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THE EFFECTIVENESS OF
A STORMWATER DETENTION POND
IN ENHANCING WATER QUALITY

By

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A Research Paper
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in Fulfillment of the Requirements
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ABSTRACT

This paper is an introductory study on the ability of a detention pond to reduce pollutant loading to a receiving water body. Three forms of water pollution are analysed in this study, trace metal (V, Ti and Mn in the water and on suspended solids and bottom sediments), organic and bacterial (bacterial indicators of fecal coliform and fecal streptococci are utilized) pollutants. Each pollutant type requires a different form of analysis to obtain concentrations for targeted pollutants. V, Ti and Mn concentrations were obtained from Instrumental Neutron Activation Analysis (INAA), organic concentrations were acquired by Electron Capture Gas Chromatography (ECGC) and bacterial concentrations were obtained from various laboratory techniques performed by technicians in the Microbiology Lab at McMaster University and in the Provincial Health Laboratories in Hamilton, Ontario. Suspended solid concentration are also analysed to determine the pond's effectiveness in reducing suspended solids load and thus the pollutants they carry. The Storm Water Management Model was used to estimate total pollutant loading into the pond via a combined sewer overflow (CSO). The pollutant concentrations obtained were analysed spatially through the sampling network and temporally between sampled dry and wet weather periods. The result of this study has led to the disturbing conclusion that the detention pond appears to have little or no effect on enhancing water quality.

ACKNOWLEDGEMENTS

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DEDICATION

This thesis is dedicated to
my parents for their support
and encouragement throughout my life.

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CHAPTER 1

1.1 INTRODUCTION

Problems of water pollution have been well documented. Early research focused on point sources of pollution such as chemical dumps and heavy industry. More recently, however, the importance of non-point sources has been investigated (Whipple and Hunter, 1977; Ammon, 1979; Malmquist, 1983). Much emphasis has been given to suspended solids which are a transport mechanism for pollutants such as trace and heavy metals, organics and bacteria.

One aspect of water treatment is to remove the suspended solids, thereby removing other harmful pollutants. Within older cities in North America, however, much of the stormwater bypasses treatment plants as a result of combined sewer overflow (CSO). A CSO occurs when the volume capacity of the sewer is exceeded and excess water flows into the natural environment. Stormwater detention ponds, originally intended for flood control, have been found to provide adequate pollution control for non-point source pollution arising from CSO (Smith and Asce, 1982). This is a result of their ability to retain water long enough for sedimentation of sands and silts to occur. It is the purpose of this study to determine the effectiveness of a stormwater detention pond in enhancing water quality.

1.2 OBJECTIVES

There were 3 objective to this research.

1. To determine the effectiveness of the pond in reducing trace metal pollutant loading.

2. To determine the effectiveness of the pond in reducing organic pollutant loading.

3. To determine the effectiveness of the pond in reducing bacterial pollutant loading.

1.3 LITERATURE REVIEW

The role of stormwater detention ponds in reducing water pollution through sedimentation has been well documented (Asselstine, 1985; Ferrara et al, 1983; McCuen, 1980; Michaels et al 1985; Miyanoto and Heinke, 1979; Randall, 1982; Randall et al, 1982; Smith and Asce, 1982). A stormwater detention pond is a planned urban water body, permanent or temporary, man-made or natural, which has storm runoff as its principal water source (Michaels et al, 1985). Detention ponds provide flood contol by retaining and attenuate flows: they also provide pollution control by ponding the flow long enough for physical and/or biochemical processes, such as sedimentation, adsorption and ion exchange to occur (Smith and Asce, 1982).

1.3.1 POLLUTANT INPUTS AND LOADING

The primary input of pollution into many urban stormwater detention ponds is from CSO carrying non-point pollution sources such as runoff from lawns, streets, playing fields, gravelled parking lots, industrial land and railway land (Irvine et al, 1987). A combined sewer is one where sanitary and storm water flow in the same pipe. Generally, urban runoff and CSO discharges occur when the infiltration capacity of the ground and the transport capacities of the drainage system are exceeded as a result of a high intensity rainfall (Smith and Asce, 1982). The CSO may contain non-point source pollution (surface runoff) and/or point source pollution from major institutions such as hospitals or industrial complexes. CSO quality characteristics depend on the relative volumes of wastewater and urban surface runoff.

The amount and type of pollutants that are settled out of suspension depend on the particle size distribution and specific gravity (Randall, 1982; Smith and Asce, 1982). Ferrara et al (1983) has shown that detention ponds are useful in decreasing concentrations of suspended solids, chemical oxygen demand and total phosphorous, but increase total Kjeldahl nitrogen concentratons and loading. Randall (1982) also showed by laboratory experiment that detention ponds reduce biochemical oxygen demand, and the concentrations of hydrocarbons (organics) and four heavy metals (lead, zinc, copper and nickel). Many dissolved particles (less than 0.45um), however, stay in the water column and pose a major problem for water quality.

Pollutant loading (ie. pollutant added to a volume of water mg/l) is a function of, among other things, volumetric flow rate (a function of catchment size), time from the last storm, time from the beginning of the storm, time from the last peak in concentration, time of day and the time of year (Klemetson, 1985). These factors afeect pollutant loading of receiving water bodies primarily by varying the suspended solid load of the combined sewers and/or overland flow.

1.3.2 SUSPENDED SOLIDS AND ASSOCIATED POLLUTANTS

Generally, it is the suspended solids which are the principle pollutants as they carry many other pollutants. About 80% of the sediment reaching the waterways of the United States arises from cropland, highways and urban construction sites (Dong et al, 1983). The majority of sediment which reaches waterways tends to be in the silt and clay fraction because the larger particles (sand) are deposited out. After reaching the waterways, the finer materials stay in suspension longer, allowing dissolved pollutants to adsorb onto the particles' surface (Dong et al, 1983). Pollutants which seem to have a high affinity for adsorption on suspended particles are phosphorous, heavy and trace metals, and petroleum based organics.

The relationship of particle size to pollution content has been studied extensively (Ackermann et al, 1983; Ongley et al, 1981; DeGroot et al, 1982; Dong et al, 1983; Whipple and Hunter, 1981; Randall et al, 1982; Irvine et al, 1987), however, there is great controversy as to which grain size adsorbs the greatest amount. Trace metals and organic compounds [such as hydrocarbons, polycyclic aromatics and polychlorinated biphenyls (PCB's)] have a high attraction for adsorption on and transport by finer particles. Ackermann et al (1983), have found that there was less metal concentration variability in a < 20um fraction than in larger fraction ranges. Ongley (1981) suggested that although the larger size particles may have reduced quantities of pollutants, they become significant if they comprise the bulk ofosuspended and bottom sediment. It is important, therefore, to determine the pollutant concentration of the complete particle size distribution.

1.3.3 ORGANIC POLLUTANTS

Many organic contaminants (such as PCB and DDT) enter natural waters from non-point sources, such as agricultural and urban land, solid waste disposal sites, and in rain and snowfall. Recently concern has shifted to halogenated organics produced by the chlorination of wastewater and drinking water to prevent microbial contamination (Pfaender, 1977). Halogenated organics are carbon atoms which have bonded with fluorine, bromine, chlorine or iodine (Fessenden and Fessenden, 1979) and generally represent man-made pollutants since the covalent carbon halogen bond does not occur in nature (except for iodinated thyroid hormones) (Rosenfeld, 1987). Andelman (1973), has shown a strong relationship of trace elements to organics. The organic compounds influence the trace elements solubility, their sorption on suspended and bottom sediments, and their uptake by biota (Andelman, 1973). Unfortunately, these trace metals and organic pollutants can enter the food chain and become concentrated in higher trophic members. This is particularly true for the persistant organic contaminants such as DDT and PCB which are relatively resistant to physical or metabolic degradation (Canale, 1977).

1.3.4 BACTERIAL POLLUTANTS

Bacteria have long been recognized as a pollution problem. The more urbanized an area is, the higher are the fecal coliform and fecal streptococci counts within the environmental waters (Davis _et al_, 1976). The release of fecal pollution into water can introduce a wide variety of intestinal pathogens (Dart and Stretton, 1980). Randall (1982) found through laboratory experiments that there was no reduction in fecal coliform counts after sedimentation. However, Davis _et al_ (1976) found that the ratio of fecal coliform to fecal streptococci was much lower for the effluent of a lake than in an adjoining lower tributary and attributed this to sedimentation resulting from the impoundment of the water during storm events. Dart and Stretton

(1980) stated that when there is a discharge of bacterial polluted water into a lake, bacteria adsorb onto particles and deposit out, or are ingested by protozoa. Lakes and their impounding effects appear similar to detention ponds.

1.3.5 THE LIMITATIONS OF STORMWATER DETENTION PONDS

Although there is extensive evidence for detention ponds reducing pollutant loads, there is also evidence for their variability in effectiveness. Asselstine (1985) reported that the loads of water pollutants were not affected by ponds, or were even increased through ponds over sample periods. Andelman (1973) found that the trace and heavy metals often had great variation (both temporally and spatially) occurring in unsystematic and unpredictable fashions.

This variability in the effectiveness of stormwater detention ponds in enhancing water quality is a result of many factors, all of which are site specific. These include discharge variations, detention time, mixing ability, depth, air and water temperature changes and pH changes. A detention pond may fail to enhance water quality if its geometric and morphological design is poor. Generally, the shallower a pond is (without scouring occurring) the better. The optimal size of the pond may depend on site specific parameters such as the maximum volume of flow and on suspended solids carried.

Detention time is very important. Settling is rapid in the initial detention period, and becomes progressively less over time. Heinke et al (1977) found that most settling occurs within 45 minutes without chemical addition, while the rate of water leaving the pond has little effect. Mixing within the pond can enhance flocculation and thus settling rate (Heinke _et al_, 1977).

1.3.6 CONCLUSION

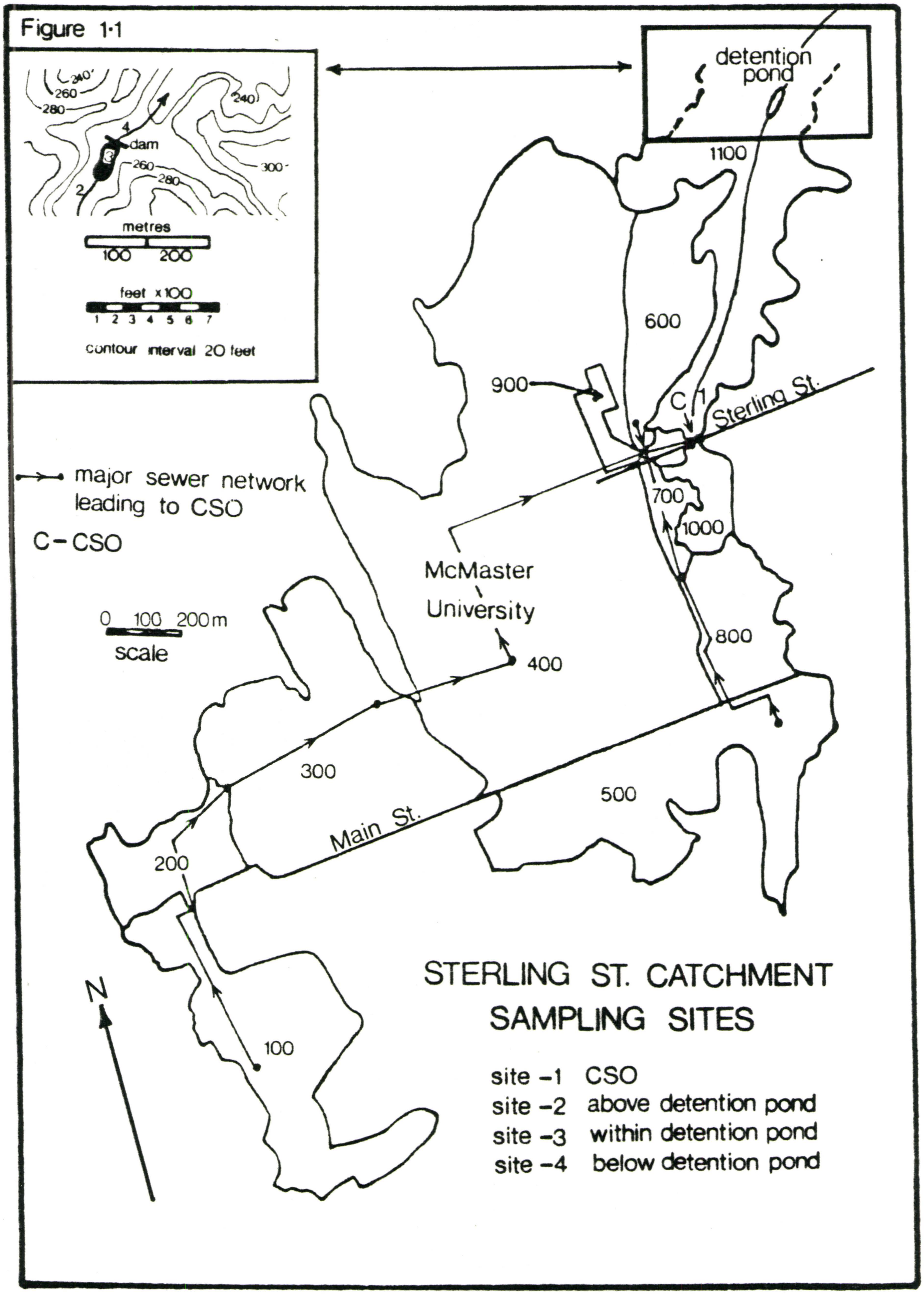
Stormwater detention ponds can be an effective means of enhancing water quality. Detention ponds appear to control non-point and/or point source pollution resulting from surface runoff and/or CSO. Through the sedimentation of suspended solids, trace and heavy metals, organics and some bacteria can be removed from the water column. However, detention ponds can be variable in their ability to enhance water quality, depending on geometric and morphological design. They have little or no effect in removing dissolved solids (pollutants). Stormwater detention ponds therefore appear to be valuable contributors in reducing water pollution as long as their design is optimized for targeted pollutants.

CHAPTER 2

2.1 STUDY AREA

The stormwater detention pond is located within the Westdale Creek ravine in the Royal Botanical Gardens (RBG) behind McMaster University in Hamilton, Ontario, Canada (Figure 1.1). The Westdale Creek catchment is 1.09 Km^2 Land use within the catchment is predominantly low to medium density, single family residential with some institutional (ie. McMaster University and Medical Centre), commercial and light industry present. Single family residential land backs the Westdale ravine. The detention pond receives water via overland flow and by CSO from a structure under Sterling Street (Figure 1.1) and may be seen in Figure A1.1. The primary combined sewer network connecting the catchment to this overflow structure may be seen in Figure 1.1. In order to combat the poor water quality characteristics in Cootes Paradise and the Hamilton Harbour, the Municipality of Hamilton Wentworth created the stormwater detention pond in June, 1985 by damming the Westdale Creek (Figures A1.2 and A1.3).

Figure 1·1



STERLING ST. CATCHMENT SAMPLING SITES

CHAPTER 3

3.1 FIELD METHODS

The field program was developed to gather data on trace metal, organic and bacterial pollutants above, in and below the Westdale Creek detention pond. Samples were taken in the summer of 1986 for both wet and dry weather flows in the ravine. Core samples of bottom sediments were also taken. Temperature and pH levels were recorded for each sampling period using a thermometer and a digital Cole-Parimer pH meter with an accuracy of 0.1°C and 0.01 pH units respectively. (Temperature and pH raw data may be seen in Table A2.11).

3.1.1 WATER SAMPLES

Water samples were taken at four sites as shown in Figure 1.1 and are summarized in Table 3.1. Water samples were taken in sterile 500ml and 80ml plastic bottles for trace metal and bacterial analysis respectively and in sterile litre glass bottles for organics. Only one sample was taken for each site and each sampling event for trace metal and bacterial analysis. Organic pollutants were sampled over ten minute intervals from the start of the CSO at site 1, 2 and 4. Approximately 200ul of nitric acid was added to the trace metal water samples prior to the freezing of samples to avoid contamination. Bacterial samples were immediately delivered to the Microbiology Lab at the McMaster University Medical Centre.

3.1.2 BOTTOM SEDIMENTS

Bottom sediments were sampled using a Livingston Deep corer. Cores were wrapped in cellophane and aluminum foil and frozen as soon

TABLE 3.1

DATE	WEATHER CONDITIONS	ANALYSES FOR DATE AND SITE SITE 1			SITE 2			SITE 3			SITE 4		
		M	O	B	M	O	B	M	O	B	M	O	B
May 29/86	Dry	x		x	x		x	x		x	x		x
July 17/86	Wet			x			x			x			x
July 25/86	Dry	x			x			x			x		
Aug. 7/86	Wet	x	x		x	x		x	x		x	x	
Oct. 3/86	Wet	x			x			x			x		

M = trace metal analysis
O = organic analysis
B = bacterial analysis

as possible to avoid contamination. One core was taken from the stream above and below the pond. Two were taken within the pond from a high and low flow area.

3.2 LABORATORY METHODS

3.2.1 TRACE METALS

Water samples were thawed and filtered on 0.45um Millipore filter paper to remove suspended solids. Two wet weather flow samples from August 7, 1986 sites 3 and 4 were fractionated into sand (62um), silt (5um), and clay (0.45um). Filters were desiccated for 48 hours and weighed to determine the total suspended solids load and grain size distributions where applicable. Filters were then sealed in plastic petri plates. The remaining water was refrozen for later analysis.

Cores were broken into their various strata and representative samples were taken. These samples were filtered into 2 grain size ranges, those between 0.45um and 20um and those between 20um and 1.4mm. Samples were dry seived through a 1.4mm metal mesh seive and then wet seived through a 20um Nitex filter sheet, followed by a 0.45um Millipore filter in order to get the two ranges. The division of 20um was used as a result of the findings of Ackermann et al. (1983).

Water, suspended solids and bottom sediment samples were all analysed for Ti, V and Mn concentrations in the McMaster University nuclear facility by Instrumental Neutron Activation Analysis (INAA) (Landsberger et al 1985). All samples were placed in acid washed plastic vials and passed through the core of the reactor via a pneumatic tube system. In the case of the bottom sediments ranging in size from 20um to 1.4mm, 0.1g of sediment was scraped off the filters and into vials. For suspended solids and for bottom sediments ranging in size from 0.45um to 20um, the filters and sediment were both placed in vials. In order for this to be done, filters had to be dampened with deionized distilled water.

3.2.2 ORGANICS

All analysis was carried out in the Central Analytical Laboratory at McMaster University Medical Centre under the supervision of Dr. J. Rosenfeld of the Department of Pathology. Organic concentrations within filtered water samples were determined by electron capture gas chromatography (E.C.G.C.) (Dressler, 1979; Stepan and Smith, 1977; Poole and Schuette, 1983). Approximately 500ug of pentafluorobenzyl pentadecanoate (PFB-PD) was added as a standard and 2.5ul of the prepared environmental solution was injected onto a Hewlett Packard 5710A E.C.G.C. The initial oven temperature was set at 140^{o}C with a rate of 8^{o}C per minute until 300^{o}C, where it held for 4 minutes. The resultant peaks represent halogenated organic contaminants which were printed out on a Hewlett Packard 3392A Integrator.

3.2.3 BACTERIA

Qualitative analysis was performed in the Microbiology Lab at the McMaster University Medical Centre. Quantitative analysis was performed at the Provincial Health Laboratory in Hamilton, Ontario. The most probable number test was used to count bacteria. This is dependent on the presence of live bacteria and has an error of +/- 5 to 10%.

CHAPTER 4

4.1 RESULTS

Stormwater detention ponds enhance water quality primarily by reducing the concentration of suspended solids (SS) within stormwater. The reduction of SS results in the reduction of pollutants, as many pollutants (trace metals, organics and bacterial) have a high attraction for adsorption onto SS (Ackermann, 1983). A detention pond can only be effective if no bottom scouring occurs and if water retention time is adequate. If bottom scouring is prevented the input of SS (and pollutants) into the water column is limited. Within the Westdale detention pond, however, bottom scouring does occur. Two cores taken in approximately the same area two months apart revealed very different stratifications, indicating a high energy system that erodes bottom sediments. Retention time is also estimated to be far less than the adequate 45 minute period specified by Heinke et al (1977). Bottom scouring in conjunction with low retention time has resulted in an increase in SS concentration and pollutants below the pond. Data obtained from the RBG (Table A2.1) confirm this result, as do the SS concentration data obtained from water samples in this study (Figure 4.1). Three of the four dates sampled showed an increase in SS concentrations.

4.2 METALS

A simulated hydrograph of the CSO (Figure 4.2) was produced by modeling the August 7 storm event with the Storm Water Management Model (SWMM). By determining the total discharge from the CSO and multiplying it by the trace metal pollutant concentrations an

Figure 4.1

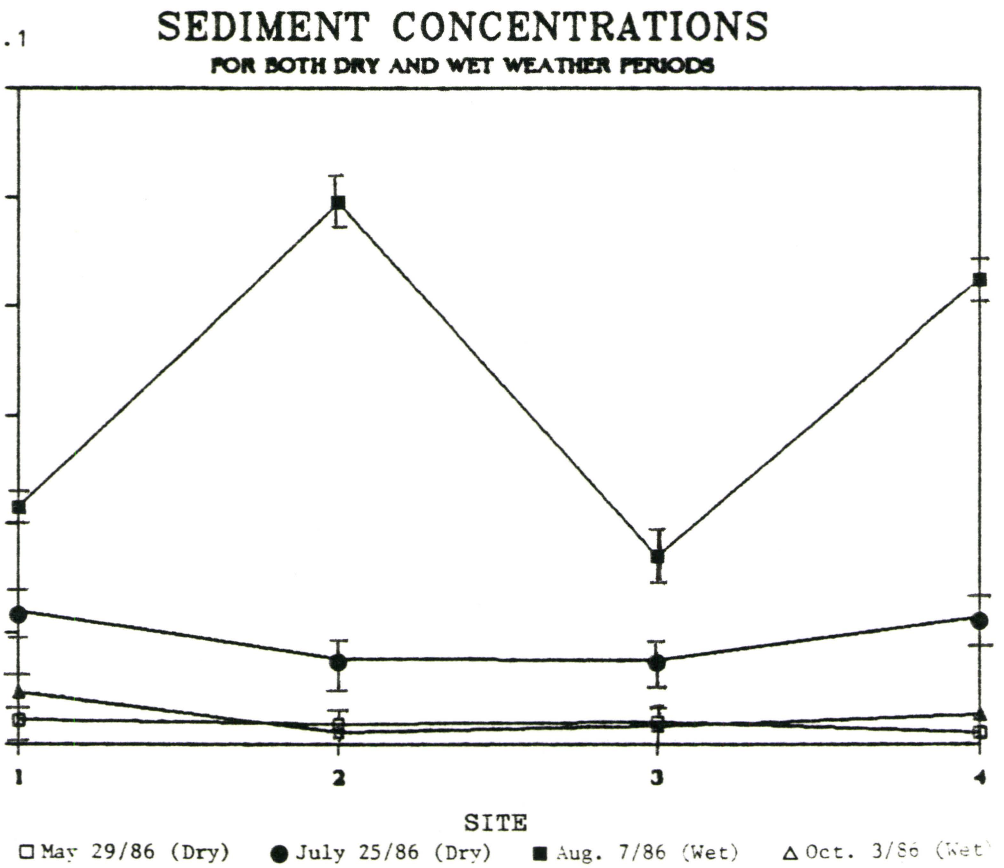
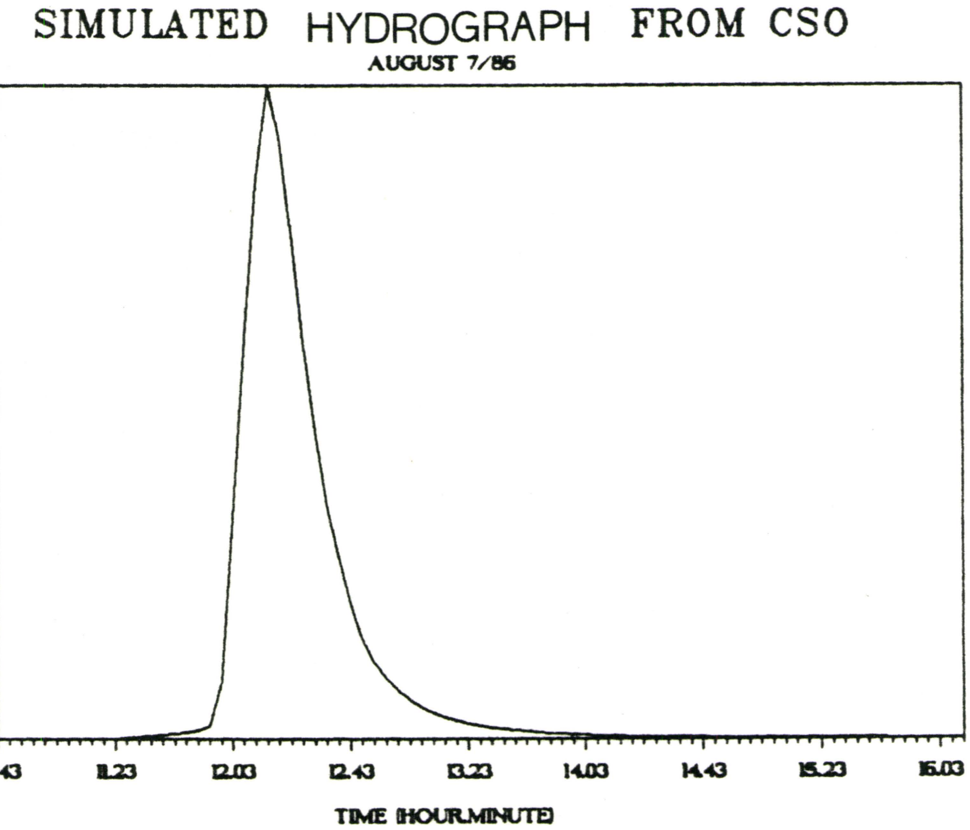


Figure 4.2



estimated total pollutant loading (tonnes/day) to the detention pond from the CSO was calculated. Pollutant loading values for SS, V, Mn and Ti may be seen in Table A2.2 and show that the SS provide a much greater pollutant load than water. This provides good support for the use of detention ponds in reducing SS concentration through sedimentation.

4.2.1 WATER

Mn and V concentrations showed extensive variability both through the system and between events (Figures 4.3 - 4.4). Ti concentrations were often below detection and were therefore not plotted. Raw data are given in Tables A2.3 - A2.5. The environmental impact of Mn is not known as no natural Mn concentration value was found in the literature.

The detention pond reduced concentrations and therefore, enhanced water quality for Mn on July 25 but not on May 29 (both are dry weather periods) (Figure 4.3). For V the opposite occurred, the pond enhanced water quality on May 29 but not on July 25 (Figure 4.4). Error values for V from the May 29 and July 25 sampling periods were large relative to the concentrations, and thus this result is not conclusive. V concentrations leaving the pond for these dry weather periods are below the typical natural value of 1ppb (Lisk, 1972) and are below the toxic level for aquatic life of 10ppm (Environment Can., 1978).

During wet weather sampling, the August 7 event reduced the V and Mn concentrations, whereas the October 3 event did not (Figure 4.3-4.4). The higher intensity rainfall and CSO for August 7 produced

VANADIUM AND MANGANESE CONCENTRATIONS IN WATER

FOR BOTH DRY AND WET WEATHER PERIODS

Figure 4.3

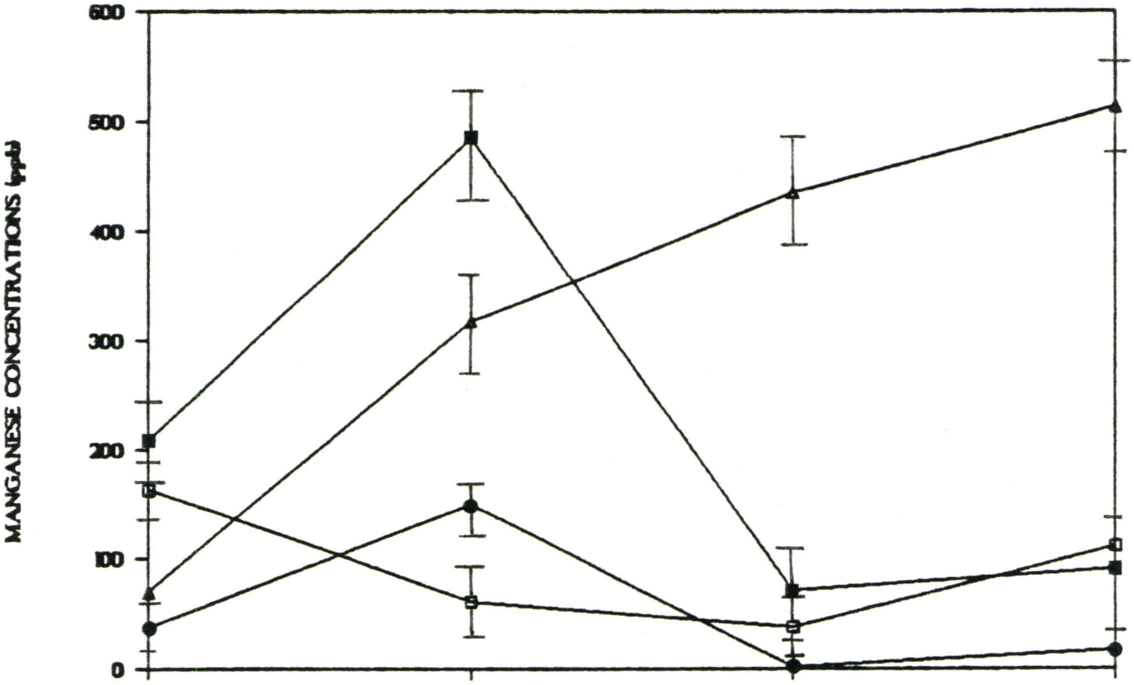
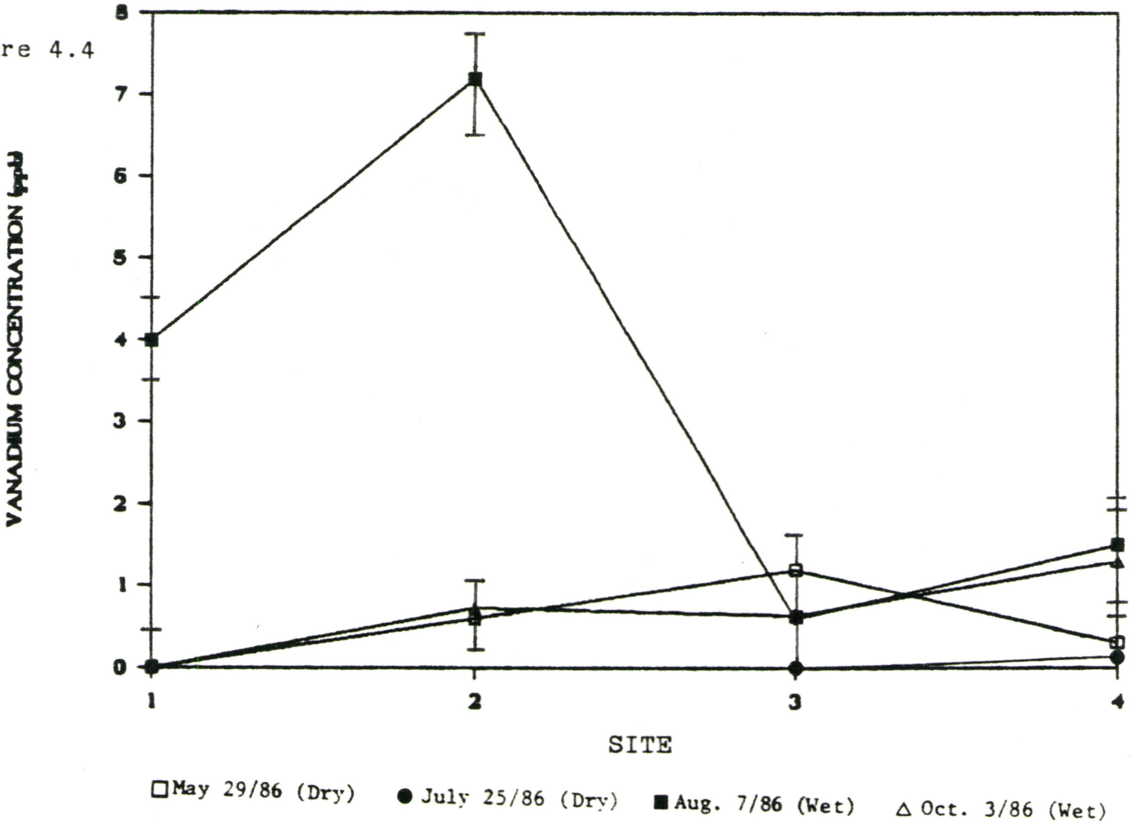


Figure 4.4



a greater volume of flow than on October 3. The August 7 event carried more SS and might be expected to have a higher concentration in the water. This may be attributed to the turbulent water dissolving more pollutants from the increased total SS surface area. This is the case for Mn and V at sites 1 and 2. At sites 3 and 4 V concentrations are similar for both events (taking into account the error involved), while Mn concentrations are much lower in the August 7 event than in the October 3 event. It appears that the detention pond is more effective with high volume flows as compared to low volume flows. Concentrations leaving the pond for both wet weather events exceeded the 1ppb natural V concentration. V concentrations are, however, below the toxic level for aquatic life at 10ppm (Environment Can., 1978). The detention pond, is sporadic in its abiltity to reduce dissolved trace metals in both wet and dry weather periods.

4.2.2 SUSPENDED SOLIDS

Irvine et al. (1987) have demonstrated that there is a relationship between total solids concentration and Mn and V concentrations, and this may also be true for Ti. For May 29, V, Mn and Ti concentrations do show a similar pattern to the sediment concentration pattern (Figures 4.1, 4.5-7). The Mn concentration gave a high correlation (0.837) with the sediment concentration for the same event. There were, however, no statistically significant relationships between sediment concentration and trace metal concentration for the data presented within this study. (The small sample sizes contributed to this insignificance.) Raw data may be seen in

Figure 4.5

MANGANESE CONCENTRATIONS ON S.S.

FOR DRY AND WET WEATER PERIODS

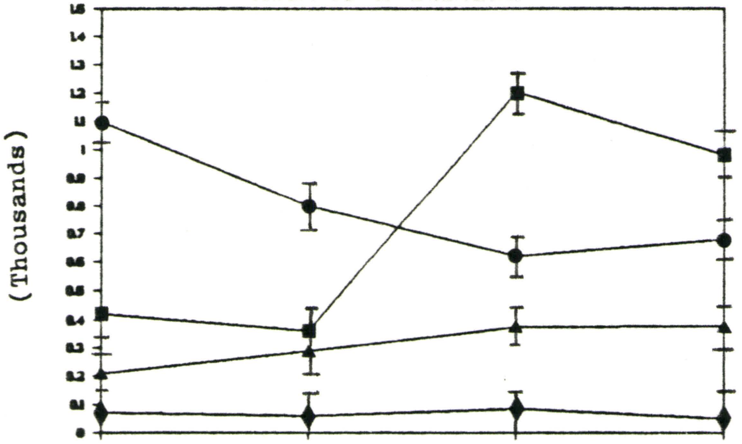


Figure 4.6

VANADIUM CONCENTRATION ON S.S.

FOR DRY AND WET WEATER PERIODS

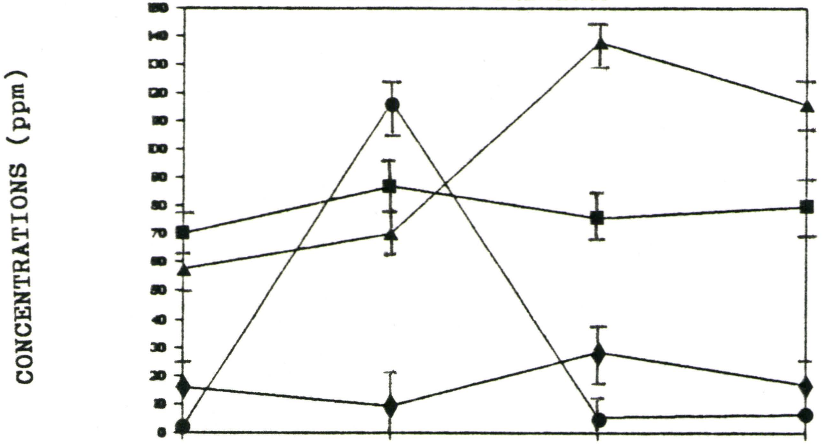
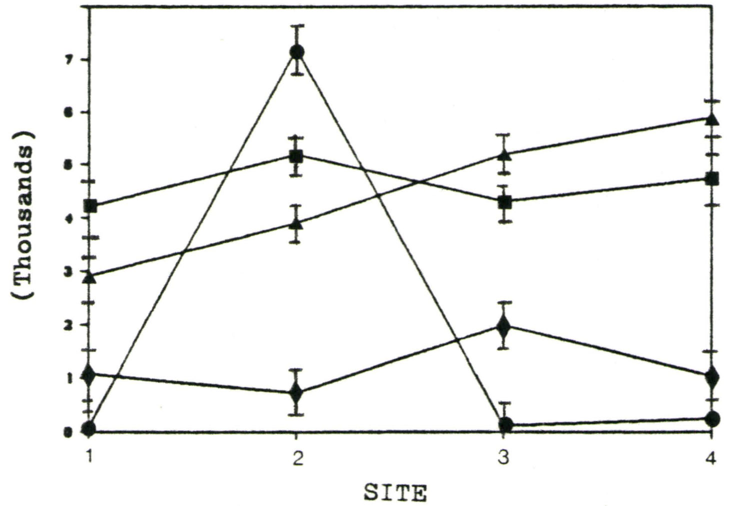


Figure 4.7

TITANIUM CONCENTRATION ON S.S.

FOR DRY AND WET WEATER PERIODS



◆ May 29/86 (Dry) ● July 25/86 (Dry) ■ Aug. 7/86 (Wet) ▲ Oct. 3/86 (Wet)

Tables A2.6 to 2.8.

Sediment concentrations (mg/l) within the water were highly variable both temporally and spatially (Figure 4.1). For the 4 dates sampled, only the May 29 period showed a reduction in SS at the effluent. All other events actually showed an increase in SS loading of the downstream water and therefore a reduction in water quality in terms of SS and the pollutants they carry.

Mn, V and Ti concentrations were also highly variable with respect to suspended solids (Figures 4.5 to 4.7). The stormwater detention pond enhanced water quality in terms of V, Ti and Mn on SS for the July 25 sampling period, and reduced concentrations from above the natural value (Lisk, 1972) above the pond to below the natural value below the pond. Error values for the May 29 sampling period (Figure 4.5 - 4.7) were large compared to the mean concentration values and thus little significance can be drawn from this event.

Within the wet weather flow, water quality in terms of Ti, Mn and V was not enhanced for the October 3 event where pollutants were contributed to the pond by localized overland flow alone (Figures 4.5 - 4.7). All trace metal concentrations increased on SS below the pond as compared to above. V concentrations were higher than the natural concentration while Ti was lower. A steady rise in Ti concentrations is evident throughout the sample network. Relative to concentration values, errors were relatively large for Mn and thus little validity can be placed on these concentrations.

Within the August 7 event, the pond did not decreased Mn concentrations. The closeness of the site 2 and 4 concentrations for

Ti and V and the relatively large errors involved, make it difficult to determine whether or not the pond has enhanced water quality. It is interesting to note, however, that the concentrations for Ti, V and Mn are the highest on this date as compared to the others. This may be a result of the CSO which occurred in this event.

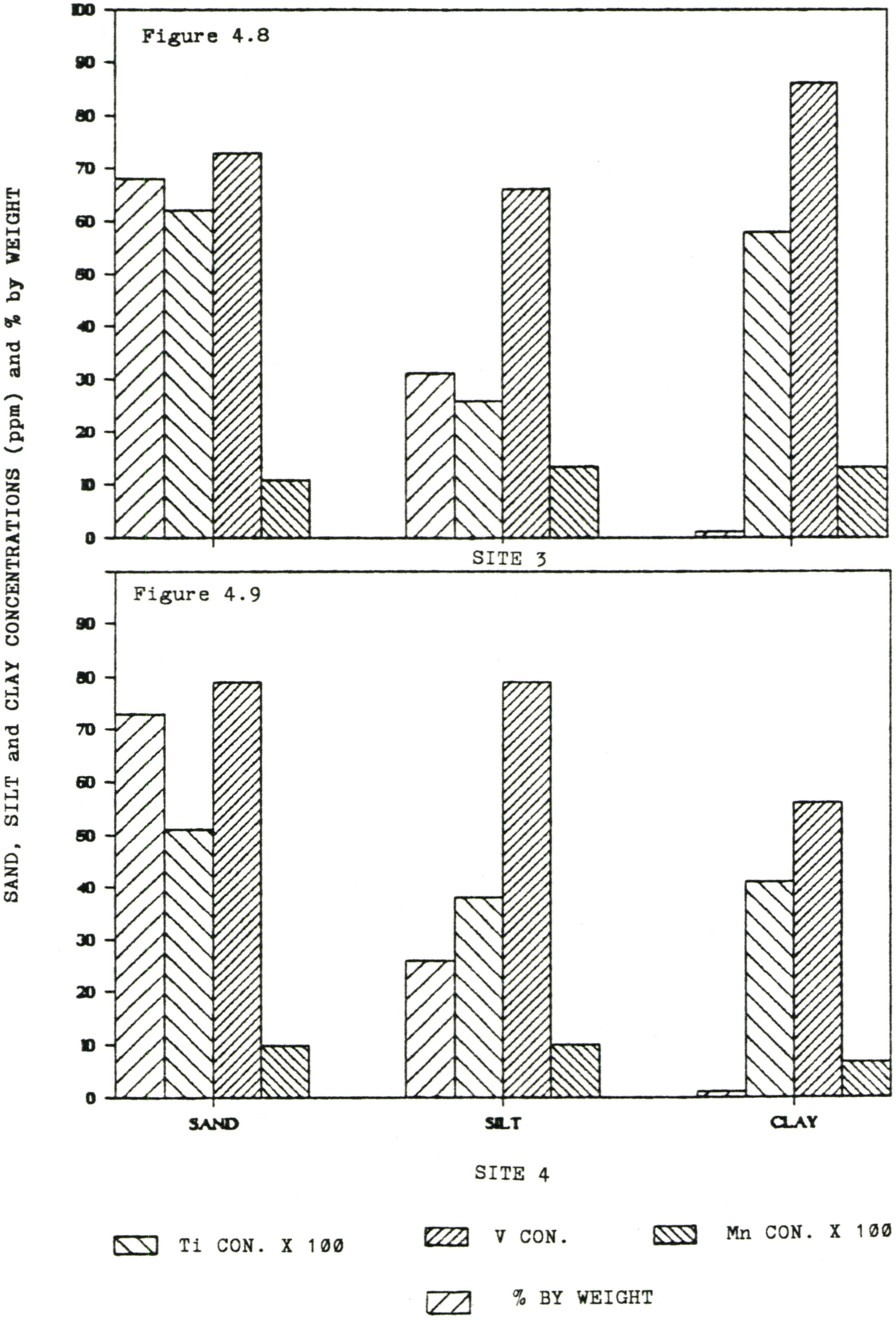
Mn, V and Ti concentrations on sand, silt and clay sized fractions of SS may be seen in Figures 4.8 and 4.9 for the August 7 event at sites 3 and 4 respectively. The sand fraction of the SS leaving the pond had Ti concentrations above the natural value. The V concentration for all size fractions was below the natural concentration. The sand fraction contained the highest or close to the highest concentrations of the three fractions, and comprised close to the majority of the sample in site 3 and the majority in site 4. The sand is the most important component to pollutant loading.

4.2.3 BOTTOM SEDIMENTS

Individual core samples yielded different fine (primarily silt and clay) and coarse (primarily sand) stratifications. Correlations of individual strata between cores were not possible. Individual core strata descriptions and concentrations at depth are given in Figures A3.1 through A3.9. Core number 4 (above the pond) was discarded from statistical analysis as it was not long enough to give a representative sample of the bottom sediment.

As sediment continuously precipitates out of suspension it adds to the pollutant loading in the bottom sediments. If bottom scouring does not occur, this results in a concentration gradient going downwards into the sediment from higher to lower values (Evans,

% SAND, SILT AND CLAY WITH ASSOCIATED
Ti, V AND Mn CONCENTRATIONS



1986). However, the sedimentological evidence in the Westdale detention pond suggests that bottom scouring does occur, and the concentrations data support this (Figures A3.1 through A3.9). No significant difference was found between depth and trace metal concentrations with the exception of a positive correlation for Ti in the 0.45 to 20um fraction of core 1, a negative correlation in core 2 for Ti and V, and in core 3 for Mn in the 20um to 1.4mm fraction.

The mechanism of adsorption leads to an expected negative relationship between grain size and trace metal concentration (Ackermann et al.,1983; Degroot et al., 1982; Dong et al., 1983; Whipple and Hunter, 1981; Randall et al., 1982; and Irvine et al, 1987) . This was the case in the cores for Ti and V concentration (using a 2 sample 2 tailed T - test), but not in the SS. The 0.45 to 20um fraction was significantly greater than the 20 um to 1.4mm fraction in Ti and V concentrations. Mn, however, only illustrated this relationship in core 1.

A two sample two tail T-test was used to determine if there was any significant difference between strata types (fine and coarse) in the two fractionated grain sizes (0.45 to 20um and 20um to 1.4mm). Generally no significant difference was found between the fine and coarse layered strata in terms of Ti, V and Mn concentrations. This was true for the two fractions present in each strata. Thus it is evident that the bottom sediments revealed some important sediment-pollutant concentration relationships and revealed the ponds apparent ineffectiveness in settling out trace metal pollutants.

4.3 ORGANICS

Financial restrictions on this study prevented the determination of the organic species by mass spectrometry, and only the relative base levels and peak areas of organics can be compared. Since species are not known, peak may represent an organic pollutant or a naturally occurring species. However, the detector is sensitive to the halogenated hydrocarbons and since a covalent carbon halogen bond does not occur in nature (except for iodinated thyroid hormones), it is reasonable to argue that these peaks do represent pollutants (Rosenfeld, 1987). To pick one peak and assume that it is an organic pollutant as an illustration of the pond's effectiveness in reducing organic pollutants is reasonable but not, as yet, conclusive. It is possible, however, to determine if the peak is within the environmental water or if it is a laboratory contaminant by comparing the peaks in the distilled water sample (representing laboratory contaminants) with those of the environmental water samples. These peaks can be ignored in the environmental samples and all other peaks can be considered to be within the environmental water. The effectiveness of the pond in reducing organic pollutant loading can only be analysed in a subjective manner. Although peaks may be used to identify trends, different organics (natural and pollutant) behave differently in various situations such as high and low flow. Their points of origin and relationship to particulate matter such as vegetation or soil may also vary. However, by using the trends in the base line levels, an overall indication of the pond's effectiveness can be determined. If the base line rises from one sample to another, then it can be concluded that there has been a general increase in organics, including organic pollutants.

Some peaks can be followed throughout the system from site 1 to site 4, while others are random in their appearance. Resultant peaks and base line levels may be seen in Figures A4.1 - A4.17.

Peak 5.11 a peak which is present in the environmental water throughout the system (Table A2.9) There is an increase in organic concentration over the sampling period at site 1 (the CSO) (Table A2.9 and Figures A4.1-3). Although between times 1 and 2 of Table A2.9 the ratio of the environmental to standard peak remains relatively constant for peak 5.11, there is an abrupt rise form 0.8% to 3.4% of the standard area from sample 2 to 3 respectively. Significant peaks unique to the system occur at retention times of 5.45, 16.85, 18.92 and 19.56 minutes at site 1 sample time 3.

Indications of base line levels below (site 4) and above (site 2) the pond give good evidence of the pond's ineffectiveness in reducing organic pollution concentrations. For example, in the August 7 event base levels below the pond (Figure 4.10) are higher and have more pronounced peaks than above the pond (Figure 4.11). Water quality is lower in terms of organics below the pond than above. Using peak 5.11 as a single organic example (Table A2.9), site 4 has the largest average percentage of the standard area over all time periods for August 7 at 4.3%. Average values above the pond were 2.4% and 1.7% at the overflow structure.

For a few individual peaks the pond appears to have enhanced water quality, assuming that these peaks are pollutants. For example, peak 15.12 appears only at site 2 in samples 1 and 2 and nowhere else in the system (Figures A4.4 - A4.5). Because the peak does not appear

FIGURE 4.10

SITE 4 SAMPLE 5

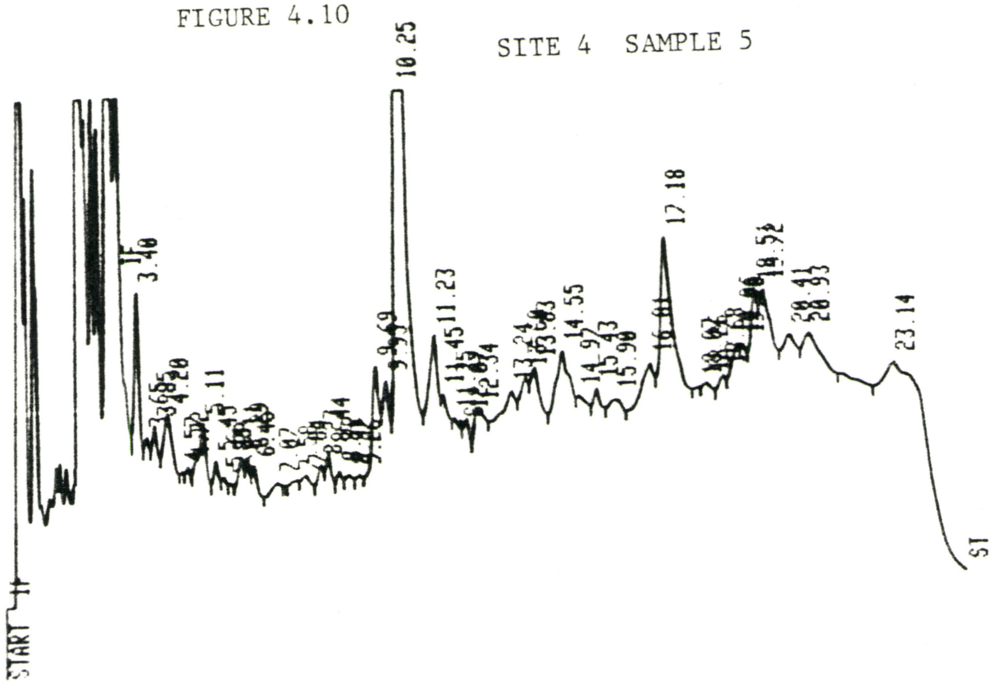
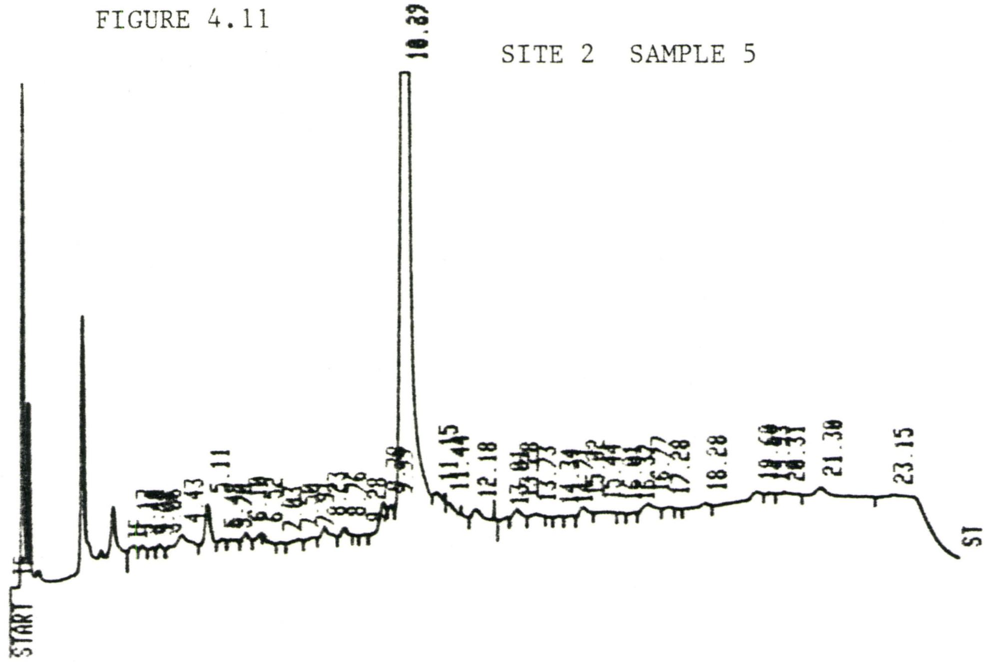


FIGURE 4.11

SITE 2 SAMPLE 5



at site 4, it is assumed that the pond has reduced its concentration below detection.

As the peak at 15.12 minutes is only found in samples 1 and 2 it can be concluded that this is an organic contributed to the system by overland flow, since the CSO "wave" was not observed passing site 2 until between samples 2 and 3. At sample 3 and beyond there is no evidence of the peak.

The dilution ability of the CSO is illustrated by the peaks at 15.12 and 5.11 minutes at site 2. The peak at 5.11 minutes (Table A2.9), for example, increases in the percentage area of the standard from sample 1 to 2 and decreases drastically from sample 2 to 3 when the CSO "wave" passes the site. A steady increase occurs again from sample 3 to 6 which is in accordance with site 1's CSO increase in organics, taking into account the lag time for the CSO inputs to travel from site 1 to 2.

It is evident that the stormwater detention pond's ability to reduce organic pollutants is poor for the overall organic system, although it does appear to have reduced some isolated peaks. Unfortunately the true environmental inpact of the organics and the detention pond cannot be determined as individual organic species are not known.

4.4 BACTERIA

Results obtained from the Microbiology lab at McMaster University and from the Provincial Health Laboratory yielded some disturbing results from an ecological viewpoint. The results suggest that for both dry and wet weather flows, the stormwater detention pond is ineffective in reducing the concentration of fecal coliforms and fecal streptococci. Results for both dry and wet weather conditions are summarized in Tables 4.1 and 4.2 respectively for the various sites. Concentrations never decrease to or below the acceptable concentrations for a stormwater detention pond effluent of 100 counts per 100ml for fecal coliforms and 20 counts per 100ml for fecal streptococci as defined by the Ministry of the Environment (Gietz, 1981). For a dry weather flow sampled on May 29, 1986, it can be seen from Table 4.1 that the fecal coliform and fecal streptococci concentrations were both greatest at site 1. Both indicator concentrations dropped at site 2 and remained constant throughout the system with one exception. The fecal coliform concentration at site 3 was considerably lower, (below the detection levels used at the Provincial Health Laboratories) perhaps due to random sampling error. Although the concentrations below the pond were less than the initial concentrations at the overflow structure, they were not less than the concentrations that entered the pond (site 2). The same concentrations of fecal coliforms and fecal streptococci that enter the pond also leave the pond and flow into Cootes Paradise.

During a wet weather flow sampled on July 17, 1986, the fecal coliform and fecal streptococci concentrations remained constant for all samples taken (Table 4.2). It is evident that the detention pond also has no effect in reducing fecal coliform and fecal streptococci concentrations during storm events.

A sample of drinking water was used as a control. Fecal coliforms were present below the detection levels used in the Provincial Health Laboratory. No fecal streptococci were detected.

TABLE 4.1

DRY FLOW

SITE	CONCENTRATION (# OF BACTERIA/L) FECAL COLIFORM	 FECAL STREPTOCOCCI
1	8.0×10^4	6.0×10^3
2	2.0×10^4	$<2.0 \times 10^3$
3	$<10^4$	$<2.0 \times 10^3$
4	2.0×10^4	$<2.0 \times 10^3$
CONTROL DRINKING WATER:	----	$<10^4$

TABLE 4.2

WET FLOW

SITE	CONCENTRATION (# OF BACTERIA/L) FECAL COLIFORM	 FECAL STREPTOCOCCI
1	$>6.0 \times 10^6$	$>2.0 \times 10^6$
3	$>6.0 \times 10^6$	$>2.0 \times 10^6$
4	$>6.0 \times 10^6$	$>2.0 \times 10^6$

In terms of reducing bacterial concentrations entering Cootes Paradise, this data suggests that the stormwater detention pond has no effect during wet and dry weather conditions. Data obtained from the RBG (Table A2.10) for both a dry and wet period (September 9 and 11 respectively) on fecal coliform concentrations yielded somewhat different results. Samples were taken in the same fashion; above, within and below the detention pond.

For the dry weather period, the general trend shows that the pond was enhancing water quality in terms of fecal coliforms. Reductions were, however, relatively insignificant with only a 3% decrease. The bacterial counts remained above the 100 counts per 100ml guideline.

Within the wet weather period the fecal coliform concentration were reduced 25% by the detention pond, however, this value was again above the governmental guidelines. These results for both dry and wet weather periods are contrary to earlier results obtained for this study. These differences in results question the significance and validity of all results obtained thus far. It is evident, however, that the stormwater detention pond is a poor mechanism for reducing bacterial concentrations in wet and dry periods as their concentrations below the pond, are still above acceptable concentrations.

CHAPTER 5

5.1 DISCUSSION

It is evident that the stormwater detention pond is variable in its ability to reduce pollutant levels. This is true for trace metals (Ti, V, and Mn) in water, SS and bottom sediments, and for organics and bacteria. Each of these pollutants will be discussed in turn to determine the factors which are contibuting to the detention pond's variability in enhancing water quality. The primary problem which weakens the pond's ability to reduce pollutants is the bottom scouring which occurs. This bottom scouring would be expected to increase the Mn, Ti, V, organic and bacterial concentrations below the pond (site 4), assuming that some of the pollutants adsorbed onto to the SS are dissolved back into the water column as a result of the turbid water. Although this seems to be true with organics, it is not always the case with the trace metals and bacteria. Other factors affecting the pond's performance such as the affects of anticedent conditions, vegetation within the pond and retention time must be evaluated.

Within the dry weather sampled periods (May 29 and July 25), the concentrations of Mn and V in water would be expected to yield similar spatial and temporal patterns. This, however, is not the case (Figures 4.3 and 4.4). The high degree of variation in the pond's effectiveness in enhancing water quality during dry weather could be attributed to differences in temperature and pH values between the sampled events (Lisk, 1972), but these values vary only slightly between events (Table A2.11). The variation may be attributed to antecedent conditions as the number of wet days before sampling has a direct effect on the concentrations of the water. The high degree of dryness before the May 24 and July sampling period (7 and 4 days respectively) makes it difficult to determine if the antecedent conditions had an effect on the water. Had it rained shortly before sampling, the trace metal concentrations may have been expected to be higher due to the added ground water flow into the ravine.

The opposite nature of Mn and V concentrations (ie. the pond enhances water quality in terms of V on May 29 but reduces water quality in terms of Mn) may be a result of a number of factors. These include such things as different valence numbers, different atomic weight, their associatied anions, their relationship to their cations and their different behavior due to pH and temperature (Lisk, 1972).

The variability between the August 7 and October 3 event may be attributed to the fact that the August 7 event included both CSO pollutant inputs and overland flow inputs, whereas the October 3 event had only localized overland flow inputs.

The reduction in trace metal concentrations for the August 7 event may be a result of the previously mentioned added volume. It was observed that the dam backed the water up to such an extent that much of the lower ravine floor was flooded (Figure A1.4). More vegetation normally on dry ground was introduced to the flood waters. These plants may have the effect of absorbing sufficient quantities of trace metals to lower their levels in the water. These plants could also add some resistance to flow and thus may help precipitate out SS, thereby reducing the trace metal concentration within the water itself. The addition of organic and bacterial pollutant by the CSO may have helped reduce concentrations in and below the pond by adsorbing or chemically reacting with the trace metals (Andelman, 1973).

The variability in concentrations between the August 7 and October 3 event may also be attributed to the antecedent conditions. The August 7 event which generally had higher concentrations only had three rainfall events in the previous two weeks and had six dry days immediately before the event. The October 3 event on the other hand had eight rainfall days in the previous two weeks and had zero dry days before the sampling event. As a result of the August 7 drier antecedent conditions, more dust and pollutants would have built up on the land surface (ie. roads, lawns). The overland runoff would then contributed greater pollutant concentrations to the Westdale Creek ravine water.

With respect to SS, the low correlation between sediment concentration and trace metal concentration for the different sampling periods may be due to factors such as velocity of flow, volume of flow, and magnitude of turbulent eddies.

The August 7 event had the highest concentrations on SS of all the periods sampled due to the CSO, which will carry more trace metals and other pollutante in general from the whole catchment (1.09 Km^2). These pollutants will come from areas of higher concentration than the localized area around the detention pond, such as streets and industrial areas.

The flooding of the lower ravine on August 7 seems to have been a positive phenomenon in terms of the quality of the water. The backing up of the water has not, however, reduced the SS trace metals.

This result is difficult to interpret, as one would expect a slower velocity of flow within the flooded area to settle out more suspended solids. It would also be expected that the submerged vegetation would reduce the SS load by intercepting the suspended particles within the water column. The variations between events in terms of the trace metal concentration on SS may again be attributed strongly to the antecedent conditions discussed previously.

The pollutant loading calculated with the simulated total discharge reveals that the SS are the primary input of trace metal pollutants into the detention pond. It is expected from the literature (Ackermann et al, 1983; Degroot et al, 1982; Dong et al, 1983; Whipple and Hunter, 1981; Randall et al, 1982; and Irvine et al, 1987), that the concentration of metals will increase as grain size decreases. For this reason many of the above authors have suggested focusing on just the smaller silt and clay grain sizes to analyze the environmental effects of trace metals on SS. The results obtained from fractionated samples in this study refute this. The sand fraction plays an important role in the overall loading of trace metals because sand often makes up the majority of the samples. The high percent by weight and concentration of pollutants on the sand may, however, be in error as the SS were not deflocculated. The particles determined to be of sand size (>62um) may in fact be a conglomerate of silts and clays. This would explain the uncharacteristic high trace metal concentrations of the sand sized particles. However, to overlook the sands input of pollutants would be to seriously underestimate the pollutant loading of the water.

The removal of settleable SS must be accomplished if water quality is to be enhanced in terms of Mn, V and Ti concentrations. Each of these elements behaves differently with respect to SS and other factors within the system, resulted in extreme variability of the detention pond's ability to enhance water quality.

Within the bottom sediment the results indicate a possible leaching downwards of pollutants. This is good as pollutants may be removed from the bottom sediment/water interface where they can be suspended or dissolved back into the water column by bottom scouring. The natural clay bottom of the pond (approximately 30 to 45 cm below the bottom sediment/ water interface) would act as a partial impervious layer. The fact that bottom sediment below the pond showed no significant difference with the sediment within the pond means some SSs are still polluting the downstream environment.

The cores served, as expected, to illustrate the inverse relationship of trace metal concentrations to particle size. As a result of this, it was expected that concentrations would be greater in the fine strata layer than in the coarse strata layers within cores. However, this was generally not the case. This may be attributed to the different environments in which the sediments were laid down (calm and turbulent) having an effect on the sediment concentrations.

This increase in organics latter in the August 7 event at the CSO is contrary to the "first flush" phenomenon as discussed by Klemetson (1985). The late rise in concentration may be attributed to the industrial area being in the far western corner of the catchment, so that a lag time would be expected between the time that the organics enter the sewer system and travel to the overflow, and their appearance in the CSO. If, as expected, the industrial area produces some of the highest organic pollutant concentrations, then this factor along with the lag time would explain the late rise in organic levels. This rise may also be a result of a discharge by the McMaster Medical Centre's holding tank late in the event. The organics which enter the system from the CSO are major contributors to pollutant loading of the detention pond.

The overall increase in the base line below the pond, arising from the increased presense of unresolved halogenated organics, is more significant than individual peaks which the pond may reduce or eliminate. The pond does not reduce pollutant loading in terms of organics for a number of reasons.

1) At the time of the August 7 event the detention pond was highly vegetated. Natural organic matter may be dissolved into the water from these water plants (Canale, 1977). This may explain the appearance of peak 17.15 which only appears below the pond.

2) Extensive humic matter was present in the pond. Pfaender (1977), points out that humic material in water is a major predecessor of chloroform ($CHCl_3$) which is a major halogenated organic. Chloroform may also be formed as a result of chlorination for disinfection, a process used extensively for wastewater and drinking water control of microbial contamination (Pfaender, 1977). If it were possible to dredge out the pond and remove the plants and humic material the problems of organic loading may be minimized.

3) Bottom scouring is known to have occurred and thus more

suspended solids are entrained in the water column. Although the ECGC only tested the water and not the suspended solids for organic concentrations, the turbid nature of the water would dissolve some of the organic contaminants into solution from the surface of the particles and increase the organic concentrations within the water below the pond. If the pond had been deeper this scouring would not have occurred and organic pollutant levels would have possibly been lower below the pond.

4) It is evident from Clements (1966) that the shape of this detention pond may also have affected its performance in enhancing water quality not only for organic pollutants but for others. Its oval shape is not as effective as a rectangular shaped detention pond (Clements, 1966).

Although there are some discrepancies in the data between this study and the RBG, it can be said that the pond is an ineffective mechanism for the reduction of bacteria since their concentrations below the pond remain above governmental regulations. The differences between the two sets of data may be a result of different sampling or analytical techniques or seasonal changes in water quality as a result in changes in water temperature and pH values.

The ineffectiveness of the pond to reduce bacteria concentrations by a significant amount may be a result of its poor geometric and morphological shape. The low retention time may also have played a large role in the pond's ineffectiveness. As fecal coliforms and fecal streptococci have a relatively short life span in the environment (they are highly temperature sensitive), the longer they are retained the lower will be their resultant concentrations. Had the detention time been longer the pond may have had a significant effect on enhancing water quality. Further studies are necessary to determine the true effect of the detention pond on enhancing water quality in terms of bacterial pollution.

If the regional municipality were able to dredge the sediment out of the pond periodically to increase its depth then water quality in terms of trace metal, organic and bacteria may be enhanced to a limited degree. The addition of flocculating chemicals to the pond would also have a positive effect on the water quality entering Cootes Paradise. Unfortunately, the "naturalist-sanctuary" use of the land prohibits such activity.

5.2 LIMITATIONS OF STUDY

The scope of this study was severely limited by the sampling method. Only one sample was taken per event and site for trace metal and bacterial concentrations, and no discharge measurements were made. Thus the stage at which the creek or pond was at during sampling could not be evaluated as a contributing factor to pollutant levels, nor could actual pollutant loading be calculated. The temporal changes in concentrations throughout the event could also not be evaluated. The small number of samples taken also made quality control difficult. Thus, in future studies, multiple samples over time and discharge measurements should be taken. In this way sample concentrations may be compared with their location on the creek hydrograph to determine the effects of flow on concentrations. An automatic sampler pump would be ideal for sampling.

In terms of organics, this study was again severely limited in that organic species were unable to be determined. Thus the true environmental impact of the pond's organic pollutants is not known. As only one wet weather flow period was analysed within this study no comparisons could be made to dry weather or other wet weather events. Also the event sampled (C) had a CSO event within it. Thus a comparison of overland flow to CSO inputs was difficult to make and could only be done by comparing the period before and during the CSO. Earlier analysis of both wet and dry events were performed for the same catchment by a different researcher, however, the methods of analysis were very different and thus the results could not be used for comparison with this study. Once again the problem of no natural hydrograph limited the analysis of the organics in relation to the pond's effectiveness in reducing concentrations over varying flow rates.

Some error was involved in comparing individual organic peaks by the ratio of the environmental to standard peaks. This was due to the standard peaks not all consisting of the same area (Figures A4.1-4.15).

The small number of events sampled for each pollutant type also limited the accuracy and validity of this study. If more sampling had been performed the quality of the results from this study would have been greatly improved.

CHAPTER 6

6.1 CONCLUSION

The stormwater detention pond within the RBG is very sporadic in its ability to enhance water quality in terms of the three pollutant types analysed within this study. In terms of the trace metal concentrations in the water and on the SS it carries no spatial or temporal patterns are evident. There is extreme variability in the pond's ability to reduce Ti, V and Mn concentrations within both the dry and wet weather samples. Often the concentrations leaving the pond are below natural concentrations and pose no environmental threat. However, there are cases were the concentrations are above the natural values. The cores of bottom sediment have served to illustrate the relationship between trace metal concentration and particle size, but they yield few conclusive results as to the effectiveness of the pond to settle out trace metal pollutants.

The stormwater detention pond also had little effect on reducing organic pollutants during wet weather flow. This was particularly evident due to the higher base level of organics below the pond as compared to above. Only a limited number of individual organic peaks were eliminated or reduced by the pond.

Bacterial concentrations obtained in this study and from one produced by the RBG are different in terms of fecal coliform counts. This result places some question into the pond's effectiveness in reducing fecal coliform concentrations. Results obtained from this study reveal that the pond does not reduce fecal streptococci concentrations. In general it appears that the pond is ineffective in reducing bacterial concentrations as a whole.

Taking into account the high degree of variability within the data presented in this study, it can be concluded as a preliminary result that the pond is generally ineffective in enhancing water quality in terms of trace metal, organic and bacterial concentrations. However, because of the severe limitations in the sampling method and thus the resultant data, more investigation is required to determine if the above conclusion is valid.

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APPENDIX 1

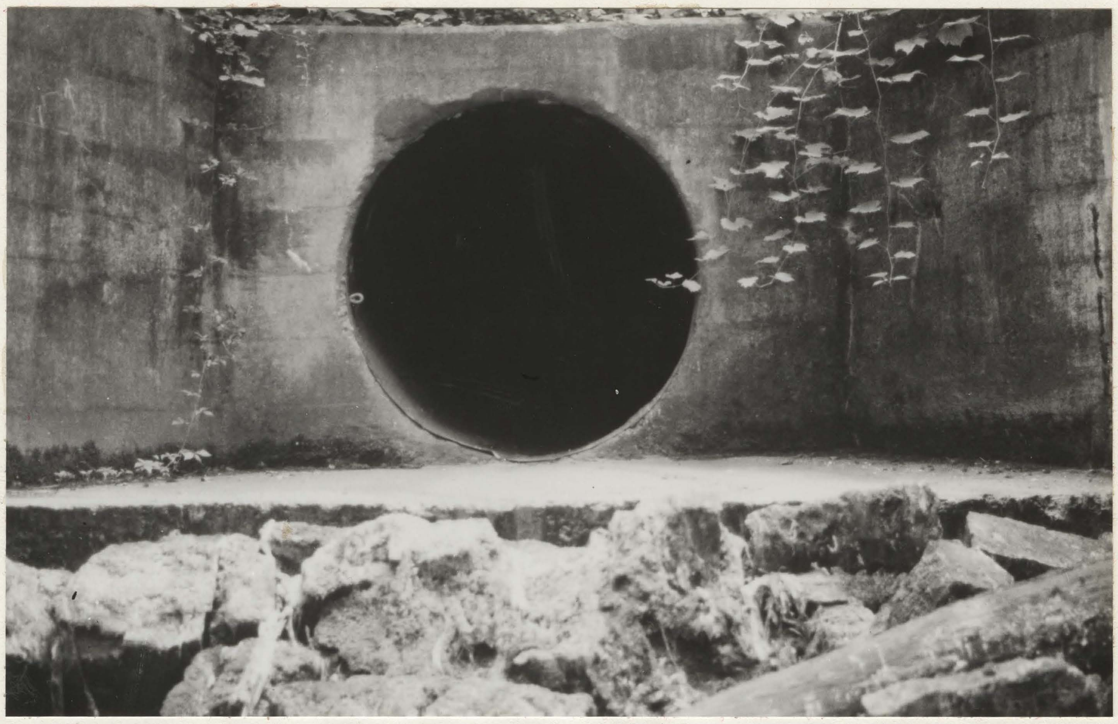


Figure A1.1 The Sterling Street combined sewere overflow structure.

Figure A1.2 The stormwater detention pond's dam early in August 7/86 storm event.

Figure A1.3 The stormwater detention pond's dam late in the August 7/86 storm event. Water is backing up behind the dam reducing water velocity.

Figure A1.4 Flooded stormwater detention pond and Westdale Ravine.

APPENDIX 2

TABLE A2.1

SEPTEMBER 9/86 DRY FLOW

SAMPLE SITE	S.S. mg/l
above pond	1.2
within pond	3.6
below pond	9.0

SEPTEMBER 11/86 WET FLOW

SAMPLE SITE	S.S. mg/l
above pond	16.0
within pond	20.0
below pond	44.0

TABLE A2.2

ESTIMATED POLLUTANT LOADING FROM THE CSO ON AUGUST 7/86

POLLUTANT	LOADING (tonnes/day)
V in water	7.08×10^{-5}
Mn in water	3.75×10^{-3}
V on SS	1.26
Mn on SS	7.54
Ti on SS	75.38
SS	3.86

VANADIUM CONCENTRATIONS FOR WATER (ppb)

TABLE A2.3

	CONCENTRATION SITE 1	CONCENTRATION SITE 2	CONCENTRATION SITE 3	CONCENTRATION SITE 4
EVENT A	___	0.60 +/- 0.60	1.20 +/- 0.50	0.30 +/- 0.50
EVENT B	___	___	___	0.14 +/- 0.27
EVENT C	3.93 +/- 0.16	7.23 +/- 0.38	0.54 +/- 0.23	1.47 +/- 0.25
EVENT D	___	0.73 +/- 0.39	0.64 +/- 0.37	1.30 +/- 0.40

TITANIUM CONCENTRATIONS FOR WATER (ppb)

TABLE A2.4

	CONCENTRATION SITE 1	CONCENTRATION SITE 2	CONCENTRATION SITE 3	CONCENTRATION SITE 4
EVENT A	___	___	50 +/- 80	60 +/- 50
EVENT B	___	___	___	___
EVENT C	___	___	___	___
EVENT D	40 +/- 70	___	___	___

MANGANESE CONCENTRATIONS FOR WATER (ppb)

TABLE A2.5

	CONCENTRATION SITE 1	CONCENTRATION SITE 2	CONCENTRATION SITE 3	CONCENTRATION SITE 4
EVENT A	163 +/- 14	61 +/- 11	38 +/- 8	111 +/-12
EVENT B	38 +/- 10	149 +/- 11	1 +/- 6	17 +/- 7
EVENT C	209 +/- 11	485 +/- 25	71 +/- 7	91 +/- 8
EVENT D	70 +/- 10	317 +/- 20	435 +/- 25	513 +/- 28

VANADIUM CONCENTRATIONS FOR SUSPENDED SOLIDS (ppm)

TABLE A2.6

	CONCENTRATION SITE 1	CONCENTRATION SITE 2	CONCENTRATION SITE 3	CONCENTRATION SITE 4
EVENT A	16 +/-1.4	9.2 +/- 0.9	28.7 +/- 2.2	16.9 +/- 1.4
EVENT B	1.7 +/- .26	117 +/- 9.0	5.3 +/- 0.5	6.4 +/- 0.6
EVENT C	70 +/- 5.0	87 +/- 6.0		
.45um			86 +/- 7.0	56 +/- 5.0
5um			67 +/- 5.0	79 +/- 6.0
62um			74 +/- 6.0	79 +/- 6.0
EVENT D	57.5 +/- 5.0	70 +/- 6.0	138 +/- 10.0	116 +/- 9.0

TITANIUM CONCENTRATIONS FOR SUSPENDED SOLIDS (ppm)

TABLE A2.7

	CONCENTRATION SITE 1	CONCENTRATION SITE 2	CONCENTRATION SITE 3	CONCENTRATION SITE 4
EVENT A	1080 +/- 100	720 +/- 80	1980 +/- 110	1040 +/- 100
EVENT B	70 +/- 60	7200 +/- 500	110 +/- 60	240 +/- 50
EVENT C	4280 +/- 260	5020 +/- 220		
.45um			5800 +/- 600	4100 +/- 400
5um			2600 +/- 320	3820 +/- 270
62um			6230 +/- 360	5090 +/- 290
EVENT D	2910 +/- 325	3910 +/- 390	5200 +/- 400	5890 +/- 350

MAGNESIUM CONCENTRATIONS FOR SUSPENDED SOLIDS (ppm)

TABLE A2.8

	CONCENTRATION SITE 1	CONCENTRATION SITE 2	CONCENTRATION SITE 3	CONCENTRATION SITE 4
EVENT A	72 +/- 6	58 +/- 5	85 +/- 7	48 +/- 5
EVENT B	1100 +/- 80	800 +/- 60	620 +/- 50	680 +/- 50
EVENT C	424 +/- 32	320 +/- 23		
.45um			1320 +/- 100	660 +/- 50
5um			1340 +/- 100	1000 +/- 70
62um			1080 +/- 80	990 +/- 70
EVENT D	206 +/- 19	289 +/- 26	375 +/- 30	377 +/- 29

TABLE A2.9

SITE	SAMPLE	PEAK	ENVIRON. PEAK AREA / PFB-PD (STANDARD) AREA x 100	AVERAGE FOR SITE
1	1	5.15	1.0	
	2	5.10	0.8	1.7
	3	5.11	3.4	
2	1	5.12	2.9	
	2	5.13	3.3	
	3	5.16	0.4	2.4
	4	5.12	1.7	
	5	5.11	2.0	
	6	5.13	4.1	
4	1	5.11	5.6	
	2	5.12	5.2	
	3	5.11	5.2	4.3
	4	5.15	4.6	
	5	5.11	2.5	
	6	5.11	2.6	

TABLE A2.10

SEPTEMBER 9/86 DRY FLOW

SAMPLE SITE	FECAL COLIFORM / 100ml
above pond	3500
within pond	2100
below pond	3400

SEPTEMBER 11/86 WET FLOW

SAMPLE SITE	FECAL COLIFORM / 100ml
above pond	40000
within pond	10000
below pond	30000

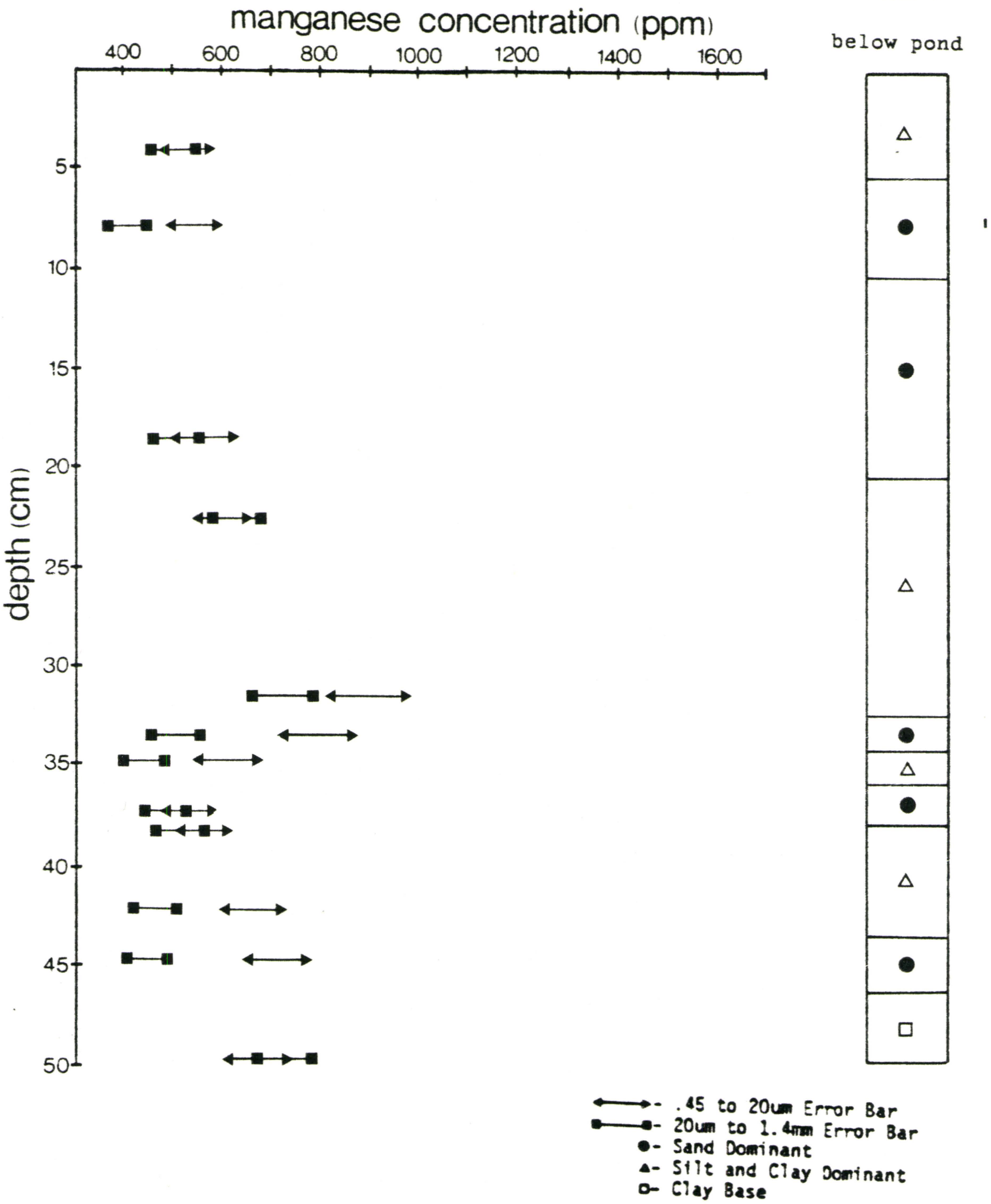
TABLE A2.11

DATE	SITE	AVERAGE WATER TEMPERATURE	AVERAGE pH
May 29/86	1	13.5	7.19
	2	19.3	7.96
	3	25.2	8.00
	4	22.4	7.95
July 17/86	1	15.6	6.97
	3	19.4	7.11
	4	19.0	7.19
July 25/86	1	13.3	7.10
	2	20.1	7.86
	3	27.3	8.23
	4	21.5	7.84
Aug. 7/86	1	----	----
	2	19.3	----
	4	18.9	6.94
Oct. 3/86	1	14.7	7.53
	2	13.8	7.56
	3	14.2	7.53
	4	14.1	7.59

APPENDIX 3

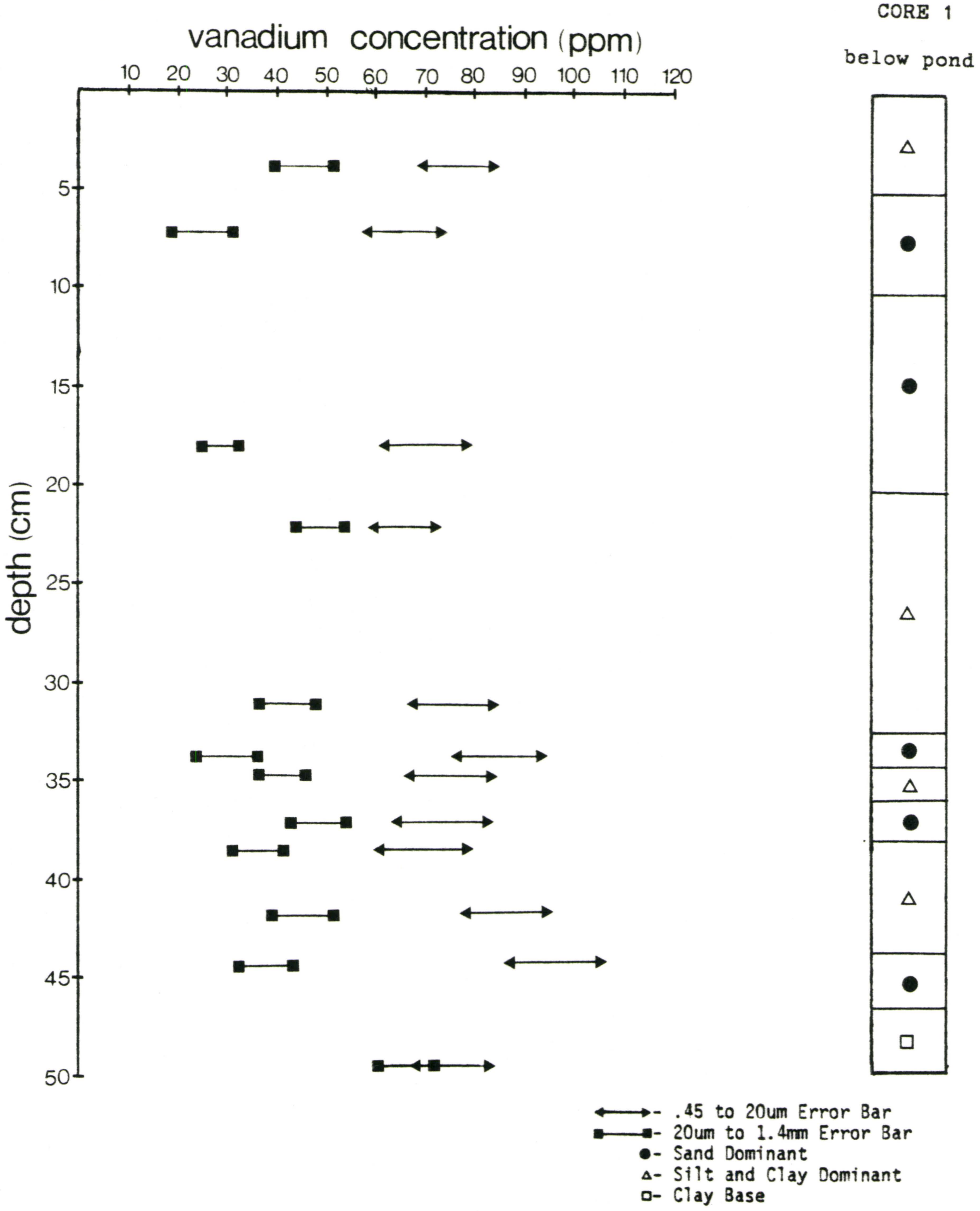
CORE STRATA
AND TRACE METAL CONCENTRATIONS

Figure A3.1



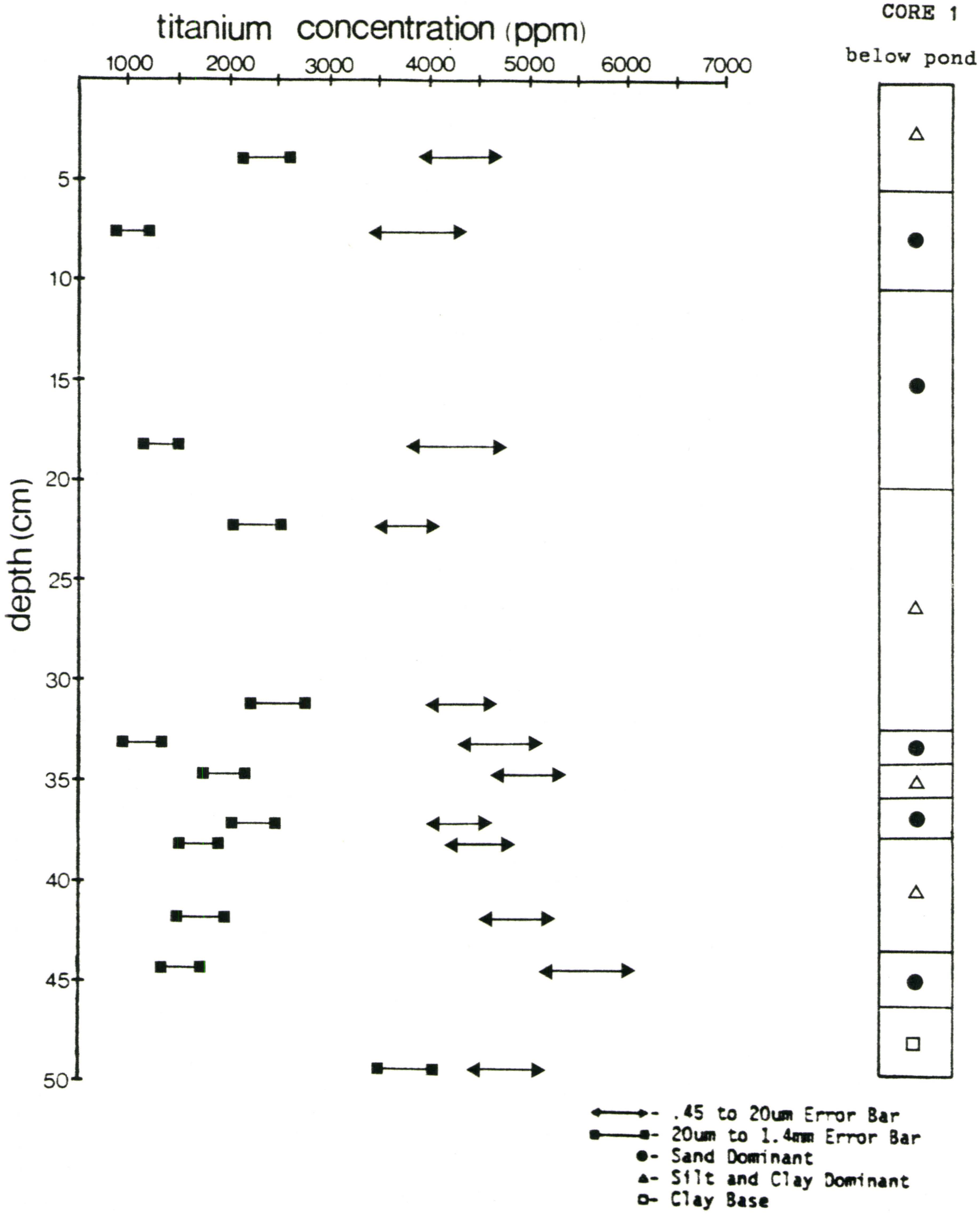
CORE STRATA
AND TRACE METAL CONCENTRATIONS

Figure A3.2



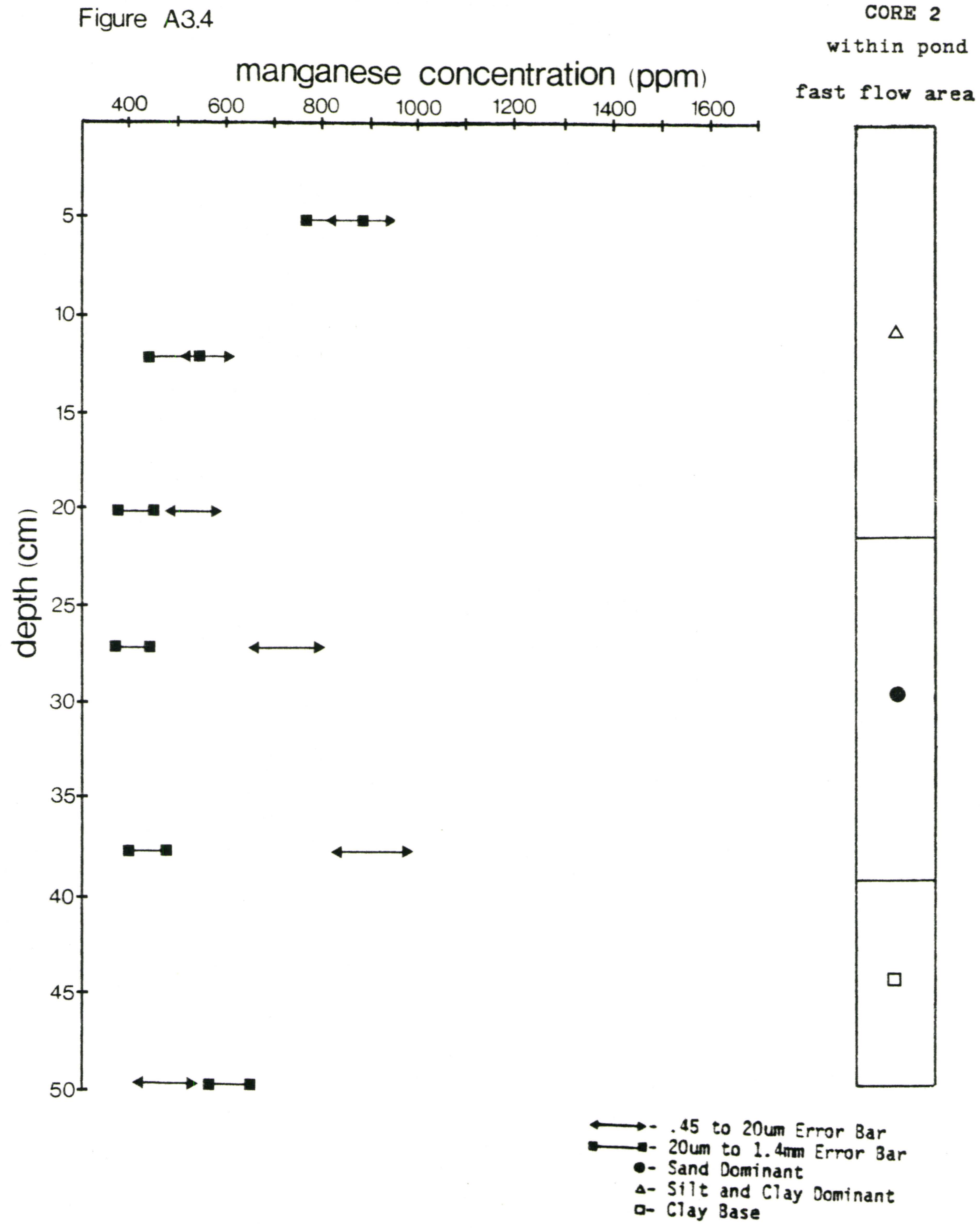
CORE STRATA
AND TRACE METAL CONCENTRATIONS

Figure A3.3



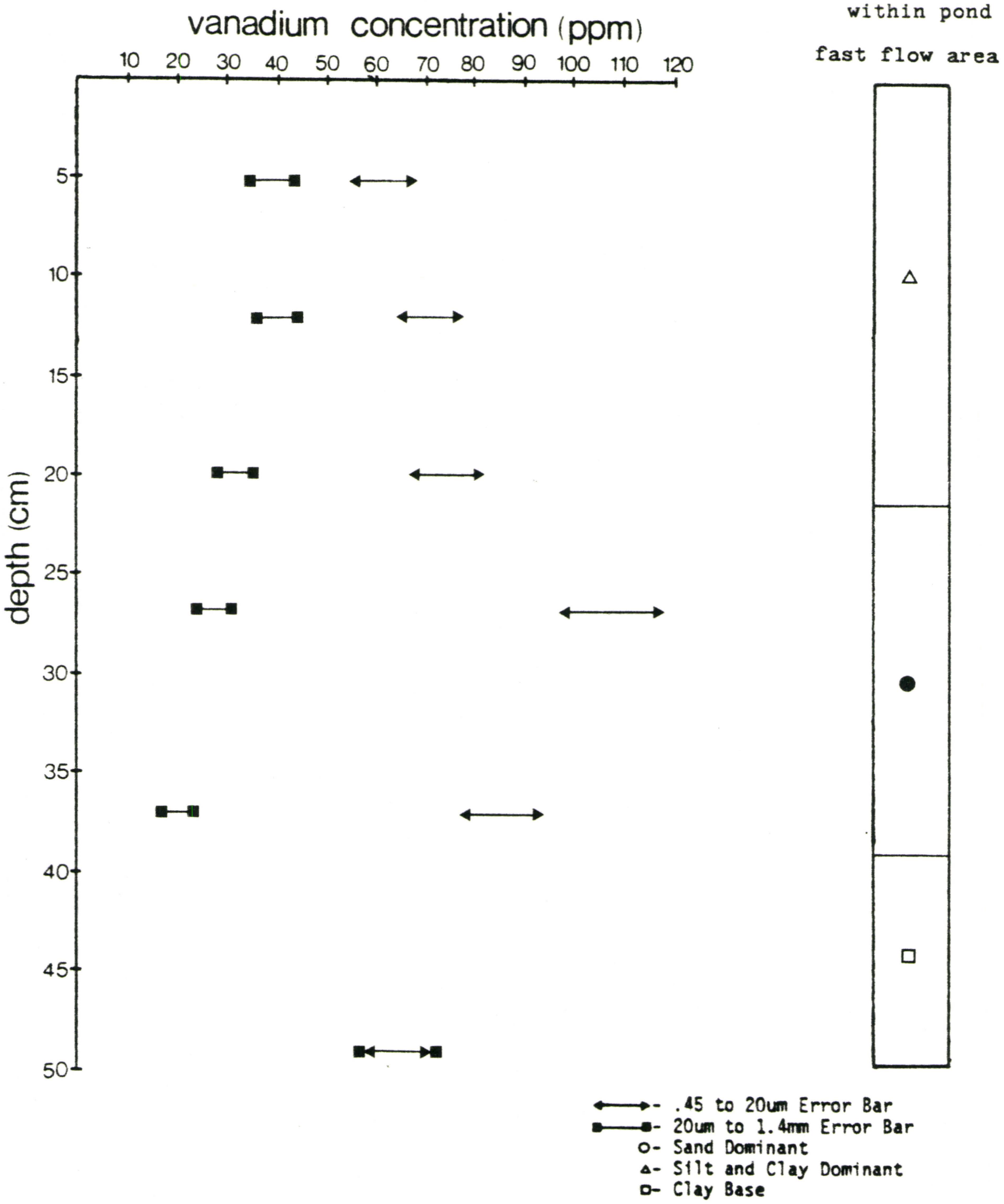
CORE STRATA AND TRACE METAL CONCENTRATIONS

Figure A3.4



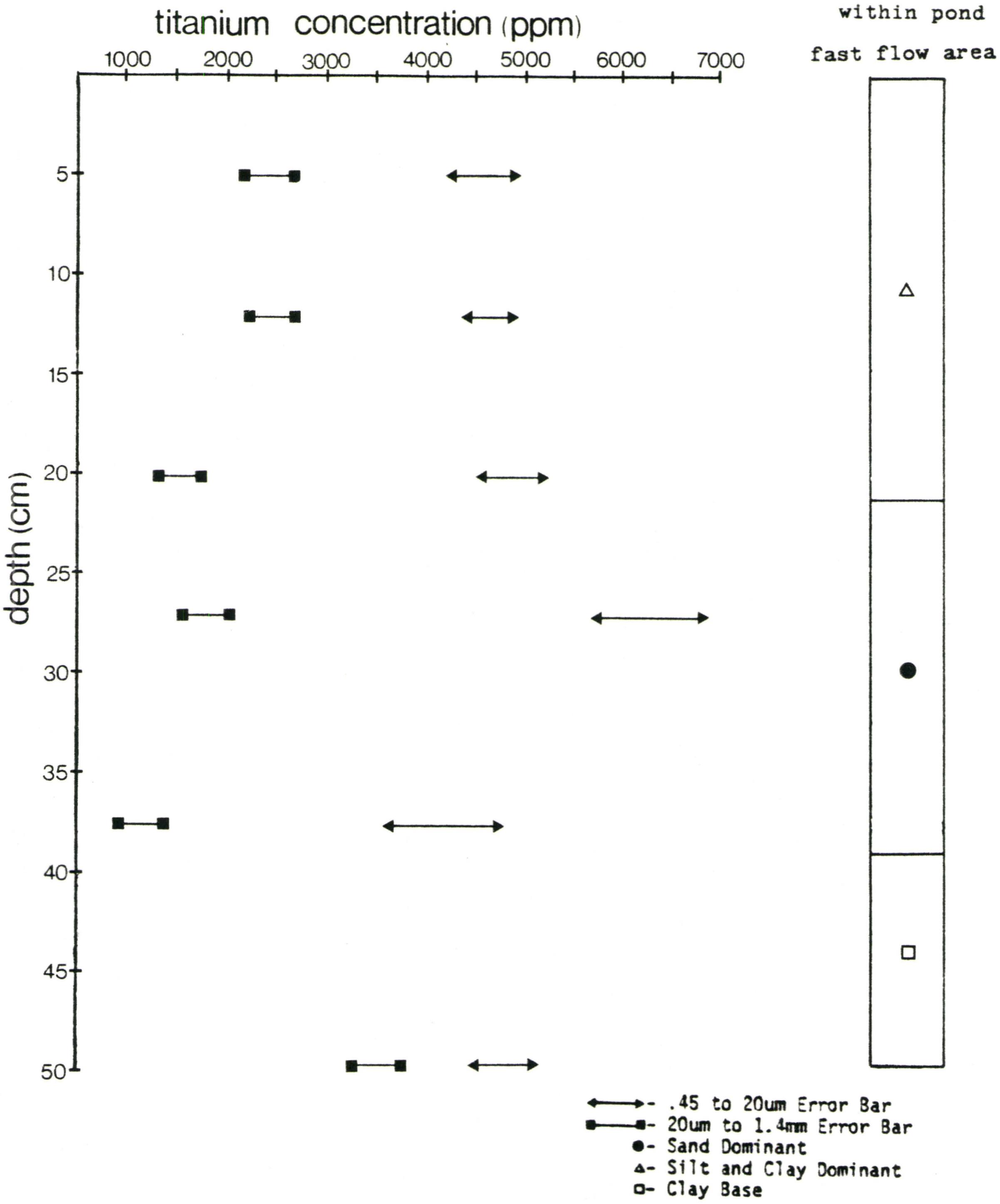
CORE STRATA
AND TRACE METAL CONCENTRATIONS

Figure A3.5



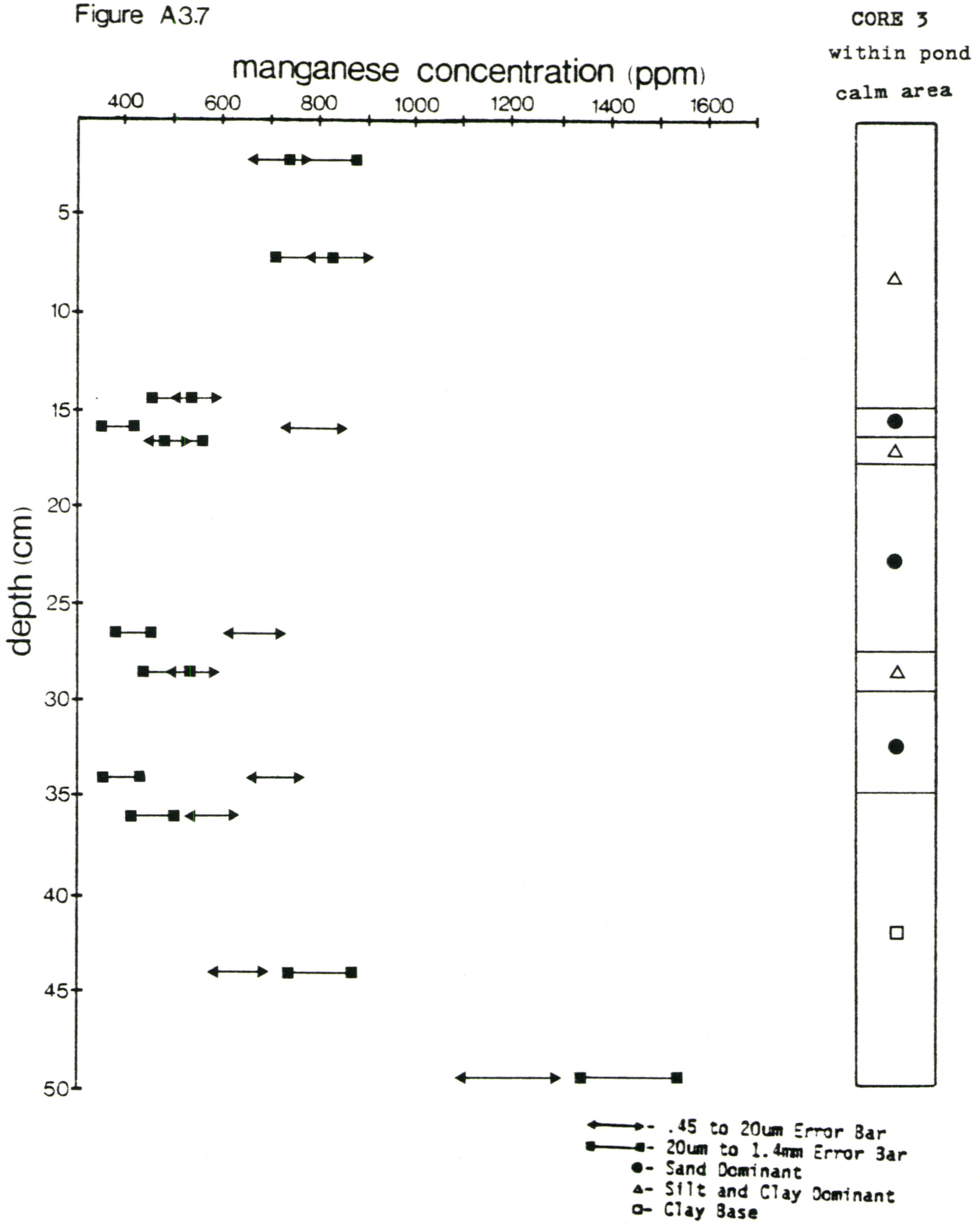
CORE STRATA
AND TRACE METAL CONCENTRATIONS

Figure A3.6



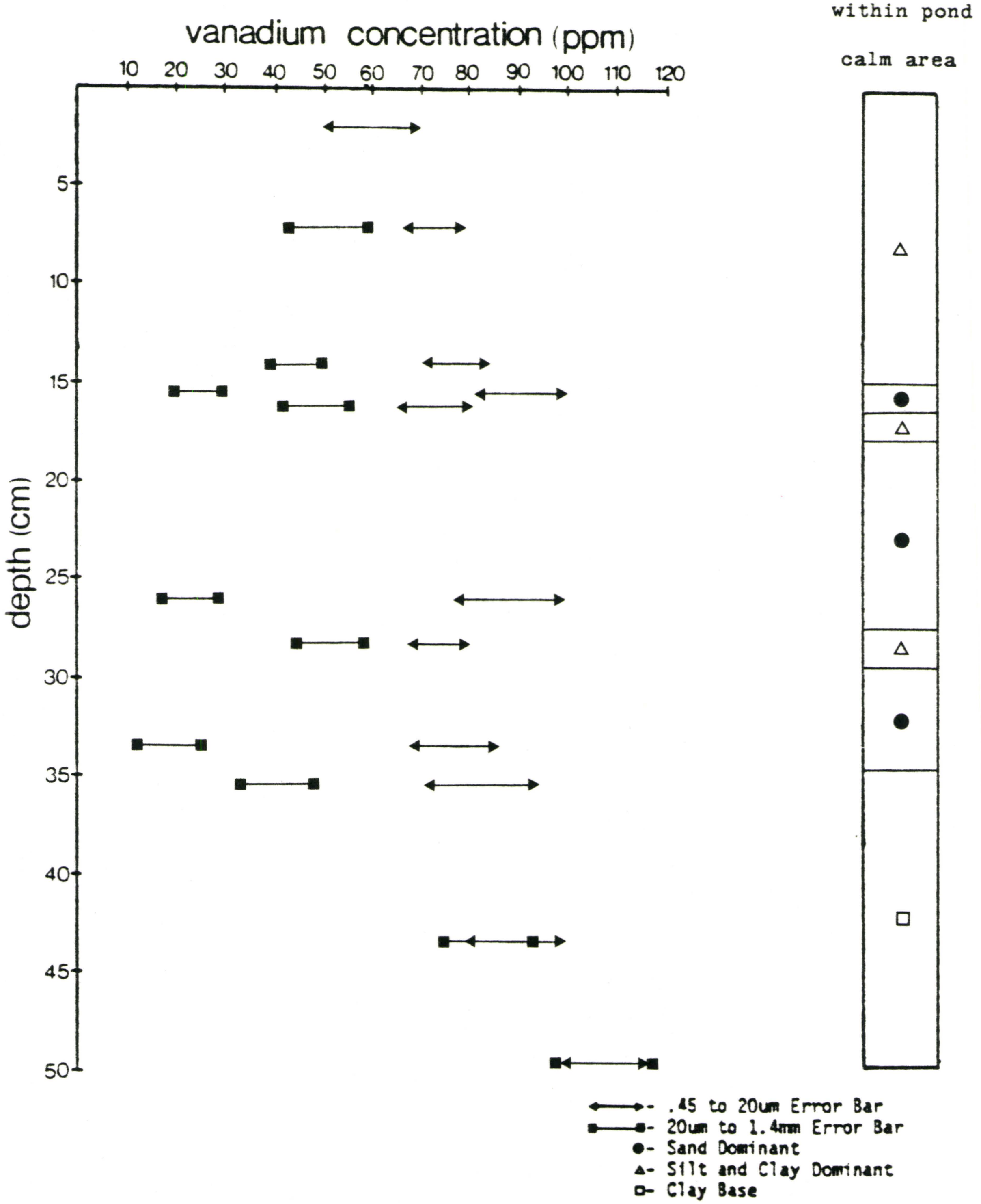
CORE STRATA AND TRACE METAL CONCENTRATIONS

Figure A3.7



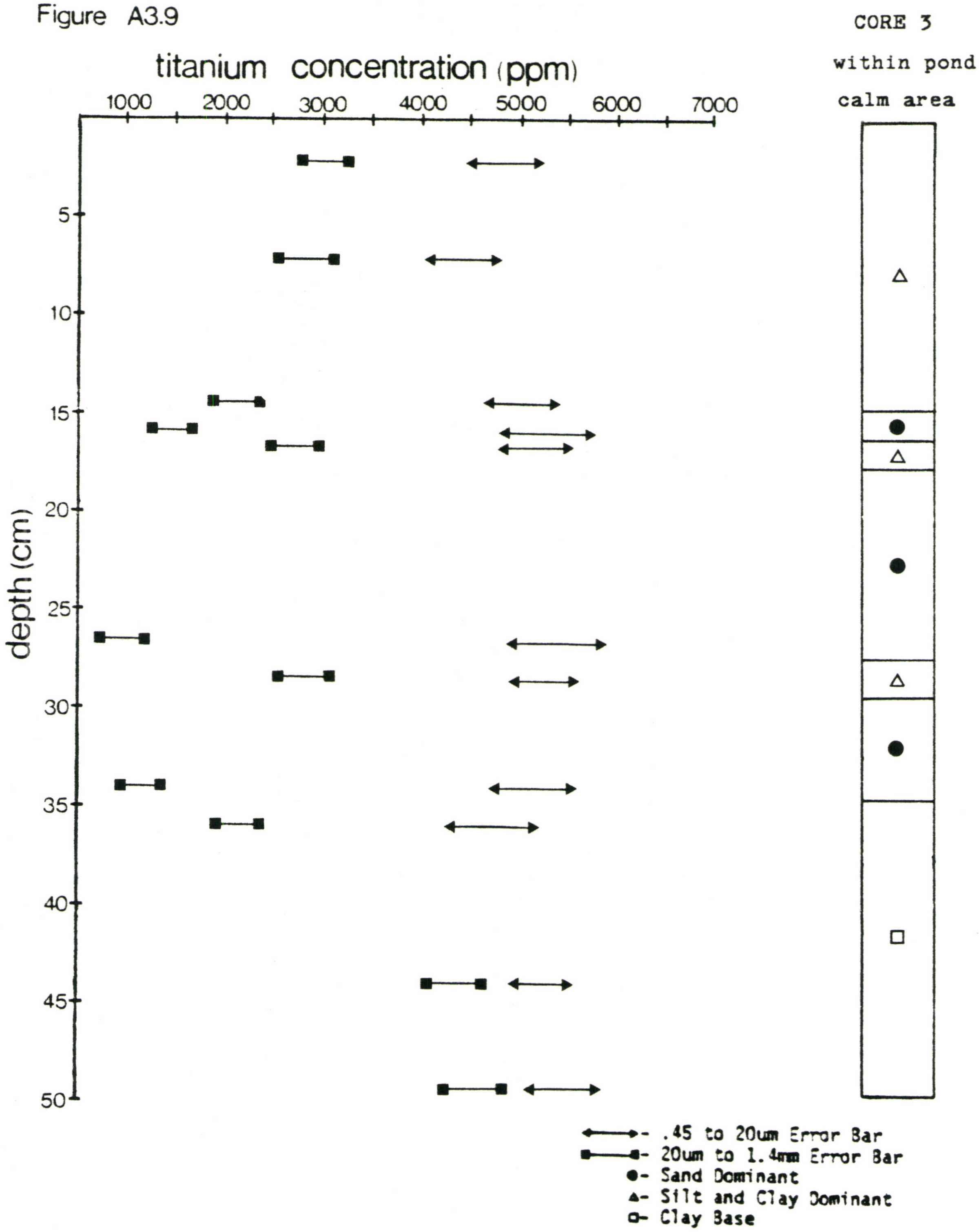
CORE STRATA
AND TRACE METAL CONCENTRATIONS

Figure A3.8



CORE STRATA
AND TRACE METAL CONCENTRATIONS

Figure A3.9



APPENDIX 4

Figure A4.1

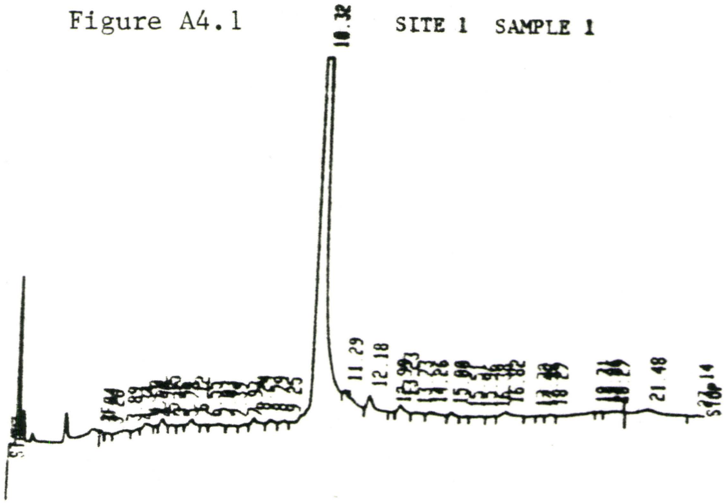


Figure A4.2

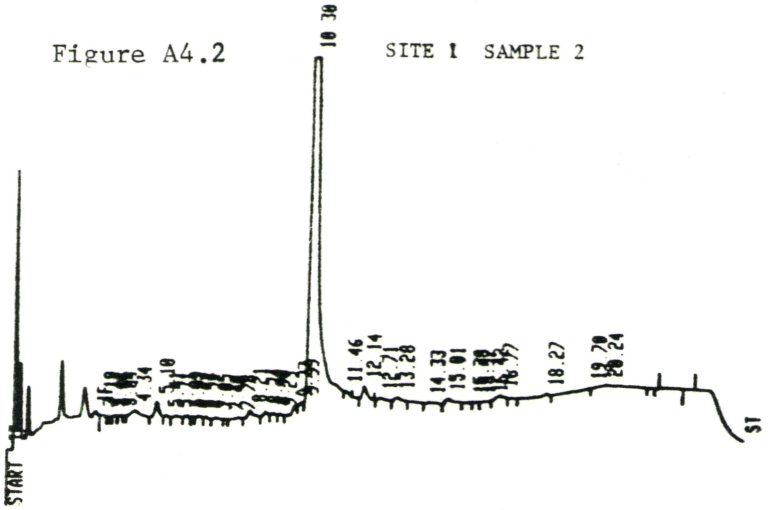


Figure A4.3

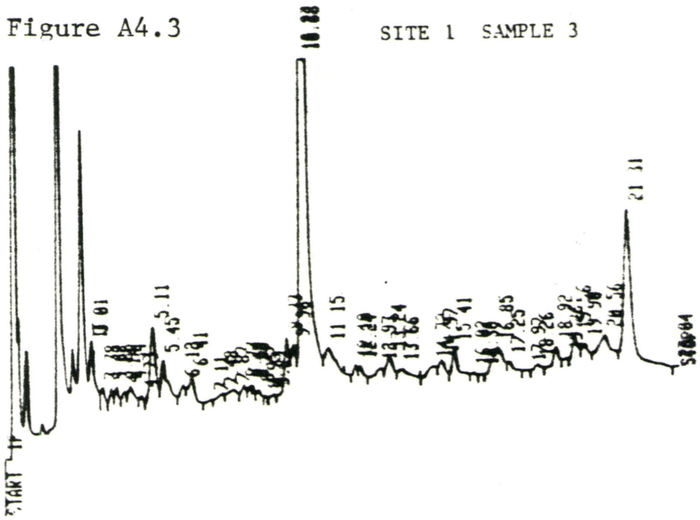


Figure A4.4

SITE 2 SAMPLE 1

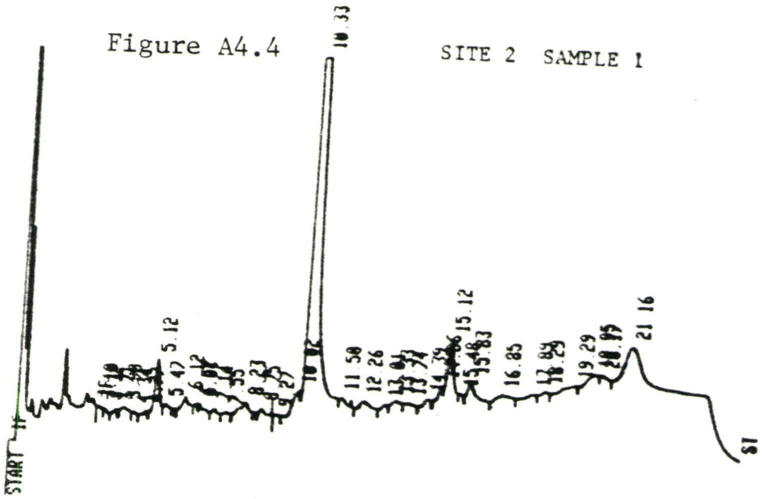


Figure A4.5

SITE 2 SAMPLE 2

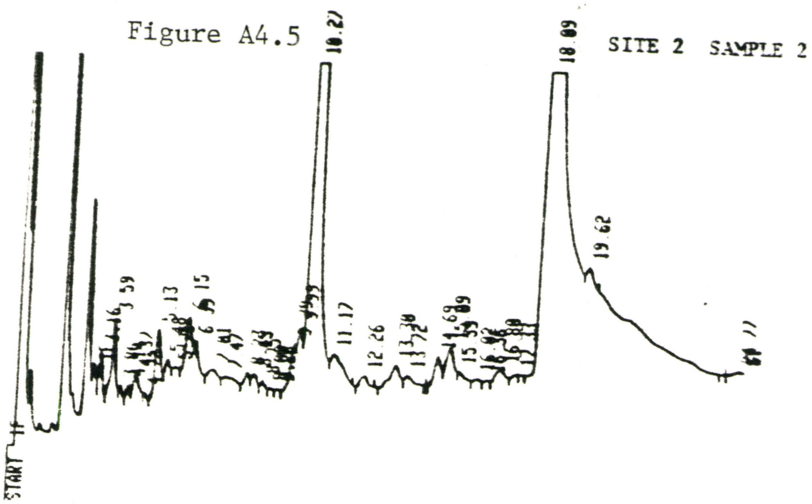


Figure A4.6

SITE 2 SAMPLE 3

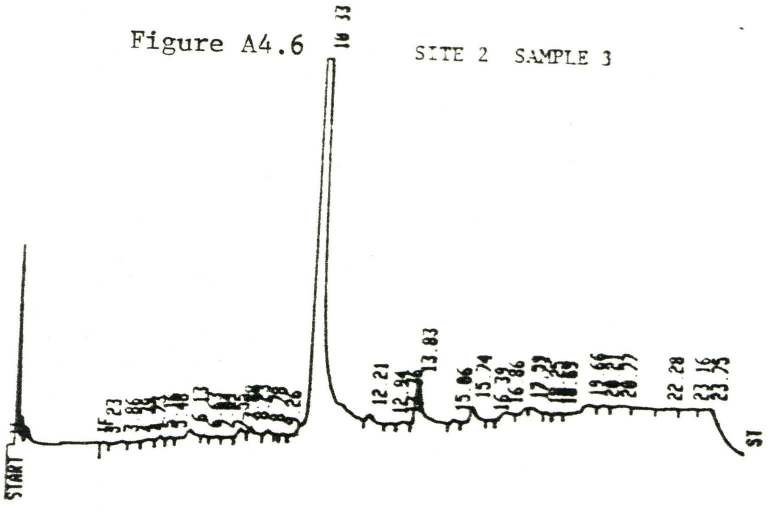


Figure A4.4

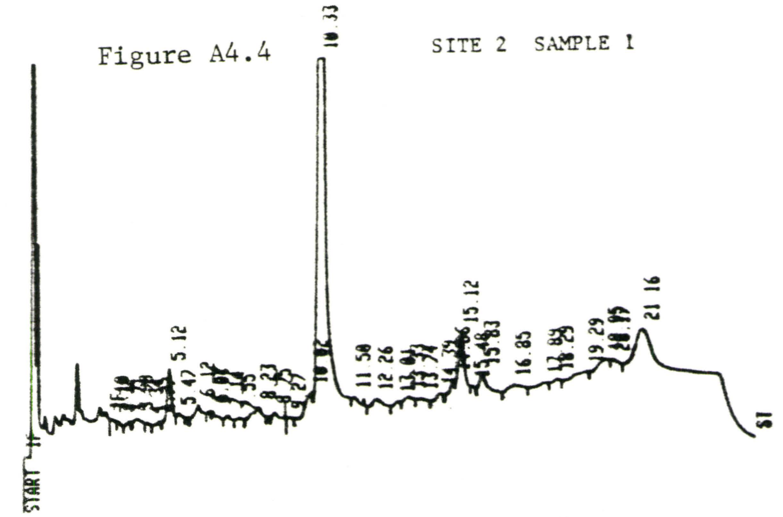
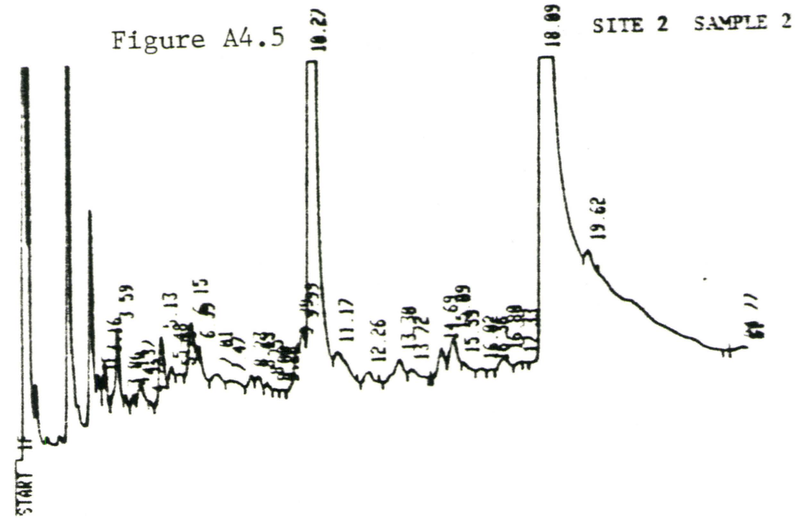


Figure A4.5



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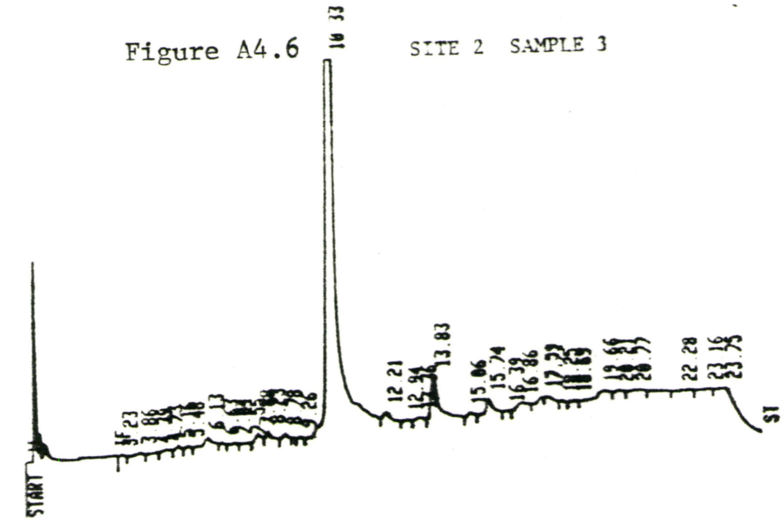

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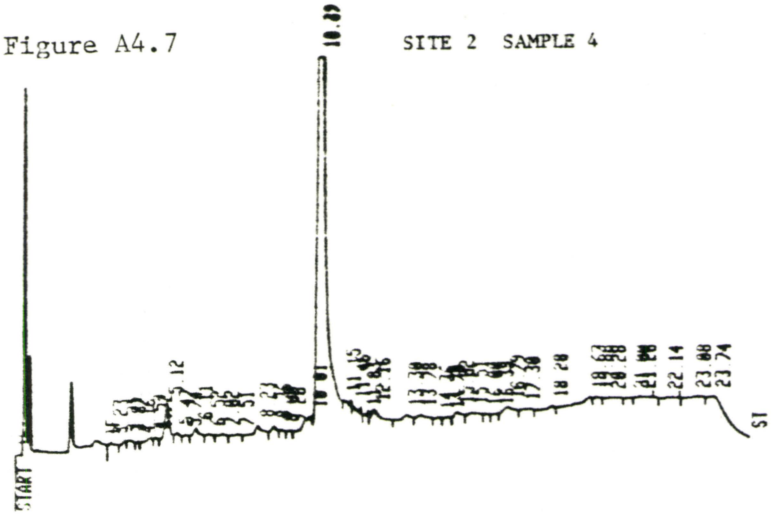


Figure A4.8

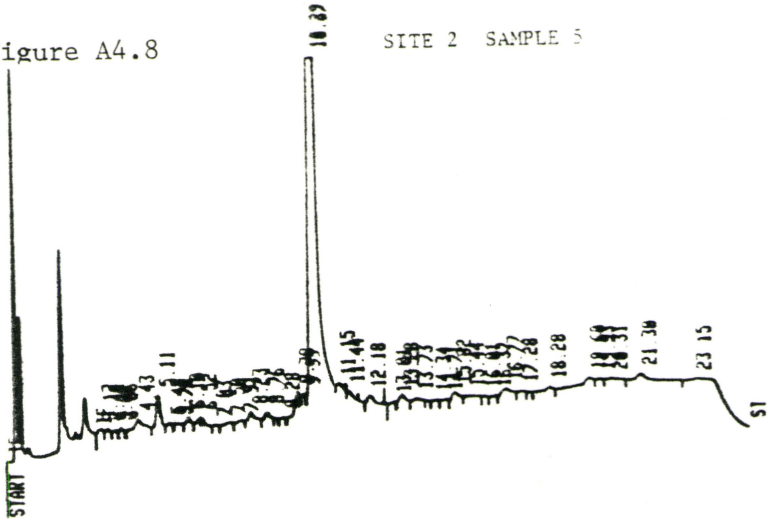


Figure A4.9

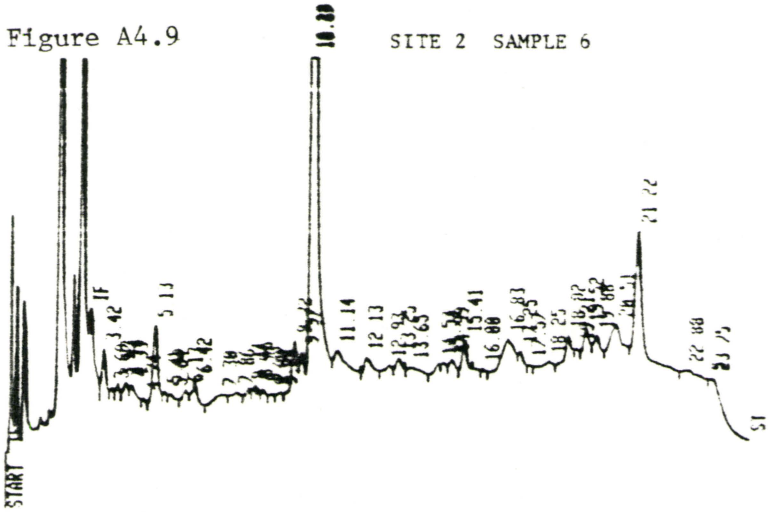


Figure A4.10

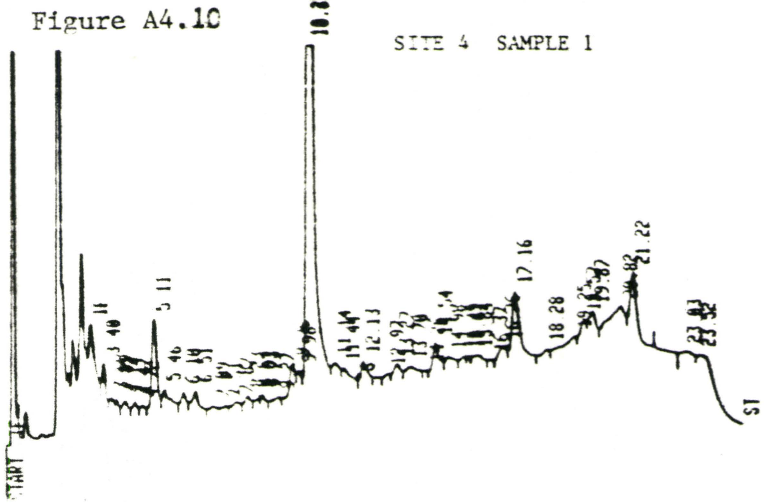


Figure A4.11

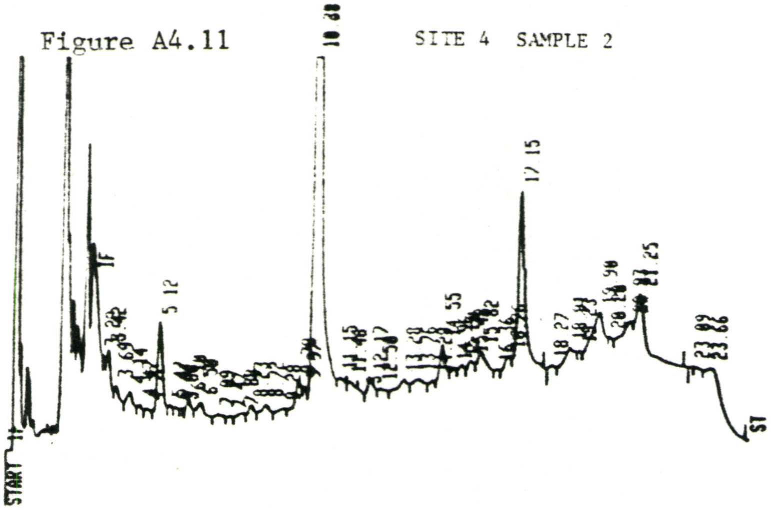


Figure A4.12

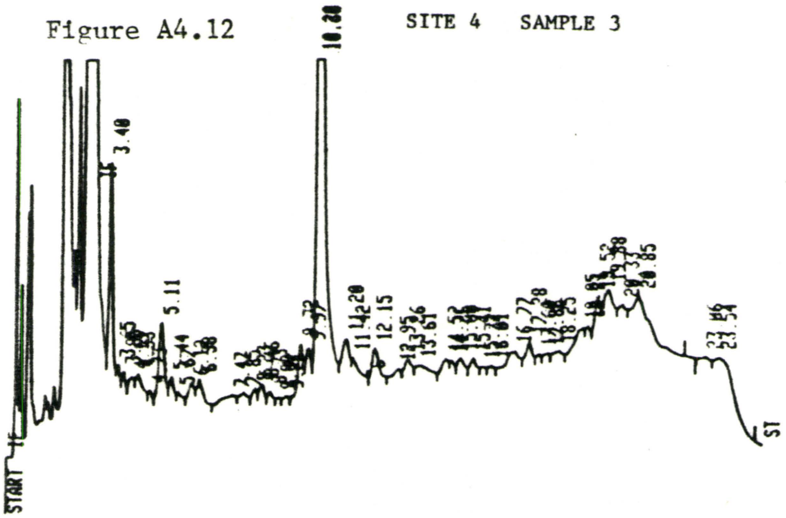


Figure A4.13

SITE 4 SAMPLE 4

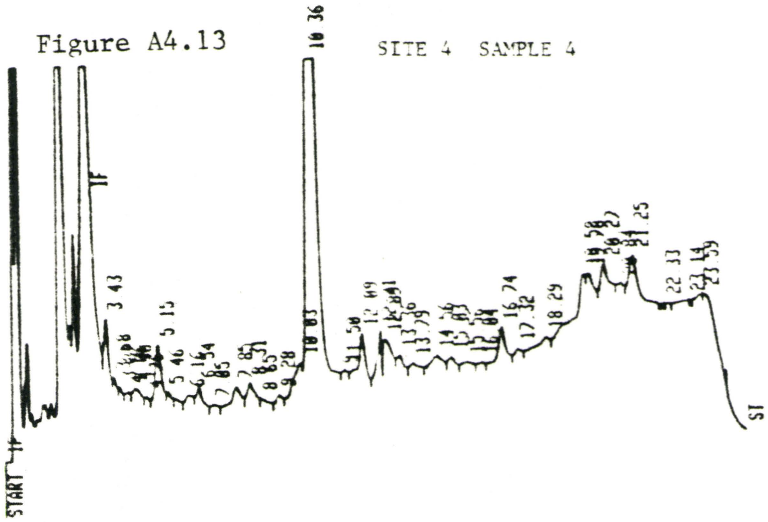


Figure A4.14

SITE 4 SAMPLE 5

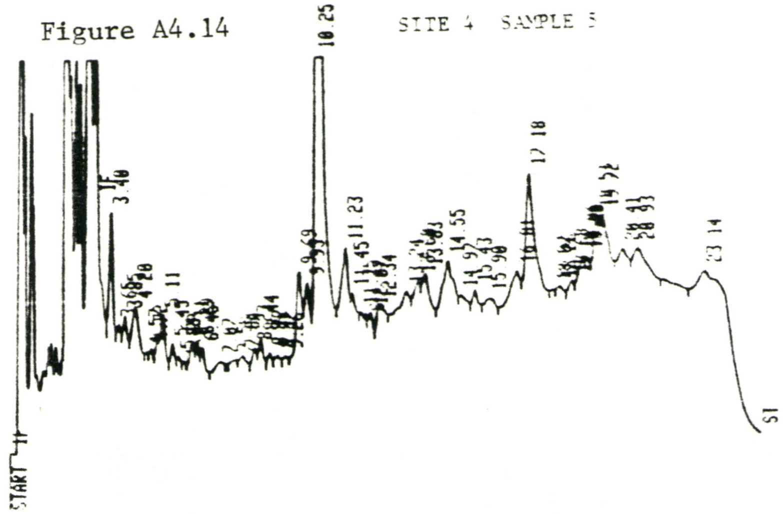


Figure A4.15

SITE 4 SAMPLE 6

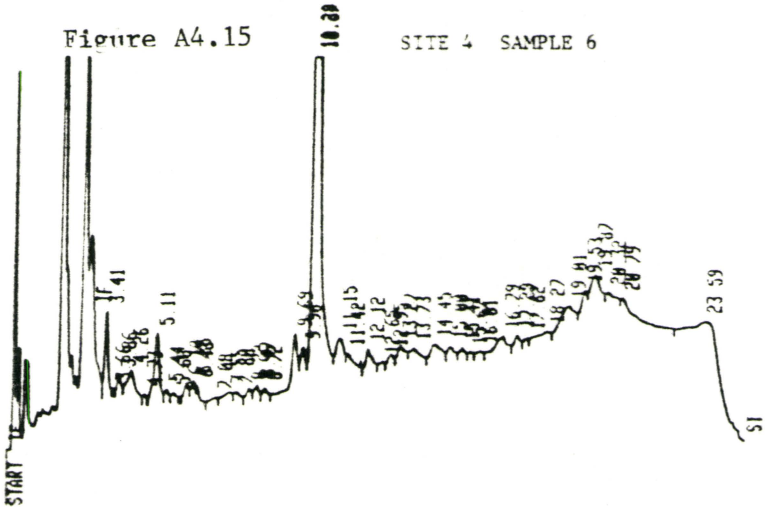
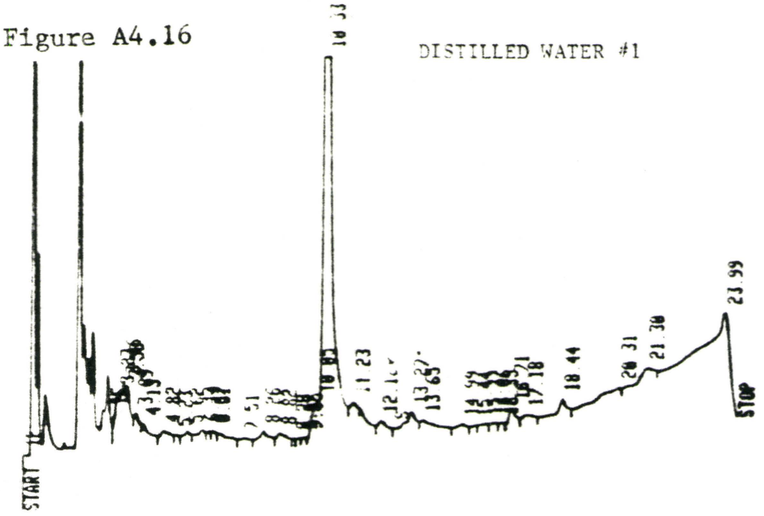
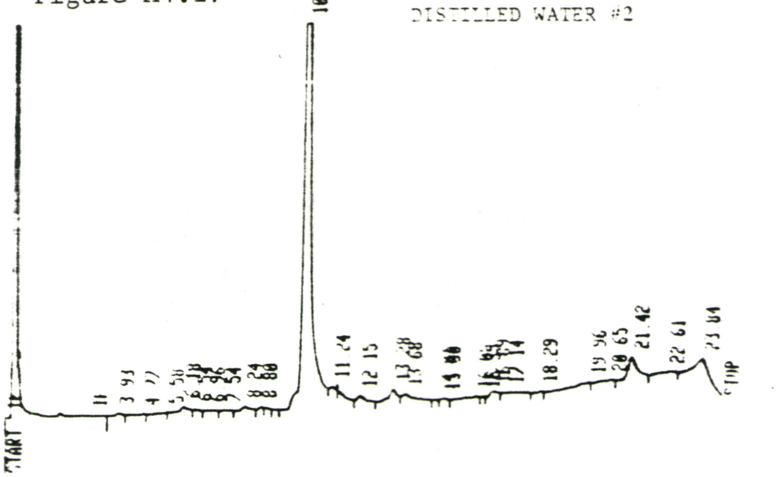


Figure A4.16



DISTILLED WATER #1

Figure A4.17



DISTILLED WATER #2