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Methodology for determining total phosphorus target water quality in total maximum daily loads

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ABSTRACT

This study presents the principles and methods used in set target water quality values of total phosphorus (TP) in three major rivers of South Korea, such as Nakdong, Geum, and Yeongsan/Seomjin River. The QUALKO model (modified QUAL2E) was applied to establish the target water quality. According to the findings, while determining total maximum daily load (TMDL) targets, the intended use of water, current water quality, load density, and future pollutant elimination plans should be considered. If a watershed fails to meet the target quality standard, then the appropriate plan for the area should be established. In areas where small amounts of pollutants are released, development should be allowed within the limits of compliance with the water quality standards, targeting both development and water quality protection, which is the basic concept of TMDLs. Heavily polluted areas tend to continue releasing large amounts of pollutants, whereas others release only small amounts. The TMDL system is designed to address the problem by encouraging heavily polluted areas to reduce pollutant emission while allowing others to release some for development. The recommendations of this paper provide a reference to the development of a methodology for determining TP water quality considering TMDL.

Keywords: Total maximum daily load; Total phosphorus; Unit area; Watershed

1. Introduction

Although the Korean government has been making efforts to improve the water quality of various policies and measures since the 1960s, the current situation is not reaching satisfactory water quality improvement. This is mainly because clean water quality policies and measures in Korea have been focused only on existing point sources such as biochemical oxygen demand (BOD) [1]. In 1998, the Korean Ministry of Environment (MOE) established comprehensive water quality management measures targeting four major rivers in the nation, which are major management zones, such as the Han River, Nakdong River, Geum River, and Yeongsan/Seomjin River. All water quality-related policies on Korea have been established focusing on watersheds of these four major rivers.

From 1999 to 2002, the Act on Watershed Management and Community Support was enacted to facilitate the implementation of measures for each river. The total maximum daily load (TMDL) management system in Korea began with acts intended to improve the water quality [2,3].

In the case of the Geum River, Nakdong River, and Yeongsan/Seomjin River watersheds, the TMDL management system became mandatory in 2004, whereas in the case of the Han River watershed, it started as a voluntary system, but became mandatory in 2013.

Under the Korean TMDL system, two phases were set according to target indicators selected by the MOE with the agreement on local governments: the first phase (2004–2010)

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with BOD targets and the second phase with total phosphorus (TP) target (2011–2015) [4–6]. After selecting an indicator, target values for that indicator were established to distinguish the impaired and unimpaired state of the water-body, and the boundary area of the city or province were established by the MOE [7].

After the selection of target indicators, water quality targets for each watershed (41 in Nakdong River, 32 in Geum River and 23 in Yeongsan/Seomjin River) are determined. Each target is announced by the mayor of the city or province where the watershed is located, with the approval of the MOE. Regarding watersheds located on borders between cities or provinces, the MOE announces the targets [8–10]. In terms of BOD targets, based on measurements applied to the end of each watershed, the target for the second phase of the plan (2011–2015) was the same as that of the first phase. However, new quality targets were determined and announced for TP [4–6].

The BOD target for the first phase of the plan was set as follows. For the Nakdong River, standard values for better water quality were determined first. Next, reducible loads and reduction ratios were evaluated for BOD reduction. In areas that met the standards, BOD released was allowed considering allowance loads (ALs) and ratio based on the standards. In the case of the Geum River and Yeongsan/Seomjin River, the levels at the end of each watershed should not exceed the 3 y average water quality, the target for watersheds with a BOD expectation of under 1 mg/L was set at 1 mg/L, and targets at borders between cities and provinces were determined on the basis of the environmental standards of each location within a range of grade II (3 mg/L) in order to secure the water quality levels at water sources [2]. Overall, different principles were applied to each watershed for setting BOD targets for the first phase, leaving room for the unfair application of TMDLs. Therefore, different targets were determined in accordance with these different principles. For this reason, uniform principles are being utilized for all the rivers in the second phase of the plan.

This paper introduces the principles and methods used in setting target water quality values of TP in three major rivers (Nakdong, Geum, and Yeongsan/Seomjin) of Korea. The water-body TMDL management system is mandatory for the corresponding act in each river (2002).

2. Material and methods

2.1. Unit watersheds and reference points

Each watershed consists of many unit watersheds (unit watershed must be defined): 49 in the Han River watershed, 41 in the Nakdong River watershed, 32 in the Geum River watershed, and 23 in the Yeongsan/Seomjin River watershed, providing a total of 96 unit watersheds.

Target water quality is set for the end of each unit watershed. The target water quality of unit watersheds is set by using a model to allow the achievement of target water quality of reference points in each watershed. The reference points are points used as the raw water source or the most downstream point of each watershed; one reference point is usually designated for each watershed. Moreover, the target water quality of a reference point is also set based on a policy decision, such as the purpose of water use in a particular watershed. Important locations on the three rivers are selected as reference points. For instance, they include the ends of watersheds, which are free from the influence of dams, lakes, and seawater circulation. Fig. 1 shows the reference points for the three major river watersheds where the mandatory system was implemented: Nakbon L (most downstream point) of Nakdong River watershed; Geumbon F (raw water source point) of Geum River watershed; Yeongbon E (most downstream point) of Yeongsan River watershed; and Seombon E (most downstream point) of Seomjin River watershed.

Target water quality represents a reference for setting the target indicators for TMDL management, and thus, it should be set considering the water used for the river, including raw water source and agricultural water use, as well as other factors, such as pollutant density, level of local development, level of investment in basic environmental infrastructure, water volume and quality, and soundness of aquatic ecosystem. As shown in Fig. 1, target water quality was set by the MOE for points where the unit watershed spanned across two or more local municipalities to prevent disputes, whereas target water quality of points was set by the head of the relevant local municipality in all other unit watersheds. The MOE announces water quality targets for the watersheds spanning across borders of metropolitan areas and provinces. For others, local government heads to announce the targets of an agreement with the MOE.

2.2. TP targets at reference points

Fig. 2 shows the principle for setting TP target water quality and the target water quality values at the reference points. Currently, the only two water quality items targeted for management under the TMDL management system are BOD and TP. BOD was set for preventing water pollution by organic matter, whereas TP was set as a management item during the second phase (2011–2015) for the purpose of controlling eutrophication. Sunlight, water temperature, and nutrients are the 3 major causative factors of eutrophication. In particular, TP was set as the item targeted for management because it is the limiting factor of eutrophication.

The final TP target value of the reference points (target to be achieved ultimately, although the target date has not been established) was set to the oligotrophic phase for Geum River watershed and the median value of the mesotrophic phase for Nakdong and Yeongsan/Seomjin River watersheds based on estimates of the water use purpose and policy.

Phased TP target, for which the TMDL management system is implemented, was set differently for each watershed by comprehensively considering current TP concentrations, distribution of water pollutants, TP pollution loading amounts, pollutant management conditions, expansion status of TP elimination facilities, and financial capacity of local municipalities.

Fig. 2 shows the TP target values to be achieved during the second and third phases (2016–2025) of TMDL at reference points of each watershed. TP in Nakbon L was in the hypertrophic stage, but because this area is used as a raw water source, it required immediate water quality improvement. Therefore, the target values were set to the

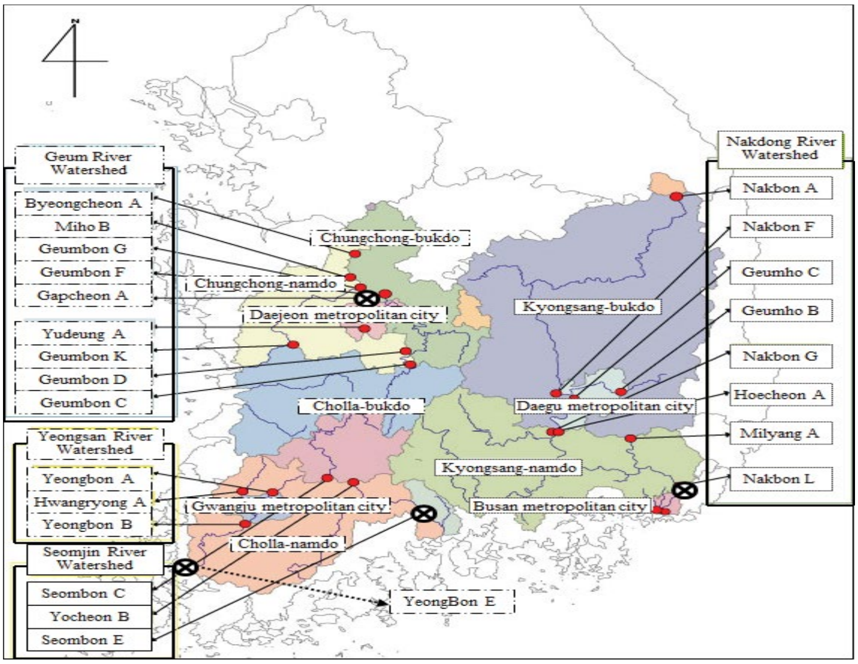

Fig. 1. Metropolis and province boundary (●) and reference (X) points for target water quality.

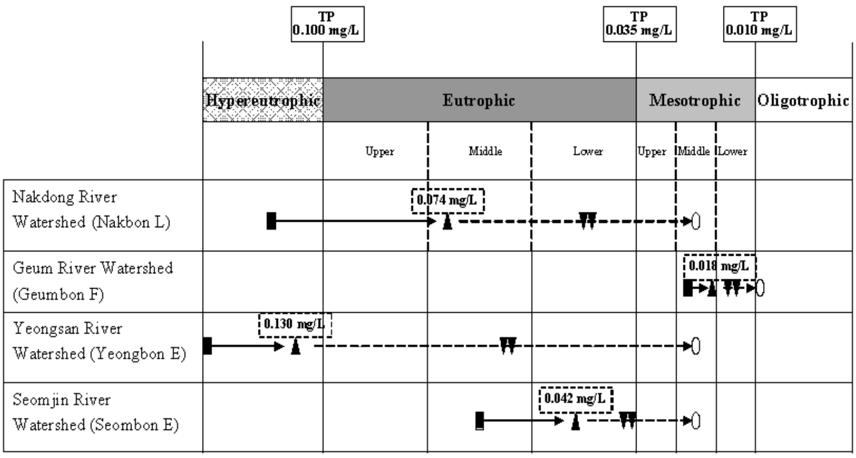

Fig. 2. Principle for setting target water quality at reference points (■: current water quality; ▲: target water quality during the second phase; ▼▼: target water quality after the third phase; ○: final water quality goal).

intermediate eutrophication level of 0.074 mg/L during the second phase and low eutrophication level of 0.065 mg/L during the third phase.

Since Geumbon F is used as a raw water source, TP was being managed at a high level as the mesotrophic phase. In addition, because immediate TP improvement is unnecessary, the target value was set to an intermediate mesotrophication level of 0.018 mg/L for the second and third phases.

As Yeongsan River watershed is used mostly as an agricultural water source, TP remained in the hypertrophic phase in this area. Therefore, there is no major need for immediate TP improvement, which would require a significant cost. Accordingly, the TP target for Yeongbon E was set to 0.130 mg/L (a slight improvement from the hypertrophic phase) during the second phase. However, the target value was set to an intermediate eutrophication level of 0.116 mg/L to induce water quality improvement on various purposes of water use, in addition to agricultural water, starting from the third phase.

As Seombon E does not have many pollutant sources and its TP water quality is in the intermediate eutrophication level, the target values were set too low eutrophication levels of 0.042 mg/L during the second phase and 0.030 mg/L during the third phase, which is a slight improvement from the second phase.

The target value of TP water quality of each watershed was set differently for each reference point considering watershed characteristics, but ultimately, targets for all watersheds were set with the long-term goal of improving TP water quality, that is, above the intermediate mesotrophic level.

2.3. Model application

To establish the target water quality, the QUALKO model (modified QUAL2E) was applied to the Nakdong, Geum, and Yeongsan/Seomjin River. Fig. 3 shows a comparison between QUALKO and QUAL2E models with respect to interactions and material changes in water bodies [11], and Table 1 shows a comparison of the specifications of the two models.

The QUALKO model is basically based on the QUAL2E model. The QUALKO model has the following improvements on the QUAL2E model. That is, the internal production part of the algae was taken into account in calculating the carbonaceous biochemical oxygen demand (CBOD). Calculation formula for bottle BOD_5 was added, and branching coefficients were applied by classifying the nature and existence of organic substances. In addition, a TOC item was added and the algae's metabolism was broken down.

Based on the pollution source locations as well as the river characteristics, the study areas were divided into junctions and reaches. Junctions reaches and pollutions sources in each river are presented in Table 2. Each reach was subdivided into uniform computational elements, and the size of these elements was set as 1 km.

The QUALKO model was calibrated in the steady-state mode using the data onto the last 2 y. The field data were gathered at 8 d intervals of the last 3 y at the end of unit areas (target water quality establishment point) of each watershed.

In order to test the ability of the applied model to predict water quality of different flow conditions, model verifications were performed using average dry season conditions and average normal season conditions. The system coefficients in the model were kept identical to those values determined during the model calibration.

3. Results and discussion

3.1. Principles for establishing target water quality

The principles of establishing water quality targets are shown in Fig. 4. A model can be used to determine the water quality value of unit watersheds located upstream of the reference point (C_b: same water quality value of all unit watershed located upstream) when the target water quality set for the reference point at the end of each unit watershed has been achieved. C_b values identified with the model may be smaller (Fig. 4 left) or larger (Fig. 4 right) than the actual measured value of water quality.

Upstream unit watersheds with current water quality value (C_e) less than C_b value determined by the model have relatively less pollutant sources, and relatively good water quality has been maintained in such watersheds to date. Thus, ALs onto partial development could be given as an incentive. In other words, by considering the allowance ratio (β) within a range that does not exceed the C_b value, target water quality (C_0) could be set and ALs corresponding to the difference between C_0 and C_e may be used for development. Typically, β of approximately 10% is applied.

Upstream unit watersheds with C_e greater than C_b have more pollutant sources and poor water quality. Thus, development causing the pollution must be deterred and reduction plans must be established to improve water quality. In order to satisfy the target water quality of a reference point, reduction in excess loading (EL, $C'_e - C_b$)

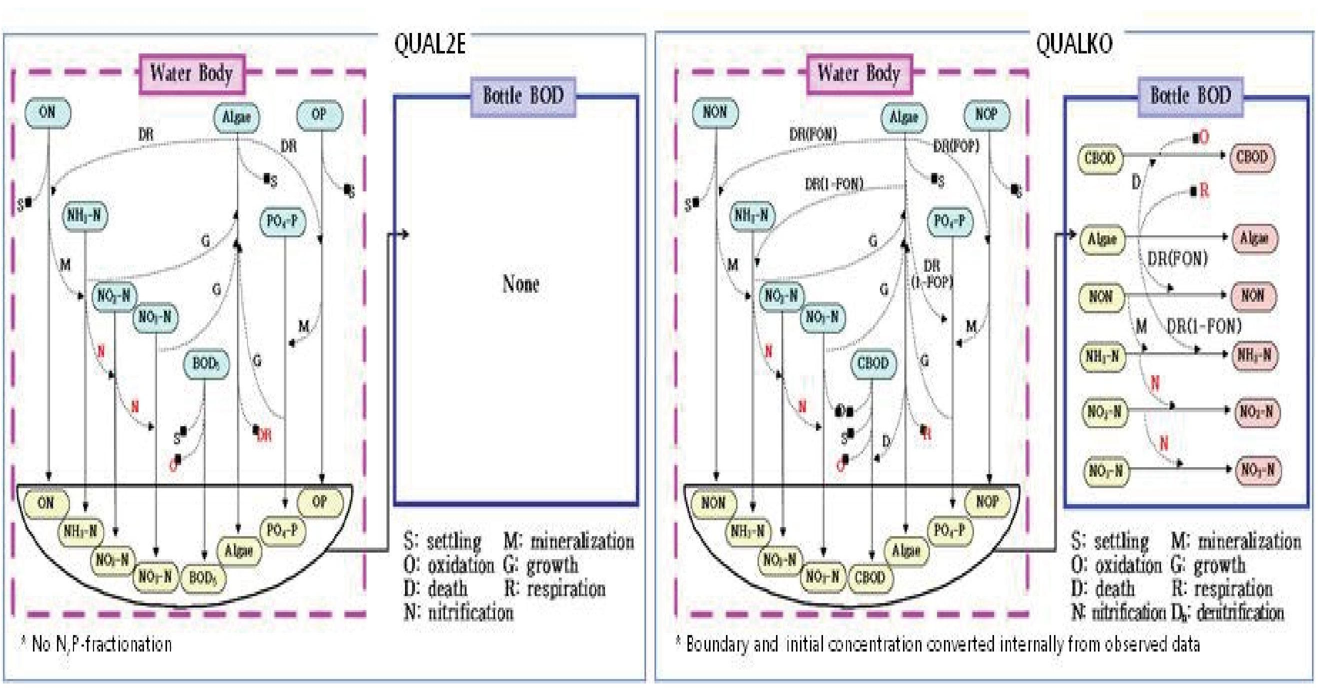

Fig. 3. Interactions and material changes in water bodies for QUALKO and QUAL2E models.

Table 1
Comparison of major contents in QUALKO and QUAL2E models

Items	QUAL2E	QUALKO
Simulation method	Steady-state	Dynamic
Estimation of diffusion coefficient	Elder et al. [12] equation	Elder et al. [12] and Fisher [13]
Biotic/abiotic form of phosphorus and nitrogen	Not isolated	Isolated⁾
Algal apoptosis/respiration	Not isolated	Isolated
Organic/inorganic emissions according to algal apoptosis/respiration	Not isolated	Isolated
Increase in organic matter in water by algae production	Not included	Included
Bottle BOD	Not included	Included
NO_2–N	Simulated	Simulated
Chemical oxygen demand (COD_{Mn})	Not simulated	Conditionally applied
Denitrification reaction	Not included	Included
Maximum number of computation elements	500	1,000
Number of upstream boundary conditions	20	50
Maximum number of connection tributaries	19	49
Maximum number of river reaches	50	100
Maximum number of point sources	50	500

Table 2
Reaches and pollution sources in the model of the three major rivers

Watershed	Distance (km)	Junctions	Reaches	Pollution sources
Nakdong River	500	41	321	551
Geum River	140	2	37	34
Yeongsan River	285	7	28	119
Seomjin River	351	6	36	136

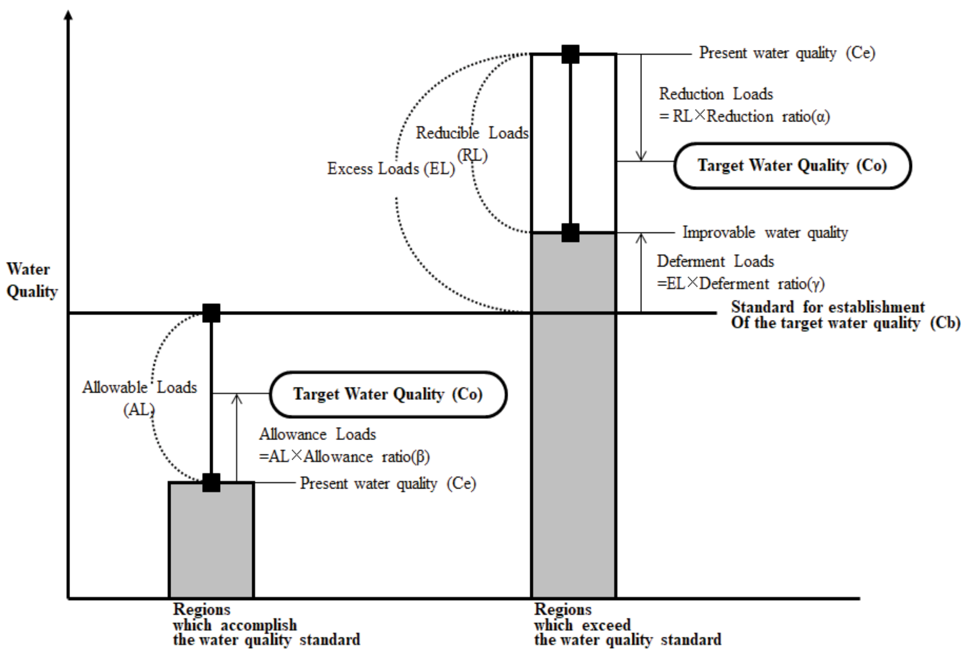

Fig. 4. Conceptual diagram for establishing target water quality.

must be achieved, and the appropriate reduction amount is estimated considering the financial condition of the local government and reduction conditions.

For the entire watershed, ELs from unit watersheds with good water quality and loads that have not been reduced in unit watersheds with poor water quality are set to a similar level to satisfy the target water quality of the reference point. In this approach, the problem is addressed by encouraging heavily polluted areas to reduce pollutant amount while allowing others to release some for development.

In summary, it should be found the same water quality value that will apply to all unit watersheds that will be able to achieve the target water quality of the reference unit watershed. Compare this water quality value of the actual water quality of each unit basin, and if the actual water quality is lower (that is, if the actual measured water quality is cleaner), allow developers to be made within the range of the water quality difference. If the actual water quality is higher (i.e., the actual water quality is worse), it will lead to a plan for pollutant reduction to improve the current water quality.

3.2. Target water quality

The procedure for setting water quality targets are given in Fig. 5 [1]. At first, pollutant sources of the endpoint of each phase plan are anticipated, and load evaluation is conducted following the TMDL guideline. The QUALKO model (modified QUAL2E) is adopted for the simulation of increasing CBOD by algae decay and bottle BOD in order to anticipate present water quality (C_e). Expectations of present water quality reflect the environment infrastructure development plans to be implemented by the national government (or local government) at the endpoint of each phase plan, and the balanced national development plan pursued by the government.

Standard value (C_b) is evaluated through simulation. This level is equal to all point sources to reach the water quality goal at reference points, and it is required to meet the goals of each phase of the plan. All areas are classified into two groups: areas where water quality level is higher than the standard value and areas where water quality level is lower than the standard. In a place where water quality level is lower than the standard, the target water quality (C_0) is determined using Eq. (1), which considers present water quality (C_e), reducible loads ($C_e - C_m$), weight (γ), and reduction ratio (α).

$$C_0 = C_e - \alpha\left(C_e - C_m\right) \quad (1)$$

3.3. Maximum possible amount of TP reduction

The reducible amount of each point is evaluated (maximum amount of loads that each area can reduce or control independently from reduction plans by the endpoint of each phase plan) and determined as shown in Table 3, taking into account reduction technology capabilities.

The maximum possible reduction amount shown in Table 3 does not represent the levels that could be currently reduced, and thus, the values were presented by including all technically feasible reduction factors without any consideration of economic aspects. In other words, all technically feasible reductions were considered irrespective of the costs.

With respect to household pollution sources, the plan includes ultimately improving all combined sewer systems to separate sewer systems; gradually reducing the rate of water leakage to 10% and managing it at that level; treating effluent TP of municipal wastewater treatment facilities to 0.05 mg/L (lowest treatable water quality at present, actually measured, and given in the literature and laboratory-scale studies); and treating effluent TP of sewage treatment facilities to 0.2 mg/L.

With respect to livestock pollution sources, it was determined that 100% recycling of livestock wastewater could be achieved to inhibit pollution, and effluent TP of livestock wastewater treatment facilities could be treated to a level of 0.2 mg/L, which is the level for a sewage treatment

Table 3
Maximum possible TP reduction amount of each pollution source

Pollution source	Reduction factors	Reduction rate or effluent concentration
Household	Combined sewer system –> separate sewer system	100%
	Rate of water leakage	10%
	Effluent TP of a municipal wastewater treatment facility	0.05 mg/L
	Effluent TP of a sewage treatment facility	0.2 mg/L
Livestock	Recycling of livestock wastewater	100%
	Effluent TP of livestock wastewater treatment facility	0.2 mg/L
Industry	TP treatment efficiency of small scale treatment facility	90%
	Rate of water leakage	10%
	Effluent TP of an industrial wastewater treatment facility	0.2 mg/L
Land	Non-point source control	20%
Landfill	Non-point source control	20%
Wastewater treatment plants	Effluent TP	0.04 mg/L

facility. With respect to industrial pollution sources, the maximum reduction rates were set to 90% for TP treatment efficiency of small scale treatment facilities; 10% for the rate of water leakage; and 0.2 mg/L (sewage treatment facility level) for effluent TP of industrial wastewater treatment facilities.

With respect to land and landfill pollution sources, non-point source level was set to 20% and effluent TP of municipal wastewater treatment facilities was set to 0.04 mg/L.

The maximum amount of TP that can be removed from each pollutant source represents the maximum amount that can be removed by current TP removal technology without considering economic factors. In other words, the maximum TP reduction is calculated first and the maximum TP reduction is adjusted in consideration of the regional characteristics and economic independence of the unit watershed.

3.4. Weight

Weight is calculated by considering the TP load (ω, TP load/size of the watershed) of each watershed following Eqs. (2) and (3) (load and weight are accessed in each watershed, and equal value is applied to all sources).

For $\omega_i < \omega_m$,

$$\gamma = 0.25\frac{\omega_i - w_{\text{mi}}}{\omega_m - \omega_{\text{mi}}} \tag{2}$$

For $\omega_i > \omega_m$,

$$\gamma = 0.25\frac{\omega_i - w_m}{\omega_{\text{ma}} - \omega_m} \tag{3}$$

where ω_i = value of each boundary point; ω_m = total boundary point average value; ω_{mi} = minimum; and ω_{ma} = maximum.

3.5. Reduction rate and allowance rate

For areas that exceed the standards, Eq. (4) is used.

$$\alpha = \alpha_m(1 + \gamma) \tag{4}$$

where α is the reduction ratio of each section, α_m is the standard reduction ratio, and γ is the weight.

The standard reduction ratio (α_m) and standard allowance ratio (β_m) might not be achieved. For this reason, the standard allowance ratio is evaluated by considering the standard reduction ratio and reserve ratio (δ). The reserve ratio is 2/3. In other words, the standard allowance ratio is 1/3 of the standard reduction ratio. Through simulation, the standard allowance ratio and standard reduction ratio is obtained.

$$\beta_m = (1 - \delta)\alpha_m \tag{5}$$

The target water quality, C_0, is calculated as follows:

$$C_0 = C_e + \beta(C_b - C_e) \tag{6}$$

where C_e is present water quality, $C_b - C_e$ is allowable loads, β is allowance ratio, and C_b is the standard value.

When C_0 of Eqs. (1) and (6) is below 1a (<0.010 mg/L) of lake water standard, the target is determined as 1a level.

The allowance of each section (β) is obtained using the standard allowance ratio (β_m) and weight (γ) as follows.

3.6. Reducible load

The maximum reducible TP amount of each watershed (Table 4) is obtained by considering the reduction plan for each river, capacity of the water treatment facility, and reduction ratio by the endpoint of each phase plan, which is given in Table 5. Nevertheless, the values of Table 4 do not

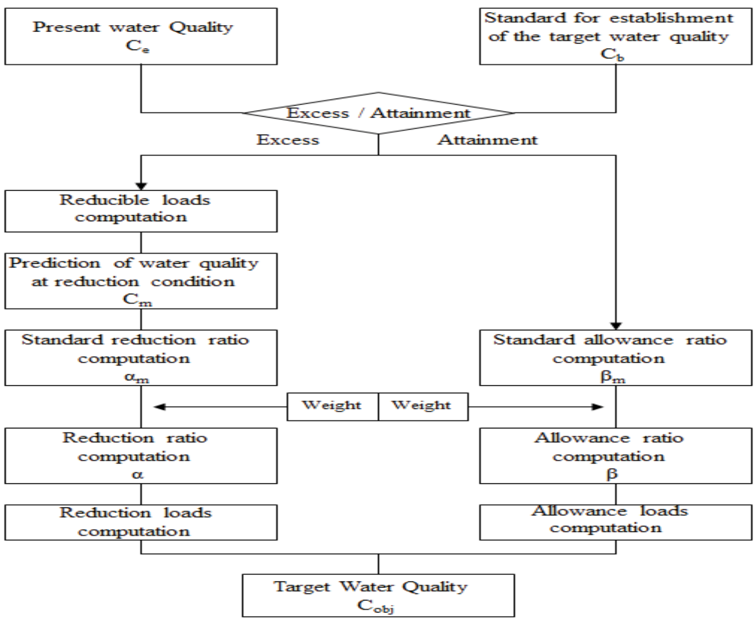

Fig. 5. Flow diagram for establishing target water quality.

Table 4
Maximum reducible TP amount (kg/d) of each pollution source

Pollution source	Yeongsan River	Seomjin River	Geum River	Nakdong River
Domestic	259.4	182	116.8	5,231.8
Livestock	0.0	0.0	65.6	163.1
Industry	45.1	29.9	23.4	542.2
Land use	137.7	98	78.0	1,201.6
Landfill	0.0	0.4	–	3.5
Wastewater treatment plants	803.1	95.5	36.9	–
Total	1,245.3	405.8	320.7	7,142.2

Table 5
Standard and reduction ratio of each watershed

Watershed	Standard, C_b (mg/L)		Standard reduction ratio, α_m (%)
	Dry season	Normal season	
Yeongsan River	0.417	0.353	35
Seomjin River	0.043	0.071	43
Geum River	0.027	0.028	25
Nakdong River	0.166	0.137	35

represent the actual reduction amount. Reduction loads are obtained by considering a reduction ratio and weight when the current water quality (C_e) of the area exceeds the standard value (C_b).

Table 4 shows that there is a difference in TP reductions depending on the type of pollutant in each water system. In the case of Yeongsan River, TP reduction in sewage treatment plants is the most likely. In the case of the Seomjin River, the potential for TP reduction was higher in the order of domestic pollution source, land pollution source, and sewage treatment plant. In the case of Geum River, TP reductions were most likely in order of domestic pollution source, land use, and livestock pollution source. In the case of the Nakdong River, TP reductions were most likely in the order of domestic sources of pollution, land use, and industrial wastewater. Therefore, it is possible to know which pollutants should be managed in order to effectively reduce TP in each water system.

3.7. Standard value, standard reduction ratio, TP pollution load density, and weight

To meet the target water quality at reference points by the endpoint of each phase, the current water quality and reduction loads are considered. At Nakbon L, the standard value is 0.137 mg/L during the normal season and 0.166 mg/L during the dry season to meet a TP target of 0.074 mg/L, and the standard reduction ratio is 35%. At Geumbon F, the TP target is 0.026 mg/L. The standard value is 0.028 mg/L during the normal season and 0.027 mg/L during the dry season, and the standard reduction ratio is 25%. At Yeongbon E, the TP target is 130 mg/L. In order to achieve the goal, the standard reduction ratio is 35%, and the standard value is 0.353 mg/L during the normal season and 0.417 mg/L during the dry season. As for Seombon E, the TP target is 0.042 mg/L. In order to meet the target, the standard value is 0.071 mg/L during the normal season and 0.043 mg/L during the dry season, and the standard reduction ratio is 43% as shown in Table 5.

TP load density of each watershed and weight are presented in Table 6. A(–) weight means additional reduction is required because water quality is higher than the standard. A(+) weight means that water quality is lower than the standard at the watershed. Therefore, a certain amount of pollutant emission can be allowed for development.

Weight is established by comprehensively considering the current water condition in each unit watershed, the difference in water quality compared to the reference water quality, the composition of the pollutants, the capacity to reduce pollutants, and the financial status.

As shown in Table 6, the units of Hwangnyeong A, Yeongbon A, Seombon E, Geumbon C, Nakbon A and Milyang A should establish a reduction plan to improve water quality since the quality of each unit watershed is higher than the reference water quality. In order to achieve the target water quality of the reference unit watershed located at the end of each unit watershed, these six-unit watersheds should reduce the contaminants to the level to which the weight given in Table 6 is considered.

Because the remaining unit watersheds are of lower water quality than the reference water quality, some partial development is allowed. However, these areas cannot be developed beyond the levels at which the weights given in Table 6 are considered. Because partial development is feared to cause water pollution, the amount of development is limited to a certain level.

Table 6
TP emission load density and weight of each watershed

Watershed	Unit area	TP emission load density, ω (kg/km²)	Weight (γ)
Yeongsan River	Hwangnyeong A	0.8	–0.250
	Yeongbon A	0.9	–0.218
	Yeongbon B	1.5	0.005
	Yeongbon E	2.3	0.250
Seomjin River	Seombon C	0.7	0.015
	Yocheon B	1.3	0.250
	Seombon E	0.6	–0.068
Geum River	Geumbon C	0.3	–0.250
	Geumbon D	0.5	0.048
	Geumbon F	0.5	0.022
Nakdong River	Nakbon A	0.7	–0.111
	Nakbon F	1.2	0.013
	Nakbon G	3.1	0.144
	Nakbon L	1.8	0.057
	Geumho B	2.1	0.075
	Geumho C	4.6	0.250
	Hoecheon A	1.2	0.011
	Milyang A	0.5	–0.158

Table 7
TP target water quality of each watershed

Watershed (unit area)	Current water quality (mg/L) (recent 1 y average)	Water quality at basic plan, C_b (mg/L)		Target water quality, C_{obj} (mg/L)	
		Dry season	Normal season	Dry season	Normal season
Yeongsan River					
Hwangnyeong A	0.102	0.109	0.093	0.130	0.113
Yeongbon A	0.153	0.133	0.134	0.134	0.151
Yeongbon B	0.779	0.725	0.569	0.620	0.496
Yeongbon E	0.238	0.169	0.144	0.130	0.124
Seomjin River					
Seombon C	0.051	0.033	0.037	0.037	0.044
Yocheon B	0.108	0.120	0.069	0.086	0.055
Seombon E	0.068	0.045	0.018	0.042	0.020
Geum River					
Geumbon C	0.023	0.010	0.012	0.013	0.014
Geumbon D	0.027	0.016	0.024	0.017	0.024
Geumbon F	0.020	0.015	0.018	0.015	0.018
Nakdong River					
Nakbon A	0.066	0.042	0.048	0.039	0.057
Nakbon F	0.099	0.061	0.057	0.060	0.059
Nakbon G	0.193	0.199	0.132	0.137	0.101
Nakbon L	0.119	0.087	0.088	0.060	0.074
Geumho B	0.083	0.041	0.032	0.041	0.033
Geumho C	0.471	0.417	0.312	0.254	0.202
Hoecheon A	0.052	0.049	0.022	0.060	0.034
Milyang A	0.036	0.011	0.012	0.031	0.028

3.8. Water quality target

Table 7 shows target water quality values based on standard values, reducible loads, weight, and allowance ratio. Target water quality during the dry season and normal season are obtained. Higher values are fixed as the actual targets (underlined values in the table). By selecting the higher value, the target can be met during both dry and normal seasons.

In the case of flood and rainy season, it was difficult to manage water quality due to heavy rainfall, so only dry and normal season were considered when setting the target water quality. This is because it is difficult to control water pollution caused by flood and rainy season not only by the TMDL but also by the non-point pollution source management policy.

Also, the reason why both dry and normal season is considered is that the water quality of the unit watershed may be poor depending on the type of contaminant, and the water quality of the unit watershed may deteriorate in the normal season. Usually, the BOD water quality of dry season is higher than that of the normal season. This is believed to be due to the dilution effect caused by rainfall.

In contrast, the water quality of TPs is often higher during the normal season, as rainfall often causes more leakage of TP from sources than from reservoirs. The reason why this phenomenon occurs is that the types of pollutants, such as rice paddies, fields, livestock and forests around the unit watershed, are different, and the characteristics of rainfall and topographical features are different.

Therefore, for TP, the target water quality was set when the water quality became the worst considering both dry and normal season. In other words, the target values were set so that both periods of water quality conditions could be satisfied.

4. Conclusions and recommendations

Target water quality must be determined by considering a variety of factors such as for purposes of water usage, current status of water body, present and future pollutant emission, water treatment facilities and future facilities construction plans, and allocated budget.

When setting the target water quality of each unit watershed, it is necessary to set the policy-based target value of unit watershed first, and then, estimate to what levels water quality should be maintained in all upstream watersheds to achieve the target for the reference unit watershed. If the actual measured water quality is cleaner than the estimated water quality, a certain amount of development loads should be assigned. Moreover, development should be deterred in unit watersheds with actual measured water quality being higher than the estimated water quality and an appropriate reduction must be induced by considering the conditions of those unit watersheds.

If the target is too high, then water quality improvement is difficult to achieve. If the target is too low, then the target itself can become an obstacle to local development. Accordingly, the key to a successful TMDL system is to pursue both water quality improvement and local development as well as to set appropriate targets.

Moreover, because the target water quality must be satisfied with all precipitation conditions, except for extreme flood and dry seasons, target water quality was set as predicted water quality that is higher than the predicted water quality of dry and normal-water seasons.

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