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Development of BMPs for management of NPS from railway bridges

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ABSTRACT

The railway is regarded as a future-oriented transportation system, because railway has advantages of environment, economic and operation. However, in Korea, the water pollution caused by non-point pollutant source from railway industry has not been considered yet. The goal of this research was development of best management practice (BMP) based on runoff characteristics and pollutant load from railway industrial area focused railway bridges. So, rainfall monitoring was conducted at two railway bridges (concrete road-bed railway bridge and gravel road-bed railway bridge) during 3 years. The major runoff characteristics in concrete road-bed railway bridge were first flush effect and high pollutant load of heavy metals and oil and grease (O&G). In gravel road-bed railway bridge, two-peaks and high pollutant load of heavy metals and O&G were major runoff characteristics. The BMPs for railway bridge were developed based on results of rainfall monitoring. The removal efficiency of BMPs was higher than different type of BMPs such as screen, filtration, vortex and mixed including of heavy metals O&G. Thus, it would be appropriate for management of NPS from railway bridges that the developed BMPs in this research.

***Keywords**:* Non-point source pollutants; Railway; Concrete road-bed; Gravel road-bed; First-flush effect

1. Introduction

The Korean railway industry has been continuously evolving due to rapid economic development and increased standards of living. Railway industry is involved in not only the industrial and welfare but also in transport. With new routes opening all across the country, the population engaged in the railway industry such as railway facilities and vehicles has also increased rapidly. Based on the annual report, the population using railways annually is estimated to be about 1.2 billion [1]. The domestic railway industry is currently developing itself through "The 3rd Railway Industry Development Plan" and has increased its interest in environmentally sustainable transportation. However, there are still many difficulties in establishing railway environmental policy due to the lack of systematic studies on railway environment [2].

In Korea, point pollution sources, such as living sewage and factory wastewater, have been emphasized in the water quality management industry, resulting in considerable advancements—for example, the regional sewer penetration rate has reached 97% and more in the treatment of point pollution sources in major industrial cities [3]. However, despite the management of point pollution sources, water quality is still deemed problematic because non-point source pollution is not systematically managed [4–6]. Non-point pollution sources are opposite in concept to point pollution sources, and their runoff routes, types of pollutants and pollutant load. Hence, most non-point pollutants are directly introduced into the water system during rainfall [7,8]. In 1998, when the first non-point pollution control policy was established in Korea, the pollution load due to non-point pollution

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sources reached 22%–37% in each water system. In particular, the pollution load from the Pal-dang area, which is one of the main water sources in Korea, was reported to be 45% and was expected to steadily increase [9]. Recently, advanced researches on non-point pollution characteristics and management methods were conducted in roads [10–13], forests [14–16], mountains [17], rivers [18–21] and cities [22–24]. Of these, the need to manage impervious areas (about 4.5% of the total land area of Korea, 4,452 km^2), of which about 70% is related to transportation [25–27], is emphasized. While many studies have been conducted on roads, the number of studies on railways is insufficient. According to the World Bank data, the global railway extension in 2016 was about 1,051,767 km, which is increased by 5% from 1,000,507 km in 1980 (in case of Korea, the increase was more than 30%).

However, the primary environmental problems to be solved in railway facilities concern noise, vibration and the air, and thus far, little research exists on railway non-point pollution in the world. Advanced research, high-strength concentrations of heavy metals and non-point pollution in railway installations are indicative of environmental pollution [28]. The first review paper on railway non-point pollution [29] also emphasizes the need for railroad non-point pollution control.

In general, non-point pollution control can be divided into prevention and follow-up management. Prevention can be defined as a method to suppress the occurrence of non-point pollution from the start, and post-management can be defined as best management practice (BMP). Recently, BMP is divided into facility type and low impact development. In particular, BMPs should be developed in consideration of non-point pollution flow characteristics of the introduction area in order to ensure stable removal efficiency. The equipment type facility is easy to install due to its small area.

The purpose of this research is development a BMP based on the runoff characteristics of railway bridges (concrete road-bed and gravel road-bed) and analysis on the applicability of developed BMPs.

2. Material and methods

2.1. Monitoring site

The study area was a concrete road and gravel road railway bridge across the Han River in Seoul, Korea. The railway bridge is located in a region where rainfall runoff is likely to be introduced directly into the water system, and non-point pollution control in its facilities is considered to be urgent. Concrete road railway bridges and gravel road railway bridges have watershed areas of 306 and 168 m^2, respectively. Concrete road railway bridges contain concrete and reinforced concrete and comprise gravel railway-bridge concrete, gravel, and reinforcing bars. Fig. 1 shows the location of the monitoring area.

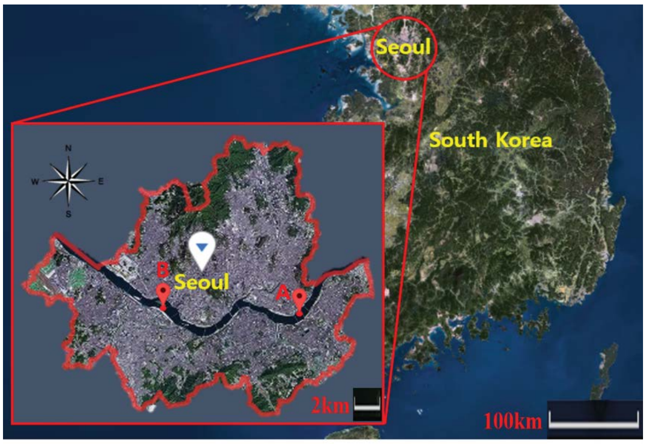


Fig. 1. Location of monitored BMPs.

2.2. Characteristics of BMPs in railway bridges

The BMP installed on the railway bridge was developed based on the runoff characteristics of the railway bridge. The main BMP mechanisms in concrete road railway bridges were heavy metal and oil flow, as well as the treatment of high-concentration non-point pollutants during early rainfall. The basic BMP mechanisms in the concrete railway bridge were filtration, sedimentation and adsorption. Wood-chip, zeolite, and sponge were used as filters and adsorbents. The main BMP mechanisms in the gravel road railway bridge were heavy metal and O&G, and they were developed to ensure even removal efficiency throughout the rainfall. Basic BMP mechanisms in the concrete railway bridge were filtration, sedimentation and adsorption, which are similar to the BMP in the concrete road railway bridge. Gravel and non-woven fabric were used as the filter and absorbent. Fig. 2 shows a schematic diagram and photograph of the monitored BMPs.

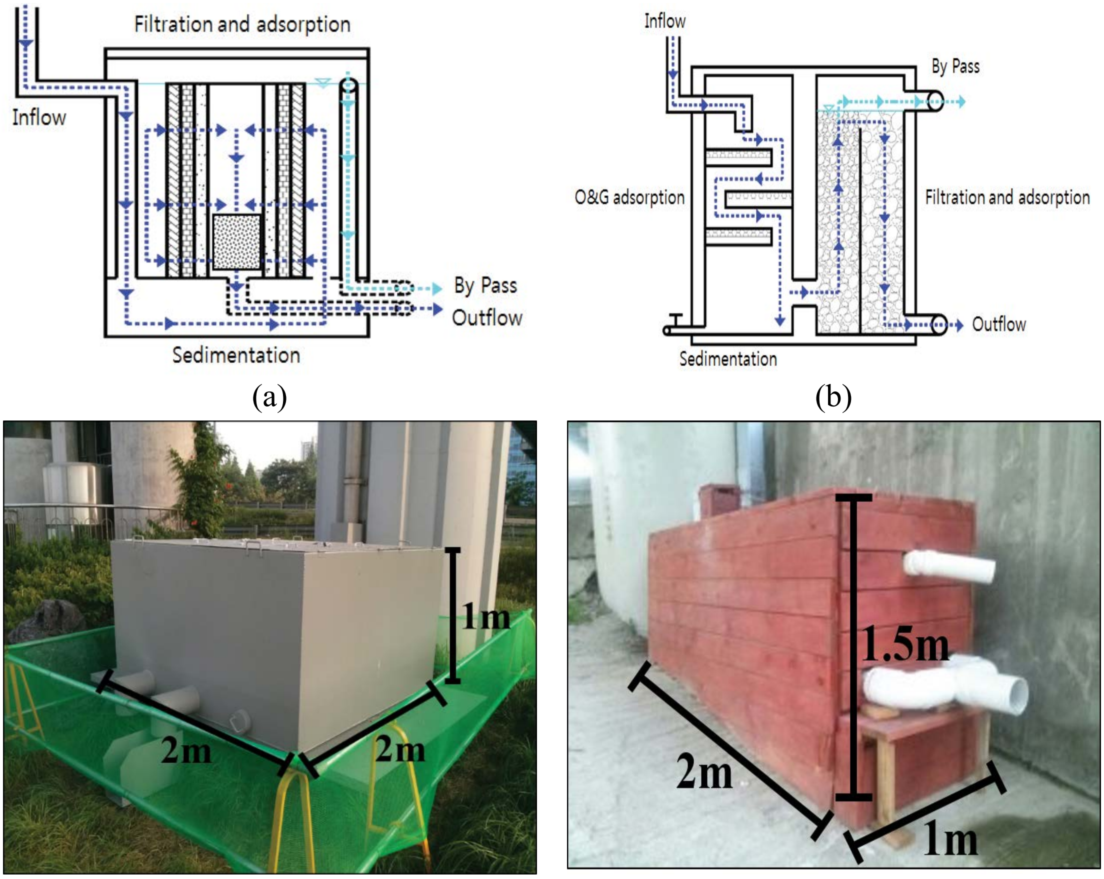
2.3. Rainfall event and monitoring method

Rainfall monitoring was performed 18 times during 3 years, and rainfall monitoring for removal efficiency evaluation was performed 12 times during for 2 years. Table 1 summarizes the rainfall events monitored on the concrete road-bed railway and gravel road-bed railway bridges. The rainfall time was 3–38 h, and the average intensity ranged from 0.5–8 mm/h. Dry days ranged from 2–20 d, and the precipitation was 6.5–174.5 mm. The gravel road-bed railway bridge had 2–20 d of dry weather monitoring, with an observed precipitation of 6.5–174.5 mm. Rainfall time was 6–38 h, and the average intensity was 0.5–6 mm/h. As shown in Table 1, rainfall monitoring was performed for all the rainfall characteristics likely to occur in Korea.

3. Results

3.1. Characteristics of the railway bridge area runoff

Fig. 3 shows a hydro-pollution graph representing the runoff characteristics of the concrete road-bed railway bridge area in rainfall event 2014-10-21. The rainfall characteristics of rainfall event 2014-10-21 was below: rainfall depth 21.5 mm, duration time: 7 h, average rainfall intensity: 3.1 mm/h. In Fig. 3, concrete road-bed railway bridges show high concentrations of pollutants during the initial stages of rainfall. Thereafter, the slope was slightly different depending on the pollutant, but it can be confirmed that the slope was discharged at a relatively low concentration



(a) (b)

(c) (d)

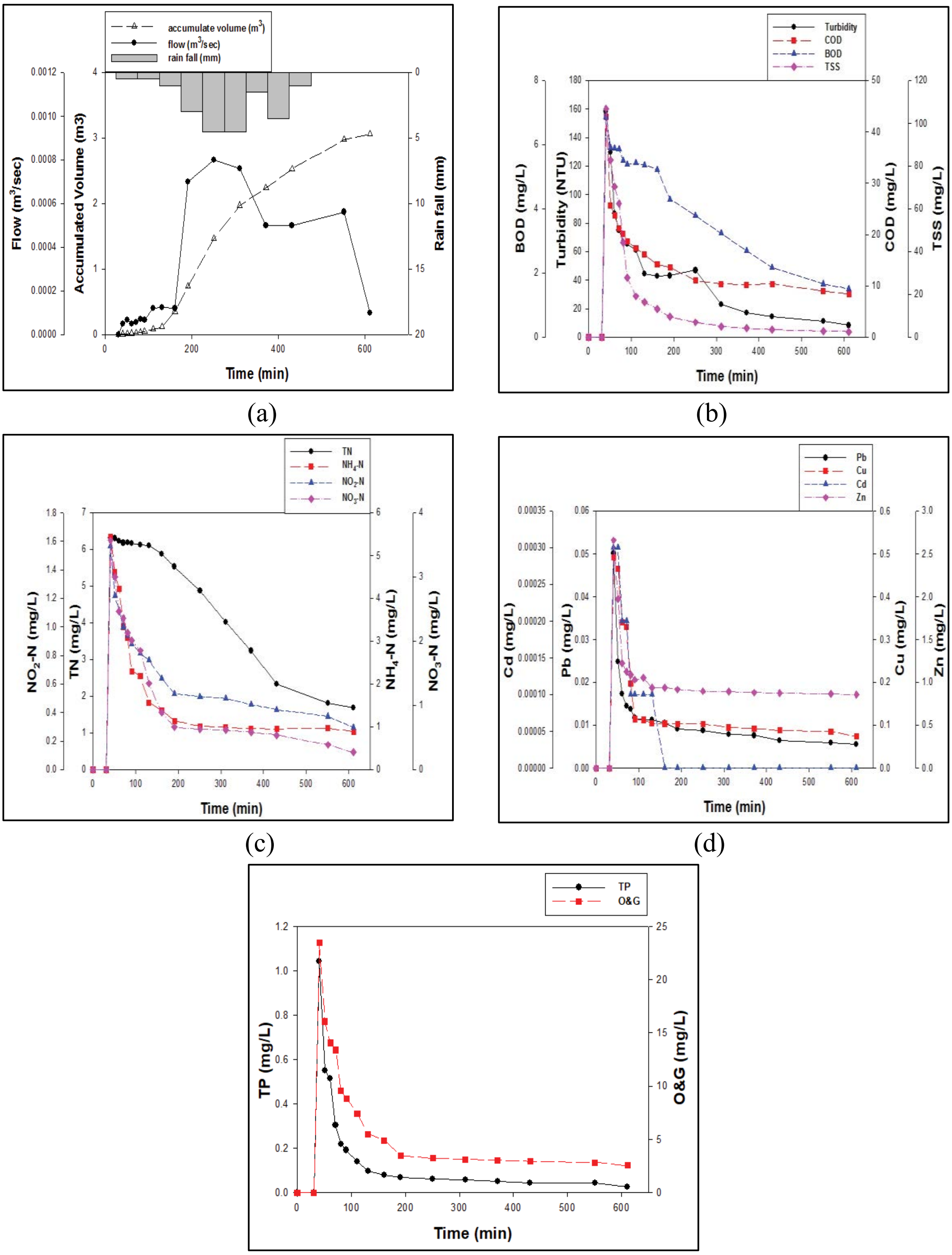
Fig. 2. Schematic diagram and photograph of monitored BMPs for (a) schematic diagram of BMP in concrete road-bed, (b) schematic diagram of BMP in gravel road-bed, (c) photograph of BMP in concrete road-bed and (d) photograph of BMP in gravel road-bed.

Table 1
Monitored rainfall characteristics

Parameters	Concrete road-bed railway bridge				Gravel road-bed railway bridge			
	ADD (day)	Rainfall (mm)	Rainfall duration time (hr)	Average intensity (mm/h)	ADD day	Rainfall (mm)	Rainfall duration time (hr)	Average intensity (mm/h)
Min	2.0	6.5	3.0	0.5	2.0	6.5	6.0	0.5
Max	20.0	174.5	38.0	8.0	20.0	174.5	38.0	6.0
Average	5.5	42.2	17.4	2.6	5.6	43.3	18.4	2.3
Median	4.0	29.5	15.0	2.0	4.0	34.5	15.5	1.9
STD	4.5	40.3	9.7	2.0	4.4	39.8	8.8	1.4

at the end of rainfall. This is a typical first flush effect. It can be seen that the first flush effect is similar to that of the impervious area in the concrete road-bed railway bridges. Because, the concrete road-bed railway bridge was comprising of materials with high runoff coefficient such as concrete and steel.

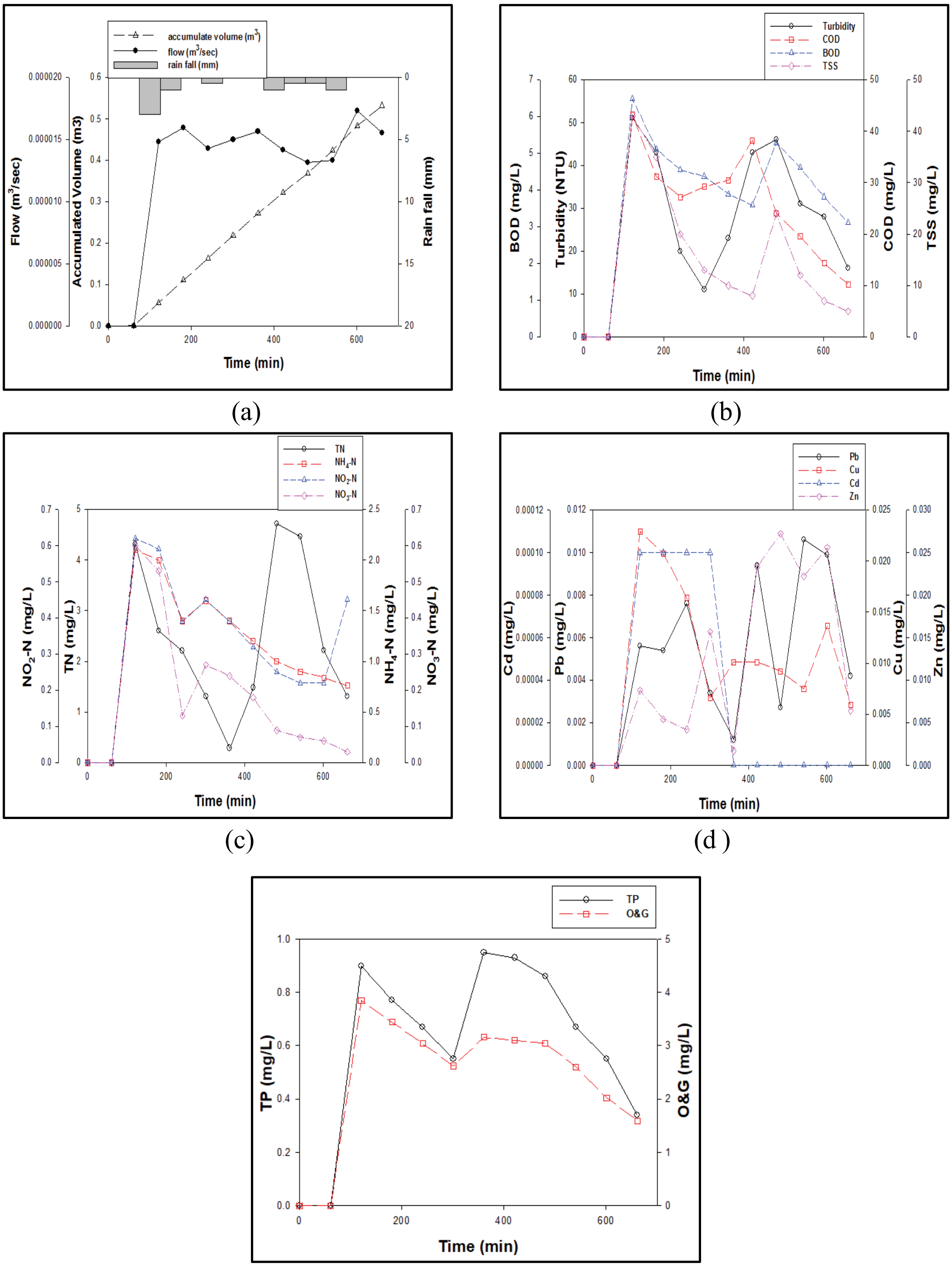
Fig. 4 shows a hydro-pollution graph representing the runoff characteristics of the gravel road-bed railway bridge area in rainfall event 2012-09-13. The rainfall characteristics in event 2012-09-13 is below: rainfall depth 15.5 mm, duration time 10 h, average rainfall intensity: 1.5 mm/h. High concentrations during the early rainfall period and heavy pollutants during the middle period (when the flow rate increases) can be confirmed for the gravel road-bed railway bridge. At the end of the rainfall, relatively low concentration is observed. This can be interpreted as a two-peak that shows high-concentration drainage at the beginning of rainfall and when the flow rate increases. This two-peak in the gravel road-bed railway bridge is attributed to the combination of high runoff coefficient materials such as concrete and steel, as well as a complex of land structure comprising low runoff coefficient material such as gravel.



(a) (b) (c) (d) (e)

Fig. 3. Runoff characteristics of the concrete road-bed railway bridge in rainfall event 2014-10-21 for (a) hydro graph; (b) turbidity, COD, BOD, and TSS; (c) TN, NH_4^+-N, NO_2^--N, NO_3^--N; (d) Pb, Cu, Cd, Zn; (e) TP and O&G.

Fig. 5 shows the summary of the major pollutant runoff type in concrete road-bed and gravel road-bed railway bridges. The runoff types were classified into five types (first flush effect, related to flow, dilution, random and two peak). In Fig. 5, the x-axis is pollutants and the y-axis is count of accumulation rainfall event about obtained runoff type each pollutant. Fig. 5(a) shows the summary of concrete road-bed railway bridge, the highest count of accumulation



(a) (b)

(c) (d)

(e)

Fig. 4. Runoff characteristics of gravel road-bed railway bridge in rainfall event 2012-09-13 for (a) hydro graph; (b) turbidity, COD, BOD, and TSS; (c) TN, NH_4^+-N, NO_2^--N and NO_3^--N; (d) Pb, Cu, Cd and Zn; (e) TP and O&G.

rainfall event obtained first flush effect in all pollutants. Especially, COD, BOD, TN, TP and O&G obtained first flush effect in overall rainfall event 80% over. Fig. 5(b) shows the summary of gravel road-bed railway bridge, the highest count of accumulation rainfall event showed two-peaks in all pollutants except TSS and Pb. COD, BOD and TP obtained two-peaks in overall rainfall event 70% over. According to Fig. 5, the first flush effect was dominant in the concrete

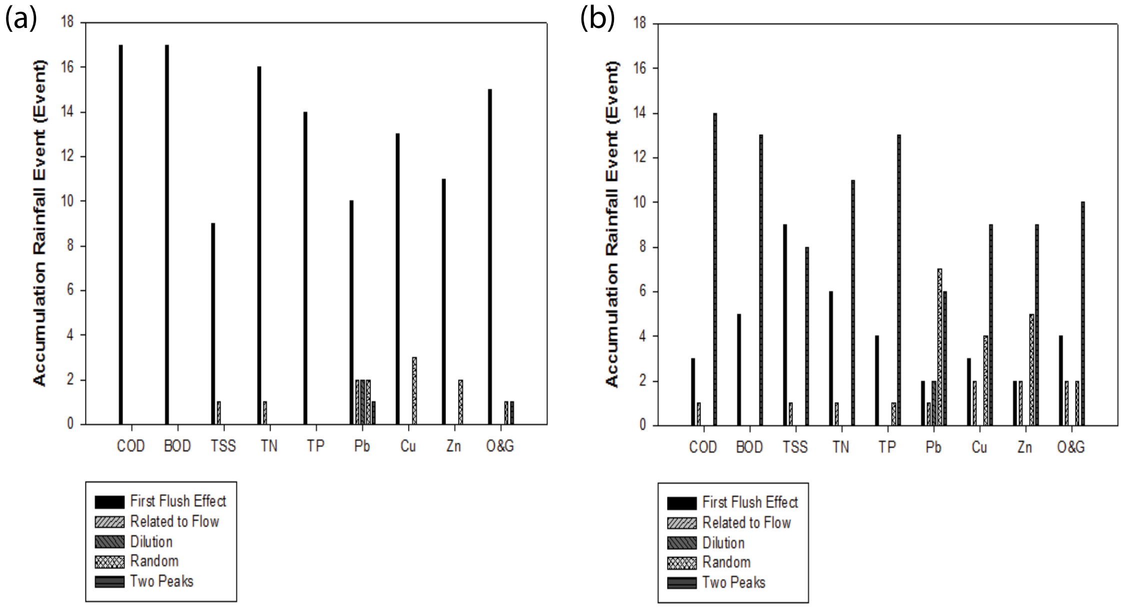


Fig. 5. Summary of railway-bridge runoff type for (a) concrete road-bed railway bridge, (b) gravel road-bed railway bridge.

Table 2
EMC and pollutant load in the concrete and gravel road-bed railway bridge

Parameter	Concrete road-bed railway bridge			
	EMC (mg/L)		Pollutant loads (kg/m^2 event)	
	Range	Median	Range	Median
COD	9.11–80.4	36.44	0.2–296.5	69
BOD	1.43–15.8	4.13	0.008–18.3	5.17
TN	0.98–10.5	4.91	0.01–46.5	10.53
TP	0.02–2.5	0.68	0.0006–15.4	3.18
TSS	7.13–81.1	39.04	0.05–471	104
Pb	0.0009–0.05	0.015	0.00001–0.13	0.04
Cu	0.03–0.27	0.11	0.0003–1.4	0.31
Zn	0.2–1.04	0.61	0.001–6.5	1.8
O&G	0.81–35.7	16.3	0.01–218	44.1

Parameter	Gravel road-bed railway bridge			
	EMC (mg/L)		Pollutant loads (kg/m^2 event)	
	Range	Median	Range	Median
COD	2.66–154.35	51.03	0.06–99.17	24.39
BOD	0.98–141.22	26.62	0.03–22.33	5.01
TN	1.80–8.34	6.28	0.03–25.12	5.57
TP	0.04–2.11	1.00	0.001–5.02	1.20
TSS	13.48–60.15	28.85	0.08–116.18	25.49
Pb	0.002–0.06	0.02	0.00003–0.05	0.01
Cu	0.01–0.16	0.04	0.0001–0.09	0.03
Zn	0.006–0.14	0.07	0.00004–0.25	0.06
O&G	0.61–20.55	8.51	0.008–53.6	9.61

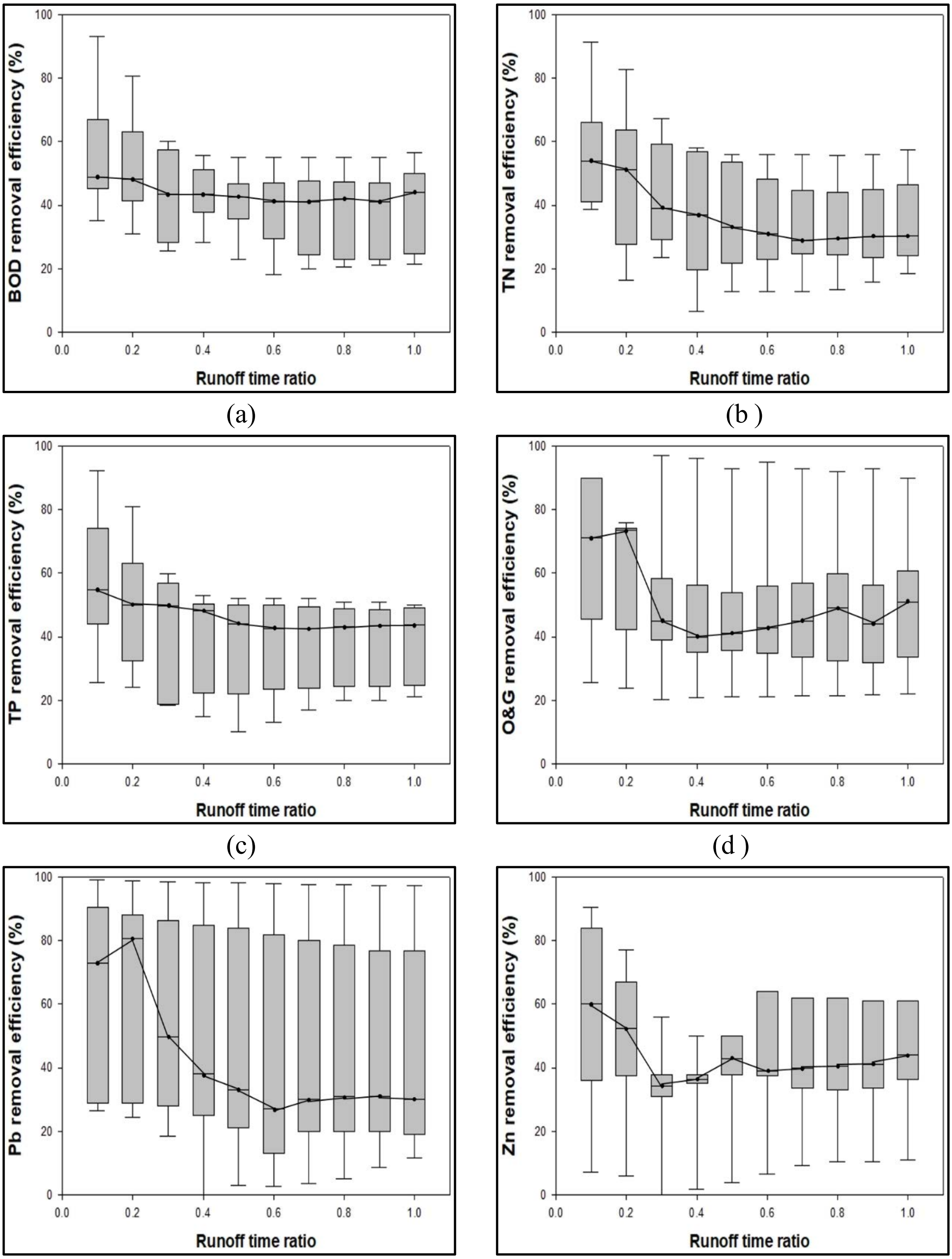
Table 3
Summary of BMP removal efficiency in the railway bridge

	Concrete road-bed		Gravel road-bed	
	Range	Median	Range	Median
Turbidity	13.87–83.13	39.51	15.30–95.45	35.59
COD	23.73–88.77	63.64	13.04–86.54	64.52
BOD	12.82–82.86	47.27	9.03–89.84	48.43
TN	15.38–84.86	53.33	27.78–92.48	59.33
NH_4-N	14.8–91.2	67.27	21.37–86.68	52.68
NO_2-N	22.3–86.20	59.74	11.82–89.17	51.98
NO_3-N	14.47–91.33	49.23	0.00–92.67	64.06
TP	3.33–98.93	55.02	10.00–91.05	53.58
TSS	52.3–87.03	69.27	29.33–92.82	54.55
Pb	77.6–94.30	76.84	0.00–95.00	37.99
Cu	17.07–83.33	49.09	23.08–100.00	62.67
Cd	7.99–99.69	77.42	0.00–99.67	79.19
Zn	22.1–85.25	39.92	47.80–100.00	85.47
O&G	12.45–97.62	48.14	15.38–86.73	47.83
TOC	30.19–86.11	63.63	5.06–85.83	56.45

road-bed railway bridge, and the two-peaks was dominant in the gravel road-bed railway bridge.

3.2. Railway bridge area EMC and pollutant load per unit area

Table 2 summarizes the event mean concentration (EMC) and pollutant load per unit area of major pollutant items in the railway bridge area, calculated from rainfall monitoring results. For concrete road-bed railway bridges, both the EMC and pollutant load unit area had their maximum values at TSS. On the other hand, for gravel road-bed railway bridges,



(a) (b)

(c) (d)

(e) (f)

Fig. 6. Removal efficiency of BMP in the concrete road-bed railway bridge according to duration time for (a) BOD, (b)TN, (c) TP, (d) O&G (e) Pb and (f) Zn.

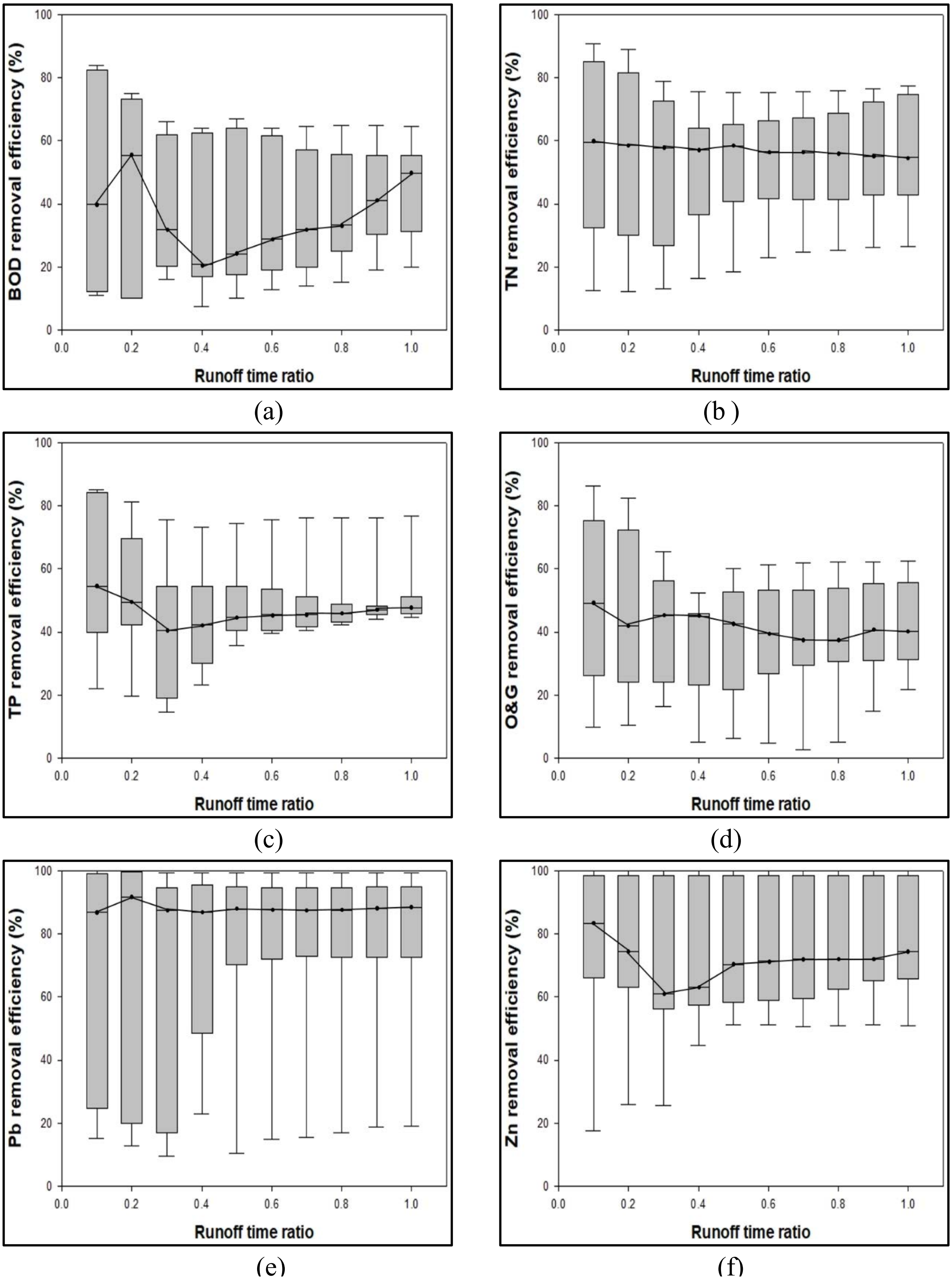
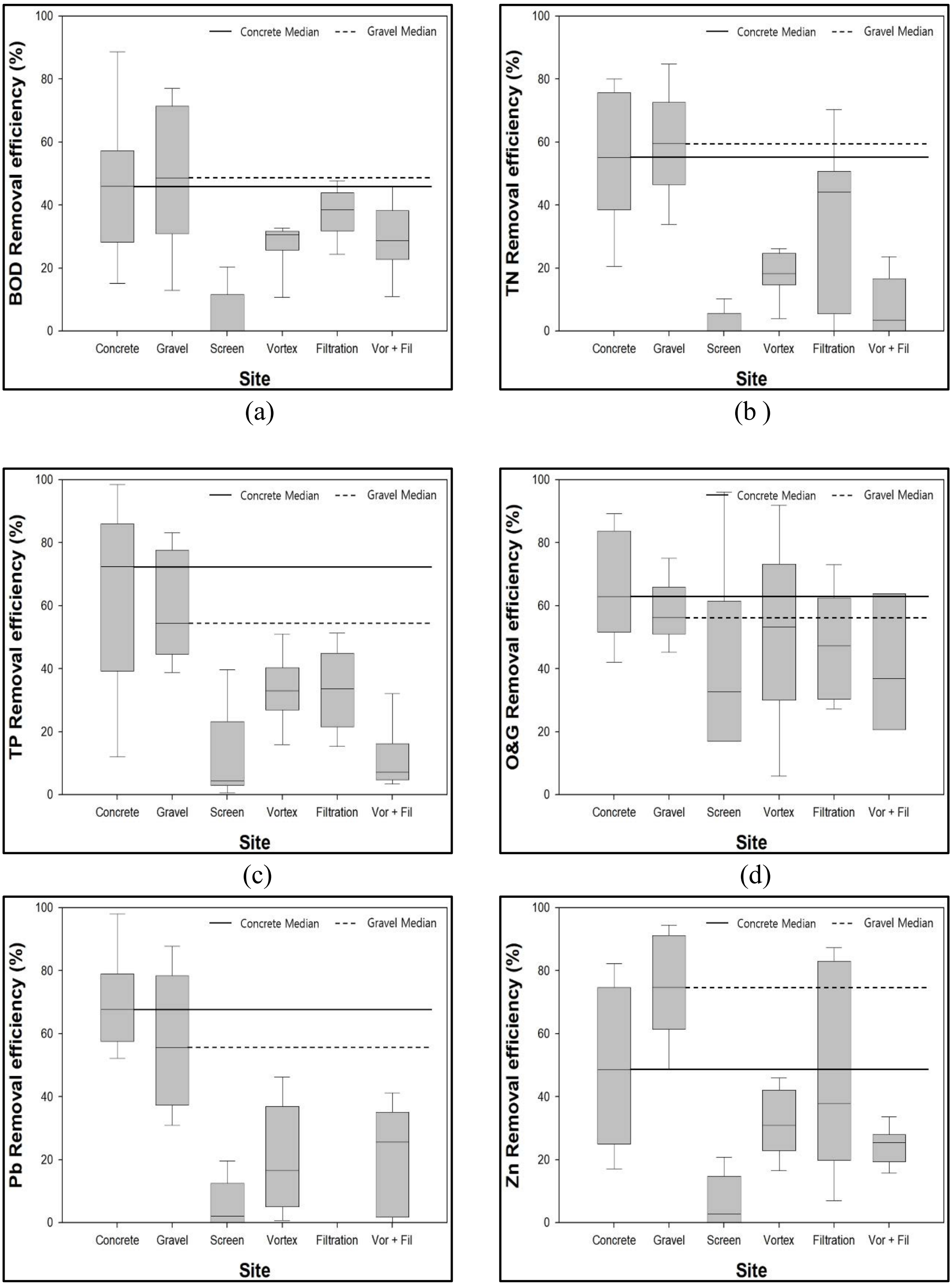


Fig. 7. Removal efficiency of BMP in gravel road-bed railway bridge according to duration time for (a) BOD, (b) TN, (c) TP, (d) O&G, (e) Pb and (f) Zn.



(a) (b)

(c) (d)

(e) (f)

Fig. 8. Comparison of removal efficiency with various BMPs for (a) BOD, (b) TN, (c) TP, (d) O&G, (e) Pb and (f) Zn.

the EMC showed maximum values in COD and pollutant load per unit area in TN. In addition, analysis revealed that heavy metals, O&G also released a significant amount of pollutants during rainfall. In particular, heavy metals were found to be similar to or higher than the previously announced roadway EMC (Pb: 0.006–1.9, Cu: 0.006–0.012, Zn: 0.06–1.7) [30]. This high concentration of heavy metal leakage is thought to be due to the friction between the wheels and railway of the railway vehicle. O&G also showed high outflow due to the influence of grease used in railway operations. These high concentrations of heavy metals and large O&G outflows are considered to be the main characteristics of the railway bridge area.

3.3. Removal efficiency of BMPs in a railway bridge

Table 3 shows the pollutant removal efficiency of BMPs installed in railway bridges. The removal efficiency was analyzed based on the summation of load (SOL) method. It can be seen that more than 50% of railway-bridge BMP removal efficiency is based on the median value. Heavy metals also showed efficiencies of 39%–77% and 38%–85% in the concrete and gravel road-bed railway bridges, respectively. It can be confirmed that stable heavy metal removal is performed overall. In addition, the O&G item also showed a removal efficiency of 55% or more, which shows that the released heavy metals and O&G were stably removed.

Figs. 6 and 7 summarize the main pollutant removal efficiency of BMPs in the railway bridges over time. In Figs. 6 and 7, the x-axis is runoff time ratio (runoff time/total runoff time) and y-axis is removal efficiency of pollutants. The concrete road-bed railway bridge showed a first flush effect, and the gravel road-bed railway bridges showed two peaks. This result implies that the BMP in the concrete road-bed railway bridge should show stable removal efficiency at the initial period of rainfall, and the BMP in the gravel road-bed railway bridge should ensure stable removal efficiency throughout the entire rainfall. So, it is necessary to analyse that changing removal efficiency according to runoff time. Because, BMP in concrete road-bed need stable removal efficiency during initial period and BMP in gravel road-bed need stable removal efficiency during initial and increasing flow period (two-peaks). Fig. 6 shows the removal efficiency of the BMP in the concrete road-bed railway bridge, according to the time ratio. As can be seen from Fig. 6, high removal efficiency was shown at the beginning of rainfall, and it can be confirmed that the removal efficiency gradually decreased. It can be seen that the BMP in the concrete road-bed railway bridge can reliably achieve removal efficiency in the initial rainfall. Fig. 7 shows the removal efficiency of BMP in the gravel road-bed railway bridge over time. The removal efficiency is uniform throughout the entire rainfall, and stable pollutant removal is considered to be possible even in two peaks.

Fig. 8 shows the comparison results of the removal efficiency with various facility type BMP such as screen type, vortex type, filtration type and combined vortex and filtration type. The basic mechanism of screen type and filtration type was filtration, but the major difference was porous size of filter. The porous size of screen type was larger than filtration type. The basic mechanism of vortex type was sedimentation by vortex, and the combined vortex and filtration type was sedimentation and filtration. Removal efficiency of other facility type BMPs in Fig. 8 analyzed advanced research result [31]. In the case of concrete road-bed railway bridge, (a) BOD was 11.5%–64.9%; (b) TP was 10.8%–88.9%; (c) TN was 21.7%–85.6%; (d) Zn was 7.4%–86.5%; (e) Pb was 5.1%–100%, and (f) O&G ranged from 32.9% to 91.5%. In the case of gravel road-bed railway bridge, (a) BOD was 9.2%–89.7%; (b) TP was 15.2%–92.5%; (c) TN was 40.2%–93.1%; (d) Zn was 47.7%–100%; (e) Pb 36.9%–95.0% and (f) O&G 42.5%–86.2%. The NPS removal efficiencies in concrete road-bed railway bridge and gravel road-bed railway bridge were found to be generally higher than those in other BMPs. In particular, (d) Zn, (e) Pb and (f) O&G showed higher efficiencies than difference type BMPs. As a result of the removal efficiency analysis, the railway bridges BMPs developed in this research showed high removal efficiency for heavy metals and O&G compared with other BMPs. Because, basic mechanism of developed BMPs in this research added the adsorption for removal of heavy metals and O&G. This shows that rainfall runoff from railway bridges can be managed stably.

4. Conclusion

- The first flush effect as dominant for the concrete road-bed railway bridge, while the two-peaks was dominant for the gravel road-bed railway bridge. This difference is considered to be due to the land composition difference of each road-bed.
- Analysis of EMC and pollutant load per unit area of railway bridges showed that the maximum value of TSS was obtained for concrete road-bed railway bridges. For gravel road-bed railway bridges, EMC was the COD, and TN was the maximum value in the pollutant load per unit area. Heavy metals and O&G were also found to have high values in common. This shows that a large amount of non-point pollutants are released during rainfall at the railway bridge.
- As a result of analyzing the removal efficiency of railway-bridge BMPs based on SOL, an overall removal efficiency of more than 50% (median) was shown: 38%–85% and 55% for heavy metals and O&G, respectively. The results show that the heavy metals and O&G in railway bridges can be reliably reduced.
- The BMP in a concrete road-bed railway bridge should be able to ensure stable removal efficiency, even in the beginning of rainfall, to reflect the railway-bridge runoff characteristics. The BMP in gravel road-bed railway bridges should ensure stable removal efficiency throughout the rainfall. The BMP in concrete road-bed railway bridges can achieve high removal efficiency at the beginning of rainfall, and the BMP in gravel road-bed railway bridges can provide stable removal efficiency throughout the entire rainfall. Therefore, it is concluded that the facility can reliably reduce heavy metals and O&G by reflecting the runoff characteristics of the railway bridge.

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