Chapter 6 ENVIRONMENTAL QUALITY STANDARDS FOR WATERS

--- NITROGEN AND PHOSPHORUS STANDARDS FOR LAKES AND RESERVOIRS ---

1. Historical Backgrounds for the Legislation

Environmental water quality standards (EWQS) in terms of COD for lakes and reservoirs were legislated in 1945 to control organic pollution and extensive efforts like effluent regulations were made to comply with the EWQS. Unfortunately, percent compliance has been around 40 %, and various problems on water use associated with eutrophication became explicit after mid 1970's. Typical problems associated with the deterioration of water quality are decrease in transparency, colored water, clogging of sand filters in water treatment plants, taste and odor in finished water, and fish kills caused by massive growth of phytoplankton.

All of these problems are originated from massive growth of phytoplankton in lakes and the growth is known to be controlled by nitrogen and phosphorus concentrations. Thus, nitrogen and phosphorus standards for phosphorus were legislated in 1982 as one of the environmental water quality standards to maintain living environment.

2. Basic Concepts for the Legislation

It is necessary to determine both nitrogen and phosphorus concentration to satisfy water uses or to prevent damages in water use caused by eutrophication in lakes and reservoirs. The first step was to identify expected water quality to prevent the problems and possible nutrient concentration.

It is known that nitrogen and phosphorus are limiting nutrients in most lakes. The changes in water quality by eutrophication are caused by the increase in organic substances originated from primary production of phytoplankton. Primary production is controlled not only by chemical parameters like nutrients but also by physical factors like light intensity, water temperature, mixing of water, hydraulic retention time and shape of lake basin. It is impossible to take all of these parameters into consideration into the expected water quality. These factors should be considered when the expected water quality is applied for specific lakes.

3. Expected Nitrogen and Phosphorus Concentration for Lakes

The expected nitrogen and phosphorus concentration for lakes and reservoirs are shown in Table 6-1. Annual average concentration in surface water (0.5 m) was adopted as representative water quality because eutrophication is associated with phytoplankton growth in photic zone. Corresponding water quality parameters are expected values corresponding to annual average total nitrogen and phosphorus concentration.

3.1 Correlation between Total Nitrogen/Phosphorus Concentration and Chlorophyll-a Concentration

Fig. 6-1 shows relationships between summer chlorophyll-*a* concentration in the surface and total nitrogen and phosphorus concentration reported by Sakamoto (1966). It is clear that higher nitrogen and phosphorus concentration support the higher concentration of chlorophyll-*a*. The increase in nitrogen concentration associated with the increase in phosphorus concentration in most lakes. Especially, linear relationship was noted within the range of N/P from 10/1 to 25/1. Thus, trophic level of lakes can be estimated either by nitrogen or phosphorus in most waters.

The relationships shown in Fig. 6-1 between summer chlorophyll-*a* concentration in the surface and total phosphorus concentration is expressed as;

$$\log[\mathrm{chl}] = 1.583 \log[\mathrm{T\text{-}P}] + 3.615 \ldots\ldots (1)$$

Similar correlation is also reported from many circles. Table 6-2 summarized some of these reported values.

Table 6-1 Expected nitrogen and phosphorus concentration in lakes and reservoirs.

category	annual average total nitrogen (mg/l)	reference parameters		
		summer chlorophyll-*a* (mg/l)	transparency (m)	hypolimnetic DO in summer
	less than	less than	more than	more than
I	0.07	1	6	50 %
II	0.15	3	4	-
III	0.40	20	2	-
IV	0.60	40	1	-
V	1.00	-	-	-

category	annual average total phosphorus (mg/l)	reference parameters		
		summer chlorophyll-*a* (mg/l)	transparency (m)	hypolimnetic DO in summer
	less than	less than	more than	more than
I	0.005	1	7	50 %
II	0.01	3	4	50 %
III	0.03	20	2	-
IV	0.05	40	1	-
V	0.10	100	-	-

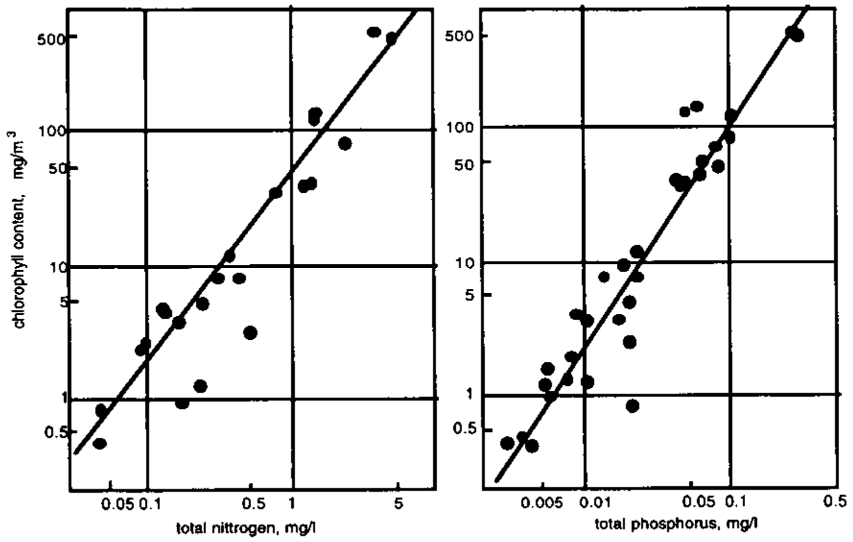

Fig. 6-1 Relationships between summer chlorophyll-a concentration in the surface and total nitrogen and phosphorus concentration (Sakamoto 1966).

Table 6-2 Estimated Chlorophyll-a concentration form T-P.

T-P (mg/l)	Chlorophyll-a concentration (mg/l)				
	Expected	Sakamoto (1966)	Dillon & Rigler (1974)	USEPA (1972)	Carlson (1977)
0.005	1	0.9	0.8	1.2	0.9
0.01	3	2.8	2.1	2.6	2.4
0.03	20	16	10	9.6	12
0.05	40	36	21	18	25
0.10	100	108	58	40	69

The relationships shown in Fig. 6-1 between summer chlorophyll-*a* concentration in the surface and total nitrogen concentration is expressed as;

$$\log[\mathrm{chl}] = 1.393 \log[\mathrm{T\text{-}N}] + 1.660 \qquad (2)$$

The values in Table 6-1 were estimated from Eq. (2) and other reported values.

3.2 Correlation between Total Nitrogen/Phosphorus Concentration and transparency

Ichimura (1956) reported the following correlation between transparency (m) and chlorophyll-a concentration from Japanese lakes.

$$\log[\mathrm{Tr}] = 0.789 - 0.49\log[\mathrm{Chl}] \qquad (3)$$

$$\log[\mathrm{Tr}] = -0.776\log[\mathrm{T\text{-}P}] - 0.982 \qquad (4)$$

$$\log[\mathrm{Tr}] = -0.683\log[\mathrm{T\text{-}N}] - 0.0244 \qquad (5)$$

Substitution of Eq. (3) into Eqs. (1) and (2) give Eqs. (4) and (5). The values in Table 6-1 were estimated from Eqs. (4) and (5) and other reported values.

3.3 Correlation between Total Phosphorus Concentration and Hypolimnetic Dissolved Oxygen Concentration

One of the most significant changes in water quality with direct impacts on aquatic organisms associated with eutrophication is decrease in hypolimnetic oxygen deficit. Thus, it is necessary to define expected water quality to prevent these problems.

Summer stratification develops in many of deep lakes in Japan. Most of phytoplankton produced is decomposed in the productive zone. However, a part of them precipitates into hypolimnetic zone and is decomposed. Although the percent precipitate is estimated to be from 10 to 15%, the decomposition consume dissolved oxygen and decrease hypolimnetic DO. Allochthonous organic matter is also decrease DO.

The rate of decrease in hypolimnetic DO is dependent on the amount of organic substances supplied from the productive zone. This amount is dependent on T-P. Thus the hypolimnetic DO deficit can be estimated from T-P, the period after the start of stratification, volume ratio between productive and hypolimnetic zone.

Based on the assumptions that the percent organics decomposed in hypolimnetic zone is 15 % of the produced, the rate of production in the productive zone is 10 mg C/mg Chl/day, and the volume ratio of productive zone is 50 %, hypolimnetic DO is estimated to decrease down to zero in four months from the start of stratification if T-P is 0.03 mg/l. Saturation percent of DO will be 50% if T-P is 0.018 mg/l. Therefore, we can expect hypolimnetic DO more than 50 % if we maintain T-P less than 0.01 mg/l.

Table 6-3 shows estimated hypolimnetic DO values in 4 months after summer stratification and corresponding T-N in Japan with the assumption that hypolimnetic water temperature is 10 deg. C. The table shows that 0.07 mg T-N/l or less will be enough to maintain hypolimnetic DO more than 50 % as shown in Table 6-1.

Table 6-3 Estimated hypolimnetic DO values at 4 months after summer stratification and T-N.

hypolimnetic DO (%)	0 %	50 %	80 %	net primary production rate
T-N in surface (mg/l)	0.21	0.072	-	10 mg C/chl-a mg/day
	0.59	0.22	0.055	5 mg C/chl-a mg/day

4. Water Use and Nitrogen and Phosphorus Standards for Lakes

The standard values both for nitrogen and phosphorus were determined based on expected uses of lake waters. The uses presumed as a basis of the standard are as follows;

1) Conservation of natural environment
2) Drinking water supply: class 1, 2, 3
3) Recreation/ bathing
4) Fisheries: class 1, 2, 3
5) Irrigation
6) Industrial water supply
7) Conservation of environment

4.1 Conservation of natural environment

The use specified for this category presumed the use of lakes as recreational purpose such as sightseeing and scenic beauty. Water quality must be kept as natural as possible. The expected chlorophyll-a concentration for this category was 1 mg m^{-3} or less. Taking water quality in Lake Mashu and Lake Shikotsu with high transparency, the standard was less than 0.005 mg l^{-1} in T-P and 0.1 mg l^{-1} in T-N.

4.2 Drinking water supply

Eutrophication of lakes and reservoirs cause various detrimental effects on drinking water supply. Clogging of slow and rapid sand filtration or musty odor in finished water frequently happens in water works taking their raw water from mesotrophic lakes. However, these troubles are not uniform for all treatment trains. The standards were determined taking treatment process into consideration.

(1) Water supply class 1

Water supply class 1 is applied to purification plants with slow sand filtration. Musty odor seldom happens in this process because odorous compounds are decomposed in filters. However, phytoplankton may clog filters.

Table 6-4 shows phosphorus and nitrogen concentration in raw water where troubles in slow sand filtration were reported. Based on this information, we estimated that there will be little troubles in filtration if T-P is less than 0.01 mg/l and T-N is less than 0.15 mg/l in Japanese water purification plants. Thus the phosphorus and nitrogen standards for class 1 are 0.01 mg T-P l^{-1} or less and 0.2 mg T-N l^{-1} or less, respectively .

Table 6-4 Nitrogen and phosphorus concentration in lakes and reservoirs for raw waters with troubles in slow sand filtration.

plants	lakes	T-N (mg/l)	lakes	T-P (mg/l)
with troubles	Michihara Reservoir	0.35-0.68	Yamaguchi Reservoir	0.03 - 0.07
	Lake Nojiri	0.15-0.41*	Murayama Reservoir	0.02 -0.05
	Yamanoda Reservoir	0.26-0.57*	Lake Biwa (South)	0.014 - 0.071
	Komoda Reservoir	0.27-0.39*	Lake Asahikawa	0.03*
w/o troubles	-	-	Ogouchi Reservoir	0.012 - 0.033

* estimated from inorganic N and P concentrations

(2) Water supply class 2 and 3

The class 2 water presumes conventional coagulation and rapid sand filtration process for purification. Table 6-5 shows phosphorus and nitrogen concentration in raw water where troubles in rapid sand filtration such as frequent clogging and increase in chemical doses were reported. There will be little troubles in rapid sand filtration if T-P is less than 0.03 mg/l and T-N is less than 0.4 mg/l.

Table 6-5 Nitrogen and phosphorus concentration in lakes and reservoirs for raw waters with troubles in rapid sand filtration.

plants	lakes	T-N (mg/l)	lakes	T-P (mg/l)
with troubles	Lake Kasumigaura	1.21	Lake Kasumigaura	0.10-0.24
	Tonden Reservoir	0.76-1.57	Lake Sagami	0.2*
	Hata Reservoir	0.40-0.66	-	-
w/o troubles	-	-	Yamaguchi Reservoir	0.03-0.07

* estimated from inorganic N and P concentrations

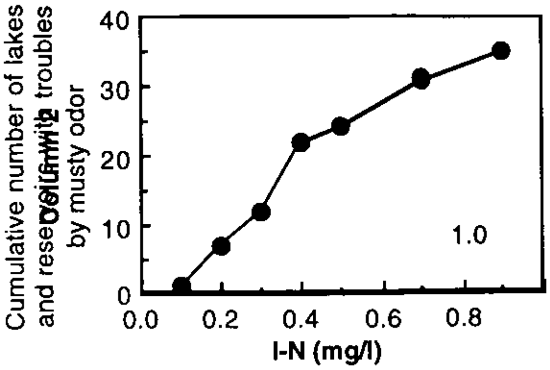

Fig. 6-2 Relationship between number of troubles by musty odor and inorganic nitrogen concentration

Another troubles associated with eutrophication is musty odor problems mainly caused by actinomycetis and/or cyanobacteria. Japan Water Works Association reported that musty odor problems are frequently reported from reservoirs with inorganic nitrogen and ortho-phosphate concentrations of more than 0.3 mg l^{-1} and 0.006 mg l^{-1} in circulation period. This phosphorus concentration generally corresponds to total phosphorus of 0.009 mg l^{-1}.

Lakes and reservoirs where cyanobacteria is abundant frequently encounter troubles by musty odor. As shown in Fig.6-2, the number of lakes with musty odor increases if inorganic nitrogen concentration is more than 0.1 mg l^{-1}. This concentration was estimated to correspond to 0.15 mg l^{-1} as T-N. Therefore, the critical T-N and T-P to prevent musty odor are 0.1 mg l^{-1} and 0.01 mg l^{-1} respectively.

To prevent increase in chemical dose and frequent clogging, total phosphorus concentration must be less than 0.03 mg l^{-1} as shown above. However, this criterion is not enough to prevent musty odor. Thus the standards for the class 2 are less than 0.01 mg T-P l^{-1} and 0.2 mg T-N l^{-1}.

If the raw water is categorized as class 3, advanced water treatment processes including pretreatment are necessary. If the additional treatment can remove musty odor, the standards are less than 0.03 mg T-P l^{-1} and 0.4 mg T-N l^{-1}. However, removal of odorous compounds is not expected by the advanced treatment, the same standards are applicable to prevent odor, i.e. 0.01 mg T-P l^{-1} and 0.2 mg T-N l^{-1} .

Iron and manganese are also serious problem for drinking water supply. These problems are caused by the decrease in hypolimnetic DO. Maximum allowable T-N and T-P concentration to prevent DO deficit in lakes with productivity of 5 mg C mg^{-1} chl day^{-1} were estimated to be 0.6 mg l^{-1} and 0.05 mgl^{-1}, respectively.

4.3 Recreation/bathing

The use specified for this category are the use of lake environment as recreational purpose for bathing/swimming. The data used was from northern basin of Lake Biwa, because some beaches are still being used as bathing area. Taking the water quality in 1960's when all the beaches were in excellent condition, the standard was 0.01 mg T-P l^{-1} and 0.2 mg T-N l^{-1}.

4.4 Fisheries: class 1, 2, 3

It is known that the increase in primary production, i.e. phytoplankton production, increases the production of secondary and higher producers, i.e. fish production. Some circles claimed that nutrient control may decrease phytoplankton production and, hence, decrease fishery production. Although fishery production increased with the increase in primary production, it leveled of at a certain level of primary production and decreased if primary productivity is too high.

Not only the amount of fishery production, but also species changed drastically with the increase in the primary production: Salmons and trout are common in oligotrophic lakes in Japan, but carps and roaches are known to be abundant in eutrophic lakes.

Fisheries class 1 corresponds to water quality to keep populations of salmons and trout. Taking the water quality of lakes where these fishes are inhabiting such as Lake Chuzenji and Lake Biwa, the standard was 0.01 mg T-P l^{-1} and 0.2 mg T-N l^{-1}.

Fisheries class 2 is expected to keep populations of intermediate pollution tolerant species such as pond smelts. Typical lakes with high production of pond smelts are Lake Suwa and Lake Hachirogata. From the water quality of these lakes the standard was determined as 0.05 mg T-

P l^{-1} and 0.6 mg T-N l^{-1}.

Production of carps and roaches increases with the increase in nitrogen and phosphorus, whereas it levels off and frequent damages like fish kills by anoxic water and odorous fishes become common if T-P is more than 0.01 mg l^{-1} and T-N is more than 0.2 mg l^{-1}. These values are adopted as standard for class 3.

4.5 Irrigation

Agricultural productions are also impaired when farmlands are irrigated by water taken from eutrophic water bodies. Particularly, nitrogen concentration higher than 1 mg l^{-1} is regarded to damage rice production by excessive growth of plant and by intolerance to diseases. Taking the water quality criteria for irrigation, the standard was determined as 1.0 mg T-N l^{-1} or less.

4.6 Industrial water supply

Another important use of lake water is industrial water supply. Surveys on the water quality of lakes being used as raw water for industrial purpose, such as Lake Biwa and Lake Kasumigaura, indicated that little problems are reported if T-N and T-P were less than 1.0 mg l^{-1} and 0.1 mg l^{-1}, respectively. These values are adopted as standard for industrial water supply.

4.7 Conservation of environment

Lake Inbanuma and Lake Kojima are among the worst in water quality. The waters frequently bother daily life of people living in the lake sides either by the odor come from massive growth and death of phytoplankton and macrophytes. T-P and T-N in these lakes are shown in Table 4. From these values, the standard for the conservation of environment was determined as 0.1 mg T-P l^{-1} and 1.0 mg T-N l^{-1} or less.

Table 6-6 Nitrogen and phosphorus concentration in the most eutrophic lakes in Japan (1995)

lakes	T-N (mg l^{-1})	T-P (mg l^{-1})
Lake Teganuma	5.3	0.51
Lake Inbanuma	2.1	0.14
Lake Kojima	2.0	0.20

Table 6-7 Nitrogen and phosphorus standards for lakes and reservoirs (mg l^{-1})

category	water use	T-N	T-P
I	conservation of natural environment, and uses II-V	0.1	0.005
II	water supply class 1, 2, and 3, fishery class 1, bathing , and uses III-V	0.2	0.01
III	water supply class 3, and uses IV-V	0.4	0.03
IV	fishery class 2, and use V	0.6	0.05
V	fishery class 3, industrial water, irrigation water, conservation of environment	1.0	0.1

water supply: class 1: sand filtration
class 2 : coagulation/ rapid filtration
class 3: pretreatment, advanced water treatment

fisheries: class 1: salmon, trout, ayu
class 2: pond smelt (wakasagi)
class 3: carp, catfish, roach

environmental protection: no odor in the vicinity

5. Classification of lakes and reservoirs

The standards for nitrogen and phosphorus mentioned above are listed in Table 6-7. There are five categories in terms of annual average total nitrogen and phosphorus concentrations. This is because basic data adopted to determine EWQS were annual average values taking large fluctuation of concentration. All of these values correspond to surface water quality at 0.5 m and phosphorus standards should not be applied for irrigation water. Not all the lakes and reservoirs, but those with high possibility of massive growth of phytoplankton are classified.

It is well known that the limiting nutrient in freshwater is generally phosphorus. Nitrogen standards, therefore, are applicable to lakes whose primary productivity might be limited by nitrogen by the following criteria;

1)T-N/T-P is less than 20, and
2)T-P is more than 0.02 mg/l.

6. Criteria for Compliance and Present State of Eutrophication

6.1 Criteria for Compliance

The compliance for the standard is evaluated based on the maximum value of annual averages of all the environmental standard points (ESP). Basic data to legislate nitrogen and phosphorus standards for lakes were annual average values of the ESP located at the center of lakes. It is reported that historical changes in water quality in various ESPs showed similar trends both in Lake Biwa and Lake Kasumigaura. The maximum value, therefore, was adopted as a criterion to represent water quality of whole lake.

6.2 Present State of Eutrophication

Table 6-8 shows total number of lakes and reservoirs where nitrogen and/or phosphorus standard are being applied and their compliance with the standard. Percent compliance was 41.7 % in 1994. As shown in Fig 6-3, however, significant improvement in the percent compliance was not noted after the start of regulation, i.e. 38.6 % in 1989.

Table 6-8 Number of lakes with N and/or P standard and compatibility (1994)

category	lakes with standard	compatible	% compliance
I	7	5	71
II	18	12	67
III	11	3	27
IV	9	0	0
V	3	0	0
total	48	20	41.7

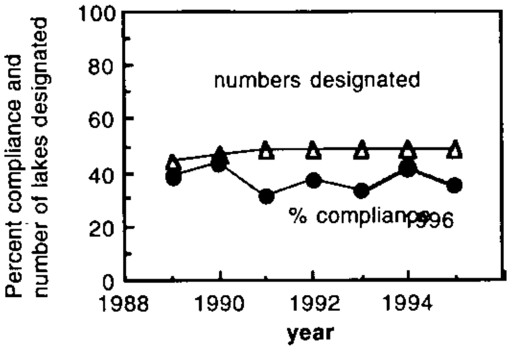

Fig.6-3 Numbers of lakes classified and percent compliance after the start of regulation.