



Conjunctive operation of river facilities for integrated water resources management in Korea

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Abstract. With the increasing trend of water-related disasters such as floods and droughts resulting from climate change, the integrated management of water resources is gaining importance recently. Korea has worked towards preventing disasters caused by floods and droughts, managing water resources efficiently through the coordinated operation of river facilities such as dams, weirs, and agricultural reservoirs. This has been pursued to enable everyone to enjoy the benefits inherent to the utilization of water resources, by preserving functional rivers, improving their utility and reducing the degradation of water quality caused by floods and droughts. At the same time, coordinated activities are being conducted in multi-purpose dams, hydro-power dams, weirs, agricultural reservoirs and water use facilities (featuring a daily water intake of over 100 000 m³ day⁻¹) with the purpose of monitoring the management of such facilities. This is being done to ensure the protection of public interest without acting as an obstacle to sound water management practices. During Flood Season, each facilities contain flood control capacity by limited operating level which determined by the Regulation Council in advance. Dam flood discharge decisions are approved through the flood forecasting and management of Flood Control Office due to minimize flood damage for both upstream and downstream. The operational plan is implemented through the council's predetermination while dry season for adequate quantity and distribution of water.

1 Introduction

The construction of dams in Korea was motivated by the main purposes of either water supply or power generation. The construction of hydropower dams started in the 1960's. According to the 5-year economic development plan starting in 1962, the Seomjin River multi-purpose dam was the first to be built, and since 1972, multi-purpose dams such as the Soyang River and Andong dams have been built subsequently. Large-scale multi-purpose dams have been built continuously in order to meet the rapid increase of water demand, as well as to prevent flood damage, until the 1980's. In the 1990's, however, mid-scale multi-purpose dams like Buan, Miryang, and Hoengseong dams were built based on environmental considerations due to the objections from environmental organizations. In addition, there have been difficulties in the construction of multi-purpose dams, for in-

stance, the nullification of the Youngweol dam construction project, following the start of the construction of Jangheung (Tamjin) multi-purpose dam in 1996. However, the construction of five new dams, including that of Buhang, is currently in progress.

Looking at the current status of the nation's dams Fig. 1, there are seventeen multi-purpose dams, fourteen water supply dams, eight hydropower dams, and two flood control dams (excepting of estuary barrages, agricultural reservoirs, pumped-storage hydroelectricity etc.). Dams are managed (operated) by different organizations depending on their original purpose such as water supply, flood control, or hydropower. Multi-purpose dams, domestic and industrial water dams are managed by the Ministry of Land, Infrastructure and Transport (K-water), hydropower dams by the Ministry of Knowledge Economy (Korea Hydro & Nuclear Power Co., Ltd.), and agricultural reservoirs by the Ministry

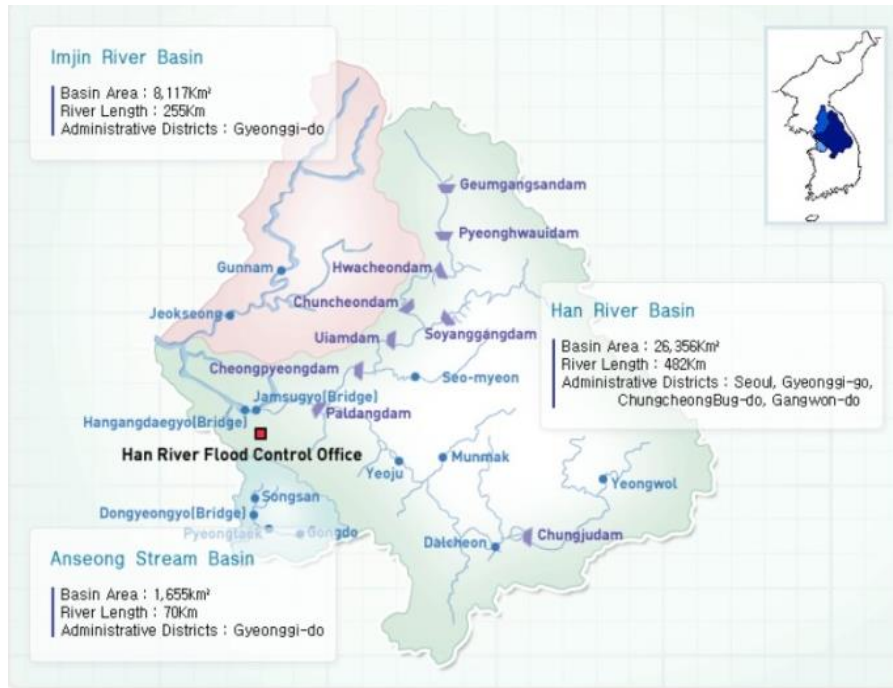


Figure 1. Dam locations in Han river (from the Han River Flood Control Office website: <http://www.hrfco.go.kr/eng/service.do>).

Table 1. Dams for conjunctive operation per watershed.

Watershed	Multi-purpose dam	Hydropower dam	Water supply dam	Flood control dam	Weir
Amount	17	8	14	2	16
Han River (17)	Soyang River, Chungju, Hoengseong	Hwacheon, Chooncheon, Uiam, Cheongpyeong, Paldang, Gwesan, Doam	Gwangdong, Dalbang	Dam of Peace, GunNam	Ipo, Yeosu, Gangcheon
Nakdong River (24)	Andong, Imha, Hapcheon, Namkang Milyang, Guneui		Yeongcheon, Angye, Gampo, Woonmoon, Daegok, Sayeon, DaeAm, Sunam, Yeoncho, Gucheon		Changnyung Haman, Hapcheon, Changnyung, Dalsung, Gangjeong Goryeong, Chilgok, Gumi, Nakdan, Sangju
Geum River (5)	Daecheong, Yongdam			Sejong, Baekjae, Gongju	
Seomjin River (8)	Seomjin River, Jooam (main), Jooam (Flood Control Reservoir)	Boseong River	Soouh, Pyunglim		Jooksan, Seungchon (Youngsan River)
Others (3)	Buan, Boryeong, Jangheung				

Table 2. The current status of dams in the Han River Watershed.

Category	Name of the Dam	Watershed area (km ²)	Normal high water level (Elevation) (m)	Total storage capacity (million m ³)	Flood control (million m ³)	Water supply (million m ³ yr ⁻¹)	Annual Energy Production (GWh yr ⁻¹)
Total		64 198	–	8104.8	1984.5	4885.5	2687.5
Multi-purpose dam	Subtotal	9560	–	5736.9	1125.5	4712.5	1203.8
	Soyang River	2703	193.5	2900.0	500.0	1213.0	353.0
	Chungju	6648	141.0	2750.0	616.0	3380.0	844.1
	Hoengseong	209	180.0	86.9	9.5	119.5	6.7
Hydropower dam	Subtotal	50 883	–	1744.2	269.0	–	1507.0
	Hwacheon	3901	181.0	1018.0	213.0	–	326.0
	Chooncheon	4736	103.0	150.0	14.0	–	145.0
	Uiam	7709	71.5	80.0	16.0	–	161.0
	Cheongpyeong	9921	51.0	185.5	19.0	–	271.0
	Paldang	23 800	25.5	244.0	7.0	–	485.0
	Gwesan	671	135.6	15.3	–	–	11.0
	DoAm	145	707.0	51.4	–	–	108.0
Flood control dam	Subtotal	7418	–	2701.6	2701.6	–	–
	Dam of Peace	3227	–	2630.0	2630	–	–
	GunNam	4191	–	71.6	70.6	–	–
Water supply dam	Subtotal	154.4	–	18.7	–	40.6	–
	Gwangdong	125	672.0	11.0	–	26.0	–
	Dalbang	29.4	112.0	7.7	–	14.6	–
Agricultural dam	Subtotal	374	–	14.5	–	132.0	–
	Gangneung	109	–	12.7	–	26.0	–
	Idong	93	–	21.0	–	34.0	–
	Gosam	71	–	16.1	–	30.0	–
	Geumkwang	48	–	12.1	–	21.0	–
	Giheung(Singal)	53	–	11.7	–	21.0	–

for Food, Agriculture, Forestry and Fisheries (Korea rural community corporation). The conjunctive operation of each dam/weir in Korea is executed as per Table 1. Water supply dams are categorized into Taebaek region, Pohang region, Woonmoon, Ulsan region, Geoje region, Yeosu region, Pyunglim, etc.

2 Dams and weirs of the Han River watershed

The current status concerning the dams/weirs of the Han River watershed is shown in Table 2, for each dam and the watershed area, normal high water level, total storage capacity, dam type, dam height, etc.

There are 3 multi-purpose dams in the Han River Watershed (Soyang River, Chungju, and Hoengseong dams) with a total storage capacity of 5736.9 million m³. There are 7 hydropower dams in the Han River Watershed, with a total power generation capacity of 494.8 MW yr⁻¹. Gwangdong and Dalbang dams are water supply dams, providing 41.0 million m³ yr⁻¹. There are five agricultural reservoirs with over 10.0 million m³ of effective storage capacity in the Han River Watershed, providing a water supply of 132.0 million m³ yr⁻¹. The dam of Peace and GunNam flood control

reservoir are flood control dams. The flood control capacity of the dam of Peace is 2630.0 million m³. Agricultural reservoirs like Gosam, Idong, Giheung, and Geumkwang reservoirs are located in the Ansong-Cheon upstream watershed.

As shown in Table 3, 16 multi-purpose weirs are built nationwide. There are 3 weirs in operation in Han River Watershed. The Gangcheon, Yeosu, and Ipo weirs have been built and are currently in operation in the Han River watershed, thus allowing to secure water and to prevent the lowering of the groundwater level.

3 The conjunctive operation of dam and weirs

The conjunctive operation of river facilities is classified under the following frameworks: flood season, drought season, and river water quality. During the flood season, facility managers should comply with water level restrictions imposed by flood risk to their facilities. They must obtain prior approval from the flood control office (FCO) within the jurisdiction in case of the need of gate operation for flood control. If the FCO judges that issuing a notification for flood watch or a warning alert for a given river is required, or if flood-related damage is likely to happen, the FCO takes the necessary mea-

Table 3. Current status of weirs in the Han River Watershed.

Category	Unit	Gangcheon Reservoir	Yeosu Reservoir	Epo Reservoir
Watershed area	km ⁻²	10 972	11 115	11 803
Height	m	8	8	6
Design Flood	m ³ s ⁻¹	16 070	16 070	16 070
Maximum water level	elevation m	38.5	33.5	28.5
Management water level	elevation m	38.0	33.0	28.0
Minimum water level	elevation m	35.2	31.7	25.3
Total Storage capacity	million m ³	9.0	11.0	14.0
Drought water level	elevation m	33.7	31.5	25.0

sures considering the overall flood situation of a given basin, including weather and river conditions, as well as the storage capacity of the relevant dams and weirs. For example, the FCO directs the facility managers to use the storage volume of each facility down to the lowest operating water level, for flood control. During the drought season, facility managers operate according to the conjunctive plan of operation. Based on the site-specific Flowing Water Volume for River Maintenance (River Act Article 51), which can represent the state of these sites in terms of river discharge, the FCO instructs facility managers to take the necessary measures to prevent a potential situation of drought. In this sense, the FCO considers all factors contributing to the water balance of the entire basin such as climate and river conditions, storage capacities of dams and weirs, and the levels of usage of agricultural reservoirs. In addition, storage is also used to secure clean water through the improvement of the quality of river water.

In order to establish good cooperation between the relevant organizations related to the utilization of water resources, and to set the basic criteria necessary for their conjunctive operation, the Regulation Council for the conjunctive operation of dams and weirs, comprising the central council and a local council for each watershed (Han River, Nakdong River, Keum River, Yeongsan River) discuss and establish agreements on a regular basis. Central council is held in February every year, each watershed's council is held every December. The council consists of government organization, local governments, facility managers and specialists from private sector related with water management. The council works out conjunctive operation plan, decides matters concerning its change and assessment and other matters needed for effective conjunctive operation and mediates opinions of stakeholders related with conjunctive operation. For example, Han River Regulation Council are consisted of three representatives from Ministry of Land, Infrastructure and Transport, one representative from Ministry of Environment, five representatives from Local Governments, three representatives from each Dam operation Company and six specialists (Fig. 2).

The Minister of Land, Infrastructure and Transport can limit the usage by the users or control the permitted levels of

water, in case the streamflow is under any of the conditions below, affecting the downstream management:

1. Difficulty to ensure in-stream flow according to the standard limit;
2. Possibility of negatively affecting the public benefits if the permitted water levels are not controlled due a prolonged drought;
3. If water users cannot use the water within the expiry date or if they have used less than the quota permitted by the Decree of the Ministry of Land, Infrastructure and Transport;
4. Difficulties using other allowed streamflow.

The adjustment of the permitted water, must be deliberated by the National River Management Commission. Before adjusting the permitted water, a Regulation Council for streamflow can be formed and act according to the residents' opinions, according to the presidential decree. The Regulation Council is under the relevant Flood Control Office, at the Ministry of Land, Infrastructure and Transport, and it is formed with less than 20 members including one chairman.

Once the annual cooperative plan is formulated, the following information is established either quarterly and monthly: matters concerning water levels and the plan of supply at certain facilities, the current and planned water usage at water intake facilities, as well as matters concerning water surface conditions and its management plan at dams and weirs. The data needed to establish cooperative plans are collected and utilized jointly by related organizations. The cooperative plans can be modified according to the resolutions emitted by the council for conjunctive operations in case of any changes in climate, rivers, electricity or intake conditions, or if there is a request of modification from the related organization. The FCO within the jurisdiction evaluates performance of conjunctive operation by season. Related organizations can request emergency drainage in case of emergency such as climate change, change of river discharge and water quality, and safety management.

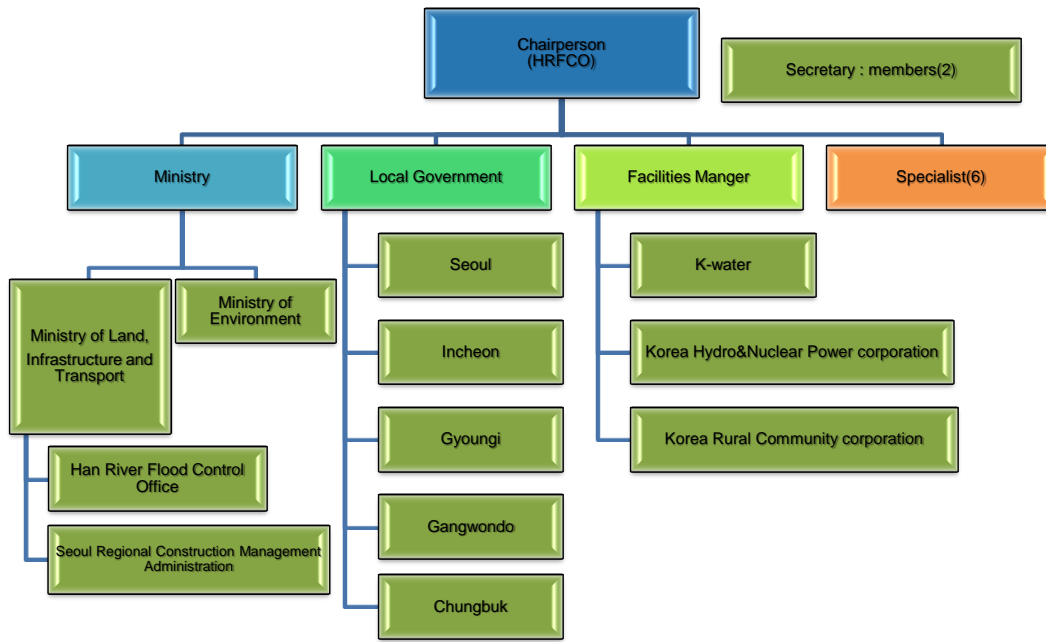


Figure 2. Regulation Council for the conjunctive operation of dams/weirs Council(18): MOLIT(3), MOE(1), Local Government(5), Dam operation(3), Specialist(6).

4 Operation of flood handling dam/weir and the case of 2006

The water level of dams is limited during the flood season in order to ensure flood control. A restricted water level is maintained for 3 months from 21 June to 20 September. The total flood control capacity of the Han River watershed is 1461.1 million m³. According to multi-purpose dam control regulation, article 14, when the dam level needs to be lowered below the flood season restricted water level, and attending the flood situation up and downstream, it is possible to set a discharge whose amount and time are to be approved by the General Director of Flood Control Office, Ministry of Land, Infrastructure and Transport. The Design Flood Level defines a dam’s maximum level that can be observed during flood control. Normal high water level is the maximum water level that can be observed in the segment that is utilized for water supply. Restricted Water Level for the flood season is the level that has been set in order to ensure flood control during the flood season, and it is the maximum level to maintain when there is no flood inflow. Regarding the dams for which there is no set Restricted Water Level, a normal high water level sets the reference. Minimum Storage Level is the lowest level at which the dam’s water can be used. The flood control capacity is the storage capacity between the dam’s Design Flood Level and Restricted Water Level for the flood season.

The procedure for discharge at multi-purpose and hydropower dams during the flood season is as follows: the dam manager requests approval for according to the discharge

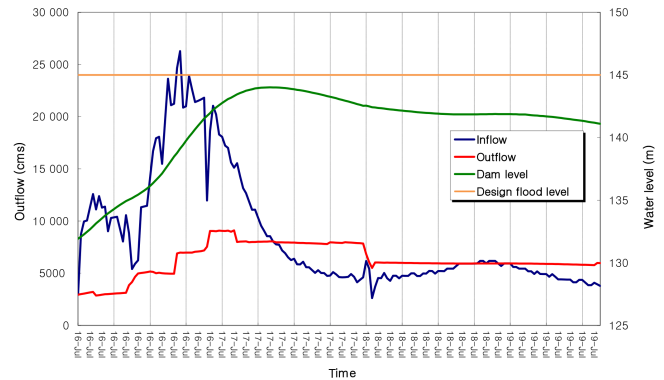


Figure 3. Flood control by Chungju dam in 2006 case.

plan and the Flood Control Office, Ministry of Land, Infrastructure and Transport analyse the state of all related streams and decides to approve, or not, accordingly. Each dam manager is requested to revise the expected inflow and discharge plans, depending on the effects of downstream rainfall. The assessment of the downstream water level and dam’s hydrologic characteristics such as dam’s upstream rainfall, inflow, discharge, minimum storage level, and flood control capacity must be established. In case of controlling a movable weir to maintain the management level as per usual, this can be done by the facility manager (K-water) without any further approval or reporting procedure required, however, the facility manager is required to broadcast a security alert, when necessary. During the flood season, approval is needed in the

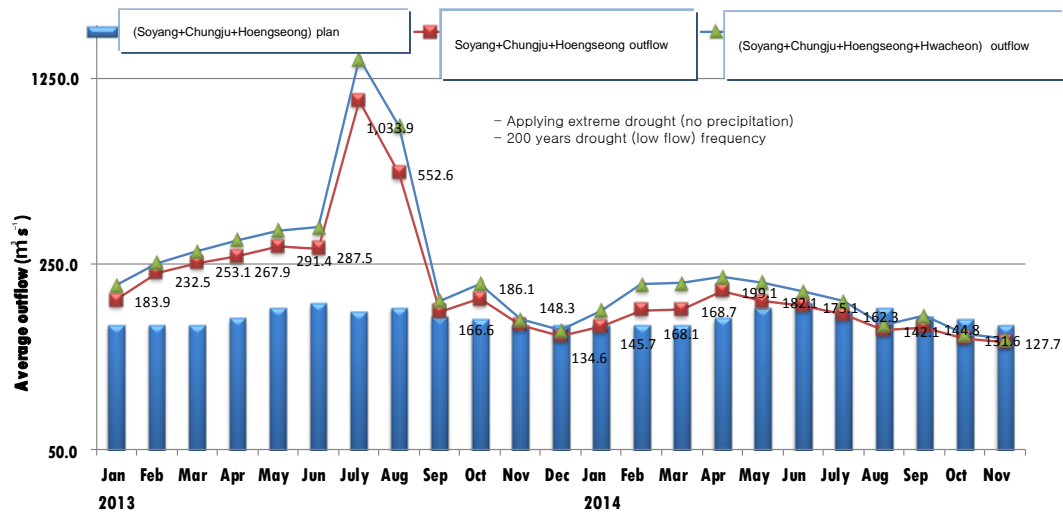


Figure 4. Providing real water demands by considering drought status and conjunctive operation.

beginning and the end stages of flood control, as well as during the maximum discharge (complete closure) at the movable weir's control floodgate. As aforementioned, the water level in the dam is controlled during the flood season in order to ensure flood control capacity.

Recently, a pre-release has not been executed because the water level of Soyang River, Chungju, Hwacheon, and Hoengseong dams has been maintained below the restricted water level. Thus, we would like to present the case of 2006, which is remembered as the most urgent and difficult dam operation performed during the flood season. The flood of July started with Ewiniar typhoon proceeding northward towards the Korean peninsula. Ewiniar dissipated when it reached the land, but the vapors within developed a seasonal rain front causing considerable rain to fall in the Han river watershed on 12 July. For this reason, the entrance to Jamsugyo Bridge, over the Han River was prohibited. The release began at the Chungju dam, on the Namhan River to ensure the security of the dam and the downstream area (Hwirin Kim et al., 2015). Due to continuous a rain front and localized heavy rain, at 02:15 LT (GMT +9) on 16 July, K-water requested the discharge of Chungju dam to be increased from 08:00 LT from 3000 to 5000 m³ s⁻¹. Five hours later, concerned with the integrity of the Chungju dam, a request was made to increase the discharge to 10 000 m³ s⁻¹. However, catastrophic effects in Yeosu and Seoul (Han River) areas were predicted in the case of the Chungju dam discharging at 10 000 m³ s⁻¹ when it was below the restricted water level. Considering the status downstream, the release had to be delayed. At 13:00 LT, K-water received an approval request for a discharge at the Chungju dam. The decision was intensely discussed between upstream and downstream regions' counterparts. The dam upstream area requested increasing its discharge amount to avoid increasing to water level at the dam. An inundation of 500 households was anticipated, with 1500

people in the need to evacuate urgently. In contrast, in the downstream area of the dam, 51 households had already been inundated, and 163 people had been evacuated. However, 20 000 people were to be evacuated if the river level increased. For this reason, they requested decreasing the discharge amount. With the dam upstream area requesting an increased discharge, and the dam downstream area requesting a decreased discharge, Han River Flood Control Office, from the Ministry of Land, Infrastructure and Transport started revising the best possible discharge amount attending to the dam's integrity. The safety at the Chungju dam was top priority. Furthermore, they assessed the constantly changing state of flood in the dam upstream and downstream areas in order to avoid later inundations. Flood forecasting based on various scenarios was established and, accordingly, they reported to K-water on the best amount and period of discharge, following on discussions with decision makers (at 15:00 LT). Fortunately, the expected result was very accurate, and, at 144 m the maximum water level of Chungju dam did not lead to an emergency situation (08:00 LT), 1 m only from the Design Flood Level (145 m, see Fig. 3, Hwirin Kim et al., 2006).

The Jamsugyo Bridge was inundated during six days and emerged at around 04:10 LT on 21 July. The highest flood since the 1990's flood was successfully handled. If there was more rainfall, if the flood forecasting was not accurate or the dam operation improper, 2006's flood may have had catastrophic consequences such as those of 1990.

5 Preventing water shortage with dam/weir management and the case of 2015

Due to the severe drought of 2015, discussions concerning the conjunctive operation of the Han River Watershed emergency case took place between the Regulation Council for streamflow of the Han River watershed and the rele-

vant offices took place. The first meeting of relevant offices was attended by the Water Resources Development Division, Ministry of Land, Infrastructure and Transport, the Han River Flood Control Office, Ministry of Land, Infrastructure and Transport, the Ministry of Environment, the Ministry of Agriculture and Forestry, the Chief of forecasting control division, the Han River Flood Control Office, the Ministry of Land, Infrastructure and Transport, K-water, Korea Rural Community Corporation, and Korea Hydro & Nuclear Power Co., Ltd in 4 March 2015. In the meeting, they agreed to execute conjunctive operations at the hydropower dams in order to lengthen water supply for a longer period. Concerns were expressed over the decrease of agricultural water from Soyang River and Chungju dams due to rainfall shortage. Keeping the minimum discharge ($124 \text{ m}^3 \text{ s}^{-1}$) of Paldang dam and considering Hwacheon dam's electricity release, they decided to decrease the discharge amount of Soyang River and Chungju dams, and established a cooperative structure to share data between Korea Hydro & Nuclear Power Co., Ltd. and K-water for conjunctive operation (Fig. 4).

Secondly, the Regulation Council for streamflow of the Han River Watershed took place. It approached regulations and handling the water intake according drought stage. Intake limitations were approved over a range of levels, and natural intake control through the promotion of water savings is being handled by K-water per agreed. Local government showed interest and requested cooperation for joint countermeasures. The majority voted in favor of intake regulations; and the conditional approval regarding the flexible intake limitation was to collect opinions from the Regulation Council. Intake limitation depending on the situation profile was determined and adopted.

6 Conclusions

Best efforts have been made in guaranteeing the facility manager's rights when it does not concern water management, not disturbing the public benefits, and giving all citizens an

even usage benefit of water resources by decreasing damages caused by flood, water shortage, and the worsening of water quality, as well as promoting the downstream maintenance of functional usage through downstream facilities' conjunctive operation such as heightened agricultural reservoirs, dams, and weirs. Recently, the Regulation Council for Streamflow and Regulation Council for Conjunctive Operation for Dams and Weirs held meetings to assess various drought alleviation measures including adjusting dam discharge level, building response guidelines and action plans, and imposing a quota on water intake. Emergency duty is also in operation to stand ready for different emergency scenarios.

The current dam storage rate in Korea is below average; therefore, the country needs to handle drought and flood at the same time. Conjunctive operation of dams and weirs is urgently needed now more than ever. In order to protect lives and property, the government needs to be alert at all times and must handle the situation wisely with the newest forecasting systems and based on the know-how of several years.

7 Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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