Examination on the Effect of Dam Flush Release for Environmental Improvement in Downstream Area of Dam

Young-Hyun Cho[1] · Sung-Tak Kim[2] · Koo-Yol Chong[3] · Young-Du Sung[4]
306-711, 560 Sintanjin-Ro, Daedeok-Gu, Daejeon, Rep. of Korea
1, E-mail: yhcho@kwater.or.kr; 3, E-mail: kychong@kwater.or.kr; 4, E-mail: ydsung@kwater.or.kr;
427-712, 560 Jungang-Dong, Gwacheoun-city, Gyeonggi-do, Rep. of Korea
2, E-mail: kst1111@mltm.go.kr

Abstract: As water activities increase with improvement of the quality of human life, it gives rise for people to require the conservation of landscape, water quality and ecosystem into rivers in social aspects. In addition, the water use pattern around the man-made reservoirs has being changed including requirement of environmental water for activation of recreations, improvement of water qualities, and protection of endangered fishes and so on. From this point of view, the effective reservoir operation becomes very important with multi-objectives considered. The flushing release project was conducted for environment improvement of the downstream areas at the 9 multipurpose dams of in 4 major rivers, and the investigation for assessing the effect was implemented for mainly water qualities. The investigation confirmed that the water quality was improved at least during the flush release period, although the spatial and temporal effects together with the duration effect of it could not be explained clearly due to the input of the non-point pollution by the precipitation.

Key words: reservoir operation for water environment improvement, flush release

1. Introduction

As water activities increase with improvement of the quality of human life, it gives rise for people to require the conservation of landscape, water quality and ecosystem into rivers in social aspects. In addition, the water use pattern around the man-made reservoirs has being changed including requirement of environmental water for activation of recreations, improvement of water qualities, and protection of endangered fishes and so on. From this point of view, the effective reservoir operation becomes very important with multi-objectives considered. Hence, it is common for multiple stake-holders including regulators on behalf of government, interest groups, environmentalists, and support groups to be involved in the decision process. Korea has the water resources characteristics that the stream flow decreases drastically in spring season due to small amount of precipitation. Although it rains in this time, the non-point pollution sources on top soil enter into water bodies and end up with deterioration of water qualities of streams and reservoirs.

Korea has 14 multi-purpose reservoirs, and they mainly take responsibilities for water supply and flood control in Korea. This study was motivated by the needs for improving water environment system in the downstream areas of the multi-purpose reservoirs with change of their operation methods. Elaborating on it, this research focuses on improving the enhancement effectiveness of water environment by triggering dynamic flushing effect with change of reservoir release pattern from uniform to pulse type. It aimed at improving water quality and eco-system such as fish habitats.

In this paper, it describes how the flush release over 9 multi-purpose reservoirs was planned and implemented in the 4 major river basins of Korea, and reviews post assessment of the results on the basis of the measured data.

2. Reservoir Operation for Improving Water Environment in the Downstream Areas of Dams

2.1 Review of Flush Release

When it comes to reservoir operation methods for improving water environment in streams, they can be broadly classified into the following items (Tsukahara and Hakoishi, 1999):

i) increasing the release for a relatively short time with such a relevant flow velocity as it is necessary for the purposes of transporting the accumulated pollutants of stream beds and the stagnated pollutants into water body;
ii) supplying water consistently for a long time enough to strengthen eco-system and activate the water activities of people such as fishing and a variety of events in association with water.

In this study, the increase of the reservoir release primarily focused on the first purpose with partially improving ecological habitats. In planning this project, the purpose of the release increase of each reservoir was reviewed first of all, and the amount of release was determined with comparison to the stream flow required for stream water quality and eco-system conservation. Secondly, it was bound to the maximum amount of power generation release in order that the spill does not take place. Finally, it was constrained within the reservoir storage available for municipal, industrial, agricultural, and instream water supply. Equation (1) refers to the process to determine the relevant release size:

$$Q_{release} = f(Q_{flushing}, Q_{w.q\,consv}, Q_{eco-system\,consv}) \le Q_{\max.\,power\,release} \le Q_{water\,supply} \qquad (1)$$

where, $Q_{flushing}$, $Q_{w.q\ consv}$, $Q_{eco\text{-}system\ consv}$ mean the amount of release enough to arise the flushing effect, conserve stream water quality, and conserve stream eco-system respectively. The $Q_{max.\ power\ release}$, $Q_{water\ supply}$ mean the maximum amount of hydraulic power generation release and maximum release to meet the storage target for municipal, industrial, agricultural, and instream water supply.

The overall release increase project was planned to be implemented for 15 days at maximum in two times with a different purpose. In case of the Andong and Hapcheon reservoirs, the release increase was planned for 3 days in order to maximize the flushing effect for short period instead of 15 days because they did not have enough storage to supply water.

The first release increase was designed to focus on flushing the accumulated pollutants of stream beds and the stagnated pollutants into water body. The second one was aimed at protecting from water quality deterioration by first flush of pollutants due to the initial rainfall in spring. It was planned for the malfunctions of the flush release to be minimized after reviewing the effects of the first release increase. Figure 1 illustrates the pattern of the flush release at the Daecheong reservoir compared to the classical release pattern for water supply. Table 1 shows the purpose of the release increase and the required stream flow by each dam.

Table 1. the plans for the release increase of each reservoir

Dam	Release increase(㎥/s)		Purpose	①Water Supply (㎥/s)	Required release(㎥/s)				Determination of Release
	1st period (15days)	2nd period (15days)			②flushing	③Max. power release	④water quality cons.	⑤eco-system cons.	
Soyang(SY)	45→60	45→60	Flushing with protection from eutrophication at the Paldang reservoir	119.9	145	250.8	105	40(min) 89(max)	①
Chungju(CJ)	80→200	80→190			330	828			①
Hyongsung(HS)	2.5→4.5	2.5→3.8	"	6.8	4.5	3.8			①,②
Andong(AD)	24→60 (3 days)	-	Flushing	-	53.5	161	57	24	②
Hapcheon(HC)	20→100 (3 days)	24→50	"	22.2	100	119			②
Namgang(NG)	22→40	22→40	Improvement of Water Quality	23	210	112			①
Daecheong(DC)	40→90	50→70	Protection of municipal water resources at stream intakes	38.7	150	264	36	33	①
Juam(JA)	1.5→5	1.5→5	Strengthening water friendly function	23.3	10	5	5.5	5	③

① margin of each reservoir in release for water supply until the beginning of flood season(June, 20)
<totally $7*10^7$㎥ in storage = the storage available for water supply($51*10^7$㎥) - the release in storage for water supply($44*10^7$㎥) >

② the required flow for arising flushing effect on the basis of the representative critical flow velocity (0.45m/s) for fine sand

④ the required flow for conservation of water quality (equal to the instream flow for water quality conservation)

⑤ the ecological flow recommendations for conservation of eco-system

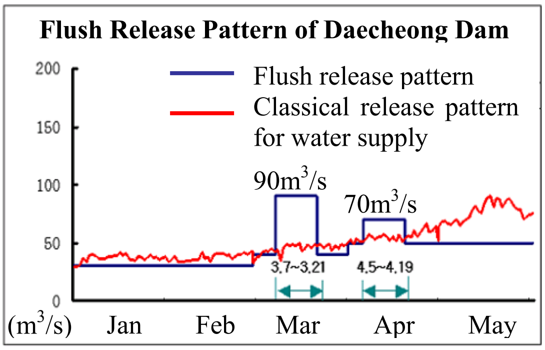


Figure 1. the pattern of the flush release

2.2 Implementation of Flush Release from Multi-Purpose Reservoirs

The flush release project for improving stream environment was implemented over 9 multi-purpose reservoirs in the 4 major river basins. The amount of total release was $5.5 \times 10^9 m^3$: the 1st discharge was $3.1 \times 10^9 m^3$ for 15 days at maximum from March, 2, and the 2nd discharge was $2.4 \times 10^9 m^3$ for 15 days at maximum from April, 23. The amount of total increased release of each basin was $3.5 \times 10^9 m^3$ in the Han River, $1.1 \times 10^9 m^3$ in the Nakdong River, $0.8 \times 10^9 m^3$ in the Guem River and $0.04 \times 10^9 m^3$ in the Seomjin River respectively. As opposed to the planning, the releases slightly increased or decreased in implementation stage because the expected hydrological conditions such as inflow were changed.

Table 2. the actual release increase in implementation stage

Classification	Han River				Nakdong River					Guem River		Seomjin River		Total discharge ($10^6 m^3$)
	SY	CJ	HS	Total discharge ($10^6 m^3$)	AD	IH	HC	NG	Total discharge ($10^6 m^3$)	DC	Total discharge ($10^6 m^3$)	JA	Total discharge ($10^6 m^3$)	
1st discharge (3.02~3.24, m^3/s)	60	200	4.5	*199.0*	57	37	100	40	*41.2*	90	*65.8*	8.5	*1.5*	*313.9*
2nd discharge (4.23~5.08, m^3/s)	120	130	3.8	*150.2*	25	17	42	42	*69.0*	70	*18.3*	8.5	*2.6*	*240.1*
Total discharge ($10^6 m^3$)	*96.8*	*248.1*	*4.3*	*355.6*	*19.5*	*9.4*	*49.4*	*31.9*	*110.2*	*84.1*	*84.1*	*4.1*	*4.1*	*554.0*

3. Evaluation of the Project

3.1 Scope of the Investigation

For assessing the release increase, the investigation was made before and after implementation of the project at the control points of each basin for water management. Investigation was carried out to acquire the hydrological data (stage, flow, etc), water quality (BOD, COD, SS, nutrients, and so on), and ecological data (movement of bed material, and so on). Hydrological investigation was done indirectly using stage-discharge rating curve. The water qualities were measured directly in the fields and analysis on the laboratory. Table 3 refers to the hydrological and water quality investigation sites. The ecological survey was made on 5 areas of the physical properties of channel, river vegetation, attached algae, fish eco-system and stream bed material in the downstream areas of the Chungju, Hapcheon, and Daecheong dams. However, they are not described in detail in this paper.

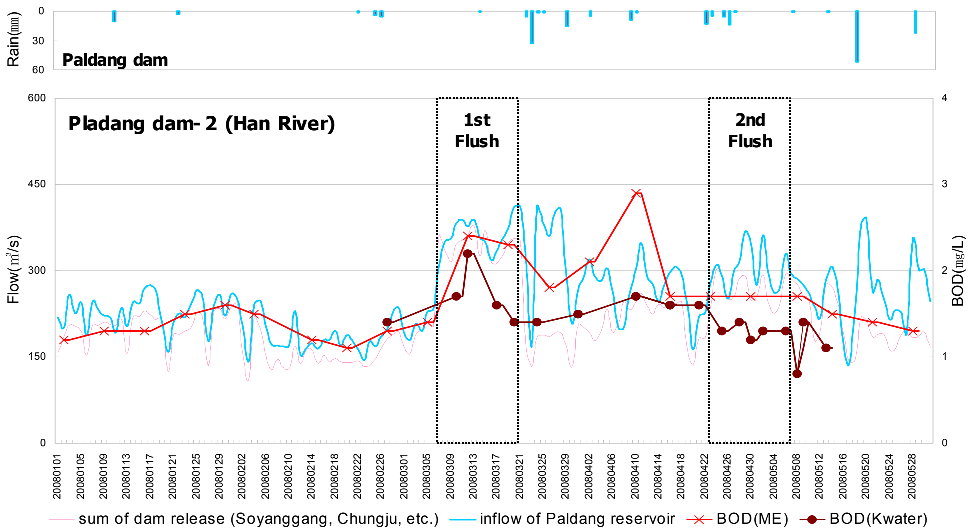
Table 3. the sites of hydrological and water quality observation

Item	Dams in Han River			Dams in Nakdong River			Dams in Guem River	Dams in Seomjin River
	Soyanggang	Chungju	Paldang	Andong, Imha	Hapcheon	Namgang	Daecheong	Juam
Water Level Measurement Points	-	Mokgye, Yeoju	Yeongdong Bridge, Hangang Bridge	Andong, Jibo, Waegwan, Hyeonpung	Hapcheon, Jeokpogyo	Jindong, Wolchon	Bugang, Gongju, Gyuam, Ganggyeong	Jukgok, Songjeong
Water Quality Measurement Points	Soang 2, Uiam	Jungwon, Yeoju 1, Paldangdam	Jamsil, Noryangjin	Andong2, Yecheon, Waegwan, Hyeonpung	Hwanggang2, Hapcheon	Namgang1, Namji, Mulgeum	Hyeondo, Cheongwon, Gongju1, Buyeo, Geumgang Estuaries2	Boseongcheon, Gurye

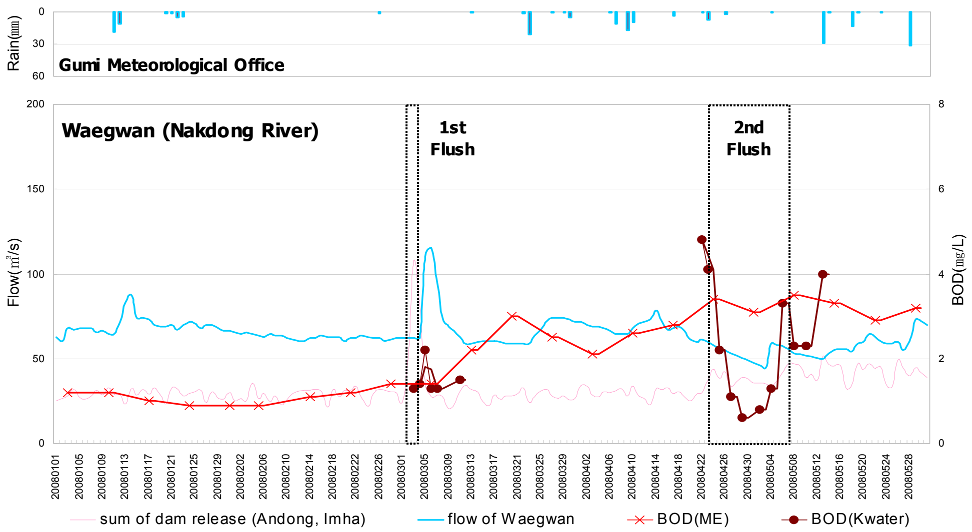
3.2 Investigation Results

As for the survey results of the discharge estimated by the rating curves and water depth at the control points during the flush release, the effect of water depth increase was identified clearly to the middle area from each dam. On the contrary, it was hard to recognize the effect as much as that of the middle area as it gets closer to the estuary area because of influence of the barrage operation and tidal phenomenon. In case of the water quality, it rose in general right after the release increase and decreased gradually as the release continued. However, the extent of variation of water quality was different by point and item, and the water qualities started deteriorating again after stopping the release increase.

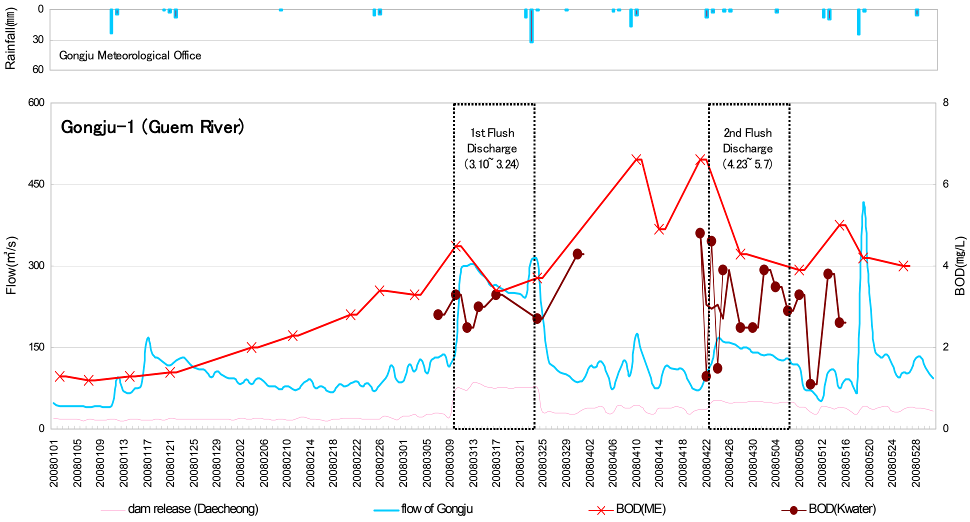
Figure 2 shows the temporal variation of the release and BOD with the precipitation at the representative measurement sites of each basin. They are Paldang dam-2 in Han River, Waegwan in Nakdong River, Gongju-1 in Guem River, Boseong-cheon in Soemjin River. The BOD data are compared with the data measured by the Ministry of Environment (ME) by plotting them together because the water qualities can be different according to a measurement point and analysis method even in the same site. As it was supposed, there were the differences between the BOD data measured by K-Water and ME. But, it can be noticed that the trends of the two data were similar.



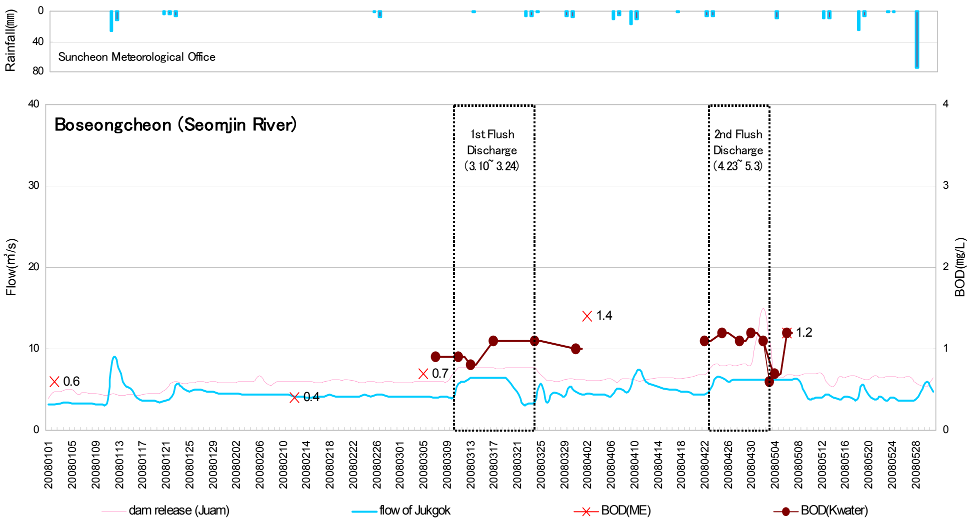
(a) Han River



(b) Nakdong River



(c) Guem River



(d) Seomjin River

Figure 2(a~d). the variation of BOD and hydrological data at the representative sites of each basin before and after the release increase

3.2 Effect of water quality improvement for flushing discharge

In Table 4, the effect of the flush release was summarized in terms of the water quality of BOD, COD, SS (suspended solid), and the representative nutrients for algal growth (such as T-N: total nitrogen, and T-P: total phosphorus) in the 4 major river basins. Table 4 shows the extent of water quality reduction with the minimum and maximum differences at the measurement sites before and after the flush release. From this, it can be recognized that the water qualities in BOD and COD were improved with a range of about 0.1~2.5㎎/L. On the other hand, the improvement effect of the nutrients such as N and P that exist in dissolved state partly, were relatively higher than non-dissoluble organic matters such as BOD. This can be explained by physical transport and dilution effect of the dissoluble matters, and floating and sediment effect of the non-dissoluble matters.

In assessing the effect of the flush release in water quality index, the following results should be analyzed synthetically:

- the extent of water quality improvement temporally during flush release;
- the duration time of water quality improvement;
- the effect of water quality improvement spatially in stream and estuary, and so on.

The investigation results confirm that the effect of water quality improvement by flush release is clear. However, it is hard to judge the pure effect by the only release increase from dams during the flush release because of the noise due to the input of the non point pollution by the precipitation at the end of the flush release. As the distance is longer from a dam, it was also complicated to analyze the flush effect by the only dam release increase spatially from a dam to an estuary in the same reason.

The graph of the Paldang-dam-2 in Han River shows that the BOD increased due to the pollutants flushed from the upstream area in the middle of the first flush release, and decreased gradually by the end of the first flush release. After stopping the first flush release, the BOD increased due to the first basin flush effect by the precipitation in spring season. Compared to the precipitation of the last spring time, the total precipitation was approximately 30% low in this spring. It accounted for the reason that the BOD sharply went up with a small amount of precipitation after stopping the flush release. It shows in addition that the BOD did not rise during the second flush discharge. The reason can be explained that the most of the accumulated and stagnated pollutants might be flushed during the first flush release.

Table 4. the extent of water quality reduction during flush release period (Unit: ㎎/L)

Division	Han River		Nakdong River		Geum River		Seomjin River	
	1st period	2nd period	1st period	2nd period	1st period	2nd period	1st period	2nd period
BOD	0.1~0.8 (7~25%)	0.1~0.8 (7~50%)	0.1~1.2 (7~22%)	0.4~2.5 (40~52%)	0.1~2.4 (4~37%)	0.1~1.8 (5~37%)	-	0.5 (45%)
COD	0.2~0.3 (7~9%)	0.1~1.5 (3~52%)	0.4~0.9 (7~38%)	1.2~2.0 (27~34%)	0.7~2.0 (15~27%)	0.2~1.1 (4~29%)	-	-
SS	0.2~2.9 (14~38%)	0.4~4.1 (57~85%)	0.5~16.1 (21~42%)	0.4~10.8 (33~44%)	-	0.8~10.8 (4~47%)	-	2.8 (44%)
T-N	0.617~4.016 (25~55%)	0.178~2.411 (9~55%)	0.014~1.148 (1~36%)	0.103~1.089 (7~32%)	1.382~1.550 (31~34%)	0.141~1.474 (5~41%)	0.119~0.597 (14~29%)	0.267~0.552 (37~62%)
T-P	0.023~0.074 (100~74%)	0.001~0.372 (4~62%)	0.022~0.088 (50~23%)	0.002~0.046 (10~29%)	0.002~0.028 (50~64%)	0.005~0.054 (42~34%)	-	0.014 (44%)

5. Conclusions and Further Study

The flushing release project was conducted for environment improvement of the downstream areas at the 9 multipurpose dams of in 4 major rivers, and the investigation for assessing the effect was implemented for mainly water qualities. The investigation confirmed that the water quality was improved at least during the flush release period, although the spatial and temporal effects together with the duration effect of it could not be explained clearly due to the input of the non-point pollution by the precipitation.

It can be thought that the flush release had an influence on ecological habitation environment to some extent. For the further study for it, the ecological assessment environment will be made based on the investigation data on 5 areas of algae, fish ecology, and so on. Finally, the methodology of dam operations for enhancing the efficiency of the environmental improvement will be studied for examining the physical, ecological and water quality impacts of the period, duration, and the amount of release. In addition, the existed water quality models will be refined using the results, and they will be integrated into a comprehensive system with embodying the multi-dimension and multi-water body analysis of water quality according to the physical properties by section from a dam to its estuary in a river. In order to enhance the accuracy of model, the basin models that can analyze the non-point pollution with runoff analysis should be developed and coupled with the water body models.

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