Examination of Critical Factors Related to Summer Chlorophyll *a* Concentration in the Sueo Dam Reservoir, Republic of Korea

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Abstract

This study examined critical factors related to the short-term variation of algae growth in reservoirs during the summer. To this end, statistical tests were carried out at a small dam reservoir to determine how chemical factors (e.g., nutrient concentrations) and physical factors (e.g., theoretical and relative residence times, temperature) influenced the chlorophyll *a* (Chl-a) concentration. Statistical tests revealed that, although phosphorus (P) concentration was significant for Chl-a, residence time had much stronger relationship to Chl-a concentration than chemical factors. In addition, the study verified that relative residence time (RRT) best explained the relation of water status to algae growth. RRT was found to be useful in identifying water status related to the summer algae bloom. Finally, this study raised the possibility of inhibiting summer algae growth by operating dam reservoirs moderately. These findings need to be seriously considered when reservoir operators establish effective strategies for water quality management in summer.

Key words: chlorophyll *a*; algae growth; nutrient concentration; water residence time; water quality management

Introduction

EUTROPHICATION OF RESERVOIRS continues to accelerate because of huge contaminant loading and stratification. As a result, reservoir water quality has deteriorated with algae bloom (Canfield and Hoyer, 1988; Heo and Kim, 2004), which causes not only harmful toxicity but also taste and odor problems. Moreover, the cost of treating water sources in which algae bloom is severe is high because of clogged filters in water treatment plants (Knappe *et al.*, 2004). For inhibiting algae bloom, in-lake methods such as air diffusing systems, dredging, and injection of ferric sulfate are generally used (Kim *et al.*, 2010; Hayes *et al.*, 1984). Despite such efforts, many reservoirs and lakes continue to suffer from algae blooms, and water quality in these reservoirs has not been improved (Pfafflin *et al.*, 2006; McAuliffe, 1990).

It is well known that algae growth is variously influenced by abiotic and biotic factors. Abiotic factors are divided into physical factors (e.g., temperature, light penetration, and residence time), and chemical factors, that is, diverse nutrient concentrations (Jones and Bachmann, 1976; Hoyer and Jones, 1983; Søballe and Kimmel, 1987; Gomes and Miranda, 2001). Although temperature and light density have a substantial effect on algae growth (Rittmann and McCarty, 2003), nutrient concentration and residence time are known to be the most important factors for algae growth in summer (Correll, 1998; Dickman, 1969; Gomes and Miranda, 2001). Many researchers have reported that phosphorus is critical value for algae growth (OECD, 1982; Schindler, 1977; Correll, 1998; Moss *et al.*, 1989). This results from the decrease of N/P ratio. Conversely, a few researchers have argued that nitrogen is limiting factor for algae growth (Ryther and Dunstan, 1971). Unlike these researchers, Dickman (1969) argued that water residence time is more likely to be important for algae bloom than nutrient concentration, especially for small reservoirs. Gomes and Miranda (2001) showed that chlorophyll *a* (Chl-a) increases with increasing residence time and decreases with increasing discharge. Reynolds and Lund (1988) reported that heavy rainfall could change the phytoplankton populations in lakes where the residence time is short. Maberly and others (2002) studied many small upland lakes in the English Lake District and demonstrated that short residence time supplied an unsuitable environment for the growth of nitrogen-fixing cyanobacteria.

Although shorter residence time generally leads to limitations on algal colonization, growth, and reproduction in

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reservoirs and lakes (Søballe and Kimmel, 1987; Jones and Elliot, 2007; Jones *et al.*, 1984; Gameiro *et al.*, 2004), some researchers have reported no correlation between residence time and phytoplankton biomass (Moss *et al.*, 1989; Kawara *et al.*, 1998; Renella and Quirós, 2006). In two shallow lakes, however, Renella and Quirós (2006) did show that phytoplankton biomass reached a higher level when the water residence time was short. These results contradict the results of Gomes and Miranda (2001) and Maberly and others (2002). We suppose that the inconsistency in the relationship between residence time and Chl-a concentration comes about because different methods were used to define residence time and because some definitions did not distinguish water status in detail.

In summary, algae growth is affected by various factors, and thus for efficient water quality management in a reservoir or lake, it is necessary to reveal the critical factors related to algae growth. Hence, this study aims to statistically elucidate the relationships between algae growth and various factors with sample data from a small dam reservoir during the summer season. To do so, regression models are built while the Chl-a concentration is regarded as a function of chemical and/or physical factors. The results are then discussed with the obtained statistics and other researchers' results. Finally, this case is expected to have important implications to water engineers and managers who are interested in restraining algae bloom and devising systematic strategies for the water quality management of lakes or dam reservoirs.

Study Area

The Sueo dam reservoir is located in a temperate region in the southern part of South Korea. It was constructed in 1978 for agricultural and industrial water supply. It has a long and narrow shape, as shown in Fig. 1A. The catchment area is 49 km^2, and the reservoir has a surface area of 1.6 km^2, total storage capacity of $27.5 \times 10^6 \text{ m}^3$, and a mean depth of 25 m. Theoretical residence time is known to be relatively short, approximately 40 days. There are two inflows and one outflow. The main inflow is the Sueo Stream, which alone does not supply enough water for dam operation. As a result, the Seomjin River was connected to the reservoir via an underground pipe across a mountain. The water quality of the Seomjin River is worse than that of the Sueo Stream, according

to the Water Management Information System (www.wamis.go.kr), a government database, and hence the Seomjin River is usually diverted from the reservoir in the summer when algae bloom is apt to occur. Stored water is discharged mainly at an intake tower, and the intake rate is nearly constant at around $3.0 \text{ m}^3/\text{s}$ in all seasons. Although a spillway has been constructed to protect the area in case of flooding, it is not being operated. It can thus be said that the reservoir has a stable outflow and two inflows that fluctuate relatively over time.

Based on data from the Water Management Information System database (www.wamis.go.kr), total nitrogen (TN) and total phosphorus (TP) concentration are about 1000–2000 and $1–39 \text{ mg/m}^3$, respectively. Thus the Sueo dam reservoir approximates a mesotrophic condition according to Nürnberg's standard (1996). Various phytoplankton species (e.g., green algae, *Coelastrum,* nontoxic cyanobacteria, *Microcystis,* and diatoms *Asterionella*) are observed in the Sueo dam reservoir. In summer, cyanobacteria, *Microcystis* is dominant. In addition, water quality in summer is generally worse than in other seasons. During the summer of 2000, for example, Chl-a reached 34.2 mg/m^3, which was much higher than the average (below 10 mg/m^3) of other seasons. As shown in Fig. 1, six hypolimnetic aerators were installed near the intake tower in 2003 to prevent summer algae bloom.

Study Methods

Sampling

To investigate the relationship of chemical factors and physical factors with Chl-a concentration, three sampling sites, A, B, and C, were added to the dam operator's two existing sampling sites, S1 and S2, as depicted in Fig. 1B. The dam operator had been measuring water quality and temperature at monthly intervals at S1 and S2. However, since we decided to collect samplings on a weekly basis for the period from early May to late September in 2008 at five sampling sites, 85 samplings (17 samples × 5 sampling sites) were separately gathered for this study. Also, at each time and point, water samples were collected at 5 m intervals of water depth. Sampling was carried out in the early morning when wind was modest.

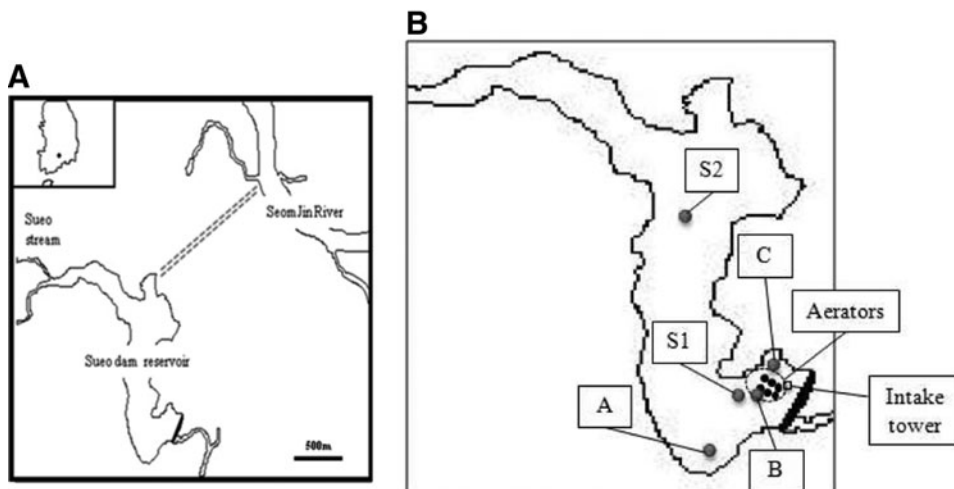Measurement items included Chl-a, temperature, water depth, dissolved oxygen (DO), TN, TP, dissolved total

FIG. 1. **(A)** Map of study area; **(B)** location of sampling sites.

nitrogen (DTN), and dissolved total phosphorus (DTP). Temperature and DO were estimated by a YSI probe after calibration, and water depth was measured by a portable depth sounder (SM-5) in the field. The other items were analyzed in the laboratory by the standard methods (APHA *et al.*, 1985). Namely, TP and DTP were determined with the ascorbic acid method, and TN and DTN were analyzed with the ultraviolet spectrophotometric method. Before estimation of DTN and DTP, each sample was filtered using Whatman GF/C filters (Soares *et al.*, 2008). To quantify the amount of phytoplankton biomass, the spectrophotometric method was used to estimate the Chl-a concentration, after phytoplanktons were extracted with 90% acetone (Lorenzen, 1967). The Chl-a samples were stored and preserved in a dark cooler with ice packs. In all cases, a laboratory analysis was performed within 10 days of sampling.

Estimation of water residence time

Data on inflow/outflow rates and water volume, accumulated over many years by the reservoir operator, is available from the Water Management Information System database (www.wamis.go.kr), and was used here to calculate three types of water residence time. Since it is assumed that reservoirs are completely mixed reactors (Kerneïs *et al.*, 1995), theoretical residence time (TRT) is often defined as water volume divided by inflow or outflow rate (Kawara *et al.*, 1998; Renella and Quirós, 2006). Depending on which flow rate dominates water status, TRT can be expressed as

$$TRT_{in} = \frac{V}{Q_{in}} \tag{1}$$

$$TRT_{out} = \frac{V}{Q_{out}} \tag{2}$$

where TRT_{in} and TRT_{out} are, respectively, the theoretical residence times on the base of the inflow and outflow (day), Q_{in} and Q_{out} are the inflow and outflow rate (m^3/s), and V is the water volume (m^3).

There is another way to define water residence time, which was presented by Gomes and Miranda (2001). Known as *relative residence time* (RRT), it is defined as the time needed to fill a changed volume, RRT (day). RRT can be expressed as the daily changed water volume divided by the inflow rate, as given below:

$$RRT = \frac{\Delta V}{Q_{in}} = \frac{V_1 - V_0}{Q_{in}} \tag{3}$$

where ΔV is the daily changed water volume (m^3), V_1 is the water volume at the present point in time (m^3), and V_0 is the water volume on the previous day (m^3). Unlike two theoretical residence times, RRT can have a negative or positive sign, depending on whether the water volume decreases or increases over time. If the water volume decreases while the outflow rate is higher than the inflow rate, hydraulic movements in a reservoir become transient. That is, when the RRT value is negative, the water body can be viewed as being in a lotic condition. In contrast, if the water volume increases while the inflow is higher due to precipitation or stream flows, the RRT value becomes positive, and the water body can then be regarded as being in a lentic condition. It is therefore

concluded that RRT helps to distinguish water status, although there is no theoretical consensus on lentic-lotic distinctions (Søballe and Kimmel, 1987).

Statistical estimation

To identify the critical factors for algae growth, the Chl-a concentration was considered as a function that potentially depends on chemical factors (TN, TP, DTN, and DTP), and physical factors (temperature, TRT_{in}, TRT_{out}, and RRT). It was anticipated that residence times were more influential than nutrient concentration for Chl-a concentration, because the targeted reservoir is relatively small. In addition, it was thought that the manner in which residence time was defined would result in different relationships between residence time and Chl-a concentration. These hypotheses were tested by using a simple regression model, presuming that the Chl-a concentration, y (mg/m^3), had the following relation with each factor x_i (temperature, TN, TP, DTN, DTP, TRT_{out}, TRT_{in}, and RRT).

$$E(y|x_i) = \alpha_i + \beta_i F_i(x_i) \tag{4}$$

where $F_i(x)$ is a predetermined function of x_i, which is the best-fitting curve on the scattergram between x_i and y, and which was selected among a line, a polynomial function, an exponential function, or logarithmic function (SPSS® ver.12.0 was used as the statistical software). α_i and β_i are regression coefficients. By defining a new variable, $z_i = F_i(x_i)$, Equation (4) becomes

$$E(y|z_i) = \alpha_i + \beta_i z_i \tag{5}$$

In Equation (5), the p-value of β_i, the correlation coefficient $\rho_{z_i, y}$, and elasticity $\frac{dy}{dx_i} \times \frac{\overline{x_i}}{y}$ are used to analyze the effect of each factor on algae growth (Ang and Tang, 2007); the p-value and the correlation coefficient for significance of x_i for y, and the elasticity are used to measure the degree to which x_i influences y.

Results and Discussion

Variation of Chl-a concentration

Figure 2 shows the Chl-a variation of the epilimnion at each sampling site. Temporal patterns were similar at all sites. The Chl-a concentration was high in the early sampling period and then decreased until 25 June. Thereafter, the concentration was below $10 \, mg/m^3$ on all days (a clear water phase), excluding 7 July and 25 August. It should be noted that notwithstanding less precipitation and sufficient sunshine, the Chl-a concentration was low during July and August. Potentially because phytoplankton biomass spreads horizontally, the largest variation of Chl-a spatially, was detected on 19 June. On 27 May and 9 June, maximum Chl-a concentrations were observed at the S2 site, which is close to the inlets of inflows. A few days later (19 June), maximum Chl-a concentrations were detected in sites B and S1, which were close to the intake tower.

Variation of temperature and nutrient concentration

During the sampling period, the temperature in the epilimnion and hypolimnion varied from 20° to 28°C and 7° to
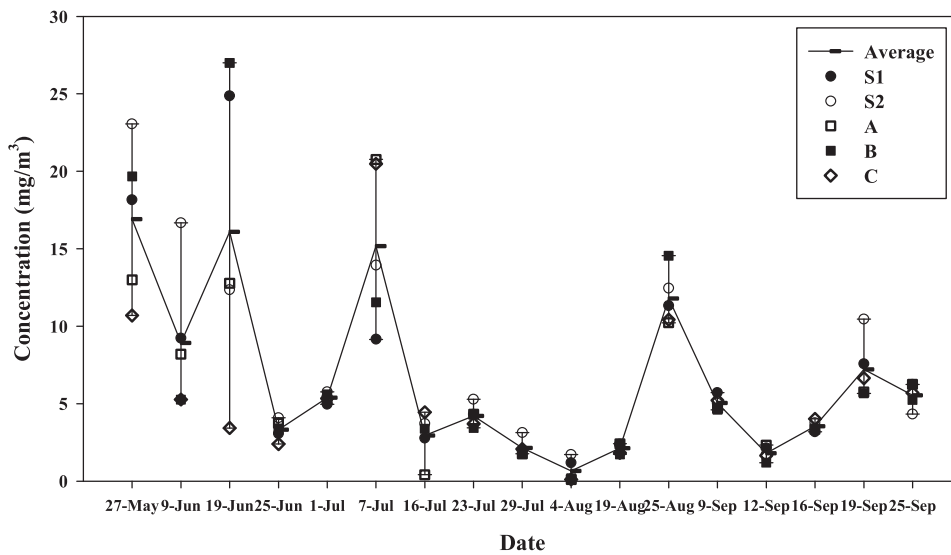
FIG. 2. Temporal and spatial variations of Chl-a concentration.

18°C, respectively, as shown in Fig. 3. It was observed that the average temperature in the epilimnion increased very slightly over time, whereas that in the hypolimnion increased rapidly. Temperature differences between the epilimnion and hypolimnion were found to be large in the early sampling period, 8° or 13°C, depending on the sampling points. The stratification decreased over time, and around 25 August, overturn was observed.

Fig. 3 shows that hypolimnion temperature manifested a much wider variation than epilimnion temperature. This is because the water depth of the hypolimnion varies by the sampling point. Temperature of the epilimnion was maintained at >20°C, irrespective of the sampling point. For the hypolimnion, the temperature was low at sites S1, A, and B, which were deep. As depicted in Fig. 4, it was therefore found that as the water depth becomes greater, the temperature difference between the epilimnion and hypolimnion increases.

In all cases, higher nutrients were observed in the earlier period (Figs. 5 and 6). This tendency was more obvious for potassium than for nitrogen. For example, at site A, the average TP and DTP concentrations were 52.5 and 21 mg/m^3, respectively, on 27 May. They were sustained at relatively high levels until 1 July. However, TP and DTP continuously decreased, dropping to 4.2 and 4 mg/m^3, on 29 July. Thereafter, TP and DTP varied slightly from 3.0 to 7.2 mg/m^3 and from 1.0 to 6.0 mg/m^3, respectively, with the exception of values of 19.5 mg/m^3 and 14 mg/m^3 on 9 September. TN and DTN concentrations started at 1371 and 886 mg/m^3 and reached peaks of 1903 and 1413 mg/m^3, respectively, on 16 July. They then decreased continuously. This trend was also observed at other sites.

The maximum nutrient concentrations were observed 35 and 14 times out of 68 times at sites B and C, respectively. Given that B and C are the closest to the intake tower among sampling sites, this may have been caused by the transportation and accumulation of nutrients. Indeed, all the hypolimnions were continuously in an oxic condition, based on the results of measured DO concentration. It is thought that nutrients are not released in large amounts from sediments
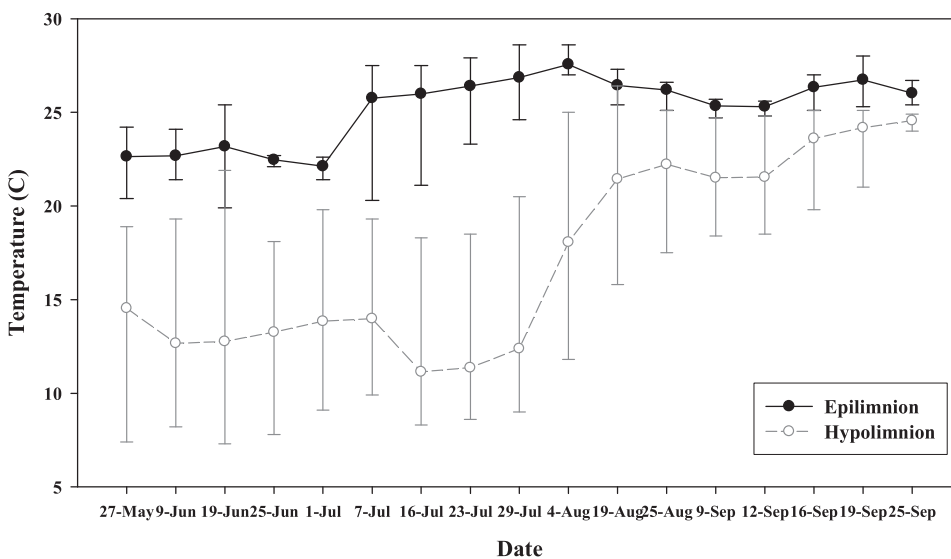

FIG. 3. Variation of temperature in the epilimnion and hypolimnion. The upper and lower parts of the individual error box denote the maximum and minimum values among five sampling points.
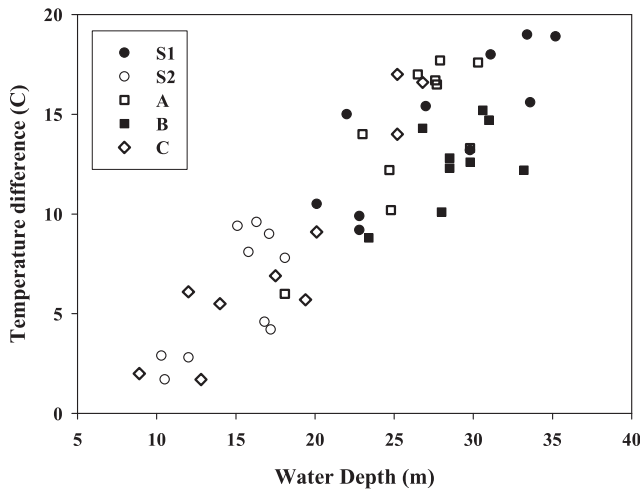
FIG. 4. Temperature difference versus water depth (*y*-axis denotes temperature difference between epilimnion and hypolimnion). Data are observed at each sampling point from 27 May to 25 August.

(Penn *et al.*, 2000). It is therefore concluded that the variation of nutrient concentrations depended on the accumulation of external loadings.

Variation of residence time

Variations of hydrologic conditions (e.g., two inflows, outflow, and water volume), were first estimated, as shown in Fig. 7. Inflow from the Sueo Stream was greatly increased by heavy rainfall on 27 May, 18 June, 28 June, and 2 July, and the maximum amount was roughly $20\,m^3/s$, recorded on 18 June. After early August, inflow changed moderately as there was no rainfall during this period. Inflow from the Seomjin River was vastly different. The maximum was merely $2.7\,m^3/s$ recorded on 16 June, and the inflow was cut off between 18 June and 3 August. As previously mentioned, the outflow was nearly constant at $3.0\,m^3/s$. For this reason, water volume was mainly changed by inflow. Water volume sharply increased from 18 June to 4 July, when heavy rainfall in-

creased the inflow from the Sueo Stream, and later decreased gradually.

Water residence time changed according to variations of hydrologic conditions. Figure 8 presents the variations of three types of water residence time obtained using Equations (1)–(3). Because outflow was nearly constant, TRT_{out} was quite proportional to water volume. Variation of TRT_{out}, ranging from 127 to 202 days, was modest compared to other residence times. TRT_{in} was not only affected by water volume but also determined by instantly varying inflows. As a result, its temporal variation was more severe, ranging from 10 to 147 days. Since RRT was estimated with deviation of water volume and inflows, it showed the largest variation over the period. Furthermore, RRT was positive or negative according to the direction to which water volume deviated. As seen in Fig. 8, RRT was negative for most of the period. This is because water volume was raised by large inflows several times between late May and early July. For the remaining period, water volume stagnated or decreased.

Effects of chemical factors on algae growth

Table 1 shows the results of applying the regression model of Equation (5), including the effects of chemical factors nutrient concentrations) on Chl-a concentration. From the results of the analysis of the effects of nitrogen concentrations, high p-values (0.447 for TN and 0.364 for DTN) reveal that nitrogen concentrations were not significant in terms of changing algae growth. Consequently, the correlation coefficient between nitrogen concentration and Chl-a concentration was 0.198 for TN and 0.235 for DTN. These values are too low to consider their effects serious. For phosphorus concentrations, p-values were estimated to be low, 0.099 for TP and 0.118 for DTP, and the correlation coefficient rather high, 0.414 for TP and 0.394 for DTP. Nevertheless, it was estimated that phosphorus concentrations did not have a strong influence on algae growth. The elasticity of TP $\frac{dy}{dx_2} \times \frac{\overline{x}_2}{\overline{y}}$ was about 0.005. This reveals that the effect of TP was trivial in comparison with elasticities of DTP or residence time, which were later identified as influential. The elasticity of DTP was
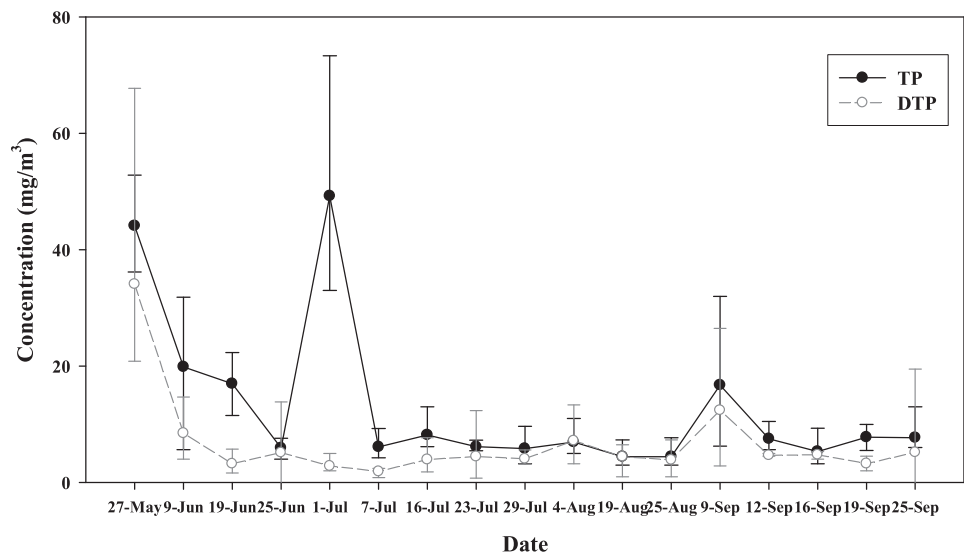
FIG. 5. Variation of TP and DTP. The upper and lower parts of the individual error box denote the maximum and minimum values among five sampling points.
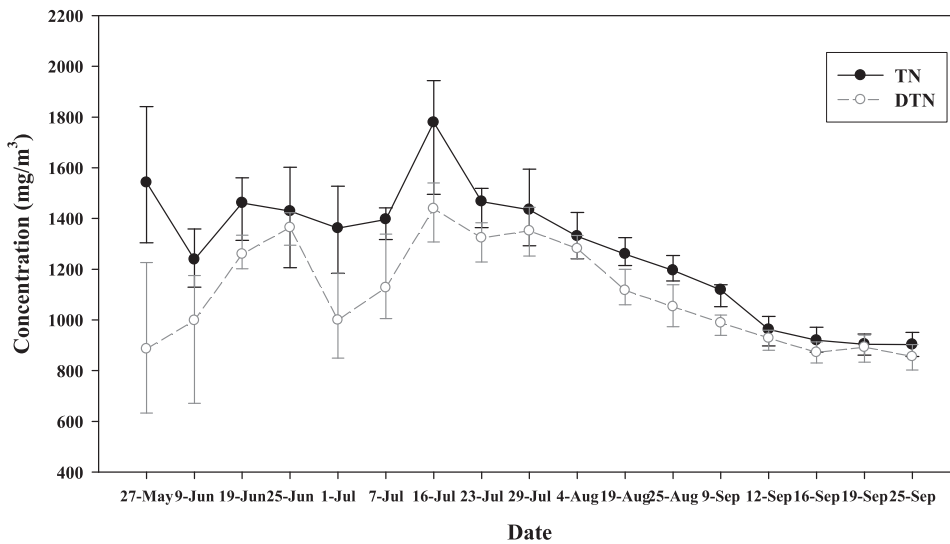
FIG. 6. Variation of TN and DTN. The upper and lower parts of the individual error box denote the maximum and minimum values among five sampling points.

estimated to be 0.281, meaning that the effect of DTP on algae growth cannot be ignored. It is therefore concluded that TP is a statistically significant but less influential factor for algae growth and DTP is an influential factor for algae growth. The above results are different from findings of some studies (Cloern, 1999; Howarth and Marino, 2006; Guildford and Hecky, 2000; Hecky and Kilham, 1988), asserting that nutrients are strongly related to algae growth in freshwater. We believe that amounts of nutrients in the reservoir did not always mean that of nutrients fed by phytoplanktons.

Effects of physical factors on algae growth

Table 2 shows the results of the statistical analysis of physical factors (temperature and three types of residence times). The results appear to imply that the effect of epilimnion temperature was very meaningful. This is, in part, because the temperature seemed to have a plausible effect on Chl-a concentration, given that the p-value of the regression parameter β_1 was estimated to be around 0.05. The correlation coefficient between temperature and Chl-a concentration was 0.465. This value can be considered high, especially in light of

the fact that algae growth is theoretically influenced by a variety of factors and that all samples included unavoidable errors in field conditions. However, the Chl-a change over the temperature change $\frac{dy}{dx_i} = \beta_5 e^{x_5}$ was less than zero. This means that the algae bloom decreased with increasing temperature. The dominant species, cyanobacteria *Microcystis*, is unique in that its growth is more activated with higher temperature (Rittmann and McCarty, 2001). Thus, it is deemed that the estimated correlation between temperature and Chl-a does not reflect the real relation. Rather, it is inferred that temperature followed a similar trend with other factors that are influential for Chl-a. (Temperature was closely correlated with RRT, although there is no direct reason to explain why the two factors would affect each other. RRT was later identified to be an influential factor for Chl-a.)

TRT_{out} is definitely insignificant for algae growth, as the p-value of the regression parameter was very large and the correlation coefficient was almost zero. This finding is similar to that of Renella and Quirós (2006) who argued that there was no relationship between phytoplankton biomass and theoretical residence time.
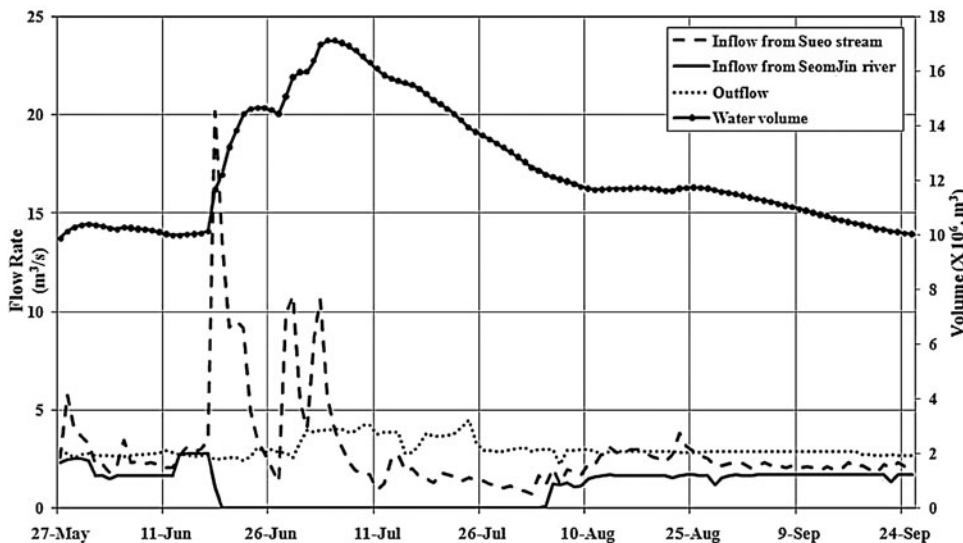

FIG. 7. Variation of inflow/ outflow rate and water volume during sampling periods.
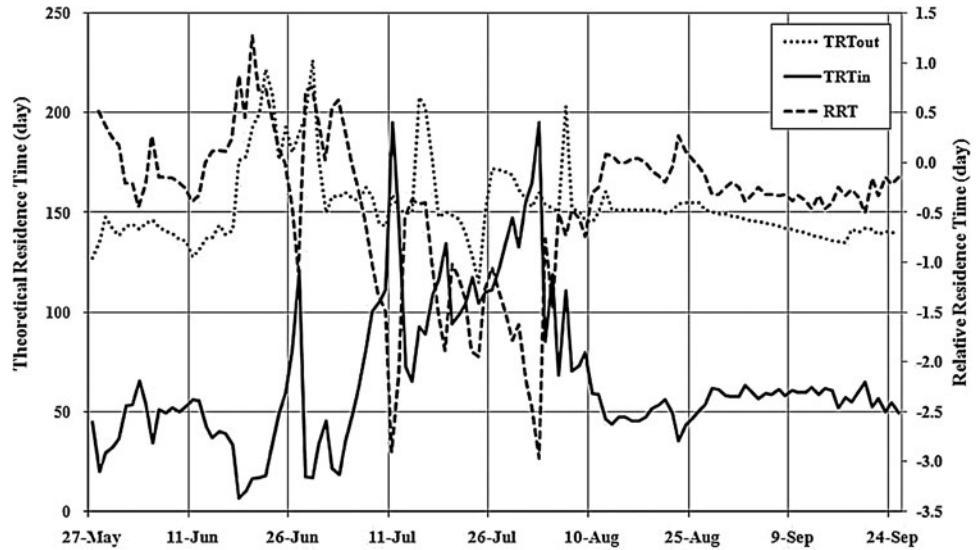
FIG. 8. Residence time during sampling period.

Two other residence times are very significant for algae growth, as shown by low p-values and high correlation coefficients. The elasticities of TRT_{in} and RRT, $\frac{dy}{dx_7} \times \frac{\overline{x}_7}{\overline{y}}$ and $\frac{dy}{dx_8} \times \frac{\overline{x}_8}{\overline{y}}$, imply that when TRT_{in} and RRT underwent a 1% change, the Chl-a concentration varied from 0.59% to 8.00% and from 0.05% to 0.59%, respectively. The elasticities of TRT_{in} and RRT are rather high in comparison with those of TP and DTP. Therefore, the first hypothesis is well verified: Residence time is more influential than nutrient concentration for phytoplankton biomass in the Sueo dam reservoir.

However, there is a serious problem in relating TRT_{in} to algae growth. Since $\frac{dy}{dx_7} = \frac{\beta_7}{x_7} < 0$, it can be argued that Chl-a concentration increased as TRT_{in} shortened. This is in opposition to the finding of many researchers that suspended biota do not contact nutrients well and thus do not grow well if the residence time is short (Søballe and Kimmel, 1987; Maberly et al., 2002; Jones and Elliot, 2007; Jones et al., 1984; Gameiro et al., 2004). Therefore, it is necessary to understand the mechanism underlying this case. As a rule, short residence time indicates a water body in the lotic condition in which algae do

not have time to accumulate and thus algae growth is restricted (Søballe and Kimmel, 1987). However, when TRT_{in} is adopted in this case, the low value resulted from hydrologic conditions in which inflow was high and water volume increased because outflow was constantly small. That is, the water body was stagnant. The short TRT_{in} can be interpreted as the water body being in the lentic condition, not the lotic condition. In the same manner, this explains why the Chl-a concentration was low at long TRT_{in}. Despite satisfactory statistics, TRT_{in} incorrectly describes water status.

As seen in Table 2, the RRT reasonably explains how residence time affected algae growth. The Chl-a change over RRT change $\frac{dy}{dx_8} = \beta e^{x_8}$ was more than zero, indicating that as RRT increased, so did Chl-a. This agrees with the general understanding (Søballe and Kimmel, 1987; Maberly et al., 2002; Jones and Elliot, 2007; Jones et al., 1984; Gameiro et al., 2004), and is supported by the statistics. This validates the second hypothesis that the manner in which residence time is defined will yield different relations between residence time and Chl-a concentration. Although statistical significances are found for TRT_{in} and RRT, the two residence times explain the opposite relation with the Chl-a concentration. Only RRT makes it

TABLE 1. EFFECTS OF CHEMICAL FACTORS ON CHLOROPHYLL *A* CONCENTRATION

i	x_i	Range	$z_i = F_i(x_i)$	β_i	p-value	$\rho_{zi,y}$ (correlation coefficient)
1	TN	$903.1 \leq x_i \leq 1779.1$	x_i	0.004	$\gg 0.10$	0.198
2	TP	$4.4 \leq x_i \leq 49.2$	$\ln x_i$	2.933	≈ 0.10	0.414
3	DTN	$714.0 \leq x_i \leq 1200.2$	x_i	-0.006	$\gg 0.10$	0.235
4	DTP	$1.9 \leq x_i \leq 34.1$	x_i	0.278	≈ 0.10	0.394

TABLE 2. EFFECTS OF PHYSICAL FACTORS ON CHLOROPHYLL *A* CONCENTRATION

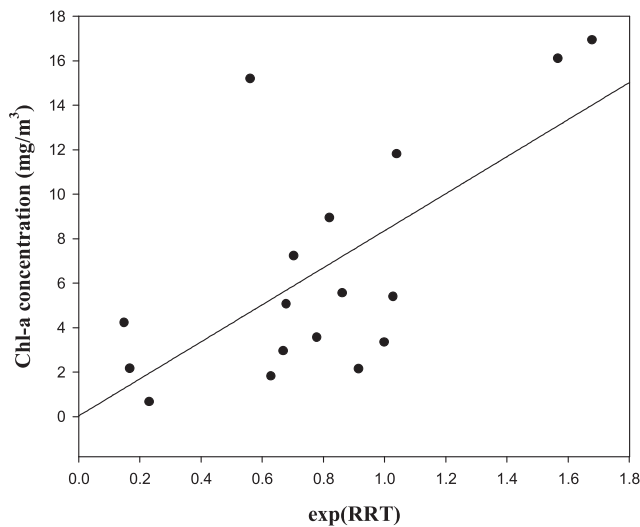| i	x_i	Range	$z_i = F_i(x_i)$	β_i	p-value	$\rho_{zi,y}$ (correlation coefficient)
5	Temp.	$22.1 \leq x_i \leq 27.6$	e^{xi}	-1.05×10^{-11}	≈ 0.05	0.465
6	TRT_{out}	$127.48 \leq x_i \leq 202.78$	x_i	-0.007	$\gg 0.10$	0.026
7	TRT_{in}	$10.36 \leq x_i \leq 147.15$	$\ln x_i$	-5.694	< 0.05	0.684
8	RRT	$-1.90 \leq x_i \leq 0.52$	e^{xi}	8.330	< 0.05	0.661

FIG. 9. Variation of Chl-a and RRT over the sampling period

possible to identify the influence of water status on algae growth. Positive values of RRT imply that the water status enters the lentic condition where algae growth is active, and negative values imply the lotic condition in which algae growth is restricted. All results obtained by testing the two hypotheses indicate that the summer algae growth can be inhibited by controlling the outflow. In order to lower Chl-a below 10 mg/m^3, for example, Fig. 9 shows that RRT should be maintained at less than 0.3 day ($e^{0.3} \approx 1.35$). This value can be achieved, provided the outflow is raised beyond around 0.7 of the inflow, assuming that evaporation is negligible compared to inflow and outflow.

Because nitrogen and potassium are essential for algae growth and reproduction, it is easy to think that TN and TP concentrations are important for algae growth. In fact, it has been demonstrated that the effect of DTP concentration cannot be disregarded. However, the present case clearly proves that short-term variation of algae growth is more influenced by residence time. Algae bloom in the summer of 2000, for example, can be explained by residence time. Because, according to the Water Management Information System database (www.wamis.go.kr), outflow rate was not increased with inflow rate only in the summer of 2000 water residence time increased in 2000 and algae bloom occurred. This tendency may turn out to be clearer in small reservoirs having short residence times (Dickman, 1969; Reynolds and Lund, 1988). Therefore, we plan to carry out further studies in a large number of small dam reservoirs to reexamine how Chl-a concentration is controlled by residence time.

Conclusions

This research investigated the impact of chemical factors (TN, TP, DTN, and DTP) and physical factors (temperature, TRT$_{in}$, TRT$_{out}$, and RRT) on phytoplankton biomass in a small dam reservoir during the summer season by using a simple regression model. Based on data obtained from sampling in the summer season of 2008 and from a government database, we arrived at the following conclusions:

1. It is widely known that nitrogen and potassium concentrations are essential for algae growth. From analyses of the data it was found that TP and DTP concentrations had more significant relationships with Chl-a than other chemical factors. However, none of the chemical factors studied here was a limiting factor on summer phytoplankton growth in the Sueo dam reservoir.

2. Residence times, except TRT$_{out}$, were found to be statistically meaningful for Chl-a. Although TRT$_{in}$ is statistically related to Chl-a, in contrast with findings of most studies, higher Chl-a concentration was observed at shorter TRT$_{in}$. Not all inflow could be discharged, since the outflow was constantly small, and thus, the water volume greatly varied. Hence, large inflow implied a water status that was lentic rather than lotic. It is thus concluded that TRT$_{in}$ is not an appropriate parameter to determine whether water status is lotic or lentic in the Sueo dam reservoir.

3. The Chl-a concentration exponentially increased with RRT, which agrees with previous studies that showed long residence time can provide sufficient time for phytoplankotn to come into contact with nutrients. It is thus found that positive and negative values of RRT can distinguish water status between lentic and lotic conditions, respectively. From these results, we expect that RRT can be used as an indicator to examine whether water status is lotic or lentic for the purpose of inhibiting algae growth.

4. According to previous studies, it is likely that the effects of residence time are more significant on algae growth in small dam reservoirs than in large dam reservoirs. Further studies are planned to verify this, targeting a number of dam reservoirs. It will then be possible to establish a cost-effective and reasonable strategy for controlling short-term algae bloom as watershed management for decreasing nutrient loading inevitably is costly and demanding.

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