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Interannual and Seasonal Fluctuations of Nutrients, Suspended Solids, Chlorophyll, and Trophic Sate along with Other General Water Quality Parameters Near Two Intake Towers of Daechung Dam

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The study objects were to analyze long-term and seasonal variations of nutrients (N, P), suspended solids, N : P ratios, algal chlorophyll, and trophic state along with general water quality parameters in four sampling sites including two intake tower sites supplying drinking water in Daechung Reservoir. For the analysis, we used water quality long-term data sampled during 1998 ~ 2007 by the Ministry of Environment, Korea. Interannual and seasonal trends in inflow and discharge near the intake tower facilities over the ten years were directly influenced by rainfall pattern. The distinct difference between wet year (2003) and dry year (2001) produced marked differences in water temperature, pH, dissolved oxygen, organic matter contents, nutrients, and these variables influenced algal biomass and trophic state. Values of TP varied depending on the year and locations sampled, but monthly mean TP always peaked during July ~ August when river inflow and precipitation were maxima. In contrast, TN varied little compared to TP, indicating lower influence by seasonal flow compared to phosphorus. The number of *E. coli* were highest in Site 2 (Chudong intake tower) and varied largely, whereas at other sites, the numbers were low and low variations. Contents of chlorophyll-*a* (CHL), as an estimation of primary productivity, varied largely depending on the year and season. The maximum of CHL occurred at Muneu intake tower (S4) during 2006 when the precipitation and inflow were lowest. In contrast, another CHL peak was observed in Site 2 (Chudong intake tower) in 2006 when one of the largest typoons (Ewinia) occurred and river runoff were maximum. So the CHL maxima were associated with both wet year (high flow, high nutrient supply) and dry year (low flow, nutrient supply by littoral zone). Such conditions influenced trophic states, based on Trophic State Index of nutrients and CHL. Based on all analyses, we can provide some clues for management and protection strategies of two intake tower sites.

Key words : intake tower, nutrient, inflow, reservoir management, trophic state

INTRODUCTION

One of the most important functions in large dam reservoirs in Korea is to supply drinking water to citizen near the reservoir along with electrical generation, agricultural irrigation, and industrial supply. Especially, this is true in Water Resource Corporation, Korea, which supplies tap waters to citizens.

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Daechung Reservoir is one of the large dam reservoirs in Korea with some reservoirs of Soyang, Paldang, Chungju, Andong, and Juam dams. It has two Chudong intake tower (CIT) and Muneu intake tower (MIT) for drinking water supply of Daejeon and Chungju citizens in Dong-gu and Muneu-myeon, respectively. In Daechung Reservoir, intaking capacity from CIT and MIT is 0.46 million m^3 per day and 0.25 million m^3 per day, respectively. Waters in the reservoir comes from rainfall and up-river inflow of the mainstem. About 68% of the total annual precipitation enters into the reservoir annually and this volume is up to 280 million m^3. About 160 million m^3 of the total volume is supplied to near big cities. For this reason, protections of water environment and chemical water quality in ambient reservoir water have been emphasized for the public health. Urbanization, and population increases in up-reservoir regions, however, resulted in acceleration of eutrophication (An *et al.*, 2001; An *et al.*, 2008), organic matter (BOD, COD), bacteria community (Bing *et al.*, 2002), suspended solids, chlorophyll-*a* or primary production (Park, 2005; Lee *et al.*, 2008) in Daechung Reservoir, causing in frequent algal blooms and toxic blue-green blooms (Cheon *et al.*, 2006).

Recently, numerous studies of reservoirs (Persson, 1982; Codd and Poon, 1988; Robert *et al.*, 1993; Smith and Gilbert, 1995; Pouria *et al.*, 1998) have shown that greater algal biomass, organic matter pollution, deficit dissolved oxygen resulted in greater chemical toxicity by chlorine treatments and biogenic toxicity by blue-green algae (i.e., microcystin by microcystis) in tap waters for drinking waters. Thus, filtering facilities for tap water were frequently clogged and such water produced bad odor in the drinking water. According to recent studies of Cheon *et al.* (2006) in Daechung Reservoir, the magnitude and frequency of algal bloom are getting increase due to greater eutrophic conditions. Currently, Daechung Reservoir has surveillance system for algal predictions and algal bloom alerts and massive break have been increased yearly. In 2001, reduced rainfall and inflows from the river increased water residence time by 499 days, and this condition resulted in careful algal bloom watch of 35 days, algal bloom alerts of 47 days, and massive breaks of 7 days, resulting in severe water quality problems in two intake towers (Cheon *et al.*, 2006). Such massive algal blooms may be influenced by constructions of the up-reservoir (Yeoungdam dam), due to increased water residence (Lee *et al.*, 2008). Dominant phytoplankton species in observed in Daechusng Reservoir is as known diatom, brown flagellates, and blue-green algae (i.e., cyanobacteria, An, 2001; Cheon *et al.*, 2006), and the blue-green among these taxa is considered as the key species producing severe water odor and neurotoxin in drinking water (Cheon *et al.*, 2006). So, data assessments on interannual trophic state, nutrient dynamics, and algal blooms are eminent for efficient water protection.

In spite of these problems in water quality, little is known about water quality dynamics of nitrogen, phosphorus, TN : TP ratios, and chlorophyll-*a* near the intake tower sites, which are most important locations for a protection of water resource. Recent study of Lee *et al.* (2003) suggested that after the eutrophication was reported in 1984, trophic level is getting up and severe algal blooms occur in Daechung Reservoir. This major source of nutrients flowing to Daechung Reservoir is known as non-point sources from residential area and agricultural runoff and point sources of dairy farms and wastewater disposal plants in the up-river regions.

In this paper, we selected four sites including two intake towers near Muneu-myon, Chungbuk province and Dong-gu, Daejeon city for interannual, monthly, and seasonal patterns of premonsoon, monsoon, and postmonsoon in total phosphorus, total nitrogen (TN), TN : TP ratios, chlorophyll-*a* (CHL), and Trophic State Index (TSI) along with general water quality parameters. This research may provide important seasonal and interannual patterns near two intake towers supplying drinking water to two big cities and give some clues how the nutrients are associated with algal blooms in this reservoir.

MATERIALS AND METHODS

In this study, four sites including two intake towers near Muneu-myon, Chungbuk province and Dong-gu, Daejeon city (Fig. 1) were selected for pattern analysis of water quality in the lacustrine zone of down-lake region. The reservoir was constructed in 1980 on mid-region of Keum River about 150 km upstream from its estuary to supply a water resource, and is located in the central part of Korea. Site 1 is located near Whenam

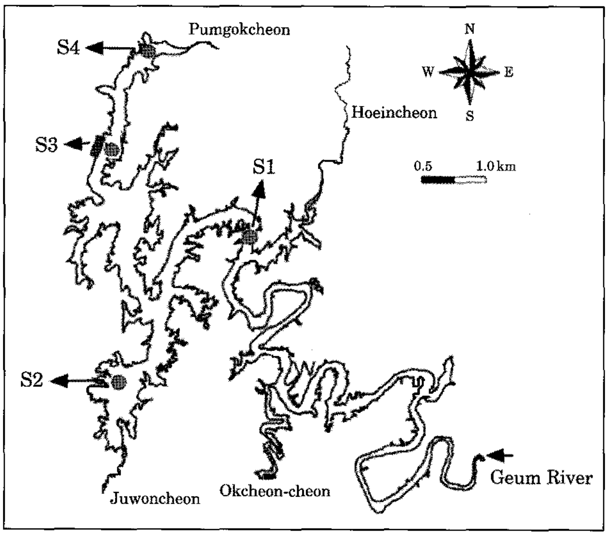

Fig. 1. Locations of water quality monitoring stations near the two intake towers in Daechung Reservoir.

Bridge, and had frequent algal blooms. Dong-gu intake tower, which is Site 2, is located right-side of the dam and is located in the embayment with length of 1.5 km and width of 3 km. Site 3 is located in the front of the dam with wears. Site 4 is Muneu intake tower, which is located in the left-side of the dam (127° 30′N and 36° 30′W). Muneu intake tower supplies industrial water (1.6×10^6 m^3 d^{-1}) as well as drinking water to Chongju citizens. The descriptions of two locations are already published in previous paper (An *et al.*, 2001).

Data from the four sites were obtained from water resource information center (www.me.go.kr) and the study period was ten years of 1998~2007. Inflow and outflow data were obtained from Water Resource Corporation. Precipitation data obtained from Daejeon Meteorological Station were analyzed for comparisons of monthly, seasonal, and annual patterns. Water quality parameters used here are water temperature, pH, chemical oxygen demand (COD), suspended solid (SS), dissolved oxygen (DO), total phosphorus (TP), total nitrogen (TN), chlorophyll-*a* (CHL), and total coliform bacteria. Also we calculated TN : TP ratios using the raw data. In this study, we analyzed seasonal data using three seasonal categories of premonsoon (May~June), monsoon (July~August), and postmonsoon (September~October).

In addition, we analyzed Trophic State Index (TSI), based on trophic variables of TP and CHL after the approach of Carlson (1977) and based on trophic variable of TN after the approach of Kratzer and Brezonik (1981). The equations are as follows:

$$TSI(TP)=14.42\times\ln TP(\mu g\ L^{-1})+4.15$$
$$TSI(CHL)=9.81\times\ln CHL(\mu g\ L^{-1})+30.6$$
$$TSI(TN)=10\times[6-\ln(1.47/TN(mg\ L^{-1})/\ln 2]$$

RESULTS AND DISCUSSION

1. Precipitation and hydrological patterns

According to long-term analysis of precipitation during 1998~2007, annual mean precipitation was 1,326 mm and >80% of the total rainfall occurred during May~October. Intensive rainfall was observed during summer period of July~August and the volume was comprised of >40% of the annual total. Mean rainfall were >1,100 mm during the study period. Year 2003 was wet year (1,822 mm) and 2001 was dry year (794 mm, Fig. 2). Actually, the amount of rainfall during the monsoon period in 2003 (659.9 mm) was high by about 3.4 fold relative to 2001 (195.6 mm), and was slightly greater than 50% of total annual precipitation (Fig. 2). Comparisons of wet year vs. dry year showed that monsoon period showed largest difference in the rainfall and this result is accord with previous analysis of seasonal rainfall (An, 2000).

2. Inflow and outflow regime

Interannual inflows influenced by precipitation pattern during the study. Inflow volume from the up-river in 2001 was 414.3 m^3 sec^{-1}, which was minimum in the study period, whereas it was 2,125 m^3 sec^{-1} in 2003 and the value was highest in 2003. The minimum flow in 2001 was due to reduced rainfall and reduced discharge from the upper-dam of Yeoungdam Reservoir, which was built in 2000 (Lee *et al.*, 2008). During the study, we found that inflow volume was nearly equal to discharge volume (i.e., outflow) from the dam, except for in 2002. In 2002, outflow was much less than the inflow. This result indicates that inflow water in Daechung dam did not release much like other years in order to minimize the influence of water storage capacity of Daechung Reservoir by construction of Yeoungdam Reservoir. Such construction resulted in marked differences in water budget between inflow and outflow in Daechung

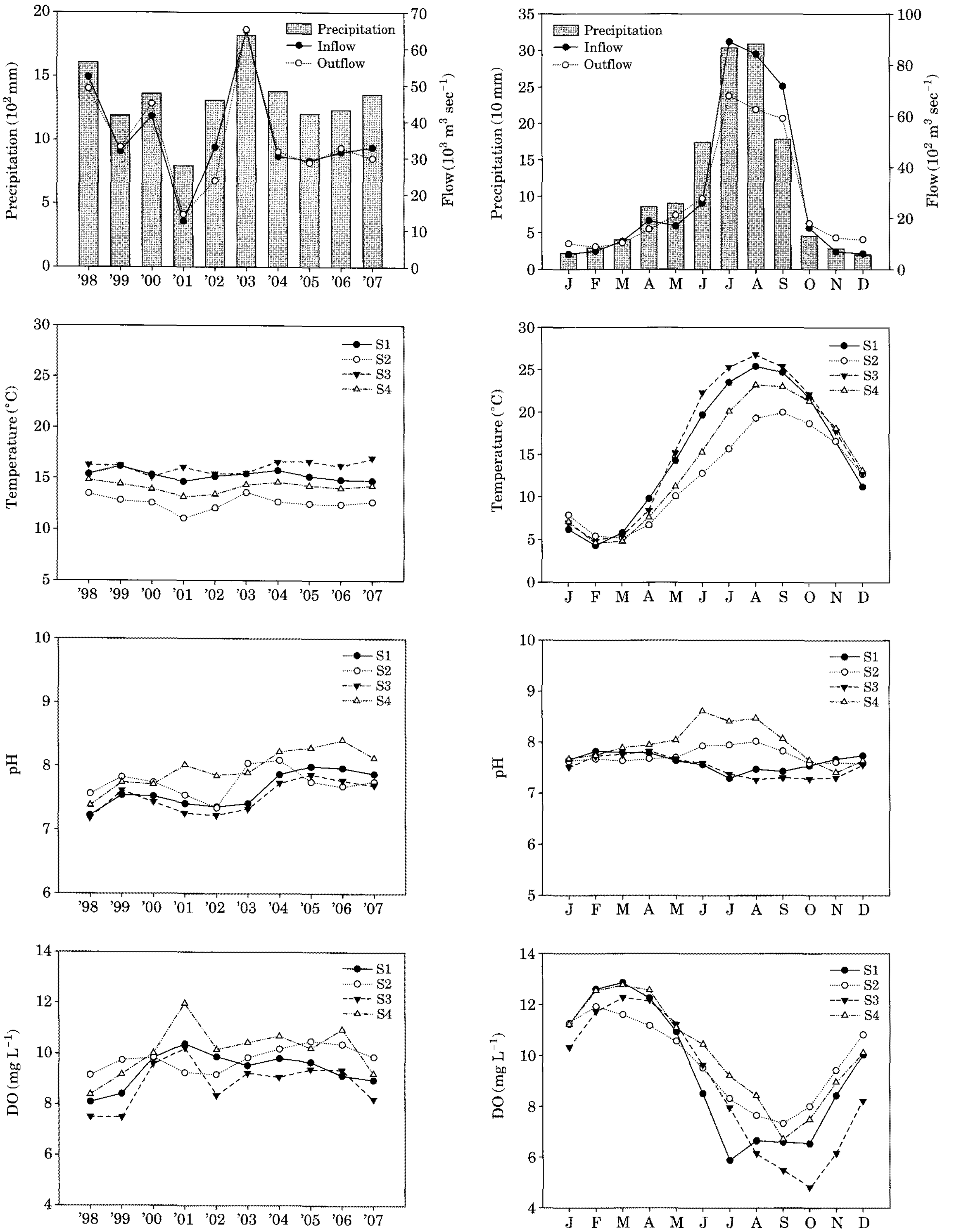

Fig. 2. Interannual and seasonal (monthly) variations of general water quality parameters and their relations to hydrology during 1998 ~ 2007.

Reservoir. According to comparisons of monthly inflow to outflow (Fig. 2), distinct water difference between inflow and outflow occurred during July ~ September. This was due to increases of water storage of monsoon runoff after low water level in dry seasons of premonsoon.

3. Physico-chemical water quality

Annual mean temperature ranged between 11 and 17°C. The mean epilimnetic temperature was greater in S3 than any other sites (S1, S2, and S4,) and was lowest in the site of S2. We believe that the highest surface temperature in the dam site is due to higher surface temperatures (>27°C) by strong thermal stratification in summer period and the turnover of deep warm water in winter season. Monthly surface water temperatures showed a minimum in February, and then increased by August maximum. This pattern was same as air temperature pattern, which is directly influenced by seasonal light intensity of sun. During the summer monsoon period of July ~ August, surface temperature was lower in Site 2 than any other sites and this was probably due to greater temperature decreases by rainfall and near-by runoff in the a shallow area than other sites.

Annual mean pH ranged between 7.0 and 8.5, which is good conditions by the criteria of the physic-chemical water quality by the Ministry of Environment, Korea. Generally, pH showed an increasing trend over the study period from 1998 to 2007. Annual trend of pH also showed higher in Site 4 than any other sites and increasing rate over the year was greatest (Fig. 2). Monthly pH values during June ~ August were greater in two intake tower sites within embayments of S2 and S4 than other mainstem sites of S1 and S3. In contrast, during June ~ August pH values decreased largely in two sites of S1 and S3 and this was probably attributed to greater dilution of high pH lake water by low pH rainwater and river runoffs. This indicates that the pH at the mainstem sites (S1 and S3) is more influenced by the river inflow from the up-stream than in the embayment waters (S2 and S4). Also greater pH in the embayments of two intake towers was attributed to greater photosynthesis due to more favor environment of phytoplankton by greater water column stability and greater primary production by higher nutrient supply from the shallower littoral zone (S2 and S4) than deep mainstem zone (S1 and S3). Our results is supported by a recent water quality study of Daechung Reservoir (Bing *et al.*, 2002).

Annual mean of dissolved oxygen (DO) at all four sites were >7.5 mg L^{-1}, which is judged as an excellent condition of Ia, by the criteria of the physic-chemical water quality by the Ministry of Environment, Korea. Annual mean DO by site was greater in the two intake tower sites (S2 and S4) than in the mainstem sites of S1 and S3. This pattern was similar to annual mean pH by site, so, the DO pattern was closely associated with pH fluctuation, which is mainly influenced by phytoplankton photosynthesis under a given same geology of Daechung Reservoir (Wetzel, 1983; Reynolds, 1984). Monthly values of DO were directly inverse functions with water temperature as shown in limnology textbook. Thus, mean DO was mininma (4.8 mg L^{-1}) during July ~ October, when water temperature were high, whereas DO was maxima during February ~ March when temperature were lowest. High DO value of >15.0 mg L^{-1} at Site 4 (Muneu intake tower) occurred in 2001 when inflow was minimum, indicating a supply of dissolved oxygen by active photosynthesis in the dry year.

4. Organic matter contents, solids, and nutrients

In this study, chemical oxygen demand (COD) was used as an indicator of organic matter pollution as shown in previous lake and reservoir studies. At all four sites, annual mean of chemical oxygen demand (COD) were judged as the rank of Ib ~ II, by the criteria of the physic-chemical water quality by the Ministry of Environment, Korea. Values of annual mean COD at Site 2, which is intake tower site at Dong-gu, started to increase after 2001, and then peaked in 2003 when the rainfall was highest. In this result indicated that rainfall runoff may trigger organic matter inputs to the reservoir, so the main source of the organic matter in the reservoir may be a runoff by precipitation (Fig. 3). Thus, organic matters in the intake tower site (Dong-gu) may be more influenced by the rainfall than other sites. Monthly mean COD by site decreased by <3 mg L^{-1} at all four sites, indicating a rank of Ib by the criteria of the physic-chemical water quality by the Ministry of Environment, Korea. The COD values, however, started to increase from June, and then peaked in August, resulting a deteriora-

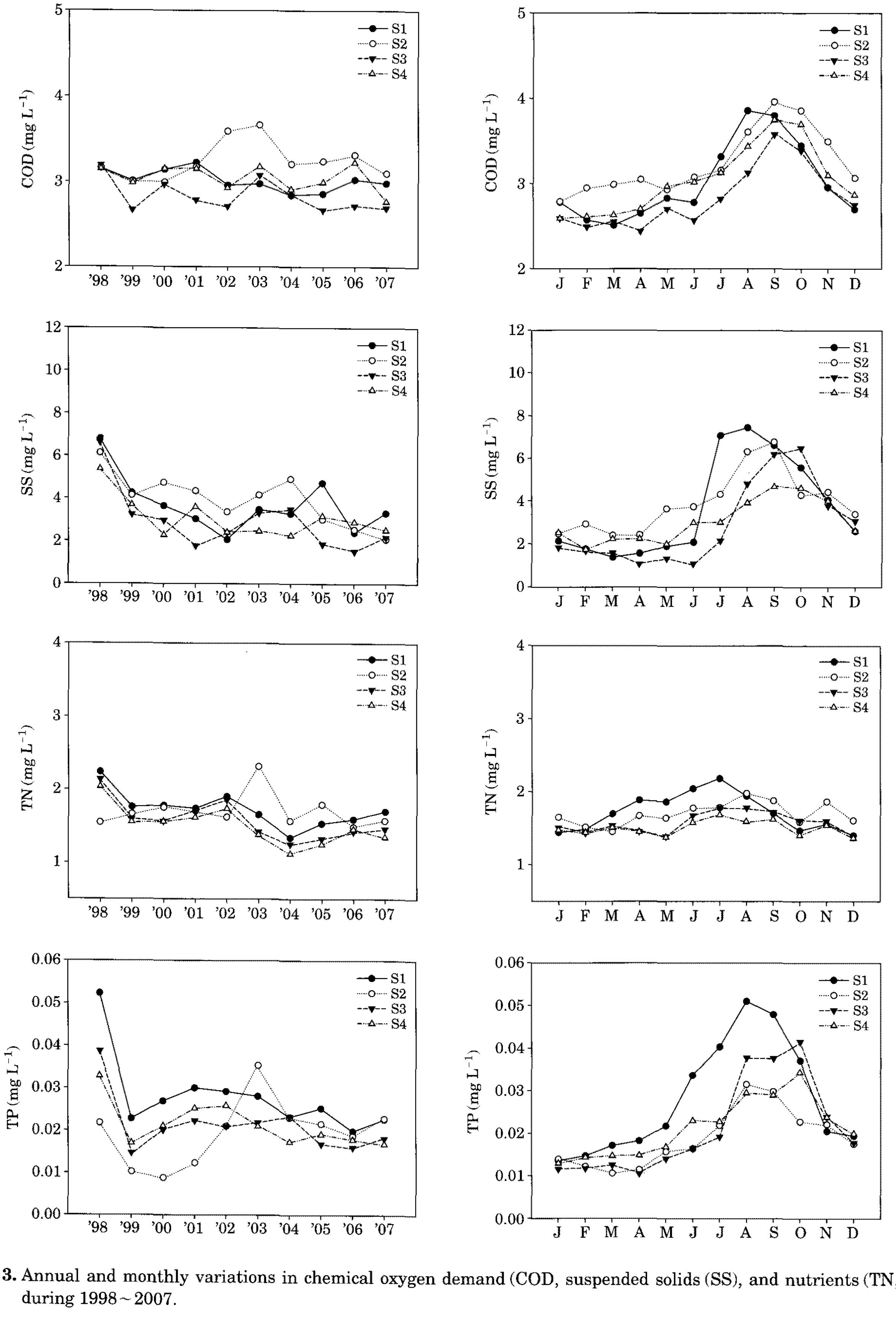

Fig. 3. Annual and monthly variations in chemical oxygen demand (COD, suspended solids (SS), and nutrients (TN, TP) during 1998 ~ 2007.

tion of water quality as a rank of II. Mean monthly COD reached maximum at the Site 1 in August, while in other sites the values reached maxima in September, indicating that organic mater originated mainly from the mainstem up-river influenced the up-reservoir site first, and then influenced down-lake sites (Fig. 3). The high COD during August ~ September was probably due to increased phytoplankton biomass by higher light availability as inorganic solids decreased during intense runoff. For these reasons, organic matter of COD peaked immediately after the monsoon flow.

Annual mean of suspended solids (SS) showed maximum (6.3 mg L^{-1}) in 1998, indicating a rank of III, by the criteria of the physic-chemical water quality by the Ministry of Environment, Korea. The values of SS, however, declined over the study period, resulting in a rank of Ib ~ II in 2007 as 2.5 mg L^{-1}. The minimum values of SS were observed in 2001 and 2002, which were the years after the upper-dam construction of Yeoungdam Reservoir. Total suspended solids (SS) are composed of volatile suspended solids (VSS; mainly, phytoplanlton biomass) and inorganic suspended solids (ISS). So, upper dam construction probably resulted in reduced ISS contents by decreased inflow from the up-river, indicating an influence of upper dam construction on solid loading in the reservoir. Such SS loading are well shown in seasonal pattern of monthly SS (Fig. 3); Values of SS were highest during summer monsoon of July ~ August when ISS increase in agricultural area and urban land. This is also supported by typical longitudinal gradients of SS from S1 to S4; Values of SS by site were highest in S1, most up-river site in the study, and then followed by S2, S3 and S4. These longitudinal differences were considered as a time-lag phenomenon on residential time that suspended solids lapsed in arriving (An, 2001). This phenomenon is frequently demonstrated by transport processes in dendritic long reservoir.

At all four sites, annual mean of total nitrogen (TN) were >1.5 mg L^{-1}, indicating an eutrophic-hypereutrophic conditions, based on only TN measurements. Nitrogen may not used for trophic indicator because N-limitation may not occur under the circumstances. when TN : TP ratios of the physic-chemical water quality by the Ministry of Environment, is greater 16. Mean ratios of TN : TP by site were >96 at all four sites, so the trophic judgement by criteria of TN may be excluded from the analysis. Annual mean TN decreased slightly in 1998, but increased up to 1.35 ~ 1.7 mg L^{-1} in 2007. Also, monthly mean TN values ranged between 1.7 ~ 2.2 mg L^{-1} at all four sites, indicating a nitrogen-rich system regardless of season and locations during the study. In addition to the spatial variation, seasonal variation of TN was low, so the effect by rainfall and monsoon runoff were considered minor, compared to phosphorus, which is largely influenced by river inflow. In spite of high nitrogen in the ecosystem, influence on algal growth seemed to be minor due to high N : P mass ratios of >96.

Dynamics of TP were influenced by up-reservoir constructions and monthly mean TP was function of river inflow. Annual mean TP was highest in 1998 and values were judged as the rank of II ~ IV, by the criteria of the physic-chemical water quality by the Ministry of Environment, Korea. These values decreased continuously over 10 year period. The upper dam construction probably resulted in reduced phosphorus by decreased inflow from the up-river, indicating an influence of upper dam construction on phosphorus loading in the reservoir. This phenomenon was demonstrated by previous research of Lee *et al.* (2008). In the mean time, levels of monthly TP were low during January ~ May, but increased in June, and then peaked during July ~ August when river inflow and precipitation were maxima. Also, monthly mean TP was highest in Site 1, which is directly influenced by the up-river inflow and the fractions of particulate phosphorus may be large because of high inorganic suspended solids. In contrast, monthly means of TP in the down-lake sites of S3 and S4 peaked in early October, indicating that large spates of river runoff of July ~ August arrived in down-lake on early October after 2 ~ 3 month later. This phenomenon of delayed response of TP to the flow may be also associated with metalimnetic interflow current during the strong thermal stratification in the reservoir. An (2001) proved the evidence of massive interflow current during the heavy flood period of 1993 and this current resulted in large spatial variation in epilimnetic TP. These circumstances resulted in peak TP at the down-lake zone (S3 and S4) in October. These results suggest that phosphorus loading mainly occur during the intense monsoon, but the phosphorus may not highly available for phytoplankton growth due to higher proportion of particulate fractions.

5. Biological water quality of *E. coli* and chlorophyll

Biological water quality based on the number of *E. coli* in all sites except for S2 were judged as the rank of Ia, by the criteria of water quality by the Ministry of Environment, Korea. The numbers were <50 per 100 mL at the sites (S1, S3, S4). However, the number varied highly in the site 2 (S2) depending on the year sampled, and the number was highest as 139 per 100 mL in the Site 2. Our observation of high *E. coli* at Site 2 is same as previous research of Yim (2007) which the high number is due to accidental release of untreated wastewater in the rainy season near the location and high nutrient loading from the wastewater disposal plants. Monthly mean of *E. coli* in all sites except for S2 did not show seasonal variations as shown in annual mean variation in three sites of S1, S3, and S4. The high monthly means in the Site 2 were attributed to influence of wastewater as shown above, and the peaks during July ~ October were also contributed favor temperatures for *E. coli* during the season.

Concentrations of chlorophyll-*a* (CHL), as an estimation of primary productivity, varied largely depending on the year and season. CHL values ranged between 6.2 and 12.1 $\mu g\ L^{-1}$ in 1998 (Fig. 4), judging as a rank of Ia ~ II by the criteria of the physic-chemical water quality by the Ministry of Environment, Korea, while the values ranged between 4.1 and 7.9 $\mu g\ L^{-1}$ in 2007, judging as a rank of Ia ~ Ib. The peak of CHL occurred in Site 4 (Muneu intake tower) during 2006 when the precipitation and inflow were lowest (Fig. 4). Such peak may be a result of high water column stability favored phytoplankton growth during the summer and phosphorus supply by frequent surface mixing with bottom due to extremely reduced water level in this site. This result is shown in highest TP values in Site 4 (Fig. 3). Also we found that another CHL peak was observed in Site 2 (Chudong intake tower) in 2006 when one of the largest typoon (Ewinia) occurred and river runoff were maximum. Previous research (Keum-River Watershed Research Center, 2006) reported that high CHL in the S4 during 2006 were due to algal transport with water movements from a tributary of Chuso-ri (inlet of tributary) and mainstem up-river of Janggae Bridge.

Monthly pattern in mean CHL by site was exactly followed the dynamics of total phosphorus. The CHL increased abruptly after July and the peaks of CHL occurred in August ~ October. During January ~ May, values of monthly CHL showed a rank of Ia ~ Ib by the criteria of the physic-chemical water quality by the Ministry of Environment, Korea, but after the period CHL increased during the monsoon, resulting a deterioration of water quality as a rank of < II ~ III. Monthly mean CHL at the Site 1 which is located in the main-axis of the reservoir and thus influenced by the up-river runoff, had highest values in the observation of August. In the mean time, monthly mean CHL values in other sites (S2, S3, and S4) were highest in October. So, the seasons of CHL peaks were evidently different in response to arrival of river runoff water containing high phosphorus, which is a typical limiting nutrient in this system (An, 2001). Thus, the magnitude of CHL was higher near the up-river site in terms of longitudinal gradients from the up-lake to down-lake, and higher in shallower area in the down-lake zone. Also, the seasons of CHL peak were slower in the down-lake zone than in up-lake zone. In the down-lake zones, CHL maxima occurred immediately after the summer monsoon of July ~ August and this phenomenon may be related to time-large of nutrient-rich runoff water between the up-lake and down-lake and also better underwater light availability in postmonsoon than in the intense monsoon (Horne and Goldman, 1994). These results suggest that the magnitude of annual algal biomass or chlorophyll varied with season and site, but is closely related with dry year with low water level and wet year (flood year) with high flushing.

6. Reservoir trophic conditions, based on Trophic State Index

Trophic state, based on equations of Trophic State Index (Carson, 1977) varied depending on the seasons and the sites sampled (Table 1). Mean TSI (CHL), TSI (TN), and TSI (CHL) values were 56.4 ± 8.1 (32.8 ~ 84.7), 61.0 ± 3.5 (50.0 ~ 75.8), 46.5 ± 6.6 (24.6 ~ 66.6), respectively (Table 1). Thus, trophic states, based on TSI (CHL) and TSI (TN) were mesotrophic by the criteria of Carson (1977), while trophic state by TSI (TP) was eutrophic during the study period. According to values of TSI (CHL), highest values occurred in Site 1 during August when nutrients of N and P were highest, resulting in a hypereutrophy by the criteria

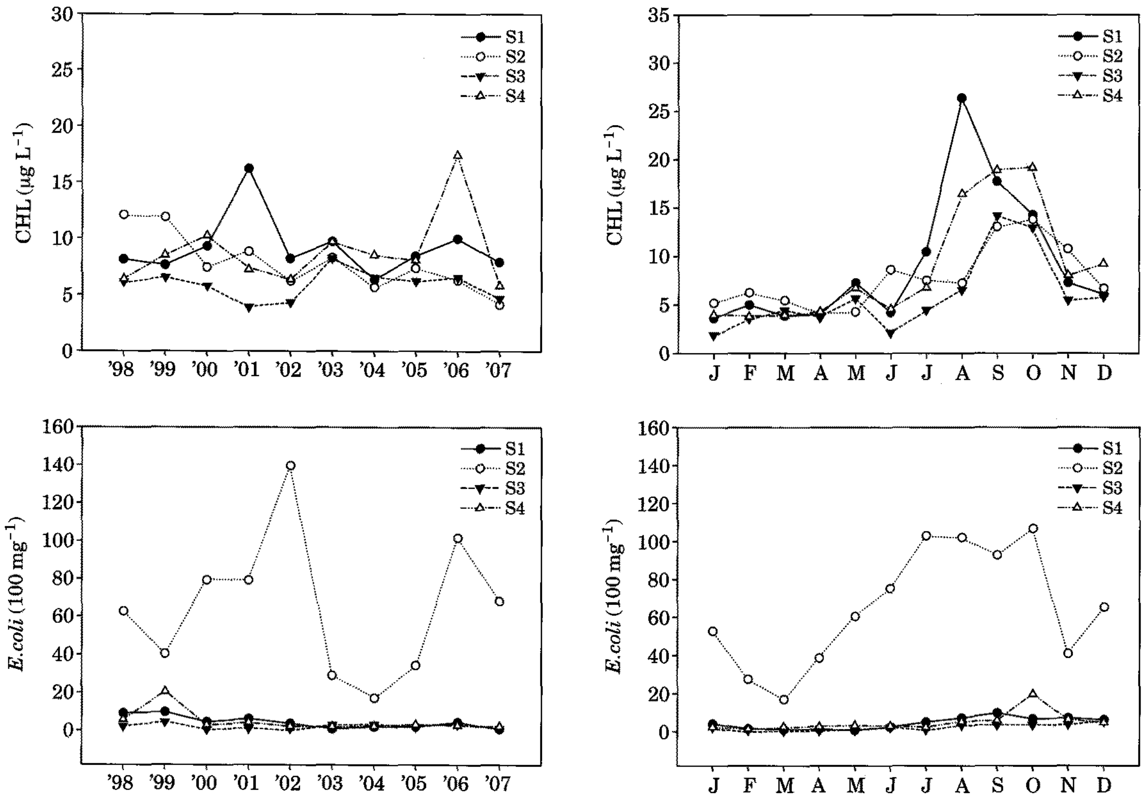

Fig. 4. Annual and monthly variations of *E. coli* and chlorophyll-*a* (CHL) during 1998~2007.

Table 1. Average variation of trophic state index (TSI) and Mean TN : TP atomic ratio during 1998~2007.

Site		Trophic state index			TN : TP ratio
		CHL ($\mu g\ L^{-1}$)	TP ($\mu g\ L^{-1}$)	TN ($mg\ L^{-1}$)	
S1	Mean	57.5±8.4	48.4±7.1	61.8±3.8	94.5±60.1
	Range	40.5~84.7	35.5~66.6	50.3~71.8	18.9~285.3
S2	Mean	57.7±6.4	45.2±6.4	61.7±3.2	126.7±81.4
	Range	44.2~75.3	31.5~64.5	55.8~75.8	15.9~468.5
S3	Mean	53.3±8.4	45.7±7.0	60.6±3.4	116.1±93.7
	Range	32.8~72.2	24.6~63.8	54.8~73.5	19.0~771.0
S4	Mean	57.1±8.3	46.8±5.5	59.9±3.4	95.1±71.3
	Range	40.5~83.4	31.5~60.0	52.5~70.8	24.5~557.3
Total	Mean	56.4±8.1	46.5±6.6	61.0±3.5	108.1±78.6
	Range	32.8~84.7	24.6~66.6	50.0~75.8	15.9~771.0

of Carson (1977), while highest values in other sites (S2, S3, S4) occurred during September~October (Fig. 5). Such seasonal differences in the sites was probably due to growth differences in response to arrival of river runoff water containing high phosphorus, which is a typical limiting nutrient in this system (An, 2001), as shown in Fig. 4. Also, greater trophic state after the monsoon may be explained by greater underwater light availability (Kimmel and Groeger, 1984; Horne and Goldman, 1994) in postmonsoon than in the intense monsoon and greater water column stability favored for phytoplankton growth (Thornton *et al.*, 1981; An, 2000). Values of TSI (TP) increased immediately after the monsoon inflow, and the values were highest in the Site 1, where the lake

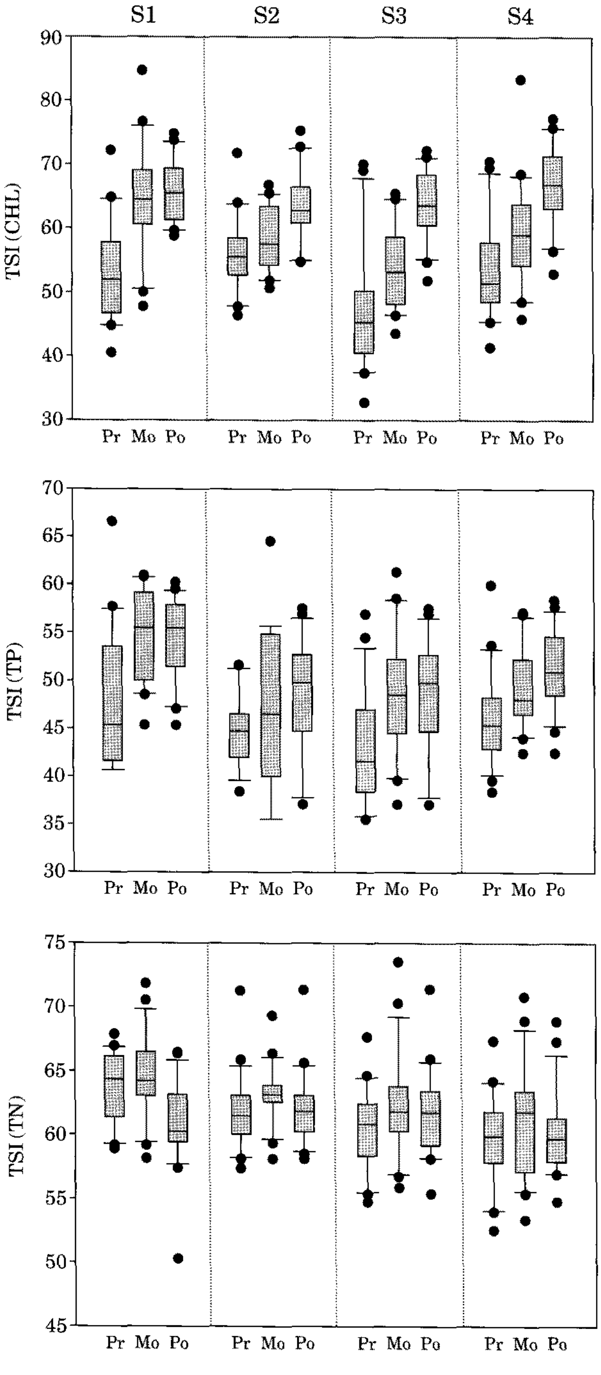

Fig. 5. Trophic State Index based on chlorophyll-*a* (CHL), total phsophorus (TP), and total nitrogen (TN) during the study period.

water is directly influenced by the river runoff from the watershed. This indicates that high trophy in the S1 is regulated by external phosphorus loading from the watershed during the monsoon. In contrast, TSI (TP) values at the sites of S3 and S4 were increased in the postmonsoon, so the there was one month difference in the peak of TSI (TP) between S1 and other two sites of S3 and S4. Our results on lower trophic state in the down-lake sites than the up-lake of Daechung Reservoir is accord with previous studies of An (2000) and Thornton *et al.* (1981).

In the mean time, values of TSI (TN) were >60 at all four sites, indicating an eutrophic - hypereutrophic conditions. Also, seasonal (premonsoon, monsoon, and postmonsoon) and spatial variations were low, compared to TSI (TP) and TSI (CHL). This result indicates that trophic state of TSI (TN) is not closely associated with summer rainfall and seasonal monsoon runoff. As shown in Table 1, overall mean of mass TN : TP was 108.1+78.6 and the N : P ratios were >90 at all sites, indicating a severe phosphorus limitation for phytoplankton growth and never N-limitation in this system. For this reason, even if the trophic state, based on TSI (TN), ranged between eutrophy and hypereutrophy, nitrogen may not be an influential nutrient like phosphorus because this system is evidently P-limited system (An and Park, 2002; An and Park, 2003).

Overall results indicate that interannual over the ten years and seasonal fluctuations in hydrological variables such as inflow, water level, and discharge near the intake tower facilities (S1 ~ S4) were directly influenced by rainfall pattern. During the long-term monitoring, 2003 was wet year and 2001 was dry year. The interannual difference produced marked differences in water temperature, pH, dissolved oxygen, organic matter contents, nutrients, and these variables influenced algal biomass and trophic state. In the intake towers of S2, water quality were more rapidly degradating especially during the drought year and postmonsoon seasons. If lowering of intaking water depth at Muneu intaking tower site (Site 2) may be helpful for the protections of drinking water in the site because of frequent algal blooms in the surface water. In the mean time, an introduction of new efficient wastewater purification system in Chudong intake tower, the control of nutrient loading from near-land, and nutrient removals by planting of nutrient-absorbing plants using artificial floating island may provide better water quality for the tap water. Such strategies may reduce frequent high number of *E. coli* in the intake tower and algal growth, resulting better water quality.

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