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The Limnological Survey and Phosphorus Loading of Lake Hoengsung

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A limnological survey was conducted in a reservoir, Lake Hoengsung located in Kangwondo, Korea, from July 2000 to September 2001 on the monthly basis. Phosphorus loading from the watershed was estimated by measuring total phosphorus concentration in the main tributary. Secchi disc transparency, epilimnetic (0-5 m) turbidity, chlorophyll *a* (Chl-*a*), total phosphorus (TP), total nitrogen (TN) and silica concentration were in the range of 0.9-3.5 m, 0.1-8.5 NTU, 0.3-32.4 mgChl m^{-3}, 5-46 mgP m^{-3}, 0.83-3.55 mgN L^{-1} and 0.5-9.6 mgSi L^{-1}, respectively. Green algae and cyanobacteria dominated phytoplankton community in warm seasons, from July through October, 2000. In July a green alga (*Scenedesmus* sp.) was dominant with a maximum cell density of 10,480 cells mL. Cyanobacteria (*Microcystics* sp.) dominated in August and September with cell density of 3,492 and 296 cells mL, respectively. Species diversity of phytoplankton was highest (2.22) in July. The trophic state of the reservoir can be classified as eutrophic on the basis of TP, Chl-*a*, and Secchi disc transparency. Because TP concentration was high in flood period, most of phosphorus loading was concentrated in rainy season. TP loading was calculated by multiplying TP and flow rate. The dam managing company measured inflow rate of the reservoir daily, while TP was measured by weekly surveys. TP of unmeasured days was estimated from the empirical relationship of TP and the flow rate of the main tributary; $TP = 5.59Q^{0.45}$ ($R^2 = 0.47$). Annual TP loading was calculated to be 4.45 tP yr^{-1}, and the areal P loading was 0.77 gP m^{-2} yr^{-1} which is similar to the critical P loading for eutrophication by Vollenweider's phosphorus model, 0.72 gP m^{-2} yr^{-1}.

Key words : Lake Hoengsung, limnological survey, phosphorus loading, trophic state

INTRODUCTION

Most of the Korean reservoirs are constructed for multiple purposes such as flood control, hydroelectricity generation, agro-industrial uses, and drinking water supply. Although there are about 18,000 lakes of both natural and artificial origins in South Korea, the initial limnological data are absent in most of the cases.

Korean reservoirs, the major supplier to the agricultural water demand, are facing the growing problem from the consequences of cultural eutrophication. As Korean irrigation system is still managed in traditional way, receiving water bodies are excessively enriched by the nutrients discharged from the catchment area, resulting in higher primary production. Biomass of aquatic plant is often taken as an important basis for classifying the lakes due to their higher effects

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on the overall productivity of the aquatic ecosystem.

As most of the Korean reservoirs are built by damming the rivers, increased transport of the allochthonous nutrients from the nearby land and the relatively lower flushing rate helps in accelerating the eutrophication. Thus, poor management of a catchment area can be pointed as a major reason for the rapid cultural eutrophication (Kim *et al.*, 1997).

Increased inflow of nutrients sustain the accelerating growth rates of phytoplankton and marcophytes and thus increase the vulnerability to eutrophication. Most of artificial lakes in Korea are subject to eutrophication because of increasing pressure of development and livestock in the watershed, and poor watershed management (Kim *et al.*, 1997). Preventing eutrophication of lakes is often difficult, as the restoration program is usually associated with high cost and long time (Kim *et al.*, 1999).

After 1980s, accelerating rates of industrialization and urban development resulted in rapid eutrophication of most of the Korean lakes. Increased concentration of organic matters was the major water quality problem. In order to establish management measures of water bodies, limnological perspectives are required to understand the lake ecosystem function, the quality and quantity of pollutants flowing into water bodies, the interrelation of biotic and abiotic factors within lakes (Kim *et al.*, 1998).

The discharge of nutrients from watersheds occurs mostly in the rainy seasons in Korea due to summer monsoon climate. Phosphorus input is one of the most important factors in the eutrophication of lakes (Schindler and Fee, 1974; Bloesch *et al.*, 1977). It is also an important indicator in classifying the trophic state of lakes and in predicting the biomass of phytoplankton (Stauffer, 1985). In most of the Korean reservoirs phosphorus loading during summer account for 70–80% of annual phosphorus loading (Heo *et al.*, 1992; Lee *et al.*, 1993; Kim *et al.*, 1997; Heo *et al.*, 1998).

Lake Hoengsung constructed in the Sum River, has a surface area of 5.82 km^2, average annual rainfall of 1,320 mm, total water capacity of 8.69 $\times 10^7$ m^3, and the watershed area of 209 km^2. This study was carried out from July 2000 till September 2001 to investigate the basic limnological characteristics and to assess of phosphorus loading from the watershed.

BACKGROUND AND HYDROLOGICAL PROPERTIES

Lake Hoengsung is located on a tributary of the Han River in Hoengsung–Gun county of the Kangwondo province (Fig. 1). Apart from generating hydro–electricity of about 10.4 GWH, Lake Hoengsung also serves as an important multipurpose water resources, supplying water of about 111.6×10^6 m^{-3} yr^{-1} to the cities of Wonju, Hoengsung, and Munmak for domestic, agricultural and industrial uses.

It has mean hydraulic residenc time of 0.42 yr (Table 1). It is located in the central part of Korean Penninsula and it has average climate condition of Korea.

Data from the regional meteorological stations in nearby of Wonju, Chuncheon and Hoengsung showed that the yearly averages of temperature, precipitation and relative humidity of Lake Hoengsung were 10.5°C, 1,320 mm, and 71% respectively (Ministry of Construction, 1991).

The annual precipitation is 1,3770 mm and the watershed had alluvial soils, making it a favorable place for growing mixed crops (Ministry of Construction, 1991). Forest covers 76.7% (1,438.13 km^2) of the watershed, and 16.2% (304.07 km^2) is agricultural fields. The area of upland fields is

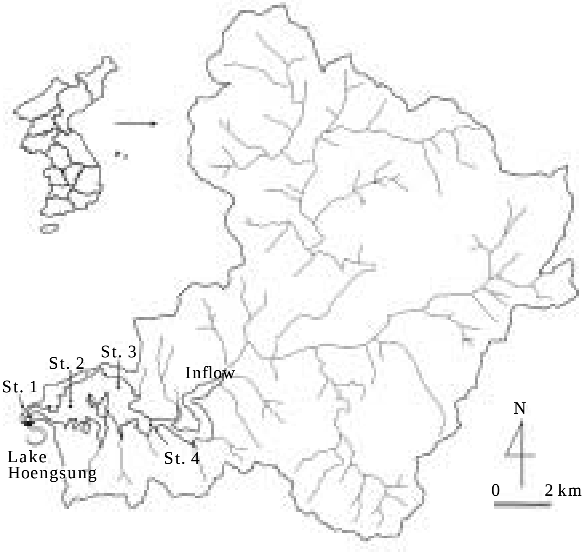

Fig. 1. Map showing the sampling site and watershed of Lake Hoengseong.

Table 1. Hydrological characteristics and the land use in the watershed of Lake Hoengsung (Ministry of Construction, 1991).

Surface area (km^2)	5.82
Water capacity ($\times 10^6$ m^3)	86.9
Average water volume	73.4
Annual water inflow ($\times 10^6$ m^3)	176.0
Water supply ($\times 10^6$ m^3 yr^{-1})	111.6
Drainage area (km^2)	209.0
Hydraulic residence time (year)	0.42
Ratio of (drainage area/lake surface area)	35.9
Maximum depth (m)	38.2
Mean depth (m)	14.9
Total population in the watershed (persons)	5,135
Agricultural area in the watershed (km^2)	15.1
Forests area (km^2)	112.7
Air temperature (°C)	10.3
Annual precipitation in drainage basin (mm yr^{-1})	1,377.0
Length of main axis (km)	8.0
Mean width (km)	0.73

larger than paddy fields by the ratio of 57 : 43 (Ministry of Construction, 1991).

Inflow rate, outflow rate, and the surface water elevation of Lake Hoengsung are shown in Fig. 2. This newly constructed dam was impounded since the year 2000 and was filled up in October, 2000. In the rainy seasons of 2000 and 2001, the highest monthly average precipitations were 270.6 mm mon. and 263.3 mm mon., respectively. Highest annual inflows (>80%) occurred during the rainy season (Fig. 2).

A population of 5,135 inhibited watershed of Lake Hoengsung in 2000 and the major livestock were cows and pigs numbering 2,293 and 835, respectively. The ratio of upland field to paddy field was successively increasing with the non-paddy field covering an area of 213.2 km^2. Monthly and yearly generation of TP was calculated using the unit generation rate calculated by the Ministry of Environment (Table 2). The monthly average of TP generation loading was about 6.0 tP $month^{-1}$. and the generation loading from the livestock alone amounted to be 5.0 tP $month^{-1}$ (91.9%). The yearly TP generation loading amounted to be 72.34 tons.

Table 2. The amount of phosphorus discharge from the sources in the watershed of Lake Hoengsung.

Source			Annual phosphorus loading (tP yr^{-1})
Population		5,135 person	3.06
Livestock	Cattle	2,292 head	60.23
	Pig	835 head	5.12
Land	Rice field	19 km^2	1.18
	Upland	12 km^2	0.74
	Forest	113 km^2	1.01
Total			71.34

MATERIALS AND METHODS

Monthly sampling of the lake water was conducted at three or four stations from July 200 till September 2001, except in the freezing season (shown in Fig. 1). To measure the TP loading into the reservoir, the inlet water was sampled

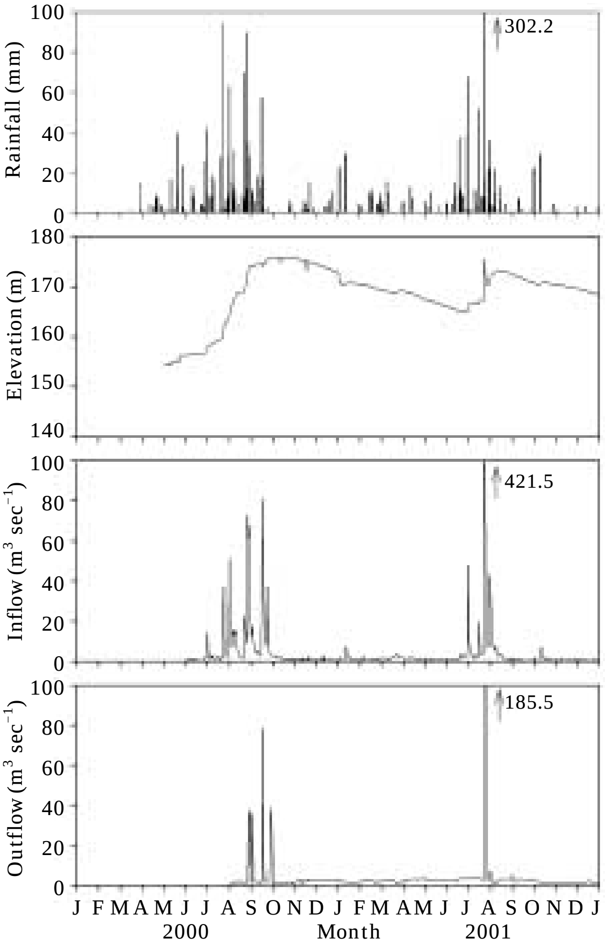

Fig. 2. Monthly variations of hydrological parameter of Lake Hoengsung.

more than once a week. The sampling site for the main tributatry was located in the upper region of the lake near Gapcheon Elementary School.

Using PVC Van Dorn water sampler, vertical samples of the lake water were collected from three depths (0, 2, 5 m) above the 5 m depths and at every 5 m interval below the 5 m depths. Samples of chlorophyll *a* were obtained by filtration through Whatman GF C glass fiber filter. Until the extraction of chlorophyll *a*, the filters were preserved in a sealed plastic container with silica gel and kept in a freezer. The amount of chlorophyll was determined spectrophotometrically according to the method of Lorenzen (1967).

DIP and DIN were measured for filtered water, while TP and TN were measured with non-filtered sample. DIP was determined by ascorbic acid method, and TP was determined by persulfate digestion method according to Standard Methods (1992). Nitrogen was calculated according to the cadmium reduction method with an autoanalyzer (BRAN+LUEBBE AutoAnalyzer3). Water temperature and turbidity were measured at the study site using a Multiprobe (YSI 6000). Phytoplankton samples collected by PVC Van Dorn sampler, were fixed by adding Lugol's solution. Then, the samples were transported to the laboratory to be stored for one week. The samples were concentrated by settling and siphoning the supernatant. Phytoplankton samples were examined under an optical microscope with the magnification of 400× by 600×. Phytoplankton species were identified according to the Pictorial handbooks of Mizuno (1964) and Algae of Japanese Freshwater (1977).

RESULTS AND DISCUSSION

Physical characteristics

The variations of air and surface water temperature showed similar patterns. The horizontal variation of water temperatures was not significant. In August 2000, thermocline was formed at the elevation of 165 m. After October autumn turnover occurred breaking the thermocline and consequently reducing the temperature from 16.5°C in October, 11°C in November, 6°C in December and was finally ice covered. Spring turnover occurred at the temperature was below 6°C in May 2001. Although an artificial aeration system was started in May 2001, the thermocline was slowly formed, which might be due to insufficient aeration power of the aerator (Fig. 3). In the case of Lake Dalbang, thermocline was reported to be destroyed completely by aretificial aeration system (Heo *et al.*, 1999; Heo and Kim, 2004).

Surface water (average of 0-5 m) turbidity was in the range of 0.1-58.5 NTU (mean 2.0 NTU) (Table 3). Turbidity was found to be higher in the inlet areas than at the dam sites. Vertical variation of turbidity was high in rainy seasons because most of turbid storm runoffs flowed into the metalimnion along the layer of same water density. The interflow of turbid runoffs was also observed in Lake Soyang and Lake Andong (Heo *et al.*, 1988, 2000). It is thought that after the rainy season inorganic suspended particles are dispersed from metalimnion to epilimnion, affecting the primary production.

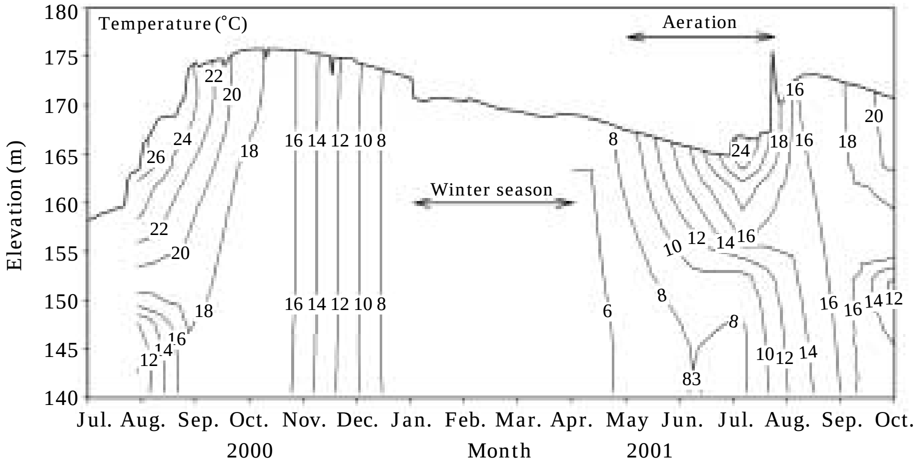

Fig. 3. The isopleths of temperature (°C) in the Dam site (St. 1).

Table. 3. A statistical summary of nutrient and the relevant hydrographical parameters (0–5 m average data of all site).

Site	Mean	SD	SE	Min	Max	N
Temp.	16.7	6.7	0.6	3.4	29.6	149
Cond.	83	9.	0.8	67	113	149
pH	7.75	0.88	0.07	6.29	9.88	149
Tur.	2.0	1.9	0.2	0.1	8.5	149
DO	9.0	2.4	0.2	2.0	14.2	123
SD	2.1	0.7	0.1	0.9	3.5	42
TP	16	9	0.8	5	46	124
DIP	4.1	2.8	0.3	0.2	13.3	124
TN	1.59	0.49	0.04	0.83	3.55	124
NO_3-N	1.12	0.41	0.04	0.09	3.33	124
NH_3-N	0.08	0.04	0.01	0.04	0.23	66
NO_2-N	0.00	0.00	0.00	0.00	0.00	58
SiO_2	6.1	2.3	0.2	0.5	9.6	124
Chl. *a*	8.8	6.7	0.6	0.3	32.4	118

1. SD = standard deviation; SE = standard error (SE = $SD/N^{0.5}$)
2. Units for nitrogen–mg L^{-1}, phosphorus–mg m^{-3}.
3. The units for the hydrographic parameters are as follows: mg L^{-1} (DO), mg m^{-3} (Chl. *a*), m (SD), °C (temperature), μS cm^{-1} (conductivity).

Secchi disc transparency was in the range of 0.9–3.5 m. The dam site (St. 1) showed higher transparency than the upper reach of the reservoir (St. 3) because of the effect of turbid storm runoff. Since U.S. EPA (1976) classifies lakes of transparency 2.0–3.7 m as mesotropic, Lake Hoengsung can be classified to be mesotrophic.

Chemical characteristic

Conductivity in the epilimnion (0–5 m average) ranged from 67–113 μS cm^{-1} (mean 83 μS cm^{-1}), upstream area (site 4) had the highest value. The metalimnion showed highest conductance during the rainy seasons. DO concentration in the epilimnion (0–5 m) was in the range of 2.0–14.2 mgO_2 L^{-1} (mean 9.0 mgO_2 L^{-1}). In July and August of 2000 DO in the epilimnion was in the range of 8.4–14.1 mgO_2 L^{-1}, but the hypolimnion was in oxygen-deficient condition (Fig. 4). Also in July and September of 2001, St. 1 recorded very low DO concentration of about 1.0 mgO_2 L^{-1} in the hypolimnion. Because the study reservoir is at the beginning stage of impoundment, terrestrial organic matter that had been accumulated before impoundment might have contributed oxygen consumption significantly (Lee, 2001). Also in August and September 2001, in the dam site (St. 1) DO minimum was observed at the metalimnion with DO of about 1.0 mgO_2 L^{-1} DO.

Fast *et al.* (1973) reported that after the artificial aeration the hypolimnion had excess DO concentration more than epilimnion. Heo *et al.*, (1999) showed that in Lake Dalbang, below the metalimnion, DO concentration increased after the artificial aeration. But in Lake Hoengsung, DO concentration in the hypolimnion depleted after the artificial aeration because of the temporary oxygen deficient phenomenon prior to the dam construction and also due to the lower aeration capacity of the aerator. Capacities of aerators are important for achieving increase in DO concentration (Fast, 1989).

Average TP of the whole lake in the epilimnion (0–5 m average) was in the range of 5–46 mgP m^{-3}

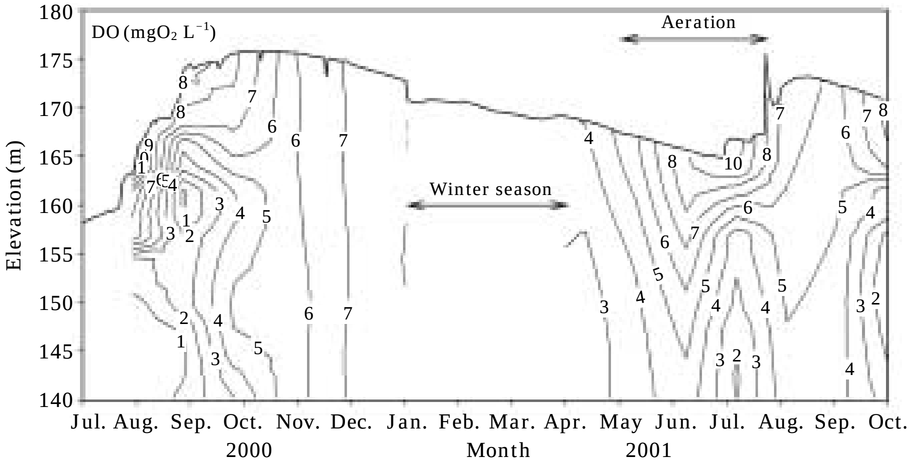

Fig. 4. The isopleths of dissolved oxygen (mgO_2 L^{-1}) in the Dam site (St. 1).

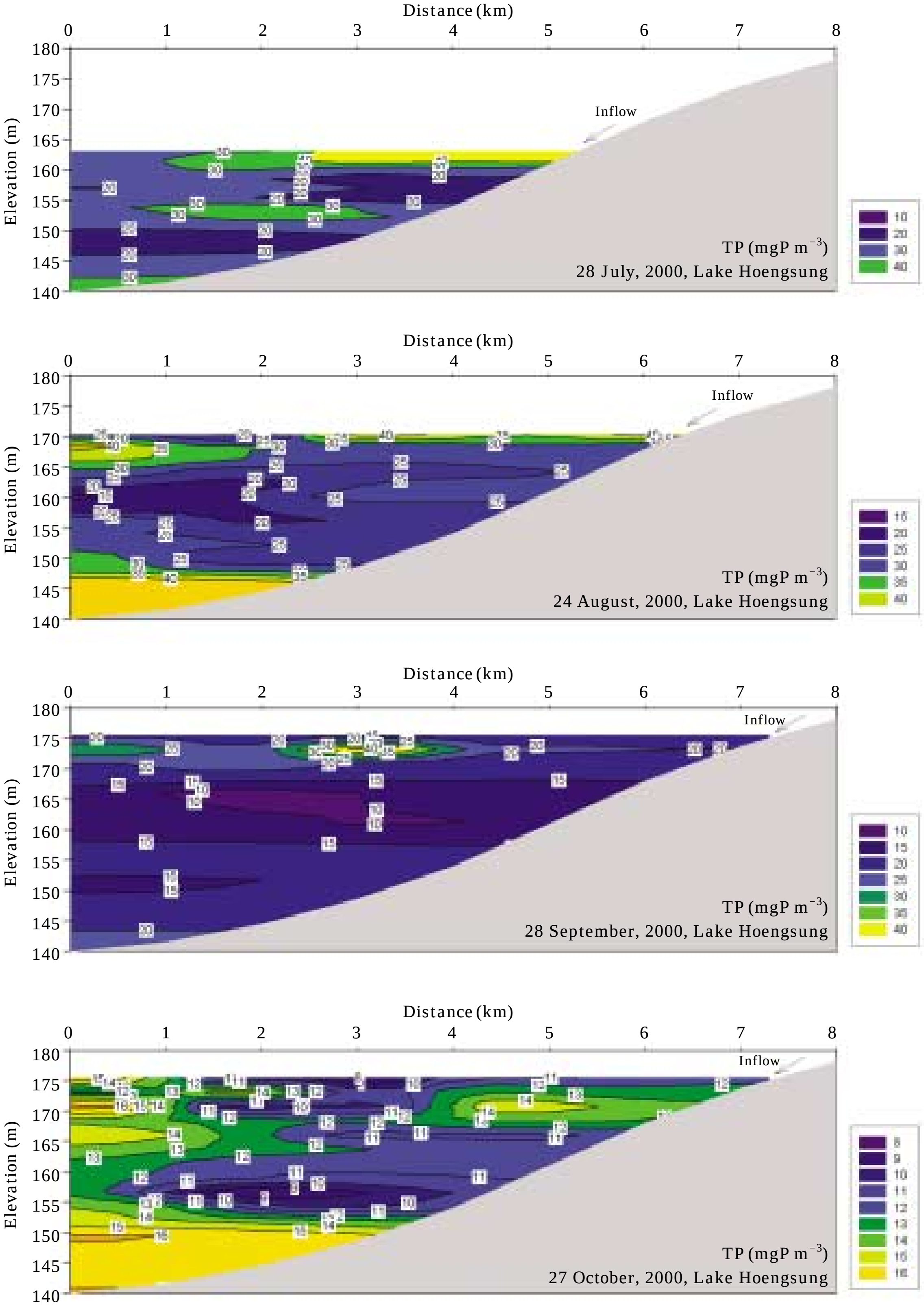

Fig. 5. The vertical and horizontal isopleths of total phosphorus (mgP m^{-3}) in the July to December 2000.

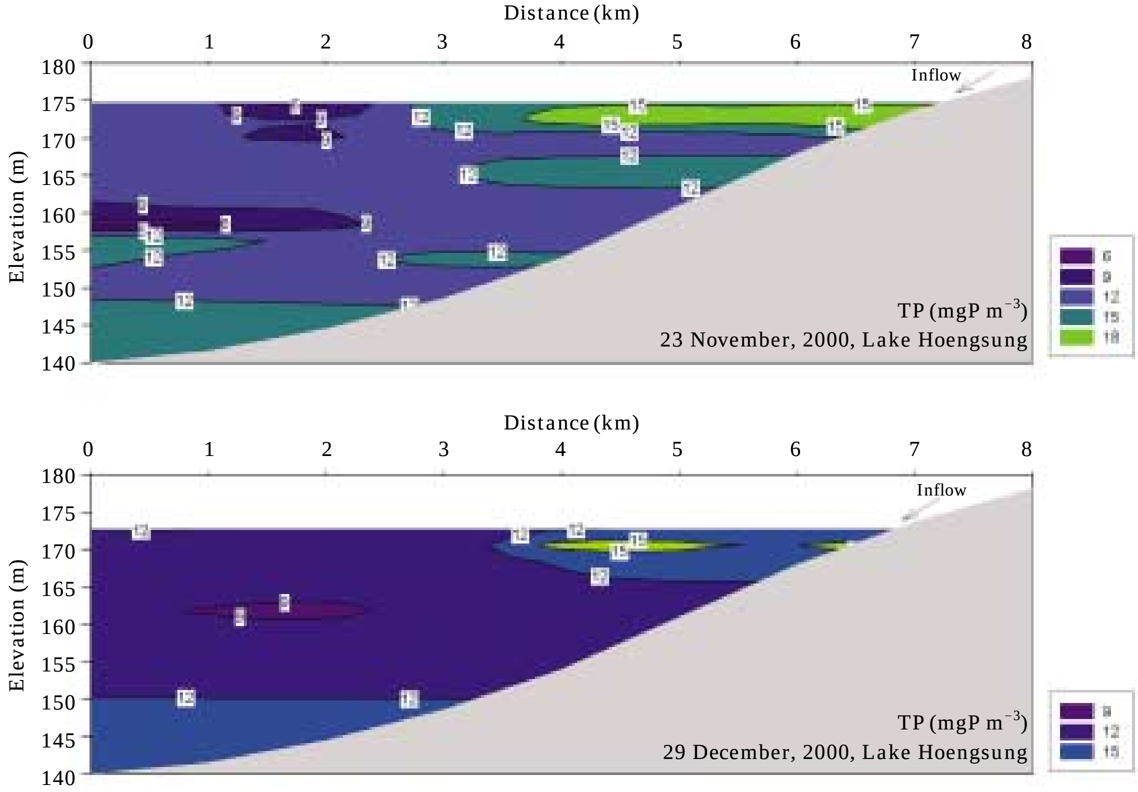

Fig. 5. Continued.

(mean 16 mgP m^{-3}), with higher values mostly near the inlet areas. Seasonally TP concentration was higher after turnover in the early spring and after the rainfall. In September 2001, vertical distribution of TP was high at site 1 (near 2 m and hypolimnion), and site 2 (Fig. 5). Below 15 m depth, site 1 and 2 had TP concentration in the range of 137−164 mgP m^{-3} because suspended solid inflowed in the metalimnion during the rainfall. Usually phosphorus concentration of inflowing water increases during rainy seasons (Heo *et al.*, 1992). Similarly high phosphorus concentration and particulate organic matter (POM) during high rainfall affects the eutrophication process of the lakes with longer residence time. Vollenweider (1968) and Carlson (1977) classified lakes as mesotrophic with the TP concentration in the ranges of 10−30 mgP m^{-3} and 12−24 mgP m^{-3} respectively. Thus on these basis Lake Hoengsung can be classified as a mesotrophic lake.

DIP uptake is a very important factor in supporting the growth rate of phytoplankton. Harmful algae bloom occurs when the DIP concentration exceeds the concentration of 10 mgP m^{-3} (Sawyer, 1947). Average DIP concentration of the whole lake in the epilimnion was in range of 0.2−13.2 mgP m^{-3} (mean 4.1 mgP m^{-3}). Most of the DIP concentration was below 10 mgP m^{-3}, except in September 2001. In this period, the highest concentration was recorded below the depth of 10 m as for the reasons similar to the variation of TP.

Therefore for preventing Lake Hoengsung from being eutrophic, higher control of phosphorus loading from the non−point source is needed. TP of inflowing water was high during the rainy season. But in the dry seasons no high fluctuations were found. Inflow rate and TP concentration were used in the equation $TP = 5.59Q^{0.45}$ ($R^2 = 0.47$) to calculate the TP loading from the watershed (Fig. 6). Monthly TP loading is shown in Table 4. TP loading during the study period (of about 18 months) was about 6.67 tons, with the yearly loading of 4.45 tons. Inflow rate highly affected the phosphorus loading. Phosphorus loading during the rainy season (July−September) was 90% of 4.45 tonP yr^{-1} (2001). In July 2001 alone, with the tropical monsoon rainfall, a total of 3.8 ton of phosphorus was loaded. In the rainy seasons, phosphorus loading concentrated around 72–80% of the total yearly loading. Phosphorus generation in the watershed was about 71.34 ton and the delivery rate of just 6.2% was recorded in Lake Hoengsung, which is much lower in comparison with other lakes of Korea (10–20%) (Heo *et al.*, 1993). As the cattle urine was collected in a storage tank and later transported to a treatment plant outside the watershed, very less phosphorus was delivered in the lake although TP generation from the cattle amounted to be 85% of the total phosphorus generated in the watershed.

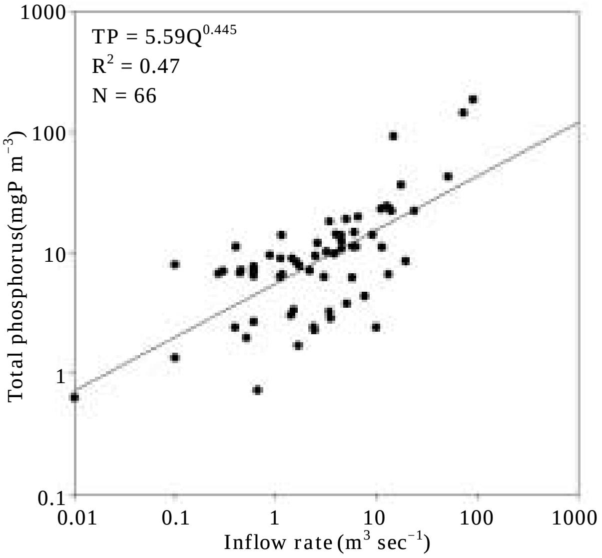

Fig. 6. Plot of inflow rate vs. total phosphorus in the inflowing water (Data from July 2000 to May 2002 are included).

Table 4. Total phosphorus loading of Lake Hoengsung.

Month	Phosphorus loading (kgP month^{-1})
Jul. 2001	345.6
Aug.	1,191.4
Sep.	799.9
Oct.	22.3
Nov.	8.6
Dec.	5.6
Jan. 2002	30.2
Fer.	9.1
Mar.	36.4
Apr.	18.4
May	6.8
Jun.	157.1
Jul.	3,801.8
Aug.	199.6
Sep.	2.8
Oct.	30.2
Nov.	3.8
Dec.	3.1
Total (all months)	6,673
Total (kgP yr^{-1})	4,449

On the basis of the empirical model proposed by Vollenweider (1976), the critical phosphorus budge for Lake Hoengsung was calculated as 0.72 gP m^{-2} yr^{-1}, but the study showed the phosphorus loading of about 0.77 gP m^{-2} yr^{-1} (Table 5). So, phosphorus reduction should be given serious considerations for preventing further degradation of water quality in Lake Hoengsung.

Average TN of the whole lake were in the range of 0.83–3.55 mgN L^{-1} (mean 1.58 mgN L^{-1}). In September 2001, lowest TN was recorded in site 1. During the spring and autumn turnover, TN of the whole lake, was in the range of 1.4–1.5 mgN L^{-1}. After the rainfall seasons, TN concentrations decreased below the metalimnion. Nitrogen showed high fluctuations due to the increased use of fertilizers and consequent leaching from the soil.

Forsber and Ryding (1980) classified lakes as eutrophic with the TN concentration in the range of 0.6–1.5 mgN L^{-1}. So, Lake Hoengsung can be classified as eutrophic lake on the basis of TN concentration.

Average NO_3–N concentrations in the epilimnion in the whole lake were in the range of 0.09–3.33 mg N L^{-1} (mean 1.1 mg N L^{-1}). In June 2001, the TN concentration was at the lowest. Average NH_3–N concentrations in the epilimnion of the whole lake were in the range of 0.04–0.23 mg N

Table 5. Hydrological characteristic and phosphorus loading from the watershed of Lake Hoengsung.

	Unit	L. Hoengsung
Drainage area	km^2	209
Water volume	m^3	7.34×10^7
Surface area	km^2	5.82
Outflow rate	m^3 yr^{-1}	1.16×108
Mean depth	m	13
Flushing rate	yr^{-1}	1.58
Hydraulic residence time	yr	0.63
Surface hydraulic loading, Qs	m^2 yr^{-1}	20
$Qs\,(1+(z+Qs)^{0.5})$		36
Permissible TP loading	gP m^{-2} yr^{-1}	0.34
Dangerous TP loading	gP m^{-2} yr^{-1}	0.72
Annual phosphorus loading	tP yr^{-1}	4.45
P loading	gP m^{-2} yr^{-1}	0.77

L^{-1}. The average TN/TP weight ratio of the epilimition was 126. This value is similar to the values of other artificial lakes (40–160) in Korea (Kim *et al*., 1997). The TN/TP weight ratio increased because of the reduced phosphorus concentration. Unlike this case, TN/TP weight ratio in Lake Andong decreased because of the reduced TN concentration (Heo *et al*., 2000).

Average silicate concentrations in the epilimnion of the whole lake were in the range of 0.5–9.6 mgSi L^{-1} (mean 6.1 mgSi L^{-1}). In May 2001, lowest silicate concentration was recorded in site 4. The vertical distribution of silicate was found low. Silicate concentration from April till July 2001 was lower in the epilimnion than the hypolimnion. Seasonally, spring had the lower silicate concentration and it gradually increased after the rainy season because spring was the diatom's growing season. Kwon *et al*., (2002) showed that in the lagoons of eastern coast of Korea, silicate concentration decreased as the consequence of uptake by diatoms in the spring.

TSI was calculated using the data from May till September as it was the growing season for phytoplankton. In 2000 and 2001 the average TSI were of 59 and 57, respectively (Table 6). In the early 1980s TSI of Lake Soyang was 40 but in the early 1990s it increased to 50–60 (Kim *et al*., 1988; Heo *et al*., 1993). TSI values of Lake Hoengsung were in the range of 50–64 immediately after the completion of dam construction. On the basis of guidelines provided by Haven (2000), the differencing TSI value brings us to the conclusion that phosphorus is not the limiting factor. Light dispersion could be a limiting factor due to the larger particle sizes of suspended solid. The algal growth might also have been limited by zooplankton grazing (Fig. 7).

Chlorophyll a concentration and distribution of phytoplankton communities

Chlorophyll *a* concentrations in the epilimnion of the whole lake were in the range of 0.3–32.4 mg m^3 (mean 8.8 mg m^3). During the summer season higher concentration of Chl. *a* were found in the upper stream due to the shallow water depth and high inflow of nutrients during the

Table 6. TSI : trophic state index. TSI was calculated from warm season average (May–September).

	TSI				Average
	SD	Chl	TP	TN	
2000	56	60	62	58	59
2001	50	57	64	58	57
Average	53	58	63	58	58

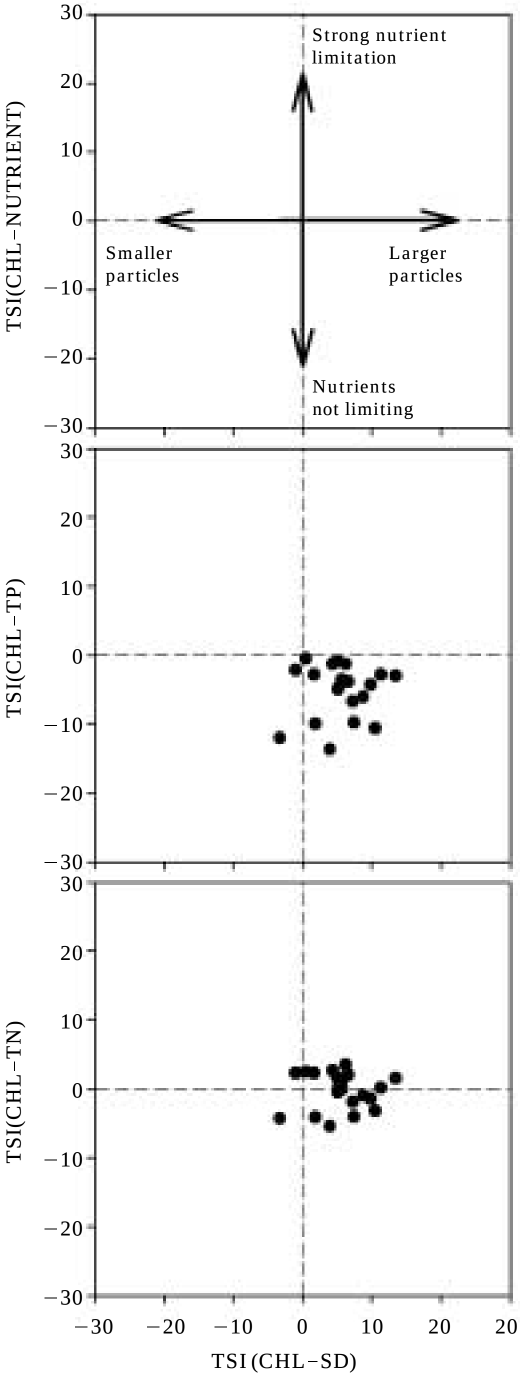

Fig. 7. Differences among trophic state index (TSI) values indicate both the degree of nutrient limitation and the composition of seston.

rainy season. Inlet areas are highly affected by wind rather than the dam ward sites due to the shallow depth. US EPA (1976) classifies lakes as eutrophic if the Chl. *a* concentration is over 10 mg m^{-3}. Similarly, Forsberg and Ryding (1980) classified lakes as eutrophic if the Chl. *a* concentration is in the range of 7−40 mg m^{-3}. Thus, Lake Hoengsung can be categorized as an eutrophic lake.

During the study period, a total of 66 species of phytoplankton were found compromising of Bacillariophyceae (23%), Chlorophyceae (56%), Cyanophyceae (6%), Chrysophyceae (2%), Cryptophyceae (2%), Dinophyceae (9%) and Euglenophyceae (2%). Chlorophyceae and Cyanophyceae were the dominant species during the summer season while in the winter season species of Bacillariophyceae dominated (Table 7).

Communities of Chlorophyceae and Cyanophyceae were the monthly dominant species from July till October 2000. In July, Chlorophyceae *Scenedesmus* sp. with biomass of 10,480 cells mL^{-1} dominated, while August and September were dominated by Cyanophyceae *Microcystis* sp. with the biomass of 3,492 and 296 cells mL^{-1} respectively. But in October, Chlorophyceae *Coelastrum microporum* appeared with the cell density of 133 cells mL^{-1}. In November, Bacillariophyceae *Asterionella formosa* with biomass of 2,654 cells mL^{-1} dominated. In December, the biomass was very low and Bacillariophyceae *Aulacoseira granulate* was recorded with the cell density of 29 cells mL^{-1}.

Again, in 2nd April, 2001 the biomass was very low and Chlorophyceae *Ankistrodesmus falcatus* with biomass of 17 cells mL^{-1} was recorded, but in the 27th April biomass sharply increased due to the presence of Bacillariophyceae *Aulacoseira granulata var. angustissima* with the cell density of 592 cells mL^{-1}. In July, Chlorophyceae *Sphaerocystis schroeteri* with the biomass of 413cells mL^{-1} dominated. In September 2000 Cyanophyceae *Microcystis* sp. were the dominant species but Bacilariophyceae *Aulacoseira* sp. with biomass of 404 cells mL^{-1} dominated in September 2001 (Table 7). Cyanophyceae communities failed to reappear in 2001. In Lake Dalbang, after the operation of artificial aeration Bacillariophyceae (*Asterionella formosa*, *Melosira granulara*) succeeded the previously dominant Cyanophyceae (*Anabaena* sp., *Microcystis* sp.) (Heo *et al.*, 1999). But in Lake Hoengsung, Bacillariophyceae's succession of Cyanophyceae was only a temporary phenomenon which occurred immediately after the completion of lake construction. In August 2000, the species richness index was at the highest of 25 while December reported the lowest value of 1. Species richness index in 27th April

Table 7. Dominant species and standing crops (cells mL^{-1}) of phytoplankton at the surface in the dam of Lake Hoengsung From July 2000 to September 2001.

Dominant species	2000						2001			
	Jul. 28	Aug. 24	Sep. 28	Oct. 27	Nov. 23	Dec. 29	Apr. 2	Apr. 27	Jul. 27	Sep. 28
Asterionella formosa				83	2,654			167		
Aulacoseira granulata var. *angustissima*					321			592		29
Aulacoseira granulata						29				
Aulacoseira sp.					42				25	404
Ankistrodesmus falcatus							17	4		
Coelastrum microporum				133						
Scenedesmus sp.	10,480	283	4		17				83	133
Sphaerocystis schroeteri		133			279				413	346
Microcystis sp.	760	3,492	296		104					
Standing crops of dominant species	11,240	3,908	300	133	763	29	17	596	521	913
Total cell number	36,640	4,604	379	317	3,592	29	58	1,083	820	1,178
Species richness	20	25	10	6	19	1	7	15	13	5
Diversity	2.22	1.09	0.96	1.38	1.06	0	2.03	1.57	1.39	1.31
Dominance	0.15	0.58	0.62	0.30	0.56	1	0.22	0.34	0.28	0.23
Evenness	0.89	0.43	0.43	0.84	0.46	0.00	0.91	0.70	0.78	0.96

2001 was 15, which is relatively low as compared to that of 2000. During the whole study period, July 2000 had the highest diversity index of 2.22 and the highest biomass of 36,640 cells mL^{-1}. In April 2001, diversity index was comparatively high by 2.03 and decreased with the approaching summer season. Dominance index in September 2000 were 0.62 and the highest value in 2001 were much lower than that of 2000.

CONCLUSIONS

For the maintenance of high standards in the water quality and effective water management of the multi−purpose Lake Hoengsung the following steps must be taken: 1) Control storm−water by constructing either a settling pond with fully developed macrophytes on the littoral regions or a diversion for storm−water in the upstream area. 2). Recognize and implement appropriate sustainable land management practices to restore the lake. 3) Treatment or diversion of livestocks feces and control of discharges from non−point sources.

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< **국문적요** >

횡성호의 육수학적 조사와 인부하

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횡성호에서는 수중폭기 기간에도 수온약층이 형성되었으며, 수중폭기로 인한 영향이 크지 않은 것으로 판단된다. 모든 정점의 표층(0-5 m) 평균 탁도는 0.1-8.5 NTU로 우기 이후에 중층 및 심층에서 높았다. 투명도는 0.9-3.5 m의 범위로 댐 하류(St. 1) 정점에서 크게 나타났으며, 상류로 갈수록 낮았다. 용존산소는 2000년 7월과 8월에 전 지점의 0 m에서 8.4-14.1 $mgO_2 \cdot L^{-1}$로 높았으나 심층에서는 고갈 상태를 보였다. 또한 2001년 7월과 9월에도 정점 1의 심층에서 1 $mgO_2 \cdot L^{-1}$내외로 매우 낮았다. 전 정점의 표층(0-5 m)평균 총인 농도는 5-46 $mgP \cdot m^{-3}$로 초봄의 turnover 직후 및 우기이후에 높았으며 용존 무기인 농도는 0.2-13.2 $mgP \cdot m^{-3}$로 2001년 9월을 제외하고는 대부분 10 $mgP \cdot m^3$ 이하 이였다. 횡성호의 연간 인부하량은 약 4.45 ton 정도로 유역내에서 발생되는 총인 발생량 71.34 ton 중 약 6.2%만이 호수내로 유입되는 것으로 나타났다. 수면적당 인부하량은 0.77 $gP \cdot m^2 \cdot yr^{-1}$으로 횡성호의 환경용량이라 할 수 있는 과잉임계부하량 0.72 $gP \cdot m^2 \cdot yr^{-1}$을 0.05 $gP \cdot m^2 \cdot yr^{-1}$ 초과한 수준이다. 전 정점 표층(0-5 m)평균 총질소 농도는 0.83-3.55 $mgN \cdot L^{-1}$로 우기 이후에 중층 이하 지역에서 높았다. 질산성 질소는 전 정점의 표층(0-5 m)평균이 0.09-3.33 $mgN \cdot L^{-1}$로 2001년 6월에 가장 낮았다. 암모니아성 질소는 전 정점의 표층(0-5 m)평균이 0.04-0.23 $mgN \cdot L^{-1}$이였다. 전 정점 표층(0-5 m)평균 규소농도는 0.5-9.6 $mgSi \cdot L^{-1}$로 봄철에 낮았으며, 우기이후에 다시 증가하였다. 평균 TSI는 2000년과 2001년에 각각 59와 57이었다. 전 정점 표층(0-5 m)평균 엽록소 *a* 농도는 0.3-32.4 $mg \cdot m^{-3}$로 여름철에 높은 경향을 보였으며, 정점별로는 상류지역에서 높았다. 식물플랑크톤은 2000년 7월에 녹조류인 *Scenedesmus* sp.가 10,480 $cells \cdot mL^{-1}$, 8월과 9월에는 남조류인 *Microcystis* sp.가 각각 3,492와 296 $cells \cdot mL^{-1}$로 우점하였다. 10월에는 녹조류인 *Coelastrum microporum*이 133 $cells \cdot mL^{-1}$, 11월에는 규조류인 *Asterionella formosa*가 2,654 $cells \cdot mL^{-1}$, 12월에는 규조류인 *Aulacoseira granulata*가 29 $cells \cdot mL^{-1}$ 우점종이였다. 특히 2000년 여름철에 우점종이였던 남조류가 2001년에는 출현하지 않았으며 종 다양성(diversity)지수는 2000년 7월에 2.22로 가장 높았으며, 생물량도 조사기간중 36,640 $cells \cdot mL^{-1}$로 가장 많았다.