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Determination of the first-flush criteria from railway bridge area

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ABSTRACT

The management of non-point source pollution is necessary, because it may degrade the water quality. The railway facility areas located in South Korea are considered significant non-point source pollution. Therefore, the method of managing non-point source pollution in the railway areas is crucial. This study was conducted to quantify the first flush in the railway bridge area and to suggest the method of reducing the pollution level of the facilities that create non-point source pollution. The first-flush criteria are analyzed using the volume ratio method, the dynamic event mean concentration method, and the mass first-flush ratio method. As a result of an effective rainfall analysis, the first-flush effective rainfall depths were determined to be 8.4 mm in the concrete roadbed area and 16.5 mm in the gravel roadbed area. These first-flush rainfall depths are greater than the sizing criteria (5 mm) of best management practices (BMPs) for capturing first flush in South Korea. Thus, a rigorous rainfall-runoff management is required in the gravel roadbed area. This study implies that BMP must be properly installed upon consideration on the characteristics of the railway facility areas, which have rarely received attention as a significant non-point source as opposed to paved urban areas such as parking lots and roadways.

Keywords: Non-point source pollutants; Railway; Concrete roadbed; Gravel roadbed; First-flush criteria; Dynamic EMC

1. Introduction

Non-point source pollution is difficult to manage in terms of the cause of its occurrence, the generated amounts, and the outflow course. In particular, Korea has a high level of potential for non-point source pollution on the ground given non-point source pollutant runoff after rainfall events [1,2]. If non-point source pollutants enter the water system, the quality of water system is degraded. According to existing research findings, non-point source pollution contribution rates are gradually increasing, and various types of pollutants, such as organic compounds, nutrients, heavy metals, and toxic substances, are entering the water system [3–6]. Non-point source pollution threatens the quality of the water system in many ways according to research by various researchers of non-point source pollution characteristics and management methods. However, the characteristics of non-point source pollution are not clearly understood, as this type of pollution shows different characteristics depending on the land usage, natural conditions, and rainfall

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characteristics (natural phenomena) [7–9]. To manage non-point source pollution and prevent harmful effects on the quality of the water system, various types of best management practices (BMPs) should be developed and installed. However, the design and installation of BMPs incur many problems, as regulations and standards pertaining to BMPs are not clearly established. In particular, the first-flush criteria, the key factor in the design of the size of BMPs, are not clearly determined with regard to their proper analysis and calculation methods [10–12].

Recently, railways have attracted much research attention due to their good safety records, cost-effectiveness, low energy use, and environmental friendliness. Accordingly, research pertaining to the construction of railways and their operation to the effects on the environment has been uncovered new problems [13–16]. However, recent research in this area has mainly considered noise, vibration, and air pollutants, but not water pollution. Water pollution directly linked to human life is less considered in the railway industry. Railway industry has image of eco-friendly transportation such as good construction, operation, and maintenance. Non-point source pollution, one of the main factors affecting water system pollution, management is required [17–19].

In this research, the first-flush criteria, a key factor in the design of the size BMPs, are calculated for a railway bridge area. Based on rainfall monitoring results, first-flush criteria are calculated using the volume ratio method, the dynamic event mean concentration (EMC) method, and mass first-flush ratio (MFFn) method.

2. Experimental methods

2.1. Monitoring sites

The monitoring sites in this study are shown in Fig. 1, and the characteristics of the monitoring sites are summarized in Table 1. The storm water discharge areas are a concrete roadbed area in Dang-san dong, Yeongdeungpo gu, Seoul, South Korea (Dang-san railway bridge). The concrete roadbed area was constructed using steel and concrete. Gravel roadbed area in Shin-chun dong, Songpa gu, Seoul, South Korea (Jam-sil railway bridge). The gravel roadbed area was constructed using steel, concrete and gravel. The sizes of these sites are 306 m^2 for the concrete roadbed area and 168 m^2 for the gravel roadbed area. All pollutants were analyzed according to standard methods [20].

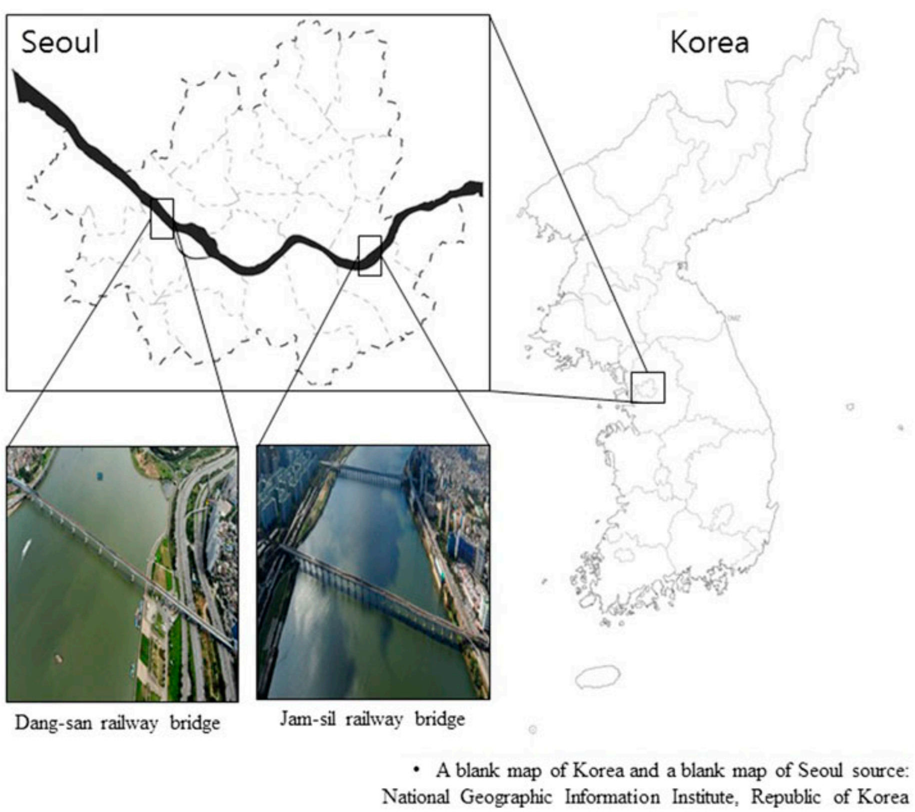
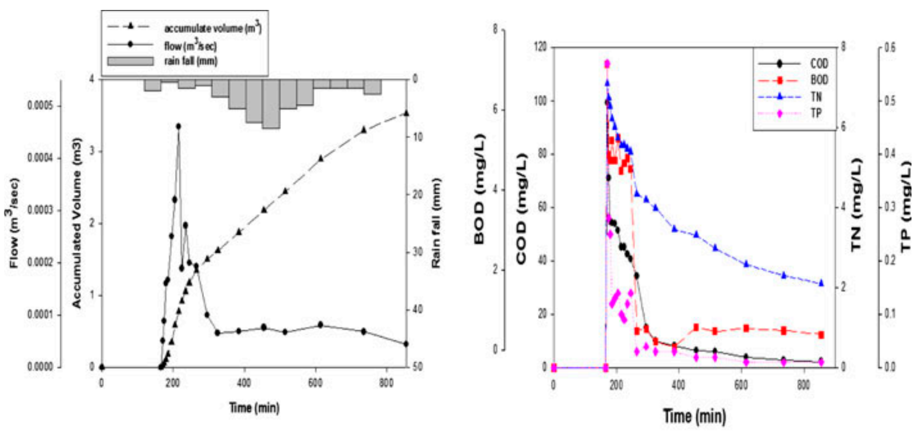


Fig. 1. Map showing the monitoring sites.

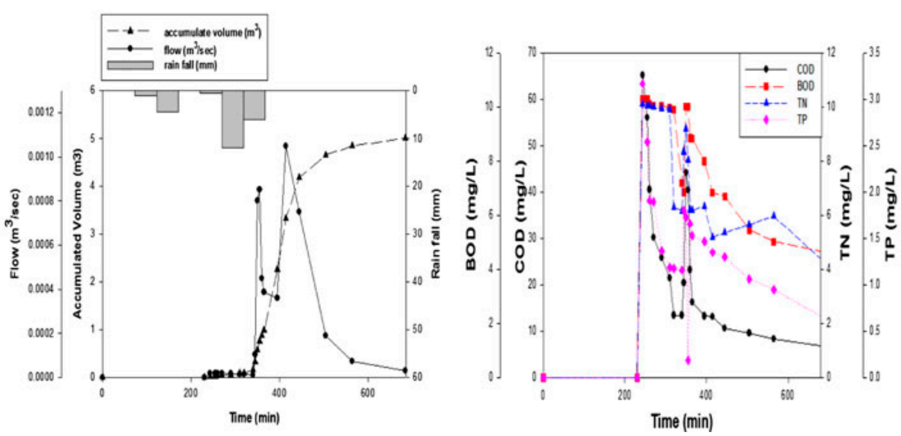
Table 1
Characteristics of the monitored rainfall

Event	Event date (yy/mm/dd)	ADD (d)	Total rainfall (mm)	Duration time (h)
E-1	2012/04/21	9	56.5	36
E-2	2012/05/15	10	6.5	6
E-3	2012/06/29	20	89.5	15
E-4	2012/07/05	2	174.5	38
E-5	2012/09/13	4	15.5	10
E-6	2012/10/27	4	44.0	14
E-7	2013/05/18	5	34.0	17
E-8	2012/05/27	7	68.0	31
E-9	2013/06/17	4	12.5	24
E-10	2013/07/02	3	43.5	13
E-11	2013/07/27	2	14.7	19

ADD: Antecedent dry day.

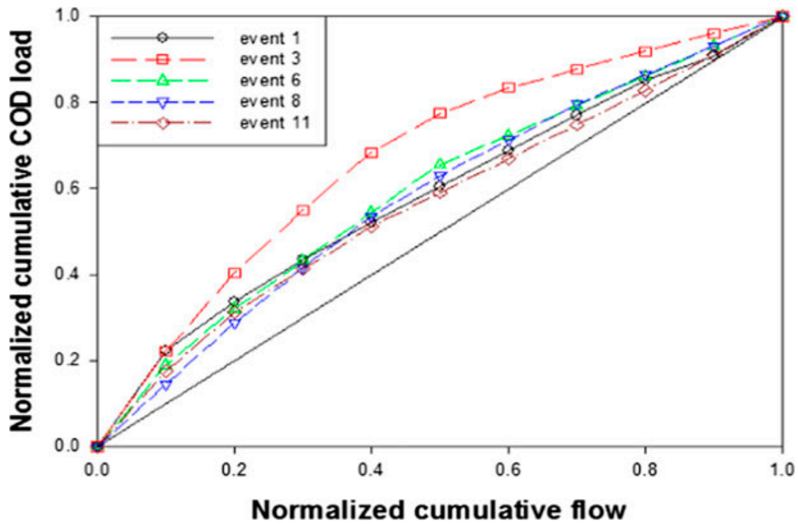


(a) Concrete roadbed area

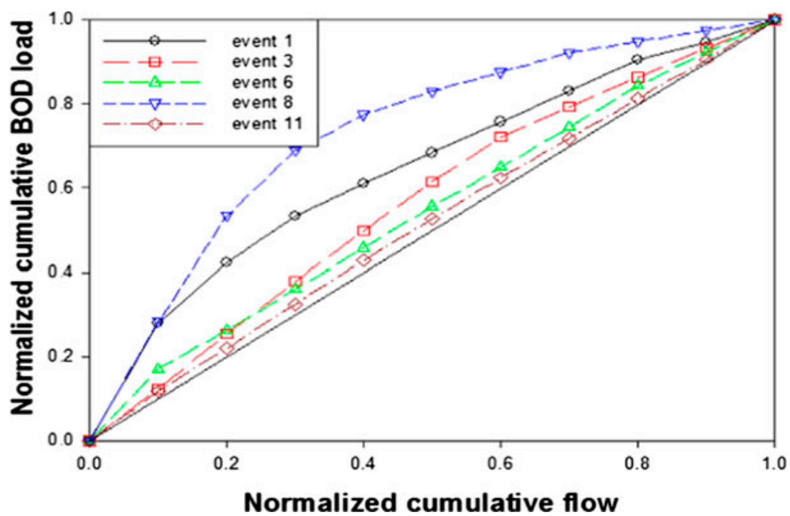


(b) Gravel roadbed area

Fig. 2. Hydro – pollute graph in railway bridge area: (a) concrete roadbed area and (b) gravel roadbed area.



(a) COD



(b) BOD

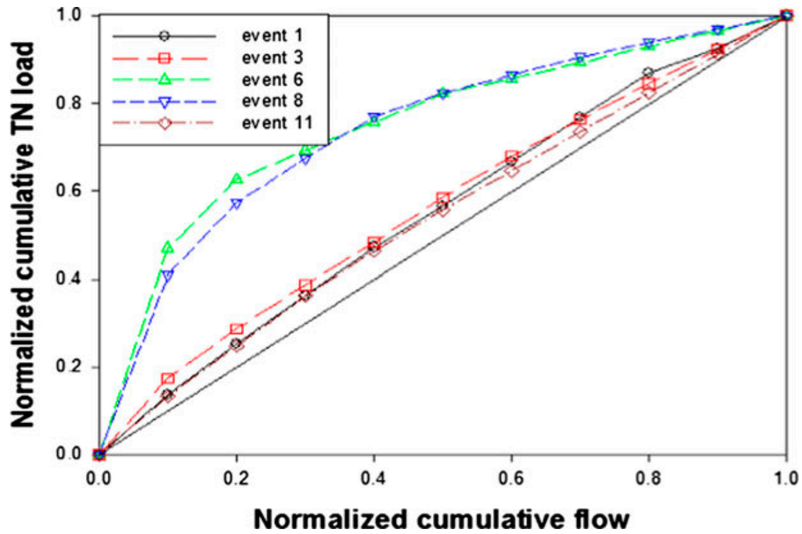
Fig. 3. Analysis of the volume ratio method in the concrete roadbed area.

2.2. First-flush calculation methods

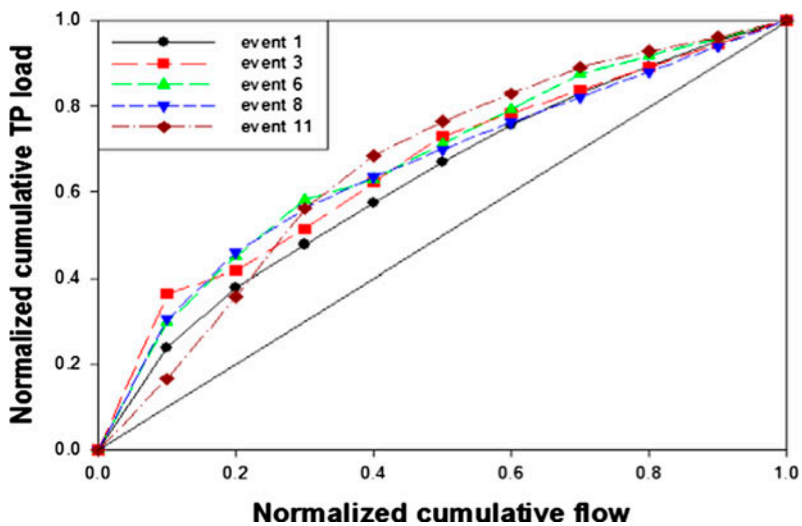
It is necessary to establish the cost-effective on non-point source pollution management standards by researchers in their efforts to explain and calculate the first-flush effect. It is an economic way of reducing pollution to capture and treat only the initial part of rainfall runoff (i.e. first-flush) containing greater pollutant concentration and load. The first-flush criteria, an important factor in the design of BMPs, are calculated using the volume ratio method, the dynamic EMC method, and the MFFn method.

2.2.1. Volume ratio method

The volume ratio method is used to calculate the first-flush criteria. The volume ratio of the first-flush criteria is determined using the pollutant load and the cumulative volume line gradient on the x-axis in relation to the cumulative volume at time 't' divided by the cumulative volume during all rainfall events on the y-axis, in relation to the cumulative pollutant load at time 't' divided by the cumulative pollutant load of all rainfall events. If the pollutant load and cumulative volume line gradient exceed one, this indicates the first-flush effect, referring to a high mean concentration



(c) TN



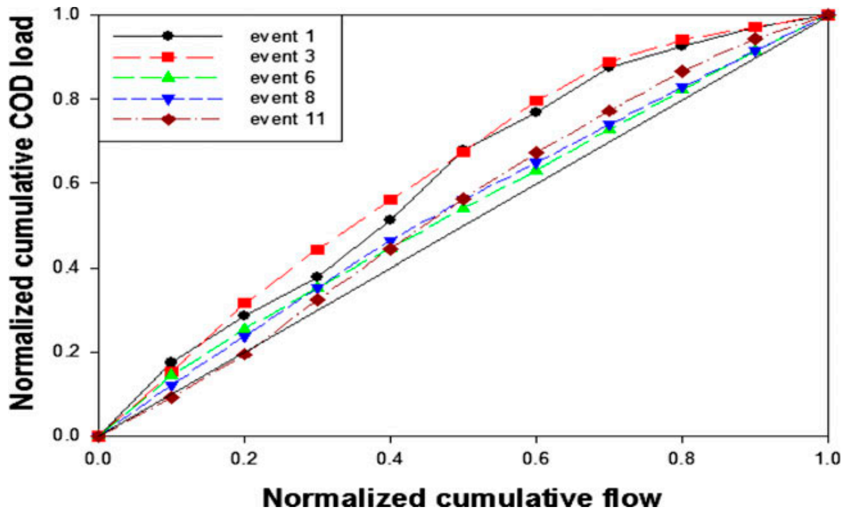
(d) TP

Fig. 3. (*Continued*).

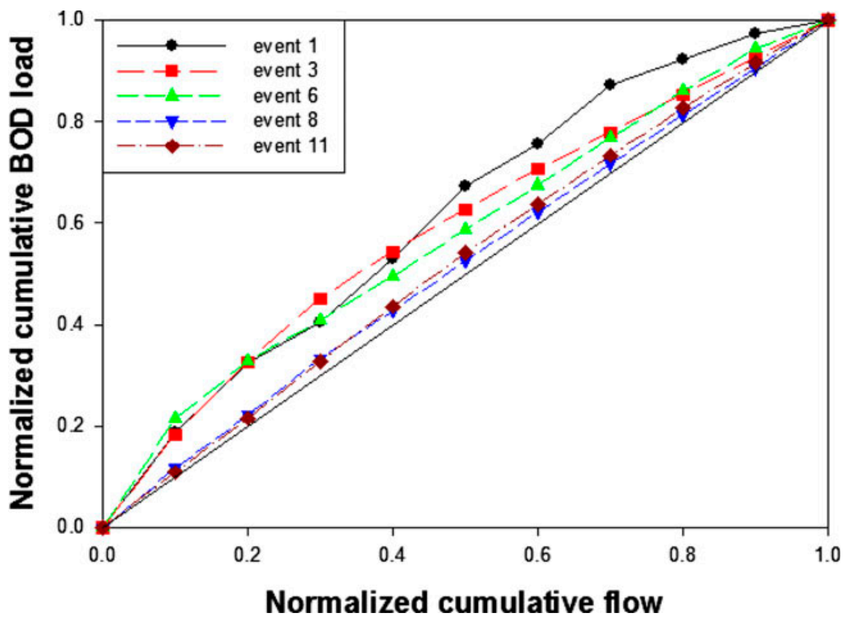
pollutant during the runoff at the initial rain. This result means that the initial cumulative pollutant load is higher than the cumulative volume. If the pollutant load and cumulative volume line gradient are equal to or lower than one, the first-flush effect is absent. For determining first-flush criteria using volume ratio method, the first-flush criteria are determined to the point of decrease in gradient [10].

2.2.2. *Dynamic EMC method*

The EMC has an advantage for showing the total runoff pollutant concentration during a complete series of rainfall events and a disadvantage of not determining the first-flush criteria. A new equation to calculate the first-flush criteria with the dynamic EMC is shown in Eq. (1). The dynamic EMC shows the runoff pollutant concentrations at time '*t*' during a rainfall event. Thus, the EMC can determine the runoff pollutant concentration for all rainfall events, but the dynamic EMC shows changes in the runoff pollutant concentration according to the rainfall event. For determining first-flush criteria using dynamic EMC method, the first-flush criteria are determined at the point to stabilize dynamic EMC concentration [9,10,12,21].



(a) COD



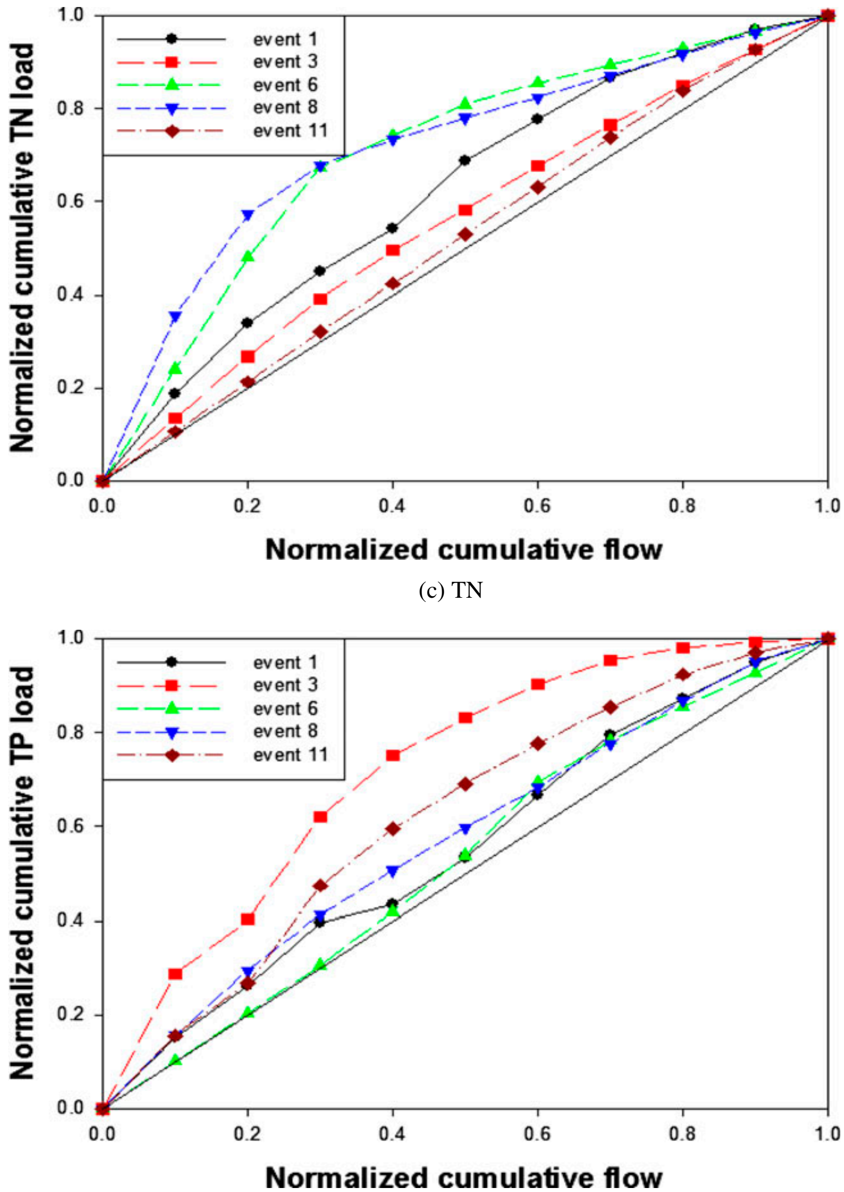
(b) BOD

Fig. 4. Analysis of the volume ratio method in the gravel roadbed area.

$$\text{Dynamic Event Mean Concenration (mg / L)} = \frac{\sum_{t=1}^{t=t} c(t)q(t)}{\sum_{t=1}^{t=t} q(t)} \tag{1}$$

2.2.3. Mass first-flush ratio method

The MFFn ratio calculation is as follows: pollutant load ratio at the time 't' ratio (pollutant load at time 't'/total pollutant load from all rainfall events) divided by the cumulative volume at the time 't' ratio (cumulative volume at time 't'/total cumulative volume from all rainfall events). This is shown Eq. (2). The MFFn method is used to analyze the first-flush criteria through changes in the pollutant load changes in the cumulative volume during rainfall events. For determining first-flush criteria using MFFn method, the first-flush criteria are determined at the point to decrease in MFFn value [10,22].



(c) TN

(d) TP

Fig. 4. (*Continued*).

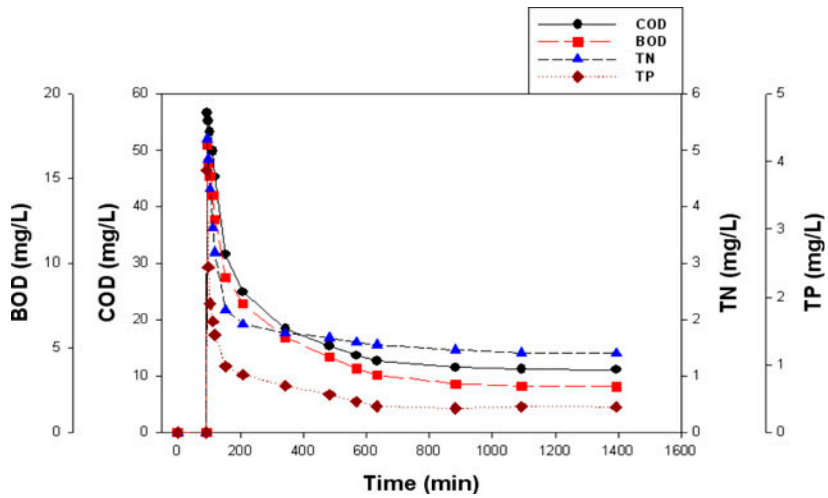
$$\text{Mass First Flush ratio} = \frac{\frac{\int_0^{t1} c(t) \times q(t)dt}{M}}{\frac{\int_0^{t1} q(t)dt}{V}} \tag{2}$$

3. Results and discussion

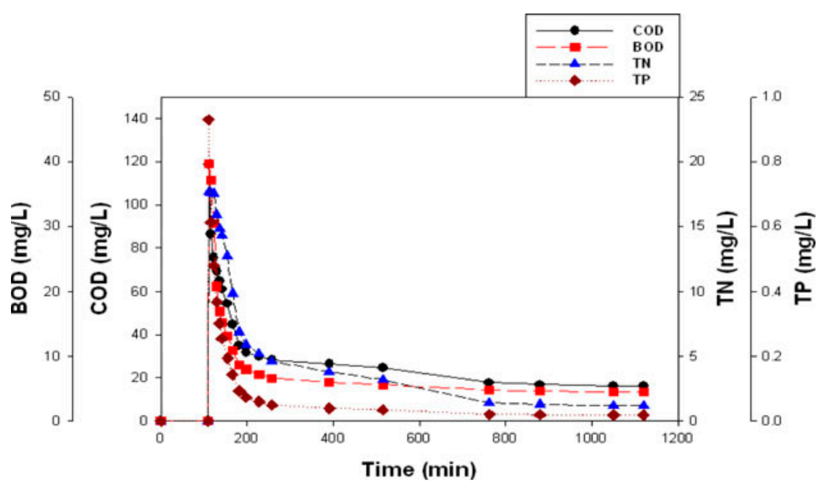
3.1. Rainfall events

Rainfall monitoring was conducted for two years (2012 and 2013) for a total of 11 rainfall events. In order to gather valuable monitoring data in railway bridge areas, rainfall monitoring events were conducted while targeting various sized rainfall events. Table 1 shows the characteristics of the monitored rainfall events. The monitored rainfall events antecedent dry day (ADD) range from 2 to 20 d, and the total rainfall amounts range from 6.5 to 174.5 mm. The durations range from 6 to 38 h.

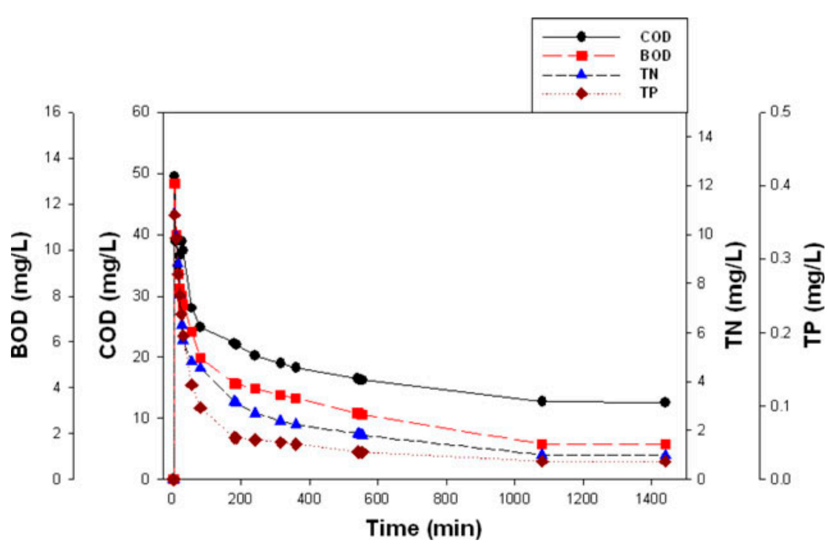
Fig. 2 shows hydro–pollute graph in railway bridges during representative rainfall event: (a) concrete roadbed area and (b) gravel roadbed area.



(a) Event 1

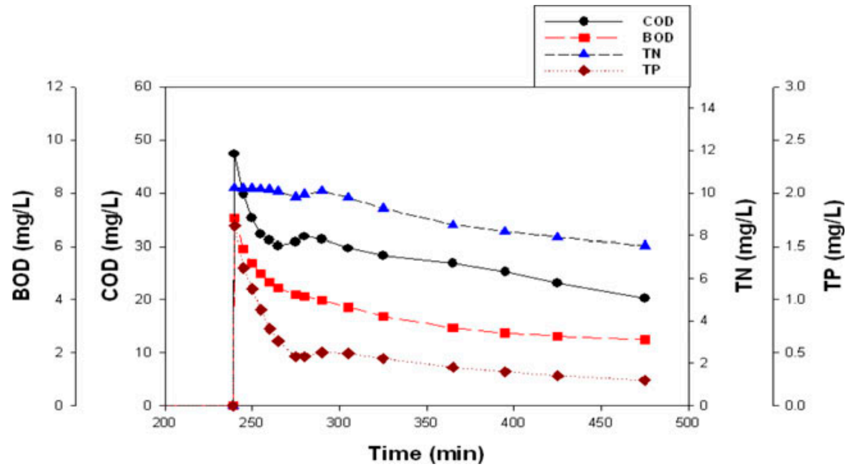


(b) Event 3

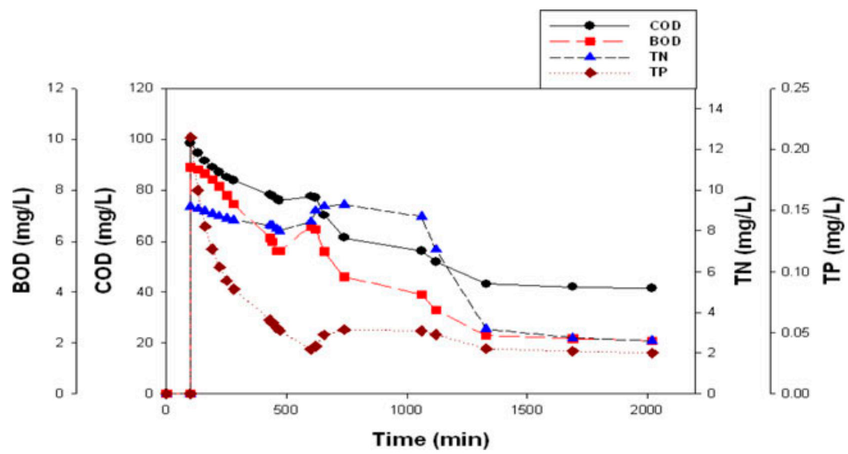


(c) Event 7

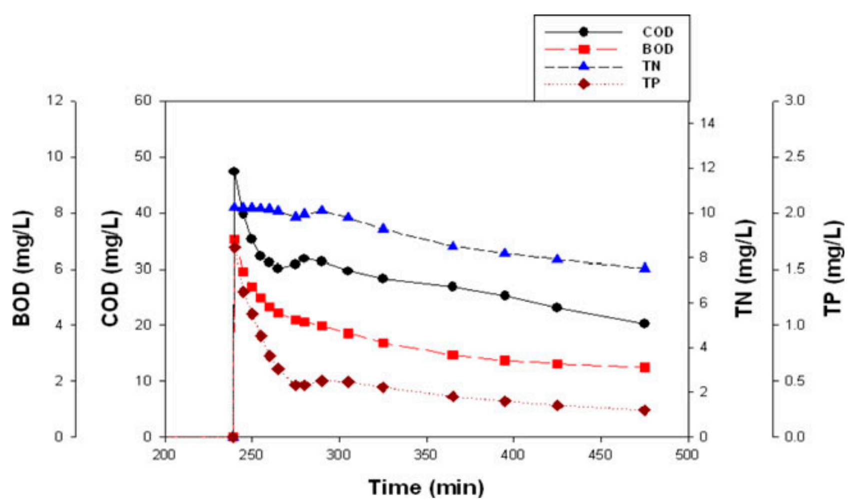
Fig. 5. Analysis of the dynamic EMC method in the concrete roadbed area.



(a) Event 1

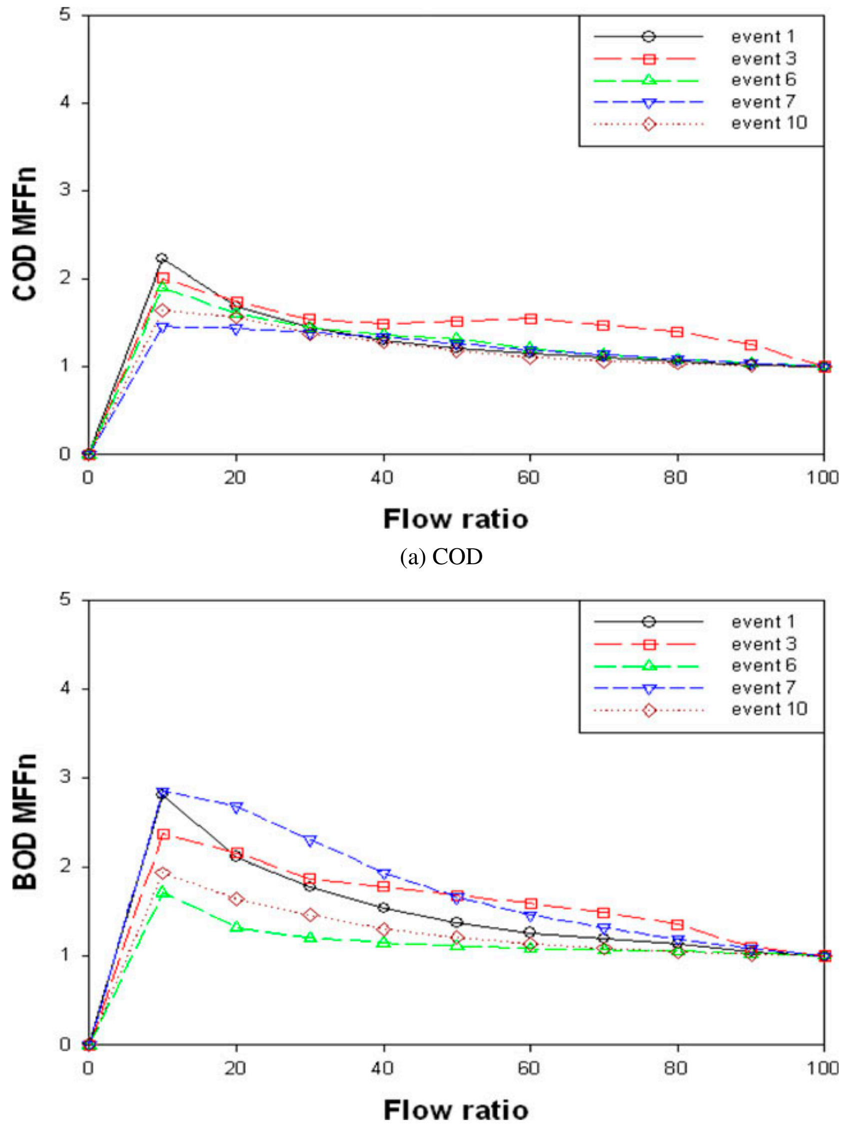


(b) Event 3



(c) Event 7

Fig. 6. Analysis of the dynamic EMC method in the gravel roadbed area.



(a) COD

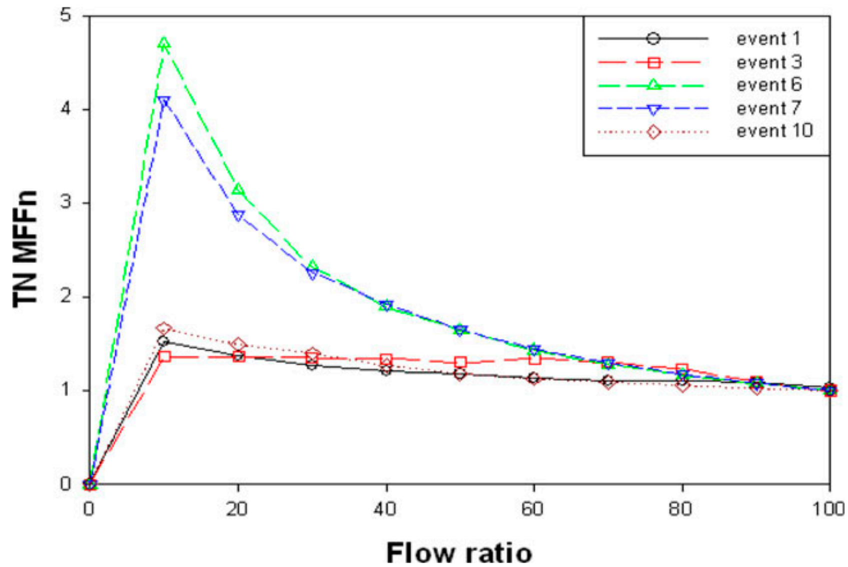
(b) BOD

Fig. 7. Analysis of the MFFn method in the concrete roadbed area.

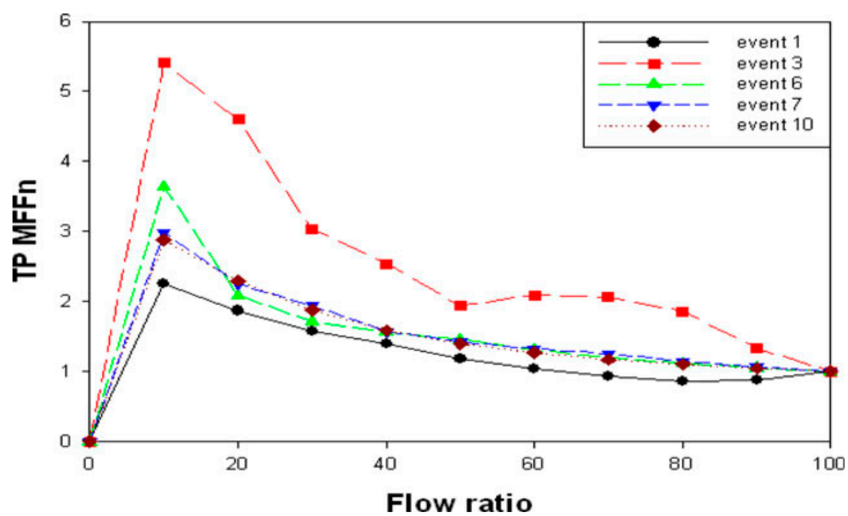
Fig. 2(a) shows that in concrete roadbed area, non-point source pollutants were washed out with high concentration during initial rainfall event. This is first-flush effect like runoff characteristics of pavement area. The reason showing first-flush effect in concrete roadbed is that concrete roadbed area was constructed with materials of high coefficient of discharge such as steel and concrete. Fig. 2(b) shows that in gravel roadbed area, non-point source pollutants were washed out with high concentration during initial and middle (increased flow rate) rainfall events. This phenomenon in gravel roadbed area was affected by land-use characteristic of pavement and non-pavement areas that were mixed.

3.2. Analysis of the volume ratio

Fig. 3 shows the results of the assessment of the first-flush criteria using the volume ratio method for (a) COD, (b) BOD, (c) TN, and (d) TP at the concrete roadbed area. Five representative rainfall events were selected. All of the pollutants (COD, BOD, TN, and TP) showed higher pollutant loads and a cumulative volume line gradient greater than one upon the initial rainfall event in the concrete roadbed area. This result indicates that the concrete roadbed area shows the first-flush effect. Moreover, BOD and TN clearly show first-flush effect as compared to the other pollutants (COD and TP). The first-flush criteria range determined for the cumulative volume ratio period was



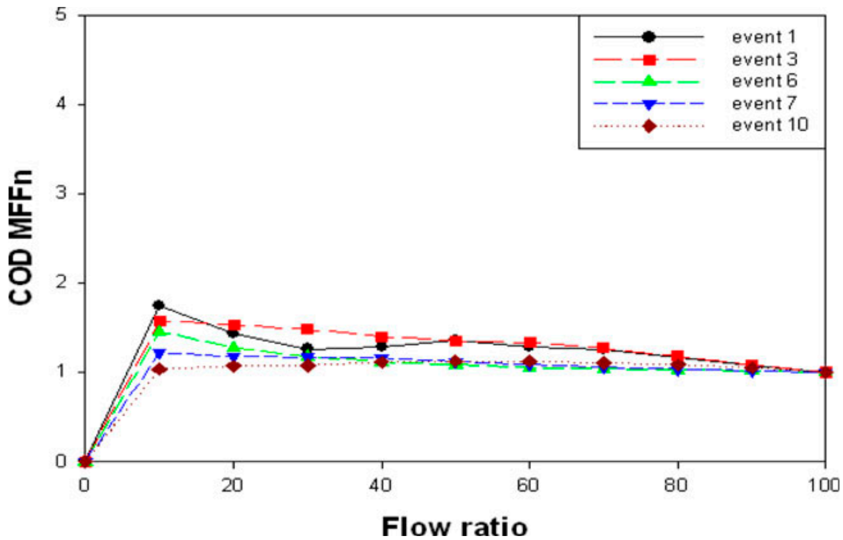
(c) TN



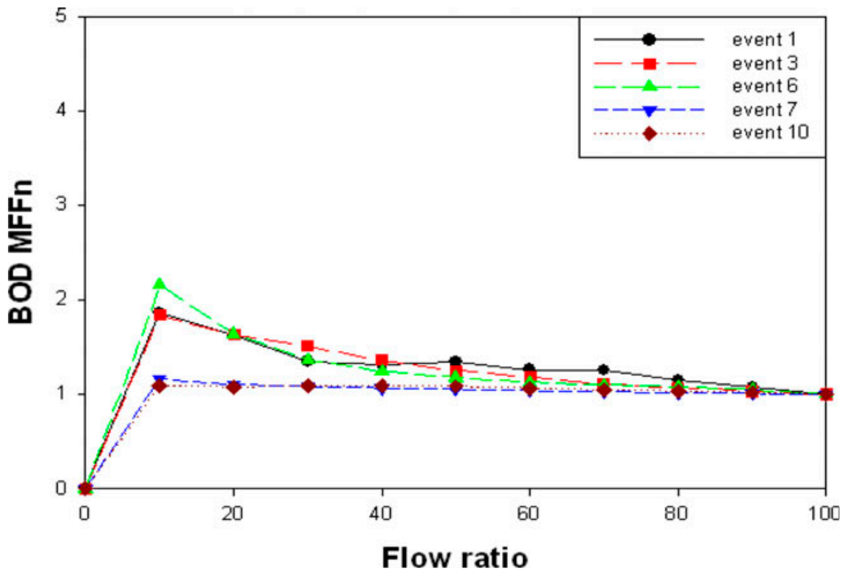
(d) TP

Fig. 7. (*Continued*).

0.1–0.2 in the concrete roadbed area, showing a decrease as regards to the gradient period. Based on the analyzed result, the first-flush criteria in the concrete roadbed area were analyzed for an effective rainfall range of 7–10 mm. Fig. 4 shows the results of the first-flush criteria using the volume ratio method for (a) COD, (b) BOD, (c) TN, and (d) TP in the gravel roadbed area. Five representative rainfall events were selected, as shown in Fig. 3. Gradient of pollutant loads and cumulative volume curve was showed higher value than 1 in all pollutants during the initial and middle (increased flow rate) rainfall event. These results indicate a high concentration of pollutants in the runoff, which go into the water system upon the initial and middle rainfall events. It is important to note that the gravel roadbed area was composed of different types of materials, such as gravel, concrete, and steel materials. Thus, the gravel roadbed area shows a high level of pollutant runoff upon the initial and middle rainfall events likely due to its mixed land-use characteristics. A sufficient BMP size to treat high-concentration pollutant for the initial and middle rainfall events is required for effective management of non-point source pollution at gravel roadbed area. Based on the analyzed results of the first-flush criteria, the first-flush criteria range is determined to a



(a) COD



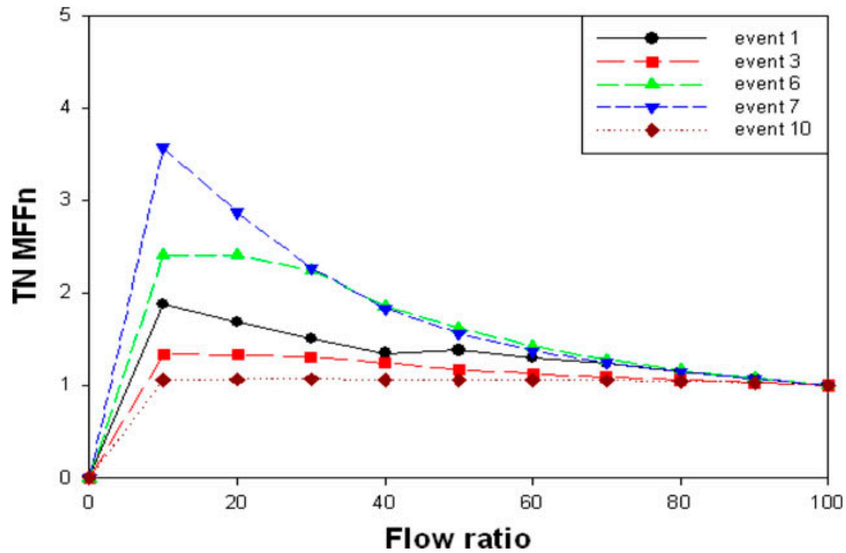
(b) BOD

Fig. 8. Analysis of the MFFn method in the gravel roadbed area.

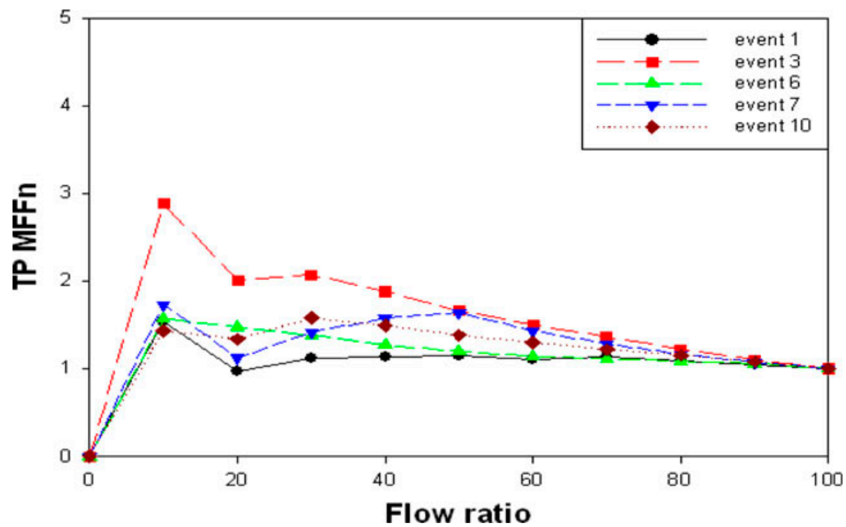
cumulative volume ratio period of 0.3–0.4 with an effective rainfall range of 13–16 mm.

3.3. *Analysis of the dynamic EMC method*

Figs. 5 and 6 show the results of the analysis of the first-flush criteria using the dynamic EMC method for COD, BOD, TN, and TP at the concrete roadbed area and the gravel roadbed area. Three representative rainfall events were selected. The concrete roadbed area shows a high dynamic EMC value upon the initial rain; this is gradually reduced by to the rainfall duration. This is a general characteristic of the first-flush effect. The first-flush criteria range is determined for a rainfall duration time of 100–200 min (dynamic EMC was stabled) in the concrete roadbed area. Based on this monitoring result, the first-flush criteria in the concrete roadbed area were calculated for an effective rainfall range of 8–11 mm. The gravel roadbed area shows a high dynamic EMC upon the initial and middle rainfall events, gradually reducing according to the rainfall



(c) TN



(d) TP

Fig. 8. (*Continued*).

duration time. This is the first-flush effect, which is affected by the rainfall flow rate. Therefore, a high concentration of pollutants exists in the runoff. The characteristic of gravel roadbed area is a mixed pavement area (high coefficient of discharge) and a non-pavement area (low coefficient of discharge). For the gravel roadbed area, the first-flush criteria range is determined from rainfall duration times of 50–200 min (initial rain) and 400–600 min (middle rain). Based on this analyzed result, the first-flush criteria in the gravel roadbed area were calculated for an effective rainfall range at 10–30 mm.

3.4. Analysis of the mass first-flush ratio method

Figs. 7 and 8 show the results of the first-flush criteria using the MFFn method for (a) COD, (b) BOD, (c) TN, and (d) TP at the concrete roadbed area and the gravel roadbed area. Four representative rainfall events were selected. The concrete roadbed area shows a high MFFn value followed by the initial rain, after which it is gradually reduced. After analyzing the first-flush criteria, the initial rain was determined when the initial cumulative volume ratio was 0.1–0.2. The point at which the cumulative volume of

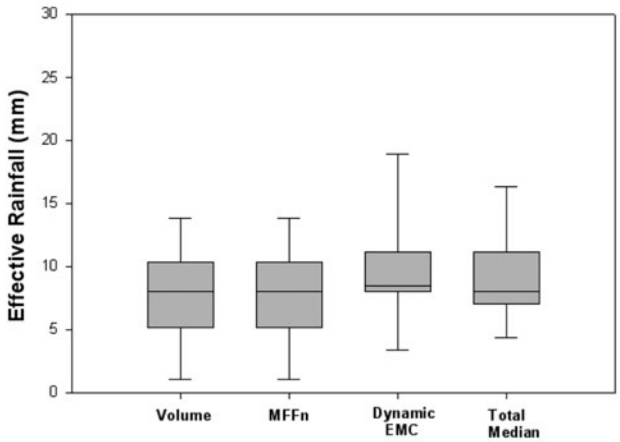


Fig. 9. Analysis of the MFFn method in the concrete roadbed area.

pollutants is reduced can be the point that the MFFn value is reduced. The effective rainfall was 7–10 mm. The MFFn value increased to the initial and middle rainfall events at the gravel roadbed area indicating large quantity of pollutants leaked out from the initial and middle rainfall periods. This finding is similar to that from the volume ratio method and the dynamic EMC method as explained before analyzed, showing different features from the concrete roadbed method. This finding also indicates that the high pollutant level should be reduced from the initial rainfall, and at that time, the flow rate increases for the effective control of storm water at this type of gravel roadbed area. Based on this conclusion, the cumulative volume ratio was 0.3–0.4 and the effective rainfall was 13–16 mm, respectively.

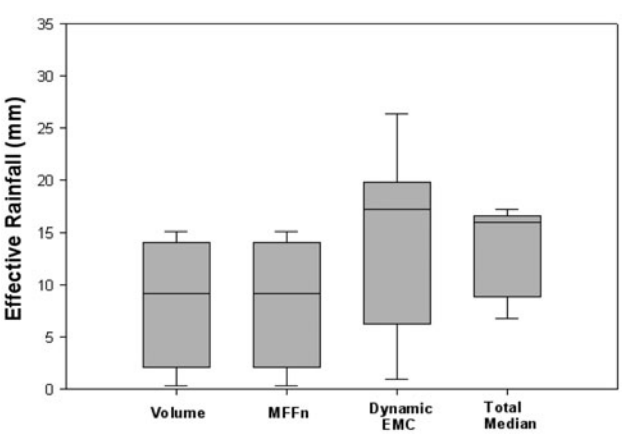


Fig. 10. Analysis of the MFFn method in the gravel roadbed area.

3.5. Analysis of the first-flush criteria

Fig. 9 and Fig. 10 show first-flush criteria as analyzed by the volume ratio method, the dynamic EMC method, and the MFFn method on the railway bridge area. The result of the volume ratio method was similar to that from the MFFn method, but the first-flush criteria as analyzed by the dynamic EMC method are different from the results of other two methods. The first-flush criteria of the concrete roadbed area and the gravel roadbed area were 8 and 16 mm, respectively.

4. Conclusion

After referring to the rainfall monitoring results at the railway bridge area, the following conclusions can be made regarding the first-flush criteria.

The first-flush criteria value of the concrete roadbed according to the volume ratio method was 7.4 mm. According to the dynamic EMC method, it was 11.4 mm, and according to the MFFn method, it was 7.4 mm; the first-flush criteria value for the gravel roadbed area according to the volume ratio method was 10.5 mm. According to the dynamic EMC method, it was 30.1 mm, and the MFFn method gave 10.5 mm. The first-flush criteria values for the concrete roadbed area and the gravel roadbed area as assessed here were 8.4 and 16.5 mm, respectively, indicating that management efforts pertaining to the effective rainfall (8 mm) are required so as to minimize the first-flush criteria at concrete roadbed areas. Proper control of storm water is even more necessary than removing the pollutants when instigating BMPs at gravel roadbed areas. Conducting eleven instances of monitoring measurements represents too difficult a task when attempting to estimate the first-flush criteria precisely. However, doing so can provide important data, especially when it is performed using various analysis methods for the first-flush criteria. The first-flush criteria values at railway facility areas are higher than the existing effective rainfall amount (5 mm) as currently applied for the nonpoint source pollutant volume in Korea. This indicates that BMPs for railway facility area should take into account larger values than those of normally used for facilities. The use of BMPs designed using other area data can lead to problems because railway facilities pass through the center of urban areas. Therefore, there will be restraints when instigating BMPs. Therefore, BMPs should be enacted properly, considering the characteristics of railway facility locations. Research for precise estimations of the first-flush criteria should keep pace with the basis of the selection of BMPs, and continued studies should be done to ensure that this foundation is suitable for railway facility areas for all times.

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