EVALUATION OF THE WATER RESOURCES ASPECT OF THE OPERATING RESULTS OF THE DAECHEONG MULTIPURPOSE DAM

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Abstract: This paper evaluated the water resources aspect of the operating results of the Daecheong Multipurpose Dam for the last 21 years. The elements that were evaluated included the amount of water supply from the dam, volume of outflow from the regulating dam, changes in the runoff volume at the dam site and downstream, and variations in the water supply capacity of the Daecheong Multipurpose Dam and the Geum River Barrage Dam situated in the estuary. The rainfall-runoff model was used to evaluate the changes in the runoff volume, and the water balance analysis system was used to evaluate the variations in the dams' water supply capacities. The volume of domestic and industrial water supply from the Daecheong Multipurpose Dam increased to 6.1 times for the last 21 years from 61×10^6 m^3 in 1981 to 375×10^6 m^3 in 2001. The rate of outflow to inflow of the Daecheong Dam was analyzed 1.30 times in dry season, 1.12 times in semi-dry season, and 0.90 times in rainy season. The volume of inflow to the Geum River Barrage Dam downstream after the dam's construction increased to 1.25 times in dry season and 1.02 times in semi-dry season and decreased to 0.94 times in rainy season. The water supply capacity of the estuary barrage dam almost did not change in cases with or without the Daecheong Multipurpose Dam, but storages were largely affected by the outflows of the Daecheong Multipurpose Dam.

Keywords: dam operation, streamflow evaluation, runoff modeling, water supply capacity

1. INTRODUCTION

The construction of most of multipurpose dams in Korea peaked in 1970s and 1980s. The operating results of multipurpose dams in Korea accumulated over 20 to 30 years. Evaluation of the dams' operating results therefore has to be done systematically. The water supply has been increased gradually, flood damages were greatly decreased, and the water quality downstream has been largely improved by these multipurpose dams for the last years. High flow variations characterize river flows in Korea. The coefficients of the river regime, expressed as maximum river discharge over minimum river discharge, usually range from 100 to 700 in Korea. Such large range of variations in the flow discharge causes serious problems in river management, particularly concerning flood control and water use. If a dam is constructed upstream, the runoff volume in the downstream is questioned to decrease or increase. Water from the Daecheong Multipurpose Dam upstream was supplied to municipal regions such as Daejon, Cheongju, etc., and was then returned to rivers downstream as return flows through its tributaries. Water flowing out of the Daecheong Multipurpose Dam was regulated in a regulating dam, situated 2 km downstream from the main dam.

The Daecheong Multipurpose Dam was constructed in 1980 and has been operating for more than 20 years. If inflows to the dam are compared with outflows from the dam, the effects of flow regulation in the dam could be analyzed. Likewise, if inflows to the barrage dam situated in the Geum River Esturary are compared before and after the upstream dam construction, the effects of downstream flow regulation by the dam could be analyzed. Although it is ideal for observed data to be used as a basis for streamflow, the reliability of the observed data quality in the Geum River is low. Therefore, simulated streamflows in the estuary will be used to evaluate the effects of flow regulation by dam. Moreover, changes in storage in the Geum River will be affected to regulate flow downstream by dam. A runoff model is required for the analysis of changes in the flow volume of the river downstream and a model for simulating the daily water storage of reservoirs is required for the analysis of water supply capacity in dams. The definition of river flows can be expanded to include natural flows and return flows to rivers via watersheds in a returned and lagged form from various water sources. The national planning of water resources in Korea is based on water balance within sub-watersheds. Runoff phenomena in each sub-watershed are considered natural, and return flows from various water sources are added to this. Runoffs were simulated by the TANK model in "*Water Vision 2020*" (Ministry of Construction and Transportation, 2000) and by the SSARR model in the "*Development of a 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 to express soil water storage in the TPHM (Kim, 2001). Furthermore, CN was used to express soil water storage in the SWAT model (Kim and Kim, 2003). The TANK model was applied to the Soyanggang Dam and the Chungju Dam, considering snow accumulation and snow melting (Lee et al., 2003). These models, however, could not simulate streamflows which responded return flows from various water sources. On the other hand, the applicability of the DAWAST model to the simulation of inflows to the Daecheong Dam was tested, considering return flows from various water sources (Noh et al., 2003b). When return flows were considered, the ratio of the simulated inflows to the observed inflows was 97.8%. When return flows were not considered, the ratio of the simulated inflows to the observed inflows was 90.9%. The simulated results were greatly improved by considering the return flows in the DAWAST model. This model that considers return flows will be used in this study to simulate streamflows in the downstream river.

The water supply capacity could be analyzed by simulating storage in reservoirs. A module for analyzing water supply capacity in reservoirs is included in the reservoir sizing decision support system (Kim and Noh, 2000). Various water demands could be applied on a daily basis in this system. Moreover, a model for simulating daily water storage in an estuary barrage dam was developed to analyze water supply capacity in the Geum River Barrage Dam (Noh et al., 2003a). These models will be applied to the analysis of the water supply capacity in dams.

In this study, the water supply capacity of the Daecheong Multipurpose Dam was evaluated based on its operating results and storage simulation results for the last 21 years. Moreover, the effects of flow regulation by dam will be evaluated using observed data from the dam and simulated data from the estuary.

2. DESCRIPTION OF THE STUDY AREA

All areas in the Geum River Basin were covered in this analysis of the water resources aspect of the operating results of the Daecheong Multipurpose Dam. The Geum River, which flows into the Yellow Sea from the middle part of the Korean peninsula, is 401 km long and has 9,805 km^2 of basin areas, which is equivalent to 10 % of the total area of all river basins in the Korea. As shown in Fig. 1, the Daecheong Multipurpose Dam is situated in the middle stream of the Geum River, the Yongdam Multipurpose Dam is situated in the upstream, and the Geum River Barrage Dam is situated in the river estuary.

The Daecheong Multipurpose Dam was constructed in 1980. It is located 150 km upstream from the estuary of the Geum River. It has a watershed area of 4,134 km^2, a total storage capacity of 1,490 Mm^3, and an effective storage capacity of 790 Mm^3. Its annual amount of water supply was planned to total 1,649 Mm^3, of which 1,300 Mm^3 was allotted for domestic and industrial water, and 349 Mm^3 was allotted for agricultural water. The Daecheong Regulating Dam is situated 2 km downstream of the main dam.

The Yongdam Multipurpose Dam was constructed in 2001. It is located 150 km upstream from the Daecheong Multipurpose Dam. It has a

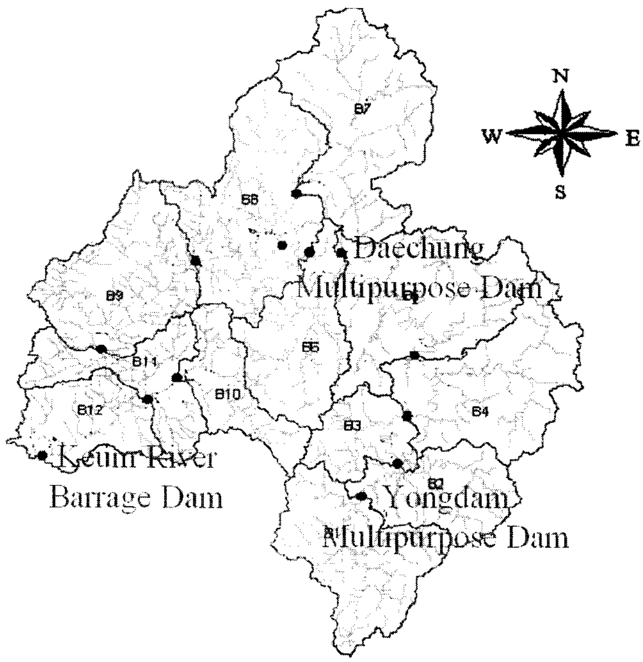

Fig. 1. Dam sites and sub-watershed boundary in the Geum River basin

watershed area of 930 km^2, a total storage capacity of 815 Mm^3, and an effective storage capacity of 672 Mm^3. Its annual amount of water supply was planned to total 650.4 Mm^3, in which 492.7 Mm^3 was allotted for domestic and industrial water, and 157.7 Mm^3 was allotted for instream water that flows out to the river downstream constantly to allow for various functions of river.

The Geum River Barrage Dam was constructed in 1990. It is located at the estuary of the Geum River. It has a watershed area of 9,313 km^2, a total storage capacity of 138 Mm^3, and an effective storage capacity of 111.87 Mm^3. Its annual amount of water supply was planned to total 365 Mm^3, of which 121 Mm^3 was allotted for domestic and industrial water, and 244 Mm^3 was allotted for agricultural water.

3. OPERATING RESULTS OF THE DAECHEONG MULTIPURPOSE DAM

Data on the dam operations over 21 years, from 1981 to 2001, were analyzed, considering that inflows to the Daecheong Dam were not affected by the construction of the Yongdam Dam.

The daily operating results of the Daecheong Multipurpose Dam are shown in Fig. 2. The figure shows that domestic water increased gradually from 2 m^3/s in 1981 to 11 m^3/s in 2001.

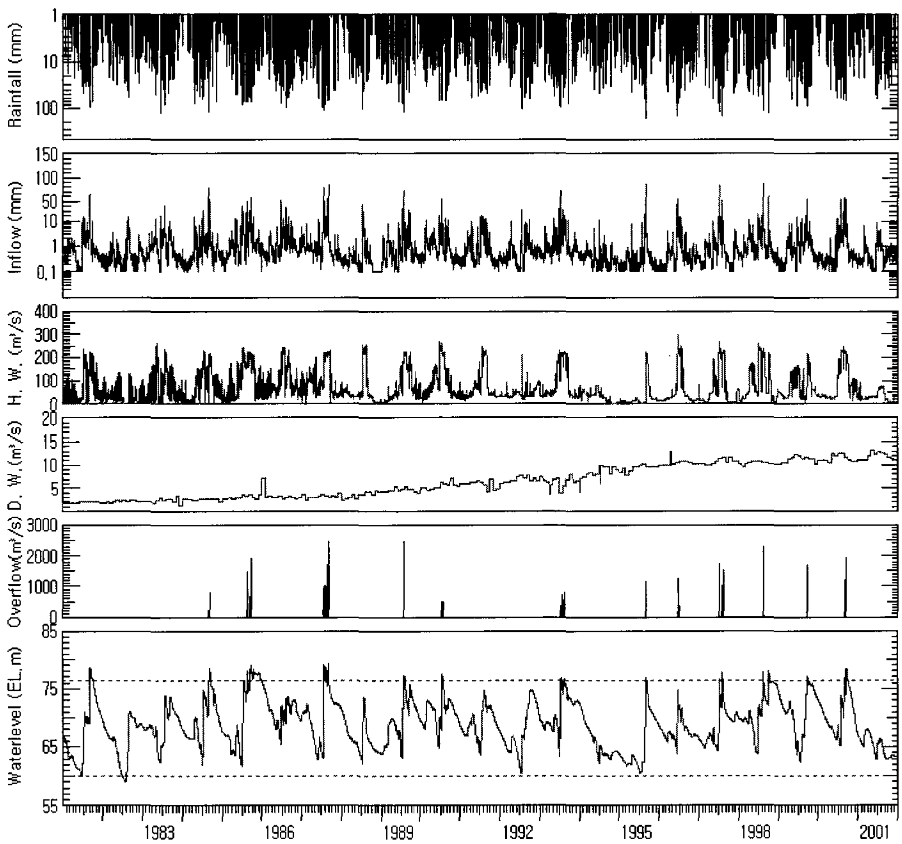

Fig. 2. Daily operating results of the Daecheong multipurpose dam from 1981 to 2001

Yearly operating results of the Daecheong Multipurpose Dam are shown in Fig. 3 and Table 1. Rainfall ranged from 694.9 mm in 1994 to 1,626.7 mm in 1985. Inflows ranged from 200.0 mm in 1994 to 1,139.3 mm in 1985. The ratio of inflows to rainfall ranged from 28.8% in 1994 to 70% in 1985. Hydropower water ranged from 872 Mm^3 in 2001 to 3,359 Mm^3 in 1985. Domestic and industrial water have been increasingly supplied 6.1 times from 61 Mm^3 in 1981 to 375 Mm^3 in 2001. A maximum overflow of 1,774 Mm^3 was recorded in 1987. The amount of rainfall used in the water supply ranged from 284.0 mm in 1982 to 836.1 mm in 1985. The ratio of rainfall use ranged from 30.2% in 1994 to 65.6% in 1986. The water use ratio, which is defined as the ratio of water use to inflow, ranged from 73.4% in 1997 to 147.1% in 1994. The storage ratio, which is defined as the ratio of the effective storage capacity to the inflow, ranged from 17.1% in 1987 to 98.4% in 1994. The reservoir use ratio, defined as the ratio of water use to effective storage capacity, ranged from 144.2% in 1982 to 424.6% in 1985.

On a yearly average from 1981 to 2001, the amount of rainfall was 1,155.1 mm and of inflow, 644.3 mm; the ratio of inflow to rainfall was 55.8%; the volume of hydropower water was 2,147 Mm^3, of domestic and industrial water, 203.5 Mm^3, of overflow, 342.4 Mm^3, and of used rainfall, 568.6 mm; the water use ratio was 94.8%; the storage ratio was 38.5%; and the reservoir use ratio was 288.7%.

Superposition of daily storage on the Daecheong Multipurpose Dam from 1981 to 2001 is shown in Fig. 4. This case in 2002 was affected by the stor-

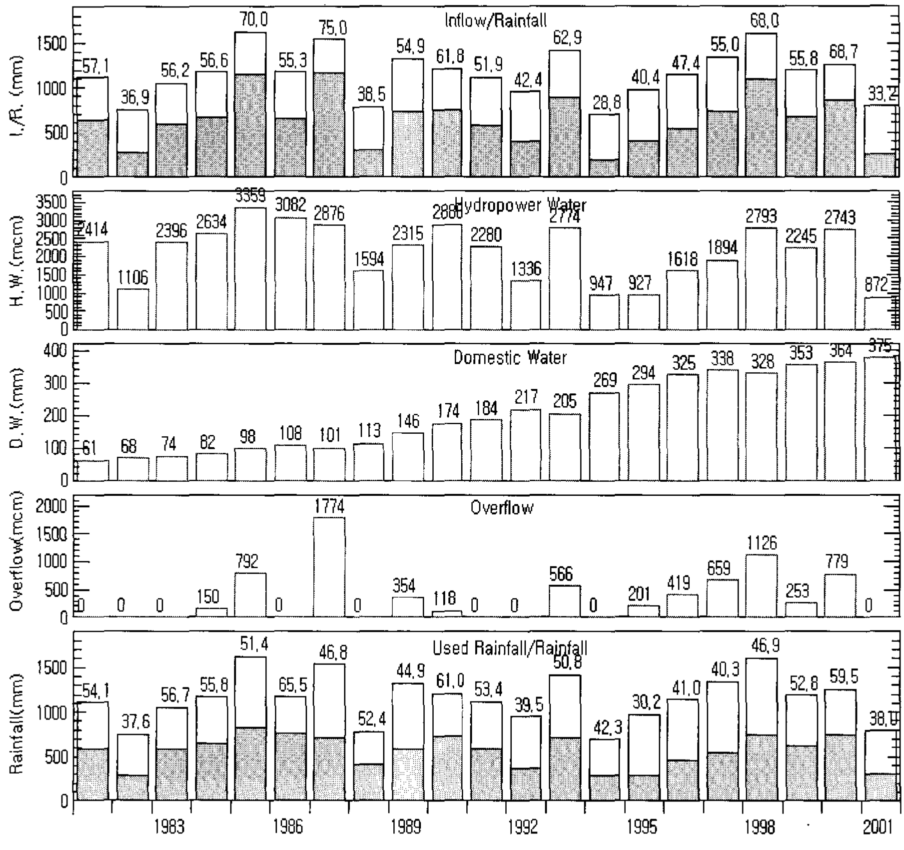

Fig. 3. Yearly operating results of the Daecheong multipurpose dam from 1981 to 2001

age effect of the Yongdam Dam, located upstream. The relationship between water level and hydropower water was dispersed broadly and did not show a trend, as can be seen in Fig. 5.

Water supply capacity was planned to total 1,649 Mm^3, of which 1,300 Mm^3 was allotted for domestic and industrial water, and 349 Mm^3 was allotted for agricultural water. Based on the dam operating results for the last 21 years, from 1981 to 2001, the dam's water supply capacity totaled 2,350.5 Mm^3, of which 2,147 Mm^3 was hydropower water and 203.5 Mm^3 was domestic and industrial water.

On the other hand, using the daily water balance model in the reservoir, the water supply capacity of the Daecheong Dam was analyzed, and the observed inflow had to be used and water deficit had to happen one time in 21 years, from 1981 to 2001. Daily simulated results of storage changes in the Daecheong Dam are shown in Fig. 6, and yearly results of daily simulated storage of the Daecheong Dam from 1991 to 2001 are shown in Table 2. The amount of water surface evaporation ranged from 34.1

Table 1. Yearly operating results of the Daecheong multipurpose dam from 1981 to 2001

Year	rainfall (mm)	inflow (mm)	inflow rate (%)	hydro-power water (mcm)	domestic water (mcm)	overflow (mcm)	used rainfall (mm)	water use ratio (%)	storage ratio (%)	Reservoir use ratio (%)
1981	1106.3	631.2	57.1	2413.6	61.0	0.0	598.6	94.8	31.2	304.0
1982	754.6	278.7	36.9	1106.3	67.6	0.0	284.0	101.9	70.7	144.2
1983	1053.2	591.5	56.2	2395.7	73.8	0.0	597.3	101.0	33.3	303.3
1984	1178.2	666.8	56.6	2633.9	81.6	149.6	656.9	98.5	29.5	333.6
1985	1626.7	1139.3	70.0	3358.6	97.9	792.3	836.1	73.4	17.3	424.6
1986	1177.0	651.1	55.3	3081.8	107.7	0.0	771.5	118.5	30.2	391.8
1987	1537.4	1153.3	75.0	2875.9	100.6	1774.0	720.0	62.4	17.1	365.6
1988	788.2	303.2	38.5	1594.1	112.5	0.0	412.8	136.1	64.9	209.6
1989	1326.8	728.5	54.9	2315.2	145.5	354.1	595.2	81.7	27.0	302.3
1990	1213.7	749.7	61.8	2886.3	174.4	118.4	740.4	98.8	26.3	376.0
1991	1116.3	579.0	51.9	2279.5	184.0	0.0	595.9	102.9	34.0	302.6
1992	950.7	403.2	42.4	1335.9	216.6	0.0	375.5	93.2	48.8	190.7
1993	1417.6	891.9	62.9	2773.8	204.5	565.7	720.4	80.8	22.1	365.8
1994	694.9	200.0	28.8	946.9	269.2	0.0	294.2	147.1	98.4	149.4
1995	976.5	394.2	40.4	926.6	294.3	201.4	295.3	74.9	50.0	150.0
1996	1146.3	543.5	47.4	1617.6	325.0	418.7	469.9	86.5	36.2	238.6
1997	1338.0	735.8	55.0	1893.9	337.6	659.4	539.8	73.4	26.8	274.1
1998	1608.1	1093.7	68.0	2792.6	327.9	1125.9	754.8	69.0	18.0	383.3
1999	1189.9	664.5	55.8	2245.3	352.7	253.1	628.4	94.6	29.6	319.1
2000	1262.0	866.8	68.7	2742.5	364.1	778.8	751.5	86.7	22.7	381.6
2001	794.6	263.7	33.2	871.9	374.9	0.0	301.6	114.4	74.7	153.2
mean	1155.1	644.3	55.8	2147.0	203.5	342.4	568.6	94.8	38.5	288.7

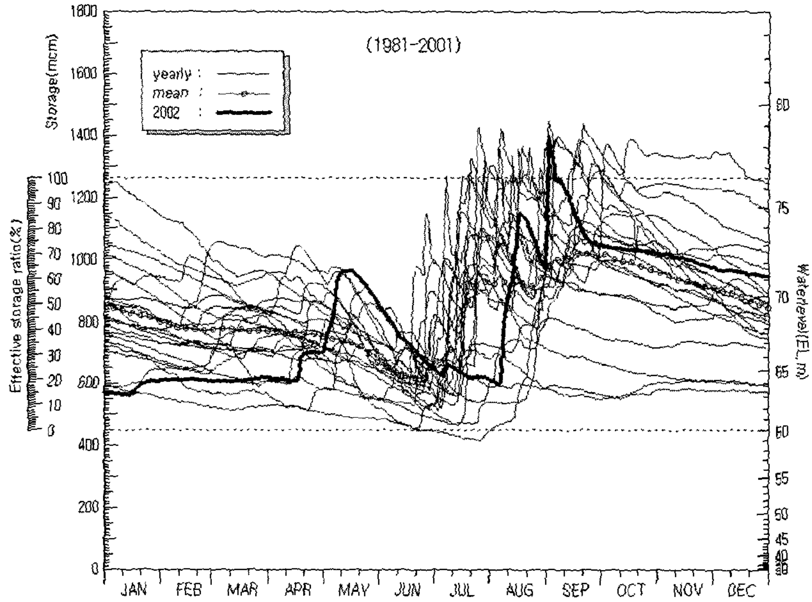

Fig. 4. Daily storage superposition of the Daecheong multipurpose dam from 1981 to 2001

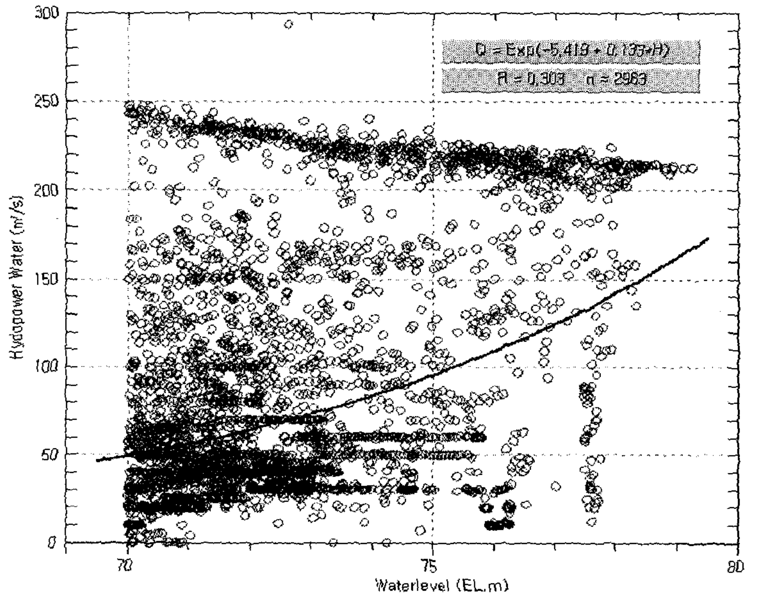

Fig. 5. Relationship between hydropower water and the water level of the Daecheong multipurpose dam from 1981 to 2001

Mm^3 in 1995 to 66.6 Mm^3 in 2000. The basic allotted outflow ranged from 792.1 Mm^3 in 1994 to 2,124.3 Mm^3 in 1985. Additional domestic and industrial water ranged from 326.6 Mm^3 in 1995 to 368.3 Mm^3 in 2000. Overflow was recorded to have reached a maximum of 2,428.7 Mm^3 in 1987 and was recorded 16 times in 21 years. A storage deficit happened one time in 1995 and had a volume of 17.6 Mm^3. The amount of rainfall used in the water supply of rainfall ranged from 280.5 mm in 1994 to 602.7 mm in 1985. The water use ratio, defined as the ratio of water use to inflow, ranged from 50.6% in 1997 to 140.2% in 1994. The storage ratio, which is defined as the ratio of effective storage capacity to inflow, ranged from 17.1% in 1987 to 98.4% in 1994. The reservoir use ratio, defined as the ratio of water use to effective storage capacity, ranged from 142.4% in 1994 to 306.1% in 1985.

On a yearly average from 1981 to 2001, rainfall was 1,155.1 mm, inflow was 644.3 mm, the ratio of inflow to rainfall was 55.8%, surface water evaporation was 40.5 Mm^3, basic allotted outflow was 1,559.6 Mm^3, additional domestic and industrial water was 365.7 Mm^3, overflow was 730.6 Mm^3, used rainfall was 465.7 mm, the water use ratio was 81.1%, the storage ratio was 38.5%, and the reservoir use ratio was 236.5%. Water supply capacity totaled 1,925.3 Mm^3 per year, of which 1,559.6 Mm^3 was basic allotted outflow and 365.7 Mm^3 was additional domestic and industrial water. In other words, the water supply capacity of the Daecheong Dam was analyzed to be extra 276.3 Mm^3 per year compared with its designed value of 1,649 Mm^3 per year.

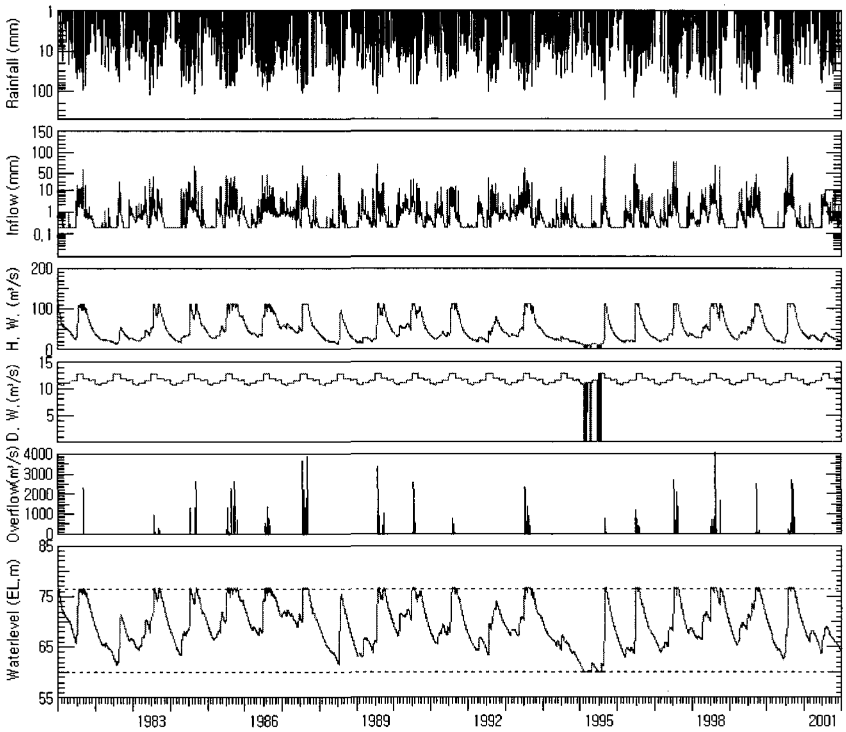

Fig. 6. Examples of daily simulated storages of the Daecheong multipurpose dam (1981-2001)

Table 2. Yearly results of daily simulated storages of the Daecheong multipurpose dam from 1981 to 2001

year	rainfall (mm)	Inflow (mm)	water surface evapo. (mcm)	basic allotted outflow (mcm)	add. water supply (mcm)	overflow (mcm)	deficit storage (mcm)	used rainfall (mm)	water use ratio (%)	storage ratio (%)	reservoir use ratio (%)
1981	1106.3	631.2	44.9	2091.5	367.4	553.7	0	594.8	94.2	31.2	302.1
1982	754.6	278.7	37.9	867.2	367.4	0	0	298.7	107.2	70.7	151.7
1983	1053.2	591.5	42.2	1673.5	367.4	261.6	0	493.7	83.5	33.3	250.7
1984	1178.2	666.8	40.5	1650.9	368.3	643	0	488.4	73.2	29.5	248
1985	1626.7	1139.3	41.3	2124.3	367.4	2007.5	0	602.7	52.9	17.3	306.1
1986	1177	651.1	42.4	2046.1	367.4	323.9	0	583.8	89.7	30.2	296.5
1987	1537.4	1153.3	39.7	2045.3	367.4	2428.7	0	583.6	50.6	17.1	296.4
1988	788.2	303.2	37.5	1088.1	368.3	0	0	352.3	116.2	64.9	178.9
1989	1326.8	728.5	38.7	1519.3	367.4	844.1	0	456.4	62.6	27.0	231.8
1990	1213.7	749.7	38.1	2008	367.4	739.3	0	574.6	76.6	26.3	291.8
1991	1116.3	579.0	37.2	1658.8	367.4	348.6	0	490.1	84.6	34.0	248.9
1992	950.7	403.2	35.9	1179.5	368.3	0	0	374.4	92.9	48.8	190.1
1993	1417.6	891.9	37.7	1908.9	367.4	1336.4	0	550.6	61.7	22.1	279.6
1994	694.9	200.0	37.4	792.1	367.4	0	0	280.5	140.2	98.4	142.4
1995	976.5	394.2	34.1	885.7	326.6	183.8	17.6	293.3	74.4	50.0	148.9
1996	1146.3	543.5	40.6	1372.5	368.3	476.8	0	421.1	77.5	36.2	213.8
1997	1338	735.8	44.4	1477.1	367.4	1061.4	0	446.2	60.6	26.8	226.6
1998	1608.1	1093.7	39.6	2052.3	367.4	1998.2	0	585.3	53.5	18.0	297.2
1999	1189.9	664.5	39.6	1780.3	367.4	515.7	0	519.5	78.2	29.6	263.8
2000	1262	866.8	66.6	1626.7	368.3	1620.9	0	482.6	55.7	22.7	245.1
2001	794.6	263.7	34.2	904.3	367.4	0	0	307.6	116.6	74.7	156.2
mean	1155.1	644.3	40.5	1559.6	365.7	730.6	0.8	465.7	81.1	38.5	236.5

4. COMPARISON OF INFLOW TO OUTFLOW OF THE DAECHEONG MULTIPURPOSE DAM

To compare streamflows after dam construction with streamflows before dam construction, outflow from the Daecheong Regulating Dam was compared with inflow to the Daecheong Multipurpose Dam. This is to evaluate flow regulation by dam and will be completed based on the observed values from damoperations during the last 21 years, from 1981 to 2001.

Fig. 7 shows an example of the comparison of inflow to the Daecheong Dam with outflow from the Daecheong Regulating Dam on a daily and monthly basis. The daily comparison shows larger values of outflow than of inflow in dry seasons, and lower values of outflow than of inflow in rainy seasons. The monthly comparison also shows larger values of outflow than of inflow in January, February, May, June, October, November and December, and lower values of

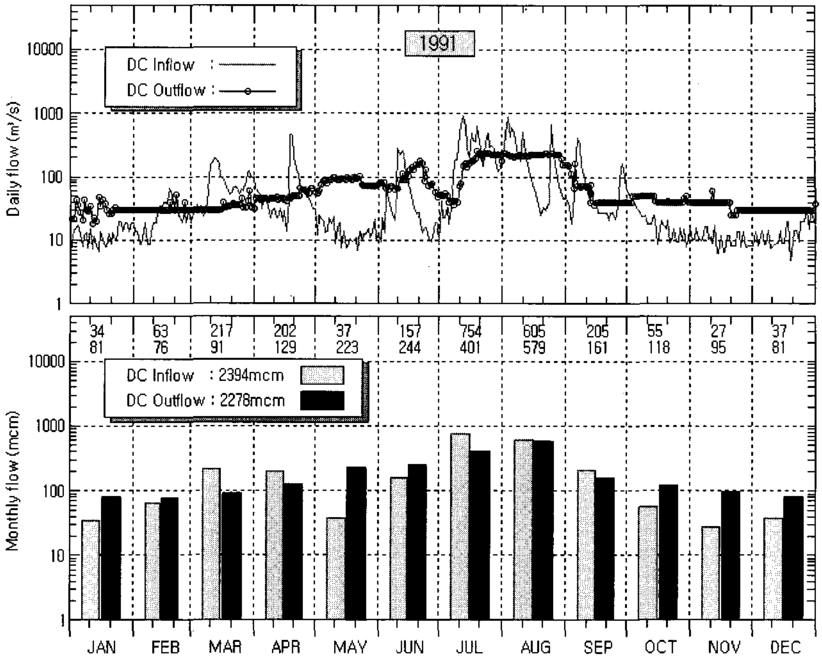

Fig. 7. Example of the comparison of inflows to the Daecheong dam and outflows from the Daecheong Regulating dam on a daily and monthly basis (1991)

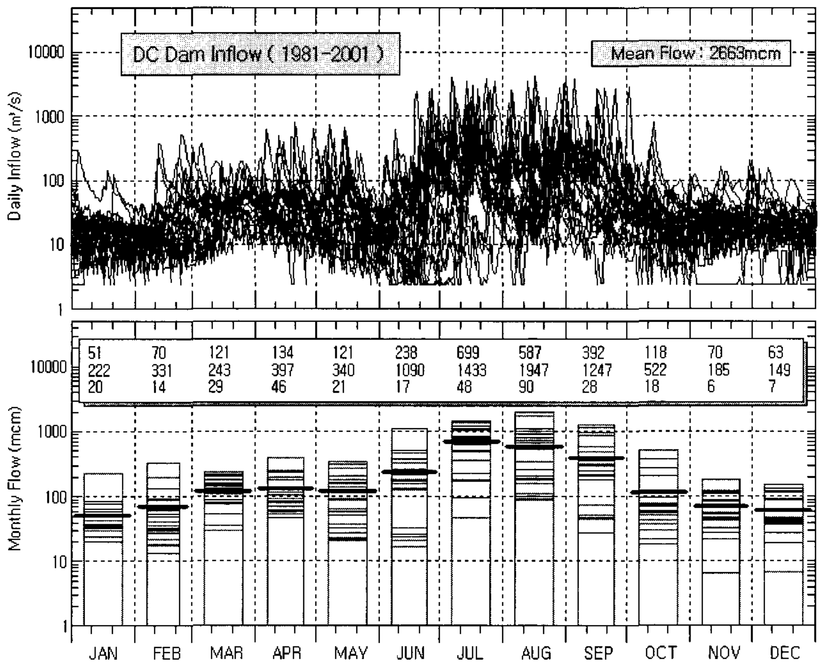

Fig. 8. Superposition of daily and monthly inflows to the Daecheong dam (1981-2001)

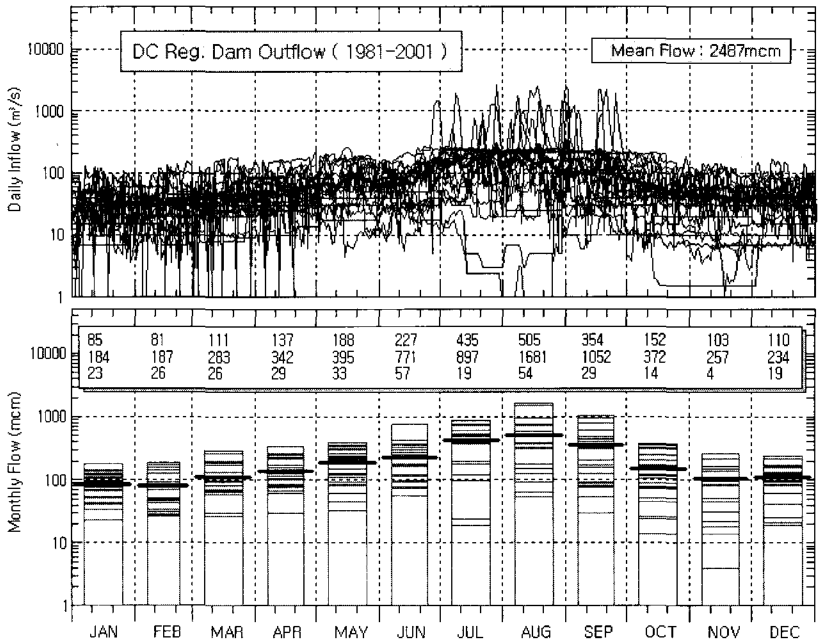

Fig. 9. Superposition of daily and monthly outflows from the Daecheong regulating dam (1981-2001)

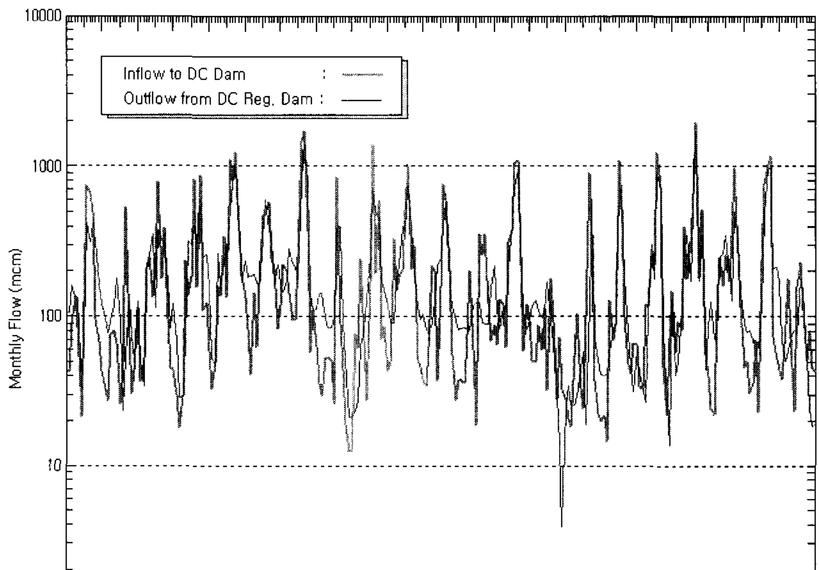

Fig. 10. Comparison of monthly inflows to the Daecheong dam and monthly outflows from the Daecheong regulating dam

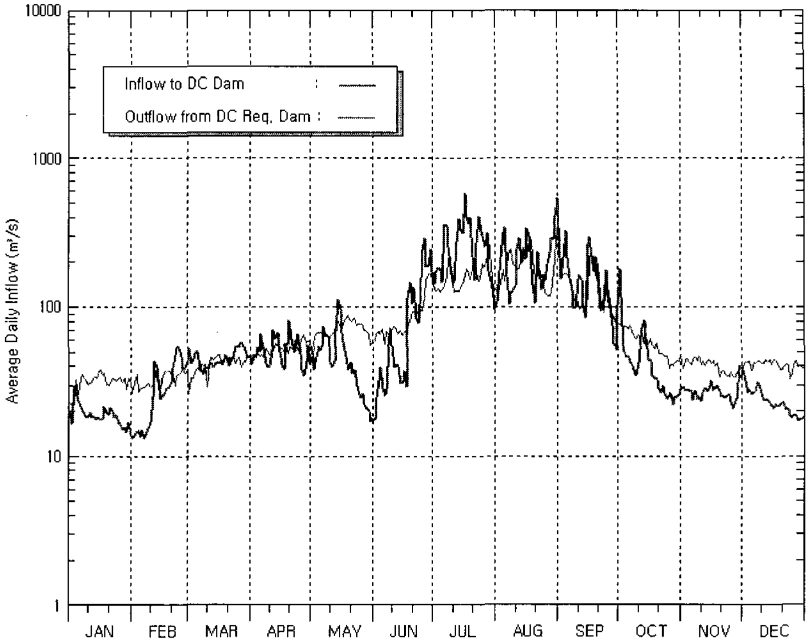

Fig. 11. Comparison of average daily inflows to the Daecheong dam and average daily outflows from the Daecheong regulating dam (1981-2001)

outflow than of inflow in March, April, July, August and September.

Fig. 8 shows the results of superposing daily and monthly inflows to the Daecheong Dam during the last 21 years, from 1981 to 2001. Fig. 9 shows the results of superposing daily and monthly outflows from the Daecheong Regulating Dam during the last 21 years, from 1981 to 2001. The values in the box of graphs show monthly averages, maximum and minimum values, respectively. Setting January, February, March, October, November and December as dry season, April, May and June as semi-dry season, and July, August and September as rainy season, and using the average value, the amount that flowed into the dam in dry season was 493 Mm^3 and the amount that flowed out of the regulating dam in dry season was 642 Mm^3. Thus, the ratio of outflow to inflow was 1.30. Using the same method, 493 Mm^3, 552 Mm^3 and 1.12 were the results that emerged in semi-dry season, respectively, and 1,678 Mm^3, 1,294 Mm^3 and 0.77 were the results in rainy season, respectively. From these results, it was concluded that river flows increased to 1.30 times in dry season and 1.12 times in semi-dry season, and river flows decreased to 0.77 times in rainy season at the dam site after the construction of the Daecheong Dam. This phenomenon of seasonal flow change could be validated from the monthly data shown in Fig. 10 and from the daily data shown in Fig. 11.

5. COMPARISON OF INFLOWS TO THE GEUM RIVER BARRAGE DAM BEFORE AND AFTER THE CONSTRUCTION OF THE DAECHEONG MULTI-PURPOSE DAM

To analyze the change of flows at the Geum River Estuary by the Daecheong Dam, the runoff model was utilized to simulate flows before and after the dam construction. The DAWAST model was used to simulate flows in 12 sub-watersheds within the Geum River basin, and return flows from various water sources were considered in this model (Noh et al., 2003b). Agricultural water requirements were simulated using the "model for estimating daily paddy water requirements" (Noh and Ko, 2003). To determine the model parameters, data on inflows to the Daecheong Dam were used. The analysis period was from 1983 to 2001, and considered the usage of data on water demand. The calibration period was for 3 years from 1989 to 1991, and the verification period covered all years, from 1983 to 1991. The rate of return of agricultural water was 35%, and the rate of return of domestic and industrial water was 65% (Ministry of Construction and Transportation, 2000). Using the Simplex method, which was attached to "the system for the DAWAST model"(Noh, 1999), the parameters of the DAWAST model in which return flows were considered were as follows: UMAX of 315.2 mm, LMAX of 21.5 mm, FC of 136 mm, CP of 0.018, and CE of 0.007. Fig. 12 shows the process of converging model parameters using the Simplex method. Fig. 13 shows an example of daily simulated inflow to the Daecheong Dam by the DAWAST model considered return flows. The ratio of simulated inflow to observed inflow was very high at 99.7%, and Nash-Sutcliffe's model efficiency was 0.838. On a yearly average from 1983 to 2001, the observed inflow was 667.3 mm and the simulated inflow was 652.6 mm. Thus, the rate of simulated inflow to observed inflow was very high at 97.8%. The results of the simulation were found to be very reasonable.

Thus, using the DAWAST model that considered return flows, flows in 12 sub-watersheds within the Geum River basin were simulated on

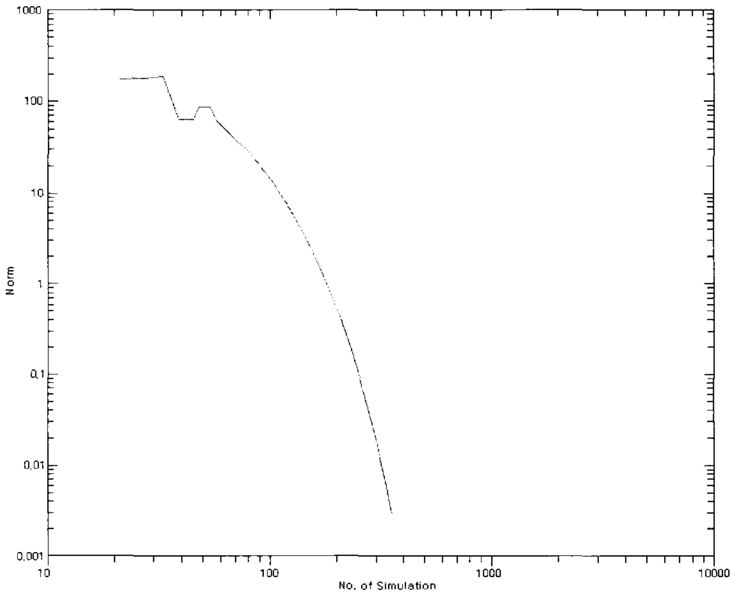

Fig. 12. Parameter optimization of the return flows-considered DAWAST Model using the simplex method

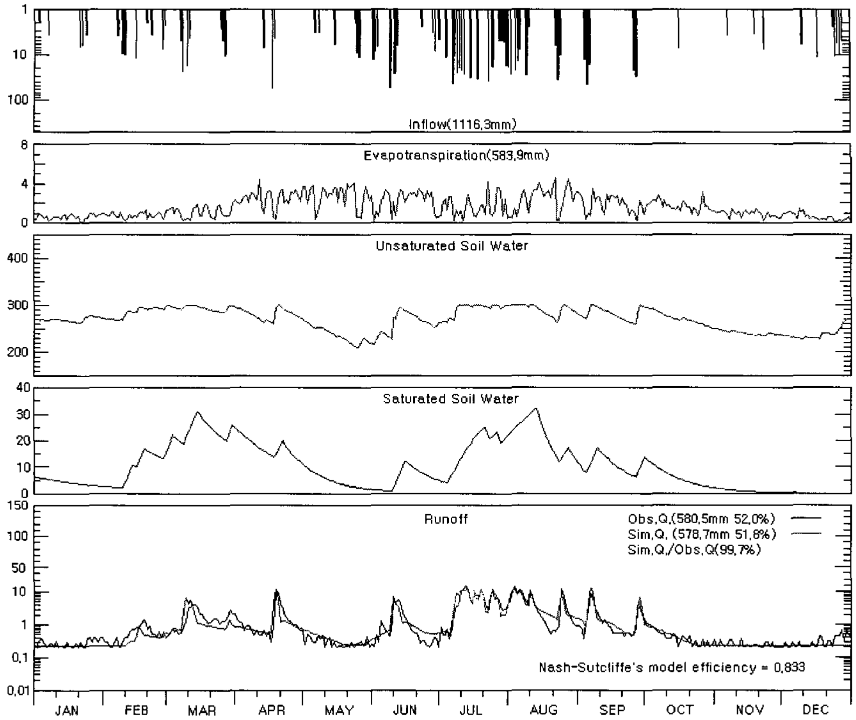

Fig. 13. Example of daily simulated inflows to the Daecheong dam by the return flows-considered DAWAST Model (1991)

a daily basis. In the case of considering outflows from the Daecheong Dam, inflows to the Geum River Barrage Dam were calculated, including outflows from the Daecheong Regulating Dam to flows from the number 6 sub-watershed to the number 12 sub-watershed. In the case of not considering outflows from the Daecheong Dam, inflows to the Geum River Barrage Dam were calculated to include flows from the number 1 sub-watershed to the number 12 sub-watershed.

Fig. 14 shows the results of superposing daily and monthly inflows to the Geum River Barrage Dam during the last 19 years, from 1983 to 2001, in the case of considering outflows from the Daecheong Dam. Fig. 15 shows the results of superposing daily and monthly inflows to the Geum River Barrage Damduring the last 19 years, from 1983 to 2001, in the case of not considering outflows from the Daecheong Dam. The values in the box of graphs express the monthly averages and the maximum and minimum values, respectively. Setting January, February, March, October, November and December as the dry season, April, May and June as the semi-dry season, and July, August and September as the rainy season, and using the average value, the amount that flowed into the barrage dam in the dry season was 1,233 Mm^3 in the case of considering outflows from the Daecheong Dam, and the amount that flowed into the barrage dam in the dry season was 989 Mm^3 in the case without the Daecheong Dam. Thus, the ratio of inflows to the barrage dam with and without the Daecheong Dam was 1.25. Using the same method, 1,396 Mm^3, 1,371 Mm^3 and 1.02 were the results in the semi-dry season,

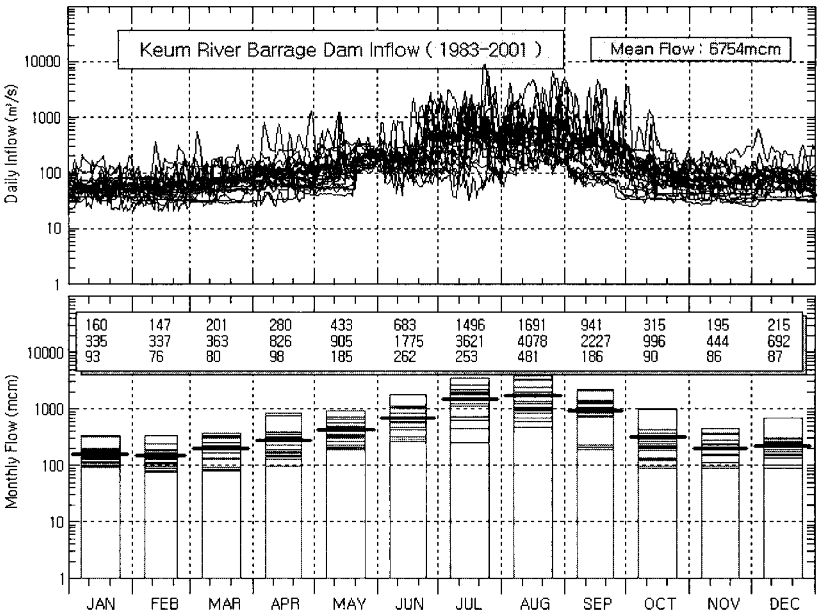

Fig. 14. Superposition of daily and monthly inflows to the Geum River barrage dam with the Daecheong dam upstream (1983-2001)

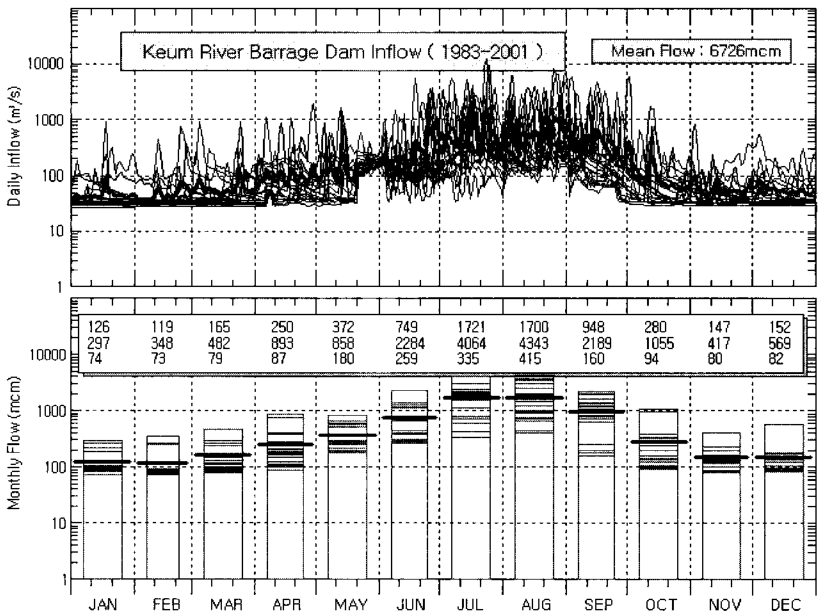

Fig. 15. Superposition of daily and monthly inflows to the Geum River barrage dam without the Daecheong dam upstream (1983-2001)

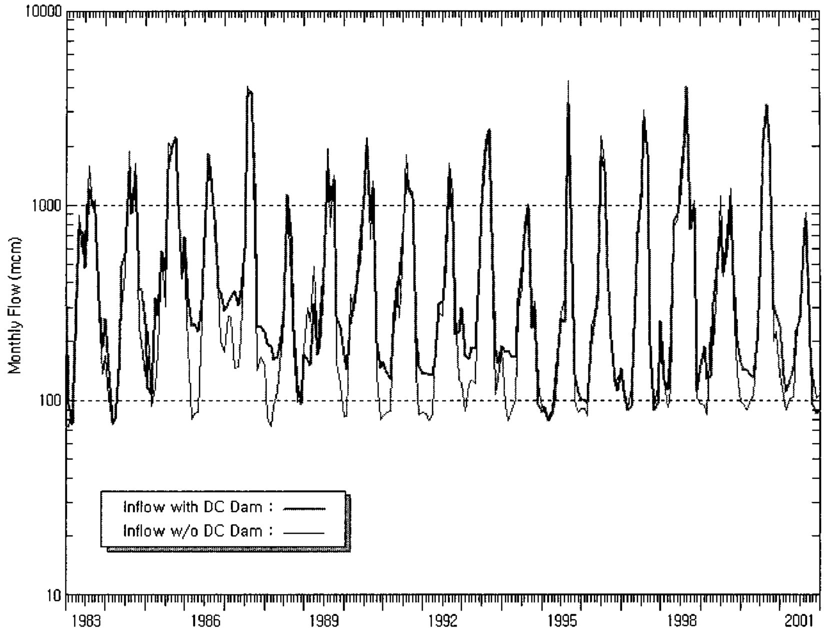

Fig. 16. Comparison of monthly inflows to the Geum River barrage dam with and without the Daecheong multipurpose dam

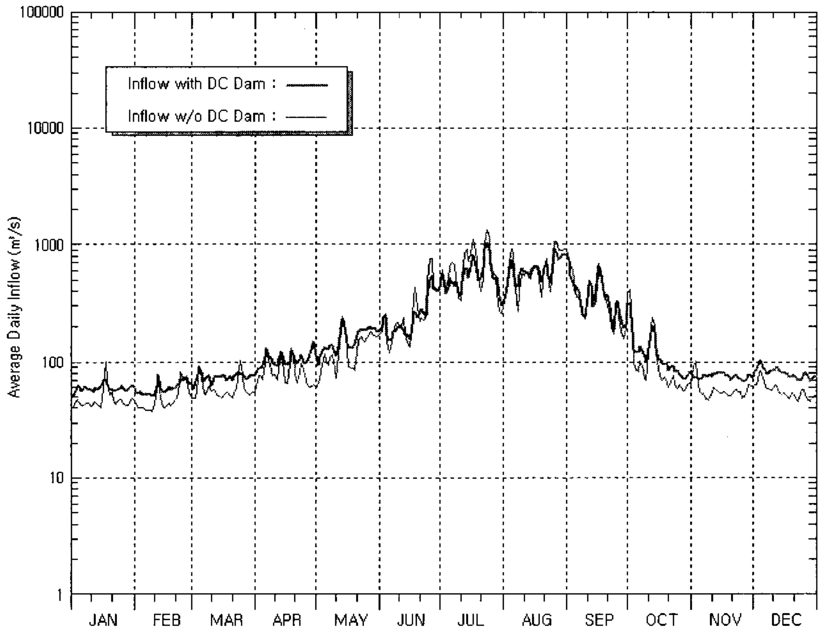

Fig. 17. Comparison of average daily inflows to the Geum River barrage dam with and without the Daecheong dam upstream (1981-2001)

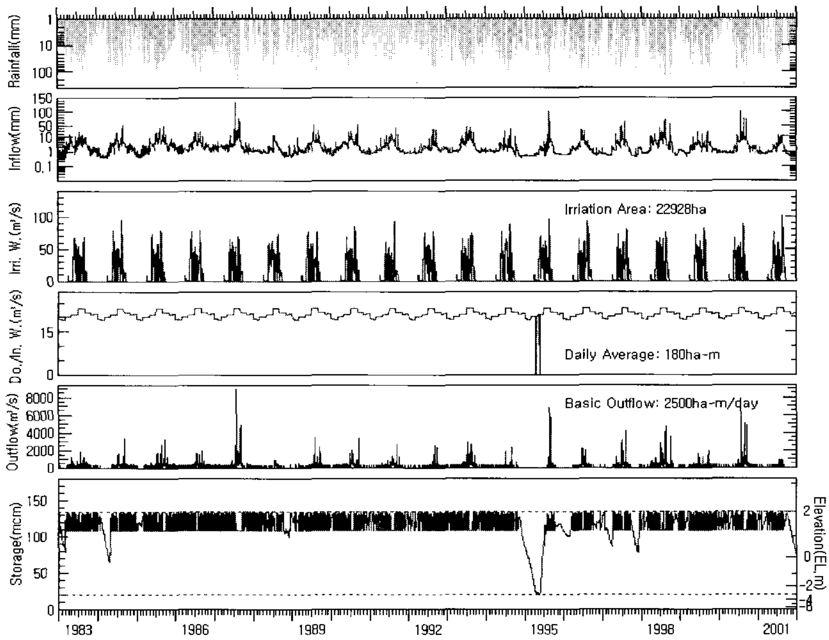

Fig. 18. Daily simulated storages of the Geum River barrage dam with the Daecheong dam upstream (1983-2001)

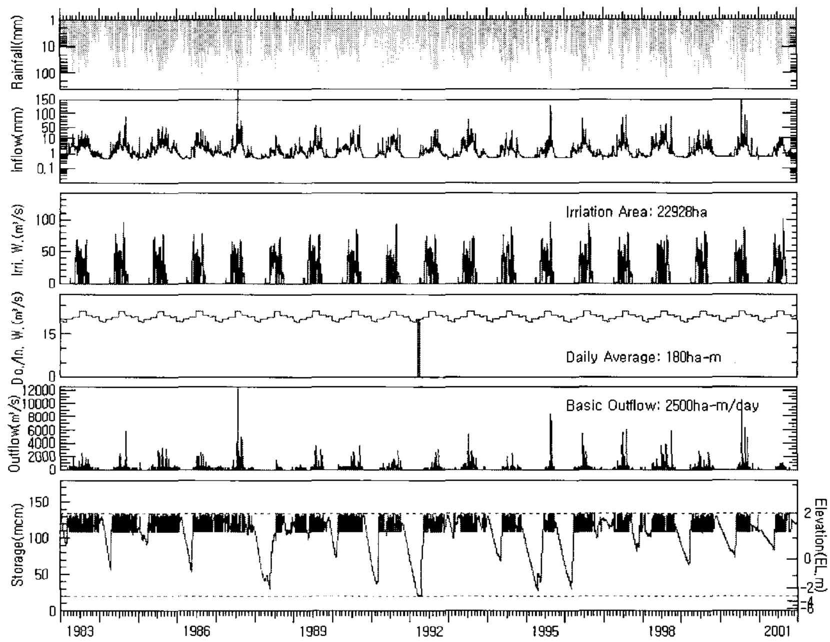

Fig. 19. Daily simulated storages of the Geum River barrage dam without the Daecheong dam upstream (1983-2001)

respectively, and 4,128 Mm^3, 4,369 Mm^3 and 0.94 were the results in the rainy season, respectively. From these results, it was concluded that river inflows to the Geum River Barrage Dam increased to 1.25 times in dry season and 1.02 times in semi-dry season, and that river flows decreased to 0.94 times in rainy season with the construction of the Daecheong Dam. This phenomenon of seasonal flow change could be validated from the monthly data shown in Fig. 16 and from the daily data shown in Fig. 17.

On the other hand, using " the model for simulating daily water storage in the estuary barrage dam " (Noh et al., 2003a), storages in the Geum River Barrage Dam were simulated on a daily basis with the same conditions in cases with and without the Daecheong Dam. Fig. 18 shows daily simulated storages of the Geum River Barrage Dam with the Daecheong Dam upstream during the last 19 years, from 1983 to 2001. Fig. 19 shows daily simulated storages of the Geum River Barrage Dam without the Daecheong Dam upstream for the same period. Storages in cases with the Daecheong Dam upstream changed sharply in comparison with storages in cases without the Daecheong Dam. This phenomenon is attributed to flow regulation by dam.

6. CONCLUSIONS

Using the operating results of the Daecheong Multipurpose Dam for the last 21 years, dam effects on water resources were evaluated. The return flows were considered in the DAWAST model and the daily water storage simulation model was used to evaluate flow regulation by dam and to analyze water supply capacities. The obtained results are summarized as follows.

The amount of domestic and industrial water supply from the Daecheong Multipurpose Dam increased to 6.1 times for the last 21 years from 61 Mm^3 in 1981 to 375 Mm^3 in 2001.

Water supply capacity was planned to total 1,649 Mm^3 per year, of which 1,300 Mm^3 was allotted for domestic and industrial water, and 349 Mm^3 was allotted for agricultural water. Based on the dam's operating results for the last 21 years from 1981 to 2001, however, water supply capacity totaled 2,350.5 Mm^3, of which 2,147 Mm^3 was hydropower water and 203.5 Mm^3 was domestic and industrial water. Water supply capacity simulated by model totaled 1,925.3 Mm^3, of which 1,559.6 Mm^3 was basic allotted outflow, and 365.7 Mm^3 was additional domestic and industrial water. In other words, the water supply capacity of the Daecheong Dam had a room of 276.3 Mm^3 per year compared with its designed value of 1,649 Mm^3 per year.

The rate of outflow to inflow of the Daecheong Dam was 1.30 times in dry season, 1.12 times in semi-dry season, and 0.90 times in rainy season. The volume of inflow to the Geum River Barrage Dam downstream after the dam construction increased to 1.25 times in dry season and 1.02 times in semi-dry season, and decreased to 0.94 times in rainy season.

It is ascertained that the volume of flow downstream increases in semi-dry and dry season, and decreases in rainy season by dam construction. This is able to be a reference guideline to operate a multipurpose dam particularly in semi-dry and dry season in Korea.

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