estuary reservoir increases, the chances of inundation in the riverside areas also increase. If the water level goes down, the ability to pump water from the reservoir becomes limited.

Waters originating upstream flow into estua-ries via various paths. They will be supplied to agricultural lands, municipal and industrial areas

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

to cope with increasing water demands. Many reservoirs have been constructed to use water resources from upstream watersheds. Land use, e.g., agricultural lands, industrial complexes, and residential areas, has largely changed. Therefore, the water supply capacity in an estuary reservoir must be analyzed systematically.

A kernel element must be able to estimate inflows accurately. Therefore, a runoff simulation module for simulating inflows must be attached to the system. Natural flows are equivalent to river flows that are added to return flows, which flow into rivers via watersheds from various water supplies. The national distribution of water resources in Korea is based on the water balance within sub-watersheds. The runoff in each sub-watershed is natural, followed by return flows from various water supplies. Runoffs are simulated by a tank model, in "Water Vision 2020" (Ministry of Construction and Transportation, 2000), and by the SSARR model in "Development of Real-time Optimal Operating System for Managing Low Flows in the Nakdong River Basin" (Korea Water Resources Corporation, 1996). The DAWAST model (Noh, 1991) introduced the concept of soil water storage to simulate runoff in Korea. The hyperbolic function was also used in expressing a soil water storage in TPHM (Kim, 2001). Likewise, CN was used in expressing a soil water storage in the SWAT model (Kim and Kim, 2003). The tank model was applied to the inflow simulation of the Soyanggang and Chungju Dams, considering the rate of snow accumulation and snow melting (Lee *et al.*, 2003). These models are not able to be accepted to simulate stream flows included return flows from various water supplies. On the other hand, the applicability of the DAWAST model was tested by simulating inflow to the Daecheong Dam after considering return flows from various water supplies (Noh *et al.*, 2003). By considering return flows, simulated inflows rated 97.8% over observed inflows. Excluding return flows, however, the ratio of simulated inflows to observed inflows was 90.9%. The simulated results considerably improved by considering return flows in the DAWAST model.

Water supply capacity is analyzed by simulating storage in reservoirs. The module for analyzing water supply capacity in reservoirs is included in the reservoir sizing support system (Kim and Noh, 2000). Various water demands are applied on a daily basis using this system.

The purpose of this study was to develop a computerized system for hydrological practitioners, who will then analyze water supply capacity in estuary reservoirs.

Ⅱ. Design of the System

A system for analyzing water supply capacity in estuary reservoirs was designed to consist of two basic modules. One module was for the daily inflow model, and the other module for the daily water balance model. Using only one form from Visual Basic Ver. 6.0, a systemized module was developed and designed to assign inflow analysis to Tab 1 control and to assign water balance analysis to Tab 2 control as shown in Fig. 1. The daily inflow models helped the water balance model. The output module was designed to superpose the PictureBox Control for graphs and the FlexGrid Control for tables.

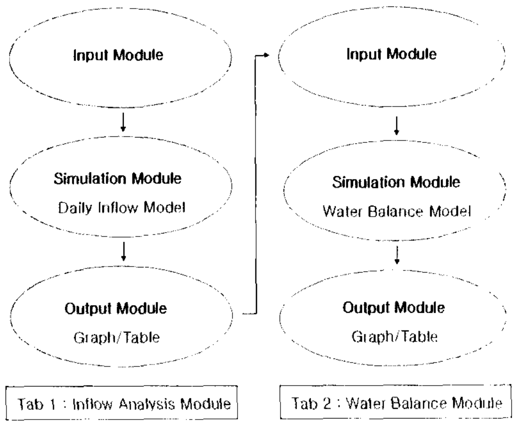

Fig. 1 Schematic diagram for a system design

Ⅲ. Development of the System

The inflow analysis module was based on the DAWAST model considered return flows, which was then used at the Daecheong multi-purpose dam. Its applicability was validated (Noh *et al.*, 2003).

The water balance in estuary reservoirs is different from that in the reservoir situated upstream. Outflows through the sluice gates have to be considered in water balance. Equation (1) expresses water balance through an estuary reservoir, whereas equation (2) expresses over-flow, amount above volume at full water level, and basic outflows to the sea:

$$S(i) = S(i-1) + Qkr(i) - EW(i) - AW(i) - DW(i) \cdots (1)$$

$$OV(i) = S(i) - Vfwl + SW(i) \cdots\cdots\cdots\cdots (2)$$

where S denotes water storage, Qkr inflow to the estuary reservoir, EW water surface evapo-ration, AW agricultural water demand, DW

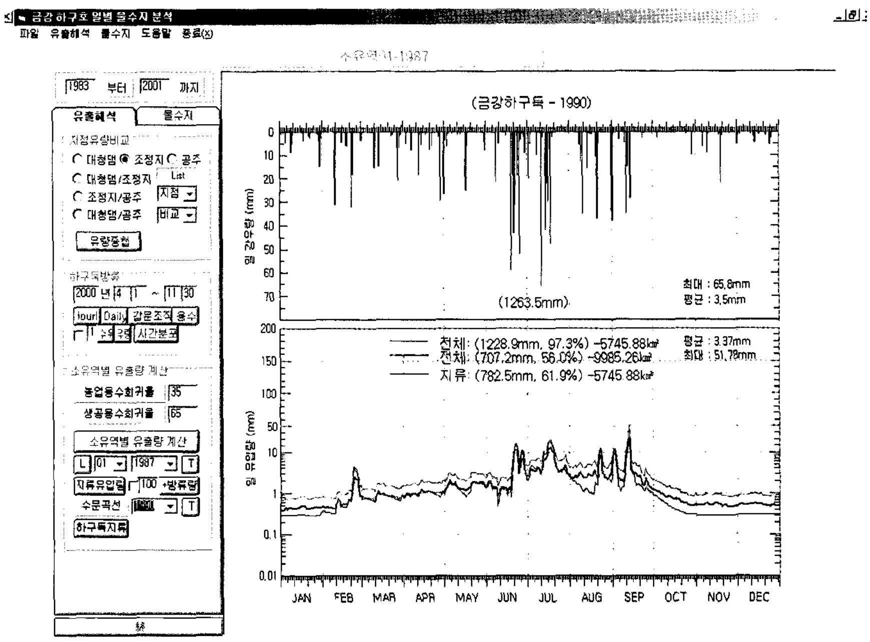

Fig. 2 Runoff analysis module

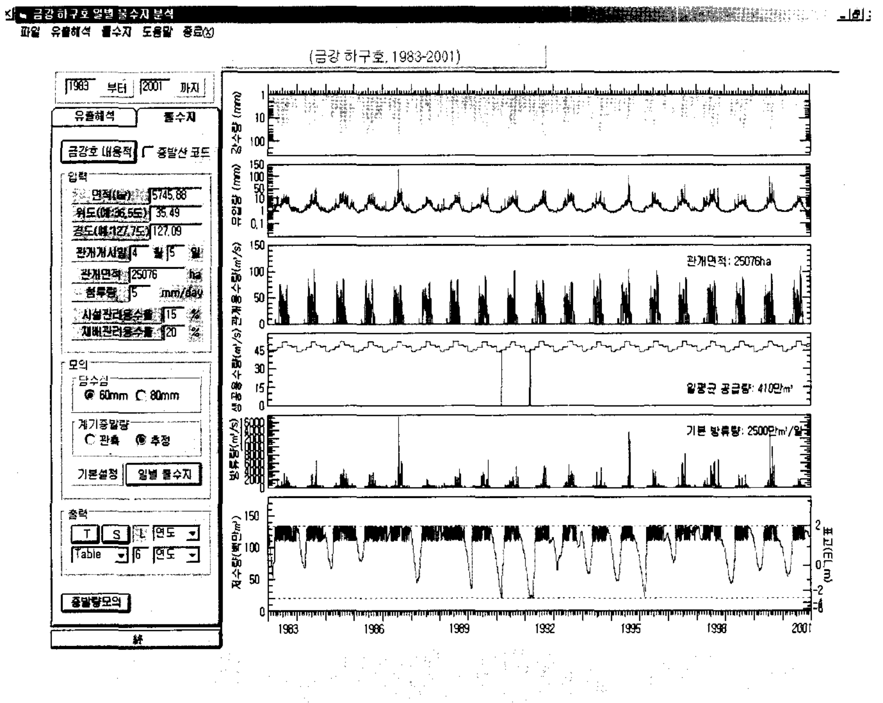

Fig. 3 Water balance analysis module

domestic and industrial water demand, OV overflow, Vfwl water volume at full water level, and SW basic outflows to the sea. Subscript (i) expresses time.

The water balance model was simulated on a daily basis, and the daily inflow data simulated by the DAWAST model considered return flows was inputted to a water balance model. Irrigation water requirements were estimated daily by calculating the values of the decreased pond depth in paddy fields and multiplied by the areas of the paddy fields. Domestic and industrial water demands were estimated by considering monthly weighing coefficients to average water demands. Water surface evaporation was considered in water storage levels.

The system was constructed very simply for practitioners to use on PC, wherein set the inflow analysis module to "Tab 1 control" as shown in Fig. 2 and the water balance analysis module to "Tab 2 control" as shown in Fig. 3. Menus, command buttons, and labels in the system were written in Korean to provide Korean hydrological engineers with easy and user-friendly instructions.

The inflow analysis module was constructed for simultaneous simulations in sub-watersheds, where upstream outflows must also be considered.

Ⅳ. Application of the System

1. Study Area

The developed system was applied to the Geum River estuary reservoir to analyze

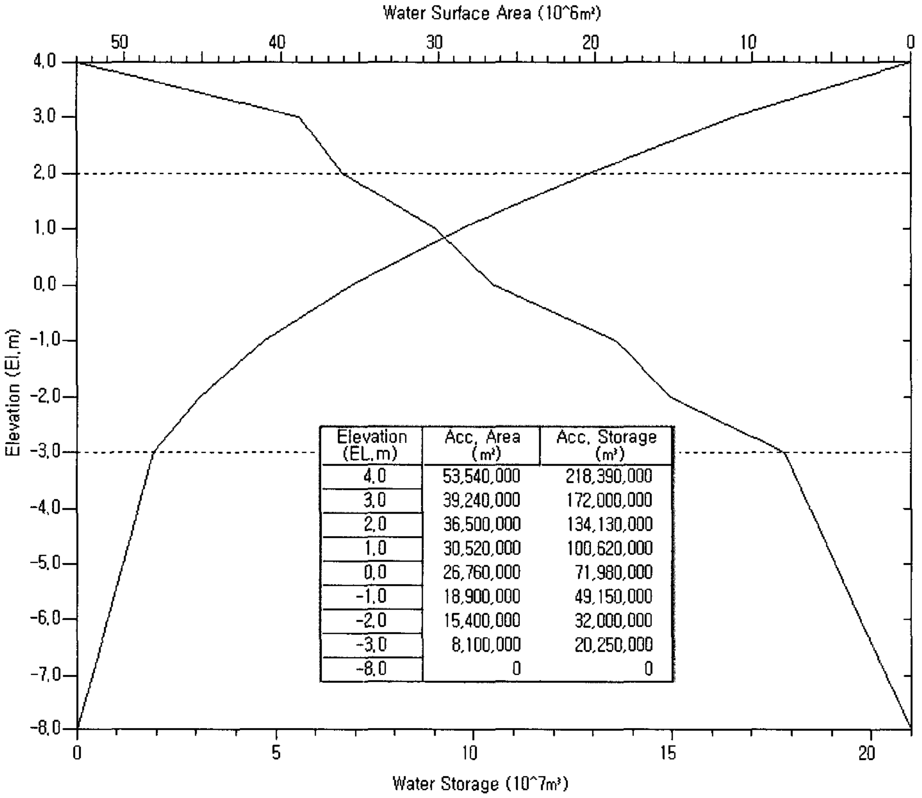

Fig. 4 Area capacity curve of the Geum River estuary reservoir

different water supplies in each scenario. Fig. 4 shows the area-capacity curve of the Geum River estuary reservoir, which had watershed area of 9,828 km^2, water surface area at full water level of 3,650 ha, maintaining water levels of EL.+2.00 m from March to June and EL+1.00 m from July to February, flood water level of EL+4.62 m, dead water level of EL−3.00 m, total storage capacity of 138 Mm^3, and effective capacity of 111.9 Mm^3. The annual amount of water supply was planned at a total of 365 Mm^3, of which 121 Mm^3 was allotted to domestic and industrial water supply and 244 Mm^3 to agricultural water supply. The maximum flood discharge was 13,000 m^3/s.

2. Inflow Analysis

Using the DAWAST model considered return flows in this developed system, inflows to the Geum River estuary reservoir were simulated by each sub-watershed downstream of the Daecheong multi-purpose dam. Each inflow simulated was summarized, and outflows from the Daecheong regulating dam were added. On a yearly average from 1983 to 2001, rainfall was 1,205.1 mm, inflow 676.0 mm, and rate of inflow to rainfall 56.1 %. Fig. 5 shows water demands in sub-watershed number 7, wherein domestic and industrial water demands was increased gradually. Fig. 6 presents a graph superposing daily

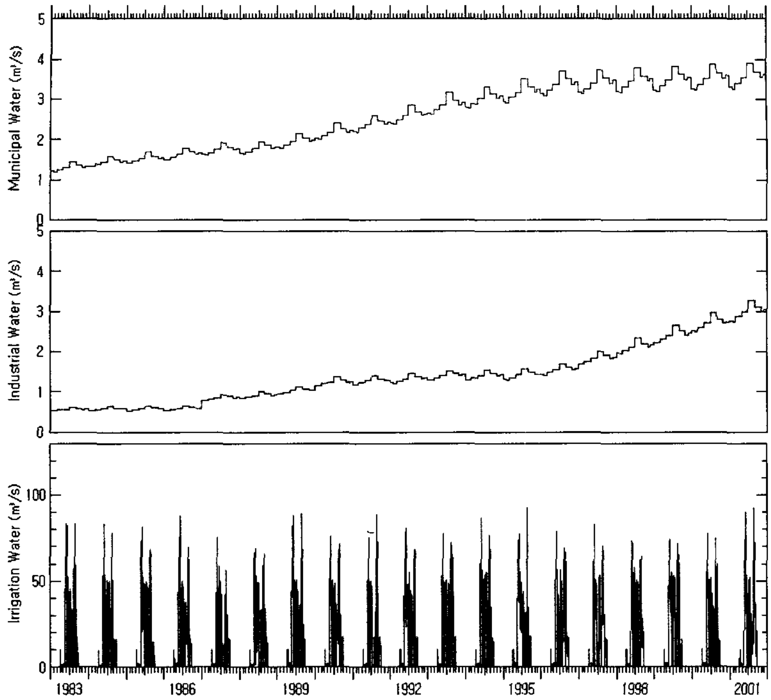

Fig. 5 Daily water demands in sub-watershed no. 7

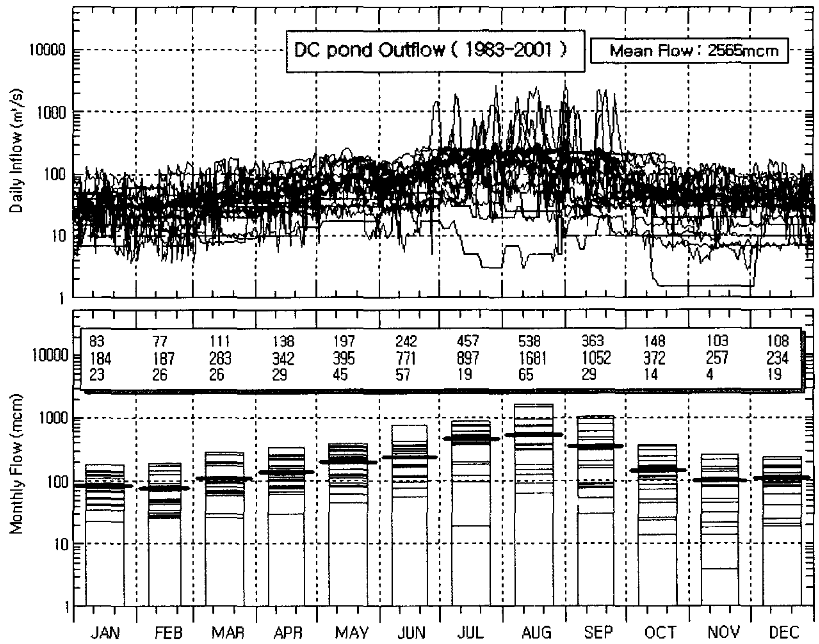

Fig. 6 Superposition of daily and monthly outflows from the Daecheong regulating dam (1983-2001)

and monthly outflows from the Daecheong regulating dam for the last 19 years, from 1983 to 2001. Fig. 7 illustrates an example of simulating daily inflow to the Geum River estuary reservoir.

3. Analysis of Water Supply Capacity by Scenario

The scenario for analyzing water supply capacity for the Geum River estuary reservoir was arranged with the combination of the irrigation area from the Geum River estuary reservoir and the inclusion and exclusion of outflows from the Daecheong regulating dam. The irrigation area was 27,554 ha in the original design in 1991 and 22,928 ha in the 2002 analysis (Korea Agricultural and Rural Infrastructure Corporation, 2002). Outflows from the Daecheong regulating dam were divided into original outflows and yearly average outflows.

Therefore, assigned scenarios were as follows: Case ① was the combination of the irrigation area with 27,554 ha and operational outflows from the Daecheong regulating dam. Case ② was the combination of the irrigation area with 27,554 ha and average outflows from the Daecheong regulating dam during the last 19 years. Case ③ was the combination of the irrigation area with 27,554 ha and zero outflows from the Daecheong regulating dam, i.e., excluding the watershed of the Daecheong multi-purpose dam. Case ④ was the combination of the irrigation area with 22,928 ha and operational outflows from the Daecheong regulating dam. Case ⑤ was the combination of the irrigation area with 22,928 ha and average outflows from the Daecheong regulating dam during the last 19 years. And case ⑥ was the combination of the irrigation area with 22,928 ha

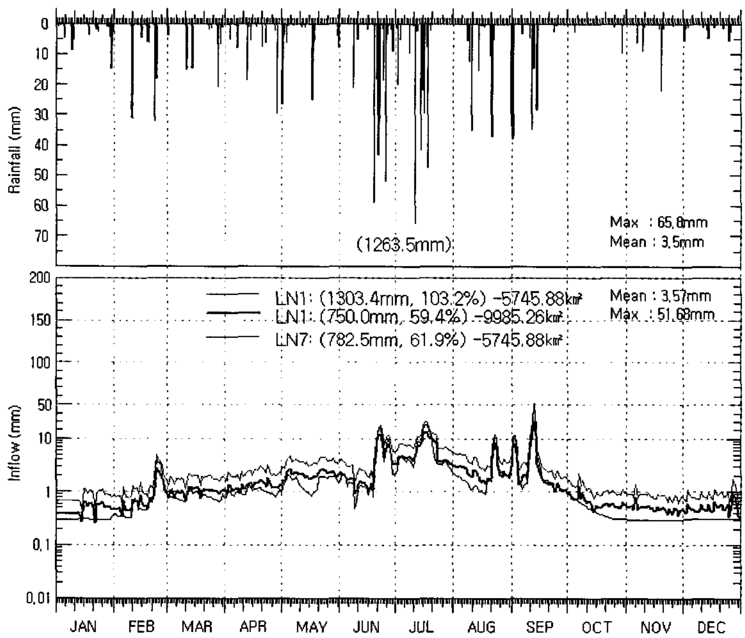

Fig. 7 Example of a simulated daily inflow

and zero outflows from the Daecheong regulating dam.

Fig. 8 shows an example of simulating daily storages in the Geum River estuary reservoir in the last 19 years, from 1983 to 2001. Table 1 presents the results of analyzing water supply capacities in the Geum River estuary reservoir based on six scenarios.

Water supply capacity reflected a water storage deficit only once during the last 19 years. Case ③ applied the original design, showing a domestic and industrial water supply capacity of 70 ha−m/day compared to the previous 33 ha−m/day level. Case ② involved average outflows from the Daechung regulating dam and showed results that were far from the results obtained from original outflows. Case ④ involved operational outflows from the Daecheong regulating dam, showing a domestic and industrial water supply capacity of 180 ha−m/day with the cascaded operation of the Daecheong multipurpose dam upstream.

V. Conclusions

A system for analyzing the daily water balance in an estuary reservoir was developed to consider outflow conditions through sluice gates. This system operates on PC Windows. Hydrological practitioners can analyze water supply

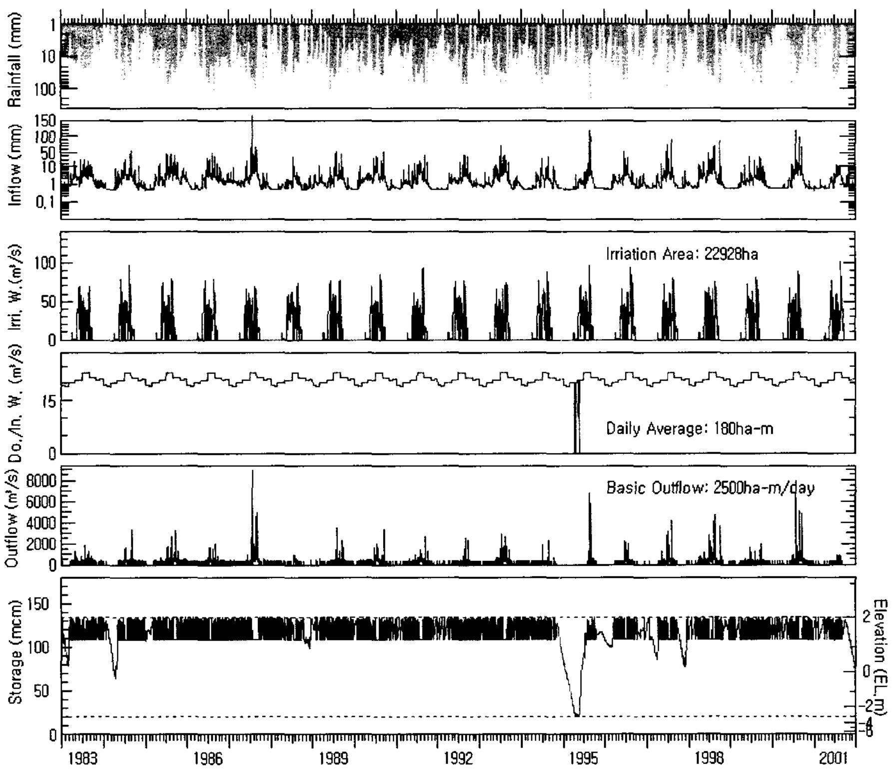

Fig. 8 Example of simulating storages in the Geum River estuary reservoir (case ④)

Table 1 Water supply capacity of the Geum River estuary reservoir

Case	Municipal, industrial water (10^4 ㎥/day)	Rainfall (mm)	Inflow (10^6 ㎥)	Runoff ratio (%)	Irrigation water (10^6 ㎥)	Municipal, industrial water (10^6 ㎥)	Outflow (10^6 ㎥)	Past result (10^4 ㎥/day)
①	176	1,205	6,755	54.7	383	647	5,070	
②	400	"	6,766	56.7	383	1,470	4,256	
③	70	"	4,189	34.2	383	257	2,894	33
④	180	"	6,755	54.7	319	661	5,120	
⑤	400	"	6,766	56.7	319	1,470	4,320	
⑥	80	"	4,189	34.2	319	294	2,923	

capacities easily with simple mouse clicks. The system can also act as a Korean analysis tool to substitute for the HEC 5 program. The DAWAST model considered return flows from agricultural, domestic, and industrial water demands was attached in this system.

This system was applied to the Geum River estuary reservoir, and water supply capacities in the Geum River estuary reservoir were analyzed at 180 ha-m/day (661 Mm³/year) of domestic and industrial water in case of including the watershed of the Daecheong multi-purpose dam, and at 80 ha-m/day (294 Mm³/year) of domestic and industrial water demands in case of excluding the watershed of the Daecheong multi-purpose dam. Two cases also included the agricultural water supplied to paddy areas, the supply reached 22,928 ha. (319 Mm³/year).

Acknowledgement

This research was supported by a grant (code number 2-4-1) from Sustainable Water Resources Research Center of the 21st Century Frontier R/D Program.

References

1. Ministry of Construction and Transportation, 2000, Water Vision 2020. Kwacheon, Gyeonggi. (in Korean)
2. Korea Agricultural and Rural Infrastructure Corporation, 1991, Report on the Geum River Estuary Reservoir Project. Uiwang, Gyeonggi. (in Korean)
3. Korea Water Resources Corporation (1996). Development of real time operating system for managing low flows in the Nakdong riverbasin. Daejon. (in Korean)
4. Korea Agricultural and Rural Infrastructure Corporation, 2002. A Integrated Study on Water Use Planning to the Geum River II Region. Uiwang. Gyeonggi. (in Korean)
5. Kim, Chul-Gyum and Hyeon-jun Kim, 2003, Application of SWAT model to Gyeongancheon watershed. for estimating stream flows and sediment yields, *Proceedings 2003 of Korean Society of Agricultural Engineers*, 527-530. Jeju, Korea: KSAE. (in Korean)
6. Kim, Hyeon-jun, 2001, Development two parametric hyperbolic model for daily streamflow simulation, Ph. D. dissertation, Seoul, Korea: National University. (in Korean)

7. Kim, Seong Joon and Jaekyoung Noh, 2000, Development of a decision support system for reservoir sizing, *Journal of the Korean Society of Agricultural Engineers*, 42:17 · 23.
8. Lee, Sang Ho, Tae Jin Ahn, Byung Man Yun, and Myung Pil Shim, 2003. A tank model application to Soyanggang dam and Chungju dam with snow accumulation and snow melt, *Journal of Korea Water Resources Association*, 36(5): 851-862. (in Korean)
9. Noh, Jaekyoung, 1991. A conceptual watershed model for daily streamflow based on soil water storage. Ph. D. dissertation. Seoul, Korean: Seoul National University. (in Korean)
10. Noh, Jaekyoung, 1999. Development of system for simulating daily runoff by DAWAST model. *Proceedings 1999 of Korea Water Resources Association.* 69-74 Seoul, Korea: KWRA. (in Korean)
11. Noh, Jaekyoung. 2000. Effect of increasing water supply capacity of reservoir from limiting water supply. *Proceedings 2000 of Korean Society of Civil Engineers,* 3:432-435. Yongpyoung, Korea: KSCE. (in Korean)
12. Noh, Jaekyoung, Jinyoung Lee, and Yongshin Jin, 2003. Return flows considered DAWAST model. *Proceedings 2003 of Korean Society of Agricultural Engineers*, 503-506, Jeju, Korea: KWRA. (in Korean)