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Predicting the effect of impervious area change on water circulation rate in the Geum River watershed using HSPF modeling

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ABSTRACT

Rapid urbanization in recent years has increased the area of impervious surfaces in South Korea. Increasing impervious areas increases the direct runoff when rain falls, which adversely affects the health of watersheds through increased pollution from nonpoint source pollutants. However, few studies have investigated the relationship between hydrological phenomena in broad watersheds and nonpoint sources of pollution. In this study, a watershed model to simulate the flow and water quality of rivers, with different impervious area coverages, was developed using the Hydrological Simulation Program – Fortran. The effect of different impervious area reduction scenarios on direct runoff and loading of nonpoint source pollution in the Geum River watershed, South Korea, was analyzed and the water circulation rate was used as a proxy for the health of the watershed. The impervious area coverage in the medium influence area of Gapcheon, where Daejeon Metropolitan and Sejong Cities are located, was 23.17%, approximately two times higher than that of other areas. Based on the impervious area reduction scenarios, the direct runoff, and a load of nonpoint source pollution showed maximum reductions of 51% and 41%, respectively. The water circulation rate showed a maximum improvement of 21%. Realistically, it is impossible to reduce the impervious area rapidly in regions with high proportions of urban development or built-up land. Therefore, low-impact development methods should be applied when conducting the development of public facilities or projects larger than a certain size.

Keywords: Impervious area; Nonpoint source pollution; HSPF watershed model; Direct runoff; Water circulation rate

1. Introduction

The impervious area of South Korea, that which rainwater cannot infiltrate, more than doubled from 3% to 7.9% between 1970 and 2012. Increasing the impervious surface area increases the direct surface runoff during rainfall events and a load of nonpoint source pollutants entering water bodies, thereby threatening the water quality of rivers and the health of the aquatic ecosystem [1–3].

In South Korea, a water circulation distortion problem, caused by an increase in the impervious surface area, has appeared in both urban and rural regions. Therefore, impervious area reduction plans should be implemented to resolve the water circulation distortion problem and maintain a healthy aquatic environment [4]. An increase in the impervious area leads to a reduction in soil infiltration and baseflow, which, distorts the healthy water circulation system. Furthermore, an increase in surface runoff leads to increased loading of nonpoint source pollutants to water bodies, thereby degrading water quality. Hence, the Ministry of Environment has set mid and long-term water circulation management goals to restore the healthy water

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circulation system and prevent nonpoint source pollution. To reflect and manage this in the comprehensive plan for nonpoint source pollution management, the Aquatic Environment Conservation Act was revised. Article 53(5) of the Aquatic Environment Conservation Act was revised in September 2018 so that the impervious area and water circulation management goals for the city, province, and small influence areas are set by the Minister of Environment and evaluated when comprehensive plans are established for nonpoint sources; this revision will come into force in September 2019 [5].

A range of studies have considered water circulation and impervious area in relation to the health of a watershed [6] expressed the health of a watershed using an index based on the impervious area; when the impervious area of a watershed was more than 8%–10%, the health of the watershed was classified as "below average," and when 25% or higher, the health was classified as "bad." Considering watersheds in South Korea, a study investigated the total maximum daily load (TMDL) for the Han River system and found that good water quality was not achieved in small watersheds with an impervious area between 10% and 25% [7,8] analyzed the effect of changes to the impervious surface area, due to seashore basin development, on the water quality of 14 basins in Apalachicola Bay, Florida, USA; this demonstrated that as the impervious area increased, pH, N and S series, total phosphorus (TP), and *E. coli* increased [9]. Noted that an increase in impervious area, due to urban development, had no significant relationship with the average concentration of dissolved oxygen in surface river water, but had a significant relationship with the average dissolved oxygen concentration at the river bottom. Where studies have used a watershed model [10], analyzed the nonpoint source pollution reduction effect in farm fields in watersheds by applying a rice straw ground cover scenario to a Hydrological Simulation Program – Fortran (HSPF) model by targeting small watersheds of agricultural regions [11] simulated the runoff characteristics according to the past and present land-use changes in the Gwynns Falls watershed, Maryland, USA using an HSPF model [12] used the SWAT model to evaluate changes in hydrological (precipitation, melting of snow, ground surface runoff, evapotranspiration, and river runoff) and water quality factors (sediment discharge, total nitrogen, and TP) of the watershed according to climate change and land-use change scenarios.

In South Korea, with increasing interest in the effect changes of impervious surfaces on water quality, monitoring has been undertaken to aid research. However, monitoring alone is not sufficient and the majority of studies considering the impervious area of watersheds are based on statistical modeling using monitoring data. Where watershed models have been used, the majority of studies have focused on changes in flow over impervious areas; few studies have considered the causal relationship between water quality and nonpoint source pollution. Appropriate hydrological water quality models, using appropriate watershed characteristics, are required to quantitatively analyze complex hydrological phenomena and the occurrence and discharge of nonpoint pollution sources to develop effective reduction plans.

This study aims to examine the effect of land-use change on the flow and quality of water in the Geum River watershed in South Korea by applying an HSPF watershed model. A subsequent aim is to analyze the current state of the watershed and the improvement in watershed health by deriving the water circulation and changes in the direct runoff and load of nonpoint source pollution based on an impervious area reduction scenario.

2. Material and methods

2.1. Study area

This study was conducted in the Geum River watershed in South Korea, which includes Daejeon Metropolitan City. The total watershed area is 9,914 km^2 and consists of 14 medium influence areas and 78 small influence areas. The river length is 3,720.13 km with a channel length of 397.79 km and consists of seven national rivers and 461 local rivers. Two multipurpose dams (Yongdam and Daecheong dam) and three weirs (Sejong Weir, Gongju Weir, and Backje Weir) are in operation as a result of the Major River Project in 2012. The average annual rainfall across 12 major meteorological stations (e.g., Boeun, Buyeo, Cheongju, Chungju, Chupungnyeong, Cheonan, Daejeon, Gunsan, Gongju, Geumsan, Jangsu, and Jeonju) is 1,047.4 mm and the medium influence areas the Yongdam dam area has the largest average rainfall of 1,200.9 mm. The medium influence area of Mihocheon (Miho Stream) shows the lowest rainfall value of 896.2 mm [13]. The land-use status shows that the total area of the watershed is about 17,582 km^2 (2014), forests occupying the largest area (53.3%), followed by paddy fields (18.6%), farm fields (9.1%), urban or built-up land (9.0%), and other land-uses (10.0%) [14]. In the past 5 y, the proportion of forests, paddy fields, and farm fields has been decreasing, and the proportion of urban or built-up land has been increasing.

The study area, the Geum River watershed map of South Korea, is illustrated in Fig. 1 and the watershed status of the medium influence areas are shown in Table 1.

2.2. Impervious area and water circulation rate calculation methods

Water circulation management indices have been previously defined using impervious area and water circulation rates [15]. The Aquatic Environment Conservation Act [5], revised in August 2018, also defined the water circulation management indices in the same way. The method to calculate the water circulation management indices used in the [15] study is described here for detail. The land registration map, land-use zoning map, and seamless digital map were used to calculate the impervious area coverage using Eq. (1).

$$\text{Impervious area coverage} = \left(\frac{\text{Impervious area}}{\text{Total area}}\right) \times 100 \quad (1)$$

The water circulation rate was calculated by classifying the single event rainfall condition and the long-term event rainfall condition, respectively. In this way, a local government

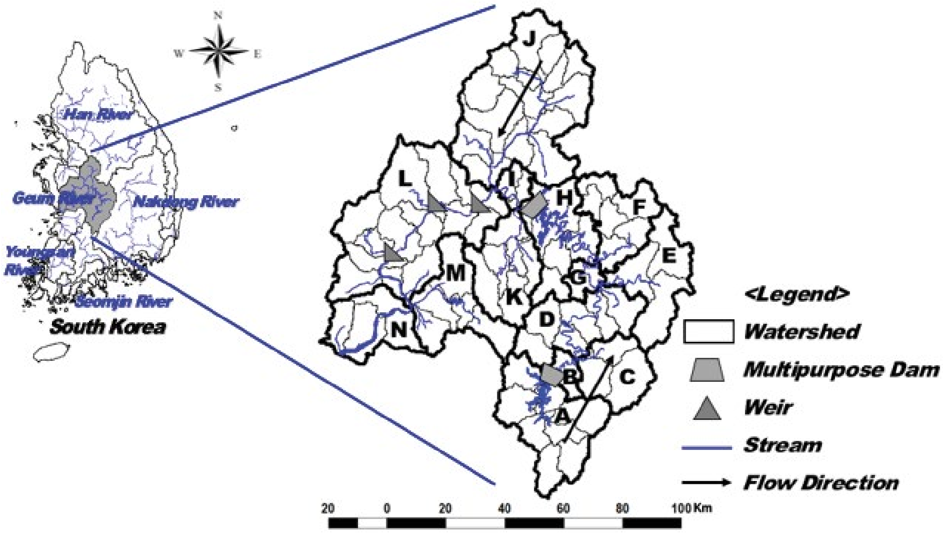


Fig. 1. Study area (Geum River watershed).

Table 1
Current status of Geum River watersheds

Water shed	Medium influence area	Watershed area (km²)	Number of small influence areas	Water shed	Medium influence area	Watershed area (km²)	Number of small influence areas
A	Yongdam dam	930	8	H	Daecheong dam	667	5
B	Downstream of Yongdam dam	128	1	I	Downstream of Daecheong dam	130	2
C	Muju namdaecheon	464	3	J	Mihocheon	1,855	15
D	Yeongdong cheon	706	6	K	Gapcheon	649	6
E	Chogang	665	3	L	Geumriver Gongju	1,844	14
F	Bocheong cheon	554	6	M	Nonsancheon	666	5
G	Upstream of Daecheong dam	120	1	N	Geumriver estuary dam	537	3

will not need to use a complex watershed model with large time and cost requirements when evaluating water circulation management performance in the future. The water circulation rate at the single event rainfall condition was calculated as follows: the direct runoff from the watershed was calculated using the Natural Resources Conservation Service (NRCS)–Curve Number (CN) method [16], and after dividing it by total precipitation, the direct runoff was calculated and subtracted from 1.

$$S(\text{mm}) = \frac{25,400}{\text{CN}} - 254 \quad (2)$$

where the potential maximum retention (S) is the amount of water that can be maximally retained in the watershed and refers to the infiltration and storage capability; and CN is the runoff curve number.

$$Q(\text{mm}) = \frac{\left(p - (0.2 \times S)\right)^2}{p + (0.8 \times S)} \quad (3)$$

where Q is the direct runoff and p is the total precipitation (mm).

For the long-term rainfall event condition, the annual direct runoff model (Eq. 4) is used when calculating the direct runoff in the same process.

$$Q_f\left(m^3\right) = \sum_{i=1}^{n}\left(Q_{\text{land category } i} \times A_{\text{land category } i}\right) \quad (4)$$

$$R_f = \frac{Q_f}{P \times A} \quad (5)$$

where Q_f is the direct runoff, $Q_{\text{land category},i}$ is the direct runoff by land category × 10^{-3} (m), $A_{\text{land category},i}$ is the area by land category (m²), and A is the total area of the target region (m²).

Finally, the water circulation rate calculation method is shown in Eq. (6):

$$\text{Water circulation rate } (\%) = \left(1 - R_f\right) \times 100 \quad (6)$$

2.3. Construction of the watershed model

The HSPF watershed model was selected because it can be used to investigate the relationship between river water flow and quality in the watershed. Moreover, it is suitable to apply for urban and rural watersheds and a variety of impervious area reduction scenarios can be easily incorporated. The spatial information in the Geum River watershed model was constructed using the 78 small influence areas as the minimal unit. For input data, the land-use data [17] that reflected the latest impervious area information were used to construct the topography. Furthermore, the following watershed information was inputted in the model: the meteorological data of 12 meteorological stations located in the Geum River watershed, the point source pollution of national discharged loads (domestic life, livestock, and land types) in 2013–2017 and discharge of basic environmental facilities, water quality information, and water intake data (Table 2).

The simulation was performed by selecting T–P water quality as a simulation factor, which can show the flow of the river and nonpoint source pollution runoff characteristics of urban areas better than other factors. T–P is a representative non-point source, and the target water quality exists in medium influence areas [22]. The results of this study are also referred to as significant influences according to the proportion of land area [23]. The direct runoff flowing into the river and the T–P nonpoint source pollution loads were simulated in each watershed unit.

To increase the accuracy of predictions in the simulation model, calibration, and validation (calibration period: 5 y, validation period: 5 y) were performed by adjusting the parameters for flow and water quality. The accuracy assessment of calibration and validation was performed by using the average relative error (percentage difference) of simulation values and observation values and the standards presented by [24] were applied (Table 3). To improve the accuracy of model predictions, the calibration, and validation were performed by selecting parameters that could adjust the river water quality and flow, and affect the total runoff, ground surface runoff, and baseflow.

2.4. Analysis of water circulation and water quality improvements

The impervious area reduction scenarios were applied based on the analysis of water circulation and nonpoint source pollution management in each small influence area. For each scenario, river flow and pollution load changes were simulated using the average annual direct runoff, nonpoint source pollution load reduction effect, flow duration curve (FDC), and load duration curve (LDC) of each watershed based on 10 y simulations.

Six scenarios (Table 4) were constructed; scenario S-1 was based on the current impervious area-watershed health state of each watershed, while scenarios S-2–S-6

Table 3
Range of percentage differences (absolute value) used to classify the reliability of each model constituent

Constituent	Very good	Good	Fair
Hydrology/flow	<10	10–15	15–25
Water quality/nutrients	<15	15–25	25–35

Table 2
Status of input data for construction of the watershed model

Data	Analysis items	Scale	Reference
DEM	Digital elevation model; 30 m × 30 m	1:5,000	National Geographic Information Institute [18]
Land-use	Land cover classification (urban, agriculture, forest, pasture, water, wetland, and barren land)	1:25,000	K-ECO [17]
Weather data	Rainfall, average temperature, dew point, solar radiation, wind speed, etc. (16 items)	Hourly (2008–2017)	Korea Meteorological Administration [19]
Hydrological	Discharge Flow: Dams (Yongdam, Daecheong) and weirs (Sejong, Gongju, Baekje); Automatic and water environment network	8 d/month (2008–2017)	WAMIS [20]*/Water Environment Information System [21]
Water quality	Water environment network (T–P)	8 d/ month (2008–2017)	Water Environment Information System
Environmental foundational facilities	Flow, biochemical oxygen demand (BOD), concentration of total ammonia (TAM), NO_3, organic nitrogen (ORN), PO_4, and organic phosphorus (ORP)	Daily (2008–2017)	NIER*
Pollutant loads	BOD, TAM, NO_3, ORN, PO_4, ORP	Daily (2013–2017)	NIER*
Administration boundary	Catchment basin map	–	MOE*

*WAMIS stands for water resources management information system.
*NIER stands for National Institute of Environmental Research.
*MOE stands for Ministry of Environment.

Table 4
Impervious area reduction scenarios

Scenario	Scenarios information
S-1	The current impervious area state
S-2	The impervious area state considering natural increases and developments up to 2025 (including national projects)
S-3	The impervious areas of small influence areas are all fixed at 35% when higher than 35%
S-4	The impervious areas of small influence areas are all fixed at 25% when higher than 25%
S-5	The impervious areas of small influence areas are all fixed at 15% when higher than 15%
S-6	The impervious areas of small influence areas are all fixed at 5% when higher than 5%

relate to the impervious area-watershed health state indices reported by an existing study [25,26] is an impervious surface of the entire watershed, based on the model developed impervious surface within at least 8%–10%, and development focus areas are recommended to keep within 25% [6]. A presented impervious area in the study was based on watershed health indicators. The watershed was composed of six types: 5% representing the good state, 15% representing the normal state, 25% the boundary of transition to the bad state, and 35% the bad state.

3. Results and discussion

3.1. Watershed model construction

When the HSPF model was constructed, because of block generation limitations, the small influence areas were largely conflated into (a) the Yongdam dam watershed (8 areas), (b) the upstream watershed of the Daecheong dam (20 areas), and (c) the downstream watershed of the Daecheong dam (50 areas). The flow and water quality were then linked using the LINK method in the HSPF model. Fig. 2 shows the HSPF watershed extraction results after watershed construction.

After constructing the model, calibration and validation were conducted. The factors that had a relatively large impact on the flow simulation of HSPF included pervious land segment, module's LZSN, INFILT, AGWRC, DEEPER, INTFW, and IRC (Table 5). The parameters that most affected the water quality simulation were KBOD20, KODSET, KNO220, CVBPC, and CVBPN (Table 5). As shown in Fig. 3, parameter calibration and validation were performed by comparing the simulation values and observation values.

The results of the flow and the water quality (T–P) simulations (Fig. 3) all indicate that the parameters were appropriately calibrated and validated since the percentage error

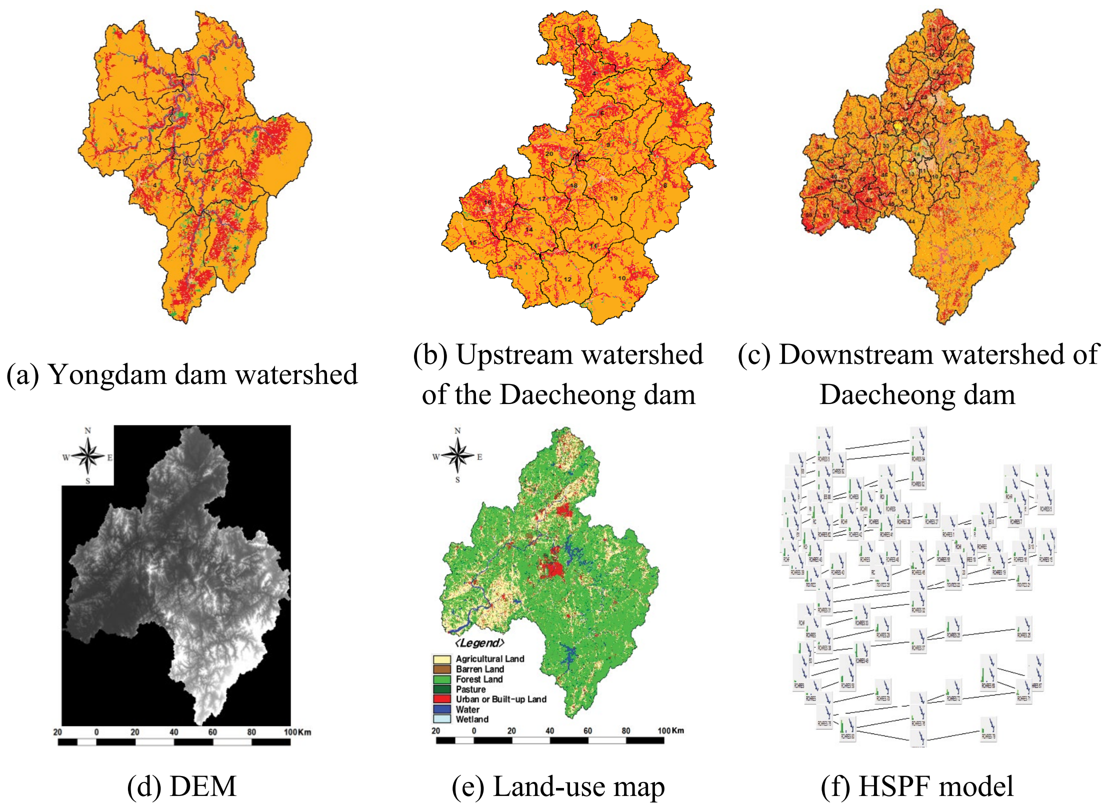


Fig. 2. HSPF model input data and construction results.

Table 5
Major parameters related to flow and water quality in the HSPF model

	Parameter	Description	Unit	Model range	This study
Flow	LZSN	Lower zone nominal soil moisture storage	In	0.01–100	4.0–6.5
	INFILT	Index to infiltration capacity	In/h	0.0001–100	0.15–0.5
	AGWRC	Base groundwater recession	None	0.001–0.999	0.91–0.98
	DEEPER	Fraction of GW inflow to deep recharge	None	0.0–1.0	0.001–0.8
	INTFW	Interflow inflow parameter	None	0.0–none	0.75–10
	IRC	Interflow recession parameter	None	0.1–30.0	0.3–0.85
Water quality	KBOD20	Unit BOD decay rate at 20°C	1/h	0–none	0.004
	KODSET	BOD settling rate	Ft/h	0–none	0.027
	KNO220	Nitrification rates of nitrate at 20°C	1/h	0.001–none	0.002
	CVBPC	Conversion from biomass expressed as phosphorus to carbon	moles/mol	50–200	106
	CVBPN	Conversion from biomass expressed as phosphorus to nitrogen	moles/mol	10–50	16

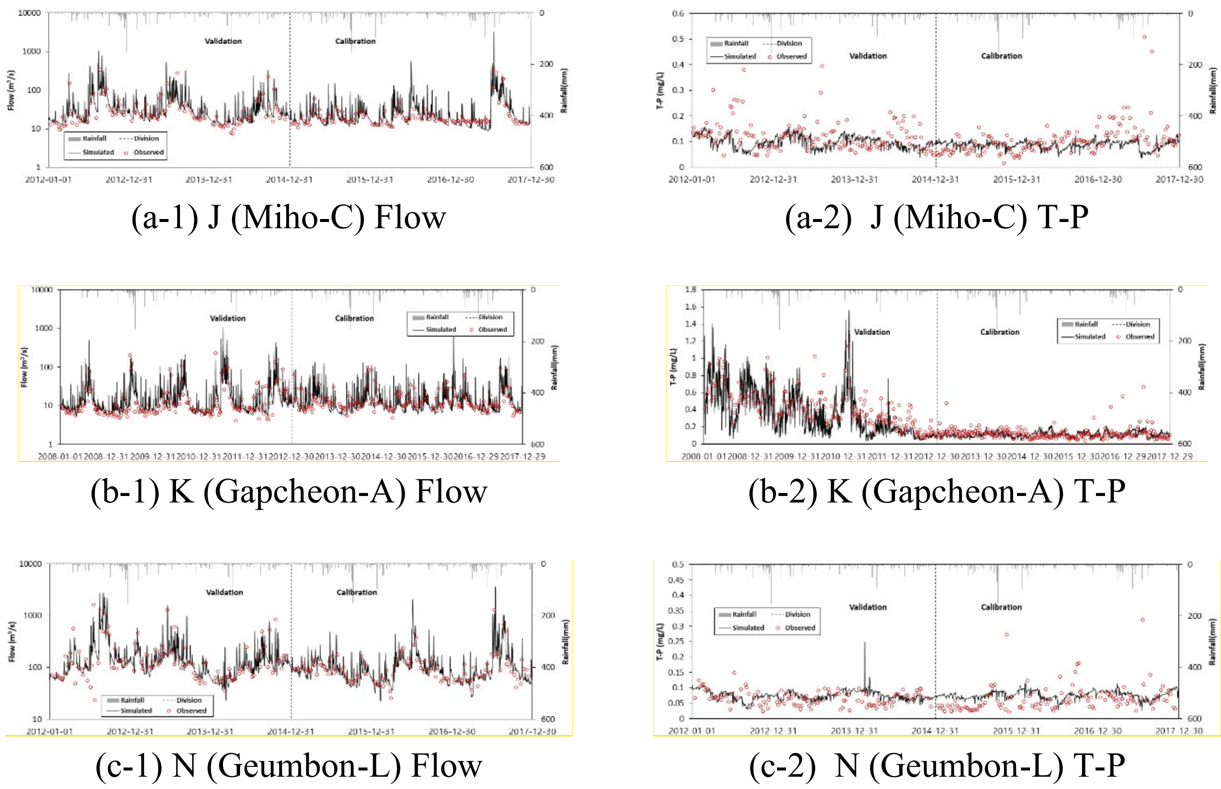


Fig. 3. Comparison of HSPF simulated values and observed values at major medium influence areas (2008–2017).

fell within the fair and very good ranges based on the average relative error proposed by [24] (Table 6). Furthermore, it was determined that the applicability of the model was high because the simulated values estimated the observed values appropriately, as shown in Table 6.

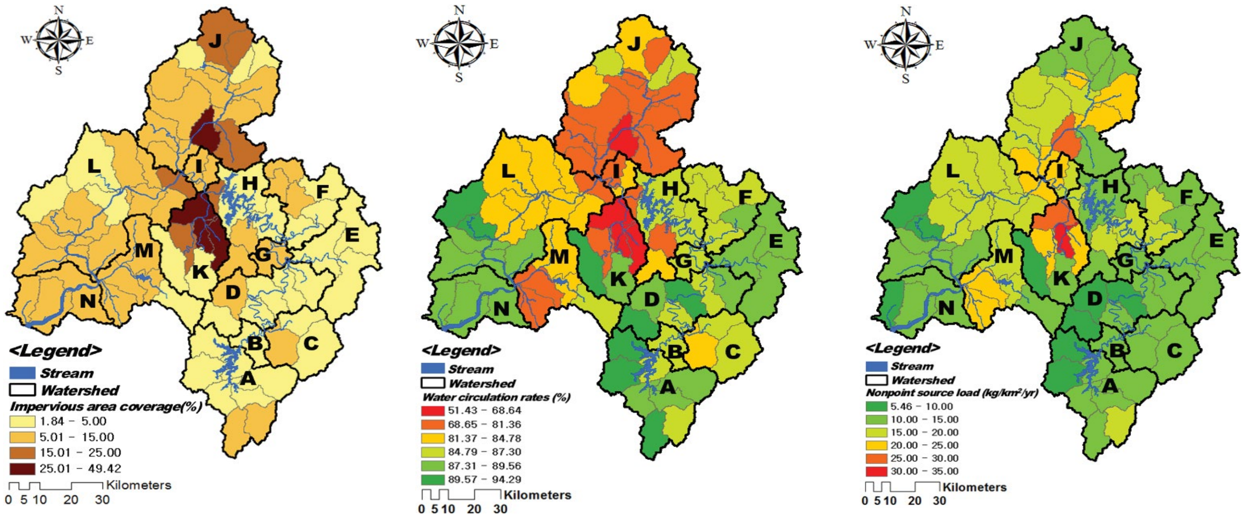
3.2. Assessment of watershed water circulation and nonpoint source pollution load

Runoff scenarios were constructed according to changes in the impervious area coverage in the Geum River watershed. The long-term water circulation rate (%) was determined using 10 y rainfall conditions and 10 y average nonpoint source pollution load per unit area (kg/km^2/y) for each medium influence area using the impervious area coverage of [17].

Fig. 4 and Table 7 show the current (2017) impervious area, nonpoint source pollution load, and water circulation rate of the watershed by using the impervious area coverage [17] used as input to the HSPF model. The analysis was conducted by combining medium influence areas A–I as a single upstream watershed of Daecheong dam, since the health of these areas was high. The average impervious area coverage across the Geum River watersheds

Table 6
Validation and calibration results

Medium influence area	Section	Period		Analysis items	Flow (m^3/s)		T–P (mg/L)	
		Calibration	Validation					
				Observation	7.29	4.02	0.04	0.03
A–I	Bocheong-A	`12–`14	`15–`17	Simulation	7.27	4.47	0.03	0.03
				Percentage difference	0.18 (very good)	–11.24 (good)	15.23 (good)	–0.07 (very good)
				Observation	37.91	28.31	0.12	0.11
J	Miho-C	`12–`14	`15–`17	Simulation	41.34	31.81	0.10	0.09
				Percentage difference	–9.05 (very good)	–12.37 (good)	18.74 (good)	18.87 (good)
				Observation	19.07	15.64	0.42	0.12
K	Gapcheon-A	`08–`12	`13–`17	Simulation	18.12	16.47	0.36	0.11
				Percentage difference	4.99 (very good)	–5.32 (very good)	13.98 (very good)	7.02 (very good)
				Observation	110.70	74.20	0.09	0.08
L	Geumbon-H	`12–`14	`15–`17	Simulation	121.79	77.99	0.07	0.08
				Percentage difference	–10.02 (good)	–5.11 (very good)	19.87 (good)	3.11 (very good)
				Observation	12.91	8.22	0.14	0.12
M	Nonsan-A	`12–`14	`15–`17	Simulation	11.78	7.95	0.11	0.15
				Percentage difference	8.74 (very good)	3.30 (very good)	22.32 (good)	–24.16 (good)
				Observation	187.63	114.18	0.07	0.06
N	Geumbon-L	`12–`14	`15–`17	Simulation	180.53	113.44	0.08	0.08
				Percentage difference	3.79 (very good)	0.64 (very good)	–12.23 (very good)	–19.80 (good)



(a) Impervious area coverage(%) (b) Water circulation rates (%) (c) Nonpoint source pollution load(kg/km^2/yr)

Fig. 4. Water circulation and nonpoint source load status assessment results.

Table 7
Current water circulation and nonpoint source load status

Medium influence area	Impervious area coverage (%)	Water circulation rates (%)	Nonpoint source load (kg/km^2/y)
A	3.81	88.90	12.85
B	2.79	86.42	12.81
C	3.66	85.93	12.22
D	4.67	89.45	10.06
E	3.82	89.07	11.35
F	5.60	86.40	15.06
G	6.53	85.70	13.94
H	8.55	83.28	15.74
I	12.65	80.32	18.95
J	13.30	79.70	18.39
K	23.17	72.89	21.46
L	7.46	85.62	14.87
M	8.92	81.80	18.11
N	8.90	87.74	10.89

was 8.13%. Two medium influence areas had high impervious area coverage; area K, where Daejeon Metropolitan City and Sejong City are located, was 23.17% and that of the medium influence area J, where many industrial complexes are located, was 13.3%.

The nonpoint source pollution load was high downstream of Daecheong dam where the impervious area coverage was high compared to the area upstream of Daecheong dam where the infiltration rate was high. The nonpoint source pollution loads in medium influence area K (21.46 kg/km^2/y) and J (18.39 kg/km^2/y) were about 1.2 and 1.5 times higher than the watershed average (14.55 kg/km^2/y), respectively.

In medium influence area K, where the impervious area and the nonpoint source pollution load were high, the water circulation rate was less than 73% (Table 7), which was noticeably lower than the watershed average (85%). Medium influence area J, with the second-highest impervious area coverage, also low had a water circulation rate of 79%. Among medium influence areas A–I, area I, in which a green algae problem has recently been identified, had a water circulation rate of 80%, less than the watershed average. Among the downstream watersheds of Geum River, only medium influence area M had a water circulation rate (81%) below the watershed average.

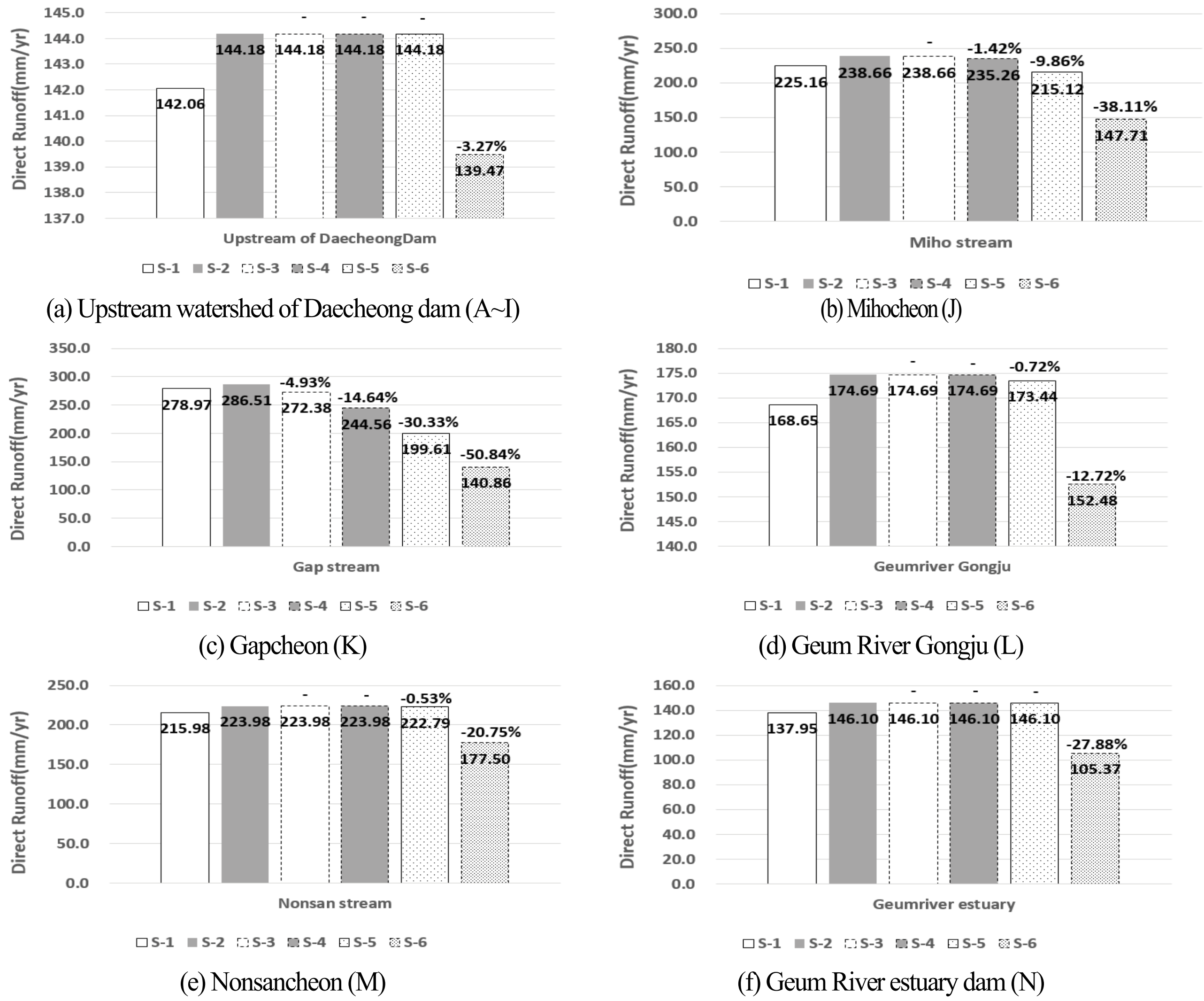
3.3. Water circulation and water quality improvement scenario analysis

3.3.1. Water circulation improvement effect

Improvements in water circulation and water quality for each major medium influence area were analyzed with the medium influence areas A–I combined, since the health of watershed was high at the upstream watershed of Daecheong dam (Table 7).

Fig. 5 shows the changes in direct runoff for each impervious area reduction scenario for medium influence areas A–I, J, K, L, M, and N. The medium influence area K had a high direct runoff, which had a large variability and changed greatly depending on the scenario. This is because this area (K) has a large number of small influence areas having impervious area coverage of over 25% (5%–49%, 22% average). The direct runoff in medium influence area K had maximum and minimum values of 286.51 and 140.86 mm/y, observed in S-2 and S-6, respectively, with a maximum reduction of 51% occurring in S-6. The medium influence area J, which had impervious area coverage from 3% to 27% (12% average), with the second-highest impervious area coverage, was largely unaffected by scenarios S-1, S-2, and S-3, and showed a maximum reduction of 38% in scenario S-6. At the upstream watershed of Daecheong dam, where the impervious area coverage was less than the watershed average (8.13%), the maximum reduction achieved was 3%, showing that the change of direct runoff was not large. In the medium influence areas L, M, and N, the reduction in direct runoff was less than 28% according to the scenario S-6.

Fig. 6 shows the changes to nonpoint source pollution load during each scenario. Similar to the direct runoff results, the highest reductions were achieved in the medium influence area K with minimum (12.58 kg/km^2/y) and maximum (20.26 kg/km^2/y) values achieved in scenario S-6 and S-2, respectively, giving a maximum reduction of 41% (S-6, Fig. 6). The medium influence area J showed a 22% reduction while areas A–I showed only a 2% reduction in nonpoint source load in scenario S-6.



(a) Upstream watershed of Daecheong dam (A~I)

(b) Mihocheon (J)

(c) Gapcheon (K)

(d) Geum River Gongju (L)

(e) Nonsancheon (M)

(f) Geum River estuary dam (N)

Fig. 5. Direct runoff (mm/y), for each scenario (S-1, 2, 3, 4, 5, 6) by medium influence area (A–I, J, K, L, M, and N).

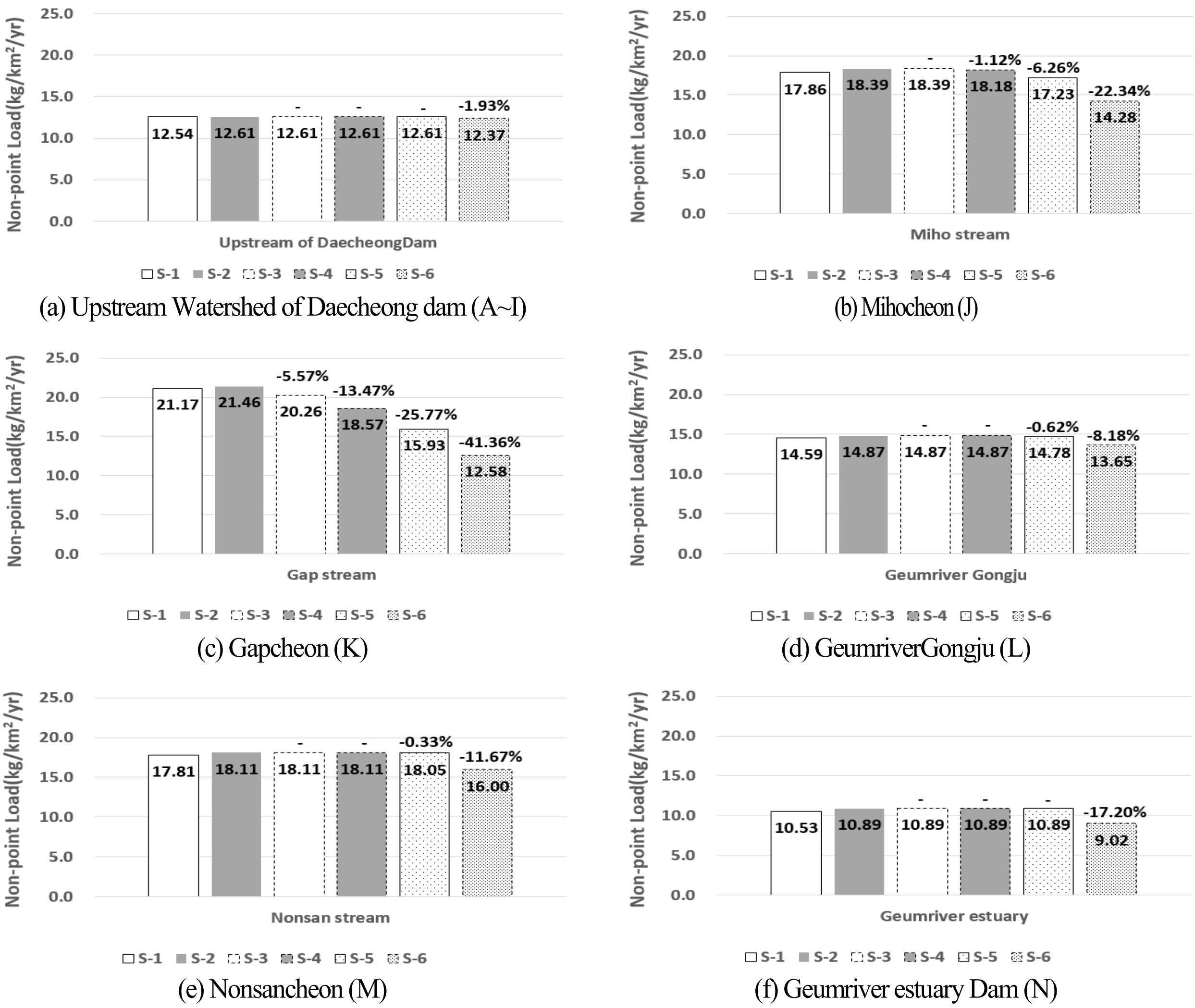


Fig. 6. Changes to nonpoint source pollution load (kg/km²/y) for each scenario (S-1, 2, 3, 4, 5, 6) by medium influence area (A–I, J, K, L, M, and N).

Fig. 7 shows the changes to the water circulation rate in each influence area, for each scenario. In comparison to the results of direct runoff (Fig. 5) and nonpoint source pollution load (Fig. 6), the water circulation rate improved as the direct runoff and nonpoint source pollution load decreased. At the medium influence area K, the initial (S-1) water circulation rate was 73% and the health of watershed was low; in scenario S-6, however, it increased to 88.36%, showing a maximum water circulation recovery of 21%. In the medium influence areas A–I, L, and N, where the initial water circulation rate was above the watershed average (85%), the water circulation recovery was somewhat low (1.66%, 2.51%, and 3.84% maximum, respectively).

3.3.2. Flow duration curve and load duration curve

The FDC and LDC methods were used to analyze the average flow changes and pollution load changes of the river by flow duration at major positions (A–I, J, K, L, M, and N) in the Geum River watershed, for each scenario. Fig. 8 and Table 8 show the average flow changes of the river at major positions by flow duration results determined using the FDC method. Relative to scenario S-2, scenarios S-3, 4, 5, and 6 all showed a decrease in average flow at each position during the wet period and rainy season, which were nonpoint source pollution influenced, and an increase in average river flow during the dry and drought seasons. In the medium influence area K, the flow decreased by ~27% during the rainy season and increased by ~16% during the dry season in the scenario S-6 compared to the scenario S-2.

Because the impervious area was changed to the pervious area in scenarios S-3 through S-6, the stormwater infiltrated into the ground during the rainy season and the wet period; consequently, the water that infiltrated into the ground flowed into the river slowly from the normal season to the dry season in a form of baseflow.

The average pollution load changes at major positions along the river were analyzed using the LDC method for respective flow durations, and the results are shown in Table 9.

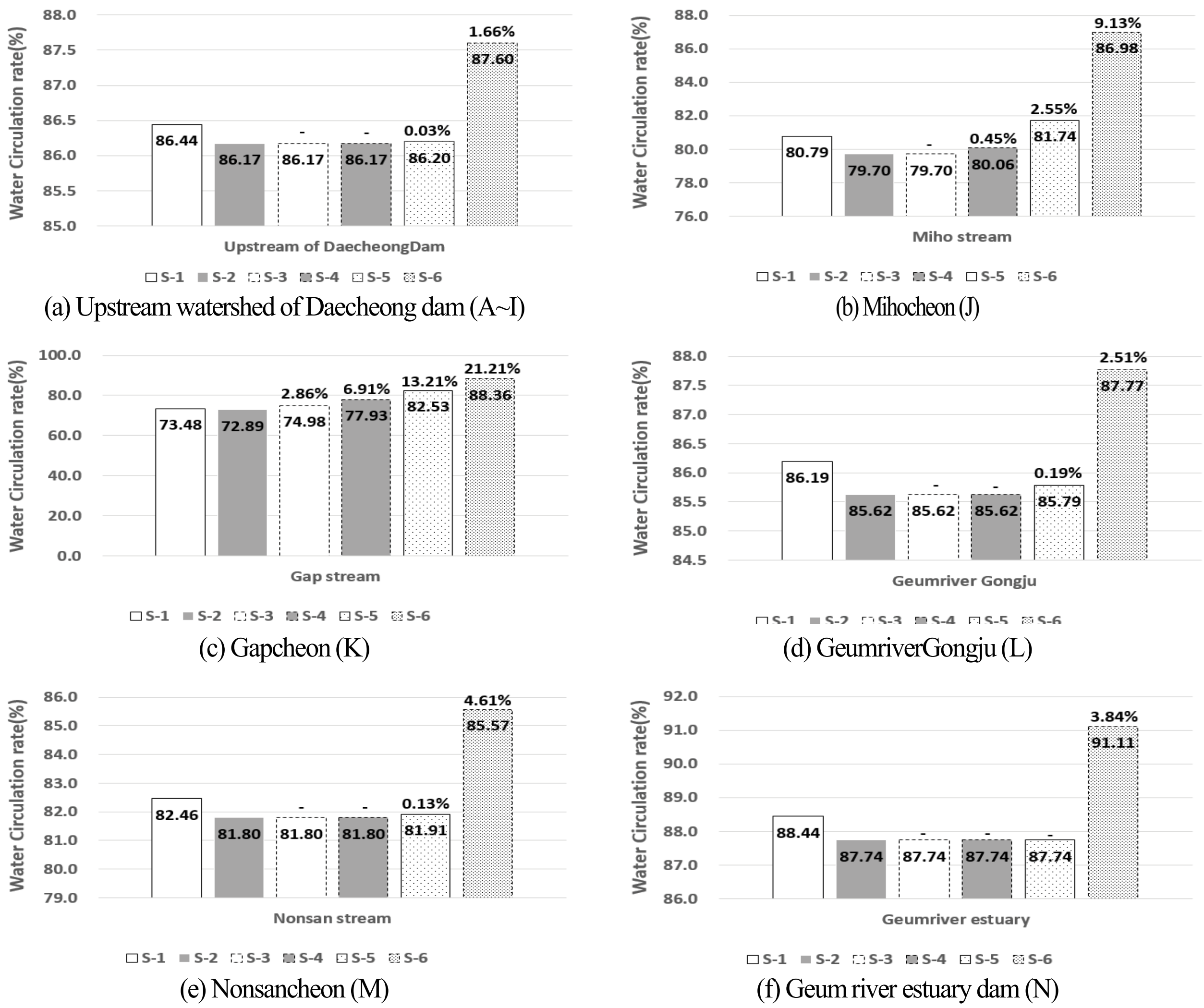


Fig. 7. Changes in water circulation rate (%) for each scenario (S-1, 2, 3, 4, 5, 6) by medium influence area (A–I, J, K, L, M, and N).

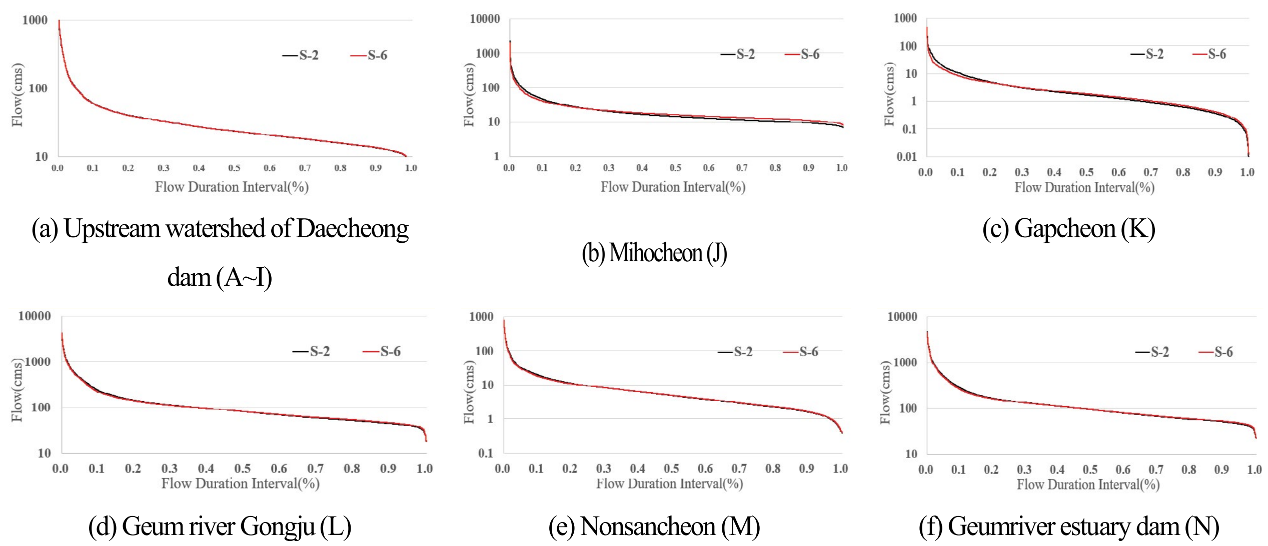


Fig. 8. Comparison of flow duration curves between scenarios S-2 and 6.

Table 8
Comparison of seasonal average flow (mm/y) from 2008 to 2017 for each impervious area scenario

Medium influence area	Scenario	Rainy season	Wet period	Normal season	Drought season	Dry season
A–I	S-1 (6.12%)	177.52	37.94	23.65	16.94	11.54
	S-2	177.96	38.01	23.65	16.93	11.53
	S-3	–	–	–	–	–
	S-4	–	–	–	–	–
	S-5	–	–	–	–	–
	S-6	176.45 (–0.85%)	37.84 (–0.46%)	23.69 (0.15%)	17.02 (0.50%)	11.64 (0.93%)
J	S-1 (26.68%)	121.96	25.21	14.64	11.21	8.62
	S-2	125.77	25.27	14.45	11.06	8.50
	S-3	–	–	–	–	–
	S-4	124.55 (–0.97%)	25.30 (0.11%)	14.53 (0.56%)	11.14 (0.71%)	8.56 (0.78%)
	S-5	117.40 (–6.66%)	25.34 (0.28%)	15.07 (4.28%)	11.67 (5.58%)	9.04 (6.43%)
	S-6	102.51 (–18.49%)	24.90 (–1.47%)	16.20 (12.08%)	12.85 (16.18%)	10.10 (18.86%)
K	S-1 (49.39%)	33.32	4.53	1.66	0.76	0.21
	S-2	33.39	4.53	1.66	0.76	0.21
	S-3	31.48 (–5.74%)	4.53 (0.0%)	1.71 (2.86%)	0.79 (3.08%)	0.22 (3.21%)
	S-4	29.85 (–10.6%)	4.51 (–0.39%)	1.75 (5.21%)	0.81 (5.63%)	0.22 (6.06%)
	S-5	26.89 (–19.46%)	4.42 (–2.44%)	1.81 (9.01%)	0.84 (10.46%)	0.24 (11.43%)
	S-6	24.32 (–27.15%)	4.23 (–6.55%)	1.84 (10.71%)	0.86 (13.13%)	0.25 (16.15%)
L	S-1 (6.17%)	643.84	134.91	81.52	55.99	39.10
	S-2	649.92	135.59	81.53	55.87	39.00
	S-3	648.76 (–0.18%)	135.43 (–0.12%)	81.52 (–0.01%)	55.87 (0.0%)	39.00 (0.01%)
	S-4	645.50 (–0.68%)	135.08 (–0.38%)	81.54 (0.02%)	55.95 (0.14%)	39.06 (0.14%)
	S-5	635.71 (–2.19%)	134.22 (–1.01%)	81.76 (0.29%)	56.42 (0.98%)	39.48 (1.22%)
	S-6	608.82 (–6.32%)	131.64 (–2.92%)	81.96 (0.53%)	57.59 (3.09%)	40.67 (4.29%)
M	S-1 (13.94%)	64.13	10.36	4.98	2.63	1.16
	S-2	65.10	10.42	4.96	2.62	1.15
	S-3	–	–	–	–	–
	S-4	–	–	–	–	–
	S-5	64.96 (–0.22%)	10.41 (–0.05%)	4.96 (0.05%)	2.62 (0.08%)	1.15 (0.08%)
	S-6	59.92 (–7.96%)	10.11 (–2.95%)	5.03 (1.35%)	2.68 (2.4%)	1.18 (2.82%)
N	S-1 (6.83%)	744.27	157.38	94.18	63.43	43.79
	S-2	751.51	158.20	94.21	63.34	43.67
	S-3	750.27 (–0.16%)	158.05 (–0.10%)	94.20 (–0.02%)	63.34 (–)	43.67 (–)
	S-4	746.91 (–0.61%)	157.71 (–0.31%)	94.19 (–0.02%)	63.40 (0.09%)	43.71 (0.11%)
	S-5	737.23 (–1.9%)	156.86 (–0.85%)	94.39 (0.18%)	63.81 (0.74%)	44.15 (1.12%)
	S-6	703.70 (–6.36%)	153.53 (–2.96%)	94.61 (0.42%)	64.84 (2.37%)	45.44 (4.07%)

Relative to scenario S-3, scenarios S-4, 5, and 6 all showed that at every position, the average pollution load decreased during the wet period and rainy season, which were nonpoint pollution influence intervals. In medium influence area L, the average pollution load showed a maximum decrease of around 27% during the rainy season in scenario S-6 as compared to the scenario S-2. In the intervals of the normal season through the dry season, the pollution load increased at each position in scenarios S-3, 4, 5, and 6 compared to scenario S-2, but it was lower than the pollution load reductions in the rainy season and wet period. This was because the stormwater infiltrated into the ground during the rainy season and the wet period and consequently, the flow that reached the river increased. As the pervious area increases, the peak flow increases due to the initial rainfall. Therefore, it can be seen that the nonpoint pollution load decreases during the rainy season. In later periods, nonpoint sources are the same or increasing. As surface runoff occur, nonpoint sources increase. It is judged that the nonpoint pollution load decreases because it is infiltrated and impound by the pervious area [27,28].

4. Conclusions

This study applied an HSPF watershed model to evaluate the effect of decreases in the coverage of the

Table 9
Comparison of seasonal average pollution load (kg/km²/y) between 2008 and 2017 for each impervious area scenario

Medium influence area	Scenario	Rainy season	Wet period	Normal season	Drought season	Dry season
A–I	S-1 (6.12%)	409.61	37.63	15.03	10.54	8.65
	S-2	410.14	37.80	15.08	10.54	8.65
	S-3	–	–	–	–	–
	S-4	–	–	–	–	–
	S-5	–	–	–	–	–
	S-6	406.84 (–0.80%)	37.18 (–1.64%)	14.83 (–1.62%)	10.48 (–0.56%)	8.69 (0.42%)
J	S-1 (26.68%)	631.27	193.90	136.01	117.45	127.29
	S-2	640.25	195.48	134.40	116.34	126.20
	S-3	–	–	–	–	–
	S-4	635.19 (–0.79%)	194.66 (–0.42%)	134.83 (0.32%)	116.83 (0.42%)	126.24 (0.03%)
	S-5	605.30 (–5.46%)	192.28 (–1.64%)	137.69 (2.45%)	120.32 (3.42%)	130.07 (3.07%)
	S-6	550.86 (–13.96%)	183.57 (–6.10%)	139.21 (3.58%)	127.78 (9.83%)	138.76 (9.96%)
K	S-1 (49.39%)	2,346.18	623.25	377.77	305.30	204.82
	S-2	2,357.12	626.49	377.28	305.27	202.38
	S-3	2,352.74 (–0.19%)	625.59 (–0.14%)	377.83 (0.15%)	305.09 (–0.06%)	203.18 (0.4%)
	S-4	2,343.21 (–0.59%)	623.65 (–0.45%)	377.13 (–0.04%)	305.71 (0.14%)	203.82 (0.72%)
	S-5	2,313.54 (–1.85%)	619.33 (–1.14%)	378.95 (0.44%)	309.82 (1.49%)	204.74 (1.17%)
	S-6	2,235.01 (–5.18%)	605.00 (–3.43%)	376.44 (–0.22%)	316.04 (3.53%)	210.83 (4.18%)
L	S-1 (6.17%)	84.93	9.60	1.78	1.76	1.34
	S-2	84.99	9.61	1.77	1.76	1.34
	S-3	79.60 (–6.35%)	9.33 (–2.98%)	1.75 (–1.26%)	1.74 (–0.71%)	1.35 (0.69%)
	S-4	75.14 (–11.59%)	8.99 (–6.5%)	1.80 (1.37%)	1.71 (–2.67%)	1.36 (1.28%)
	S-5	67.52 (–20.56%)	8.25 (–14.16%)	1.78 (0.44%)	1.64 (–6.96%)	1.49 (10.59%)
	S-6	61.74 (–27.36%)	7.16 (–25.55%)	1.61 (–9.1%)	1.60 (–9.07%)	1.44 (7.28%)
M	S-1 (13.94%)	319.10	74.58	48.06	37.87	33.08
	S-2	323.06	74.71	47.97	37.76	33.12
	S-3	–	–	–	–	–
	S-4	–	–	–	–	–
	S-5	322.25 (–0.25%)	74.63 (–0.11%)	47.98 (0.01%)	37.75 (–0.01%)	33.13 (0.04%)
	S-6	295.65 (–8.48%)	71.64 (–4.11%)	48.27 (0.62%)	38.09 (0.89%)	33.04 (–0.24%)
N	S-1 (6.83%)	3,172.10	1,040.64	713.36	589.26	447.84
	S-2	3,182.74 (–0.18%)	1,042.97 (–0.05%)	714.60 (–0.13%)	587.77 (–0.18%)	445.85 (–0.15%)
	S-3	3,176.85 (–0.43%)	1,042.48 (–0.28%)	713.66 (0.02%)	588.84 (0.13%)	445.17 (0.25%)
	S-4	3,169.02 (–0.16%)	1,040.08 (–0.16%)	714.70 (–0.16%)	588.51 (–0.16%)	446.96 (–0.16%)
	S-5	3,137.41 (–1.42%)	1,037.59 (–0.52%)	715.48 (0.12%)	591.77 (0.68%)	451.69 (1.31%)
	S-6	3,037.65 (–4.56%)	1,016.81 (–2.51%)	718.34 (0.52%)	597.07 (1.58%)	460.03 (3.18%)

impervious area on the water circulation of the Geum River watershed. The conditions of the watershed were investigated by analyzing the water circulation structure (impervious area, direct runoff, nonpoint source load, and water circulation rate) of watersheds based on impervious area reduction scenarios.

Due to previous developments, 25 and 48 small influence areas of the Geum River watershed had impervious area coverages of 0%–5% and 5%–25%, respectively, and five small influence areas had an impervious area coverage over 25%. The Gapcheon (K) medium influence area had an impervious area coverage of 23.17%, about 2.54 times higher than the overall watershed average (9.1%), because it contains major cities such as Daejeon Metropolitan City and Sejong City, and consequently, the proportion of urban or built-up land was high.

As the impervious area decreased, the flow decreased during the wet period and rainy season, which were high-flow periods; and the river flow increased during the dry and the drought seasons. Furthermore, the direct runoff decreased by ~15% when the impervious area decreased by 25%. Accordingly, the maximum nonpoint source pollution load decrease was 13%, which increased the water circulation to about 80%.

The water circulation rate of Gapcheon (K) and Mihocheon (J) medium influence areas increased from the current

73% and 79% to 78% and 80%, respectively when the impervious area was reduced by 25% according to impervious area reduction scenarios. Population and industrial facilities were concentrated in the Gapcheon (K) and Mihocheon (J) regions which have seen or are currently undergoing urban development. Consequently, it is practically impossible to reduce the impervious areas rapidly in these regions. Therefore, it was determined that low-impact development methods should be applied to the development of public facilities or projects larger than a certain size.

If the nonpoint pollution and water circulation status estimation and evaluation system constructed in this study are used, it will be possible to set goals for small influence areas with high rates of urbanization, by using a unified method. Furthermore, future studies will be required to establish more comprehensive water circulation goals to consider artificial water circulation (e.g., recycling at sewage treatment plants).

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