EVALUATION OF $CaCO_3$ AND $Ca(OH)_2$ AS ALGICIDES IN PRAIRIE DRINKING WATER DUGOUTS

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Management Perspective

Dense algal blooms in farm dugouts cause taste and odour problems, clog filters, and sometimes kill livestock. The common copper sulfate treatment must be applied frequently and it can be toxic to sheep. Lime treatment was evaluated as a replacement for copper treatment in farm dugouts.

In 1987 and 1988, calcium carbonate or calcium hydroxide was applied to several farm dugouts. The application of calcium hydroxide to two dugouts precipitated more than 99% of the algal biomass and the dugouts remained clear for two years. Most of the iron, phosphorus, and organic matter also precipitated. Calcium carbonate treatment of two dugouts precipitated about 20% of the algae; however, little phosphorus was precipitated, the algal blooms soon returned, and no effect of the calcium carbonate treatment was apparent the following year.

Farmers reported that the taste and odour of the water was greatly improved after all treatments, but only the calcium hydroxide effect continued into the next year. Farmers with dugouts treated with calcium hydroxide added rainbow trout to their dugouts and eight months later the trout were healthy.

Perspective-gestion

De denses proliférations d'algues dans les mares artificielles entraînent des problèmes d'odeur et de goût, bouchent les filtres et tuent parfois le bétail. Le traitement au sulfate de cuivre généralement utilisé doit être appliqué fréquemment; malheureusement, il peut être toxique pour les moutons. D'après certaines évaluations, le traitement à la chaux pourrait remplacer le traitement au cuivre dans les mares artificielles.

En 1987 et 1988, du carbonate de calcium ou de l'hydroxyde de calcium ont été appliqués à plusieurs mares artificielles. L'application d'hydroxyde de calcium à deux mares a permis de précipiter plus de 99 % de la biomasse des algues; l'eau des mares est demeurée propre pendant deux ans. La majeure partie du fer, du phosphore et des matières organiques ont également précipité. Le traitement au carbonate de calcium appliqué à deux mares artificielles a permis de précipiter environ 20 % des algues; cependant, peu de phosphore a été précipité, les proliférations d'algues sont revenues rapidement et les effets du traitement étaient nuls au bout d'un an.

D'après les agriculteurs, le goût et l'odeur de l'eau se sont grandement améliorés après tous les traitements, mais seul l'effet du traitement à l'hydroxyde de calcium a persisté après un an. Des agriculteurs dont les mares avaient été traitées à l'hydroxyde de calcium y ont ajouté des truites arc-en-ciel et huit mois plus tard leurs truites étaient bien en santé.

Abstract

Excessive algal biomass is a problem in prairie dugouts that are used for drinking water supplies. Algal biomass detracts from the aesthetic, agricultural, domestic, and recreational value of these water bodies. Six drinking water dugouts in northwestern Alberta were studied for two summers. These hard-water dugouts have long water retention periods (>5 yr) and accumulate nutrients from agricultural runoff. In 1987, high doses of lime (250 mg/l $CaCO_3$ or 250 mg/l $Ca(OH)_2$) were added to four dugouts to determine the efficiency of phosphorus and algal removal. Algal biomass decreased to 39% of pretreatment concentrations during the summer after $CaCO_3$ treatments but recovered to pretreatment concentrations during the next summer. In the summer, after $Ca(OH)_2$ treatments, algal biomass decreased to 12% of pretreatment concentrations and remained depressed the next year. Phosphorus concentrations were greatly decreased in $Ca(OH)_2$-treated dugouts but were relatively constant in $CaCO_3$-treated dugouts. High doses of $Ca(OH)_2$ can improve water quality in dugouts.

Key words: Lime ($CaCO_3$ and $Ca(OH)_2$), phosphorus, algal biomass, coprecipitation.

Dans les Prairies, la présence d'une trop importante biomasse algale dans les mares artificielles utilisées pour l'eau potable constitue un problème. En effet, la biomasse algale diminue la valeur esthétique, agricole, domestique et récréative de ces plans d'eau. Six mares d'eau potable situées dans le nord-ouest de l'Alberta ont fait l'objet d'études au cours de deux étés. Ces mares à eau alcaline ont des périodes de rétention d'eau longues (supérieures à 5 ans) et des éléments nutritifs provenant du ruissellement agricole s'y accumulent. En 1987, quatre mares ont été traitées à l'aide de doses élevées de chaux (350 mg/L de $CaCO_3$ ou 250 mg/L $Ca(OH)_2$) afin de déterminer l'efficacité de chacun des traitements pour lutter contre la prolifération d'algues et l'augmentation du phosphore (élément nutritif limitant). La biomasse algale a diminué pour atteindre environ 20 % des niveaux qu'elle présentait avant le traitement au $CaCO_3$; cet effet était cependant disparu au cours de l'été suivant. Après les traitements au $Ca(OH)_2$, la biomasse algale a diminué pour atteindre 1 % des niveaux qu'elle présentait avant le traitement et est restée ainsi l'année suivante. Les teneurs en phosphore ont été grandement diminuées dans les mares traitées au $Ca(OH)_2$ mais peu de changement a été remarqué dans les mares traitées au $CaCO_3$. L'intensité de la

couleur a diminué dans les mares traitées au $Ca(OH)_2$ et au $CaCO_3$.
Le traitement en doses élevées de $Ca(OH)_2$ est très prometteur pour
l'amélioration à long terme de la qualité de l'eau.

INTRODUCTION

Thousands of farmers throughout the Canadian prairies are dependent on dugouts for domestic and agricultural water supplies. Nutrient enrichment of dugouts, particularly phosphorus from agricultural runoff, results in dense algal blooms. Prolific algal growth results in poor taste and odor of water, clogging of water filters, decreased aesthetic value, summer and winter fish kills, and occasional toxic blue-green algal blooms.

The usual method for algal control in farm dugouts is application of a copper-based herbicide, i.e., copper sulfate. This herbicide is toxic to non-target organisms (Hanson and Stefan 1984), and its use can upset the community structure of lakes (Prepas and Murphy 1988). The objective of this project was to evaluate whether lime, a nontoxic substance, can be substituted for copper sulfate as an algicide in farm dugouts.

Lime is often used in water treatment plants. It is used in sewage treatment to flocculate solids and precipitate phosphorus (Rubin 1978), and in water supplies to remove turbidity and hardness (Montgomery 1985). Lime treatment of water by industries and municipalities is different from lime treatment of farm dugouts in two ways: 1) Water treatment plants have short hydraulic residence times, but farm ponds retain water for years. Industries require rapid treatment, but in most cases, farmers can wait for flocculated particles to settle before using the water. Calcium carbonate ($CaCO_3$) particles should take a few days to clear the water column (Koschel et al. 1983); 2) Industries remove

flocculated solids and phosphorus, but in limed farm dugouts, the phosphorus would be precipitated to the sediments and could be released back to the water column.

The optimal method of liming farm dugouts would regulate the natural calcite precipitation reactions. Calcite is the calcium carbonate mineral that forms in almost all hardwater lakes. In the summer months, water in the Canadian prairies is typically saturated with calcite (Prepas et al. 1989), and calcite precipitation can be induced by increasing the pH of a dugout with $Ca(OH)_2$ (calcium hydroxide). Studies in hardwater lakes have indicated that phosphorus may be precipitated by adsorption to sedimenting calcite particles (Avnimelech 1980, Murphy et al. 1983). Increasing the pH enhances the rate of calcite precipitation (Kelts and Hsu 1978) and can increase the adsorption of phosphorus to calcite (Griffin and Jurinek 1973, Fischer and Baumann 1978, Brown 1980).

Additions of $CaCO_3$ would not increase the pH of the hardwater dugouts (Stumm and Morgan 1970); thus, the above studies would indicate that $Ca(OH)_2$ should be more effective than $CaCO_3$ in precipitating phosphorus. However, an important exception exists. Reddy (1979) has noted that in $Ca(OH)_2$ treatment of sewage, phosphorus removal is optimal at pH 7.5 to 8.0, and as the pH increases with more $Ca(OH)_2$ use, the precipitation of calcite interferes with precipitation of phosphorus.

Precipitation of calcite can be induced in supersaturated water by providing nucleation sites for crystallization of calcite

(Nancollas and Reddy 1971, Brown 1980). In both industrial inductions of calcite precipitation (Roques and Girou 1974) and in natural calcite precipitation in lakes (Reynolds 1978), the rate of calcite precipitation is controlled by nucleation reactions such as polyphenol inhibition of crystallization. Industrial $Ca(OH)_2$ treatments have demonstrated that the rate of calcite precipitation is directly related to the mass of crystals present in the reaction solution (Wiechers et al. 1975); thus, addition of $CaCO_3$ crystals to a dugout saturated with respect to calcite could result in rapid calcite precipitation.

Laboratory and industrial studies of $Ca(OH)_2$ mediated phosphorus precipitation are useful guides to the lime treatments of dugouts, but dugout water is very different from previously studied systems. Unlike sewage, very little of the phosphorus in most lakes is in solution (Wetzel 1975). Flocculation and subsequent sedimentation of algae by added $CaCO_3$ could effectively sediment cellular phosphorus. Calcium carbonate is less expensive and less corrosive than $Ca(OH)_2$. Field trials are required to evaluate the most effective method of precipitating phosphorus and algae in dugouts.

Recently, $Ca(OH)_2$ has been used in British Columbia (Murphy et al. 1988), and both $Ca(OH)_2$ and $CaCO_3$ were used in Alberta, Canada (Prepas et al. 1989) to reduce algal biomass and phosphorus concentrations in eutrophic lakes (surface area 34 and 37 ha, respectively). The relatively low doses of lime (4 to 18 mg/l) applied to these lakes precipitated from 20 to 80% of the

phosphorus and algae. The comparative advantages of $CaCO_3$ and $Ca(OH)_2$ were not resolved.

In this study, relatively high doses of either $Ca(OH)_2$ or $CaCO_3$ were added to farm dugouts to identify which form of lime resulted in the best short-term and long-term water quality. Dugouts used in this study were much smaller (0.2 ha) than the lakes mentioned above, and therefore, could be easily treated with high doses of lime. Water quality variables of two untreated dugouts were also monitored for comparison.

Study Site

The study area is located 10 km south of the town of Peace River in northwestern Alberta, Canada (Table 1). More than 85% of the study area is used for agriculture with grain farming as the dominant land use. Groundwater supplies of drinking water are generally unavailable in this area. Water wells are deep (in excess of 100 m), costly to drill and often yield inadequate quantities of water. Alternative water supplies are either cisterns filled by tanker trucks or dugouts filled by precipitation and runoff. The latter are more common and are less expensive. Dugouts are either constructed specifically for water storage or from pits excavated to supply clay for road construction. They range in surface area from 200 to 7000 m^2 and range in depths from 2 to 4.5 m (Table 1).

Precipitation in the study area is low and evaporation is high (375 mm annual precipitation for a 30-year average and from 500 to

700 mm/yr mean annual evaporation, Fisheries and Environment Canada 1978). To compensate for the shortage of water, farmers divert runoff from road ditches or fields into the dugouts. This strategy increases nutrient loading and produces prolific algal growth. Dugouts used in this project had pretreatment surface total phosphorus concentrations which ranged from 34 to 355 μg/l. Surface conductivity of these hardwater dugouts ranged from 175 to 637 μS/cm (Table 2).

METHODS

Dugout Treatment

In June 1987, two dugouts (Gour #4 and Monnette) were treated with 250 mg/l (2.1 lb/1000 gal) of Ca(OH)$_2$, and two dugouts (Frey and Troup) were treated with 250 mg/l of CaCO$_3$. Two dugouts (Desrosier and Fortier) were left untreated and were used as references to compare with changes in treated dugouts. Desrosier dugout was sampled in 1987 and 1988 and Fortier dugout was sampled only in 1988.

Dugouts were treated by spraying a lime slurry produced by a prototype slurry maker (Fig. 1) onto the surface water. The system consists of two, 200-litre drums joined together by a 10-cm diameter rubber hose. Pump 'a' delivers water to drum 'a' where lime powder is added and partially mixed. The slurry is further mixed as it flows through the rubber hose into drum 'b' and then sprayed by pump 'b' onto the dugout surface. The slurry maker was mounted on a trailer and towed by a four-wheel drive truck. The

entire assembly was lightweight and provided easy access to the dugouts.

Collection and analysis of water samples

Pretreatment water samples were collected one day prior to treatment. Posttreatment samples were collected three days after treatment, and every two weeks until the end of August 1987. In 1988, samples were collected every two weeks from June to August. On all visits, pH and conductivity were measured in the field with Metrohm meters (Model E588 and E587, respectively). Secchi depths were measured with a 20-cm diameter Secchi disk.

During each visit, water samples were collected from a depth of 1.0 m for total phosphorus (TP), chlorophyll $\underline{a}$ (Chla), total alkalinity (TA), and color. Water samples for TP, TA, and color were placed in 1-l Nalgene bottles and kept cool (4°C) for a maximum of 24 h before they were analyzed. TP samples were transferred to culture tubes and analyzed according to Menzel and Corwin's (1965) potassium persulfate method. Samples for Chla analysis were collected in opaque Nalgene bottles and filtered under low pressure (-50 KPa) through Whatman GF/C filters within 24 h. The filters were placed in petri dishes, wrapped in aluminum foil and frozen until analyzed.

The concentration of Chla was determined in triplicate with a spectrophotometric technique based on the ethanol extraction procedure of M. Ostrofsky as described by Bergmann and Peters (1980). Total alkalinity was measured by the potentiometric

titration method within 24 h of collection (Environment Canada 1979). Surface (1.0 m) color measurements were determined with a Hellige Aqua Tester Model 611A. Water samples for calcium analysis were collected in 250 ml polystyrene bottles and acidified in the field with 1.0 ml of 10% HNO3. In the University of Alberta laboratory, calcium samples were filtered through Whatman GF/C filters before analysis on a Perkin-Elmer Model 3030 atomic absorption spectrophotometer (Perkin-Elmer 1982).

Correlation between TP and Chla concentrations were calculated with Lotus 1-2-3. Pretreatment data in Tables 2 and 3 were based on samples from one date. Statistical comparisons between pretreatment and posttreatment data were conducted via Standard t-test as described by Prepas (1982). The saturation of calcium carbonate (calcite) was determined with the computer program WATEQF (Plummer et al. 1984).

RESULTS

Ca(OH)$_2$ Treatment

In the two dugouts treated with Ca(OH)$_2$, surface (1.0 m) TP and Chla concentrations decreased by more than 80% and 90%, respectively, within one week of treatment (Fig. 2). Both variables continued to decline to a midJuly minimum and remained well below pretreatment concentrations for the balance of the summer of 1987. With one exception, these effects persisted through the summer of 1988. The exceptional high TP concentration

in Monnette dugout on June 7 was due to sediment contamination caused by excavation of a water pipe. After $Ca(OH)_2$ additions, Chla and TP concentrations were highly correlated (r=0.84 and 0.75 in Gour #4 and Monnette, respectively, n=11, P<0.01).

The pH in Gour #4 dugout increased from a pretreatment value of 8.6 to a posttreatment average of 10.2 for the two months following treatment in 1987. During the same period, the pH in Monnette dugout increased from 9.4 to an average of 10.5. By the summer of 1988, the pH in both dugouts had returned to pretreatment concentrations (Table 3). Secchi depth doubled and color decreased over 50% within one month after $Ca(OH)_2$ treatments (Table 2).

In 1987, calcium and TA concentrations in Gour #4 dugout decreased to a summer average of 53% and 39% of pretreatment concentrations, respectively (Figs. 2 and 3). This calcium precipitation is approximately the degree of precipitation predicted by the initial degree of calcite supersaturation (log IAP/K_t 0.5). By 1988, alkalinity had recovered to the pretreatment concentrations. The calcium concentrations in the same period exceeded the pretreatment concentrations by 23% (P<0.05).

In Monnette dugout, both calcium and alkalinity concentrations exceeded pretreatment concentrations by 3.5-fold three days after treatment. Two weeks later, calcium concentrations began to decline steadily and returned to the pretreatment concentrations by the end of August 1987 (Fig. 2). Alkalinity decreased to 55% of the pretreatment concentration in the same time period (Fig. 3). In 1988, alkalinity in Monnette increased to 50% higher than

pretreatment concentrations while calcium exceeded the pretreatment concentrations by 214% ($P<0.01$).

Approximately one half and one quarter of the alkalinity decreases in Gour #4 and Monnette dugouts, respectively, were associated with the precipitation of magnesium. Twelve mg/l of magnesium precipitated from Gour #4 dugout and five mg/l precipitated from Monnette dugout. The stability and mineralogy of the precipitated magnesium was not studied.

CaCO$_3$ Treatment

In CaCO$_3$-treated dugouts, precipitation of TP was minimal in Frey and temporary in Troup (Fig. 4). In 1987, Chla concentrations decreased in Frey and Troup to 20% and 22% of pretreatment concentrations, respectively. However, in 1988, Chla concentrations in Troup surpassed the pretreatment concentrations by early August, while in Frey, Chla concentrations increased to 55% of the pretreatment concentration in the same time period.

Chla and TP concentrations in CaCO$_3$-treated dugouts were not correlated in 1987 (r=0.3, 0.31, P>>0.05, n=11). Chlorophyll a responded more than TP to CaCO$_3$ treatments. Without a corresponding decrease in TP, Chla suppression in CaCO$_3$-treated dugouts was less effective than in dugouts treated with Ca(OH)$_2$.

Treatments with CaCO$_3$ had variable effects on Secchi depths (Table 2). The pH after treatment (1987-1988) was not significantly (P>0.05) different from the pretreatment values

(Table 3). Posttreatment color for both years was, on the average, 66% of pretreatment values.

In 1987, alkalinity in Frey dugout remained constant after treatment while alkalinity decreased to 86% of the pretreatment concentration in Troup dugout (Fig. 3). In 1987, calcium concentrations in both $CaCO_3$-treated dugouts increased an average of 6.4% above pretreatment concentrations. These dugouts were two-fold supersaturated with respect to calcite before the treatments and were six-fold supersaturated when the water became warmer. By 1988, average summer concentrations of calcium and alkalinity were 98% and 81% of the pretreatment concentrations, respectively. The $CaCO_3$-treated dugouts were similar in that calcium and alkalinity concentrations in 1988 were not greater than pretreatment.

Untreated Dugouts

In the untreated dugouts, chlorophyll a concentrations remained high (20-100 μg/l) throughout 1987 and very dense algal blooms (50-300 μg/l) occurred in 1988. The TP and Chla concentrations were significantly correlated (r=0.89 and 0.97 in Desrosier and Fortier dugouts, respectively, n=11, P<0.01). Seasonal patterns in alkalinity in these dugouts were similar to those observed in the two dugouts treated with $CaCO_3$. Alkalinity either remained stable or changed gradually throughout the summer. Calcium concentrations were highest in early June and lowest in July or August, similar to patterns in $CaCO_3$-treated dugouts in 1988.

DISCUSSION

The 1987 lime treatments decreased the concentration of algae in all four dugouts. The $Ca(OH))_2$ treatments decreased TP and Chla concentrations more than the $CaCO_3$ treatments. More than 90% of the total decrease of Chla and TP in the $Ca(OH)_2$ dugouts occurred in three days. Concentrations of Chla also decreased rapidly after $CaCO_3$ treatments, particularly in Frey dugout. The rapid decrease in Chla in these dugouts is consistent with earlier studies that observed a coprecipitation of algal cells and calcite particles (White and Wetzel 1975, Koschel et al. 1983, Murphy et al. 1988).

The effectiveness of each form of lime was dependent on the degree to which it affected pH and alkalinity. The greater flocculation and sedimentation of algae by $Ca(OH)_2$ relative to $CaCO_3$ is, in part, a reflection of a greater induction of calcium carbonate precipitation. In Gour #4 dugout, an equivalent of approximately 18% more $CaCO_3$ sedimented from the water than was added. In Gour #4 dugout, an equivalent quantity of magnesium carbonate also precipitated. The adsorption of phosphorus to magnesium carbonate is poorly documented and the mineralogy of the carbonate precipitation is likely complex. For example, aragonite, not calcite may have precipitated.

In these high $Ca(OH)_2$ doses of dugouts, the pH increase is probably as important as the induced precipitation of calcium/magnesium carbonates. The reactivity of $Ca(OH)_2$ is mediated via a 2.0 increase in pH (versus no change for $CaCO_3$ treatments). The most important reaction affected by the increased

pH was phosphorus precipitation and retention of phosphorus in the sediments. In the first three days, $Ca(OH)_2$ treatments precipitated 80% of the TP whereas the $CaCO_3$ treatments precipitated 10% of the TP. As the summer proceeded, the TP concentrations increased to pretreatment concentrations in the $CaCO_3$-treated dugouts but not in the $Ca(OH)_2$-treated dugouts.

The mechanism for sediment retention of phosphorus is not clear. Presumably, decaying sedimented algae released phosphorus into solution in all dugouts. However, in the higher pH of the $Ca(OH)_2$ dugouts, phosphorus reacted with either unreacted $Ca(OH)_2$ or with calcium/magnesium carbonates that formed from $Ca(OH)_2$. The latter hypothesis is more consistent with our calcium carbonate treatments if the higher pH enhances phosphorus adsorption to calcium/magnesium carbonates. This hypothesis is consistent with several laboratory studies (Griffin and Jurinek 1973, Fischer and Baumann 1978, Brown 1980).

In 1988, Chla concentrations in the $CaCO_3$-treated dugouts recovered to half, or on some occasions, surpassed pretreatment concentrations. The Chla concentrations in the untreated dugouts increased in 1988. Whereas, Chla concentrations in $Ca(OH)_2$-treated dugouts remained well below pretreatment concentrations. The lack of algal growth is reflected clearly in the high calcium concentrations in 1988. Low rates of algal assimilation of CO_2 resulted in pH values lower than 8.2 in the $Ca(OH)_2$ dugouts, and calcite supersaturation did not occur.

The mechanism for the continued suppression of algae in 1988 in the $Ca(OH)_2$-treated dugouts is not obvious. Enhanced sedimentation of algae could not be important because calcium concentrations remained constant. Carbon limitation is unlikely because the pH remained less than 8.2. Phosphorus limitation appears to be important but it can not be rigorously defended.

Although the TP concentrations were substantially reduced in 1988, in the $Ca(OH)_2$ dugouts, there was ample phosphorus. The dissolved phosphorus concentrations in Gour #4 and Monnette dugouts averaged 43 and 28 $\mu g/l$, respectively, and these were 43% and 60%, respectively, of the TP. Much of this dissolved phosphorus may have been unavailable; thus, the theoretical aspect of this study is not complete. Future work should evaluate phosphorus availability in drinking water dugouts, the potential for other nutrient limitation, and the possible presence of algal suppressants.

The empirical aspect of this study was highly successful. The higher chemical cost for the $Ca(OH)_2$ treatments ($200-$400 per dugout) relative to the $CaCO_3$ treatments ($90-$175 per dugout) was compensated for by better water quality and the need for fewer dugout treatments. The 250 mg/l dose of $Ca(OH)_2$, but not the 250 mg/l dose of $CaCO_3$, was effective in suppressing algal blooms for two summers.

Table 1 Dugout treatments, size and location

Dugout	N Lat.	W Long.	Area	Depth	Treatment[*]
Gour #4	56° 2'	117° 17'	1750	4.0	250 $Ca(OH)_2$
Monnette	56° 2'	117° 27'	1045	3.5	250 $Ca(OH)_2$
Troup	56° 7'	117° 20'	1300	4.0	250 $CaCO_3$
Frey	56° 4'	117° 25'	1250	4.0	250 $CaCO_3$
Desrosier	56° 1'	117° 20'	1500	2.2	untreated
Fortier	54° 10'	113° 45'	7200	4.5	untreated

[*]Lat is latitude, long is longitude, area in square meters, depth in meters, treatment in mg/l

Table 2 Dugout Water Quality

Dugout	Conductivity			Secchi depth			Color[*]		
Gour #4	420	452	37	1.0	1.9	0.2	25	10	1
Monnette	175	230	80	0.7	1.9	0.3	23	8	1
Troup	217	273	13	0.2	0.4	0.1	70	58	4
Frey	243	270	7	3.1	1.6	0.2	20	10	2
Desrosier[**]	--	435	13	--	0.9	0.1	--	29	2
Fortier[**]	--	637	55	--	0.3	0.1	--	42	8

[*]Conductivity in $\mu S/cm$, depth in meters, color in mg/l as Pt
[**]Untreated dugouts, for each set, the first value is the pretreatment measurement; the second value is the posttreatment average for 1987 to 1988; and the third value is the standard error of posttreatment data.

Table 3 The pH in study dugouts

Dugout	1987 Pretreatment pH	1987 Posttreatment Average pH	1988 Posttreatment Average pH
Gour #4	8.6	10.2	8.1
Monnette	9.4	10.5	9.3
Troup	9.2	8.8	8.9
Frey	8.3	8.4	8.6
Desrosier[**]	--	9.0	9.1
Fortier[**]	--	--	9.8

[**]Untreated dugouts

Figure Legends

Figure 1 Slurry maker and trailer

Figure 2 Total phosphorus (μg/l), chlorophyll a (μg/l), and calcium (mg/l) concentrations of $Ca(OH)_2$-treated dugouts (1987-88).

Figure 3 Total alkalinity of six study dugouts (1987-1988).

Figure 4 Total phosphorus (μg/l), chlorophyll a (μg/l), and calcium (mg/l) concentrations of $CaCO_3$-treated dugouts.

Figure 5 Total phosphorus (μg/l), chlorophyll a (μg/l), and calcium (mg/l) concentrations of untreated dugouts.

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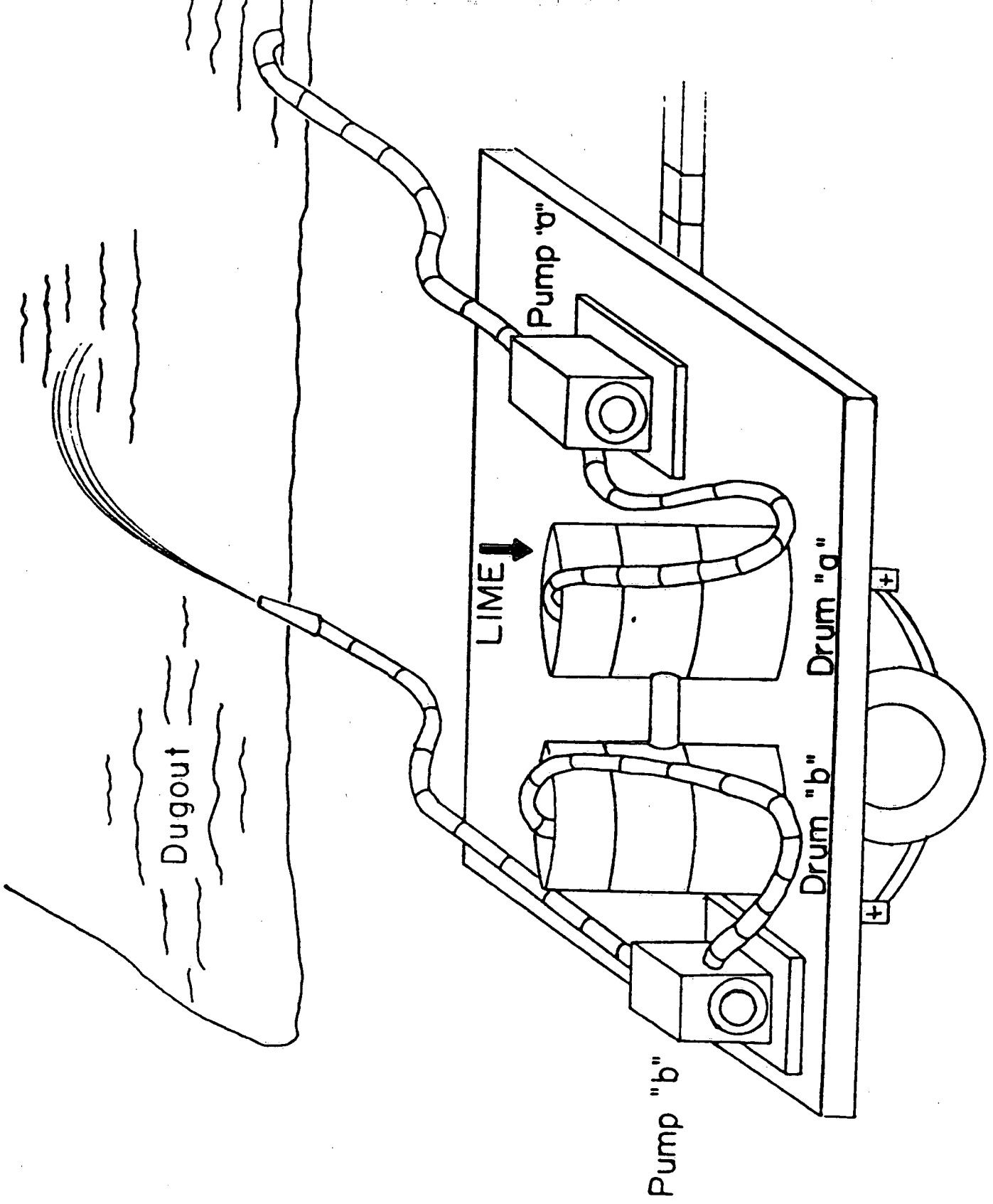Dugout

Pump "g"

LIME →

Drum "g"

Drum "b"

Pump "b"

Figure 1. Slurry-maker and trailer.

Figure 2.

Total phosphorus (ug/L), chlorophyll $\underline{a}$ (ug/L), and calcium (mg/L) for Ca(OH)$_2$-treated dugouts (1987-1988).
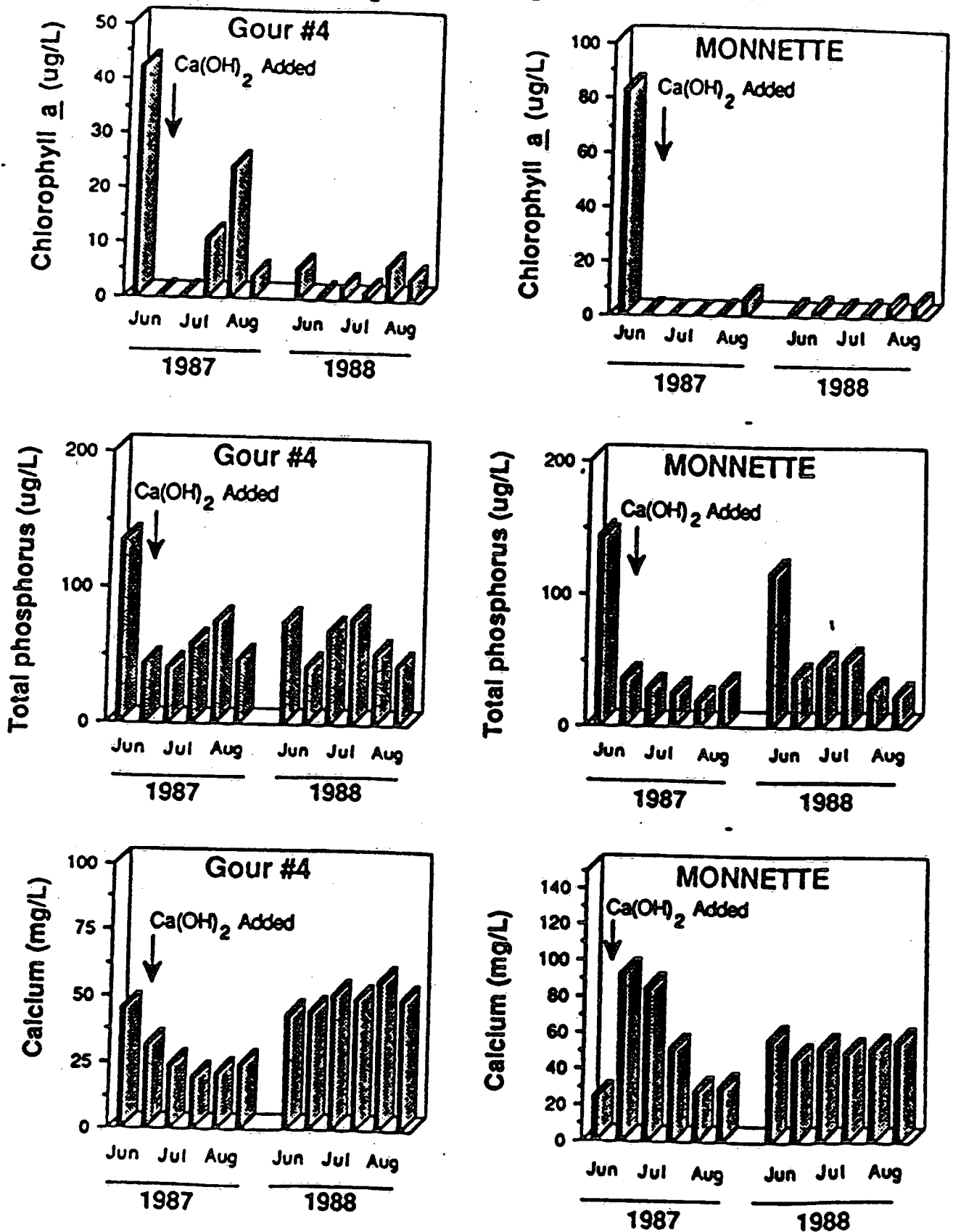
Figure 3.

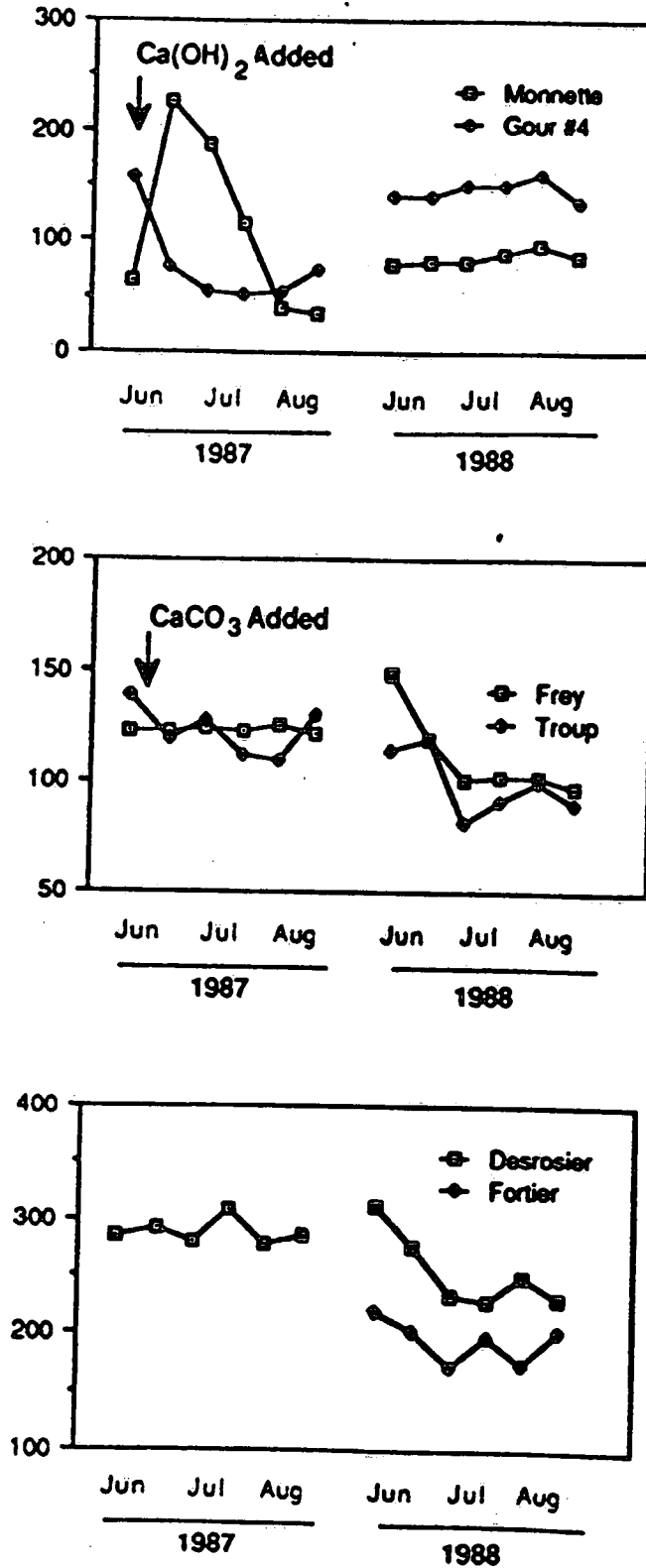Total alkalinity (mg/L as $CaCO_3$) for all dugouts (1987-1988).

Figure 4.

Total phosphorus (ug/L), chlorophyll a (ug/L), and calcium
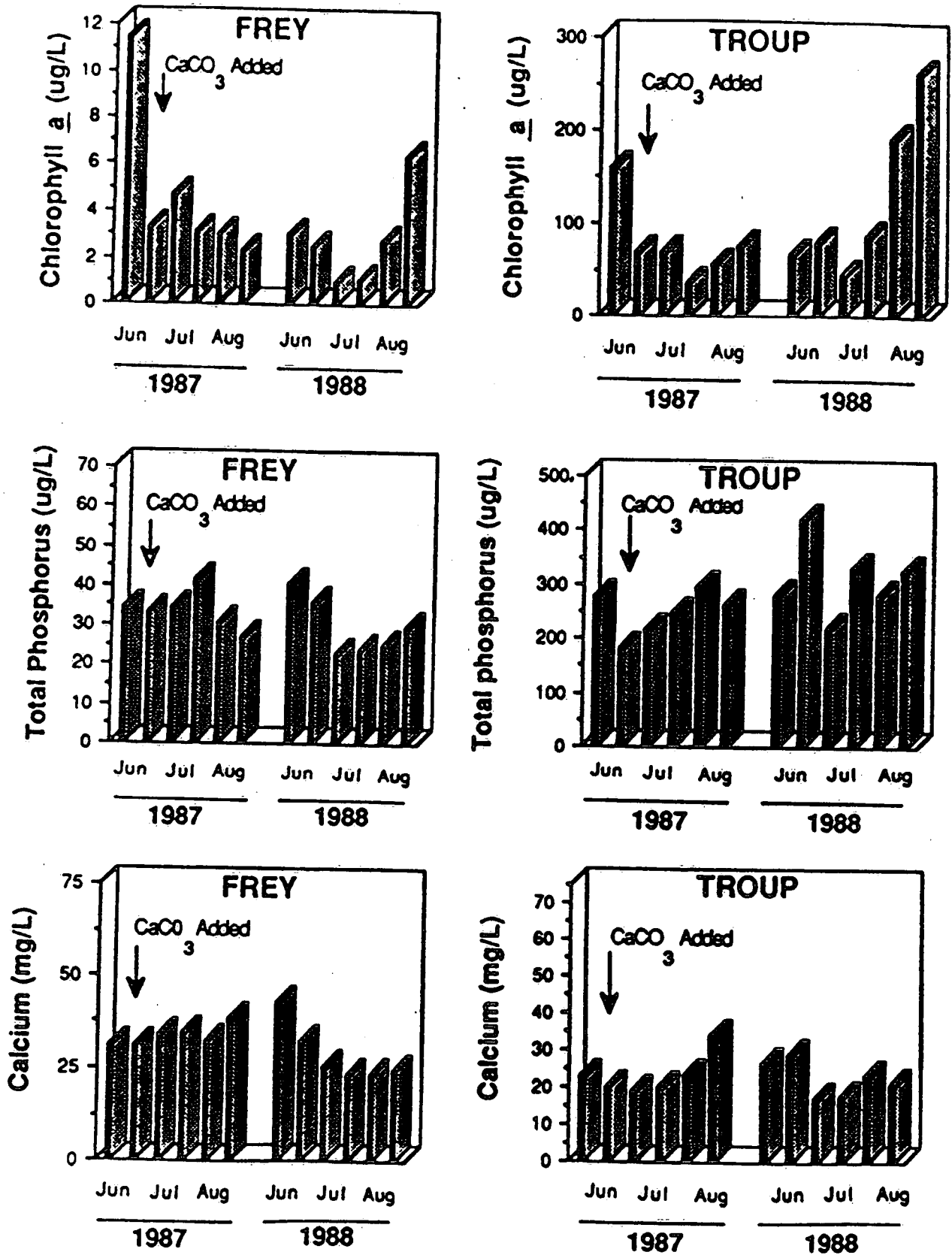(mg/L) for CaCO₃-treated dugouts (1987-1988).

Figure 5.

Total phosphorus (ug/L), chlorophyll a (ug/L), and calcium (mg/L) for control dugouts (1987-1988)