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# Nonpoint source management area monitoring and assessment of management objectives achievement

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**ABSTRACT**

A nonpoint source is not easy to take countermeasures against point sources flowed from land during rainfall. In order to establish systematic management of these nonpoint sources, a nonpoint source management area was designated in Article 54 of the Water Environment Conservation Act in Korea since 2007. Once an area is designated as a nonpoint source management area, management objectives, target substances, and concrete reduction measures are established for the management policies and implementation plans and the nonpoint reduction effect is analyzed based on the assessment of the achievement of management objectives. This study was conducted on the watersheds of Saemanguem showed both urban and rural land use and Goljicheon showed rural land use to be designated and reported as nonpoint source management areas. Accordingly, this study presented the concrete conditions of the two areas and the achievement results of the management objectives in each flow management section, which was the same as in the implementation plan. Based on these results, this study aimed to propose a monitoring method for nonpoint source management areas. The proposed method encompasses the improvement in setting management objectives, which could control the influence of nonpoint pollution, and a monitoring method for nonpoint sources.

*Keywords:* Nonpoint source; Load duration curve (LDC); Monitoring

## 1. Introduction

A nonpoint source refers to unspecified water pollutants emitted from multiple, diffuse sources, such as a city, road, farm, district, or construction site [1]. During a rainfall event, a nonpoint source takes the form of various pollution sources, such as sediment and nutrients according to land use pattern [2]. Nonpoint pollution can badly affect the quality of public waters, rivers, and the habitats of living organisms [3]. Since August 2007, the Government of South Korea's Ministry of Environment has designated areas in which rivers, lakes, people, or the ecosystem more generally have been or could be seriously damaged by rainfall runoff originating from nonpoint source pollution as "nonpoint source management areas," and has intensively managed these areas to improve the quality of public waters [4].

In accordance with Article 54, sections 1–5 of the Water Environment Conservation Act, nonpoint source management areas include ecologically risky areas, cities with a population of over 1 million people, industrial areas, areas with where the water pollution level is higher than what is considered acceptable, geologically, or topographically special areas, and other areas prescribed by the ordinance of the Ministry of Environment. As of 2019, a total of 14 areas have been designated as nonpoint source management areas, including Saemangeum and Goljicheon watersheds. Once an area has been designated, management objectives, and concrete reduction measures of target substances are

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established within management policies and implementation plans [5]. The nonpoint pollution reduction effect is analyzed based on an assessment of the extent to which such management objectives have been achieved.

In the case of Gwangju metropolitan city, Doam Lake, Soowon-si of Gyeonggi-do, and Soyang Lake, management objectives were set based on changes in annual average water quality. However, there is insufficient background data on which to assess whether water quality change in these areas has been caused by a nonpoint source of pollution. In addition, the achievement of management objectives is assessed based on total loads. In other words, management objectives are considered to have been achieved if the 3 y average performance is satisfactory in 2 consecutive years. Consequently, no differentiated assessment method has been proposed to manage nonpoint sources [6].

For effective management of nonpoint sources, management objectives – and the method for assessing those objectives – need to be scientifically set by considering the emission of nonpoint sources and the characteristics of each watershed. This study established management objectives for the Saemangeum and Goljicheon watersheds by analyzing the impact of land use patterns on loads and water bodies through Hydrological Simulation Program Fortran (HSPF) watershed models. The Saemangeum watershed showed both urban and rural land use patterns, whereas the Goljicheon watershed belongs to a rural area only. Accordingly, this study presents concrete data regarding the conditions of each area and presents an analyzes to what extent the management objectives in each flow management section and implementation plan are achieved. Based on these results, this study proposes a monitoring method for nonpoint source management areas. The proposed method encompasses the improvement in setting management objectives, which could control the influence of nonpoint pollution, and a monitoring method for nonpoint sources.

## 2. Methods

### 2.1. Conditions of target watersheds

#### 2.1.1. Saemangeum watershed

The Saemangeum watershed is divided into the Mangyeonggang watershed and the Dongjingang watershed (Fig. 1). It covers an area of 815.8 km$^2$ and includes seven national streams, 168 local streams, and extends over the cities of Jeongju-si, Gunsan-si, Iksan-si, Jeongeup-si, and Gimje-si in Jollabuk-do [7]. Agricultural land accounts for a high percentage of the area, and agricultural nonpoint sources from both arable and pastoral farming practices constitute a large proportion of total pollutant emissions. Urban and industrial areas also influence the water quality of upper streams [8].

#### 2.1.2. Goljicheon watershed

As Shown in Fig. 1b, the Goljicheon watershed encompasses 87 small watersheds, including Imgecheon and Songhyeoncheon, which are both class 2 local streams, and Danggokcheon, which rises from Samcheok city and joins Goljicheon. Goljicheon covers a total area of 398.34 km$^2$, and extends over the cities of Geongseon-gun, Gangneung-si, and Samcheok-si in Gangwon-do [9].

Upland fields cover an area of 31.38 km$^2$ (7.9% of the total area), 13.24 km$^2$ (42.2%) of which is alpine agricultural farmland at an altitude of 400 m and above and with gradient of 15% or above. In alpine regions, a rainstorm event can cause outflow water and soil loss, greatly affecting stream ecosystems. In particular, Imgye-myeon and Wangsan-myeon (of Geongseon-gun and Gangneung-si, respectively) have a high percentage of coarse sand consisting of weathered granite. Accordingly, the geological structures and strata in these regions are remarkably distinguished from

(a) (b)

Fig. 1. Modeling points of watershed (a) Saemanguem watershed and (b) Goljicheon watershed.

those of other regions, and thus, soil loss, muddy water, and nonpoint sources need to be controlled [10].

### *2.2. Implementation plan management objectives and target substances for target watersheds*

#### *2.2.1. Saemangeum watershed*

The substance to be controlled is T–P (mg/L). The management objective is that T–P concentration is in the 75th percentile in the management discharge section. Based on daily average discharge data for the last 10 y, the management discharge section was determined to be 5%–50%. This was calculated by analyzing the frequency of exceedance excluding extreme flood discharge sections [6]. The achievement of management objectives is evaluated in the same way as setting those objectives. There are five management points. The target water quality levels for each point are as follows: 0.086 mg/L for Jeonjucheon 6, 0.101 mg/L for Osan, 0.102 mg/L for Mangyeongdaegyo, 0.075 mg/L for Gunpogyo, and 0.080 mg/L for Dongjindaegyo.

#### *2.2.2. Goljicheon watershed*

As alpine agricultural fields constitute a large area of the Goljicheon watershed, SS (mg/L), a cause of muddy water, was selected as the substance to be controlled in this region. Based on an analysis of SS exceedance on load duration curve (LDC) and using daily average discharge data for the last 10 y the top 10%–30% section of the watershed was set as the management discharge section, excluding the sections of extreme flood discharge. The management objective is considered to have been achieved if SS concentration in the 90th percentile in the management discharge section satisfies the target water quality level. The critical watermark point and Goljicheon 2, where national water quality monitoring stations are located, were selected as the management points. The target water quality levels were 22.6 mg/L for the critical watermark point, and 8.7 mg/L for Goljicheon 2.

### *2.3. Monitoring of the watersheds*

Flow and water quality for the management points were checked monthly when no rainfall event occurred, and at least five times in a rainfall event. When no rainfall event occurred, the data of water quality monitoring stations, which were provided by the Ministry of Environment, were maximally utilized. The flow and water quality were collected once a month in case of no rainfall and the monitoring method in case of rainfall was carried out based on the flow and water quality survey method of "the rainfall runoff investigation method" [11]. The flow and water quality investigation method are investigated every 15 min from the start of the runoff during rainfall until 2 h, and after 2 h, every 1 h. In this case, the investigation intervals can be arbitrarily adjusted so that the rainfall runoff condition can be accurately investigated if the time duration of the rainfall runoff exceeds 6 h. In this study, if the rainfall runoff exceeds 6 h, it was investigated at 1 h intervals until the end of the rainfall runoff. The rainfall measurement method was investigated by installing a high-quality meter, and in case of difficulties in measuring rain in the target area, weather station data were used in neighbouring areas such as the Korea Meteorological Administration.

A total of six monitoring points in the Saemangeum watershed were selected, including four of the management target points (Mangyongdaegyo, Osan, Dongjindegyo, and Gunpogyo) and the additional monitoring points in the watershed, Mumyeongcheon, and Geumgucheon. At this time, the flow was measured only in Mumyeongcheon and Geumgucheon. This is because the other four points were difficult to measure the flow due to the influence of the nearby flood gate and the wide width of the stream. These four points, which are difficult to measure, are derived using the HSPF model. The monitoring points of the Golji watershed were selected for a total of five monitoring points, including Songgyegyo, Yeoranggyo1, Taebonggyo 2, Gwanmalgyo, and Geommugyo, to investigate the flow and quality. The water quality items were determined based on the target substances of each management area. Storage, on-site measurement, and testing of samples were conducted in accordance with the standard methods for the examination of water pollution [12].

### *2.4. Model construction for the watersheds*

For both the Saemangeum and Goljicheon watersheds, models were constructed using data regarding present conditions, weather, basic environmental facilities, inflow, and other data until the year 2018.

#### *2.4.1. Saemangeum watershed*

This study examined the reproducibility of the HSPF model for modelling discharge and water quality of the Saemangeum watershed from 2012 to 2018. Data from six monitoring points (Hwangsangyo, Osan, Mangyeongdaegyo, Juksangyo, Gunpogyo, and Dongjindaegyo), combined with existing water level-discharge data provided by the Ministry of Land, Transport and Maritime Affairs (Ministry of Land, Infrastructure and Transport, Water Resources Management Information System), and data from the water environment monitoring stations of the Ministry of Environment. Concrete watershed models were constructed, reflecting the agricultural, and watershed characteristics of Saemangeum, such as complicated water supply and drainage systems, and inflow. Paddy fields were also included in the models as the main land use type. Table 1 presents the list of input data. To evaluate the adequacy of discharge measurements and simulation, Nash–Sutcliffe efficiency (NSE), root mean square error (RMSE), and relative errors (%, %difference) were examined. The water levels measured or simulated were evaluated by examining the average bias, RMSE, and relative errors (%difference).

#### *2.4.2. Goljicheon watershed*

The Goljicheon watershed has a relatively lower density of human activities related to large-scale development projects. This region belongs to an upper watershed and displays natural flow conditions. However, large hydraulic structures for blocking stream flows and artificially

Table 1
Input data for constructing the watershed model

| Data | Source | Scale | Characteristics |
|---|---|---|---|
| Digital elevation model | National geographic Information Institute | 1:5,000 | Digital elevation model; 10 m × 10 m |
| Land use map (land cover map) | Ministry of Environment/Environmental Geographic Information/Korea Institute of Civil Engineering and Building Technology | 1:25,000 | Major classification of land cover (site, forest, field, paddy, watershed) |
| Weather data | Korea Meteorological Administration | Daily, hourly | Precipitation, mean temperature, relative humidity, solar radiation, and wind speed (2007–2017) |
| Discharge | Ministry of Environment/Environment Agency/Water resources Management Information System | 8 d/month | Data from automatic and manual measuring stations and total load measuring stations |
| Water quality | Ministry of Environment/Environment Agency | 8 d/month | Data from general water quality monitoring stations and total load monitoring stations (Water temperature, DO, SS, BOD, COD, TN, TP) |
| Pollutants | National Institute of Environmental Research | – | Pollutant monitoring data of each administrative unit inside the Saemangeum and Goljicheon watersheds |
| Water intake | Local administration/National Institute of Environmental Research | Monthly, daily | Data acquisition for the current conditions of intake and pumping stations in target reservoirs |
| Water budget information | Local organization/National Institute of Environmental Research | – | Data acquisition for the water budget of the main water ways in the upper stream |
| Administrative boundary map | Ministry of Land, Infrastructure and Transport/ K-Water | – | Unit watershed map, medium influence area map, large influence area map, Si/Do/Gun boundary map |

controlling discharges are located in the upper parts of Goljicheon (Gwangdong Dam) and Songcheon (Doam Dam). The HSPF model classified a total of 46 small watersheds, including 17 watersheds up to the critical watermark point, 14 watersheds from the upper part of Gwangdong dam to Yeoryanggyo 1, and 14 watersheds in Songcheon and at the end point of Golji A. The calibration and validation of the model were conducted at five points monitored in this study (Taebonggyo 2, Gwanmalgyo, Geommugyo, Gonggyegyo, and Yeoryanggyo 1), the end point of the unit watershed of Golji A, and four monitoring points (Songgyegyo, Hyeolcheongyo, Yeoryanggyo 1, and Songcheongyo) where the Ministry of Environment and the Han River Flood Control Office gather water level and discharge data. Two of these points – Songgyegyo and Yeoryanggyo 1 – were found to be redundant.

## 3. Results and discussion

### 3.1. Monitoring results of target areas

The Saemangeum watershed was monitored six times at six points during rainfall events. These monitoring points included Osan, Mangyeongdaegyo, Gunpogyo, Dongjindaegyo, and two other points of tributary streams (Mumyeongcheon, Gumgucheon). The points of Mumyeongcheon and Gumgucheon were located at the upper part of the Saemangeum watershed and thus showed typical rainfall runoff characteristics. In other words, the water quality changed according to flow during a rainfall event. Depending on the monitoring time, these points were also greatly affected by the agricultural water supply.

In contrast, Osan, Mangyeongdaegyo, Gunpogyo, and Dongjindaegyo, which were located at the lower part of the Saemangeum watershed, did not show any regular change of water quality according to flow during a rainfall event but displayed a uniform distribution of concentration in most cases. This characteristic is typical of urban-rural areas such as the Saemangeum watershed, where the agricultural fields and floral zones caused the buffer action and the operation of regulating gates was also influential. Each point shows a low correlation between the precipitation and event mean concentration (EMC) of each water quality item. The EMC of T–P was highest at the Mumyeongcheon point. As shown in Fig. 2, the results of rainfall monitoring in the Saemangeum watershed were the highest at the point of obscurity, with T–P EMC 1.958 mg/L. Accordingly, the rural areas where farming was undertaken were affected both by rainfall and the operation of regulating gates. This needs to be considered for the monitoring time.

The Goljicheon watershed was monitored six times at five points during rainfall events. These monitoring points included three priority management points (Taebonggyo 2, Gwanmalgyo, and Geommugyo) and two management points (Songgyegyo and Yeoryanggyo 1).

The EMC of each point was calculated by using the flow and water quality of rainfall runoff. The EMC of the item SS was greatly different among the points owing to

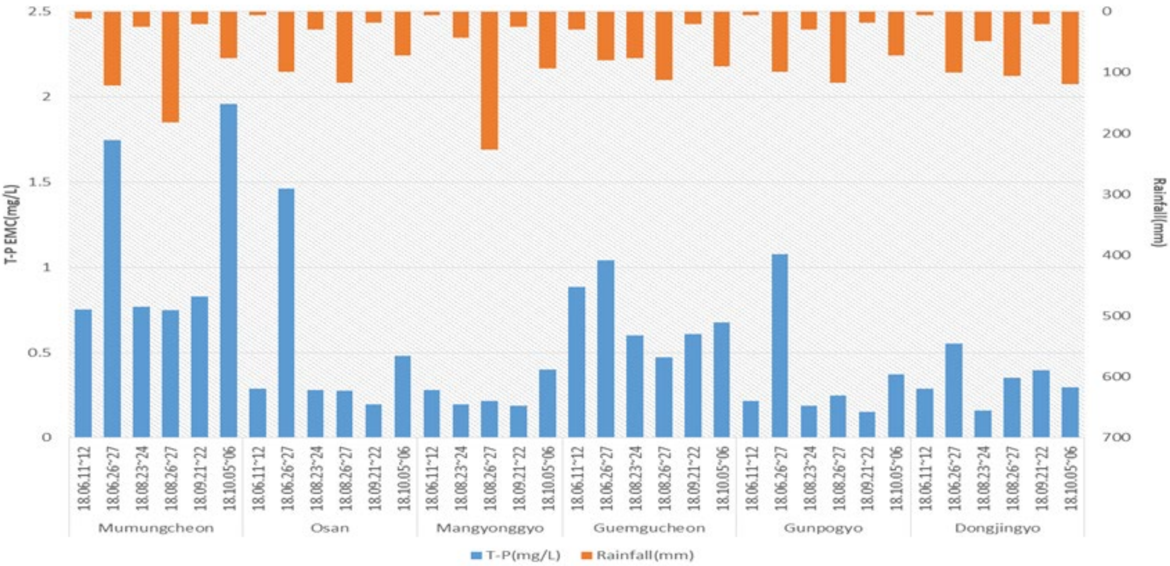


Fig. 2. EMC (mg/L) of T–P in Saemanguem watershed.

the influences of precipitation and the agricultural activities in farmlands of the upper region or other human activities.

Taebonggyo 2 had the highest EMC at each monitoring of rainfall runoff, followed by Songgyegyo, which is located in the lower part of Taebonggyo 2. As shown in Fig. 3, the results of rainfall monitoring in the Goljicheon watershed were the highest at SS EMC 4,682.0 mg/L on Taebonggyo 2.

However, EMC significantly decreased at Yeoryanggyo 1 with a long flow distance. Gwanmalgyo and Geommugyo also had a lower EMC than Taebonggyo 2. EMC differs depending on the maximum rainfall intensity, antecedent dry days, and agricultural activity. Precipitation alone did not cause any clear difference of EMC. Consequently, in case the influence of not only precipitation but also agricultural activity and other human activities is monitored in a rural area including many alpine agricultural fields, if the major factors can be distinguished, the impact of a nonpoint source will be analyzed more effectively.

### 3.2. Modeling results of target areas

#### 3.2.1. Saemangeum watershed

To calibrate and validate the flow of the watershed model, representative points were selected in the Mangyeonggang watershed (Misangyo, Samryeogyo) and the Dongjingang watershed (Hangjeonggyo, Dongjingang 3). The results of calibration and validation of flow are shown in Fig. 4.

After calibration and validation, the efficiency of the model was evaluated by using relative errors (%difference). As shown in Table 2, Misangyo of Mangyeonggang watershed had a relative error of 11.66% and thus was rated

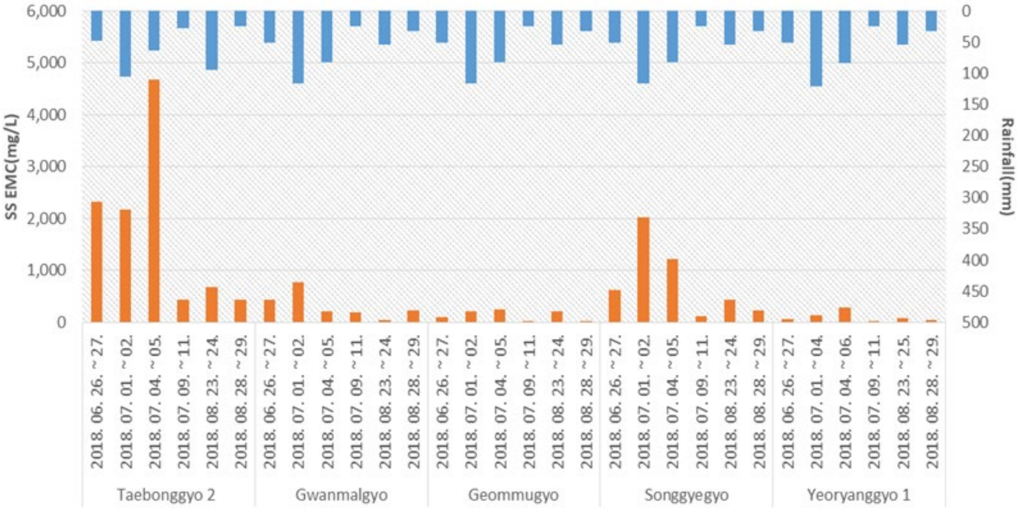
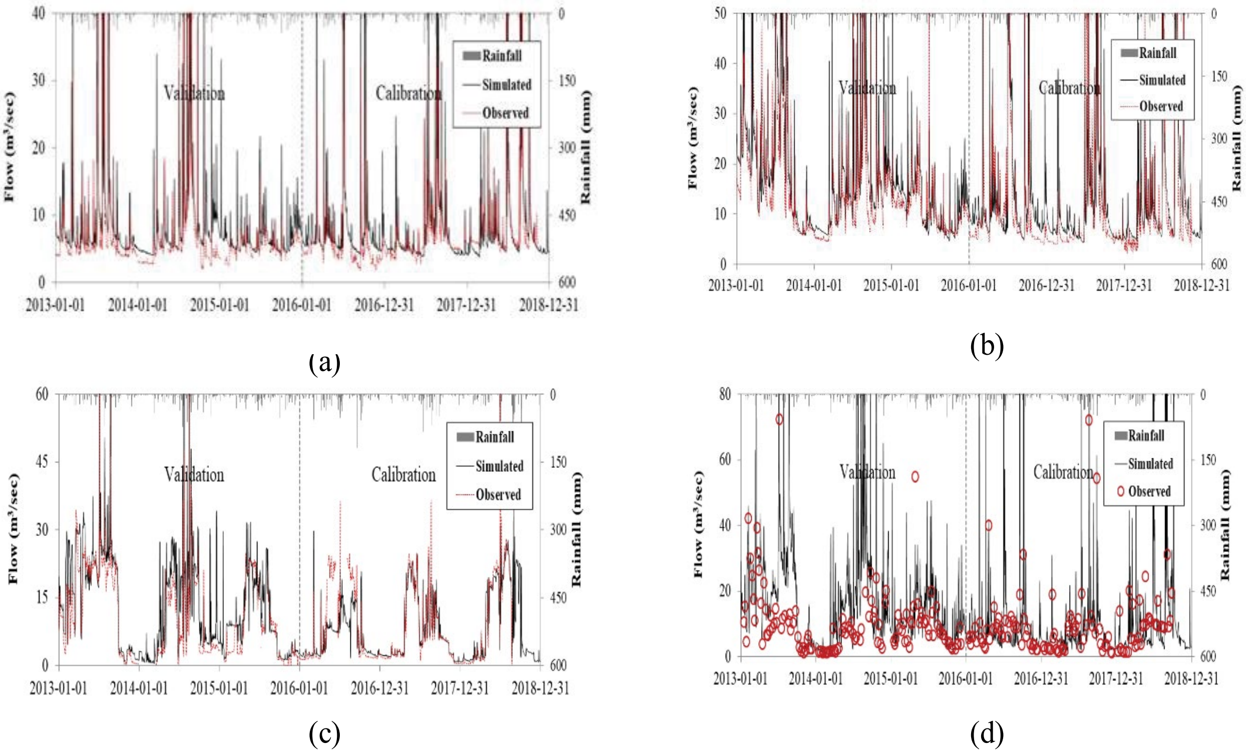


Fig. 3. EMC (mg/L) of SS in Goljicheon watershed.



(a)

(b)

(c)

(d)

Fig. 4. Calibration and validation results of flow in the Saemangeum watershed (a) Misangyo ($m^3/s$), (b) Samryeogyo ($m^3/s$), (c) Hangjeonggyo ($m^3/s$), and (d) Dongjingang 3 ($m^3/s$).

Table 2
Results of grade analysis of calibration and validation of flow in the Saemangeum watershed

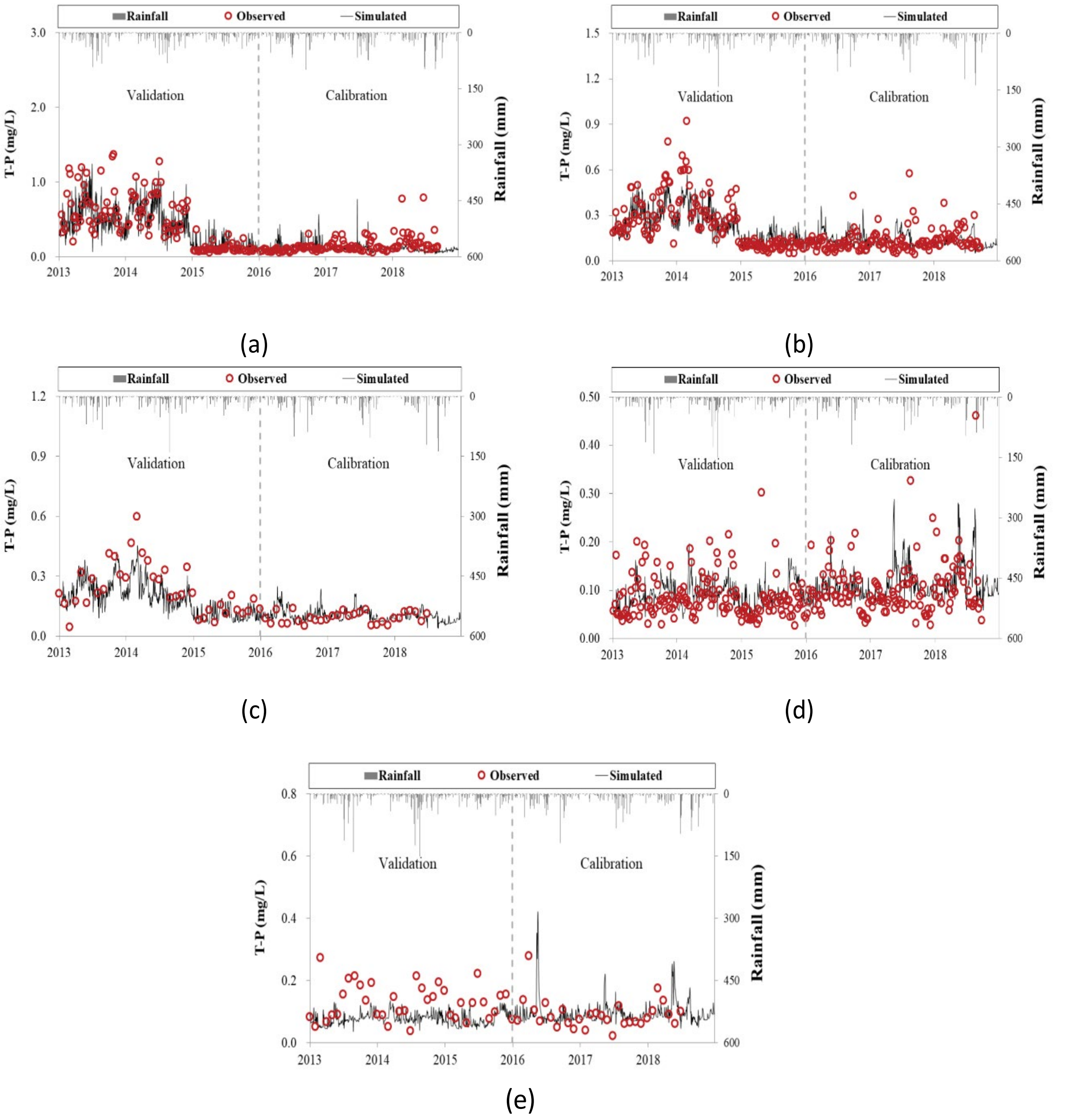
| Watershed | Point | Flow | | | |
|---|---|---|---|---|---|
| | | %Diff. | grade | $R^2$ | Grade |
| Mangyong river | Misangyo | 11.66 | Good | 0.92 | Very good |
| | Samregyo | 8.80 | Very good | 0.85 | Very good |
| Dongjing river | Hangjungyo | 17.04 | Fair | 0.77 | Good |
| | Dongjinriver3 | 11.06 | Good | 0.67 | Fair |

"good," and Samryeogyo was rated "very good" with a relative error of 8.80%. Dongjingang 3 showed a relative error of 11.06%, which corresponded to "good," and Hangjeonggyo had a relative error of 17.04% and was evaluated as "fair" but R2 was evaluated to be "good." Thus, the simulated results sufficiently reflected the measurements.

To calibrate and validate the water quality, representative points were selected in the Mangyeonggang watershed (Jeonjucheon 6, Gimje, and Mangyeongdaegyo) and the Dongjingang watershed (Dongjingang 3, Dongjindaegyo). The results of calibration and validation of water quality are shown in Fig. 5. After calibration and validation, the relative errors of T–P of Gimje and Mangyeongdaegyo in the Mangyeongdaegyo watershed were 2.07% and 7.43%, respectively as shown in Table 3. The efficiency of the model was rated "very good." The relative error of T–P at Dongjingang 3 of the Dongjingang watershed was 0.78%, which was rated "very good," and that of Dongjindaegyo was 19.56%, corresponding to "good." The precision calibration and validation results showed a difference from the modeling results of hourly calibration at each rainfall event. This was attributable to the characteristics of the Saemangeum watershed such as the operation of gates (locks). Although the model was calibrated hourly five or six times by using measurement data, it was not satisfactory. Thus, an additional analysis is necessary using long-term monitoring results.

### 3.2.2. Goljicheon watershed

To calibrate and validate the HSPF for the Goljicheon watershed, Taebonggyo 2, Gwanmalgyo, and Geommugyo (short-term rainfall runoff), which were monitored, and three water level monitoring points of the Ministry of Environment (long-term rainfall runoff: Songgyegyo, Yeoryanggyo 1, and Songcheongyo) and Golji A were



(a)

(b)

(c)

(d)

(e)

Fig. 5. Calibration and validation results of water quality in the Saemangeum watershed (a) Jeonjucheon 6 (mg/L), (b) Gimje (mg/L), (c) Mangyeongdaegyo (mg/L), (d) Dongjingang 3 (mg/L), and (e) Dongjindaegyo (mg/L).

selected as the representative points. The results of calibration and validation of flow are shown in Fig. 6.

As shown in Table 4, the flow calibration for these seven points showed that the relative errors at every point ranged from 2.35% to 13.77% and $R^2$ had the range of 0.70–0.97. The model efficiency was rated "good." However, the $R^2$ values of Songgyegyo and Songcheongyo were 0.52 and 0.58, respectively, which corresponded to a "poor" grade and a lower model efficiency than other points.

To calibrate and validate the water quality, five monitoring points (Geommugyo, Gwanmalgyo, Taebonggyo 2, Songgyegyo, and Yeoryanggyo 1) and Golji A were selected as the representative points. The results of calibration and validation of water quality are shown in Fig. 7.

As shown in Table 5, The calibration and validation results revealed that the relative error of SS ranged from 8.1% to 28.1%, and the model efficiency was "good" and above. Based on these results, it could be inferred that the soil loss

Table 3
Results of grade analysis of calibration and validation of water quality in the Saemangeum watershed

| Watershed | Point | T–P(mg/L) | |
|---|---|---|---|
| | | %Difference | Grade |
| Mangyong river | Jeonjustream6 | 8.09 | Very good |
| | Kimje | 2.07 | Very good |
| | Mangyeongdaegyo | 7.43 | Very good |
| Dongjin river | Dongjinriver3 | 0.78 | very good |
| | Dongjindaegyo | 19.56 | Fair |

was directly affected by human activities such as harvesting and construction for a specific period in some parts of the monitoring sites. In such a case, the estimations could not satisfactorily reflect the observations.

In addition, although the graphical distance is very short, rainfall may have a clear local difference owing to the geographical features of mountain. Therefore, the rainfall characteristics of the existing meteorological stations and disaster prevention monitoring stations cannot be effectively reflected. This problem needs to be improved in modeling.

### *3.3. Assessment of the achievement of management objectives for target areas*

After the reproducibility of the HSPF model for the Saemangeum watershed, which is an urban-rural area, had been completed, two sets of 3 y data (2015–2017 and 2016–2018) were applied to the model. Thus, the daily flow and T–P data of the management points were extracted. The T–P loads were comparatively analyzed with the LDC presented by the implementation plan. As presented in Table 6, the management objectives were not achieved in two consecutive years of each 3 y period.

As shown in Table 7, the existing data is the target water quality, which is the value of the implementation plan based on the model results for each watershed from 2005 to 2014. The latest data are the latest 4 y data from the latest 4 y data on the basis of 2018 when the study was conducted to assess the achievement of the management objectives using the two-time objective of the implementation plan for three consecutive years and the water quality value. This can be seen in detail by Fig. 8 together with Table 7. As shown in Fig. 8, the Goljicheon watershed, two sets of 3 y data (2015–2017 and 2016–2018) were applied to the model. The SS loads were comparatively analyzed with the LDC presented by the implementation plan. Black line indicates implementation plan for target and yellow dots the results of model and red dots the results of excess.

According to the analysis results, the load of Songgyegyo was relatively high in 2018 compared to 2017, and the excess rate was 100% or higher, which does not achieve the target water quality.

This could be changed the management period of 10 y (2005–2014), climate characteristics, farming characteristics, soil loss, etc. at the time of the implementation plan establishment, and it is necessary to review it in conjunction with climate trends that reduce the number of recent rainfall days but increase the rainfall intensity. When the flowrate constant curve was relatively low in 2017, it was assessed that the target water quality was achieved temporarily because the load exceeded 2.7%. However, the excess load rate again reached 52.1% in 2018. Therefore, management target is not achieved.

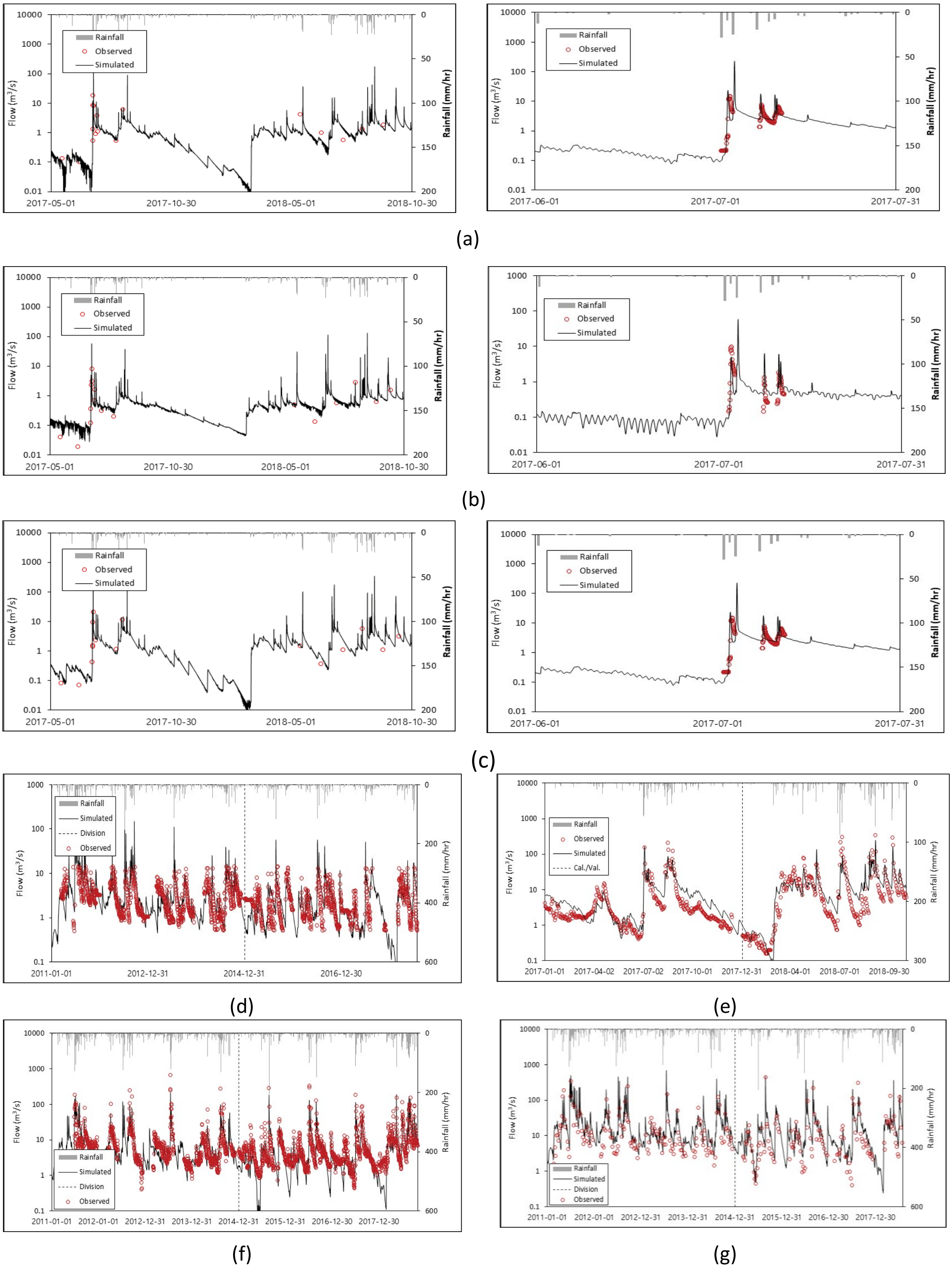
As shown in Table 7, in the Goljicheon watershed, which is mostly covered by alpine agriculture areas, Songgyegyo 100% exceeded the section of management flow duration (10%–30%) both in the 1st and 2nd periods. Yeoryanggyo 1 had the 90th percentile concentration of 8.4 mg/L in the management flow section in the 1st period. This result satisfied the target water quality level. However, the 90th percentile concentration at the 2nd period was 12.5 mg/L, which failed the target water quality level.

### *3.4. Appropriate management section for flow duration at each target area*

In the case of the Saemangeum watershed, every management point showed that the flow duration curves of the two periods (2015–2017 and 2016–2018) were lower than that of the implementation plan (2008–2013) at high flow. Especially, Osan and Mangyeongdaegyo mostly had a lower flow than that of the implementation plan, as presented in Table 8. This difference between the implementation plan and the flow duration curve (FDC) of 2015–2017 and 2016–2018 is attributable to the difference in precipitation. In the Mangyeongdaegyo watershed, the annual average accumulated precipitation was 1,245 mm during the period of implementation plan, 967 mm between 2015 and 2017, and 1,142 mm between 2016 and 2018. Thus, the precipitation decreased.

In the Goljicheon watershed, the flow at Songgyegyo was between 3,426 and 7,023 $m^3/s$, as presented in Table 9. This result was slightly lower than the management flow (4.191–9.005 $m^3/s$) specified by the implementation plan. The flow at Yeoryanggyo 1 was between 10.987 and 23.560 $m^3/s$, which corresponded to a larger flow duration section (9.3%–32.3%) than the flow of the implementation plan (9.996–25.372 $m^3/s$). The overall stream flow was low in 2017, and both the high and low flows drastically changed in 2018. This result is believed to cause the runoff curve features of large hydraulic structures (dams), which are artificially operated, a very high coefficient of river regime, and hydraulic and hydrological instability.

As shown Fig. 9, the management flow range (10%–30%) for Goljicheon was determined when the implementation plan was established. The range was based on the modeling



(a)

(b)

(c)

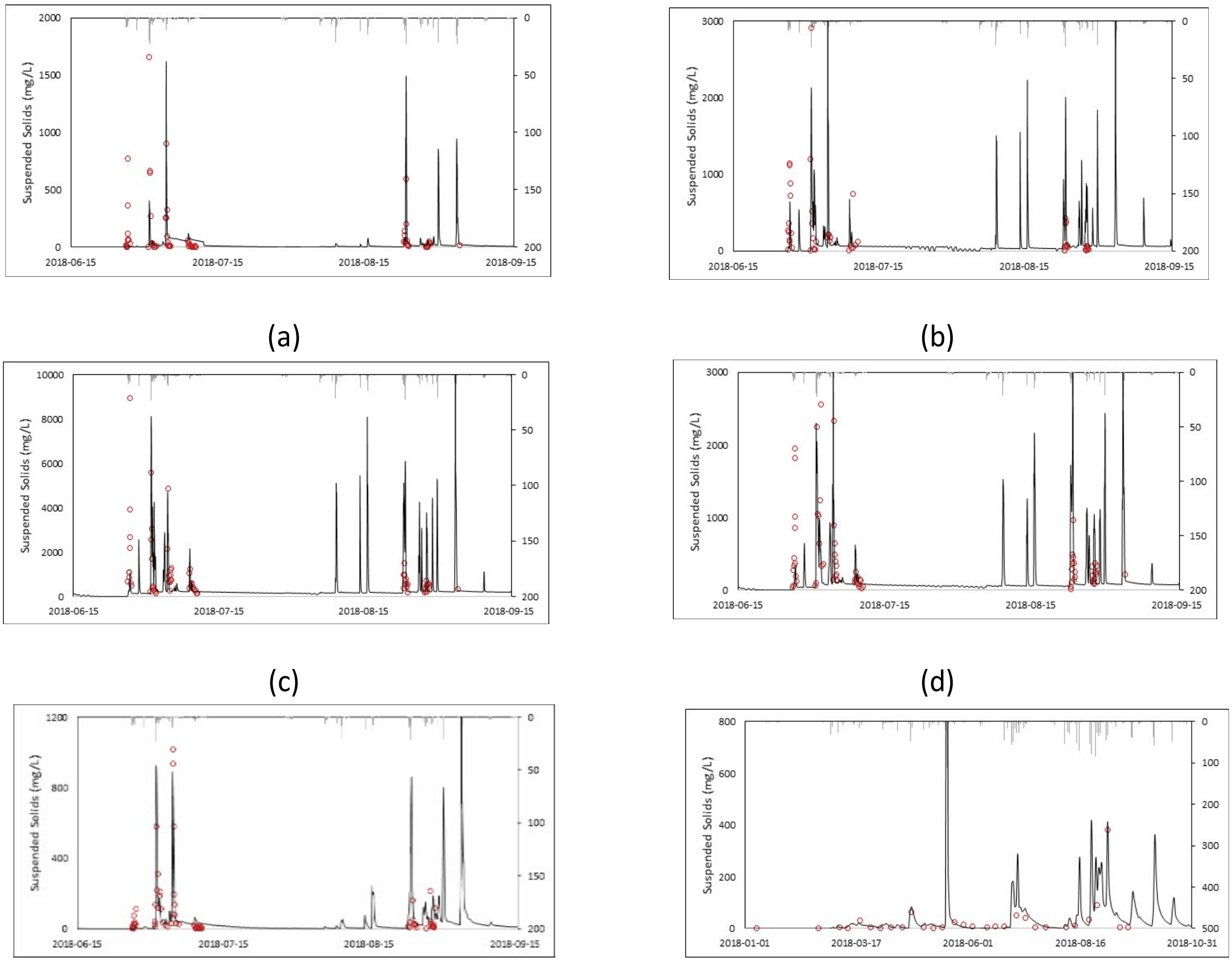
(d) (e)

(f) (g)

Fig. 6. Calibration and validation results of flow in the Golji watershed (a) Taebonggyo 2, (b) Gwanmalgyo, (c) Gummugyo, (d) Songgyegyo, (e) Teoryanggyo 1, (f) Songchungyo, and (g) GlojiA.

Table 4
Results of grade analysis of calibration and validation of flow in the Goljicheon watershed

| Point | Flow | | | |
|---|---|---|---|---|
| | %Difference | Grade | $R^2$ | Grade |
| Gwanmalgyo | (–)3.9% | Very good | 0.7974 | Good |
| Gwanmalgyo | 3.1% | Very good | 0.9654 | Very good |
| Taebonggyo 2 | 2.6% | Very good | 0.9242 | Very good |
| Songgyegyo | 9.40% | Very good | 0.517 | Poor |
| Yeoryanggyo 1 | 13.77% | Good | 0.700 | Good |
| Songcheongyo | 13.68% | Good | 0.581 | Poor |
| GoljiA | (–)2.35% | Very good | 0.863 | Very good |



(a) (b)

(c) (d)

(e) (f)

Fig. 7. Calibration and validation results of water quality in the Golji watershed (a) Geommugyo, (b) Gwanmalgyo, (c) Taebonggyo 2, (d)Songgyegyo, (e) Yeoryanggyo 1, and (f) GoljiA.

results from 2005 and 2014. However, the annual precipitation decreased owing to localized heavy rain and spring drought in 2018. Accordingly, when the recent modeling results until the year 2016 were used for analysis, the flow range to be managed was somewhat reduced.

As shown above, this study constructed models by reflecting the latest watershed conditions (~2018) in the same way as the implementation plans for each management area and evaluated the management flow sections. The Saemangeum watershed, which is an urban-rural area,

Table 5
Results of grade analysis of calibration and validation of water quality in the Goljicheon watershed

| Point | Water Quality | | | |
|---|---|---|---|---|
| | %Difference | Grade | $R^2$ | Grade |
| Gummugyo | (–)17.9% | Very good | – | – |
| Gwanmalgyo | (–)26.8% | Very good | – | – |
| Taebonggyo2 | (–)13.9% | Very good | – | – |
| Songgyegyo | 20.5% | Good | – | – |
| Yeoryanggyo1 | (–)28.1% | Good | 0.734 | Good |
| Songcheongyo | (–)27.5% | Good | 0.958 | Good |

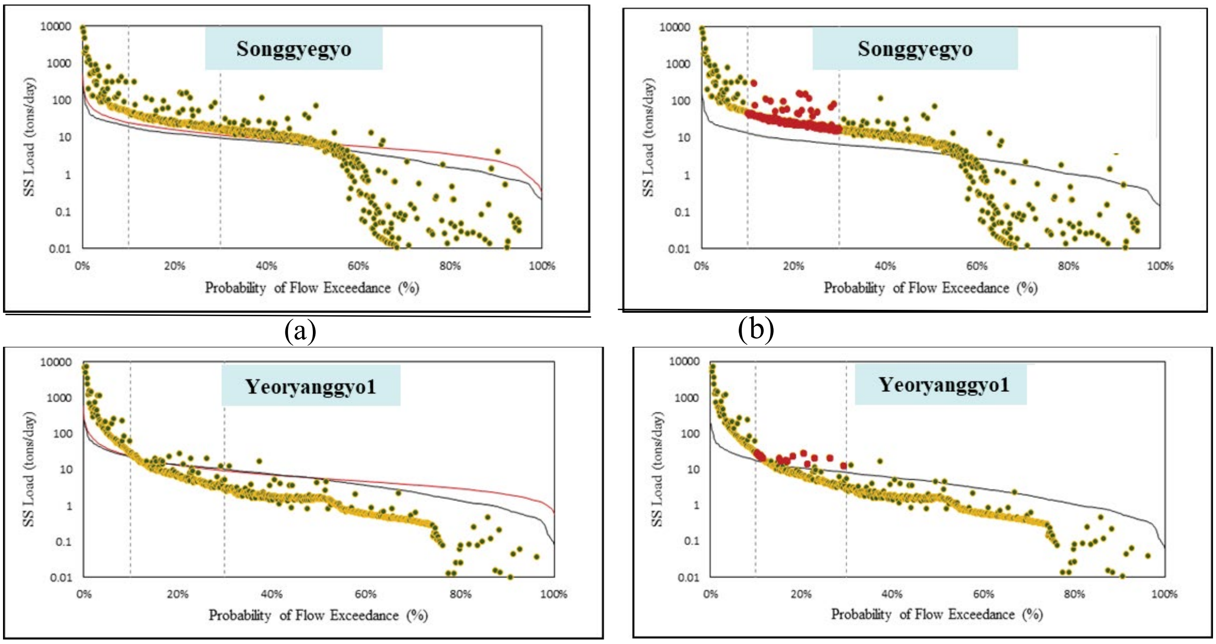
showed a decrease in the accumulated precipitation for the last 2 y (2017–2018) in comparison with the implementation plan. Therefore, the management flow section was lowered. In contrast, the Goljicheon watershed is a rural area mostly covered by alpine agricultural fields and forest. It was analyzed that this area was related to not only precipitation but also large hydraulic structures, which affect the coefficient of river regime indicating flow variability. Accordingly, the implementation plan needs to determine the management flow section by analyzing and considering annual precipitation, the coefficient of river regime, and other factors.

### *3.5. Optimal monitoring time for each target watershed*

To derive an optimal monitoring time, the daily flow data of the Saemangeum watershed (January 1, 2008–October 31, 2018) and those of Goljicheon for the last 10 y (2008–2018) were extracted by utilizing the results of models whose reproducibility was thoroughly examined. Then, the number of flows corresponding to the Saemangeum management section (5%–50%) and the Goljicheon management section (10%–30%) was analyzed on a monthly basis. As shown in Fig. 10, the Mangyeonggang watershed and the Dongjingang watershed showed a high frequency of management flow section from July to September and from April to September, respectively in Samangeum watershed. The frequency was especially high in May and June. This seems to reflect the use patterns of agricultural water in the watershed (Saemangeum Environmental Office, 2017). During the analysis period, the frequency of management flow was highest in Jeonjucheon 6 (695), and those of Mangyeongdaegyo, Gunpogyo, and Dongjindaegyo were similar (576, 564, and 590, respectively). Osan had 316 occurrences, which was lowest.

While the precipitation was concentrated, the water level in streams was high from April to October and low in the remaining months. Consequently, the rise of water level in each stream corresponded to the irrigation period. Therefore, rainfall monitoring time needs to be adjusted for some points of a rural area where regulating gates and drainage gates were influential.

In the Goljicheon watershed, both Songgyegyo and Yeoryanggyo 1, which are the target management points, showed a high frequency of management flow section in September. The frequency was generally high between August and October. The management flow section occurred most frequently in September at Songgyegyo and in March at Yeoryanggyo 1. The occurrences were analyzed to be concentrated between July and September at Songgyegyo.



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

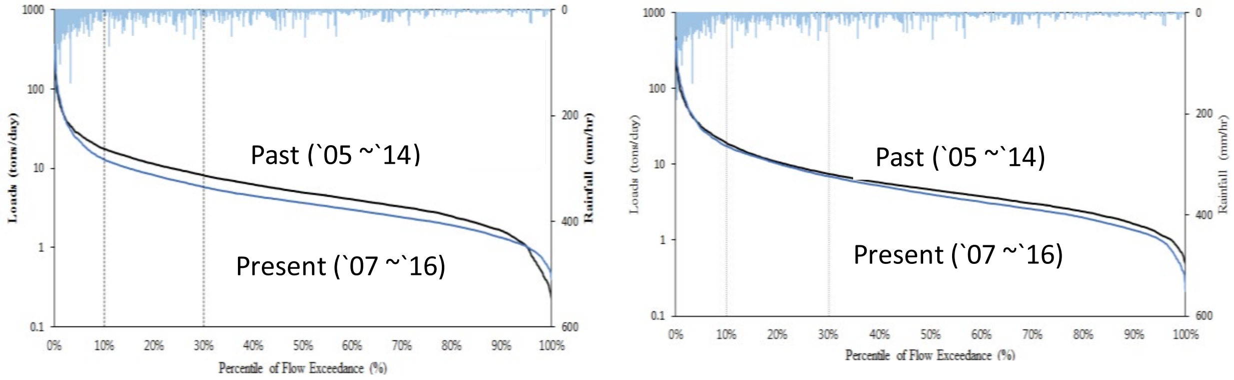
Fig. 8. Management target achievement assessment in the Goljicheon watershed (a) management target achievement assessment (2015–2017), (b) management target achievement evaluation (2016–2018), (c) management target achievement evaluation (2015–2017), and (d) management target achievement evaluation (2016–2018).

Table 6
LDC analysis results regarding the achievement of the management objectives in the management flow section (5%–50%)

| Classification | Target water quality (T–P) level (mg/L) | 2015–2017 | | 2016–2018 | |
|---|---|---|---|---|---|
| | | 75 percentile T–P level (mg/L) in the management discharge section | Percentage of load below LDC | 75 percentile T–P level (mg/L) in the management discharge section | Percentage of load below LDC |
| Jeonjucheon 6 | 0.086 | 0.148 | 22% (not achieved) | 0.125 | 38% (not achieved) |
| Osan | 0.101 | 0.160 | 21% (not achieved) | 0.139 | 31% (not achieved) |
| Mangyeongdaegyo | 0.102 | 0.134 | 39% (not achieved) | 0.125 | 46% (not achieved) |
| Gunpogyo | 0.075 | 0.109 | 21% (not achieved) | 0.119 | 3% (not achieved) |
| Dongjindaegyo | 0.080 | 0.097 | 50% (not achieved) | 0.105 | 27% (not achieved) |

Table 7
LDC analysis results regarding the achievement of the management objectives in the management flow section (10%–30%)

| Point | Target water quality (SS) level (mg/L) | 2015–2017 | | 2016–2018 | |
|---|---|---|---|---|---|
| | | 90 percentile SS level (mg/L) in the management flow section | Percentage of load below LDC | 90 percentile SS level (mg/L) in the management flow section | Percentage of load below LDC |
| Songgyegyo | 22.6 | 143.6 | 0% (not achieved) | 162.2 | 0% (not achieved) |
| Yeoryanggyo1 | 8.7 | 8.4 | 91% (achieved) | 12.5 | 68% (not achieved) |

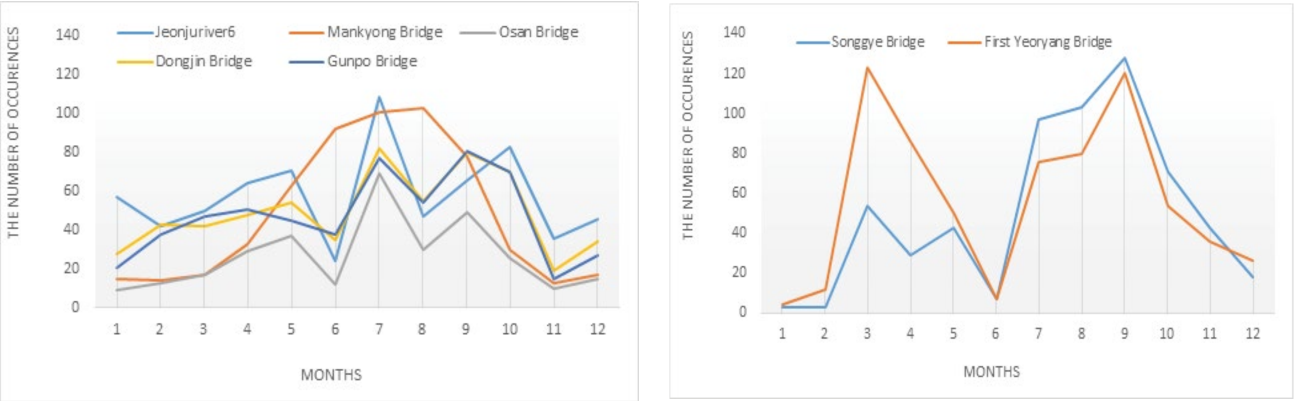


(a) (b)

Fig. 9. Analysis of management discharge sections in the Goljicheon watershed (a) management flow section at Songgyegyo and (b) management flow section at Yeoryanggyo 1.

In the case of Yeoryanggyo 1, the occurrences were concentrated between March and April and between August and September. At Songgyegyo, the management flow occurred 328 times between July and September, which accounted for 54.8% of the annual total occurrences. During the same period (July–September), the occurrences of target flow at Yeoryanggyo accounted for approximately 40.9% of the annual total occurrences. Consequently, based on the analysis results of the past flow duration and precipitation data, if the precipitation reaches approximately 10.0 mm between July and September, the observation probability of the target flow would be highest at both the points.

As for the monitoring interval, the modeling data were analyzed to identify an appropriate sampling interval in a rainfall event. As for the sampling interval, data were extracted at an equal interval such as 1, 2, 3, and 4 h during the load peak period. After the average loads were calculated for each interval, relative errors were compared. The 1 h interval rainfall monitoring result was assumed to be true, and the relative errors to the average loads of the remaining time interval data were evaluated. As the interval increased, the deviation of the relative error increased in each rainfall event. The maximum deviation of the relative errors in each rainfall event was less than 5%. As the interval decreased, the deviation decreased and the monitoring result became more accurate. If the water samples for nonpoint source monitoring are collected at an equal interval less than 1 h, the influence of a nonpoint source could be easily analyzed.



(a) (b)

Fig. 10. Analysis of monitoring time (a) Saemangeum watershed and (b) Goljicheon watershed.

Table 8
Change of management flow section in the Goljicheon watershed

| Point | 2008–2013 (implementation plan) | 2015–2017 | 2016–2018 |
|---|---|---|---|
| Jeonjucheon 6 | 5.85–25.52 | 5.82–14.14 | 5.86–19.35 |
| Osan | 20.12–91.72 | 13.47–43.65 | 12.65–53.83 |
| Mangyeongdaegyo | 22.63–114.37 | 20.05–56.33 | 18.30–70.55 |
| Gunpogyo | 8.08–45.67 | 7.01–24.21 | 5.80–27.51 |
| Dongjindaegyo | 10.36–58.50 | 9.39–31.19 | 7.84–39.55 |

Table 9
Change of management flow section in the Goljicheon watershed

| Classification | 2007–2016 (last 10 y) | | 2005–2014 (implementation plan) | |
|---|---|---|---|---|
| | Management discharge range (10%–30%) | Average management discharge | Management discharge range (10%–30%) | Average management discharge |
| Critical watermark (Songgyegyo) | 2.973–6.654 ($m^3/s$) | 4.385 ($m^3/s$) | 4.191–9.005 ($m^3/s$) | 6.088 ($m^3/s$) |
| Goljicheon 2 (Yeoryanggyo 1) | 9.316–23.192 ($m^3/s$) | 14.416 ($m^3/s$) | 9.996–25.372 ($m^3/s$) | 15.357 ($m^3/s$) |

## 4. Conclusions

This study evaluated the achievement of management objectives of each watershed, which are presented by the implementation plans, and examined the methods of monitoring and evaluating the management objectives by updating monitoring data and models for the Saemangeum and Goljicheon watersheds, which are nonpoint source management areas as of the year 2018.

According to monitoring results, results of rainfall monitoring in the Saemangeum watershed were the highest at the point of obscurity, with T–P EMC 1.958 mg/L. The results of rainfall monitoring in the Goljicheon watershed were the highest at SS EMC 4,682.0 mg/L on Taebonggyo 2.

After the Saemangeum watershed model was expanded and updated as of 2018, the calibration results for the flow and water quality showed that the model efficiency (%difference) could be rated between "very good" and "fair." This indicated that the modeling results adequately reflected the measurements. Based on the daily flow and T–P data of models, two 3 y periods (2015–2017 and 2016–2018) were distinguished and the achievement of objectives in 2 consecutive years for each period was checked. The T–P load of each point was evaluated to be 75% and below in both periods. Thus, the objective was not achieved. As there was a difference between the implementation plan and the precipitations of the recent years, the management flow section was different from the implementation plan. Accordingly, if the error between the implementation plan and the flow section is analyzed for evaluating the management objective and the error is observed to be relatively high, a standard for nonpoint high flow section needs to be established for assessing the achievement of the objective.

Furthermore, the monitoring results for the lower stream points such as Osan, Mangyeongdaegyo, Gunpogyo, and Dongjindaegyo did not show any clear change of water quality. Although these points were management objective points affected by nonpoint sources, the agricultural fields and floral zones in the watershed produced a buffer effect and the regulating gates were operated. Accordingly, in case an area is mostly covered by agricultural fields and irrigation facilities, the nonpoint source monitoring needs to select management points for evaluating the management objectives. If the management points thus selected are affected by regulating gates, an additional survey of the precipitation and flood level should be performed. In other words, the monitoring should be planned by considering a management flow section and a long-term monitoring period.

For the Goljicheon watershed, the existing HSPF model was expanded and updated by using the latest data collected until 2018. The achievement of LDC objectives for the target water quality level was analyzed by deriving the LDCs of nonpoint source management areas. Songgyegyo 100% exceeded the section of management flow duration (10%–30%) both in the first (2015–2017) and second (2016–2018) periods. In contrast, Yeoryanggyo 1 had the 90th percentile concentration of 8.4 mg/L in the management flow section at the first period (2015–2017). This result satisfied the target water quality level. However, the 90th percentile concentration in the second period (2016–2018) was 12.5 mg/L, which failed the target water quality level.

The rainfall monitoring results for the Goljicheon watershed, which is a typical rural area, showed that the EMC of SS item was significantly different depending on both precipitation and agricultural or other human activities in the upper region. In particular, the maximum rainfall intensity, antecedent dry days, and agricultural activity were remarkably influential.

Accordingly, to reduce nonpoint sources and achieve the target water levels in the Goljicheon watershed, which is a rural area, an additional rainfall analysis for decreasing the regional difference caused by local heavy rainfall needs to be conducted. Moreover, an additional monitoring plan that reflects agricultural activities in a particular period and other human activities including stream maintenance works needs to be established.

This study updated the monitoring results and models for two distinct areas and also evaluated the achievement of the management objectives. Depending on the current situations of each area, the monitoring results showed some limitations. Especially, the management flow section was different from the implementation plan according to the precipitation and water level. The monitoring results of agricultural areas were significantly different depending on the regulating gates, agricultural activities, and local heavy rainfall events. Thus, to assess the achievement of the management objectives, the error range between the management flow section and the implementation plan needs to be set, and if a result exceeds the error range, the management objective needs to be adjusted. Moreover, a monitoring plan needs to be established by considering regional development plans, agricultural activities, and the operation of regulating gates.

If the above factors are considered, the achievement of objectives for management areas and the impacts of nonpoint sources in an urban-rural area or a rural area will be analyzed more clearly.

## Acknowledgments

This study was conducted based on the monitoring data of nonpoint source management areas and the survey results of runoff loads (I, II National Institute of Environmental Research, 2017–2018).

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