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Installation and operation of automatic nonpoint pollutant source measurement system for cost-effective monitoring

Jechan Jeon[1], Hyeseon Choi[2], Dongseok Shin[1] and Lee-hyung Kim*[2]

[1]*Water Environment Research Department, National Institute of Environmental Research, 42 Hwankyungro, Seogu, Incheon Metropolitan City, 22689, South Korea*
[2]*Department of Civil & Environmental Engineering, Kongju National University, 275 Budaedong, Seobukgu, Cheonan, Chungnamdo, 331-717, South Korea*

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Abstract. In Korea, nonpoint pollutants have a significant effect on rivers' water quality, and they are discharged in very different ways depending on rainfall events. Therefore, preparing an optimal countermeasure against nonpoint pollutants requires much monitoring. The present study was conducted to help prepare a method for installing an automatic nonpoint pollutant measurement system for the cost-effective monitoring of the effect of nonpoint pollutants on rivers. In the present study, monitoring was performed at six sites of a river passing through an urban area with a basin area of 454.3 km^2. The results showed that monitoring could be performed for a relatively long time interval in the upstream and downstream regions, which are mainly comprised of forests, regardless of the rainfall amount. On the contrary, in the urban region, the monitoring had to be performed at a relatively short time interval each time when the rainfall intensity changed. This was because the flow rate was significantly dependent on the rainfall's intensity. The appropriate sites for installing an automatic measurement system were found to be a site before entering the urban region, a site after passing through the urban region, and the end of a river where the effects of nonpoint pollutant sources can be well-decided. The analysis also showed that the monitoring time should be longer for the rainfall events of a higher rainfall class and for the sites closer to the river end. This is because the rainfall runoff has a longer effect on the river. However, the effect of nonpoint pollutant sources was not significantly different between the upstream and the downstream in the cases of rainfall events over 100 mm.

Keywords: automatic measurement system; cost-effective monitoring; nonpoint pollutant source; peak discharge

1. Introduction

In the past 30 years, the Korean Ministry of Environment invested in the treatment of urban sewage, industrial wastewater, and livestock wastewater, and accomplished considerable water quality improvement in rivers (Jeon *et al.* 2017a, Kim *et al.* 2004). However, the economic growth and the improvement of the standards of living have increased the citizens' demand for higher water quality and pleasant environment. With this, the need for the managing nonpoint pollution sources has come to the fore (Jeon *et al.* 2014, Kim *et al.* 2012). According to the Korean National Institute of Environmental Research (NIER 2010), 68% of the pollutants discharged to rivers in 2010 were nonpoint pollutants, and the percentage is expected to increase to 72.1% by 2020. Therefore, high water quality is hardly expected without the stable management of nonpoint pollutants.

There are many different types of nonpoint pollutants as they are generated from various land uses, including grounds, roads, farms, construction sites, and forests. Depending on the land use in a river basin, various pollutants may exist at a high concentration, including earth materials, nutritive salts, bacteria and viruses, heavy metals, pesticides, and oils (Jeon *et al.* 2013a). The discharge of these nonpoint pollutants to rivers may cause the water quality to deteriorate, the growth of aquatic organisms to be hindered, and the rivers and lakes to have eutrophication (Jeon *et al.* 2013b). In particular, materials undergoing biological concentration, such as heavy metals and pesticides, may cause an adverse effect on human health through the food chains.

However, since nonpoint pollutants are generally generated during rainfall events and discharged to rivers through various paths, the sampling and monitoring of rainfall runoff, including nonpoint pollutants, are difficult. Thus, the data about the discharge characteristics and pollution load of nonpoint pollutants are difficult to obtain (Jeon *et al.* 2017b). Long-term investigation at different sites and accumulation of meteorological information are necessary because the reduction of nonpoint pollutants requires optimal countermeasures based on the nonpoint pollutant generation characteristics as well as the local conditions. However, much time and cost are needed to perform the monitoring at many sites in each rainfall event by means of human resources. Therefore, establishing an automatic nonpoint pollutant network is necessary to collect the fundamental data for a long time. The establishment of an automatic nonpoint pollutant network may produce important data for identifying the causes of algal blooms,

*Corresponding author, Ph.D., Professor
E-mail: leehyung@kongju.ac.kr

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which are the severest problems in the major rivers in Korea, and providing critical fundamental data needed to solve such problems as the death of fish. In addition, an automatic nonpoint pollutant network may provide the fundamental data for analyzing the inflow of nonpoint pollutants to rivers and their behavior, scientifically estimating the contribution of nonpoint pollutants to pollution loads, and investigating the effect of nonpoint pollution sources on the water quality and aquatic ecosystem.

In the 21st century, the economic growth and improvement in the standards of living have increased the citizens' demand for better water quality management. The management of nonpoint pollution sources has accounted for a large portion of aquatic system pollution is necessary to manage water environment at the level of advanced countries. In the present study, in order to install and operate an automatic nonpoint pollution measurement system that has many benefits, monitoring was performed with respect to the Jeonjucheon stream, which is an urban river that passes through the city of Jeonju in Korea. The result of the monitoring was used to analyze the flow rate increase in the river and the duration of the increase depending on the amount of rainfall. It was also used to analyze the pollutant discharge load that depends on the unit area of the drainage area and to provide the optimal installation site and monitoring time.

2. Material and methods

2.1 Research area

Jeonjucheon Stream, which was the target river of the present study, passes through the city of Jeonju in Korea. Jeonjucheon Stream is an urban river that has a total length of 41.5 km and a basin area of 454.3 km^2. The upstream is in a non-urban region that is highly natural and has water sources. The midstream is in an urban region with a high population density. The downstream merges with another river of Jeonju called Samcheon Stream. In the downstream interval, the river width is wide due to the flat geography, and the slow flow rate results in sedimentation. Jeonjucheon Stream was recovered as an ecological river in 2002, and now the water quality in the upstream is Grade 1 (the cleanest). A public sewage treatment facility is located at the river basin.

In the present study, the flow rate and pollutants were analyzed at a total of seven sites in the Jeonjucheon Stream (Fig 1). S#1 is the farthest upstream site of Jeonjucheon Stream and is surrounded by forest regions. S#2 is the site immediately before the urban area, and the river basin consists of a forest area. S#3 is the 1/3 upstream site in the urban area with a high population density. S#4 is the end of the urban area. S#5 is located after the merging point with Samcheon Stream, and a barrage is located in the immediate downstream from the site. A sewage treatment facility is located between the farthest downstream sites, S#6 and S#5, and the combined sewer overflows discharge into the river during rainfall events. Table 1 shows the characteristics of the individual monitoring sites.

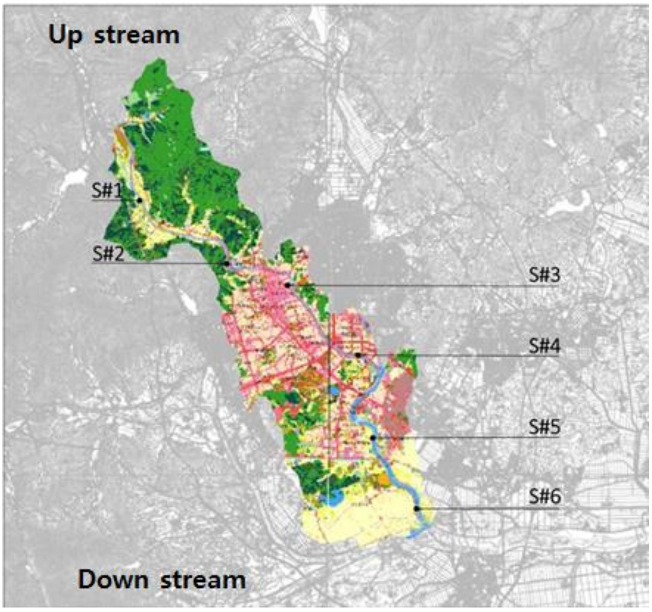

Fig. 1 Site of target area (Jeonjucheon stream)

Table 1 Site characteristics for monitoring

Parameter	Site No.	Coordinate (X, Y)	Basin Characteristic	Note
Upstream	S#1	356838.82, 214687.72	Forest	
	S#2	357219.26, 212824.56	Forest	
Midstream	S#3	359114.94, 211573.51	City	
	S#4	360032.36, 210631.68	City	
Downstream	S#5	359646.77, 211601.58	Field	Constructed weir
	S#6	365081.38, 208166.09	Field	Sewage treatment plant

2.2 Monitoring and study method

To collect the data relevant to the installation of a cost-effective automatic nonpoint pollutant measurement facility, the flow rate and water quality in the river were measured in rainfall events. The flow rate was measured consecutively at an interval of one minute by using an ultrasonic flowmeter. The pollutant was analyzed by sampling the water at an interval of 30 minutes. In addition, rainfall measuring devices were installed at the farthest upstream site S#1 and the farthest downstream site S#6 to measure the amount of rainfall accurately. The pollutants, TSS, BOD, TOC, TN, and TP, were measured by the standard methods. The monitoring was performed seven times between June and October 2016. The rainfall range was from 8.5 to 117 mm, and the rainfall duration was between 0.5 to 31.4 hours. The average rainfall intensity was in the range of 1.2 to 17 mm/hr. Very strong showers were observed in the rainfall events No. 4 and 5 (Table 2). Water samples were collected and automatically analyzed for water quality parameters on site.

Table 2 Characteristics of rainfall event

Event No.	Event Date	ADD (days)	Rainfall (mm)	Rainfall Duration (hr)	Rainfall Intensity (mm/hr)
1	2016-06-24	9.1	9.5	8.1	1.2
2	2016-07-01	3.7	83.5	31.4	2.7
3	2016-07-06	2.2	42.0	15.1	2.8
4	2016-08-06	9.8	27.5	1.6	16.8
5	2016-08-15	8.5	8.5	0.5	17.0
6	2016-09-16	4.1	117.0	27.6	4.2
7	2016-10-05	2.1	60.0	9.3	6.5

3. Results and discussion

3.1 Variation of peak flow rate at monitoring sites

Figure 2 is a plot showing the variation of the flow rate at each rainfall monitoring site. In Event 1, the flow rate at the farthest upstream S#1 and S#2 sites did not significantly change until the rainfall event finished. The increase and decrease of the flow rate were in a similar pattern at the S#3 site, where the urban area begins, and at the S#4 site at the center of the urban area. The flow rate started to increase gradually from 17:00, which was 60 minutes after the beginning of the rainfall event, and continued to increase to 19:00 when the rainfall intensity was high. After that time, the flow rate decreased with a decrease in the rainfall intensity. However, the increase of the flow rate in the river was significantly different between the S#3 and S#4 sites, despite the same amount of rainfall. The flow rate more drastically fluctuated at the S#4 site, which has a wider area of an impermeable layer than at the S#3 site. At the S#5 site, the flow rate increased from 19:00, which was two hours later than the monitoring sites in the upstream. In addition, despite the decrease in the rainfall intensity, the increased flow rate was maintained continuously at the S#5 site. This indicates that the flow rate at the S#5 site was dependent on the flow transported from the upstream, unlike the S#3 and S#4 sites, where the flow was dependent on the rainfall's intensity. A similar trend was also found at the farthest downstream S#6 and S#5 sites.

In Event 2, where the amount of rainfall was as much as 83.5 mm, the flow rate did not significantly change at S#1. At S#2, the flow rate gradually increased, but not to a high degree. At S#3 and S#4, the trend was similar to that of Event 1: The flow rate started to increase immediately after the initiation of the rainfall event, and the increase and decrease in the flow rate were dependent on the rainfall's intensity. However, at S#5 and S#6, the flow rate was slightly increased for one hour following the initiation of the rainfall event, but it was drastically increased later by the inflow from the Samcheon Stream.

Events 4 and 5, which were intensive showers, showed similar results. The flow rate did not significantly change at S#1, but the flow rate at S#2, S#3, and S#4 drastically increased at the same time during the rainfall. At S#6, the flow rate increased long after the rainfall was finished. The flow rate at S#6 started to increase, not during the rainfall, but after about one hour later in comparison with the flow rate at other monitoring sites. This is because the shower was so sudden that the barrage constructed between S#5 and S#6 did not operate immediately, and thus the flow could not be transported to S#6 for a while. In Events 4 and 5, it took about nine hours until the flow rate before the rainfall recovered after the end of the rainfall.

In Event 6, where the amount of rainfall was as much as 119 mm, the flow rate at S#1 showed almost no change in the early part of the rainfall. This may be because the rainfall runoff was firstly permeated to the permeable area around S#1 and then gradually discharged from the ground as the storage capacity was exceeded. The flow rate at S#2 showed almost no change in the early part of the rainfall because the amount of rainfall was small. However, in the middle part of the rainfall from 06:00, the flow rate increased and remained at an increased level. At S#3, the flow rate increased between 04:00 and 09:00 when the rainfall intensity was high, and then again decreased after the time period. Similarly, the flow rate at S#4 increased between 04:00 and 09:00, and then started to decrease from 12:00 at the highest decrease rate. At S#5 and S#6, the flow rate steadily increased with the beginning of the rainfall and became THE highest at the latter part of the rainfall. The high flow rate was continuously maintained, even after the end of the rainfall.

Overall, the flow rate gradually increased at the farthest upstream sites, S#1 and S#2, as the rainfall increased, but the fluctuation was not large, thereby allowing for long-term monitoring. On the contrary, at the S#3 and S#4 sites in the urban area, the flow rate was sensitive to the rainfall intensity, thereby requiring the monitoring to be done at a short time interval. At the downstream sites of S#5 and S#6, the flow rate gradually increased from about one to three hours following the beginning of rainfall, and the increased flow rate was maintained continuously until the rainfall finished. This means that the monitoring may be started later at the downstream sites in comparison with the upstream sites and performed for a longer time interval.

3.2 Determination of appropriate sites for automatic nonpoint pollutant measurement

During a rainfall, the load of nonpoint pollutants on a river is dependent on the characteristics of the river basin (basin area, land use, etc.) and the characteristics of the rainfall (amount of rainfall, rainfall intensity, anteceded dry days, etc.). Automatic nonpoint pollutant measurement facilities, which need a lot of money for the installation and operation, should be located at the optimal position by considering the drainage area and the pollutant delivery time. In the present study, to determine the appropriate location and number of the measurement facilities, the nonpoint pollutant load discharge per unit drainage area was analyzed (Figure 3).

The load was low at the upstream S#1 and S#2 sites in

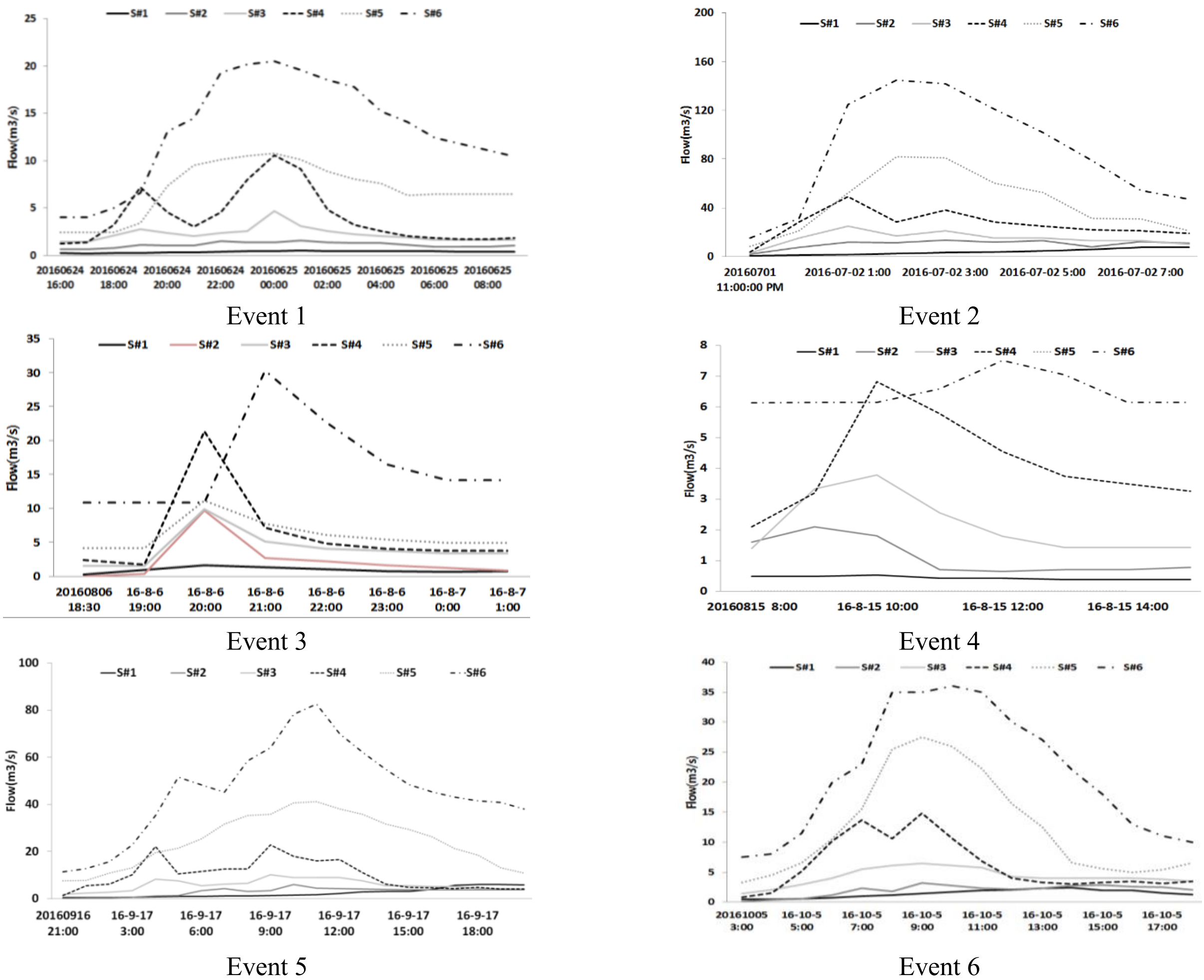

Fig. 2 Variation of flow rates at each monitoring site

the forest. The pollutant load increased as the river flowed through S#3 and S#4 in the residential and urban areas. After that, the pollutant load decreased at S#5 and S#6. In the rainfall events of the present study, the amount of rainfall was in a range from 8.5 to 119 mm, and the trend of the pollutant load was similar between the rainfall events. Considering that the drainage area was as large as 200 km^2 at S#5 and S#6, the pollutant might have been deposited or diluted because of the long pollutant delivery time. In addition, at the downstream of S#6, the flow rate was low due to the barrage, which decreased the pollutant load through the sedimentation by gravity. With a uniform land use in the river basin, the nonpoint pollutant discharge load per unit area is constant. In the absence of an inflow of pollutants from the river basin, the pollutant load may be lower in the downstream because of pollutant sedimentation or self-purification. Therefore, for the Jeonjucheon Stream, where the river basin is over 400 km^2 and the main drainage area is in the urban region, the appropriate locations and number of nonpoint pollutant measurement sites were determined as follows. In the Jeonjucheon Stream, for all the water quality variables (BOD, TOC, SS, TN, and TP), the pollutant load started to increase drastically at S#3 and S#4 in the urban area, and then decreased after the sites. This showed that the nonpoint pollutant load per unit area drastically increased as the land use changed to an urban region, and then started to decrease by self-purification in the absence of a particular pollutant source. Based on this result, the appropriate locations for nonpoint pollutant measurement sites in the Jeonjucheon Stream were determined to be three locations at S#2 (before the urban area), S#4 (after the urban area), and S#6 (end of the river).

3.3 Analysis of appropriate monitoring time

The duration of the river flow rate increase depending on the amount of rainfall was analyzed to investigate the effect of the nonpoint pollution sources on each site of the river. This may serve as important data for determining the monitoring duration. The analytical result showed that the duration of flow rate increased as the amount of rainfall increased (Figure 4). In addition, even at the same rainfall class, the duration of the flow rate increased from the upstream to the downstream. The analysis of the rainfall intensity on the duration of the flow rate increase showed that the effect of the rainfall intensity was negligible in comparison with the effect of the amount of rainfall at a rainfall intensity of 6.5 mm/hr or lower found in most of the rainfall events monitored in the present study. In the rainfall events where a higher rainfall intensity was found, including the events on August 6 (27.5 mm and 16.8 mm/hr) and August 15 (8.5 mm and 17.0 mm/hr), the

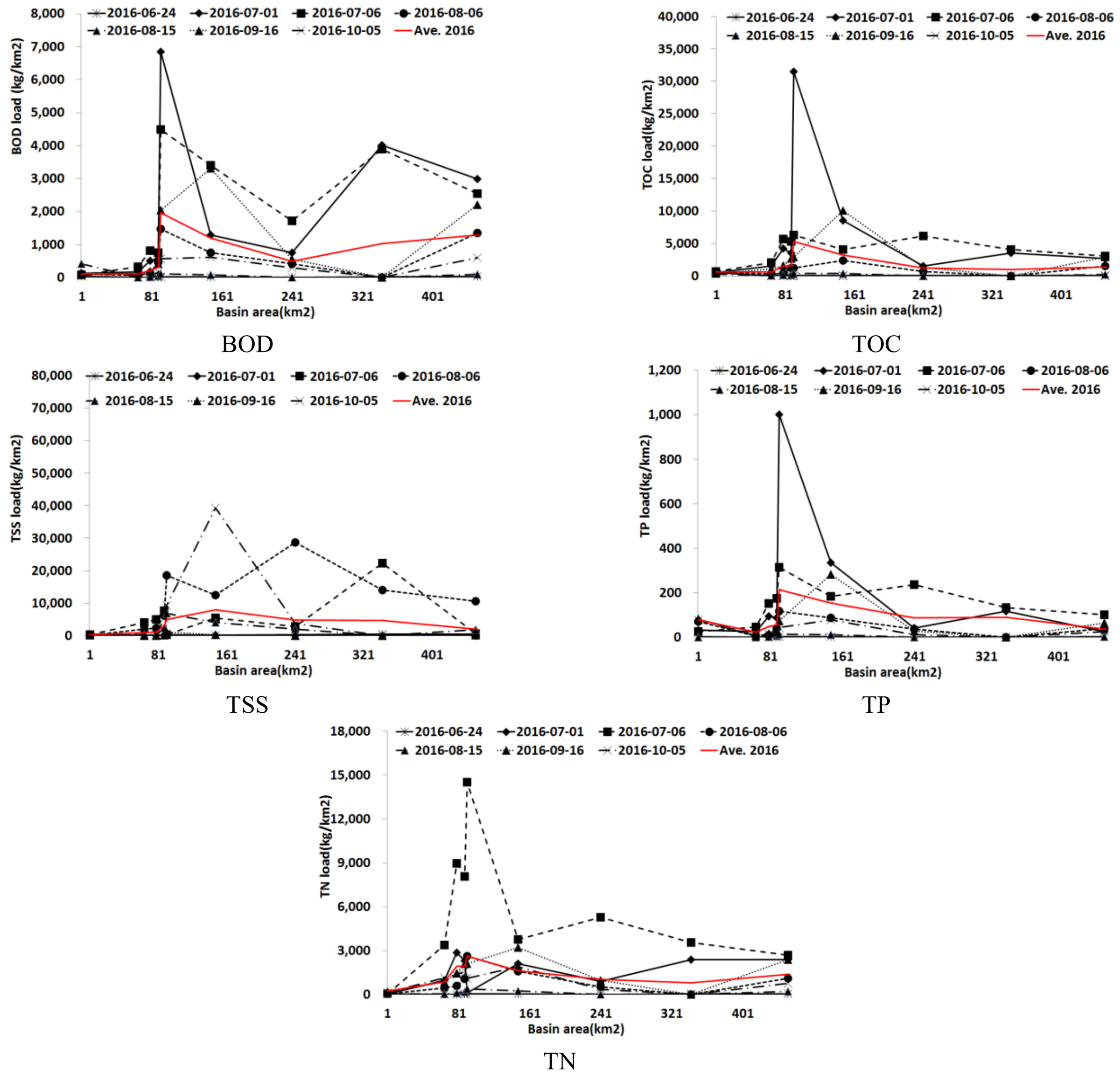

Fig. 3 Pollutant load per unit drainage area

duration of the flow rate increase was shorter in comparison with the events of the same amount of rainfall. This indicates that the duration of the flow rate increase was short in the cases of short-term showers.

On the other hand, in the rainfall events where the amount of rainfall was less than 19 mm, the flow rate was kept at an increased level for 19 hours at the farthest upstream site S#1. The duration of the flow rate increase was 22 hours at S#4 in the urban area, while it was longer at S#5 and S#6 as 29 hours and 31 hours, respectively.

At the rainfall class between 10 and 30 mm, the duration of the flow rate increase was 26 hours at S#1 and 34 hours at S#4 in the midst of the urban area. Thus, the difference was about 8 hours. The duration of the flow rate increase was 50 hours at the farthest downstream S#6, which was significantly different from that of the upstream and midstream regions. At the rainfall class between 30 and 50 mm, the duration of the flow rate increase was very different between the upstream, midstream, and downstream sites: 32 hours at S#1, 54 hours at S#4, and 70 hours at S#6.

On the contrary, at the rainfall classes of 500 to 100 mm and of 100 mm or more, the duration of the flow rate increase was not significantly different between the upstream, midstream, and downstream sites. This may be because the soil in the upstream region that consists of the forest reached the limit of the rainfall absorption capacity. Then, the rainfall runoff absorbed by the soil was continuously discharged over a long period of time. The duration of the flow rate increase was 68 hours at S#1, 67 hours at S#4, and 69 hours at S#6 at the rainfall class of 50 to 100 mm. At the rainfall class of over 100 mm, the duration of the flow rate increase was 141 hours at S#1 and 128 hours at S#4 and S#6, indicating it was longer at the farthest upstream site rather than the downstream sites. From summarizing these findings, the sampling should be performed for about 20 hours at the upstream and midstream sites and for about 30 hours at the downstream site in the Jeonjucheon Stream at a rainfall class of less than 10 mm. At a rainfall class of 10 to 30 mm, the sampling

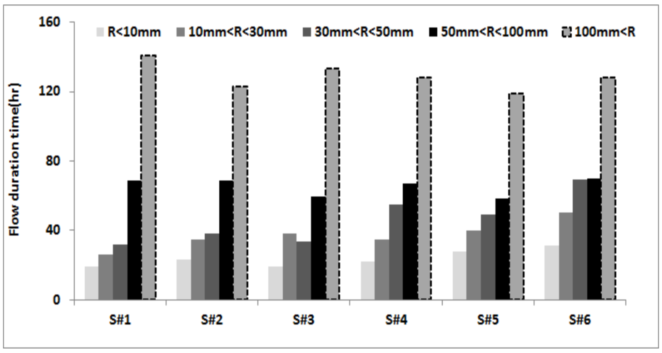

Fig. 4 Duration of flow rate increase at each rainfall class

should be performed for about 30 hours at the upstream and midstream sites and for about 50 hours at the downstream site. At a rainfall class of 30 to 50 mm, the appropriate sampling time should be 30 hours at the upstream site, 50 hours at the midstream site, and 70 hours at the downstream site. At a rainfall class of 50 to 100 mm, the appropriate sampling time should be the same between the upstream, midstream, and downstream sites at about 70 hours. At a rainfall class of over 100 mm, the sampling should be performed for about 130 hours at the upstream, midstream, and downstream sites.

4. Conclusions

In Korea, nonpoint pollutants have a significant effect on rivers, and different nonpoint pollutants are discharged depending on the characteristics of the rainfall. Therefore, intensive monitoring is needed to prepare an optimal countermeasure to nonpoint pollutants. The present study was conducted to help prepare a method for installing an automatic nonpoint pollutant measurement system for the cost-effective monitoring of the effect of nonpoint pollutants on rivers. The results showed that the flow rate measurement duration should be varied based on the monitoring sites. At the upstream sites such as S#1 and S#2, the fluctuation of the flow rate was not significant, thereby allowing for long-term monitoring. On the contrary, at the S#3 and S#4 sites in the urban area, the flow rate was sensitive to the rainfall intensity, thereby requiring the monitoring to be done in a short time interval. The flow rate at the downstream monitoring sites was not significantly affected by the rainfall intensity, but it gradually increased, reached a peak at the middle phase of the rainfall, and then gradually decreased. Therefore, monitoring the flow rate over a long period of time may also be cost-effective at the downstream sites. In the Jeonjucheon Stream, where the river basin is over 400 km^2 and the main drainage area is in the urban region, the pollutant load was not very high in the upstream, but started to increase from S#4 in the urban region, and then decreased again later on. Therefore, the appropriate locations for nonpoint pollutant measurement sites may be three locations at S#2 (before the urban area), S#4 (after the urban area), and S#6 (end of the river). The analysis also showed that the duration when the river was affected by the rainfall runoff was significantly dependent on the rainfall class and the locations of the monitoring sites: The duration of the flow rate increase was longer as the rainfall class was higher and the monitoring sites were closer to the downstream. However, at the rainfall class over 100 mm, the duration of the flow rate increase was not significantly different between the upstream, midstream, and downstream sites. Even with the same amount of rainfall, the duration of the flow rate increase was shorter in the cases of short-term showers.

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