EUTROPHICATION OF THE MAJOR RESERVOIRS IN KOREA

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ABSTRACT

Trophic state of several major reservoirs in Korea are reviewed. Most of large reservoirs are mesotrophic to eutrophic, suffering bluegreen algal blooms. Recently many reservoirs are being eutrophied at high rate mainly due to the increase of excretion by livestock in watershed and netcage-type fishfarms within the lake basins.

The trophic state changes of Lake Soyang, from oligotrophy to eutrophy in recent 10 years, are presented as a case study of rapid eutrophication. Chlorophyll a concentration increased from ca. 3mg/m^3 in early 1980s to 15 mg/m^3 in 1989. The dominant phytoplankton species in summer are changed from Peridinium to Anabaena since 1986 and the standing crop of Anabaena has been increasing. Secchidisc depth decreased from 5 to 1m. TP increased from 7 to 20 mgP/m^3. The rate of hypolimnetic oxygen deficit increased year to year from 0.028 mgO_2/cm^2/day in 1986 to 0.094 in 1989.

Fishfarms within the lake are the major phosphorus source in Lake Soyang exceeding the total phosphorus loading from the watershed. This high rate of eutrophication is expected to persist in next decade.

KEYWORDS: eutrophication, fish farm, phosphrous, Lake Soyang, oxygen deficit

INTRODUCTION

Recently many multipurpose-reservoirs have been constructed in Korea and plays the major role as the water resources. In the past, only small ponds and earth dams were built to store water for irrigation. In the early 1960s, municipal and industrial water demands rapidly increased due to the industrializtion. Since 1970s, many reservoirs have been built to meet the increasing water demand and replaced rivers as the major water resources

Large reservoirs are usually constructed at deep cannyons in the upper-mid stream region and have dendritic shape. As can be supposed from their long and narrow shape, horizontal mixing of water is fairly limited. And the horizontal heterogeneity of temperature, water quality, and phytoplankton density are observed(5,6).

The seasonal variations of rainfall is large. About 2/3 of annual precipitation, average 1200 mm, are concentrated in the season of summer wet monsoon. In rainy season most of precipitation is lost to the sea as flood runoff. To store this lost water is the major role of large reservoirs in Korea primarily for the water supply and secondarily for the flood control. The water level of the reservoirs fluctuate very much seasonally, lowest just before the rainy season to prepare for the flood control. Wide range of water level fluctuation, up to 30m in Lake Soyang, suppresses the development of macrophyte population in littoral zone, which means autochthonous organic production is performed only by phytoplankton.

Recently, most of the major reservoirs have some symptoms indicating it is getting eutrophied; the increase of chlorophyll a (8) and total phosphorus, the decrease secchi disc transparency, the advent of anoxic layer in hypolimnion(9), and the expanding blue green algae blooms (2).

Table 1. Trophic state parameters in major reservoirs in Korea. Average of surface 5m in summer period, from April to October (2,8,12)

Lake	Year	Chl (mg/m^3)	TP (mg/m^3)	SD (m)	Prim.Prod. ($mgC/m^2/day$)	Capacity ($10^8 m^3$)	Residence time(yr)
Soyang	1981	2.7	8	4.4		29	0.75
	1982	3.9		4.2			
	1983	2.1		4.5			
	1984	3.1		4.0			
	1985	3.1		3.8			
	1986	2.8		4.6			
	1987	5.0	12	3.3	875		
	1988	4.6	14	3.6	597		
	1989	9.2	13	2.7	824		
	1990	14.5	18	2.0			
Paro	1987	7.4	18	1.4	409	5.5	0.20
Chuncheon	1981	1.7	11	2.5		1.3	0.04
	1982	1.3		4.2			
	1987	4.6	12	2.2	367		
Euiam	1981	2.8		2.6		0.6	0.01
	1982	2.5		3.2			
	1987	5.5	15	2.2	375		
Paldang	1987	8.2	15	1.4		2.4	0.01
	1988	6.3	12	2.9	798		
Chungju	1986	6.2		2.6		27	0.60
	1988	3.2	16	4.3	1028		
Daechung	1989	4.5	24	2.3		8.1	0.28
	1990	4.2	14	2.6	648		
Youngsan	1989	22.9	143			1.8	
Andong	1987	7.5	25	2.6		12.5	0.9

THE TROPHIC STATE OF MAJOR RESERVOIRS

The water quality data of reservoir used to trophic state classification are shown in Table 1; the surface average chlorophyll a, total phosphorus, secchi disc transparency, and primary prouctivity during the summer period, from April to October. By the criteria for trophic state classification (1,3,13,14) reservoirs introduced in this study can be classified as mesotrophic to eutrophic lakes. Reservoirs on the upstream part of river are usually mesotrophic and those on the downstream part, such as Lake Yungsan, are more eutrophic. Chlorophyll a, total phosphorus concentraion and secchi disc transparency should be given more weight in the determination of trophic state than primary productivity, because the primary prodctivity have larger seasonal variation and the measurements were not frequent enough to estimate annual production. However, according to the criterion of Likens(10) who suggested somewhat lower boundary for primary productivity, 300 $mgC/m^2/day$ as the upper limits for

Table 2. Phosphorus loading from the watershed and fishfarms into Lake Soyang, Lake Chungju, and Lake Daechung (Kim, unpublished data) and the amount of phoshorus discharged from three sources in the watershed. The rate of delievery from the source to lakes are assumed same for three sources.

Sources	Sources in the watershed	P input into lake(tP/yr) L. Soyang	L. Chungju	L. Daechung
Fishfarm		90	129	69
Watershed		45	169	146
	Livestock	3	139	128
	Man	38	20	12
	Land	4	10	6
Total		135	298	214
$Lp(gP/m^2/yr)$		3.1	3.1	4.6
$Lc(gP/m^2/yr)$	excessive	1.7	1.8	1.9

oligotrophy, and 600 $mgC/m^2/day$ as the lower limits for eutrophy, Lake Paro, Chuncheon, and Euiam are mesotrophic, and Lake Soyang, Paldang, Chungju, Daechung are eutrophic.

THE SOURCES OF PHOSPHORUS

Large reservoirs in Korea has two major sources of phosphorus: the loading from watershed coming through the inflowing rivers and fishfarms within the lake (Table 2). The phosphorus loading from the watershed largely originates from livestock farming; cows, pigs, hens, carp, and trout. The netcage-type fishfarms within lakes are large in scale and have been the second major phosphorus source since mid 1980's. Their loading are so great that they are comparable to the rest whole loading from the watershed and sometimes even surpass it in some lakes.

The increasing demand for meat forced to import the raw material for feed of livestock from foreign countries; corn, bean, wheat, and dried fish. In a balanced ecosystem the nutrients excreted by animals are returned to the soil or plants where they originated from. But in Korea they cannot be returned because most of feeds are imported, and they are flushed into lakes and cause eutrophication. Therefore the major reason of eutrophication in Korea is the overproduction of meat in excess of the environmental capacity.

A CASE STUDY OF RAPID EUTROPHICATION; LAKE SOYANG

Eutrophication and the change of phytoplankton community

Lake Soyang is a long and narrow dendritic lake with the length of 60km, the mean width 0.5 km, the maximum depth 115 m and the mean depth 34 m. The mean hydraulic residence time is 0.75 year, which is one of the longest in Korea. It receives little municipal sewage from the watershed because it has only a few small towns in the watershed. It was an oligotrophic lake in 1970s, famous for its high transparency. However, recent reports(8) remarked the progress of its eutrophication.

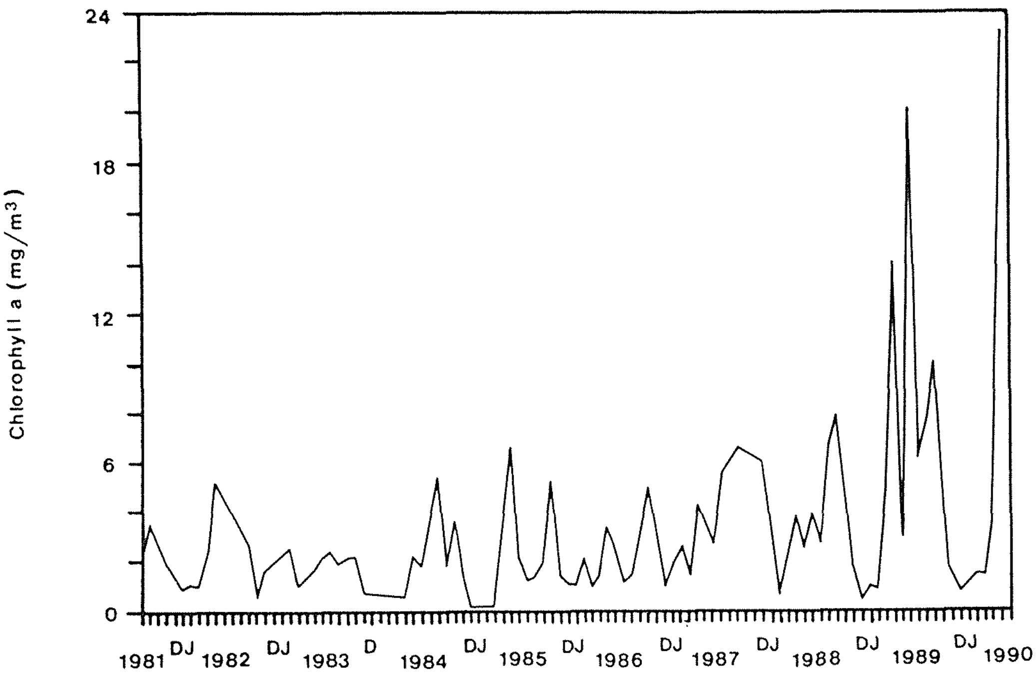

Fig.1. The seasonal variation of chlorophyll a concentration in Lake Soyang showing rapid increase in recent years (average of surface 5m).

Fig.1 shows the seasonal variation of chlorophyll a concentration for 10 years, showing that water blooms occur frequently in recent years and the chlorophyll a concentration has been increasing from summer average of 3 in 1981 to 15 mg/m^3 in 1989 at the rate of $0.4mg/m^3/yr$. With the eutrophication the dominant phytoplankton species has been changed. Peridinium bipes, the previous dominant species in warm seasons has been replaced with Anabaena in late summer since 1986, and the dominance of Anabaena increased every year. Bluegreen algae showed rapid increasing trend since 1986, while other groups, diatoms, green algae and dinoflagellates remained at the similar level of standing crop during the study period, as shown in Fig.2.

Blooms of bluegreen algae caused the increase of chlorophyll a concentration and the decrease of secchi disc transparency. Secchi disc transparency, 4 to 6 meters in the early 1980's even during the blooming seasons, decreased to 1m in blooming season of 1990.

Changes in the rate of hypolimnetic oxygen deficit

Also, the trend of oxygen decrease in Lake Soyang seems to be a response to the environmental change toward eutrophication. The advent of large anoxic layer in 1988 makes an epoch in the history of eutrophication of Lake Soyang(9). Its volume is increasing year to year.

The generation of reduced gases in anoxic zone such as methane and hydrogen sulfide is obvious from the smell of the samples, though not measured in this study. The formation of anoxic hypolimnion with low redox potential might accelerate eutrophication further due to the increase of internal phosphorus loading from the sediment by increasing the solubility of inorganic phosphorus in the sediment. Dissolved inorganic phosphorus and ammonia are almost depleted in the epilimnion,

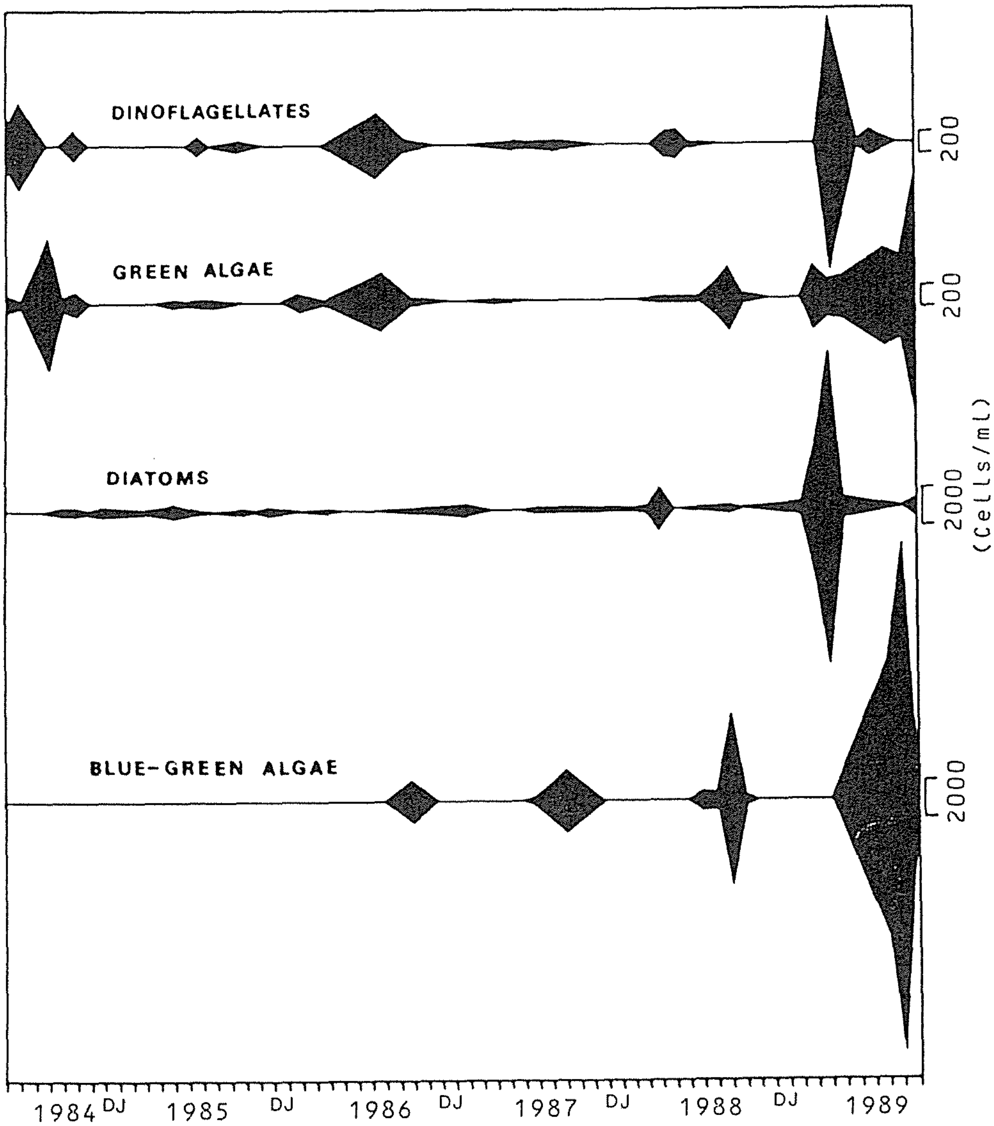

Fig.2. The monthly variations of the cell density of four phytoplankton groups in Lake Soyang showing the increasing trend of bluegreen algae.

but the anoxic hypolimnion are rich in DIP and ammonia, which implies the possibility of nutrients supply increase during turnover (9).

And the rate of hypolimnetic absolute oxygen deficit(HODR) (15) has been increasing year to year (Fig.4.). Hutchinson(4) proposed the classification of trophic state by the HODR; oligotrophy for below 0.017 $mg/cm^2/day$, and eutrophy for larger than $0.033mg/cm^2/day$. Mortimer(11) suggested different criterion; $0.025mg/cm^2/day$ as the upper limit for oligotrophy, and 0.055 $mg/cm^2/day$ as the lower limits for eutrophy. Lake Soyang could be classified eutrophic since 1987 according to the criterion of Hutchinson(4), and since 1988 according to Mortimer(11).

Water temperature distributions are not presented in this paper, however, warm winters of recent several years resulted in incomplete

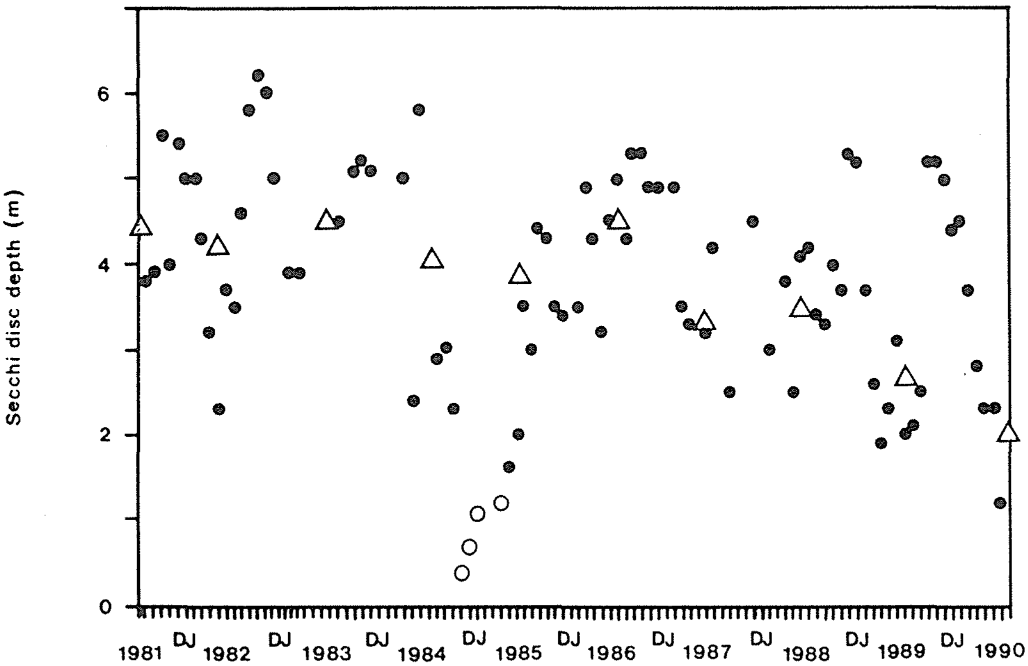

Fig.3. The Monthly variations of Secchidisc depth(●) in Lake Soyang. (○); the period of turbid storm runoff, (△); summer average from April to October.

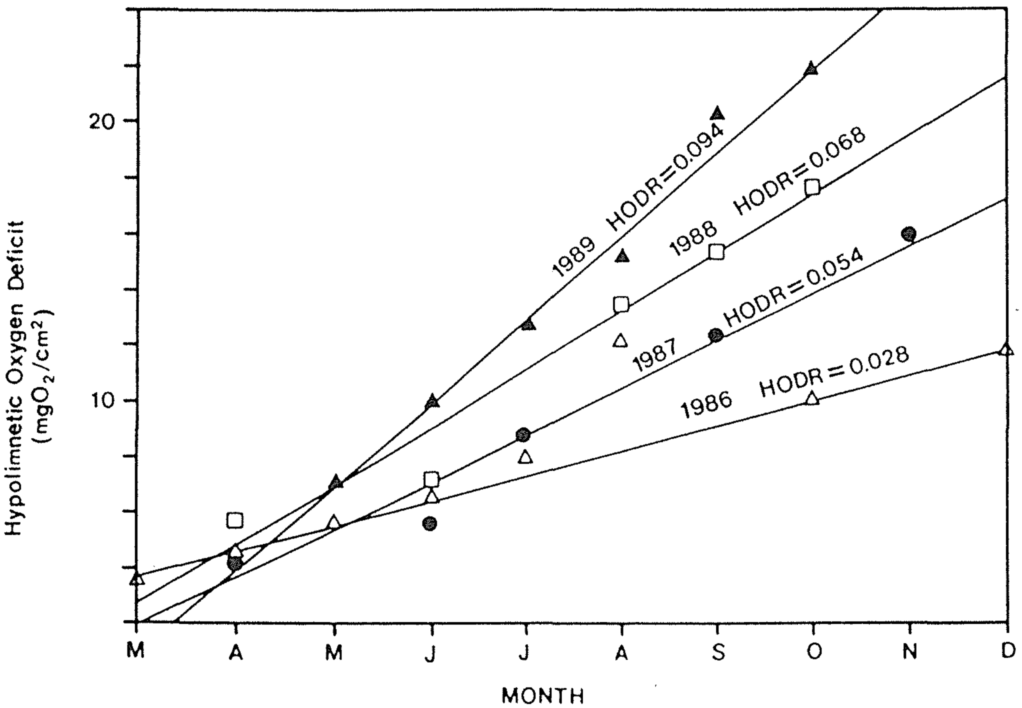

Fig.4. The hypolimnetic absolute oxygen deficit and its rate in Lake Soyang. HODR; the rate of hypolimnetic oxygen deficit in $(mgO_2/cm^2/day)$.

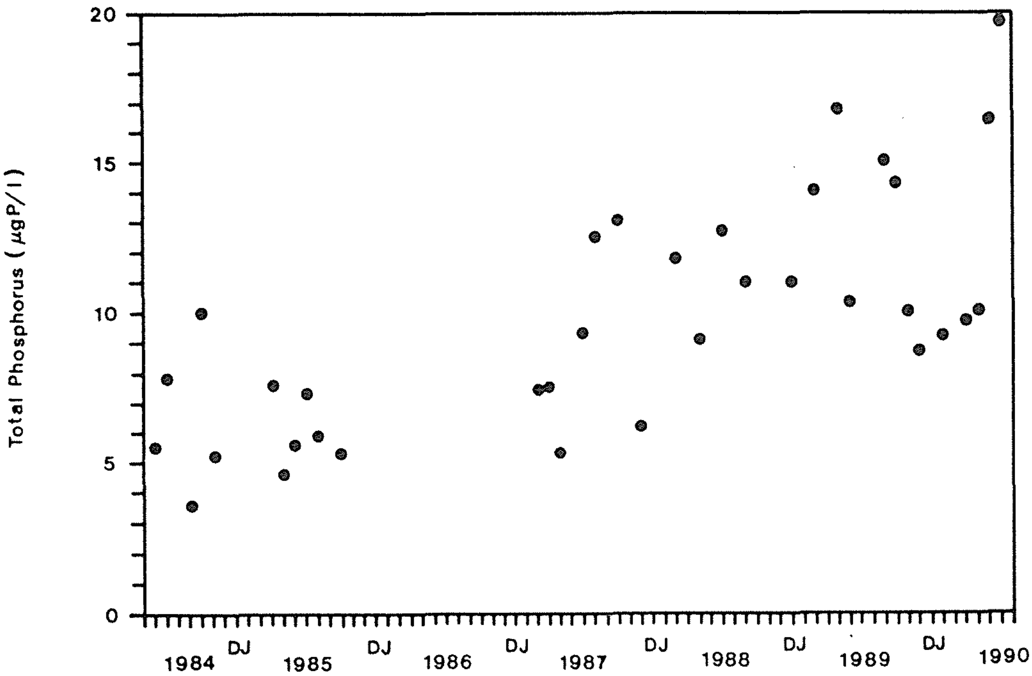

Fig.5. The variation of total phosphorus concentration in Lake Soyang.

vertical circulation during the winter turnover and it seems to have enhanced the DO decrease further. The water temperature during the turnover was 4.8°C in the winter of 1986, 4.5°C in 1987, but it was 5.0°C in 1988, and 5.2°C in 1989.

Phosphorus loading and the contribution of fishfarms

The eutrophication of Lake Soyang is obviously caused by the increse of phosphorus loading which is the limiting nutrient for algal growth. The reported high ratio of TN/TP, 150 in 1987, and the high nitrate concentration all through the year (9) implies nitrogen can not be the limiting nutrient. Total phosphorus concentration in Lake Soyang showed rapidly-incraseing trend, as shown in Fig.5. (9).

The phosphorus loading into Lake Soyang can be classified into two major sources: the loading from the watershed coming through the inflowing streams and the excretion by fish in the net-cage type fishfarms within the lake directly into the lake water. Because the watershed of Lake Soyang is sparcely populated (about 60,000 persons) and the population is decreasing, human release of phosphorus is negligible and is not thought to have increased so much. Most of watershed-origin phosphorus comes from the excretion of livestock and the agricultural fertilizer. However, it is not thought to have increased much because most of watershed is moutainous district and the agricultural activity is low. In this study the phosphorus loading from the watershed, 45 tP/yr in 1985-1986, was calculated by measuring the total phosphorus content in the main inflowing stream, the Soyang River.

The second source is the fishfarms within the lake. In this study the phosphorus loading from fishfarms were calculated by multiplying the P excretion per unit amount of feed and the total amount of feed used in Lake Soyang. Though the exact data of the amount of fishfeed application is lacking, it was estimated to be about 2000 t/yr in 1985 and increased to about 5000 t/yr in 1989. The phosphorus content of fishfeed varies from 1.3% to 3.3% with the content of dried fish and inorganic phosphate and of course phosphorus release per unit amount of feed varies with P content. P content is higher in Korea, average 2.0%, than other countries because lower limit of P content, 1.2%, instead of highest limit is established by the law. In this study 18g of P excretion per kg of feed was applied.

Table 3. shows the phosphorus input from the watershed and the fishfarms at the level of 1985 and 1989. Phosphorus input from fishfarms increased rapidly in recent years and exceeds that of watershed. The phosphorus loading is compared with the critical phosphorus loading for eutrophication by Vollenweider's model. Without the fishfarms the phosphorus loading of Lake Soyang would be smaller than the excessive loading and larger than the permissible loading. But with the loading from fishfarms added, it is much larger than the excessive loading. Therefore, it can be concluded that the fishfarms are the major cause of eutrophication in Lake Soyang.

PERSPECTIVES IN THE NEAR FUTURE

Most of large reservoirs are expected to be much further eutrophied in near future mainly due to the fishfarms and livestocks. To meet the increasing demand the production of trout and carp is sure to increase. The importance of fishfarms as a pollutant source is just beginning to be recognized by government officials. But they are not controlled effectively until now due to the lack of approapriate regulations and the officials' lack of neccessory knowledge. Fishfarms should have licence for the establishment, but the number and area of fishfarms began to be limitted in only a few lakes since 1989 and the amount of production is not controlled at all. The excessive phosphorus content in fishfeed is not controlled either, but even the lower limit is set by the fishfeed act declaring that phosphorus content should be higher than 1.2%.

It will take several years for the government officials to establish approapriate regulations to control water pollution by fishfarms. And after that most of fishfarms established in recent years will last for about 7 to 9 years from now until the expiration date of their licences that are issued in 10 years unit. Even if fishfarms are controlled, the internal phosphorus loading from the slowly-decomposing feces sedimented at the lake bottom would supply much nutrients for fairly long period. Therefore fishfarms in Korea are expected to have effect upon the eutrophication for at least 20 years from now.

REFERENCES

1) Carlson, R.E. (1977) A tropic state index for lakes. Limnol. Oceanogr., 22:361-369.
2) Cho, K.S., Kim, B.C., Heo W.M and Cho S.J. (1989) The succession of phytoplankton in Lake Soyang. Kor. J. Lim., 22(3):179-189.
3) Forsberg, C. and Riding S.O. (1980) Eutrophication parameters and trophic state indices in 30 Swedish waste receiving lake. Arch Fur Hydrobial., 89:189-207.
4) Hutchinson, G.E. (1957) A reatise on Limnology. I. Geography, Physics and Chemistry. New York, John Wiley And Sone, Inc., pp.1015
5) Kim, B.C., Cho, K.S. and Shim, J.H. (1985a) Horizontal variation of primary productivity and environmental factors in Lake Soyang. Kor.

J. Lim., 13:1-10.
6) Kim, B.C., Cho, K.S. and Shim, J.H. (1985b) Temporal and spatial variation of chlorophyll a concentration in Lake Soyang. J. Kor. Wat. Poll. Res. Contr., 1:18-23.
7) Kim B.C. (1987) An ecological study of phytoplankton in Lake Soyang. Ph.D. Thesis. Seoul National University.
8) Kim B.C., Ahn, T.S. and Cho, K.S. (1988) A comparative study of the Eutrophication In reservoirs of the Han River. Kor. J. Lim., 21:151-163.
9) Kim B.C. and Cho, K.S. (1989) The hypolimnetic anoxic zone and the metalimnetic oxygen minimum layer in a deep reservoir, Lake Soyang. Kor. J. Lim., 22:159-166
10) Likens, G.E. (1975) Primary production of inland aquatic ecosystems. In 'Primary productivity of the biosphere' ed. H. Lieth and R.H. Whittaker. Springer Verlag.
11) Mortimer, C.H. (1941) The exchange of dissolved substances between mud and water in lakes (Part I and II.) J. Ecol. 29:280-329.
12) Park, Y.K., Seo, Y.D. and Kim, J.H. (1988) A study on the evaluation of trophic state of Andong reservoir. J.KSWPRC. 4:23-30
13) U.S..Environmental Protection Agence (1976) Water Quality Criteria Research of the U.S. Environmental Protection Agency, Proceedings of an EPA Sponsored Symposium, EPA-600 (3-76-079), 185.
14) Vollenwieder, R.A. (1976) Advances in defining critical loading levels for phosphorus in lake eutrophication. Mem. Inst. Ital. Idrobiol. 33:53-83.
15) Wetzel, R.G. (1983) Limnology. 2nd ed. Saunders College Publishing.