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Evaluation of Pollutant loads at Inflow Streams under Ara Waterway Basin

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Abstract : In this study, to evaluate the characteristics of the pollution in the major inflow tributaries and major environmental facilities in the watershed of Ara waterway, An inflow flow rate measurement and water quality analysis were conducted during dry and rainy seasons. In addition, the flow rate measurement, water quality analysis, and pollutant load at each monitoring point were compared and evaluated. Influx of BOD5, T-P and T-N into the tributaries of the ARA waterway watershed, excluding the Gulpo river watershed, during dry season were only 0.007%, 0.005% and 0.004% respectively of the incoming loads in the entire ARA waterway basin. In addition, it was confirmed that the discharge pollutant loads during rainfall event was about 440 times more for BOD5, about 545 times on T-P, and about 23 times on T-N in comparison to the pollutant loads during the dry days. When the Gulhyeon rubber dam was deflated, the discharged pollutant load during a rainfall was higher than the estimated load at the G7 monitoring point because the deposited pollutants from the upstream riverbed flowed down. Therefore, during a rainy season, it is necessary to manage the influx of high-load water pollutants from the overflow and deflation of the Gulhyun rubber dam as well as to find a strategy to reduce the pollutant loads in the Gulpo river watershed.

Key Words : Ara waterway, Inflow pollutants, Tributary, Non-point source, Pollutant loads, Rubber dam

1. Introduction

To reduce water pollution, the Korean government implemented a watershed management policy called 'Water Management Comprehensive Plan' from 1998 to 2000. In 2009, they set goals such as expanding water-related functions, securing water resources, and improving water quality through the 'Four Rivers Recovery Project'.[1,2] Current water quality control system has limitations because it sets all watersheds as a management target area and utilizes the same conventional standard flow with target substances. Because the system needs to accommodate the characteristics of the watershed and tributaries, it is difficult to improve the current system due to the limitation in the technology and administration of the control system. Mainstream is influenced by tributaries that are connected like branches and these tributaries are located near areas where people reside, directly affecting the quality of the mainstream water. [3] In order to understand the influence of main stream water quality on the influx of tributaries, a customized research study focusing on tributaries and watersheds should be preceded. Therefore, actual measurement and monitoring data are needed to accurately analyze the factors that affects water quality and pollutant diffusion behavior under various hydraulic conditions. [4]

The Ara waterway extends from the west coast of Incheon to Gangseo–gu, which is Hangju Bridge in the Han River of Seoul, with a width of 80 m, an average depth of 6.3 m, and a watershed area of 134 ㎢, length 18.7 km. On January 7, 2011, the river was named "Ara waterway" and it became the first national river (Notification No. 2011-3 of the Ministry of Land, Transport and Maritime

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Affairs) to be artificially built in tidal area. Since its opening in May 2012, the canal functioned as a flood control, transportation, and tourist attraction.

From the early days of its operation, there were problems with the management of the water quality, evidenced by the low water quality, emergence of green algae, and death of fish. Due to the nature of the watershed with tidal currents, water quality is influenced by various factors, thus making it difficult to establish an effective water quality management plan. Especially in the Ara waterway basin, the waterway includes the Ara river, two other agricultural water channels as well as the Gulpo river with 14 smaller streams that flows into the basin. This complex conditions, flow of various tributaries and the inflow of unspecified pollutant sources, cause many limitations on systematic water quality management.

In this study, to evaluate the pollution characteristics of the major inflow tributaries and major environmental facilities in the watershed of Ara waterway, an inflow flow rate measurement and water quality analysis were conducted during dry and rainy seasons between December 2014 and December 2016. In addition, the flow rate, water quality, and pollutant load at each monitoring point were compared and evaluated against each other

2. Materials and Method

2.1. Watershed and Management plan

Ara River is the artificial waterway that flows from the Hangang Junction of Gaehwa-dong, Gangseo-gu, Seoul Special city to the west coast of Gyeongseo-dong, Seo-gu, Incheon Metropolitan City. It flows through Bupyeong-gu, Gyeyang-gu in Incheon metropolitan city, Bucheon city, Gimpo city in GyeongGi-do and Gangseo-gu in Seoul.

The entire Ara water basin is located 30.3 ㎢ in Bupyeong-gu, 39.75 ㎢ in Gyeyang-gu, 42.22 ㎢ in Bucheon city, 6.62 ㎢ in Gimpo city and 12.79 ㎢ in Gangseo-gu.[8,9] The Gulpo river, the largest tributary of Ara waterway basin, originates from ilsin-dong, Bupyeong-gu, Incheon Metropolitan City and is 21.2 km in length and has a watershed area of 131.81 km2. It flows into the Han River in dry season. However, in case of a rainfall, to prevent the submergence of the downstream of Gulpo River watershed, depending on the intensity of the rainfall, the rain water would either overflow above the Gulhyun rubber Dam or drain into the Ara River due to the deflation of the rubber dam.

The Ara waterway is connected to the Han River (Gimpo TM) and the West Sea (Incheon TM), and is influenced by various surrounding environments such as the weather, lock gate operation, and tidal differences. To minimize the residence time of flowing water, 10 CMS (m3/s) of freshwater from Han river and 20 CMS of seawater from west sea were supplied to the Ara waterway. The residence time of flowing water was planned at 6.5 days to prevent stagnation and to improve water quality. (Figure 1). The water quality target is set as shown in Table 1. The target took into consideration the quality of the Han River downstream and the sea water of the West Sea.[10]

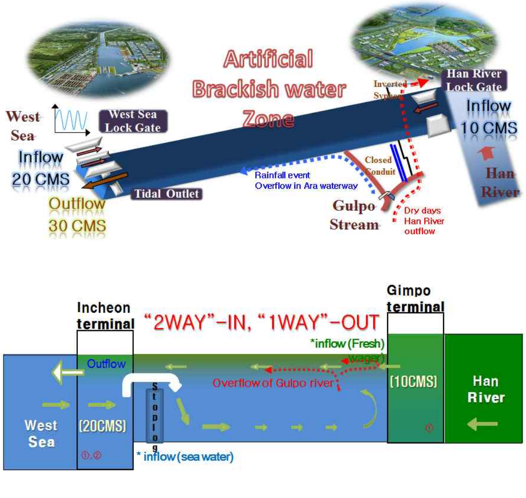

Figure 24. Flow condition diagrams of Ara waterway

Table 1. Water quality guideline for Ara waterway management

Parameters	Target water quality			Note
	Gimpo terminal	Ara waterway	Incheon terminal	
COD_{Mn}	< 7.0	< 7.0	< 6.0	Average of surface·middle·bottom
DO	< 5.0	< 5.0	< 5.0	Bottom level sample
T-N	< 7.0	< 6.0	< 5.0	Average of surface·middle·bottom
T-P	< 0.6	< 0.5	< 0.4	Average of surface·middle·bottom
Chl-a	< 35.0	< 35.0	< 25.0	`Surface sample (mg/m^3)

2.2. Monitoring points and sampling

As shown in Fig. 2, we selected 6 monitoring points (A1 ~ A6) in the Ara waterway and 8 monitoring points (G1 ~ G8) in the Gulpo river. A total of 14 monitoring sites were analyzed for flow rate and water quality in dry season (5 times) and rainy season (rainfall events). Flow rate and water quality were measured in accordance with the Water Pollution Standard Analyzing Method as defined by the Ministry of Environment.[11] Table 2 shows how to measure at each points.

Figure 2. Monitoring points of Ara waterway basin

Table 2. Measurement of flow-rate and water quality according to weather condition

Parameters		Monitoring Point	Methods of water flow-rate and water quality
Method of sampling	Dry days	A1~A6 G4~G7	- Antecedent dry days : over 5days - 5 times
	Rainfall events	G8 (Rubber dam)	- Precipitation over 20mm rainfall - 3 times monitoring in case of overflow or deflation - Water analysis 20 sampling / rainfall event - Include 2 sampling after inflated rubber dam - Flowrate data : k-water
		G1, G2, G3, G4, G5, G7	- Precipitation over 20mm rainfall - 3 times monitoring Water and flow analysis 15 sampling / rainfall event - Initial rain sampling / 30min.~1hour, 1 sampling after rainfall finished
Water Quality		BOD_5, COD_{Mn}, SS, T-N, NH_3-N, NO_3-N, T-P, PO_4-P, Chl-a, DO	

3. Result and discussion

3.1. Monitoring results

3.1.1 Dry days

Table 3 shows the results during dry days. There were 7 sampling points with higher CODMN, 4 points with lower DO, 6 points with higher T-N, 6 points with higher T-P in comparison to the Ara waterway criteria. Regarding the concentration of K-a, none of the points exceeded the criterion. Most of the monitoring points that exceeded the water quality management target were identified as the points in the Gulpo river watershed. An analysis of the water quality showed that the average values of each pollutant index at 10 monitoring points were BOD5 15.4 mg / L, CODMn 14.9 mg / L and SS 27.1 mg / L. Among them, A2 and G4 showed high concentration of water pollution and low DO concentration than other monitoring points

Analysis of the pollution degree of nitrogen showed that the average concentration of 10 sampling points was 9.812 mg T-N/L, 4.97 mg NH3-N/L and 3.48 mg NO3-N/L. G7 and G6 (gulpo sewage treatment plant) showed 82.3% and 75.5% NO3-N out of T-N, respectively. The ratio of NO3-N out of T-N was the highest at G7 and G6 points located in the mainstream of the Gulpo river. The water quality of the tributaries located downstream of Gulpo river showed higher ratio of NH3-N in T-N due to the inflow of untreated sewage. For phosphorus, the overall mean concentration was 0.634 mg T-P/L and 0.535 mg PO4-P/L. At G4 and A2, the T-P average concentration was evaluated to be at least 6 times higher than the river water criterion (0.5 mg/L based on T-P).

In the case of SS (Suspended Solid), the mean value was 27.1 mg/L, A2 62.7 mg/L and G4 56.2 mg/L. The average of DO concentration was 5.4 mg/L, while A2 and G4 were 3.9 mg/L and 1.9 mg/L, respectively. The monitoring result during dry season confirmed the presence of untreated wastewater in A2 of Ara waterway and G4 of the Gulpo river watershed. In particular, it is necessary to control the concentration of nitrogen and phosphorus, which are eutrophication-causing substances. [12] Individual sewage treatment facilities need to be inspected and guided in A2 tributary. In order to manage the downstream water quality of the Gulpo River, it is necessary to improve the sewer pipe in the G4 tributary watershed and install facilities to reduce the non-point source pollutant.[13]

Fig. 3 shows the result of the flow rate measurement during dry season. Much of the tributary flow in the Ara waterway basin occurs in the Gulpo river watershed, and most of the downstream flow originates from the effluent water coming from the sewage treatment plant[14]. During the dry season, the Gulpo

Table 3. Result of water quality analysis of Ara waterway's monitoring points during *dry days

Parameters / MPs	BOD_5	COD_{Mn}	SS	T-N	NH_3-N	NO_3-N	T-P	PO_4-P	Chl-a	DO
A1	2.4	5.4	22.3	3.494	0.28	2.84	0.078	0.056	1.8	4.4
A2	70.7	46.8	62.7	13.25	8.86	1.66	1.176	0.836	5.6	3.9
A3	8.8	11.1	28.5	12.252	7.91	2.59	0.670	0.583	8.3	4.4
A4	2.4	4.6	19.1	2.804	0.27	1.79	0.121	0.101	8.4	6.2
A5	2.6	5.3	16.0	3.53	0.32	2.32	0.119	0.106	6.8	6.5
A6	3.7	6.8	35.0	3.467	0.35	2.55	0.071	0.033	12.8	8.3
G7	4.5	7.5	9.7	10.98	0.85	9.08	0.393	0.354	8.0	6.8
G6	5.8	12.8	10.3	10.802	1.3	7.96	0.563	0.497	6.0	6.2
G5	8.8	11.3	10.8	14.504	9.92	3.28	0.910	0.830	5.6	5.5
G4	44.4	37.4	56.2	23.046	19.6	0.78	3.035	2.591	9.9	1.9
Average	15.4	14.9	27.1	9.812	4.97	3.48	0.714	0.599	7.3	5.4

River water usually flows into the Han River; however, when Gulhyeon rubber dam deflates due to the rain, the polluted water in the Gulpo river flows directly into the Ara waterway, thus having a greater impact on the water quality of the Ara waterway.

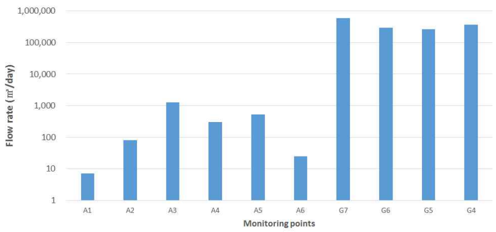

Figure 3. Result of mean water flow-rate of Ara waterway watershed's monitoring points during dry days

3.1.2 Rainfall events

For the duration of the study period, flow rate and water quality measurements were made three times during different rainfall event (2015/07/15, 2016/09/22, and 2016/12/01). The flow characteristics and the mean runoff concentration characteristics of the major water quality items (BOD5, CODMn, SS, T-N, T-P) were compared (Figure 4-6).

Flow and water quality measurements were performed on G4, G5, G7, and G8 in the first rainfall event. As rainfall increased at each monitoring point, the flow rate gradually increased and the SS concentration increased. It was confirmed that the water pollution concentration was rapidly increased by the deflation of Gulhyun rubber dam, and the water quality stabilized when the dam was inflated as the precipitation decreased.

Before overflow, the BOD5 concentration was 1.9 mg/L in downstream of the Gulhyun rubber dam(G8). After deflation, sediment materials and non-point pollutants generated in the Gulpo river watershed flowed in at once, increasing the BOD5 to a maximum of 40.6 mg / L and then decreasing to 5.5 mg/L after inflation. DO decreased from 2.27 mg/L to 0.8 mg/L by deflation. At that time, the mean SS was 205.8 mg/L and then it increased to a maximum of 620.0 mg/L.Deflation of rubber dams suddenly increases flow, and this increased flow releases upstream sediment in a short period of time. [15]

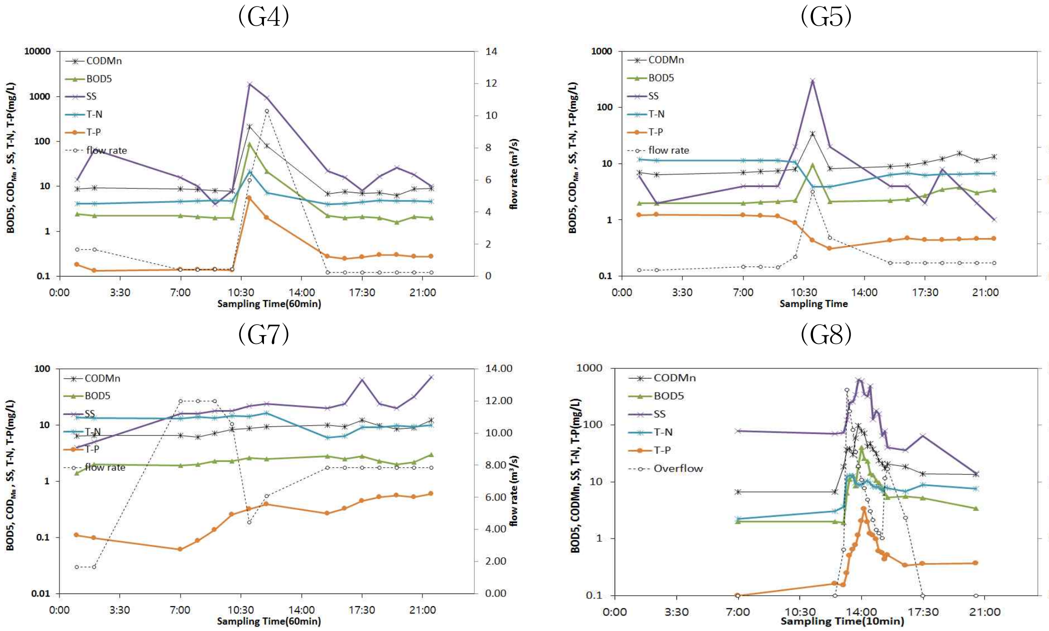

Figure 4. Result of mean water flow-rate of Ara waterway watershed's monitoring points during dry days

During the second rainfall, the rainfall lasted longer than the first rainfall event, and the flow rate gradually increased.

In addition, the water pollution concentration of G4 and G5 monitoring point increased with the increase of the flow rate, but there were not a lot of difference in the water quality at the G7 monitoring point. In the second event, the overflow of the rubber dam happened, but the deflation did not occur as the rainfall decreased. Significant differences in water quality and its behavior were found between the overflow and deflation of the rubber dam. The second event was different from the first event in that the SS did not show a sharp increase, and the items of nutrients such as T-P and T-N increased with the beginning of the overflow. DO ranged from 7.8 to 9.0 mg/L before the overflow and decreased to at least 3.1 mg/L during the overflow. During the third event, it was confirmed that the concentration of pollutant gradually increased from upstream to downstream of Gulpo river. The average SS concentration at G1 was 47.1 mg/L, but it increased to 111.1 mg/L at the G3 monitoring point due to the pollutants in the runoff from the upstream watershed until G3. The increase in flow rate by the rainfall caused SS to increase from the upstream; this is also caused by the inflow of other tributaries and CSOs (combined sewer overflow) and made the concentration of the water pollution higher downstream.

The decrease of the SS mean concentration in G7 to 19.9 mg/L is caused by the widening of the stream width and the decreasing of the flow velocity and the sedimentation of SS. The concentration of BOD and COD tended to increase with the increase of SS. T-N and T-P increased rapidly after deflation and gradually decreased with the progress of overflow.[16]

3.2. Estimation of pollutant loads

BOD5, T-N, and T-P pollutant loads (kg/day) for dry days and rainy days were calculated using average flow data and concentration at each monitoring point (Table 4, Table 5). The lowest pollutant loads during the dry season were A1 and then A6. The highest point of pollution load was G7 due to WWTPs (G6, wastewater treatment plant) effluents. The total monitoring points in the Gulpo river basin showed higher pollution load than the other monitoring points in the tributaries of Ara

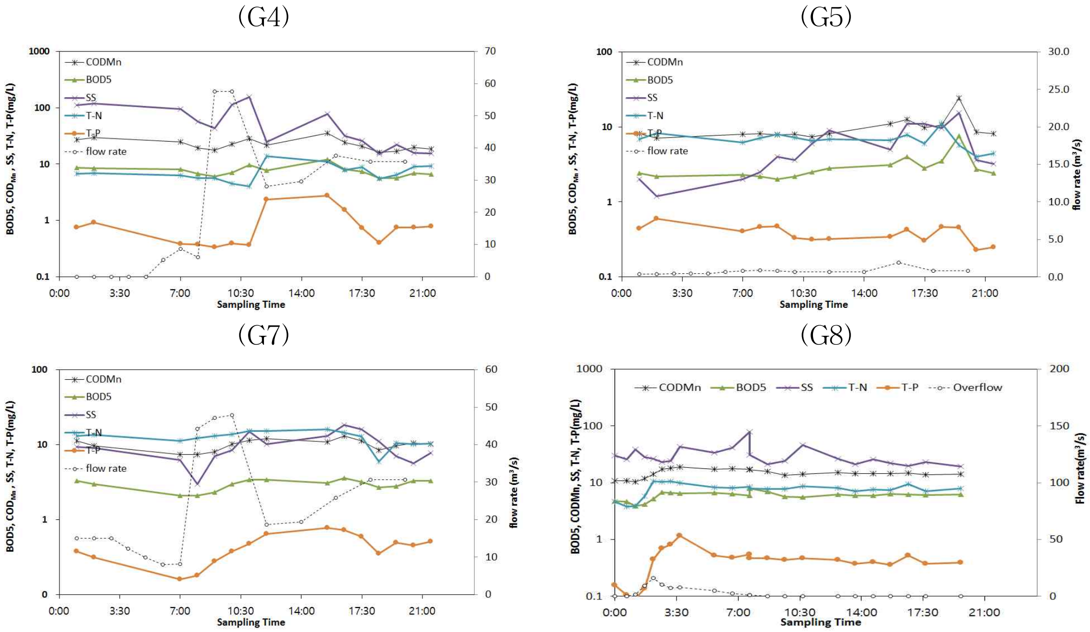

Figure 5. Variation of Flow and water quality

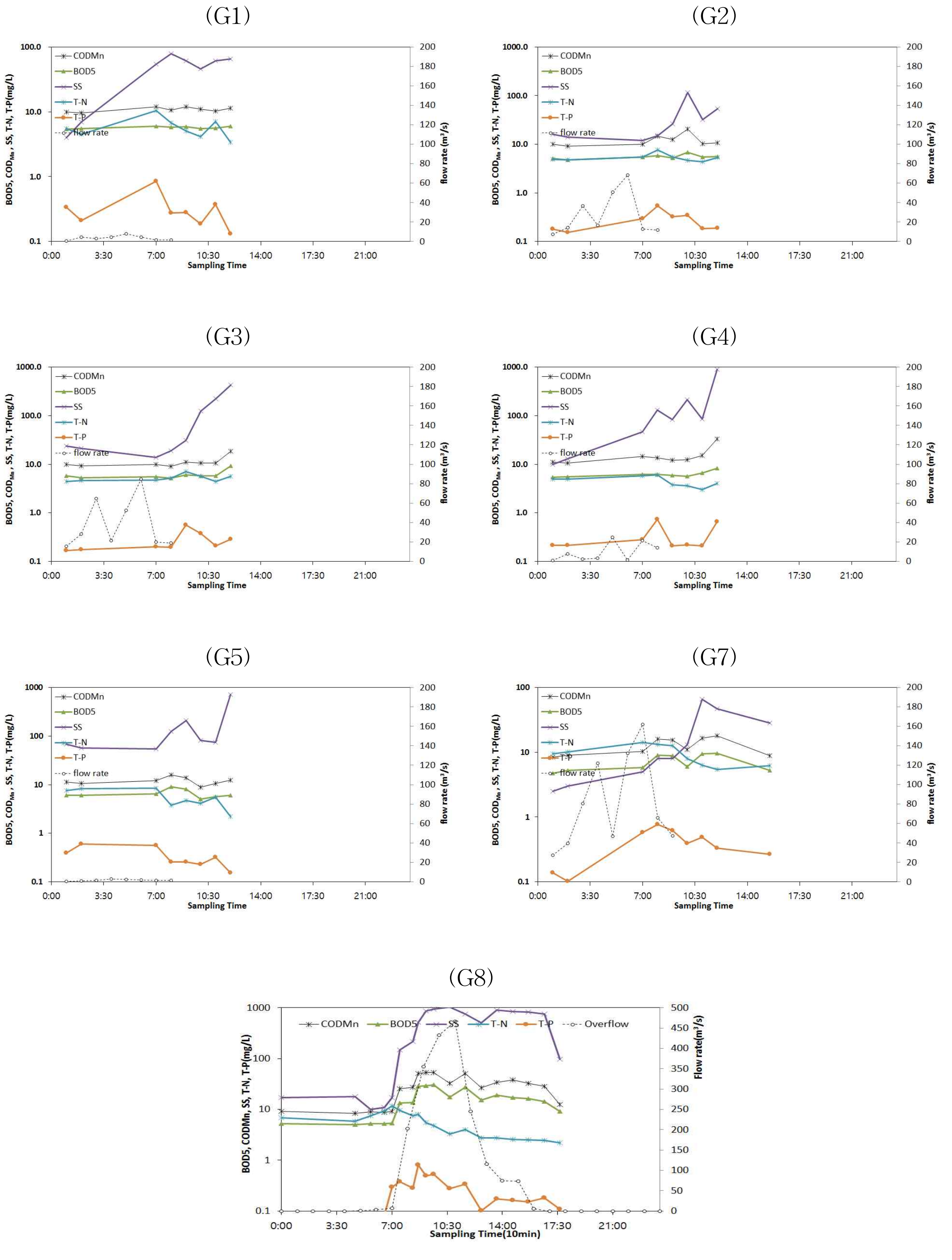

Figure 6. Variation of Flow and water quality during the third rainfall event (02/12/2016)

waterway. The pollutant load in the A3 was the highest amongst the tributaries flowing directly into the Ara waterway. In the case of A2 and G4, pollutant concentration was high, but the flow rate was not so fast, and the pollutant load was relatively low. In case of G4 (Samjeong stream), fluctuation of pollutant load was large. G8 monitoring point at the Gulhyun rubber dam showed the highest pollutant loads due to sudden flushing effect at deflation. In the case of G7 downstream of Gulpo river, CODMn and BOD5 in rainy and dry seasons showed no significant difference in pollutant load, but SS load increased with rainfall. Therefore, it is imperative to reduce the pollutant loads in the Samjung stream(G4), a tributary of Gulpo river. In addition to reducing the influx of nonpoint pollutants during rainfall, water quality management plan should be prepared during the dry season.

The BOD5, T-P, and T-N loads generated from the pollutant loads in the Ara waterway tributaries during the dry season are only about 0.007%, 0.005%, and 0.004% respectively, of the discharge loads of the entire Ara waterway basin (Fig. 7). The BOD5, T-P, and T-N loads generated from the pollutant loads in tributaries of the Gulpo river watershed during the dry season are about 44.3%, 32.1%, and 72.7%, respectively, of the discharge loads of the entire Ara waterway basin. During dry season, water pollutants in Gulpo river basin, flows to the Han River due to the Gulhyun Rubber dam and do not directly flow into the Ara waterway.

The pollution loads in the Gulpo river basin increased from upstream to downstream at the rainfall events and the load generated from the G4 (Samjung stream), one of the tributaries,

Table 4. Runoff pollutant loading from Ara waterway's monitoring point during dry days

Parameter / MP	COD_{Mn} (kg/day)	BOD_5 (kg/day)	SS (kg/day)	T-N (kg/day)	T-P (kg/day)
A1	0.04	0.02	0.2	0.02	0.001
A2	2.07	2.30	6.0	0.90	0.052
A3	18.16	10.51	73.0	15.64	0.841
A4	3.32	1.21	15.0	2.15	0.114
A5	6.37	2.00	28.7	3.79	0.198
A6	0.27	0.12	0.9	0.10	0.002
G4	14.96	4.53	25.7	3.94	0.388
G5	23.38	16.48	20.0	26.81	1.826
G6	4,909.98	2,257.01	4,038.9	4,312.07	203.922
G7	7,856.68	3,561.69	6,913.9	11,743.11	296.459

Table 5. Runoff pollutant loads from Gulpo river's monitoring point during rainfall events

Parameter / MP	COD_{Mn} (10^3kg/event)	BOD_5 (10^3kg/event)	SS (10^3kg/event)	T-N (10^3kg/event)	T-P (10^3kg/event)
G1	0.14	0.07	0.66	0.073	0.003
G2	1.05	0.58	8.75	0.552	0.033
G3	1.87	0.79	6.55	0.791	0.041
G4	8.75	3.00	18.18	3.11	0.466
G5	0.147	0.07	1.73	0.058	0.003
G7	2.83	1.4	5.043	2.359	0.108
G8	8.53	4.1	88.6	2.008	0.141

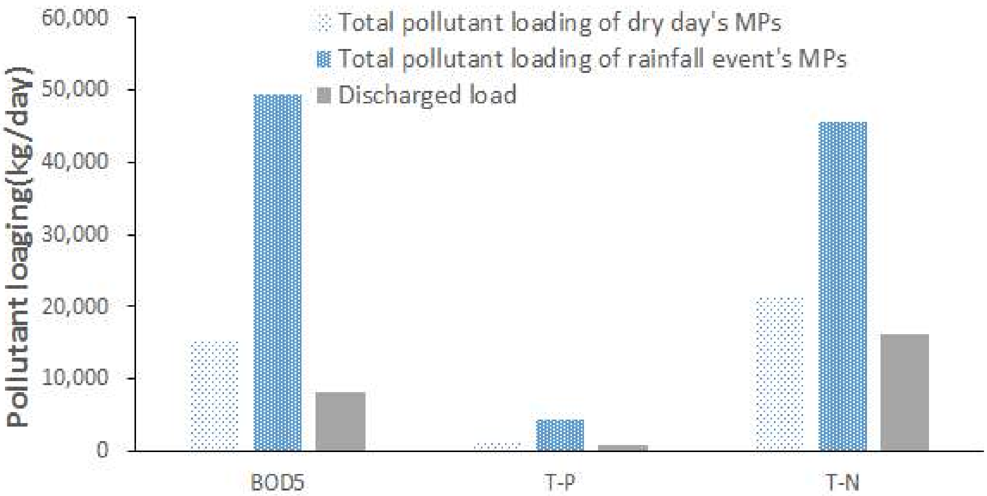

Figure 7. Discharged load of Ara waterway and runoff loading of dry days & rainfall events

was very high. In case of Gulhyun rubber dam deflation, the discharge pollutant load at the G7 monitoring point was higher than the estimated amount at the time of the rainfall. It is attributed to the large number of contaminants deposited upstream of the rubber dam. [17, 18] Therefore, it is necessary to manage the high concentration pollutants influx caused by the overflow and deflation of Gulhyun rubber dam in the rainy season and to reduce the pollutant loads in the Gulpo river watershed.

4. Conclusion

The flow-rate and water quality analysis in the dry season and the rainy season, as well as the pollutant loads estimation for the tributaries flowing into the Ara waterway and the Gulpo river are as follows:

1. The inflow from the Gulpo river to the Ara waterway is made by the overflow and deflation of the Gulhyun rubber dam during rainfall event.

The water quality at this time was highly influenced by the nonpoint pollutant sources in the Gulpo river basin, the water quality of the tributaries, the CSOs, and the effluent of the sewage treatment plant.

When the rubber dam deflated due to heavy rainfall, it was confirmed that the concentration of water pollution index rapidly increased.

2. Out of the inflow load to the Ara waterway, the pollutant load from the Gulpo river watershed of dry season included BOD5 44.3%, T-P 32.1 %, and T-N 72.7 % but the water in Gulpo river is discharged to Han River and does not directly flow into Ara waterway during the dry season.

3. Inflow of BOD5, T-P and T-N loads from the other tributaries of the ARA waterway basin, excluding the Gulpo river watershed, are only 0.007% and 0.005% and 0.004% respectively out of the incoming loads of the entire ARA basin

4. In case of rainfall event, the pollutants inflowed more than 2.6 times in BOD5, 1.6 times in T-P, and 86.1 percent in T-N than the unit discharge load of the Ara waterway basin. In addition, comparing the dry days and rainfall event, the discharge pollutant loads were about 440 times more in BOD5, about 545 times on T-P, and about 23 times on T-N during the rain fall event than the dry days.

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