A TEST OF THE EFFECTS OF LIME ON ALGAL BIOMASS AND TOTAL PHOSPHORUS CONCENTRATIONS IN EDMONTON STORMWATER RETENTION LAKES

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Management Perspective

The focus of this project is to determine the effectiveness of applying lime ($CaCO_3$ or $Ca(OH)_2$) to stormwater retention lakes in Edmonton as a means to control lake productivity. Following application of at least 50 mg/L of $Ca(OH)_2$, algal biomass and total phosphorus concentrations decreased significantly within one week of treatment. The $CaCO_3$ treatment was ineffective. The improved water clarity and park aesthetics produced by the $Ca(OH)_2$ treatment did not last beyond a major rainfall. In spite of the lack of a long-term response in these rapidly flushed lakes, the $Ca(OH)_2$ treatment is as effective as other lake treatments, costs less than most methods, and unlike many methods, doesn't require using a toxin.

Stormwater retention lakes are a common feature of many new subdivisions across Canada. Construction of these lakes reduces the capital cost of water management, provides flood and erosion control, and are designed to provide recreational areas. However, the public is often upset that the lakes are unattractive and unsafe for swimming or boating. Prior to our study, The City of Edmonton attempted to control excessive algal growth in their stormwater retention lakes with the use of copper sulphate or Reglone A. Both of these herbicides are banned in many states and countries and some studies indicate that Reglone A is a carcinogen. NWRI has helped to develop a much safer lake treatment.

Perspective-gestion

L'objet de la présente étude est de déterminer l'efficacité de l'application de chaux ($CaCO_3$ ou $Ca(OH)_2$) à des lacs de rétention des eaux pluviales à Edmonton, afin de contrôler la productivité du lac. Après l'application d'au moins 50 mg/L de $Ca(OH)_2$, la biomasse algale et les teneurs en phosphore total ont diminué de manière significative au bout d'une semaine de traitement. Le traitement au $CaCO_3$ a été inefficace. L'amélioration de la limpidité de l'eau et des valeurs esthétiques produite par le traitement au $Ca(OH)_2$ ne s'est pas poursuivie après une importante averse. Même s'il ne règle pas les problèmes à long terme dans ces lacs où le renouvellement d'eau est rapide, le traitement au $Ca(OH)_2$ est aussi efficace que d'autres traitements, coûte moins cher que la plupart des autres méthodes et, contrairement à nombre d'autres méthodes, ne comporte pas l'utilisation d'une toxine.

Les lacs de rétention des eaux pluviales sont une caractéristique fréquente de beaucoup de nouvelles subdivisions au Canada. La construction de ces lacs diminue le coût en capital de la gestion des eaux, permet de contrôler l'érosion et les crues et fournit des zones récréatives. Le public est souvent inquiet parce que ces lacs sont peu attirants; de plus, il ne s'y sent pas en sécurité pour se baigner ou faire du bateau. Avant de réaliser cette étude, la ville d'Edmonton a tenté de contrôler la croissance excessive d'algues dans ses lacs de rétention des eaux pluviales en utilisant du sulfate de cuivre ou du Reglone A. Ces deux herbicides sont interdits dans de nombreux états et pays et, d'après certaines études, le Reglone A est cancérigène. L'INRE a aidé à mettre au point un traitement des lacs beaucoup plus sûr.

RÉSUMÉ

De la chaux ($CaCO_3$ et/ou $Ca(OH)_2$) a été ajoutée au total huit fois à trois lacs de rétention des eaux pluviales d'Edmonton entre juin et août 1988. Le but était d'évaluer les effets à court terme de la chaux sur la biomasse algale et les teneurs en phosphore dans des systèmes à renouvellement d'eau rapide (les périodes de rétention d'eau prévues vont de 0,25 à 0,5 années). La majeure partie de l'écoulement se produit entre mai et septembre et peut varier beaucoup selon les précipitations annuelles. Ces lacs permettent également d'évaluer l'effet des traitements de la chaux sur des lacs alcalins dont les teneurs en sulfate et en calcium sont anormalement élevés (les teneurs estivales moyennes sont, respectivement, de 334 et de 65 mg/L). En moins d'une semaine de l'application d'au moins 50 mg/L de $Ca(OH)_2$ (avec ou sans $CaCO_3$), les teneurs en chlorophylle a ([Chla], une estimation de la biomasse algale) et du phosphore total ([PT]) ont diminué de manière significative ($P<0,05$). Dans le lac traité uniquement au $CaCO_3$ (dosage de 50 et 100 mg/L), ni le [PT] ni la [Chla] n'ont diminué de manière significative ($P>0,05$). Nous présentons ici les premiers essais afin de vérifier si la chaux peut faire baisser les niveaux de phosphore et la biomasse algale dans des systèmes à renouvellement d'eau rapide. Les résultats sont prometteurs.

ABSTRACT

Lime ($CaCO_3$ and/or $Ca(OH)_2$) was added a total of eight times to three stormwater retention lakes in Edmonton from June to August 1988. Our goal was to evaluate the short-term effects of lime on algal biomass and phosphorus concentrations in rapidly-flushed systems (designed water retention period of 0.25 to 0.5 yr); most of the water flow occurs from May to September and can vary greatly depending on annual precipitation. These lakes also provide the opportunity to evaluate the effect of lime treatments on hardwater lakes with unusually high sulfate and calcium concentrations (average summer concentrations of 334 and 65 mg/L, respectively). Within one week of the application of at least 50 mg/L $Ca(OH)_2$ (with or without $CaCO_3$), chlorophyll a ([Chla], an estimate of algal biomass) and total phosphorus ([TP]) concentrations decreased significantly ($P<0.05$). In the lake treated solely with $CaCO_3$ (dosages of 50 and 100 mg/L), neither [TP] nor [Chla] decreased significantly ($P>0.05$). We present the first tests of whether lime can control phosphorus levels and algal biomass in rapidly-flushed systems; the results are promising.

INTRODUCTION

Stormwater retention lakes are small bodies of water used to temporarily store runoff from rainfall and snowmelt. Stormwater retention lakes are constructed to: 1) decrease the construction cost of storm sewers; 2) provide temporary storage of rainfall; 3) provide recreational areas and increase community aesthetics;

and 4) decrease impact (i.e., erosion) of receiving water.

Edmonton stormwater retention lakes (ESWRL) receive water from storm sewers draining nearby streets and commercial property and overland runoff from land immediately surrounding the lakes. Land that drains directly to the lake consists of cleared parkland and urban housing. Historically the ESWRL had high concentrations of total phosphorus (50 to 500 µg/L; Prepas and Hamilton, unpublished data), a result of drainage from urban areas. Since total phosphorus concentrations are positively related to algal biomass in most lakes (Schindler 1974), high phosphorus concentrations likely result in high algal biomass in the ESWRL.

Excessive algal blooms during the summer are a major concern for the area residents as there are numerous complaints about unpleasant odors and unsightly conditions. In previous years, the City of Edmonton has applied the herbicides copper sulfate or Reglone A to control algal blooms. The Province of Alberta no longer allows the application of copper sulfate to surface waters, and Reglone A is an expensive ($17/L; $108/ha) and unreliable method of algal control.

Under natural conditions, total phosphorus levels in hardwater lakes decrease in response to calcite formation and precipitation (Otsuki and Wetzel 1972, Murphy et al. 1983, and House et al. 1986). In British Columbia, the addition of lime ($Ca(OH)_2$) to a hypereutrophic lake resulted in decreased soluble reactive phosphorus concentrations (Murphy et al. 1988). In a hypereutrophic lake in northern Alberta (residence time > 4 yr)

[TP] and [Chl*a*] decreased dramatically following application of $CaCO_3$ and $Ca(OH)_2$ (Prepas et al. 1988).

The main objective of this research was to determine the response of total phosphorus concentrations and algal biomass in rapidly-flushed waterbodies, to lime application.

METHODS

Three lakes were monitored and treated with lime: Valencia Lake, Andorra Lake, and Beaumaris Lake. These lakes are located on the north side of the City of Edmonton and are connected by storm sewers to each other. A fourth lake, Burnewood Lake, is located on the south side of the City and has two stormsewer inlets. Burnewood Lake was monitored throughout the summer but was not treated with lime. The physical characteristics of the lakes and their drainage basins are listed in Table 1. Burnewood Lake differs from the other study lakes in two major ways: 1) it is younger (built in 1981), and 2) has a relatively undeveloped drainage basin. Due to these differences the quantity of materials (ie. nutrients and biomass) in Burnewood Lake are lower than in the other lakes; however, seasonal trends observed in each lake should be similar.

Collection and Analyses of Water Samples

Each lake was sampled 16 to 19 times between 10 May and 31 August 1988. Vertical profiles were collected at a main station located at the deepest site in the centre of each lake. On each visit, temperature data were collected at 0.5-m intervals from the surface of the lake to within 0.5 m of the lake bottom with a Montedoro-Whitney resistance thermistor accurate to 0.1°C. Light penetration was determined with a Secchi disk. Water for analysis of dissolved oxygen concentration was collected from 1.0 and 1.5 m at Andorra Lake and Valencia Lake and 1.0 and 2.0 m at Beaumaris Lake and Burnewood Lake, with a 1.5-L aluminum drop-sleeve water bottle. On every visit composite (0- to 1.5-m depth) water samples were collected from 10 sites at each lake with a weighted tygon tube and analysed for: total phosphorus ([TP]) and chlorophyll a ([Chla]) concentrations, alkalinity, color, conductivity, sulfate and major cations. Data presented (unless otherwise specified) are the mean values from the composite samples for the study period (May to August).

Dissolved oxygen concentrations were determined on duplicate water samples preserved in the field and analyzed within 24 h by Carpenter's (1965) modified Winkler technique. Water for [TP] analyses was transferred to culture tubes within 6 h of collection and analyzed within 1 wk, in duplicate, by the potassium persulfate method (Menzel and Corwin 1965). Conductivity was measured with a Metrohm E587 conductometer. Within 8 h of collection, water for determination of [Chla] was filtered under low pressure (-50 kPa) through a Whatman GF/C filter and the filters frozen. [Chla] was determined in triplicate within two weeks of collection with a spectrophotometric technique based upon the ethanol extraction technique of M. Ostrofsky described by Bergmann and Peters (1980).

Water for analyses of cations (sodium, potassium, calcium, and magnesium) was preserved with 10% nitric acid and filtered through a Whatman GF/C filter. The filtrate was analyzed on an atomic absorption spectrophotometer (mean of 15 readings per sample). The pH was measured with a Fisher Accumet Model 520 pH meter. Alkalinity was determined by the potentiometric titration method (APHA 1980). Color was determined visually after samples were centrifuged for 10 min on a Hazen platinum-cobalt scale with a Helige aqua tester model 611A. Sulfate concentration was measured by the turbidimetric method (APHA 1980).

Stormwater Sampling

Runoff in storm sewers entering the lakes could only be collected following heavy rainstorms. Channelized runoff from a total of five storm sewers entering Valencia Lake, Andorra Lake, and Burnewood Lake was sampled twice. On each occasion, one litre of water was collected every 15 min to 1 h for two to three days with ISCO automatic samplers. Isco samplers were placed in two inlets to both Andorra Lake and Valencia Lake, and one inlet to Burnewood Lake. These samples were analyzed for: [TP], major cations, conductivity, and pH, and treated as described for the lakewater samples.

Lime Application

Two forms of lime were applied to the stormwater lakes: calcium carbonate ($CaCO_3$) and calcium hydroxide ($Ca(OH)_2$). Effective dosage was calculated as: mass of lime per unit lake volume at normal water level. The form and dosage of lime applied to each lake are summarized in Table 2. Lime in the form of a slurry was applied evenly over the entire surface of the lakes. The application took from 1 to 10 h depending on the amount of lime applied and logistical considerations.

Effectiveness of lime treatments was evaluated by comparing [TP] and [Chla] measured within one week prior to lime application, to values found up to one week after these treatments. The statistical test used to determine significant differences was the Mann-Whitney test with unequal sample sizes (Snedecor and Cochrane 1967). Only TP and Chla values collected in July and August were used since natural Chla dynamics in May and June may be somewhat different than in July and August.

RESULTS

Throughout the summer, the ESWRL were weakly thermally stratified for short periods lasting up to 1 wk. With the exception of two dates (21 June-Beaumaris Lake; 27 June-Andorra Lake), dissolved oxygen concentrations were higher than 5 mg/L in the water column.

Average summer values for some water quality parameters measured in the ESWRL from the composite samples are listed in Table 3.

Stormwater Runoff

Heavy rainfall occurred four times from May to August 1988: 8 to 11 June; 18 June to 6 July; 6 August, and 21 August

(Figure 1). Rainfall in storm sewers was sampled on 5 to 6 July (96 mm of rain), and 18 August (15.8 mm of rain). The July stormsewer samples were collected at the end of a relatively wet period and the August samples were collected after a relatively dry period.

[TP] in the stormwater runoff was higher than in the receiving water during both rain events, and overall was higher during the first rain event than the second (Fig. 2). Conductivity levels and calcium concentrations ([Ca]) were extremely variable in the runoff and differed between the two sampling periods. During the first period, conductivity and [Ca] were lower in the stormwater runoff than in the receiving waters. In contrast, during the second event conductivity and [Ca] were higher in the runoff than in both the receiving waters and runoff measured during the first rain event.

[TP] increased in the lakes following both periods when runoff was sampled (Figure 3). Even though [Ca] was higher in the stormwater runoff than in the receiving water during the second rain event, [Ca] decreased in the lakes after this rain event (Figure 4).

Pre-Lime Conditions

[TP] was relatively low (less than 75 µg/L) in Burnewood Lake throughout the summer; peak [TP] occurred on 5 July and 13 July following an exceptionally heavy rain event. Average [TP] was much higher in Valencia, Andorra, and Beaumaris lakes (100 to 250 µg/L) than in Burnewood Lake (37 µg/L).

[Chla] was extremely variable in all lakes (Figure 5). In Burnewood Lake, mean [Chla] was 11.2 µg/L; maximum [Chla] was recorded on 13 July (53 µg/L) following the heavy rainfall event. In the two months prior to the first lime treatments, [Chla] decreased in Andorra Lake (from 200 to 22 µg/L), increased in Valencia Lake (from 7 to 50 µg/L), and fluctuated in Beaumaris Lake (between 22 and 93 µg/L).

Calcium concentrations fluctuated in all of the lakes prior to lime treatment. All four lakes showed a pattern of generally higher [Ca] in May and June than in July and August.

pH was generally lowest in Burnewood Lake and ranged between 8.0 and 9.1. Prior to liming, pH in the other lakes fluctuated: Andorra 8.9 to 9.5; Beaumaris 8.4 to 9.2 ; and, Valencia 8.3 to 9.2.

Sulfate concentrations in the ESWRL were extremely high (mean summer values ranged from 206 mg/L in Burnewood Lake to 415 mg/L in Beaumaris Lake). As with calcium concentrations, sulfate levels were higher in all lakes during May and June, than in July and August. Color varied between the lakes; Beaumaris Lake was the most colored (34 mg Pt/L) and Burnewood Lake was the least colored (9.1 mg Pt/L).

Effects of Lime Treatment

The first lime treatments in Andorra Lake (27 June) and Beaumaris Lake (29 June) were followed by unusually heavy rainfall. The water level in both lakes rose above the high water level (Table 1). The large volume of water flowing through these two lakes removed most, if not all, of the lime that was added within one to two days of treatments. As well, the lakes received an inordinate amount of [TP] from the runoff. Flushing plus high [TP] loading neutralized any possible short-term effects of these two lime treatments. Thus, the discussion of the results of lime treatment is based on the six treatments (Table 2) that were not followed by heavy rainfall.

Within 2 to 7 d after each of the six treatments, [TP] decreased in the open water in the three lakes (Fig. 3). Mean decreases in [TP] in Valencia Lake, Andorra Lake, and Beaumaris Lake were 47, 47 and 11%, respectively. [Chl*a*] decreased from pre-treatment levels after four of the treatments. In Andorra and Beaumaris lakes, [Chl*a*] decreased 87 and 45%, respectively, following the second treatment and increased 21 and 50%, respectively, after the third treatment (Fig. 5). In Valencia Lake, [Chl*a*] decreased 59 and 82% after the first and second treatments, respectively.

When only $CaCO_3$ was added no significant decrease in [TP] or [Chl*a*] was observed ($T=5$ and 8, respectively, with $n_1=2$ and $n_2=6$ for both tests; $P>0.05$). When at least 50 mg/L $Ca(OH)_2$ was applied to the lakes (with or without $CaCO_3$), there was a significant decrease in both [TP] ($T=18$ $n_1=4$, $n_2=13$; $P<0.05$) and [Chl*a*] ($T=16$ $n_1=4$, $n_2=13$; $P<0.05$).

Secchi disk depth also responded to the lime treatments; in Andorra and Valencia lakes average Secchi disk depth increased an average of 160 and 100%, respectively, after lime treatment. In Beaumaris Lake, Secchi disk depth was unchanged after the second treatment and decreased by 25% after the third treatment.

From pre-lime conditions, pH increased in Andorra Lake, Valencia Lake and Beaumaris Lake 0.8, 0.8, 0.6 pH units, respectively. Detailed short-term changes in pH were monitored once during the summer. A surface grab sample from Valencia Lake revealed a pH of 9.2 immediately before treatment on 5 August. Immediately after treatment, the pH increased in another surface grab sample to 9.8 and then to 10.7 the following day. Two days after the treatment, pH was 10.3 and it further declined to 9.7 on the third day after treatment.

Changes in alkalinity were associated with pH changes. Although there were no systematic increases or decreases in total alkalinity levels associated with lime treatments, carbonate alkalinity increased after every addition of lime. As well, hydroxide alkalinity was only detected after the second and third lime additions in Andorra Lake and after the second lime addition in Valencia Lake.

With the exception of the first treatment of Valencia Lake, calcium concentration increased after every lime treatment. Lakes treated with $Ca(OH)_2$ (Andorra Lake and Valencia Lake) had larger average increases (37%) than were associated with the $CaCO_3$ treatment of Beaumaris Lake (4%). Sulfate concentrations remained relatively constant in Valencia Lake after both treatments, increased in Andorra Lake and Beaumaris Lake after the second treatment, and decreased in these same two lakes after the third treatment. Thus, there is no evidence that lime treatments affected sulfate concentrations in the short-term.

DISCUSSION

Edmonton stormwater retention lakes have extremely dynamic nutrient regimes. This variability is caused by differences in land use in the drainage basins. For example; Burnewood Lake is in a relatively undeveloped area and as such, receives lower nutrient loads during rain events than the other lakes. Thus the nutrient and biomass levels in Burnewood Lake are much lower than in the other lakes.

Heavy rainfall removed the lime added to Andorra Lake and Beaumaris Lake in June. Thus, any effects of the lime applications were not discernable. The following discussion is limited to the six treatments that were not followed by such heavy rainfall.

Application of lime ($CaCO_3$ and/or $Ca(OH)_2$) resulted in decreased [Chl<u>a</u>] within one week after four of the six applications in three different lakes. When $Ca(OH)_2$ was applied (with or without $CaCO_3$) at a dosage of 50 mg/L or more, [Chl<u>a</u>] and [TP] decreased significantly. When only $CaCO_3$ was used there were no significant changes in either [TP] or [Chl<u>a</u>] . Similar studies in limnocorrals (J.T. Lim, Univ. Alta., unpublished data) demonstrated that a minimum dosage of 75 mg/L $Ca(OH)_2$ was needed to ensure a decrease in [Chl<u>a</u>].

Calcite formation and precipitation in lakes causes a decrease in [TP] (Murphy et al. 1983; Koschel et al. 1983; House et al. 1986) and organic matter (White and Wetzel 1975). These decreases are caused by adsorption of phosphate or organic matter onto the calcite particles. There is an inverse relationship, for a given mass of calcite, between calcite size and the amount of adsorption.

$Ca(OH)_2$ is more effective than $CaCO_3$ at reducing [TP] and [Chl<u>a</u>]. One explanation for this is that $Ca(OH)_2$ dissociates and forms $CaCO_3$:

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O \qquad (1)$$

These newly formed calcite crystals are small and present a relatively large surface area for adsorption. Associated with the adsorption of phosphate on calcite is the molecular exchange of CO_3^{-2} and PO_4^{-3} on the surface of growing calcite crystals. Ishikawa and Ichikuni (1981) describe the chemical reaction between carbonate and phosphate:

$$3CO_3^{-2}(S) + 2PO_4^{-3}(L) \rightleftharpoons 3CO_3^{-2}(L) + 2PO_4^{-3}(S) \qquad (2)$$

where S and L denote calcite and aqueous phases, respectively. According to equation (2) the rate of exchange between phosphate and carbonate is dependent on the ambient concentration of both phosphate and carbonate. By increasing the concentration of carbonate (eg. by liming with hydroxide), the equilibrium is shifted to the right and phosphate is precipitated out in calcite crystals.

In conclusion, lime treatments ($Ca(OH)_2$) look promising as a method for short-term control of algal biomass and nutrient levels in the ESWRL. In contrast, $CaCO_3$ does not appear to be a reliable method of algal and nutrient control in fast-flushing waterbodies.

Lime application may develop as a cost- and environmentally-effective alternative to traditional herbicides; however, ongoing treatments will be required throughout the growing season. If nutrient loading can be controlled or decreased, effects of lime application would be enhanced over a longer period. Furthermore, the long-term effects of lime application on algal biomass and total phosphorus levels in these fast flushing systems need to be examined.

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Table 1. Physical measurements of the Edmonton Stormwater Retention Lakes: normal water level (NWL), high water level (HWL), Surface area (A_o), volume, maximum design depth (Z_m), drainage area (A_d), number of stormwater inlets (In).

Lake	NWL			HWL				
	A_o (ha)	Volume ($m^3 x 10^3$)	Z_m (m)	A_o (ha)	Volume ($m^3 x 10^3$)	Z_m (m)	A_d (ha)	In
Valencia	2.8	49	2.0	3.7	91	3.6	62	4
Andorra	2.0	31	2.1	3.0	66	4.5	72	5
Beaumaris	13.8	310	2.4	16.2	561	4.3	619	5
Burnewood	3.8	76	3.1	5.0	147	5.3	57	2

Table 2. Lime application dates and dosages to the Edmonton Stormwater Retention Lakes, 1988.

Lake	Date	Amount $CaCO_3$ Tonne	Amount $Ca(OH)_2$ Tonne	Effective Dosage $CaCO_3$ (mg/L)	Effective Dosage $Ca(OH)_2$ (mg/L)
Andorra	* June 27	0.8	0.8	25	25
	July 21	3.2	3.2	102	102
	Aug 25	1.6	1.6	50	50
Valencia	Aug 5	---	3.7	---	75
	Aug 29	---	3.7	---	75
Beaumaris	* June 29	17	---	55	---
	July 22	16	---	52	---
	Aug 22	32	---	103	---

*- dates of lime application followed by heavy rains

Table 3. Average summer ($\bar{X}$) and standard error (SE) for some parameters measured in the Edmonton Stormwater Retention Lakes from May to August 1988.

	ANDORRA		VALENCIA		BEAUMARIS		BURNEWOOD	
	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE
TP (ug/L)	168	16.5	112	9.14	247	11.6	37.9	4.15
Chl*a* (ug/L)	58.3	11.0	32.7	5.14	66.7	9.14	11.2	3.17
Secchi disk depth (cm)	42.0	5.80	57.1	5.54	55.9	5.76	161	25.4
Ca (mg/L)	62.5	2.88	67.3	4.71	82.3	7.63	57.4	4.42
Sulfate (mg/L)	343	21.5	371	34.1	415	46.3	206	16.8
Conductivity (us/cm)	809	46.5	925	67.5	969	79.6	655	37.9
colour (mg Pt/L)	18.9	2.9	12.2	1.27	34.4	4.76	9.16	1.62

LIST OF FIGURES

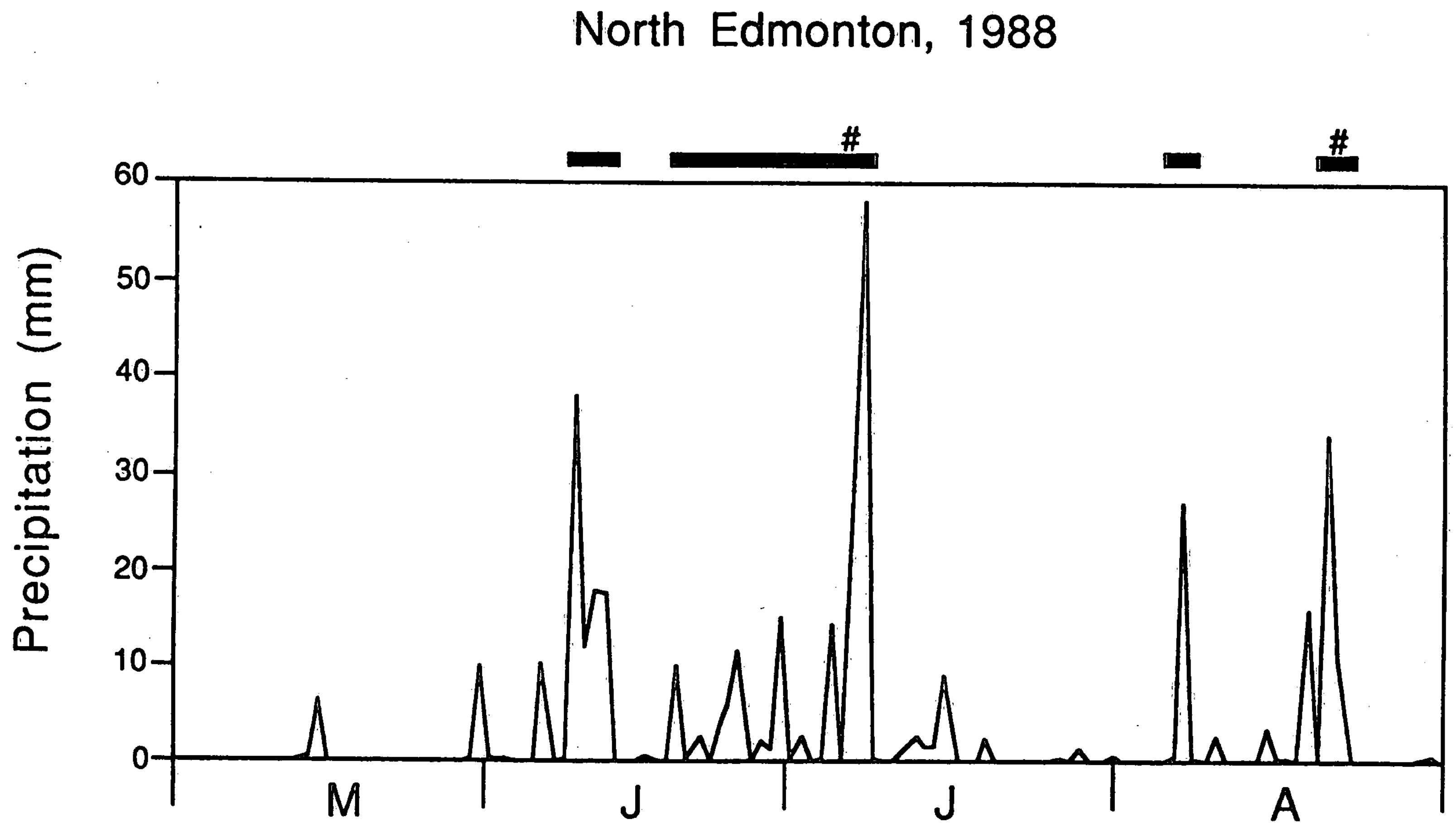


FIGURE 1

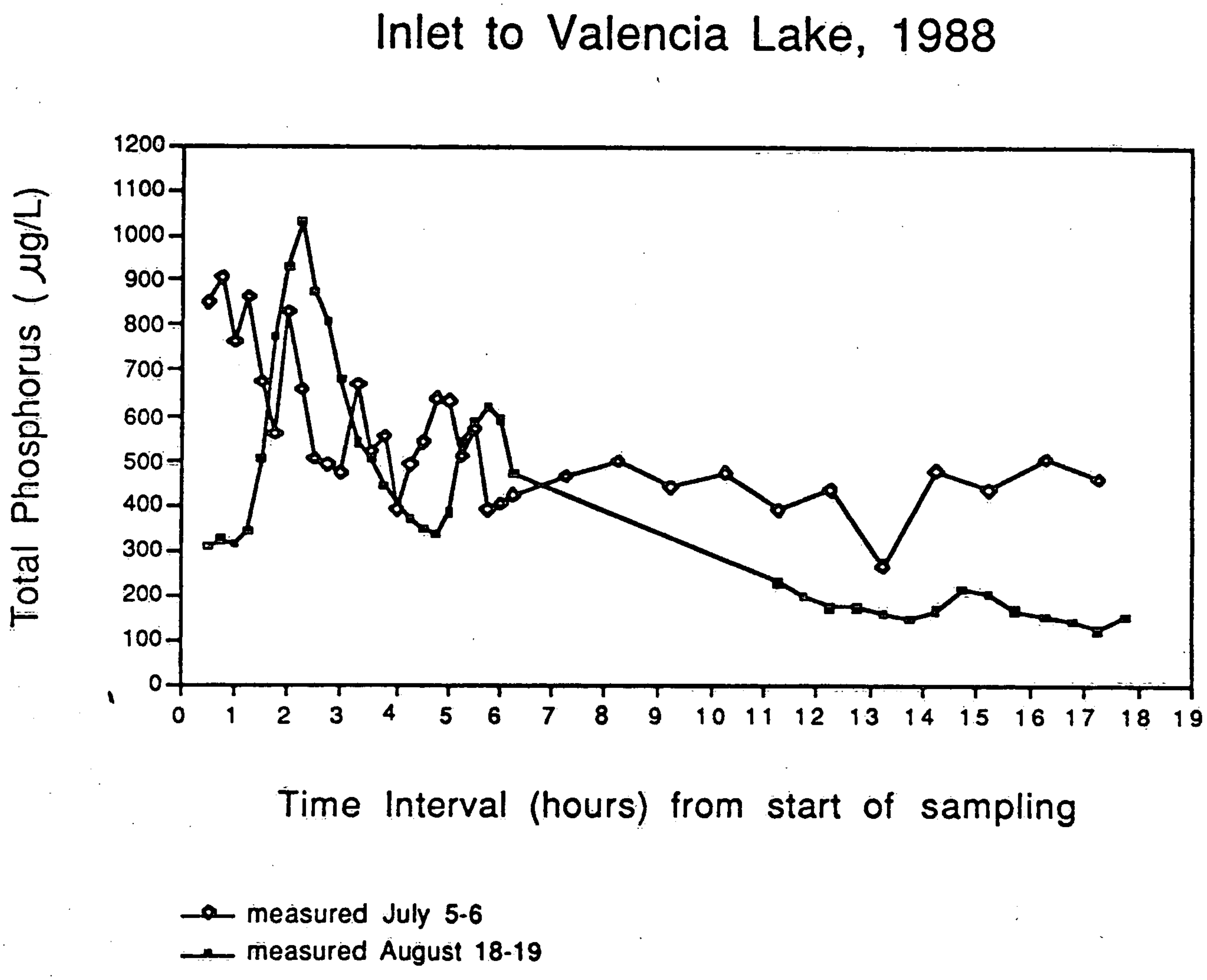
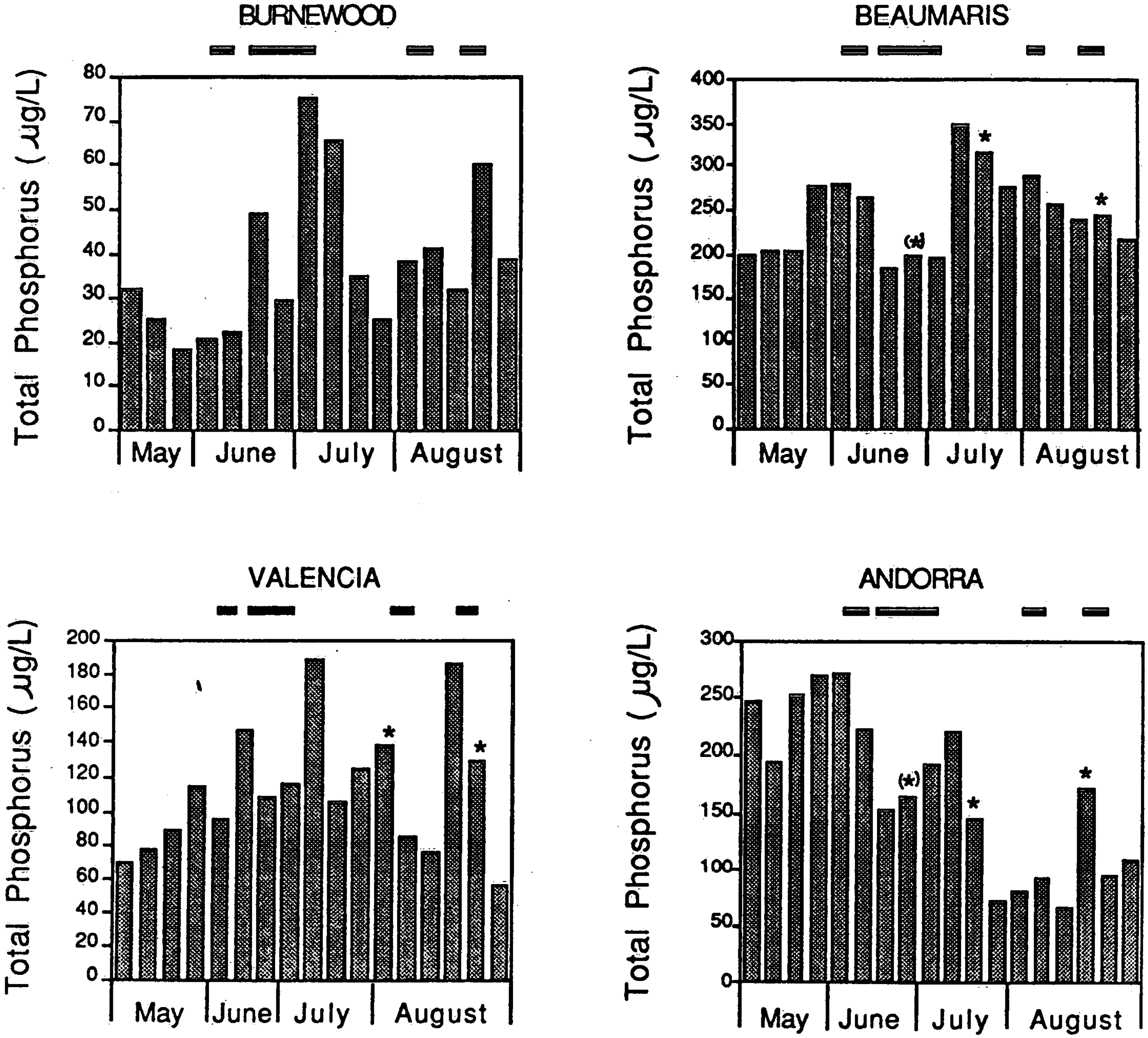

Inlet to Valencia Lake, 1988
Total Phosphorus (µg/L)
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
Time Interval (hours) from start of sampling
measured July 5-6
measured August 18-19

FIGURE 2

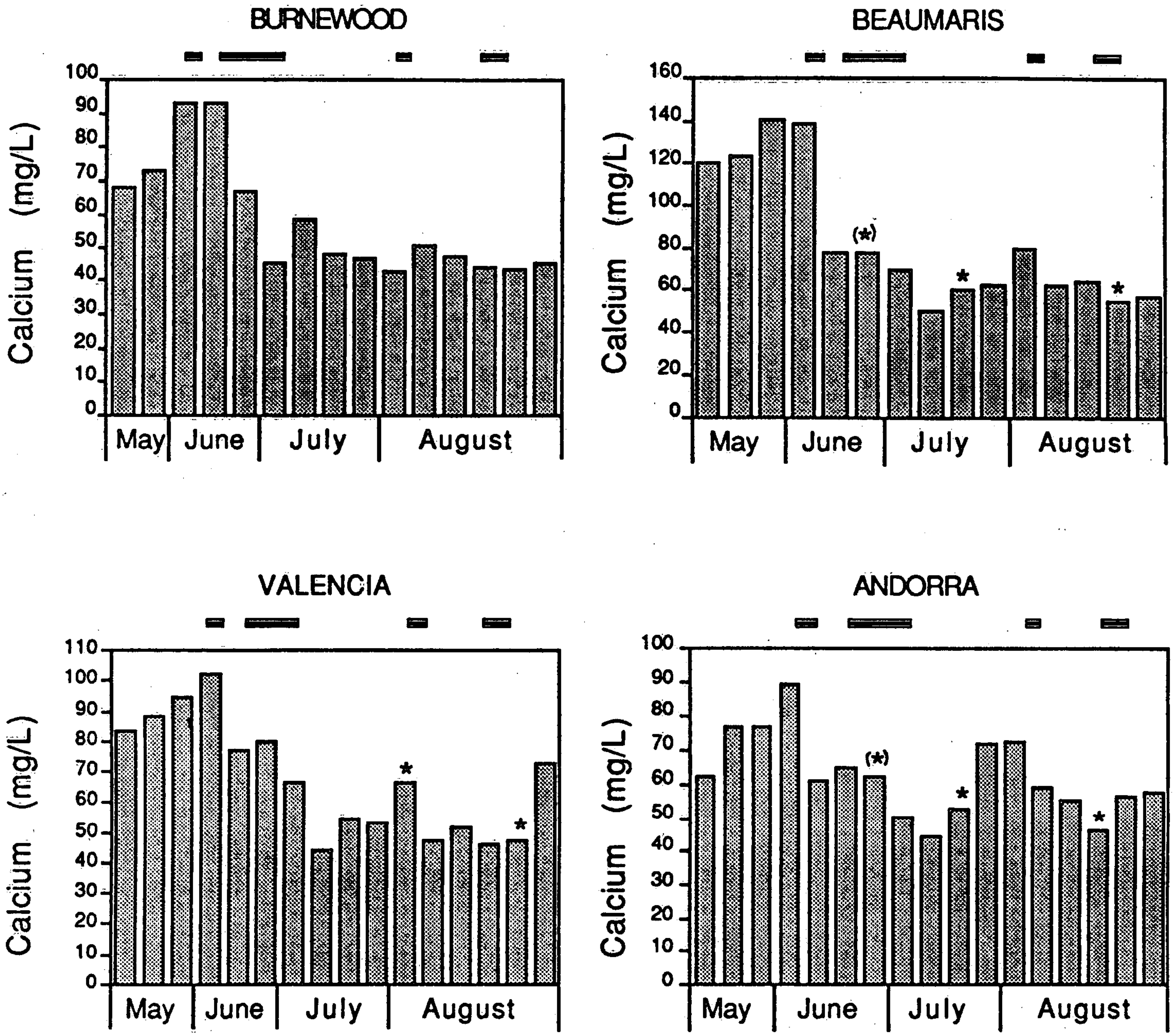
Edmonton Stormwater Retention Lakes



1988

FIGURE 3

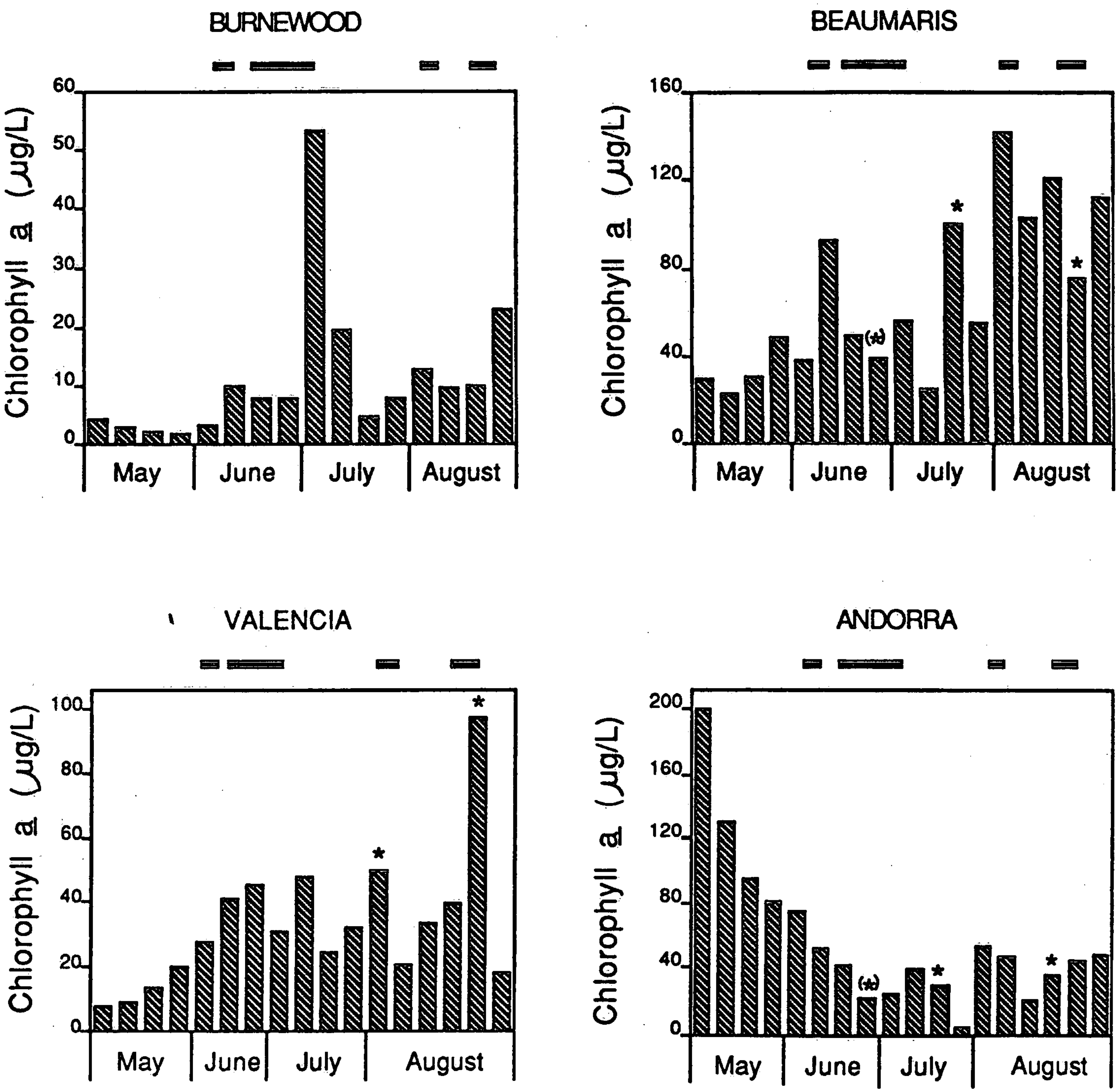
Edmonton Stormwater Retention Lakes



1988

FIGURE 4

Edmonton Stormwater Retention Lakes



BURNEWOOD

BEAUMARIS

VALENCIA

ANDORRA

1988

FIGURE 5