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LIME TREATMENT OF HARDWATER LAKES
TO REDUCE EUTROPHICATION

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NWRI Contribution No. 90-10

Lime Treatment of Hardwater Lakes to Reduce Eutrophication

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Abstract

Lime, calcium hydroxide [$Ca(OH)_2$], or calcium carbonate [$CaCO_3$] was added a total of 31 times to six lakes and nine dugouts in Western Canada to reduce eutrophication. In 21 trial treatments with calcium hydroxide and ten trial treatments with calcium carbonate, chlorophyll a concentrations were reduced by averages of 60% and 33% respectively, and phosphorus concentrations were changed by averages of -40% and +7%, respectively. Long-term reductions of phosphorus and chlorophyll a concentrations were observed in high-dose treatments and in water bodies with low flushing rates. A series of limnocorral experiments confirmed that $Ca(OH)_2$ was more effective than $CaCO_3$ in improving water quality. In Figure Eight Lake, the improved water clarity did not enhance macrophyte growth and oxygen depletion under the ice was reduced by lime treatment by approximately 50%. The reactions regulating the effect of lime treatment exist naturally in lakes; thus, few negative side effects were expected or observed. Lime treatment is a cost-effective method to reduce eutrophication of some hardwater lakes.

Management Perspective

The application of lime to lakes and farm dugouts in Alberta has been studied with the University of Alberta. The objective was to determine which reactions regulated the precipitation of phosphorus and algae and whether calcium carbonate or calcium hydroxide treatment was more cost effective.

For farm dugouts, the treatment protocols are relatively simple. High doses of calcium hydroxide (250 mg/l) result in good drinking water for two years. Treatment of lakes is more complex. Calcium hydroxide is more effective, but care must be used to avoid producing water with a high pH toxic to fish. Calcium carbonate is less effective in precipitating phosphorus but it sediments algae immediately after application. Furthermore in the winter, most of the added calcium hydroxide and calcium carbonate recycles from the sediments back to the lakewater to result in further precipitation of algae by calcium carbonate precipitation in the following year. This long-term effect is strongest in deep lakes with little flushing and can be enhanced more cost-effectively by calcium carbonate.

Lime treatments could enhance water quality in many recreational lakes in Alberta which are often eutrophic. They have excessive nutrient concentrations which result in intense algal blooms and fish kills. At times, toxic algae kill pets, wildlife, and livestock. The same concerns apply to farm dugouts. Dugouts are often the only drinking water supply available in the prairies.

ABRÉGÉ

Des additions de chaux, d'hydroxyde de calcium $[Ca(OH)_2]$ ou de carbonate de calcium $[CaCO_3]$ ont été effectuées, un total de 31 fois, dans le but de réduire l'eutrophisation de six lacs et de neuf fosses-réservoirs situés dans l'Ouest du Canada. À la suite de 21 traitements expérimentaux à l'hydroxyde de calcium et de dix traitements au carbonate de calcium, on a observé des diminutions respectives de 60 % et de 33 % de la concentration de chlorophylle _a_, et des modifications respectives de -40 % et de +7 % de la concentration de phosphore. L'abaissement durable de la concentration de phosphore et de chlorophylle _a_ a été observé dans le cas de traitements à fortes doses et d'étendues où le taux de renouvellement de l'eau est faible. Une série d'expériences sur le limnocorail a confirmé que le $Ca(OH)_2$ est plus efficace que le $CaCO_3$ pour rehausser la qualité de l'eau. Dans le lac Figure Eight, l'amélioration de la clarté de l'eau n'a pas été accompagnée par une stimulation de la croissance des macrophytes; l'appauvrissement en oxygène sous la glace a diminué de 50 % à la suite du traitement à la chaux. Les réactions associées au traitement à la chaux sont d'occurrence naturelle; conséquemment, peu d'effets indésirables étaient attendus ou ont été observés. Le traitement à la chaux est une méthode abordable permettant de réduire l'eutrophisation de certains lacs qui sont caractérisés par une eau très dure.

PERSPECTIVE DE GESTION

L'addition de chaux dans des lacs et fosses-réservoirs situés en Alberta a été étudiée conjointement avec l'Université de l'Alberta. L'objectif de l'étude était d'identifier les mécanismes régissant la précipitation du phosphore et des algues, et de comparer le rapport coût/efficacité des traitements au carbonate de calcium et à l'hydroxyde de calcium.

Dans le cas de fosses-réservoirs, la méthode de traitement est relativement simple. De fortes doses d'hydroxyde de calcium (250 mg/l) permettent d'obtenir une eau potable pendant deux ans. Le traitement des lacs est plus complexe. L'hydroxyde de calcium est plus efficace, mais il faut éviter une trop forte élévation du pH, qui serait toxique pour les poissons. Le carbonate de calcium est moins efficace relativement à la précipitation du phosphore, mais il entraîne la sédimentation des algues immédiatement après son addition. En outre, durant l'hiver, la majeure partie de l'hydroxyde de calcium et du carbonate de calcium est recyclée vers l'eau du lac, ce qui permet une reprise du cycle de précipitation des algues par le carbonate de calcium durant l'année suivante. Cet effet de longue durée est plus prononcé dans les lacs profonds où le renouvellement de l'eau est faible, et il peut être accru, moyennant des coûts raisonnables, par l'addition de carbonate de calcium.

Les traitements à la chaux pourraient être utilisés pour améliorer la qualité de plusieurs lacs à vocation récréative en Alberta, lacs dont les eaux sont souvent eutrophes. Ces lacs présentent des concentrations élevées de matières nutritives, qui

engendrent la croissance excessive d'algues et tuent les poissons.
Il arrive que certaines algues toxiques puissent tuer des animaux
domestiques, des animaux sauvages et des bestiaux. Les mêmes
préoccupations existent relativement aux fosses-réservoirs,
puisqu'elles constituent souvent les seules sources d'eau potable
à travers les Prairies.

INTRODUCTION

Several studies of calcium carbonate precipitation led to the hypothesis that the addition of lime to lakes can reduce eutrophication. Calcium carbonate precipitation often occurs naturally in hardwater lakes during summer algal blooms (Kelts and Hsu 1978). This process reduces the productivity of hardwater lakes by enhancing sedimentation of algae (Wetzel 1975, Koschel et al. 1983, Stabel 1986) and by precipitating algae with calcium carbonate (Rossknecht 1980, Avnimelech 1983, Murphy et al. 1983a). Electron microscopic techniques indicate that the surface of calcium carbonate crystals forming in some hardwater British Columbia lakes contains 1-2% phosphorus (Murphy et al. 1985).

Lime is often used in sewage treatment plants to flocculate solids and precipitate phosphorus (Rubin 1978) and in drinking or industrial water supplies to remove turbidity and hardness (Montgomery 1985). However, the lime application techniques developed for water treatment are not directly transferable to in situ lake treatment. The problem of in situ treatment is to find application techniques that promote phosphorus and algal precipitation without damaging the biota.

Lime has been added to several lakes and dugouts in western Canada (Table 1) to improve water quality. These hardwater lakes are eutrophic due to high natural, agricultural, or urban loadings of phosphorus. Source control of phosphorus loadings would be extremely difficult at all sites. Most of the lakes are primarily used for recreation but the dugouts have been used for human and

agricultural water supplies. Intense algal blooms result in fish kills, and poor water quality for domestic use.

In two of the study sites, Figure Eight Lake (Manning et al. 1989) and Frisken Lake (unpublished), most of the sediment iron is converted into pyrite. These lakes have little reactive iron and presumably phosphorus biogeochemistry is not controlled by iron reactions (Murphy et al. 1983b).

Table 1 Study Sites

Lake	Lat		Long		Depth	Area	Conduct[*]
Frisken	50°	27'	120°	08	11/5.5	33.8	374
Fig.8	56°	18'	117°	54'	6/3.1	36.8	220
Andorra	53°	37'	113°	29'	4.5	3.0	1100
Beaumaris	53°	37'	113°	30'	4.3	16.2	1400
Valencia	53°	37'	113°	29'	3.6	3.7	1200
Halfmoon	53°	27'	113°	05'	4.8	40	410
Gour	56°	03'	117°	17'	4.0	0.18	420
Monnette	56°	02'	117°	27'	3.5	0.11	175
Desrosier	56°	01'	117°	20'	2.2	0.15	435
Frey	56°	04'	117°	25'	4.0	0.13	243
Fedora	53°	55'	113°	19'	2.5	0.04	295
Pederson	54°	09	113°	43'	1.0	0.03	490
Sullivan	53°	50'	113°	19'	2.7	0.04	80
Schreger	53°	57'	113°	39'	3.3	0.05	80
Limno	53°	25'	113°	15'	2.0	^	-

[*]Latitude, Longitude, maximum/mean depth in metres, area in hectares, and conductivity (μS/cm) at 25°C in summer before treatment.
^ Sixteen limnocorrals were used in Pretzlaff dugout near Edmonton, mean values of replicated treatments are used.

METHODS

Calcium hydroxide was added to Frisken Lake via a slurry maker which was mounted on a small barge to distribute the lime around the lake (Murphy et al. 1985, Murphy 1987, Murphy et al. 1988, Prepas and Murphy 1987, Prepas et al. 1988, Prepas et al. 1989a). The lime treatments of Andorra, Beaumaris, Halfmoon, and Valencia lakes were carried out with a barge equipped for pneumatic transfer of lime from a tanker truck. The barge could hold six tonnes of lime which was fed to a slurry maker via an auger (Prepas and Babin 1988, Babin et al. 1989). The lime treatments of the dugouts were done with a slurry maker composed of two barrels and two water pumps (Prepas et al. 1989b). At all sites, the lime slurry was sprayed onto the surface of the water.

Details of sample collection and analytical procedures can be found in the preceding references for each site. In general, samples were analyzed in laboratories at the University of Alberta or Environment Canada using primarily Technicon procedures (Envir. Can. 1979).

Chemical data were used in the programs PHREEQE and WATEQF to calculate the degree of calcium carbonate and hydroxyapatite saturation (Parkhurst et al. 1980, Plummer et al. 1984).

RESULTS

Short-term Effects of Lime Addition on Water Chemistry

Additions of $Ca(OH)_2$ were more effective than $CaCO_3$ in precipitating algae from hardwater lakes (Fig. 2). In all but three of 21 treatments with $Ca(OH)_2$, at least a third of the chlorophyll a precipitated within a week after treatment. Two of the unsuccessful treatments were in the Edmonton stormwater retention lakes which have high nutrient loadings in all seasons. The other unsuccessful treatment was with a low treatment dose of 4 mg/l in pristine Frisken Lake, that receives rich nutrient loadings only in the spring. Later, two other $Ca(OH)_2$ applications to Frisken Lake of 4 mg/l and 8 mg/l, respectively, effectively precipitated the algae. With the exception of water bodies receiving continuous high nutrient loadings, $Ca(OH)_2$ additions greater than 10 mg/l precipitated at least one half of the chlorophyll a.

Seven of the ten $CaCO_3$ treatments greatly improved water quality and the three failures occurred in water bodies receiving a high continuous nutrient loading. In lakes receiving less abusive nutrient loadings, at least one half of the chlorophyll a was precipitated by $CaCO_3$ additions.

Relative to the precipitation of chlorophyll a, much less phosphorus was precipitated by either $Ca(OH)_2$ or $CaCO_3$ application (Fig. 2). The amount of phosphorus precipitated by $Ca(OH)_2$ was highly variable and only at high doses (250 mg/l) did the amount of phosphorus precipitation significantly increase beyond

approximately 40% to 75%. Unlike the low doses of Ca(OH)$_2$, the high doses of Ca(OH)$_2$ resulted in water with a pH higher than 10.

In 12 limnocorral trials, the addition of CaCO$_3$ did not significantly enhance the effect of Ca(OH)$_2$ additions on phosphorus or chlorophyll _a_ precipitation (P>0.95, Lim et al. 1989). The utility of adding the less reactive but less expensive CaCO$_3$ to Ca(OH)$_2$ may be in the long-term reactions.

Long-term Responses to Lime Treatment

In Frisken Lake, more than 95% of the phosphorus and calcium that precipitated during the lime treatments, dissolved in the winter (Fig. 3). Presumably because of the enhanced precipitation of calcium carbonate that occurred the year following treatment, the phosphorus concentrations in the epilimnion of Frisken Lake were much lower in the summer after treatment. The clarity of Frisken Lake also improved from approximately a 2.0 m Secchi disk depth before treatment to about 4.0 m as long as a year later.

The long-term responses to lime additions in Figure Eight Lake were slightly different from those observed in Frisken Lake in that most of the precipitated phosphorus redissolved in the summer (Fig. 4). The lime treatment in 1986 appeared to result in more effective lime treatment in 1987. In 1987, the Secchi disk depth for the ice-free period exceeded two metres (Fig. 5). The average Secchi disk depth in 1988 was only marginally better than in pretreatment years. This comparison of mean values masks one strong long-term effect. In early summer of 1987 and 1988, the

Secchi disk depth exceeded five metres. This clarity was established by calcium carbonate precipitation. All of the added lime dissolved in the winter so that when the water warmed, the water column was highly saturated with calcite (Fig. 6). By midJuly 1988, calcium precipitation ceased and phosphorus release from the sediments allowed intense blue-green algal blooms.

The degree of saturation of Figure Eight Lake with respect to apatite in 1988 provides some insight into the biogeochemistry of phosphorus (Fig. 7). Geochemical calculations indicate that apatite should precipitate in summer and lime treatments would enhance this reaction. Verification of this apatite precipitation hypothesis is difficult. Sediment release of phosphorus prevents the use of simple correlation analysis to test this hypothesis. Isolation of apatite was not attempted.

To maximize phosphorus precipitation, high doses of $Ca(OH)_2$ were required. In farm dugouts, a 250 mg/l dose of $Ca(OH)_2$ resulted in a long-term suppression of algal biomass (Fig. 8). However, these high doses resulted in water with a pH greater than 10 (Murphy et al. 1989b). Although the pH is reduced within weeks through the decay of algae and carbon dioxide entry, the pH shock would kill a few sensitive organisms.

DISCUSSION

The flocculation and sedimentation of algae by lime treatment was the primary cause of the greatly improved clarity in the lakes. Calcium hydroxide was more effective than $CaCO_3$ in reducing the density of algae and two mechanisms appear to explain this effect. First, $Ca(OH)_2$ increased the pH and resulted in substantial formation and precipitation of calcium carbonate and in turn, more algal precipitation. Second, $Ca(OH)_2$ was more effective in precipitating phosphorus, and presumably $Ca(OH)_2$ treatments produced more phosphorus limitation than $CaCO_3$ treatments.

The observed long-term enhancement of $CaCO_3$ precipitation in Figure Eight and Frisken lakes can be predicted with simulation analyses using the computer program PHREEQE (Parkhurst et al. 1980). Initially $CaCO_3$ would form and precipitate in summer lime treatments, and cooling and mixing of the lake in the winter would result in complete dissolution of the $CaCO_3$ and the adsorbed phosphorus. Similar calculations predict enhanced $CaCO_3$ precipitation in future summers when the epilimnion warms.

Although biological reactions must influence phosphorus biogeochemistry, the effect of lime treatment on phosphorus biogeochemistry can be easily explained via apatite formation. The generally accepted model for apatite formation is that phosphorus initially adsorbs to calcite and then a surface rearrangement produces phosphate heteronuclei that ultimately form the stable mineral apatite (Stumm and Leckie 1970, Griffin and Jurinak 1974). Geochemical calculations with WATEQF indicate that

$Ca(OH)_2$ additions would result in supersaturation of hydroxyapatite.

The optimal method of enhancing calcite and apatite formation in lakes is not obvious, but several recommendations are possible. Lakes with rapid hydraulic flushing or high and continuous nutrient loading are less appropriate for lime treatment; however, lakes with a high short-term spring loading of nutrients respond well to lime treatment. Deep lakes should respond better than shallow lakes to lime treatment in that sediment release of phosphorus would be less able to overcome the effect of enhanced calcite precipitation of algae and phosphorus. In lakes without fish, a large dose of $Ca(OH)_2$ should be used. In lakes with valuable fisheries, alternative approaches to enhance apatite formation could include hypolimnetic injection of $Ca(OH)_2$ or larger surface applications of $CaCO_3$.

Long-term studies are required to develop simple lake treatment protocols and resolve important uncertainties. Although there is limited long-term data, the Figure Eight Lake results indicate that sequential treatments result in suppression of sediment phosphorus release. The effect of lime treatment on the rates of apatite and pyrite formation warrant further study.

Acknowledgments

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Figure Legends

Fig. 1 Map of Study Sites.

Fig. 2 a) effect of $Ca(OH)_2$ concentration on chlorophyll a concentrations (☐). (■) are trials with both $Ca(OH)_2$ and $CaCO_3$.

b) effect of $CaCO_3$ concentration on chlorophyll a concentrations.

c) effect of $Ca(OH)_2$ concentration on total phosphorus concentrations (▲). (◬) are trials with both $Ca(OH)_2$ and $CaCO_3$.

d) effect of $CaCO_3$ concentration on total phosphorus concentrations.

Fig. 3   Epilimnetic soluble reactive phosphorus (SRP) in Frisken Lake. The arrows denotes the lime additions.

Fig. 4   Total phosphorus concentrations in Figure Eight Lake. The arrows indicate the lime additions.

Fig. 5   Average summer (May-Sept) Secchi disc depth in Figure Eight Lake from pretreatment to posttreatment.

Fig. 6   The degree of saturation of calcium carbonate (IAP/K_{sp}) in Figure Eight Lake a year after treatment.   The arrows indicate time of sampling.

Fig. 7   The degree of saturation of apatite (IAP/K_{sp}) in Figure Eight Lake a year after treatment.   The arrows indicate time of sampling.

Fig. 8   The long-term suppression of eutrophication by high doses of $Ca(OH)_2$ in farm dugouts. (■) Monnette and (▲) Gour dugouts received 250 mg/L of $Ca(OH)_2$ while (●) Desrosier Dugout remained untreated.

STUDY SITES

ALBERTA

BRITISH
COLUMBIA

Figure Eight
Lake

● Dugouts

Stormwater
Retention
Lakes

EDMONTON

● CALGARY

● Frisken Lake

● VANCOUVER
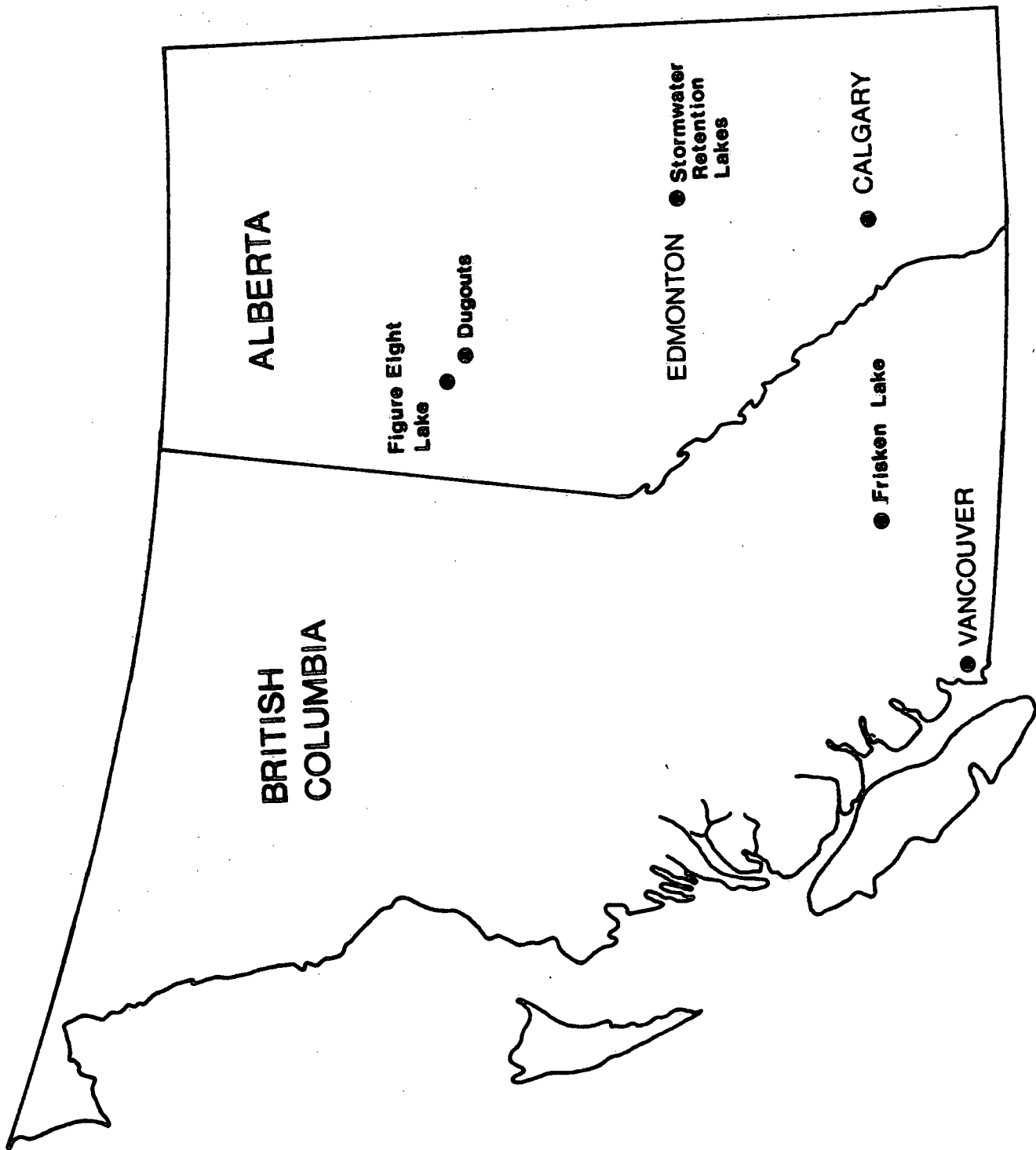
FIGURE 1

Ca(OH)₂ Treatment
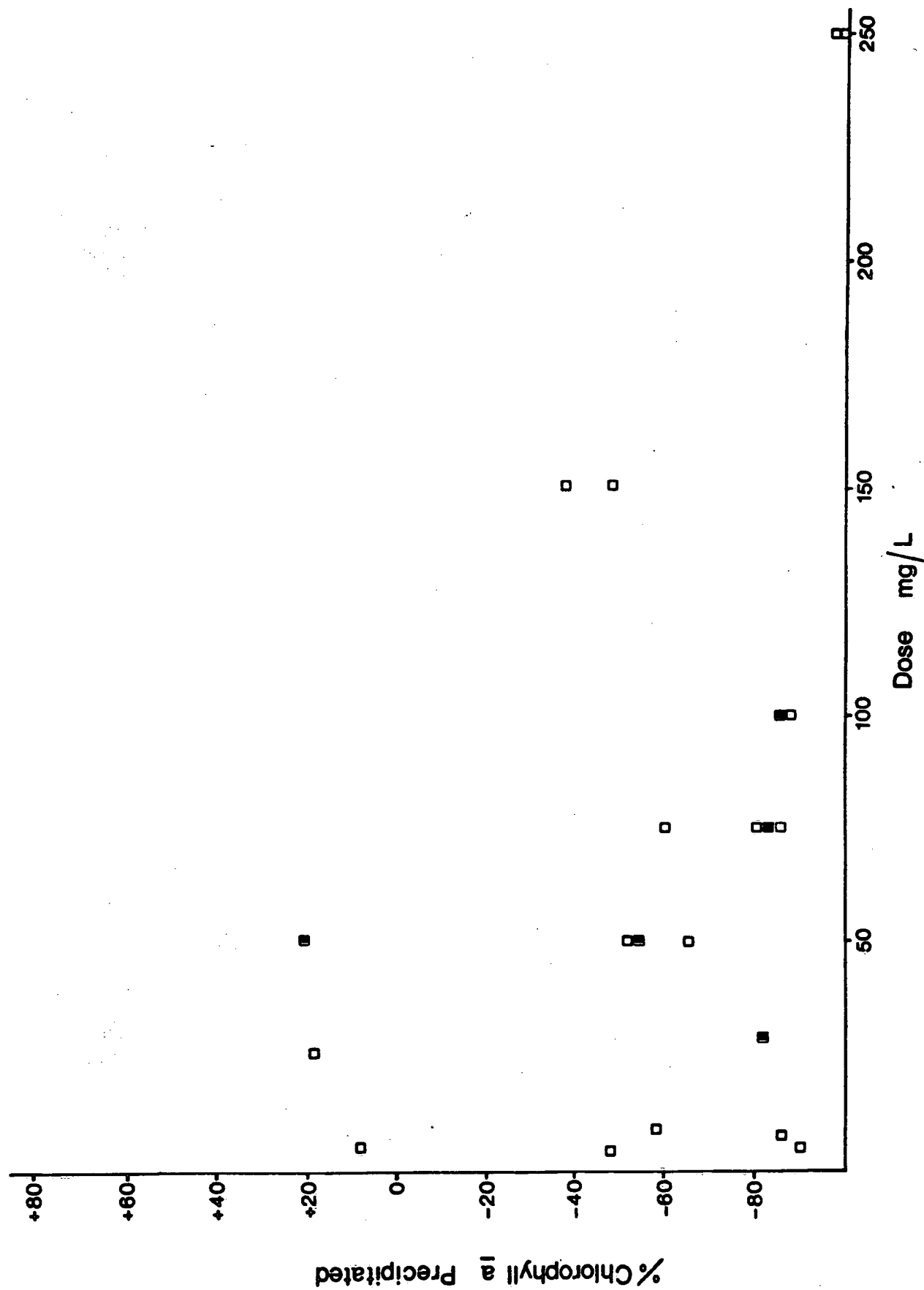
FIGURE 2a

CaCO₃ Treatment

Dose mg/L

FIGURE 2b

% Chlorophyll a Precipitated

Ca(OH)$_2$ Treatment

% Total Phosphorus Precipitated

Dose mg/L
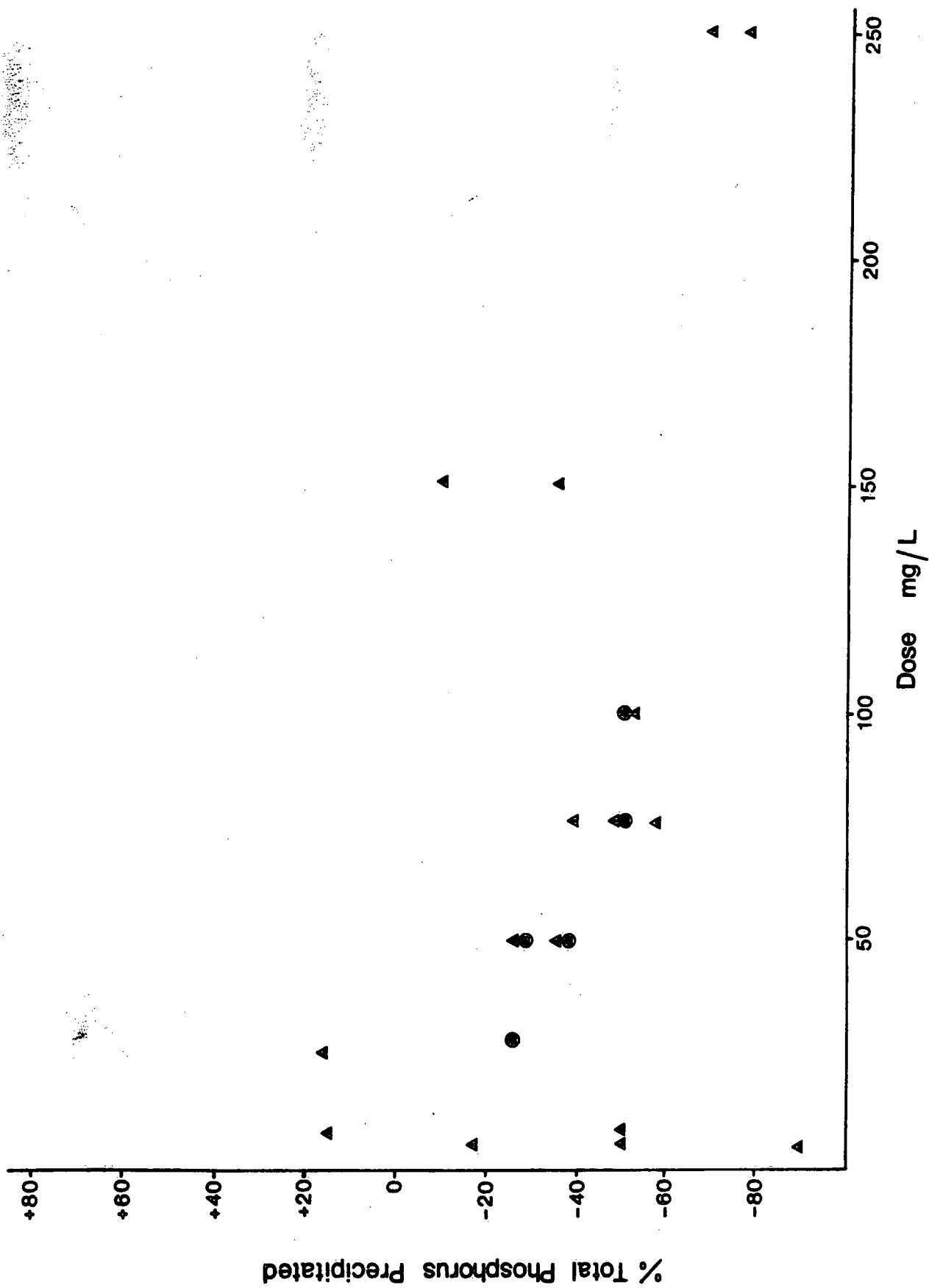
FIGURE 2c

CaCO₃ Treatment

% Total Phosphorus Precipitated

Dose mg/L
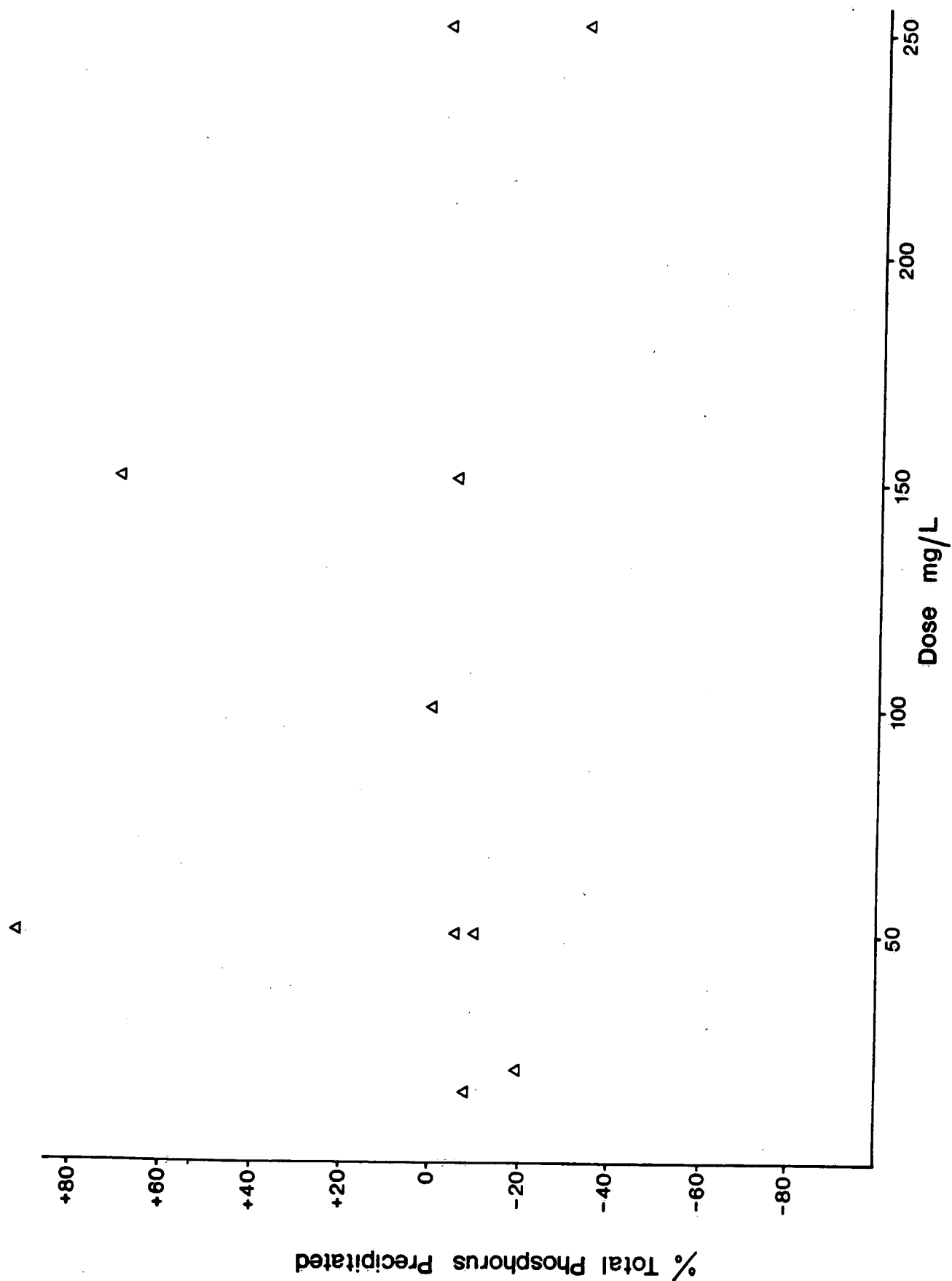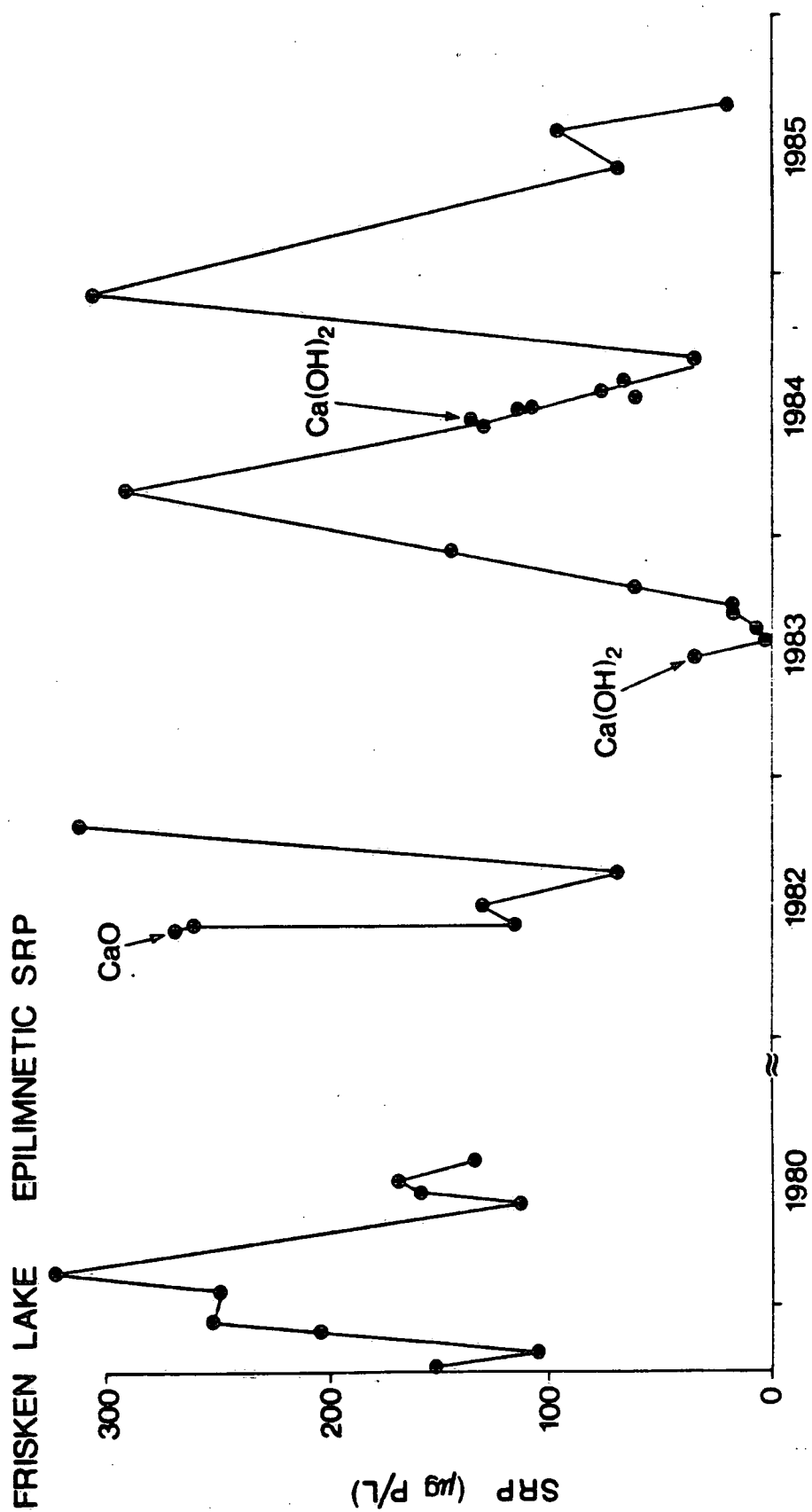
FIGURE 2d

FIGURE 3

Figure Eight Lake Total Phosphorus at 1 m
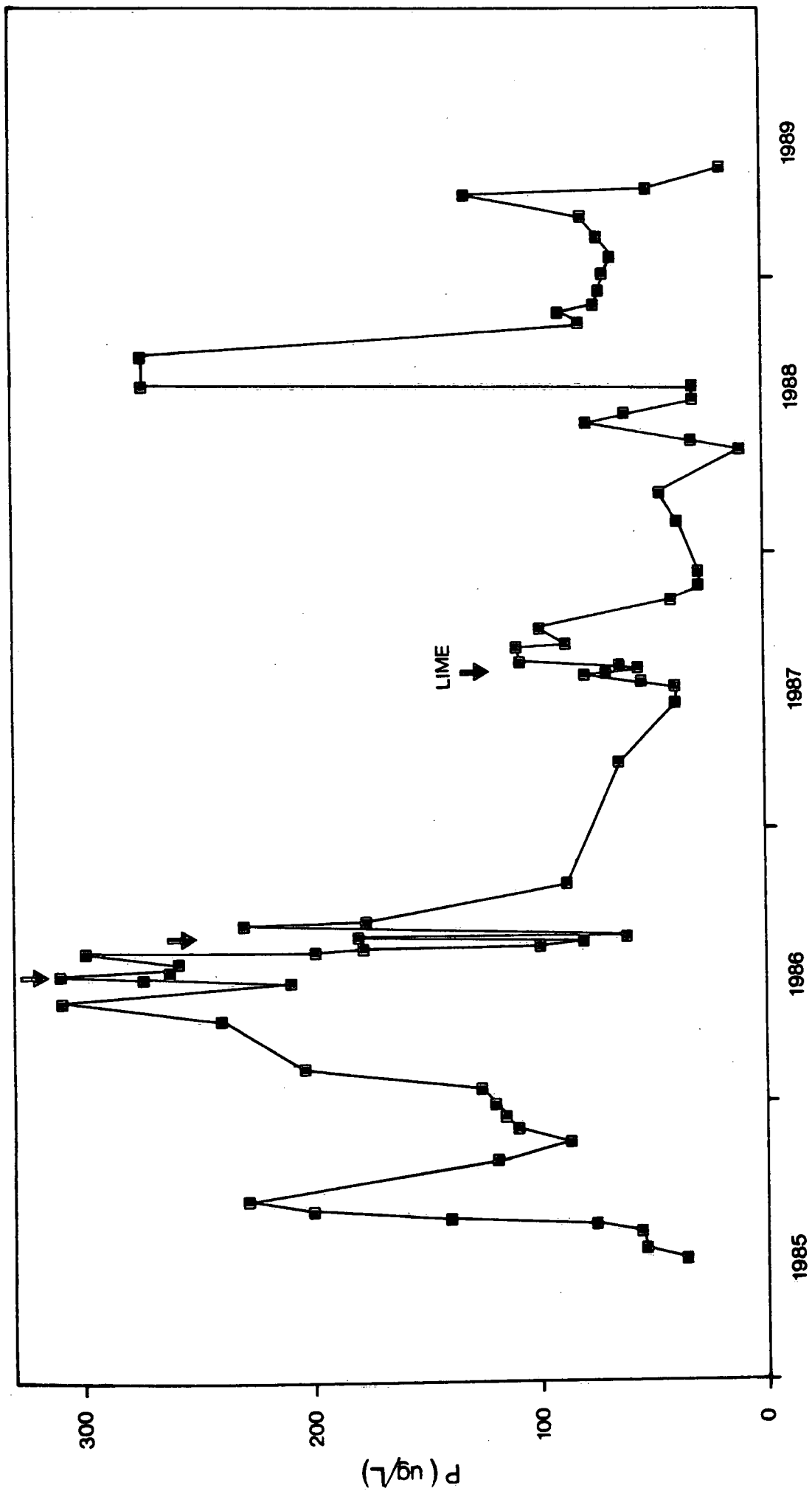
FIGURE 4

Figure Eight Lake
Secchi Disk Depths (m)

Year	Depth
1985	1.0
1986	1.4
1987	2.5
1988	1.6
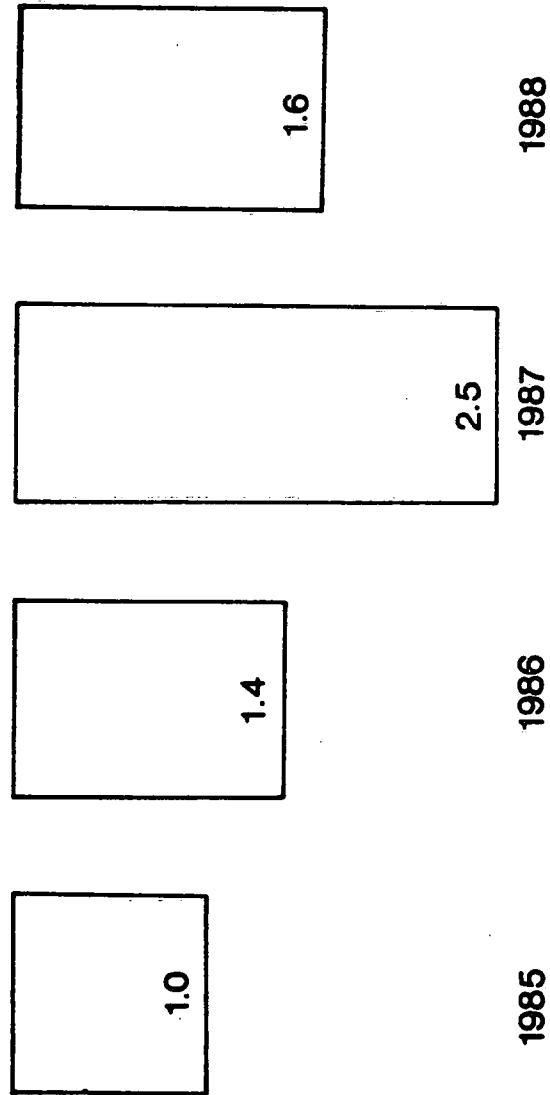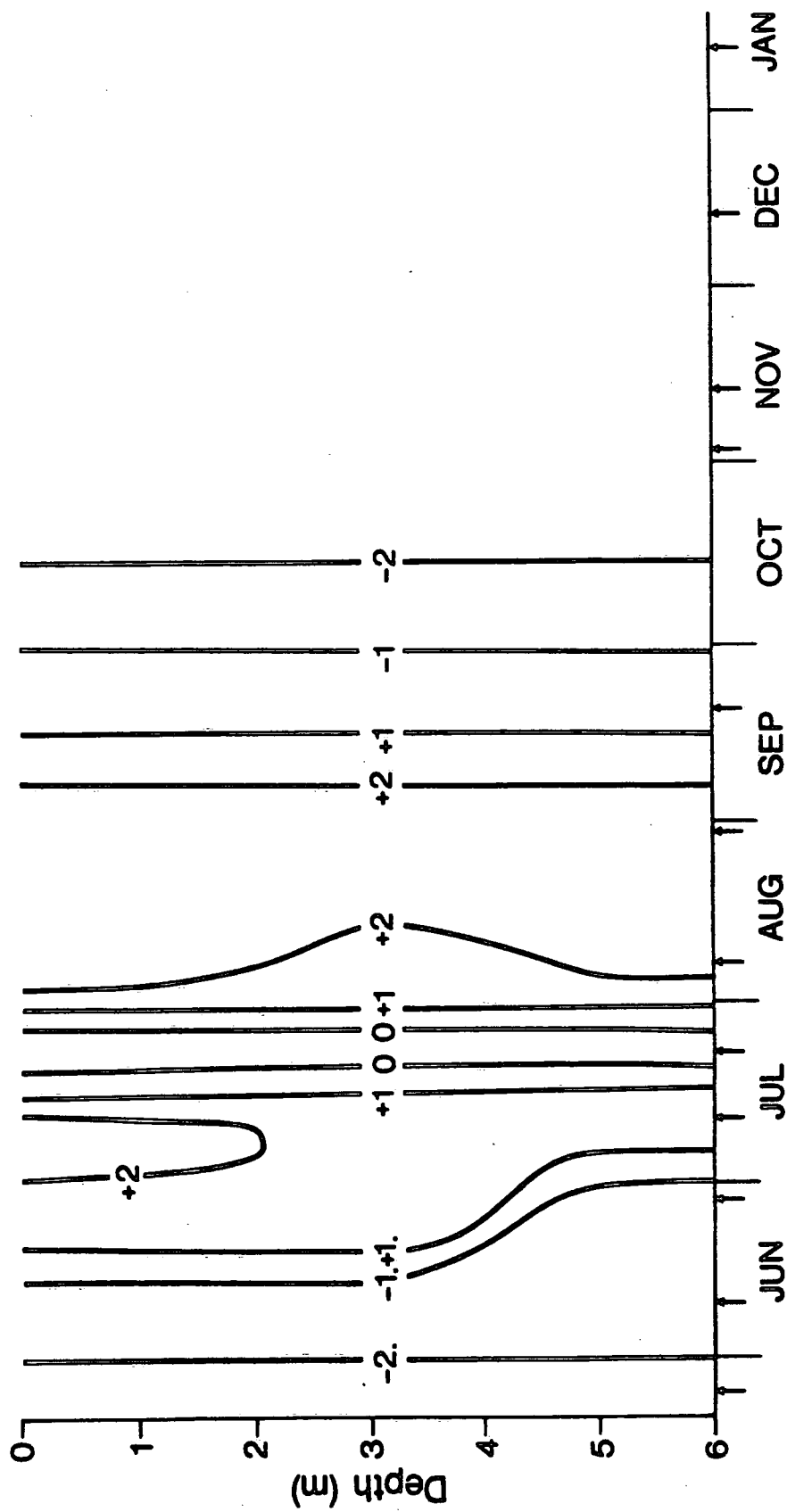
FIGURE 5

Hydroxyapatite Saturation Log IAP/Kt 1988
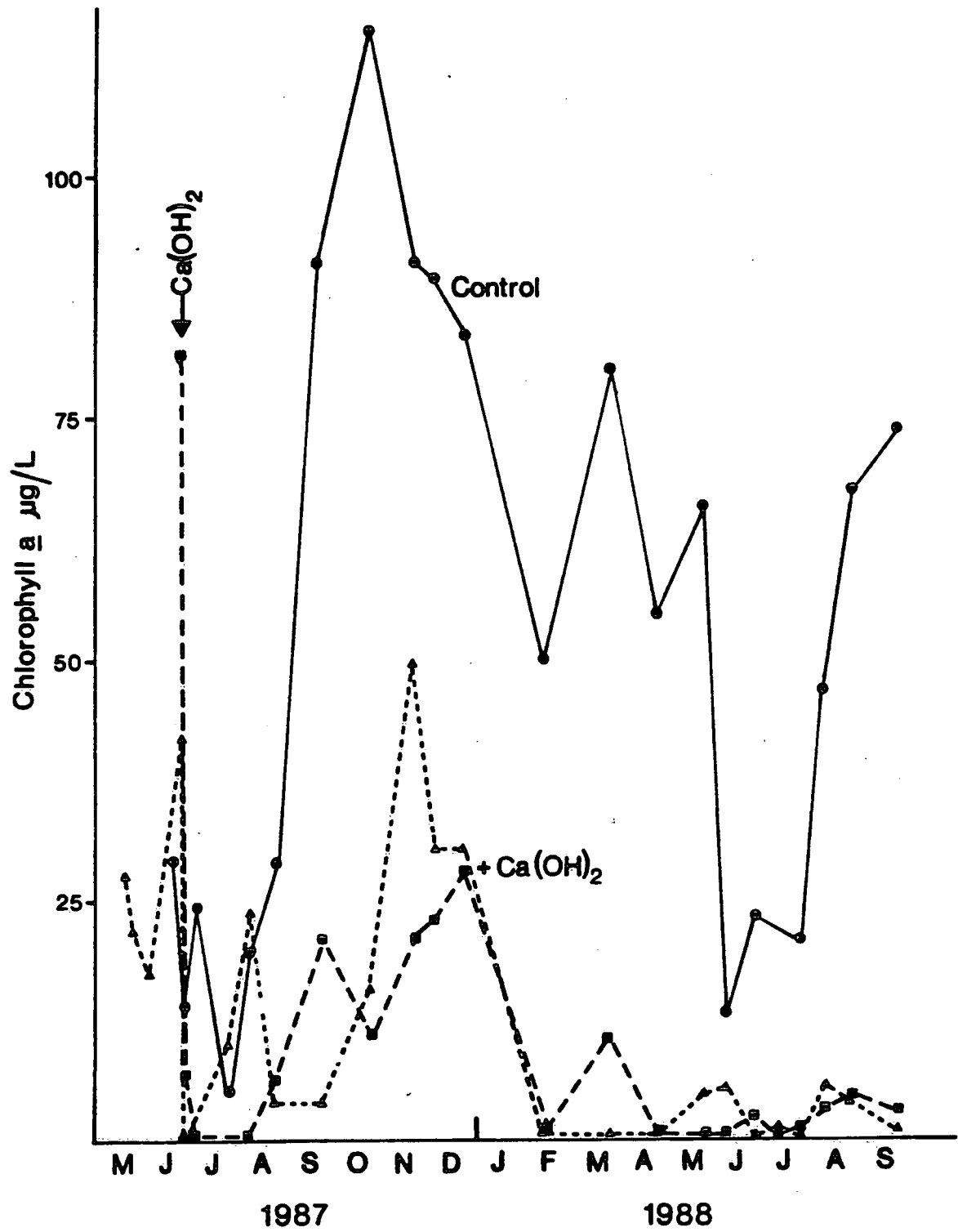
FIGURE 7
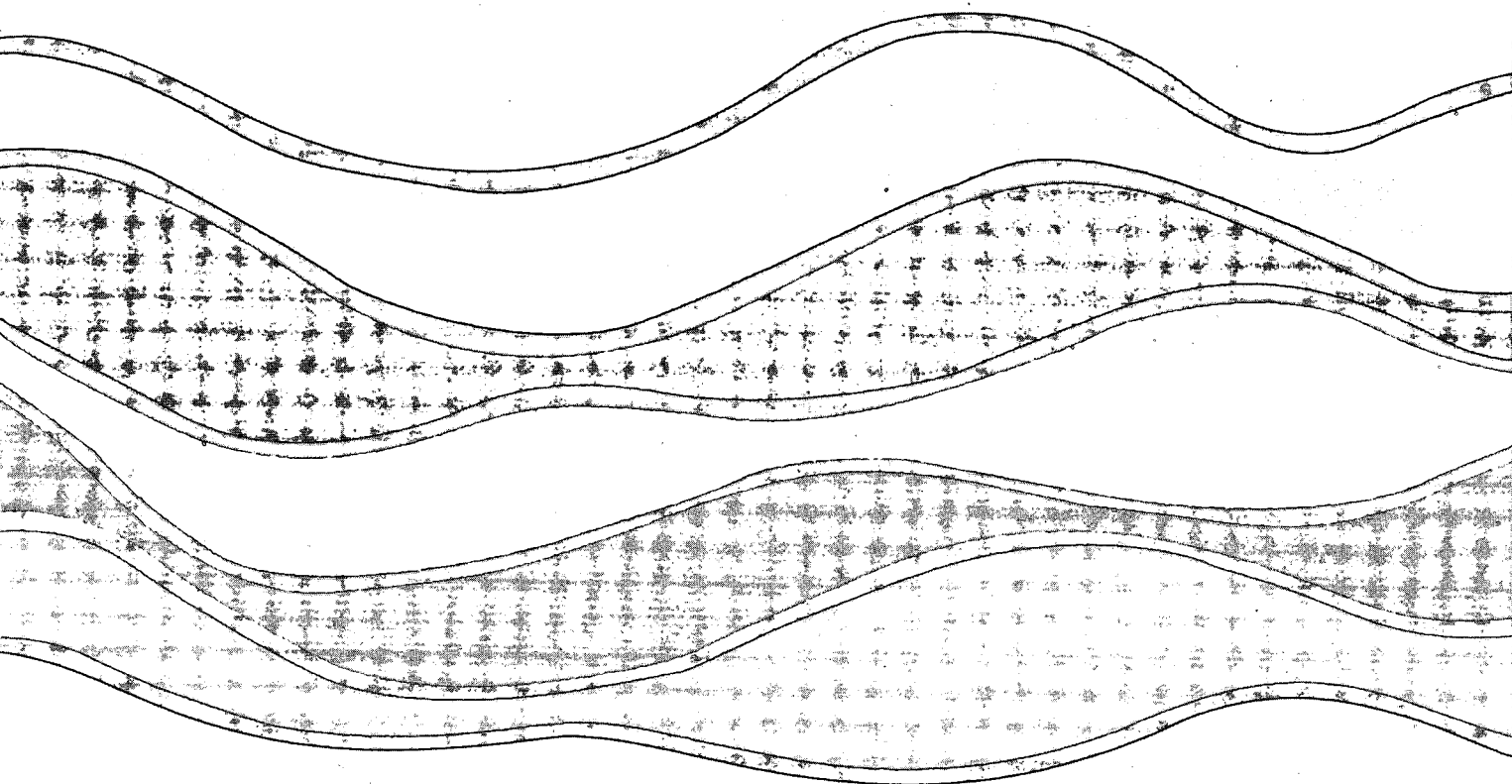
FIGURE 8

Think Recycling!

Pensez à Recycling!