New Evaluation Method for the Achievement Rate of Target Water Quality in Nakdong River, Republic of Korea

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Abstract: Water quality in the four major river basins in South Korea has been managed by introducing total maximum daily loads (TMDLs) to achieve or maintain a target water quality (TWC); TMDLs can be obtained by discharging the allocated pollutant loads from the watershed. The Nakdong River basin is the most important source of water supply among these four river basins and consists of 41 watershed units. The current method for evaluating the rate of load management involves calculating the measured values over the past 3 years through a log transformation process and assessing whether the TWC is achieved after comparing the values with the reference TWC. The objective of this study is to compare and analyze the results of a flow duration curve (FDC) and load duration curve (LDC) evaluation based on the current method for TWC evaluation and the daily flow data measured at 8-day intervals (weekly) to present an efficient TWC assessment method for more relevant flow conditions. The daily flow data were from 1995 to 2004, and the flow data measured at 8-day interval were from 2005 to 2015. The target study areas included the 41 watershed units on the Nakdong River basin (14 main streams and 27 tributaries). Biochemical oxygen demand (BOD) and total phosphorus (TP) constituted the water quality indicators studied. LDCs were prepared using the estimated daily flow rate, and the measured flow data at 8-day intervals based on the BOD and TP revealed similar results. Thus, even the data measured at 8-day intervals are considered applicable for creating FDCs and evaluating LDCs without requiring complex tests, calibrations, and prediction processes using a watershed model based on accumulated data over many years. **DOI: 10.1061/(ASCE)HE.1943-5584.0002165.**

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Introduction

South Korea introduced a water pollution load management system that comprehensively manages the discharge of pollutants from the target water quality (TWC) limit to ensure the balance and coexistence of the entire basin for water use and regional development (MOE 2004). Since 2004, biochemical oxygen demand (BOD) has been used as a target indicator for the total maximum daily loads (TMDLs) in the four major river basins of South Korea (including the Nakdong River basin). In 2011, total phosphorus (TP) was adopted as an indicator for TMDLs. The objective of a water pollution load management system is to manage the pollutant load discharged from a basin and achieve and maintain the TWC (MOE 2013a). It is crucial to precisely assess water quality at the terminal point of a unit basin because meeting the TWC affects pollutant load reduction and basin development plans. The current method for evaluating the achievement rate of target water quality involves evaluating the average water quality over the past 3 years to determine the planned target established in accordance with the Nakdong River Basin Act (MOE 2007) (Article 12 of Enforcement Rules). However, this method does not consider changes in water quality due to changes in the flow rate of the stream. Moreover, the discharge load is satisfied by assessing whether the TWC is achieved; however, the TWC is not attained. Changes in the flow rate vary depending on the geographical location and characteristics of each unit basin, and water quality changes at the endpoint of the unit basin according to changes in the flow rate, even though the pollution load discharged from the basin remains the same

(Park et al. 2011). It is difficult to consider the change in water quality due to changes in the flow rate of the stream if the TWC is evaluated only from water quality data in the unit area, and this can cause distortion if the flow rate of the stream is significantly altered by severe drought or flooding. Therefore, it is necessary to assess the achievement of the TWC by considering the size of the pollution load or water quality changes depending on the flow rate conditions of the stream in order for the actual evaluation to occur (Park et al. 2012). The load duration curve (LDC) produced from the flow rate and pollution load data in the unit basin serves as the basis for a LDC user's guide for the development of water pollution load management plans by the USEPA. This curve can help identify the water quality and load characteristics of the total flow rate conditions in a stream. Furthermore, the guide can be used to establish a load management plan by calculating the current pollution, allocated, and reduced loads (USEPA 2007). Recently, there has been a need for the application of this water pollution load management system based on LDCs to improve and supplement this system in South Korea (Park and Oh 2012; Hwang et al. 2011; Kang et al. 2011; Park et al. 2013). In general, the LDC is prepared using the daily flow data, but it is difficult to apply the LDCs due to the lack of daily flow data for each unit basin. Actual flow measurement data at 8-day intervals since 2004 are available in South Korea. These data may be utilized in LDC evaluation. In this study, a more relevant and efficient TWC evaluation method was suggested to take into account the flow rate condition by measuring the flow duration curve (FDC) and LDC evaluation results using the flow rate data measured every 8 days. These data were compared and analyzed with the current evaluation method for TWC and the LDC evaluation result using the daily flow rate. We aimed to compare and analyze the current evaluation method and that of the new LDC using the 8-day-interval flow rate and confirm the applicability of the new method.

Materials and Methods

Research Target Basin and Data

The target area of this study included the watershed units in the Nakdong River basin, which has an area of 23,817.3 km^2 and an extension of the flow path of 521.5 km. Furthermore, various industries have arisen in the region, including those within major cities such as Andong, Gumi, Daegu, and Busan. In addition, this river basin is used for various kinds of domestic and industrial water (21.6%), agricultural water (51.0%), and river maintenance water (27.4%) and acts as a water source for 13 million people living in the basin (Jung et al. 2019). The Nakdong River basin consists of 41 watershed units (14 main streams and 27 tributaries) (Fig. 1), and the monitoring sites were located at each end of the unit basins. The flow data used in this study included: (i) the daily flow values (NIER 2006) estimated using the hydrological model (SWAT_Soil and Water Assessment Tool) that was constructed using meteorological and hydrological data for 10 years from 1995 to 2004; and (ii) values measured at 8-day intervals for 11 years from January 2005 to December 2015 were used (WEIS 2019). Moreover, for BOD and total phosphorus (T-P) water quality data, values measured at 8-day intervals for 4 years from January 2012 to December 2015 were used (WEIS 2019).

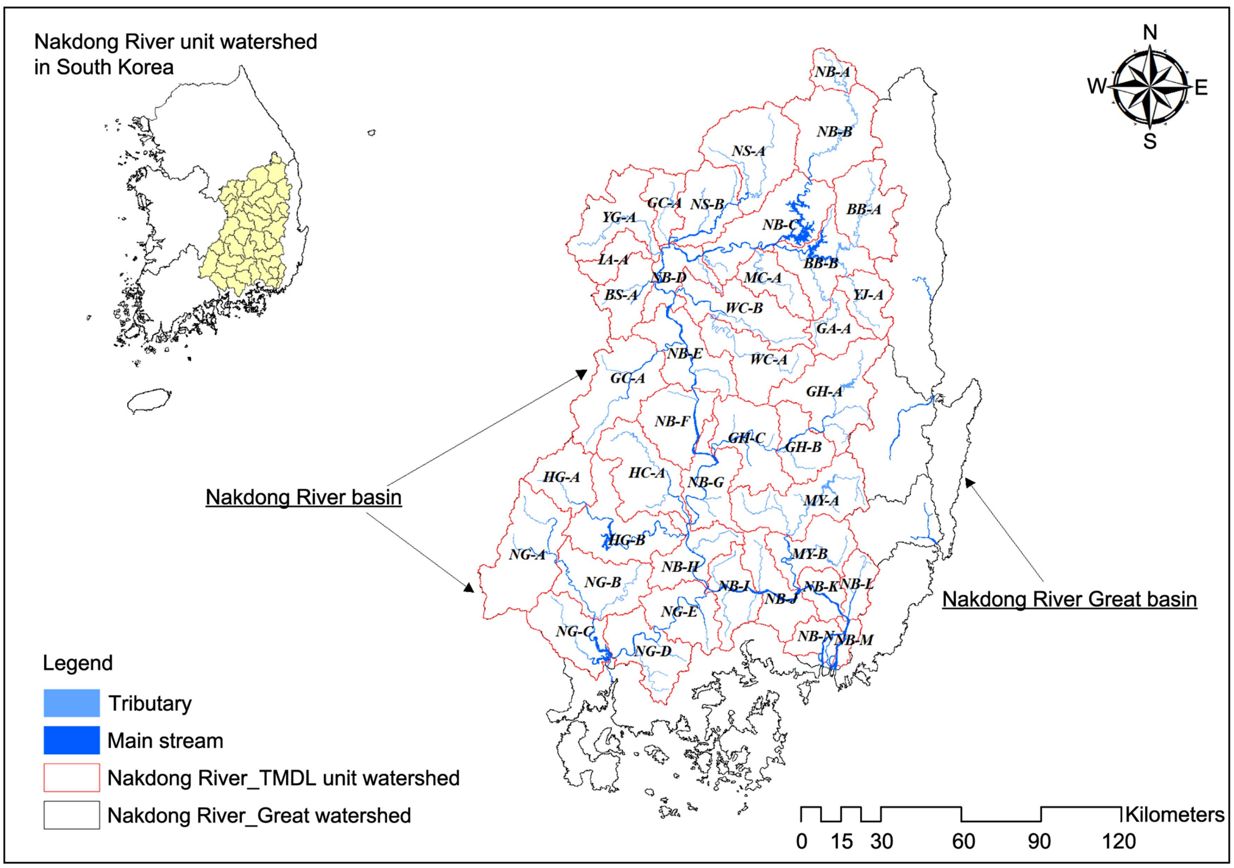

Fig. 1. Forty-one unit watershed units of Nakdong River basin.

Daily Streamflow (m^3/sec)	Rank	Percent of Days Flow Exceeded
26,100	1	0.01%
14,000	2	0.03%
11,500	3	0.04%
11,200	4	0.05%
…	…	…
0.32	7301	99.95%
0.27	7302	99.96%
0.26	7303	99.97%
0.19	7304	99.99%
0.01	7305	100%

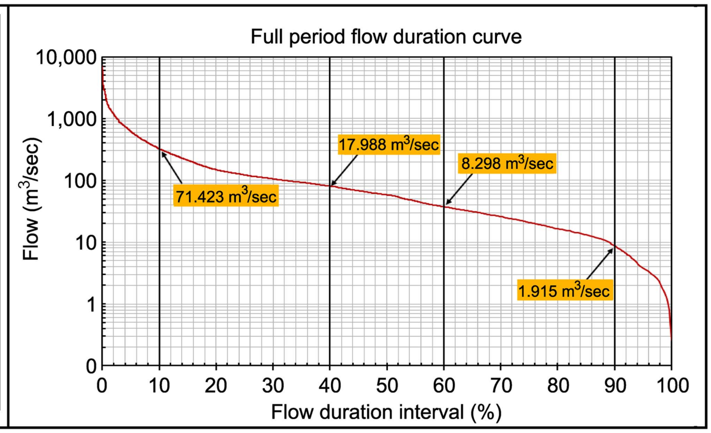

Fig. 2. Flow duration curve.

Comparison of Flow Duration Curves

The FDC represents the flow rate fluctuation in a basin based on the observed flow data and is used as a tool for predicting flow rates in areas without measured data in watersheds or with insufficient hydrological information through a localization method (Grover et al. 2002; Yu et al. 2015). Furthermore, FDC is a technique to analyze changes in the flow rate of a river and is used as an important tool for analyzing short- and long-term flow rate changes in watersheds and identifying the factors for water quality changes (Vogel and Fenessey 1994; Park and Oh 2013). A FDC must be created to assess the achievement of the TWC using the reference flow calculation or the pollution LDC (Park and Oh 2012). Hence, researchers have calculated the FDC after estimating daily data using intermittent actual data as a watershed model (Shon et al. 2009; Hwang et al. 2010, 2011). During the creation of the FDC, the available flow data for the subject point are sorted from maximum to minimum flow rate based on the daily data, and the number of days exceeding a specified flow rate is calculated as a percentage according to Eq. (1). Then the flow duration section or probability of exceeding is presented on the x-axis and the corresponding flow rate on the y-axis (Lee 2013). Fig. 2 shows an example of the flow rate data and created FDC

$$\text{PDFE} = \text{Rank}/\text{number of data points} \times 100 \tag{1}$$

where PDFE = percentage of days flow exceeded the specified rate (%).

Evaluation Methods for Target Water Quality

Current Evaluation Method for Target Water Quality

Pollution load management in South Korea uses water quality analysis data produced more than 30 times per year at intervals of 8 days for each set point of the TWC in the unit watershed target and calculates the evaluation quality according to Eqs. (2)–(4). Here, the average water quality evaluation method was used to determine the target of the implementation plan for pollution load management based on the four-river refurbishment method (Article 12, Enforcement Rules), and the water quality was measured over the past 3 years from the time of calculation. Furthermore, in areas where the TWC was exceeded twice consecutively, a pollution load management plan was established and executed (MOE 2013b). In the present study, the water quality of the evaluation was calculated as follows based on current regulations, and achievement was evaluated after comparison with the target quality (Jung et al. 2019):

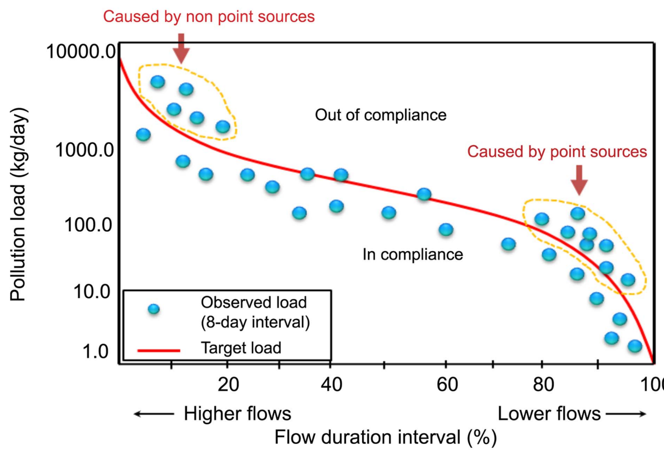

Fig. 3. Load duration curve.

$$EC = e^{(\text{TAC}+\frac{TV}{2})} \tag{2}$$

$$\text{TAC} = \frac{\ln(C_n) + \ln(C_{n+1}) + \cdots}{n} \tag{3}$$

$$TV = \frac{\{\ln(\text{C}_n) - \text{TAC}\}^2 + \cdots}{n-1} \tag{4}$$

where EC = estimated concentration; TAC = transformed average concentration; and TV = transformed variance.

Evaluation Method for TWQ Using LDC

The LDC can be used in different ways for pollution load management. First, it can be used to determine the time and level of exceedance of the allowable water quality standards and the source of contaminants and calculate the TMDL and reduction load required to satisfy the water quality standards. In addition, the current load can be applied to the LDC according to the water quality standard in the performance evaluation to determine whether the allowable quantity has been satisfied. Furthermore, the LDC provides visual data to ensure that environmental experts and policy officials will easily identify the water quality of the body (Cleland 2006; Jung 2009). To create the LDC, the daily flow data for the set point of the TWC were sorted from maximum to minimum, and the number of days above this value was calculated as follows as a percentage (overflow percentage) for each flow rate [Eq. (5)]:

Table 1. Results of water quality evaluated by current method and LDC method

Unit	TWQ	EWQ (current)		EWQ (LDC by daily flow data)		EWQ (LDC by 8-day interval flow data)		EWQ (current)		EWQ (LDC by daily flow data)		EWQ (LDC by 8-day interval flow data)	
Watershed	(mg/L)	2012–2014	Evaluation	Excess rate (%)	Evaluation	Excess rate (%)	Evaluation	2013–2015	Evaluation	Excess rate (%)	Evaluation	Excess rate (%)	Evaluation
NB-A	1.5	1.2	○	26.9	○	26.9	○	1.2	○	31.4	○	31.4	○
NB-B	1.4	1.0	○	19.5	○	19.5	○	1.1	○	28.8	○	28.8	○
NB-C	1.5	1.1	○	15.6	○	15.6	○	1.0	○	12.9	○	12.9	○
NB-D	1.5	1.5	○	56.6	×	56.6	×	1.6	×	62.5	×	62.5	×
NB-E	1.8	2.1	×	62.7	×	61.4	×	2.2	×	67.0	×	67.0	×
NB-F	2.0	2.4	×	63.2	×	61.4	×	2.3	×	62.3	×	61.4	×
NB-G	2.9	2.5	○	31.9	○	31.9	○	2.6	○	38.1	○	37.3	○
NB-H	2.7	2.5	○	33.6	○	32.8	○	2.4	○	36.1	○	36.1	○
NB-I	3.1	2.3	○	18.3	○	18.3	○	2.2	○	12.4	○	12.4	○
NB-J	2.9	2.4	○	23.7	○	23.7	○	2.4	○	19.2	○	19.2	○
NB-K	3.0	2.3	○	19.4	○	19.4	○	2.2	○	13.9	○	13.9	○
NB-L	3.1	2.5	○	28.3	○	28.3	○	2.3	○	20.7	○	20.7	○
NB-M	2.5	2.0	○	25.0	○	23.5	○	2.1	○	24.8	○	24.8	○
NB-N	4.3	4.1	○	41.8	○	41.8	○	4.0	○	35.8	○	35.8	○
BB-A	1.4	0.9	○	16.8	○	16.8	○	1.1	○	25.6	○	24.0	○
YJ-A	1.4	1.4	○	42.9	○	42.9	○	1.3	○	35.5	○	33.9	○
GA-A	1.5	0.7	○	5.9	○	5.0	○	0.9	○	14.9	○	14.0	○
BB-B	1.4	1.3	○	41.4	○	38.7	○	1.4	○	47.4	○	46.0	○
MC-A	1.5	1.3	○	39.2	○	36.1	○	1.3	○	34.7	○	33.9	○
NS-A	1.5	1.1	○	18.3	○	18.3	○	1.1	○	20.7	○	20.7	○
NS-B	1.5	0.9	○	14.7	○	31.3	○	0.9	○	17.4	○	38.9	○
GC-A	1.5	1.4	○	54.3	×	36.1	○	1.4	○	44.1	○	33.9	○
YG-A	1.5	1.4	○	40.4	○	40.8	○	1.5	○	42.9	○	41.3	○
IA-A	2.0	1.3	○	16.7	○	15.0	○	1.8	○	29.8	○	25.6	○
BS-A	2.0	1.7	○	30.0	○	27.5	○	1.8	○	36.4	○	33.3	○
WC-A	1.5	1.0	○	21.0	○	17.6	○	1.0	○	15.7	○	12.4	○
WC-B	1.5	2.1	×	75.4	×	73.9	×	2.4	×	90.6	×	89.3	×
GC-A	1.8	1.5	○	19.7	○	18.5	○	1.3	○	17.4	○	16.5	○
GH-A	1.9	1.7	○	36.1	○	36.1	○	1.7	○	30.6	○	31.4	○
GH-B	3.8	3.0	○	28.6	○	28.6	○	3.7	○	28.1	○	28.1	○
GH-C	4.0	3.6	○	37.5	○	36.8	○	4.0	○	45.1	○	43.8	○
HC-A	1.5	1.6	×	45.4	○	44.5	○	1.6	×	48.8	○	47.9	○
HG-A	1.5	1.4	○	35.3	○	34.5	○	1.6	×	40.5	○	39.7	○
HG-B	1.0	0.8	○	29.2	○	29.2	○	0.9	○	38.8	○	35.5	○
NG-A	1.5	1.4	○	27.7	○	27.7	○	1.4	○	28.1	○	28.1	○
NG-B	1.6	1.5	○	31.1	○	31.1	○	1.6	○	32.2	○	32.2	○
NG-C	1.2	1.1	○	36.8	○	36.8	○	1.3	×	52.9	×	52.9	×
NG-D	2.5	1.8	○	16.8	○	16.8	○	1.9	○	18.2	○	18.2	○
NG-E	3.1	2.4	○	22.9	○	20.8	○	2.4	○	22.4	○	18.8	○
MY-A	1.4	1.2	○	36.1	○	36.1	○	1.3	○	37.2	○	37.2	○
MY-B	2.5	1.9	○	27.7	○	27.5	○	2.1	○	32.2	○	31.4	○

Note: EWQ = estimation water quality; and evaluation = evaluation of TWQ (*achieved* is denoted by an empty circle, *not achieved* by a multiplication sign).

$$\text{PDFE} = \text{Rank}/\text{number of data points} \times 100 \tag{5}$$

Then a FDC can be produced with the excess flow rate on the x-axis and the corresponding flow rate on the y-axis. Based on the FDC created in the foregoing process, the load can be calculated by multiplying each FDC by the water quality standard (TWC). The LDC can be produced with the excess load percentage corresponding to the percentage of excess flow on the x-axis and the corresponding load on the y-axis [Eq. (6)]

$$L(\text{kg/day}) = \text{Flow}(\text{m}^3/\text{s}) \times \text{water quality standard}(\text{mg/L}) \times 86.4 \tag{6}$$

where L = load.

The daily load can be calculated using the measured flow rate and water quality data at the set point of the TWC. Then the excess flow rate corresponding to the measured flow rate was checked, and the load calculated at the corresponding point was plotted. It was possible to identify the characteristics of point and nonpoint sources considering the flow rate by applying the LDC (Fig. 3). In general, the excess of water quality standards that occurs during high-flow-rate periods is the effect of nonpoint sources, and the excess of water quality standards that occurs during low-flow periods is likely to be due to the point source (Nevada Division of Environmental Protection 2003; Park and Oh 2012). The target quality is assessed if the actual load measured after creating the LDC is below 50% based on the excess rate (Hwang et al. 2011; Park et al. 2013; Kim et al. 2015; Cheong et al. 2016).

Results and Discussion

Comparison of Attainment of Target Water Quality

A FDC was created using the estimated daily flow for the evaluation of the TWC achievement rate and the actual 8-day interval flow measurement data. The TWC for three consecutive years that was achieved twice in a row was divided by the target items (BOD, TP) to compare the excess rate by dividing the LDC multiplied by the target quality of the second stage into two periods: 2012–2014 (once) and 2013–2015 (twice) (Tables 1 and S1). The current evaluation method was compared against the LDC evaluation method.

The results of the LDC evaluation were slightly different from those of each applied method and showed that the LDC evaluation method achieved a higher TWC than the current assessment method. Furthermore, the LDC evaluation results from the flow rate data at 8-day intervals showed that the TP had a slightly higher achievement rate. In the case of BOD, the LDC evaluation result using the daily flow rate and the flow rate data at 8-day intervals showed that only the GC-A (Kumcheon) watershed unit represented different results (54.3% of the daily flow rate and 36.1% of the flow rate at intervals of 8 days) in the evaluation of 2012–2014. In the case of TP, the MC-A (Micheon) watershed unit showed 56.3% of the daily flow rate and 42.6% of the flow rate at intervals of 8 days in the evaluation of 2012–2014. In the evaluation of 2013–2015 for the HG-B (Hwang River) watershed unit, there was a difference between the daily flow rate (51.2%) and the flow rate at intervals of 8 days (46.3%). However, the others appeared to be the same.

Water quality evaluation using the current method indicated that the BOD values were 1.6 mg/L in the 2012–2014 period and 1.6 mg/L in the 2013–2015 period in the HC-A (Hoecheon) watershed unit (Table 1). This result indicated that the water quality exceeded the TWC of 1.5 mg/L twice in a row and that an additional BOD implementation plan should be established. However, in the evaluation using the LDC method, the results satisfied the excess rate of 45.4% and 48.8% in 2012–2014 and 2013–2015 twice in a row; hence, an additional plan need not be established. Therefore, considering the various administrative affairs and costs of establishing additional implementation plans, it is believed that the LDC evaluation method will also contribute to the flexibility of the pollution load management system.

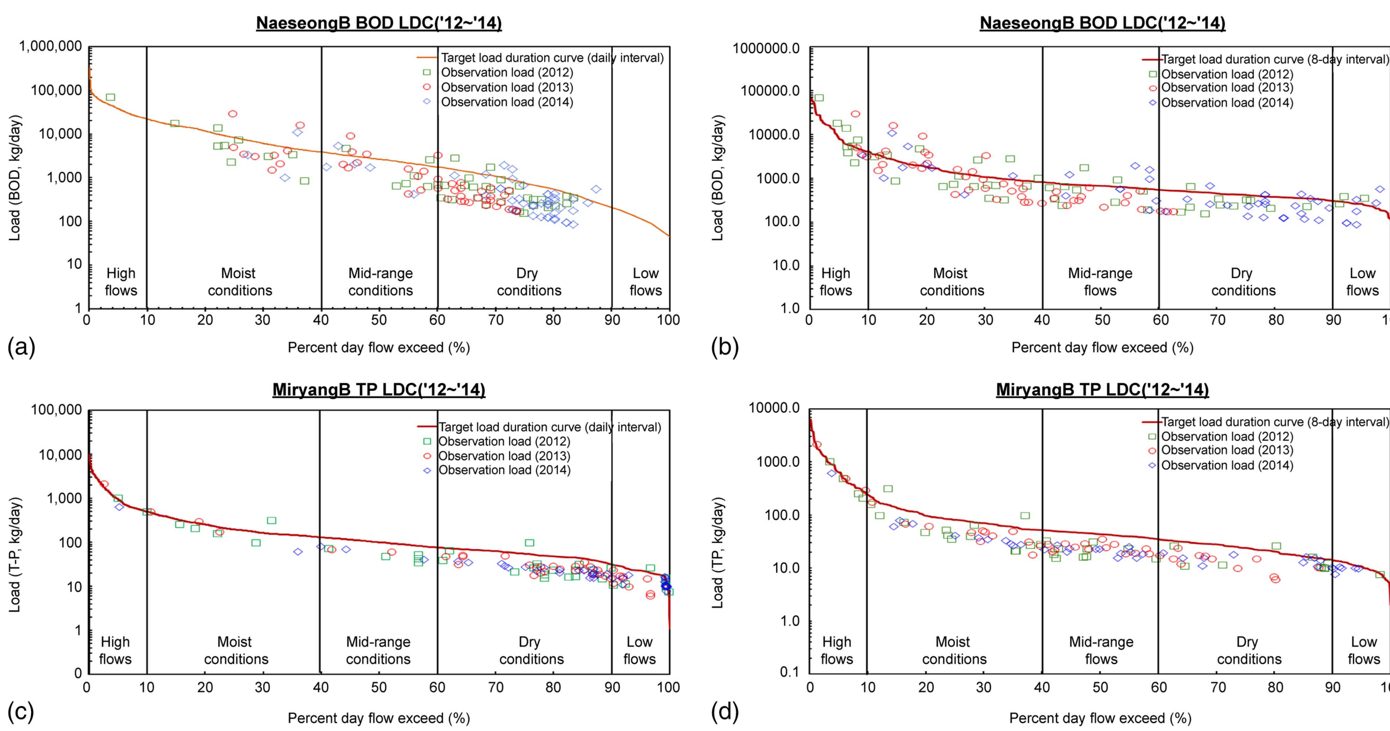

Fig. 4. Comparison of results between daily and 8-day intervals of LDC (example).

Table 2. Each evaluation method result of achievement rate of TWQ

Target materials	BOD						TP					
Method	EWQ (current)		EWQ (LDC by daily flow data)		EWQ (LDC by 8-day interval flow data)		EWQ (current)		EWQ (LDC by daily flow data)		EWQ (LDC by 8-day interval flow data)	
Evaluated year	2012–2014	2013–2015	2012–2014	2013–2015	2012–2014	2013–2015	2012–2014	2013–2015	2012–2014	2013–2015	2012–2014	2013–2015
Achievement rate (%)	90.2	82.9	87.8	87.8	90.2	87.8	85.4	92.7	90.2	95.1	92.7	97.6
Average	86.6		87.8		89.0		89.0		92.7		95.1	
Rate1 (%)	86.6		87.8		89.0		89.0		92.7		95.1	
Rate2 (%)	13.4		12.2		11.0		11.0		7.3		4.9	

Note: Rate1 (%) = consecutive achievement rate for two times; and Rate2 (%) = consecutive excess rate for two times.

In addition, the comparison and analysis of the current TWC evaluation methods suggested that the method based on the daily flow rate data simulated watershed models. Furthermore, it indicated that the method using the water quality and flow rate data measured every 8 days with data accumulated over many years is likely applicable to the creation of FDCs and evaluation of LDCs. Moreover, complicated tests, calibration, and prediction processes using a watershed model were not required.

The actual measured loads calculated from the measured flow rate and water quality data were evaluated by comparing and assessing whether the actual loads exceeded the TWC after producing the LDCs for BOD and TP of the pollution load management based on the daily flow rate data and the flow data at intervals of 8 days. The actual loads of two watershed units (tributaries) are presented in Fig. 4.

Achievement Rate of Target Water Quality for Each Evaluation Method

The data obtained from the 2012 to 2014 (once) and 2013 to 2015 (twice) periods, which showed twice in a row, were evaluated using water quality analysis data for the three latest years during the second stage of pollution load management. Furthermore, the two consecutive achievement rates and the exceed rate were evaluated. The evaluation results are presented in Table 2. First, for BOD, the achievement rate evaluated by the current average conversion method was 86.6% on average twice, and the achievement rates evaluated by the LDC evaluation method based on the daily flow rate data and the flow rate data at intervals of 8 days were 87.8% and 89.0% on average twice, respectively. However, in the case of TP, the achievement rate evaluated by the current average conversion method was 89.0% on average twice, and the achievement rates evaluated by the LDC evaluation method based on the daily flow rate data and the flow rate data at intervals of 8 days were 92.7% and 95.1%, respectively. Among these three methods, the LDC evaluation method yielded a high achievement rate. In particular, the LDC evaluation method based on the flow rate data at intervals of 8 days showed a high achievement rate. The two consecutive excess rates were shown to be less for TP than BOD in the LDC evaluation method.

Table 3 shows the comparison and analysis results of the achievement rate of the TWC for each evaluation method according to the main stream and tributaries. In the results of the evaluation, in the case of BOD, the achievement rate in the main stream evaluated by the current method was 82.1%, and the LDC evaluation method showed the same achievement rate of 78.6% for both the daily flow rate data and the flow rate data at intervals of 8 days. Furthermore, the achievement rate in the tributaries evaluated by the current method was 88.9%, and those of the LDC evaluation method based on the daily flow rate data and the flow rate data at intervals of 8 days were 92.6% and 94.4%, respectively. In addition, in the case of TP, the achievement rate in the main stream evaluated by the current method was 92.9%, and the LDC evaluation method showed the same achievement rate of 100.0% for the daily flow rate data and the flow rate data at intervals of 8 days. Furthermore, the achievement rate in the tributaries evaluated by the current method was 87.0%, and those of the LDC evaluation method based on the daily flow rate data and the flow rate data at intervals of 8 days were 88.9% and 92.6%, respectively. Here, the results from the LDC evaluation method showed a high achievement rate. Considering the two consecutive achievement rates, both BOD and TP represented similar or equal achievement rates in the main stream and the tributaries. Furthermore, the LDC evaluation method using the LDC showed high achievement rates. In the case of the two

Table 3. Each evaluation method result of achievement rate of TWQ (main stream and tributaries)

Target material	BOD						TP					
Method	EWQ (current)		EWQ (LDC by daily flow data)		EWQ (LDC by 8-day interval flow data)		EWQ (current)		EWQ (LDC by daily flow data)		EWQ (LDC by 8-day interval flow data)	
Condition	Main[a]	Tributary[b]	Main	Tributary	Main	Tributary	Main	Tributary	Main	Tributary	Main	Tributary
Achievement rate (%)	82.1	88.9	78.6	92.6	78.6	94.4	92.9	87.0	100.0	88.9	100.0	92.6
Rate1 (%)	82.1	88.9	78.6	92.6	78.6	94.4	92.9	87.0	100.0	88.9	100.0	92.6
Rate2 (%)	17.9	11.1	21.4	7.4	21.4	5.6	7.1	13.0	0.0	11.1	0.0	7.4

Note: Rate1 (%) = consecutive achievement rate for two times; and Rate2 (%) = consecutive excess rate for two times.
[a]Main indicates 14 watershed units, Nakdong River.
[b]Tributary indicates 27 watershed units, Nakdong River.

consecutive excess rates, BOD appears to be higher in the main stream than in the tributaries and TP lower.

Conclusions

In this study, the current evaluation method, a method using the estimated daily flow LDC, and a method using 8-day interval flow measurement data were compared and analyzed. Then these methods were applied to the 41 watershed units of the Nakdong River basin controlled by the pollution load management system. The results of this study are summarized as follows:

- The achievement rate of the TWC evaluated by the current evaluation method was approximately 86.6%–89.0%. The LDC evaluation method exhibited an achievement rate of 87.8%–92.7%. The achievement rate evaluated by the weekly flow rate data was 89.0%–95.1%.
- In the evaluation of whether the TWC was achieved, the excess rate evaluated by LDC had decreased by about 5% (two watershed units) from the current method, which seemed to be because the current method did not take into account changes in water quality that were due to changes in the flow rate of the stream. In addition, the measured flow rate at intervals of 8 days was shown to represent the interpolated cumulative flow rate, except for some flow rates. Thus, it is believed that if the actual data were periodically accumulated for many years, then they would represent the overall frequency in flow rates of the stream more accurately.
- In the case of the evaluation of the TWC using the LDC method, it is considered that the administrative requirements of pollution load management would be reduced because an additional implementation plan is not necessary due to decreases in the number of cases in which the TWC is exceeded, such as the BOD item of HC-A (Hoecheon). Reducing the target subject areas is regarded as a development of the pollution load management system, and this is also expected to contribute to increasing the flexibility of the pollution load management system, such as the introduction of the pollution load management system in tributaries to solve regional issues through the management of small watersheds. Furthermore, since it is possible to determine which watershed conditions exceed the TWC, it is possible to select the pollutants (point or nonpoint) that are subject to intensive management. Thus, it is deemed that the reduction plan of the pollution load management system or the analysis of the causes of exceeding the allocated load may be used for performance evaluation.
- From this study, it is considered that the FDC can be used for LDC evaluation without the need for complicated testing, calibration, and prediction processes using a watershed model if actual data are accumulated for more than 10 years at intervals of 1 week. This was demonstrated by the similarity between the FDC and LDC results using daily flow rate data and weekly flow rate data, even though it is difficult to represent all the flow conditions of a stream based on the measured flow rate data at 8-day intervals only.

Data Availability Statement

All data, models, and code generated or used during the study appear in the published article.

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Supplemental Materials

Table S1 is available online in the ASCE Library (www.ascelibrary.org).

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