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The Application of Aluminum Coagulant for the Improvement of Water Quality in Three Recreational Ponds

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Aluminum coagulant was applied to two eutrophic lakes (Lake Sukchon, in Seoul, and a pond on the campus of Kangwon National University), to precipitate suspended particles and phosphate from the water column. Aluminum sulfate (alum) was used for seven treatments and polyaluminum chloride (PAC) was used for one treatment. The effect of treatment varied depending on the dose of alumium coagulant. Particles and phosphate were completely precipitated from the water column with a dose of 10.0 mgAl/l. Partial removal was observed at doses of 3.3 and 1.8 mgAl/l, but not at 0.45 mgAl/l. Therefore, coagulant should be applied at a dose over the threshold in order to remove particles effectively, which seems to be between 1.8 and 10.0 mgAl/l. The length of treatment effect was determined by new inputs of nutrients and particles from external sources. Renewal of pond water by stream water caused recovery of algal growth in Lake Sukchon, and rainfall runoff and ground water pumping caused a return of turbid water in the campus pond. During treatment there was no sign of decreasing pH, or harmful effects on fish or mussels. Aluminum coagulant may be an economically feasible alternative for water quality improvement when the external control of pollutant sources is difficult. However, repeated application is required when there is a renewal of lake water or new input of nutrients.

Key words : aluminum coagulant, restoration, water quality, alum

INTRODUCTION

Algal blooms in eutrophic lakes are a nuisance for both recreational use and water supply. Phosphorus and nitrogen are the primary factors controlling algal biomass in lakes. Phosphorus has a more crucial role compared to nitrogen in limiting algal growth in Korea, because natural background concentrations of nitrogen are relatively high and the N/P ratio is much higher than the Redfield ratio (Kim *et al.*, 2001). Therefore, phosphorus reduction is a primary concern for the control of algal blooms.

Phosphorus control measures in lakes may be either preventive or curative; that is, source control in the watershed or suppressing algal utilization of phosphorus within the lake. Preventive measures of source control are known to be more effective and economical than curative measures dealing with phosphorus in lake water (Henderson-Sellers and Markland, 1987). However, the control of nutrients in watersheds is not possible in many circumstances, especially when the major source of nutrients is non-point. Because nutrient discharge from agricultural fields and urban areas occurs only after heavy rainfall and the amount of discharge water is enormous, it is not feasible to collect all the storm runoff and treat it. In such circumstances in-lake treatment is the only available method to abate eutrophication symptoms.

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Common methods of in-lake eutrophication control are phosphorus inactivation, artificial destratification, and biomanipulation. Among these methods, phosphorus inactivation is superior in regard to certainty of treatment effect, whereas artificial aeration and biomanipulation are not effective in many cases (Cooke *et al*., 1993).

The main purpose of aluminum treatment in lakes is to reduce phosphorus release from sediments by covering the sediment surface with aluminum hydroxide floc (James *et al*., 1991). Aluminum ion can form insoluble $AlPO_4$ precipitate with orthophosphate which is stable even under anaerobic conditions. Phosphate released from the sediment is trapped by aluminum at the sediment surface, and internal loading of phosphorus can be reduced to nearly zero (Garrison and Knauner, 1984).

Another mechanism of water quality improvement is coagulation of suspended particles by aluminum hydroxide floc. Clay particles commonly have negative charges on the surface and the electric repulsion prevents particles from making large aggregates and settling to the bottom. Aluminum cations can neutralize the negative charges on particle surfaces, enhancing aggregation to form fast-settling large particles. Because aluminum ions have low solubility at neutral pH, hydoxide precipitate floc is formed. When the floc settles, suspended particles are concurrently coagulated and settled.

Among the various coagulants, aluminum sulfate (alum) and polyaluminum chloride (PAC) are most commonly used for lake restoration projects. Alum is known to be a good coagulant that is inexpensive and effective without causing harm to organisms if used carefully and according to directions. Alum had been used for the purification of water supply for decades. However, PAC has been in wide use for water purification recently because PAC produces less residual dissolved aluminum in tap water.

In practical applications of aluminum coagulant in lakes the amount of coagulant required is a critical factor for treatment effectiveness and cost. Another point of concern is the duration of effectiveness. After settling the particulate materials from the water column, algae can grow again if phosphorus is supplied from external sources or the sediment.

In this paper two case studies of aluminum treatment in lakes are described, and the effect of water clarification and the duration of the treatment effect are evaluated. Factors governing the usefulness of aluminum treatment also are discussed.

MATERIALS AND METHODS

Aluminum treatments were performed in December 1995 and March 1996 in two lakes: Lake Sukchon in Seoul City and the campus pond at Kangwon National University. The basin of Lake Sukchon was formerly a part of the Han River channel. In the course of development along the river, the channel was straightened, and a separated curvature part remained as a lake for recreational use. The lake is separated from the streams, and there is no inflow water except ground water seepages. For this reason, water is artificially pumped into the lake from a nearby tributary stream in order to compensate water seepage. Ground water seepage into the lake also seems to supply water through the sandy bottom.

The downstream reach of the Han River receives discharges from a densely populated watershed, and the pumped water from the stream is rich in nutrients. Lake Sukchon has been suffering from eutrophication with dense algal blooms. Since an amusement park exists on the shore of Lake Sukchon, its aesthetics are very important. The aluminum treatment of this study was performed to improve aesthetic quality of the lake.

Lake Sukchon has two circular basins--the east basin (Dongho) and the west basin (Suho), which are connected with a narrow channel. Even though aerators were installed and several diffusers were placed over the basin for the water quality improvement, algal blooms were not suppressed because of shallow depth. When aluminum was applied to the lake, aerators were in full operation to aid mixing of coagulant. Aeration then was stopped to facilitate sedimentation of aluminum floc. The concentration of aluminum in alum solution and PAC solution was 45 gAl/l and 24 gAl/l, respectively.

The campus pond in Kangwon University, named Yonjokji, is an artificial pond made for a small park area. It consists of two basins (upper and lower) separated by a barrier wall. Because it does not have an inflowing stream, ground water is pumped into the upper pond occasionally to sup-

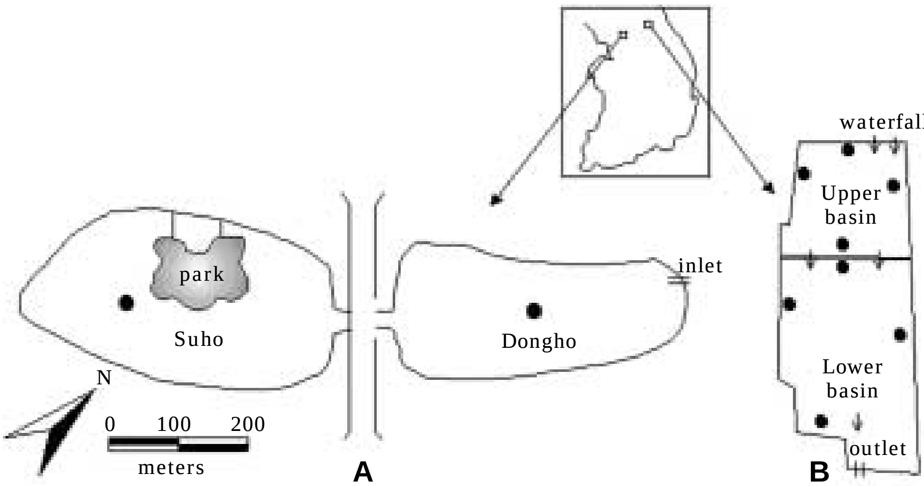

Fig. 1. Map showing the study sites. Dark circles mean sampling stations. Arrows in panel B indicate the flow of water. Pannel A: Lake Sukchon, Pannel B: campus pond.

plement evaporation and infiltration loss. High nutrient concentrations in the ground water cause year−round algal blooms. Aluminum treatments were performed three times by using alum −−in November 1997, April 1998, and May 1998. While applying alum solution, an outboard motor was operated to mix pond water and facilitate flocculation.

Samples for water quality analysis were taken with a Van Dorn sampler and stored in polyethylene bottles. Temperature, pH, and dissolved oxygen (DO) were measured at 1m depth intervals in the lakes. Samples were filtered with GF/C glass fiber filters, which were kept frozen until analysis of chlorophyll−*a* concentration. Chlorophyll−*a* concentration was determined by a spectrophotometric method using acetone extraction (Lorenzen, 1967). Total phosphorus concentration was determined by persulfate digestion followed by the ascorbic acid method for orthophosphate analysis. Trophic State Index (TSI) values were calculated according to Carlson (1977). Aluminum content of alum solution specified by the manufacturer was 4.5% by weight, and that of PAC solution was 2.4%. Aluminum content of alum powder was 8.5% by weight.

RESULTS

Lake Sukchon

The water quality in the two basins of Lake

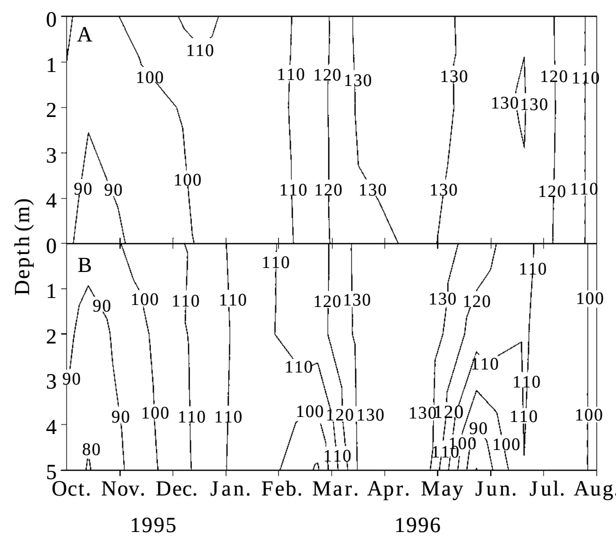

Fig. 2. Depth−time isopleths of relative saturation of dissolved oxygen concentrations (%) in Lake Sukchon (A: Dongho, B: Suho).

Sukchon did not differ, even though they are connected by a narrow channel (Fig. 1). Active aeration was thought to be the reason why lake water is well mixed. Stratification was not observed even in summer, and DO was saturated year−round (Fig. 2).

The N/P atomic ratios were in the range of 29 to 137, implying phosphorus should be limiting nutrient for algal growth. Lake Sukchon could be classified as a eutrophic lake with TSI (SD) of 56, TSI (TP) of 54, and TSI (Chl) of 57 (Forsberg and

Ryding, 1980) (Table 2). The close correspondence between TSI (TP) and TSI (Chl) further supports the view that P is limiting, and the close correspondence between TSI (Chl) and TSI (SD) indicates that algae are the main factor controlling light attenuation in this lake (Havens, 2000).

Table 1. Water volumes of study lakes and the amount of aluminum applied.

	Lake Sukchon	Campus pond upper basin	Campus pond lower basin
Water volume	508,000 m^3	870 m^3	1,980 m^3
Maximum depth	5.3 m	0.8 m	1.0 m
Treatment 1	Dec. 13, 1995 alum 1.77 mgAl/l (total 20 m^3)	No application	Nov. 19, 1997 alum 10.0 mgAl/l
Treatment 2	Mar. 27, 1996 PAC 0.45 mgAl/l (total 10 m^3)	Apr. 13, 1998 3.3 mg Al/l	Apr. 13, 1998 alum 3.3 mg Al/l
Treatment 3		May 18, 1998 10 mg Al/l	May 18, 1998 alum 10 mgAl/l

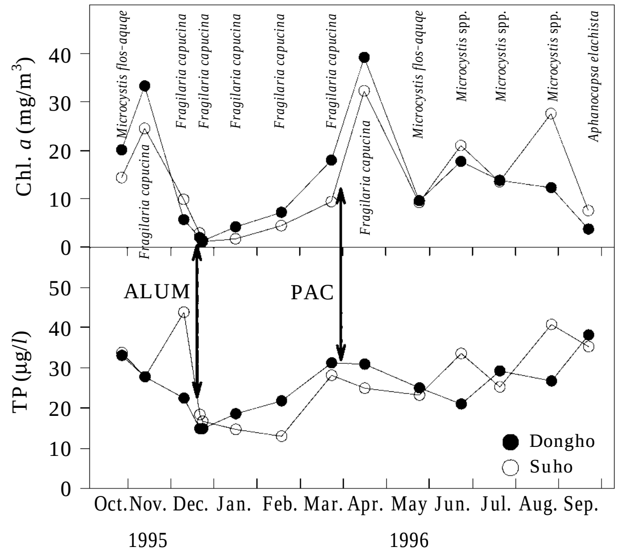

Fig. 3. Variation of total phosphorus (TP) and chlorophyll −*a* (Chl. *a*) concentration in two basins (Dongho and Suho) of Lake Sukchon. Italic names are dominant phytoplankton species in each sample. Arrows of ALUM and PAC indicate the time of treatments.

Table 2. Monthly average water quality parameters in Lake Sukchon. SD; Secchi disk depth (m), Temp; temperature (°C), DO; dissolved oxygen (mgO_2/l), Tur; turbidity (NTU), TN; total nitrogen (mgN/l), TP; total phosphorus (μgP/l), DIP; dissolved inorganic phosphorus (μgP/l), COD; chemical oxygen demand (mgO_2/l), Chl. *a*; chlorophyll *a* concentration (mg/m^3), SS; suspended solid (mg/l), Alk; alkalinity (mg$CaCO_3$/l), N/P; atomic TN/TP ratio.

	1995					1996								
	Oct.	Nov.	Dec. 5	Dec.16	Dec.18	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
	Dongho													
SD	1.2	1.5				4.0	2.9	1.4	0.8	1.6	1.4	1.8	1.4	0.9
Temp	17.5	12.2				3.9	3.6	6.7	12.0	21.1	25.2	26.4	29.6	28.7
DO	9.6	9.7				13.9	13.5	14.2	14.2	11.7	10.7	10.6	8.4	
pH	8.56	9.34	9.01	7.15	6.81	7.27	7.37	9.50	9.80	8.80	9.18	9.06	9.36	9.65
Tur.	6.4	5.5	1.6	1.3	0.9	1.4	1.1	1.8	2.4	2.2	3.8	3.2		5.0
TN	0.74	0.70	0.72	0.87	0.91	0.75	1.20	1.37	1.23	0.97	1.03	0.50	0.54	0.73
DIP	1.6	2.3	1.6	1.8	1.2	2.7	8.6	6.7	3.5	2.8	4.6	5.4	8.5	9.7
COD	9.3	8.5	6.0	5.7	5.8	3.9	3.6	6.4	7.8	7.5	8.1	5.2	5.7	5.9
SS	10.5	9.4	3.9	3.0	2.4	3.9	1.3	8.4	4.0	4.6	5.8	6.6		14.4
Alk.		33.1	39.9	35.5	36.1	36.5	39.4	39.8	41.8	43.0	40.4	40.4		23.6
N/P	50	56	71	130	137	90	122	97	89	86	109	38	45	42
	Suho													
SD	1.2	1.3				3.0		1.5	0.8	1.9	1.2	1.9	1.4	0.9
Temp	17.4	12.0				2.2	2.9	6.5	11.9	21.5	26.1	26.8	29.5	28.8
DO	9.0	9.3				15.4	14.5	13.1	14.3	12.2	8.8	9.0	7.7	
pH	8.72	9.04	8.91	6.78	6.68	7.60	7.40	9.47	9.70	9.07	9.11	9.07	9.08	9.67
Tur.	6.1	5.7	1.8	1.1	1.0	0.8	0.8	1.7	2.2	1.9	5.2	3.4		4.4
TN	0.42	0.44	0.36	0.42	0.42	0.60	0.80	1.20	0.97	0.90	0.95	0.47	0.54	0.63
DIP	1.3	2.4		1.6	1.8	2.9	3.6	7.5	3.9	2.9	7.4	5.0	4.7	7.7
COD	7.0	8.2	7.7	6.1	6.7	3.5	3.3	6.1	8.0	7.9	8.0	5.3	6.7	6.6
SS	7.8	8.2	6.6	5.2	2.7	1.7	1.8	7.1	7.3	1.7	9.5	6.6		13.6
Alk.		38.4	37.4	34.9	36.2	37.1	39.2	40.3	42.5	44.1	41.6	42.1		22.6
N/P	29	35	18	51	57	91	137	95	86	86	63	41	30	40

Table 3. Alum concentration (mgAl/l) consumed to pH 6.0 in Lake Sukchon (Sep. 1996).

	Dongho	Suho
Initial pH	9.6	9.6
Initial alkalinity ($mgCaCO_3$/l)	23	22
Maximum alum dose (mgAl/l) estimated according to Cooke *et al.* (1993)	5.0	5.0
Measured maximum alum dose (mgAl/l) with pH over 6.0	6.4	6.8

It is remarkable that nitrogen concentrations in Lake Sukchon are lower than in nearby streams, the Han River and its tributaries. Because of low nitrogen concentrations, nitrate depletion occurred in summer when phytoplankton density was high. It seems that nitrogen limits algal growth in summer. The low nitrogen content in the lake water might be the effect of ground water seepage that has low nitrogen content; this requires further study.

The background pH was higher than 9, but it became lower than 7 with the application of alum in the first treatment. The pH increased again in March 1996 when inputs of water occurred from the tributary of the Han River (Sungnaechon). Even after the second treatment in spring when PAC was applied, pH remained over 9. Both inputs of the river water and the increase of algal density seem to have contributed to the high pH in spring. From the lack of change in pH it can be concluded that the amount of alum and PAC applied in this study was within the pH buffering capacity of the lake (Table 2, Table 3).

In the first treatment when alum was applied at the dose of 1.77 mgAl/l, TP dropped from 22 to 15 mgP/m^3 in the East Basin, and from 44 to 15 in the West Basin (Fig. 3). Chlorophyll−*a* concentration also decreased, from 4.3 to 1.9 mg/m^3 in the East Basin, and from 9.8 to 2.8 in the West Basin. Chlorophyll−*a* concentration increased again gradually, and it reached the level of pre−treatment after two months. During the treatment fish had normal swimming behavior and there was not any sign of harmful effects upon fish.

In the second treatment when PAC was applied at a dose of 0.45 mgAl/l, TP and chlorophyll−*a* concentrations did not decrease. SS even increased from 1.3 to 8.4 in the East Basin and from 1.8 to 7.1 in the West Basin. The reason why water quality was not improved is thought to be the insufficient PAC application, which was 1/4 of the first treatment. It is known that below a critical concentration of coagulant suspended particles are not effectively coagulated or settled. In the second treatment fine particles of aluminum hydroxide were observed in the water, causing

Table 4. Monthly average of water quality parameters in the campus pond.

	1997						1998										
	Jun.	Jul.	Aug.	Nov. 1−19	Nov. 20−30	Dec.	Jan.	Mar.	Apr. 1−13	Apr. 14−30	May 19−31	May 1−18	Jun.	Jul.	Aug.	Sep.	Oct.
	Upper basin																
SD	0.6	0.6	0.7	0.9	1.0	0.9		0.7	0.8	0.8	0.8	2.1	0.8	0.7	0.6	0.8	0.6
Temp	27.2	27.3	29.2	8.1	7.8	6.6	3.9	12.7	18.9	22.8	24.6	25.7	25.8	26.0	25.6	21.5	16.4
pH	7.57	7.19	7.19		6.93	6.90	7.41	7.47	7.08	8.33	8.40	6.89	7.42	7.07	7.21	7.64	7.33
Tur.				3.4	3.3	4.3	4.5	11.9	4.4	5.5	4.6	2.4	3.8	6.5	9.5	4.5	5.4
TN	2.38	2.46	2.32	3.41	3.13	2.56	1.68	2.36	3.82	2.57	2.69	1.82	2.11	2.44	1.92	3.10	3.69
SS	19.6	17.6	16.6	8.2	12.1	7.5	3.8	9.1	8.8	10.0	10.0	4.8	9.0	18.9	17.3	14.5	15.6
Alk.	105	100	95		76.7						99.1	42.7					
N/P	85	81	74	176	202	150	158	82	149	155	141	168	132	106	64	112	172
	Lower basin																
SD	0.6	0.6	0.7	1.1	2.5	0.8		0.7	0.6	0.7	0.8	1.3	0.8	0.6	0.6	0.7	0.6
Temp	27.4	27.7	28.6	5.9	6.5	6.2	4.1	11.7	18.1	22.0	24.4	25.4	26.1	25.9	25.4	22.2	17.0
pH	8.32	7.44	7.36		6.56	6.45	7.42	7.73	8.22	8.40	8.27	7.07	7.73	7.15	7.12	7.69	7.70
Tur.				5.0	2.0	4.2	3.6	9.5	9.7	6.2	5.4	3.7	4.3	8.0	10.1	7.5	8.4
TN	1.68	1.28	0.85	2.29	2.38	1.94	1.27	1.44	2.62	2.20	1.00	1.15	0.85	1.29	1.05	2.63	2.98
SS	25.6	31.4	10.8	10.6	2.7	4.3	5.3	8.5	11.8	13.6	10.5	7.1	7.5	18.2	20.8	24.5	22.1
Alk.	108	105	103		46.0						97.5	40.6					
N/P	67	47	42	101	342	232	93	62	82	114	51	97	45	50	32	63	101

high turbidity, because the PAC dose was below the threshold level for coagulation.

Campus pond

The campus pond also was eutrophic, with higher TSI values than in Lake Sukchon: TSI (SD) was 67, TSI (TP) was 63, and TSI (Chl) was 62. Again it is noteworthy that the values were quite similar. Because water in the Lower Basin was pumped to the Upper Basin occasionally, the water quality in two basins were similar (Table 4). The major cause of eutrophication in the pond was high nutrient concentrations in the pumped ground water. TP in the ground water was about 50 mgP/m^3, and TN was about 4 mgN/l (Table 5).

The first treatment alum was applied at the dose of 10.0 mgAl/l, which was much higher than the doses to Lake Sukchon. The pond dose was determined from preliminary alkalinity tests to find the maximum possible dose of alum without lowering pH below 6.0. The maximum dose estimated from the alkalinity measurement and the empirical relationship of Cooke *et al.* (1993) was 13 mgAl/l. The measured maximum dose of alum for the pond water was 11.0 mgAl/l. Therefore, the amount of alum applied in the first treatment was almost at the maximum level (Table 6).

The beneficial effects of alum in the first treatment were obvious. All phytoplankton and suspended particles settled from the water column. TP decreased by 88% and chlorophyll-*a* decreas-

Table 5. Water quality of the ground water that was supplied into the campus pond.

	Aug.	Sep.	Oct.
Temp (°C)	15.5	14.9	14.6
pH	7.28	6.99	6.87
Turbidity (NTU)	0.3	0.4	0.3
TN (mgN/l)	3.58	3.97	3.96
TP (μg/l)	50.7	50.8	48.1

Table 6. Maximum alum dose with pH over 6.0 in the lower basin of the campus pond (Nov. 1997).

Initial pH	7.8
Initial alkalinity (mgCaCO$_3$/l)	100
Maximum alum dose (mgAl/l) estimated according to Cooke *et al.* (1993)	13
Measured maximum alum dose (mgAl/l) with pH over 6.0	11.0

Table 7. The removal efficiency (%) of TP and Chl. *a* after 1 day of alum treatment in the campus pond.

	Treatment 1		Treatment 2		Treatment 3	
	TP	Chl. *a*	TP	Chl. *a*	TP	Chl. *a*
Upper basin	No application		32%	34%	71%	92%
Lower basin	88%	99%	58%	57%	72%	91%

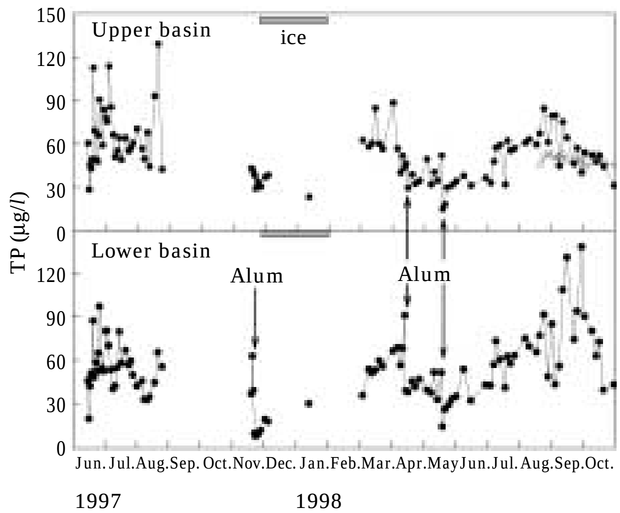

Fig. 4. Variation of total phosphorus concentration (TP) in the campus pond. The gray bar in each panel indicates ice-covered period. Dark circles are data of the lake, and open circles in the upper panel represent TP of ground water that was pumped into the pond.

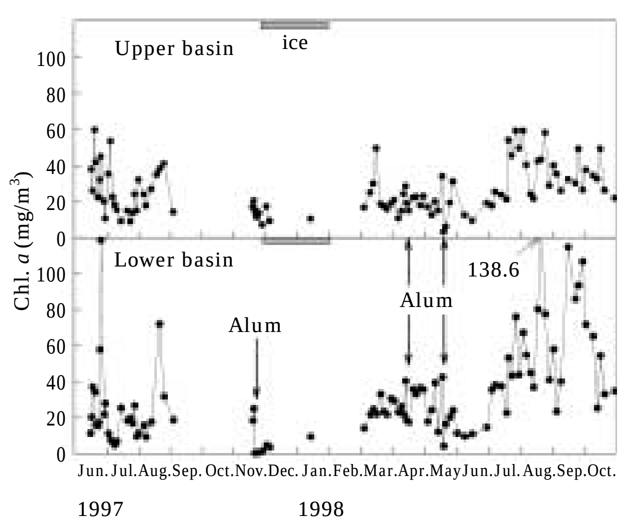

Fig. 5. Variation of chlorophyll-*a* concentration (Chl. *a*) in the campus pond. The gray bar in each panel indicates ice-covered period. Arrows indicate time of three alum treatments.

ed by 99% (Table 7, Figs. 4, 5). The pond water became so clear that the pond bottom and fish could be seen clearly. Because the maximum depth was only 1m, even mussels crawling on the sediment could be observed from the water surface. The water remained clear for three weeks, and then ice cover formed. During the treatment period there was no sign of harmful effects on fish or crawling mussels.

In the second treatment the alum dose was reduced to 3.3 mgAl/l (1/3 of the first treatment) in order to observe the effect of a lower dose. Both the Upper Basin and the Lower Basin had a 40% reduction of TP and chlorophyll−*a*, which was a much lower removal efficiency than with the first treatment. The duration of effect also was shorter−−one week after the treatment, there was a small rain and turbidity increased due to the input of turbid runoff from the surrounding land. Chlorophyll−*a* also increased after the rain.

In the third treatment of the campus pond alum was applied at the same dose as the first treatment (10 mgAl/l). The removal efficiency was better than the second treatment, with 70% efficiency for TP, and 90% for chlorophyll−*a*. However, the duration of beneficial effects was shorter than in the first treatment, possibly due to input of more ground water. Within one week of the treatment, TP and chlorophyll−*a* concentrations returned to pre−treatment levels.

DISCUSSION

Aluminum coagulant has been used to block phosphorus release from lake sediment or to facilitate sedimentation of particles in lakes. The major purpose of alum treatment is to block phosphorus release from sediment in lakes where the proportion of internal loading is significant. The maximum possible dose is of concern in lakes where sediment blocking is major target of alum treatment, and it is determined by pH, alkalinity, and stirring intensity (Cooke *et al.*, 1993). In order to reduce application labor cost and increase the longevity of the treatment effect it would be economical to apply alum as much as possible at one time.

The purpose of treatment in this study was to precipitate suspended particles and phosphate. Internal loading from sediment was not a significant contribution compared with external inputs. In such cases the minimum threshold dose is of concern. Of eight treatments in this study the treatment at the dose of 10.0 mgAl/l had the best effect, removing all particles from the water. The treatment doses of 3.3 and 1.77 mgAl/l had partial effects, removing a substantial portion of phosphorus and particles. However, a dose of 0.45 mgAl/l had no significant benefits. It seems that application at the dose of more than the threshold level (possibly 5 mgAl/l) is required to remove over 80% of particles in eutrophic Korean lakes of this type.

Longevity of treatment effects seemed to be dependent on external nutrient loading. In the treatment of the campus pond, turbidity increased just after a rain event. Pumping of ground water into the lake might have stimulated re−growth of algae. In winter, when there was no rain runoff or pumping, the treatment effect lasted for a month. However, in spring the effect ended when there was a rain and ground water was pumped in. It seems that the effect of water clearing with coagulant is vulnerable to external loading, as reported in other studies (Connor and Martin, 1989). Even with small loadings the effect of treatment eventually ended. It can be said that preventing external loading sources is crucial to the longevity of coagulant treatment in these lakes.

Possible harmful effects of aluminum on aquatic animals were another concern. However, there was no sign of harmful effects on fish or mussels in this study, as in many other reports. Fish were seen swimming with normal behavior. In some reports a long term reduction of benthic animals was reported, however it is not clear whether that was due to harmful effects of alum or indirect effects of reduced plankton and food. The chronic effects of coagulant on lake ecosystems need to be studied further.

Aluminum coagulant seems to be a good treatment for water quality improvement in lakes, as long as external sources of nutrients and particles are controlled. If treatments are required repeatedly, it would lower the economic feasibility of coagulation treatment in lakes, especially in reservoirs. However, because its effect is clear and prompt, alum can be a feasible alternative for the improvement of lakes where source control is not available.

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<**국문적요**>

알루미늄 응집제를 사용한 호수수질 개선 사례 연구

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부영양호의 수질정화를 위하여 알루미늄 응집제를 호수에 첨가하고 조류와 부유물의 침강제거효과, 및 인의 감소효과를 측정하였다. 서울 석촌호와 강원대학교 구내 연못을 대상으로 8회에 걸쳐 첨가량을 달리하여 실시하였다. 7회의 처리에서는 황산알루미늄을 사용하였고 1회는 PAC를 사용하였다. 부유물질의 침강제거효과는 첨가량에 따라 좌우되었다. 10.0 mgAl/l를 첨가한 경우에는 부유물질, 조류, 인 등이 완전히 제거되었으나, 3.3 mgAl/l와 1.8 mgAl/l를 첨가한 경우에는 부분적인 제거 효과가 있었다. 그러나 0.45 mgAl/l 로 첨가한 경우에는 거의 개선효과가 보이지 않았다. 알루미늄 첨가가 부유물을 침전제거에 효과를 나타내기 위해서는 최소역치(약 5 mgAl/l) 이상을 투여하여야 하는 것으로 결론지을 수 있다. 효과 지속시간은 외부로부터의 추가부하량 유입에 의해 좌우되는 것으로 보인다. 석촌호에서는 인근 하천수의 펌핑에 의해 곧 다시 혼탁해 졌으며, 구내연못에서는 강우후 주변의 토사가 유입되거나 지하수 펌핑으로 영양염류가 유입되면 곧 다시 조류가 번성하고 혼탁해 졌다. 응집제 투여의 결과로 pH가 지나치게 낮아지는 피해나 어패류에 대한 유해성 징후는 발견되지 않았다. 외부 오염원을 제거할 수 없는 호수에서는 응집제의 투여가 호수수질 개선의 임시적 대안으로 활용될 수 있을 것으로 보인다.