B-ZONE PIT:

THE FATE OF ARSENIC AND NICKEL

The proof is in the sediment

FINAL REPORT 1998

For

CAMECO Corporation

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1.0 INTRODUCTION

In the winter of 1991, the B-Zone Pit was force-flooded with Collins Bay water and, in the following summer, the process of collecting limnological data was initiated. These data, which include depth profiles of pH, Eh, O_2, electrical conductivity, temperature and water chemistry (47 parameters in all), have since been collected and analysed 3 to 5 times a year. The samples have been collected every 5 m, to the bottom of the pit - a maximum depth of 52 m.

Details of the limnology of the pit were described in July 1993, in Appendix 4A of the Cameco report entitled: *"Collins Bay B-Zone Decommissioning Year 1-Proposed Target Levels"*. This man-made lake stratifies and turns over after the breakdown of the thermocline in fall, when it is ice-covered. After the pit was flooded, the concentrations of the principal contaminants, As and Ni, were an order of magnitude higher than the SSWQ-defined objectives for the protection of aquatic life. In an attempt to reduce the already, relatively-low concentrations of As and Ni (0.3 mg/L), the use of supplemental TSS (consisting of inorganic and organic compounds) was evaluated. The objective of using this procedure to satisfy the SSWQ objectives was to minimize additions of chemicals which could produce environmentally unstable sludges in the pit bottom. The TSS would serve to stimulate and regulate the natural cleansing mechanisms of the lake, a process referred to as Biological Polishing.

Cameco engaged in an intensive research program to analyse and document the Biological Polishing processes which were taking place in the pit. An interpretation of the limnological and biological data, in conjunction with laboratory and field experiments on the absorption of the contaminants, lead to the formulation of a hypothesis which appeared to 'explain' these contaminant removal processes. In January, 1995, the overall limnology of the flooded pit was documented in a Cameco report entitled: *"Collins Bay, A-Zone, D-Zone and Eagle Point Waste Management Plan".*

After three growing seasons, it was evident that total and suspended As and Ni loads in the pit had decreased by 22% to 35%, and that Fe had been reduced by 39%. The transport from the surface water to the thermocline appeared to be facilitated by a mucilage forming algae, *Dictyosphaerium pulchellum.* Based on the quantity of material collected in sedimentation traps, as well as an evaluation of this algae's productivity, it was estimated that 31 tonnes of dry weight biomass per growing season was produced by this algae. The algal biomass and the inorganic component of TSS in the 2 m sedimentation traps could account reasonably well for the decrease in Ni and Fe concentrations in the surface water, but they could not explain the reduction in As concentrations. By our estimation, they could account for only one-tenth of the As load in the surface water. This finding suggests that the adsorption behaviour of As differs from that of Ni.

The report, *"B-Zone Pit Limnology 1993 to 1996 and the Fate of Arsenic and Nickel"*, submitted to Cameco in May of 1997, summarized the pit limnology up to the end of 1996 and described the results of the research program's experiments. It concluded that the contaminant removal processes taking place were as follows. As the biomass reaches the thermocline, some decomposition of the algal biomass takes place, resulting in the release of previously adsorbed Ni. The As, however, adheres or adsorbs onto inorganic, especially iron, particulates, which facilitates its complete movement to the bottom sediments. The sedimentation traps at 32 m below the thermocline contained some TSS material, which showed enrichment of As (up to 0.3%) and Ni (up to 0.1%).

The growth characteristics of the dominant algae in the B-Zone Pit, and the adsorption characteristics of As and Ni to the biomass, were studied extensively and reported in detail in 1996 by M. Kalin and M. Olaveson in: a) *"Controlling Factors in the Production of Extracellular Polysaccharides in Phytoplankton"*, pp.109, CANMET contract # 23440-5-1136/01 SQ; and in 1997 by M. Kalin in b) *"Nickel and Arsenic Adsorption onto Mucilage Producing Algal Colonies"*, CANMET Biotechnology, pp 28, CANMET Contract # 23440-6-1011/001/SQ. These studies confirmed the difference in rates at which As and nickel removal from surface water takes place. Nickel adsorption reached a maximum at 2.5 mg/L, and decreased with higher concentrations, whereas As adsorption onto the biomass was very low. This explains the changes in the seasonal concentrations of nickel in the surface water of the pit, and the lack of cycling of arsenic concentrations.

The data interpretation that was carried out for the period 1992-1996 suggested that, by increasing the biomass in the surface water, nickel concentrations might be further reduced. A greater mass of nickel would be transported by the biomass to the thermocline, thereby increasing the fraction which might reach the pit bottom, despite the cycling of the majority of the pit's nickel load.

To determine the measures that would increase biomass in the pit, factors controlling biomass production had to be determined. It was postulated that ecosystems without a picoplanktonic algal (an algal population smaller than 2 :m, not visible with an optical microscope) are stressed systems and, therefore, limit biomass production. At the same time, it was recognized that, since picoplankton can form up to 80% of the primary productivity in surface water, its presence or absence is relevant to natural ecosystem processes required for contaminant removal.

Generally, picoplankton has low light and temperature requirements, conditions which prevail in the lower parts of the pit. For *Dictyosphaerium pulchellum,* the larger and dominant algae in the pit with colonies held together by the mucilage, the cells deteriorate with depth. This process could release nutrients, which would feed the microbial populations at the thermocline. Picoplankton were found at depth during the 1996 investigations and these findings were summarized in 1997 in a report by M. Kalin, W. Wheeler and M.P. Smith: *"The Role of Picoplankton as Primary Producers in Mining Waste Water Effluents"*, CANMET Contract #23440-5-1302/001/SQ.

Although picoplankton was contributing to primary productivity, whether these small particles/biomass were involved in the transport of As and Ni (i.e., they represent material with adsorptive capacity but are not separated by 0.45 :m filtration), was unknown.

The role of particles in the pit was examined in more detail in a 1998 University of Toronto MSc thesis (Department of Geology) by E.A. Lowson. Entitled *"Chemical, Physical and Biological Characteristics of Particulates Formed in Mine Drainage Environment"*, the thesis evaluated the particle size and the nature of the material collected in the sedimentation traps.

It was clear that the contaminants in the pit were associated with very small particles, which remained suspended in the water column for a long time. In addition, the chemical form of “dissolved” As and Ni, as defined by 0.45 :m filtration, did not apply, since pit water chemistry is dominated by colloidal chemical reactions. Colloids may be relevant, not only to an explanation of the transport of particles, but also to altering the toxicity of the B-zone pit water.

If the contaminants are indeed colloidal, they could be less toxic than those in ionic form. With a series of experiments using various iron salts and surface active materials such as bentonite, the chemical forms of As and Ni in the surface water were indirectly defined. Organically complexed Ni and As were shown to be the likely prevailing forms of particulates.

All of these studies aided in the formulation of the currently proposed transport mechanisms and, building on this previous work, this report presents the 1997 and 1998 data, and interprets those data in light of our current understanding of both the pit’s limnology and contaminant behaviour.

1.1 The contaminant transport process

The As and Ni transport process, as it is currently understood, is based on the well-documented behaviour of the water body in the B-zone pit, and is summarized below. The process is governed by the seasonal dynamics in the surface strata and the formation of the physical conditions associated with the dimictic pit lake, as well as the growth dynamics of the primary productivity in the pit.

The transport of Ni from the surface water to the thermocline, which can extend to depths of 8-10 m, is brought about by adsorption onto algal biomass. The physical conditions, i.e., the complete turnover of the water body during the winter months and the decomposition of the organic material in the lower portion of the pit, result in the re-release of the Ni which was removed from the surface water during the summer months. Both organic and inorganic material, collected in sedimentation traps positioned at different depths in the pit, suggested that a small fraction of the contaminants are carried to the sediments. The sedimentation trap data suggest that the total load of contaminants in the pit water is being reduced year by year. This confirms the water quality monitoring data, which also suggest ongoing removal, particularly of arsenic, and to a lesser extent of nickel.

A small fraction of As and Ni binds to very small iron/silica oxide particles, which are unable to overcome the hydrodynamic conditions which prevail in the pit while a thermocline is present. Particles can only settle to the bottom of the pit during the brief period when the pit is not stratified, underneath the ice. A larger fraction of Ni than As is re-circulated back to the surface water, since Ni is mainly adsorbed to the biomass which decomposes at the thermocline, whereas As, adsorbed to the inorganic oxides, is not decomposed, and hence is more likely to reach the bottom. In general, the biomass in the surface water is instrumental in transporting both As and Ni to the thermocline. Once there, the biomass no longer influences their pathways to the sediment at the bottom of the pit, since the As adsorbs to the iron particles and the Ni is released from the biomass. The fraction of each contaminant reaching the bottom of the pit, however, remains a function of the total amount reaching the thermocline.

1.2 Limitation of biomass production

If the proposed role of biomass in contaminant transport is correct, then an increase in biomass would assist in the cleansing process. It was predicted, however, that the productivity and growth of biomass would decrease, since nutrient depletion clearly reduced productivity between 1995 and 1996. It appears that the pit closely resembles an isolated water body, receiving no new inputs of contaminants or other elements. The pit chemistry profile can be accounted for by all the internal processes, which are driven by photosynthesis of algae, bacterial respiration and the physical changes induced by temperature, which govern the hydrodynamics of particle settlement to the sediment.

The biological/natural recovery of pit water quality to SSWQ objectives (particularly with respect to Ni) is likely to be a slow process but, if the postulated processes are indeed taking place, its progress would be assisted by nutrient additions. An estimated 720 kg of nitrate, added to the epilimnion, would be adequate to significantly increase biomass. Before initiating a full-scale test of the procedure, however, it was decided to continue to observe the role of biomass by allowing its growth and productivity to further decline. At the same time, from 1997 through 1998, the proposed mechanisms were tested by:

a) sampling the sediment in the pit bottom, and quantifying the mass of As and Ni which had reached there since the pit was flooded, relative to the material collected in sedimentation traps;

b) confirming the association of As and Ni with particles smaller than 0.45 :m by filtration, ranging from 0.1 :m to 1.0 :m.

c) quantifying nutrient cycling in the pit and the biomass role, or ecosystem development.

Early in 1998, the 1997 data on the limnology of the pit was summarized in support of the current report. All of the data are given in Appendix 1, dated March, 1998. No changes in the pit behaviour which would alter the proposed transport and removal processes were noted, which was very encouraging. It was decided to perform chemical analyses on the materials from sedimentation traps that had been collected in previous years, in order to elucidate the relationship between elements in the water and particles.

2.0 PHYSICAL/CHEMICAL/BIOLOGICAL PARAMETERS OF THE PIT

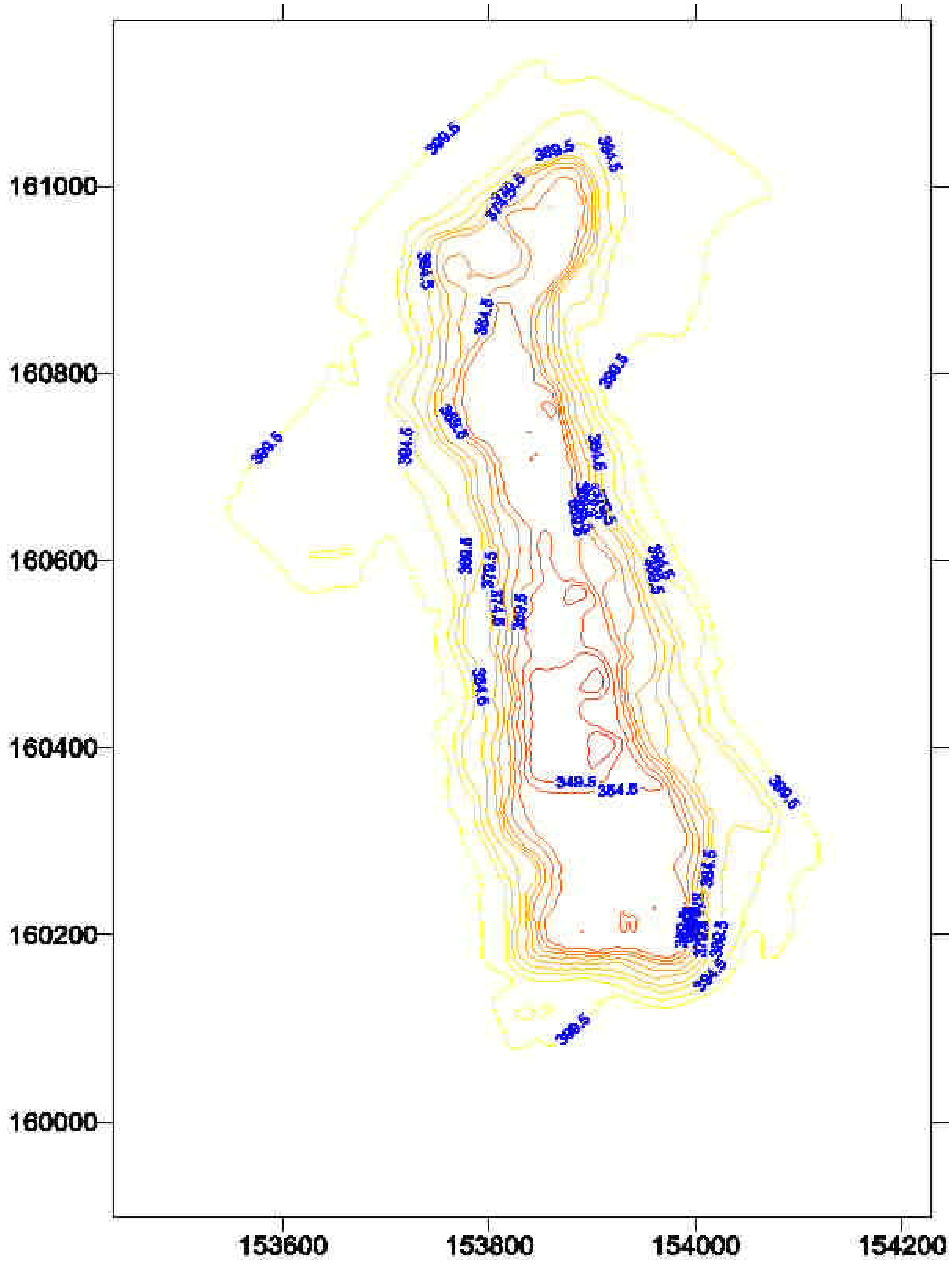
Up until 1997, it was estimated that the flooded pit contained approximately 5 x 10^6 m^3 of water, and had a surface area of 240,000 m^2 and an elevation of 398 m. These estimates were based on hand approximations of contours taken from a spot elevation map of the pre-flooded open pit (Cameco drawing, February 26 1991), which were then digitized. Estimates of the surface areas of various depths were generated using DesignCad 2D software. These were then multiplied by the thickness of the layer to give an estimate of the volume of water between the depth intervals at which the sedimentation traps were suspended.

An aerial photograph taken in 1995 showed the actual extent of the pit flooding, and it warranted a modification of area and volume estimates. These matched an October 1995, pit surface elevation of 399.6 m. Using the software (Surfer V6), pit volume, planar area and pit wall surface area were calculated for various intervals.

The revised pit volume is currently estimated at 5.7 x 10^6 m^3, and the pit planar area at 304,842 m^2. A comparison of the old and new areas and volumes is provided in Table 1; more details are given in Appendix 2, Table 1. On the following page, Map 1 shows the revised pit shape. The 1.5 m increase in pit surface elevation, combined with a more detailed analysis of the planar area using the Surfer program, accounts for the relatively large changes in the planar areas of the 32-42 m and the 42 m-bottom intervals.

Table 1: Areas and depth contours of the flooded pit as report in 1996 versus 1998.

Depth Interval	Area of Interval			Volume of Interval		
m	1996 m^2	1998 m^2	% change	1996 m^3	1998 m^3	% change
0-2	240,000	304,842	27	480,000	510,160	6
2-12	168,000	223,317	32	1,680,000	1,858,760	10
12-22	131,000	155,743	19	1,310,000	1,352,610	3
22-32	100,000	120,102	20	1,000,000	1,051,468	5
32-42	43,000	87,774	104	430,000	721,753	68
42-bottom	43,000	52,340	22	344,000	203,389	-41


161000
160800
160600
160400
160200
160000
153600
153800
154000
154200
349.5
364.5
384.5
379.5
374.5
369.5

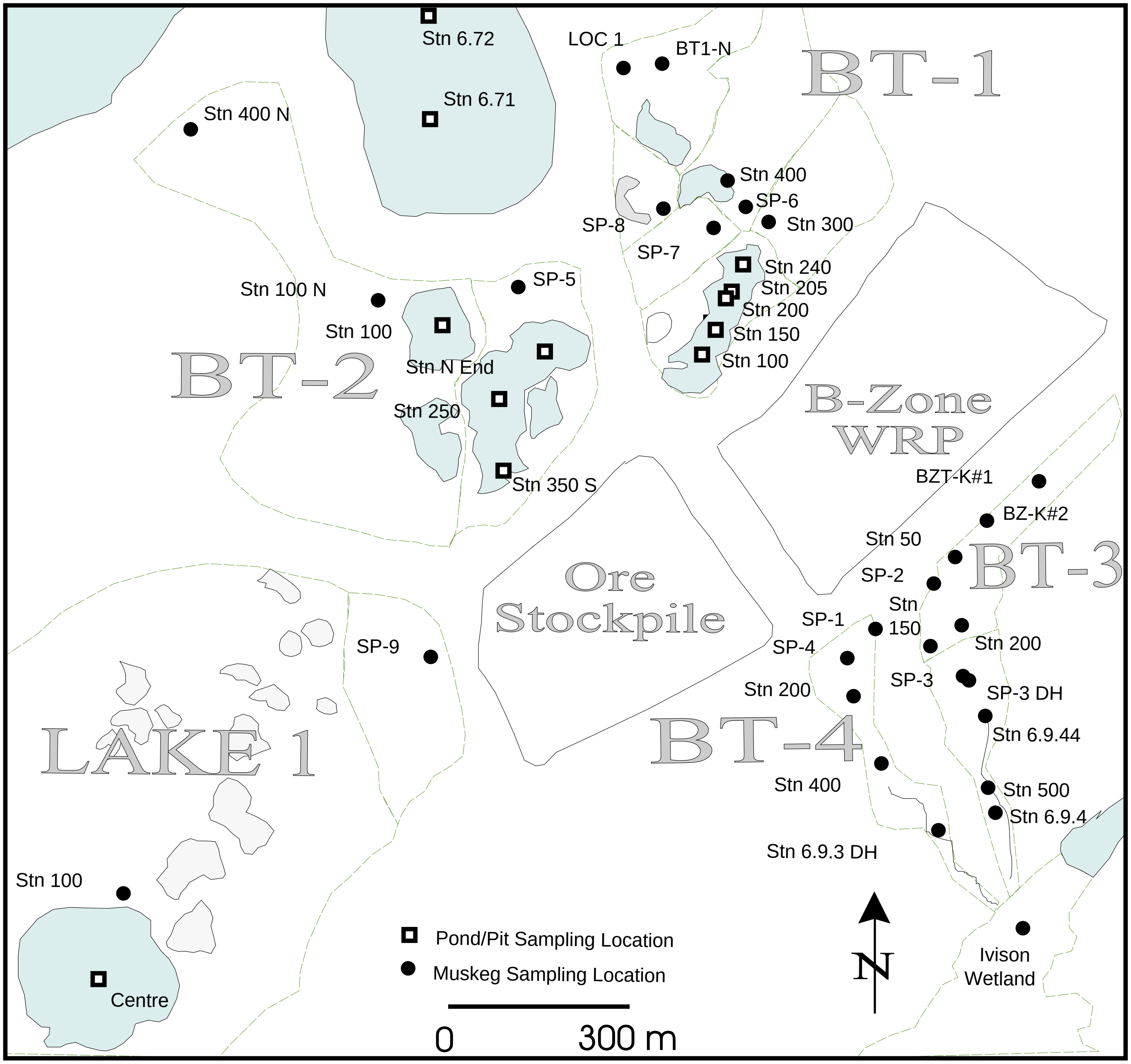
The chemistry profile and physical parameters of the pit (measured by depth for 4 separate seasonal sampling periods) are summarized for the period 1993-1997 in Appendix 1. For ease of reference, sampling stations in the pit are shown on the following page in Map 2. In order to evaluate the changes relevant to the transport mechanisms, only those profiles from locations 6.72, which reach the deepest part of the pit, needed to be considered.

In attempting to provide an effective way to present the changes in the pit parameters, the years 1993 to 1997 are presented in Appendix 1; they are referred to by the same figure numbers (Figures 1 to 17) that are used here in the main text to present the data for the most recent years, 1997/1998.

The stratification, as expressed by temperature, did not change between 1993 and 1997 (Figures 1a to 1d, Appendix 1) and it consistently reached a depth of about 20 m by the end of the growing season. The pit was warmer (20^0C) in the 1998 summer season than in any previously-measured summer (Figures 1a to 1d, page 11). Dissolved oxygen was generally lower in 1997 during the ice free season, and remained low, at around 9 mg/L below a depth of 25 m, throughout the season (Figure 2a to 2d, Appendix 1). More oxygen was consumed each year, as increased algal growth generated organic matter. This organic matter would have moved slowly through the water column, supplying nutrients for heterotrophic bacteria which consume O_2 and release CO_2 by respiration. Oxygen concentrations remained low throughout the growing season of 1998, unlike previous summers, when marked increases were noted. These lower 1998 summer levels were to be expected given the lower levels of biomass growth, since algae produce O_2 during growth, as opposed to bacteria, which consume it (Figures 2a to 2c, page 12).

Starting in 1997, lower oxygen concentrations were reflected in low Eh values, evident from June until October 1997 (Figures 3a to 3d, Appendix 1). In 1998, the Eh remained low at the beginning of the year, and increased only somewhat over the previous year's low Eh maximum of about 100 mV during the growing season (Figures 3a to 3d, page 13). This is indicative of fewer redox reactions taking place, compared to previous years.

Map 2: B-Zone Sampling Stations.



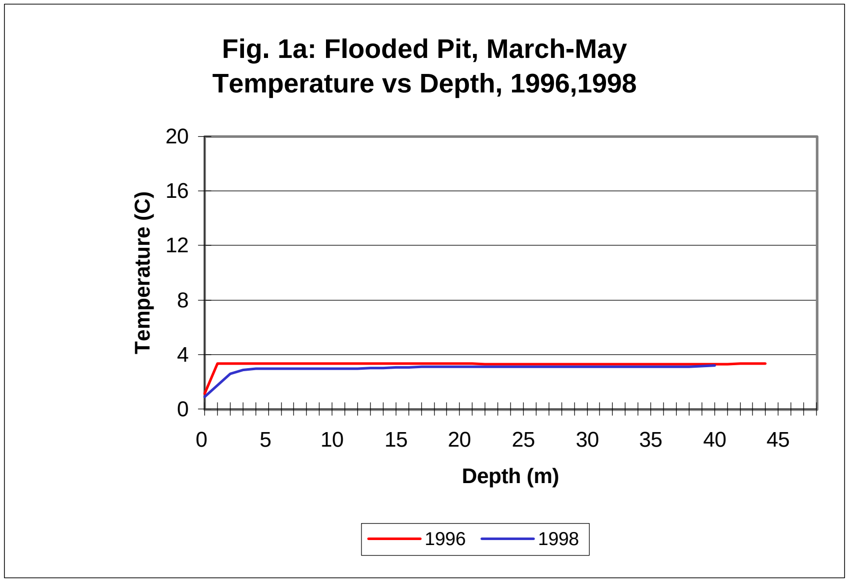


Fig. 1a: Flooded Pit, March-May Temperature vs Depth, 1996,1998

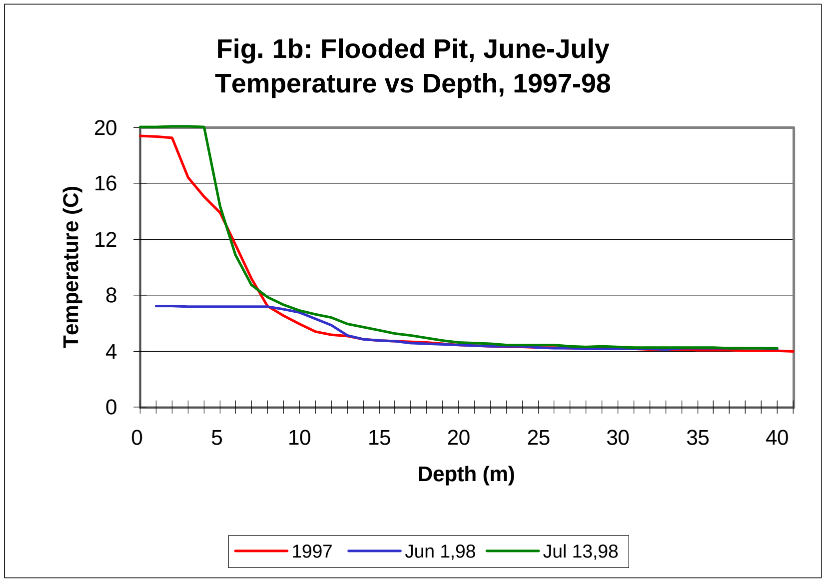


Fig. 1b: Flooded Pit, June-July Temperature vs Depth, 1997-98

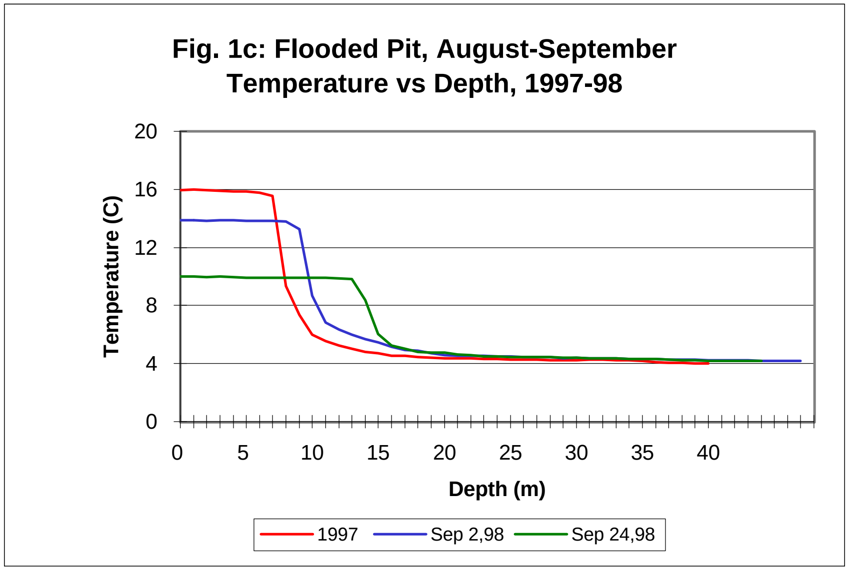


Fig. 1c: Flooded Pit, August-September Temperature vs Depth, 1997-98

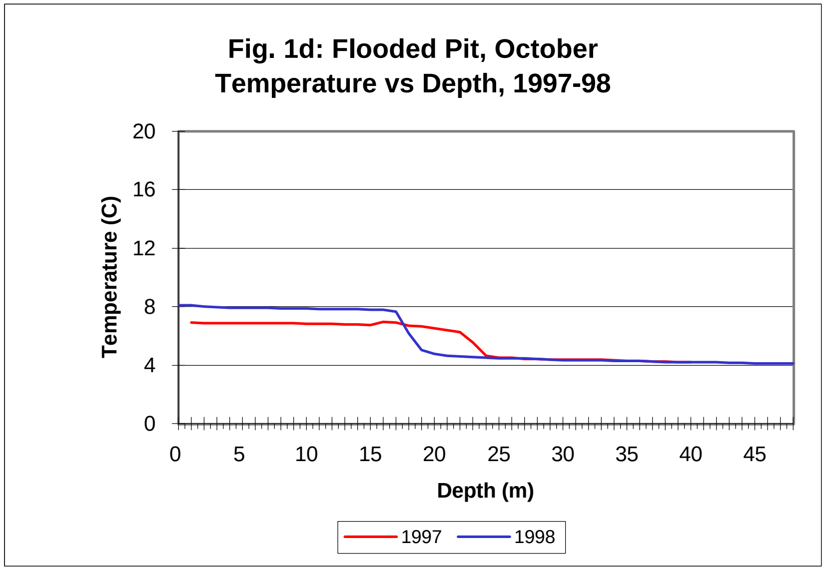


Fig. 1d: Flooded Pit, October Temperature vs Depth, 1997-98

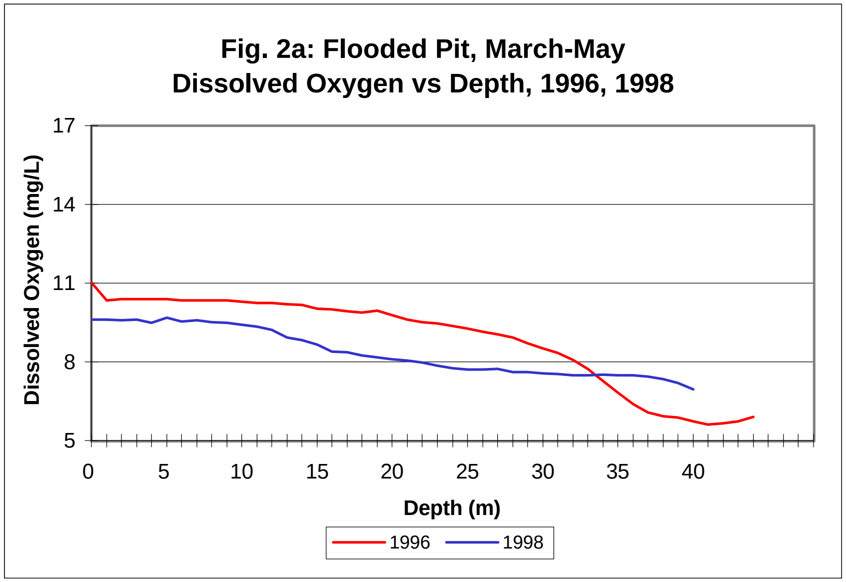


Fig. 2a: Flooded Pit, March-May
Dissolved Oxygen vs Depth, 1996, 1998

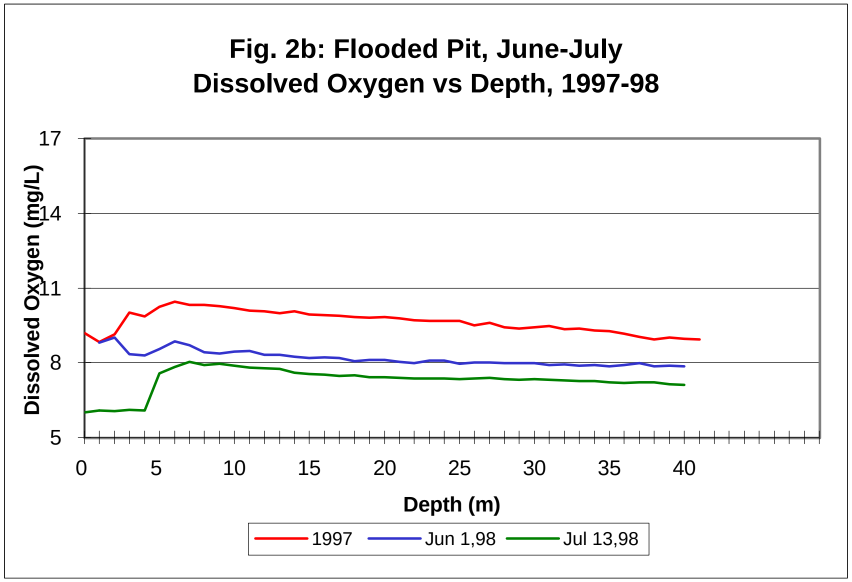


Fig. 2b: Flooded Pit, June-July
Dissolved Oxygen vs Depth, 1997-98

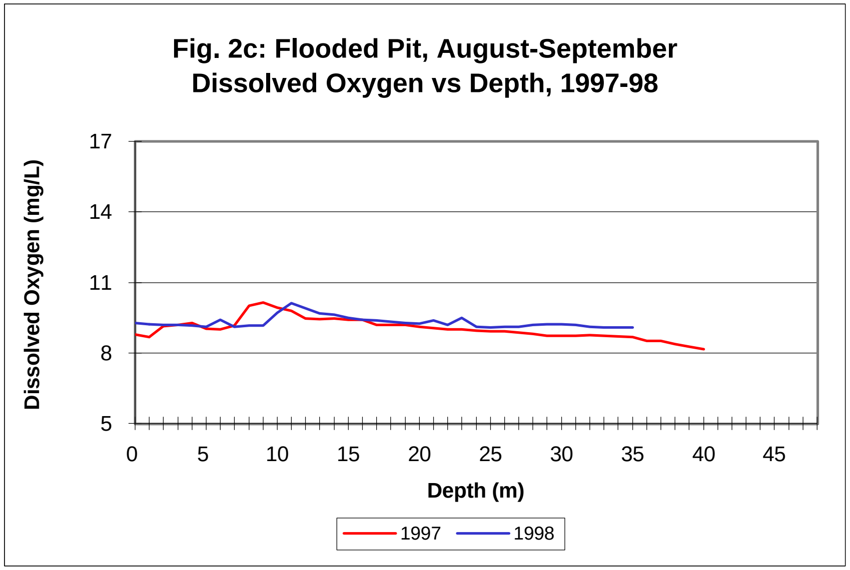


Fig. 2c: Flooded Pit, August-September
Dissolved Oxygen vs Depth, 1997-98

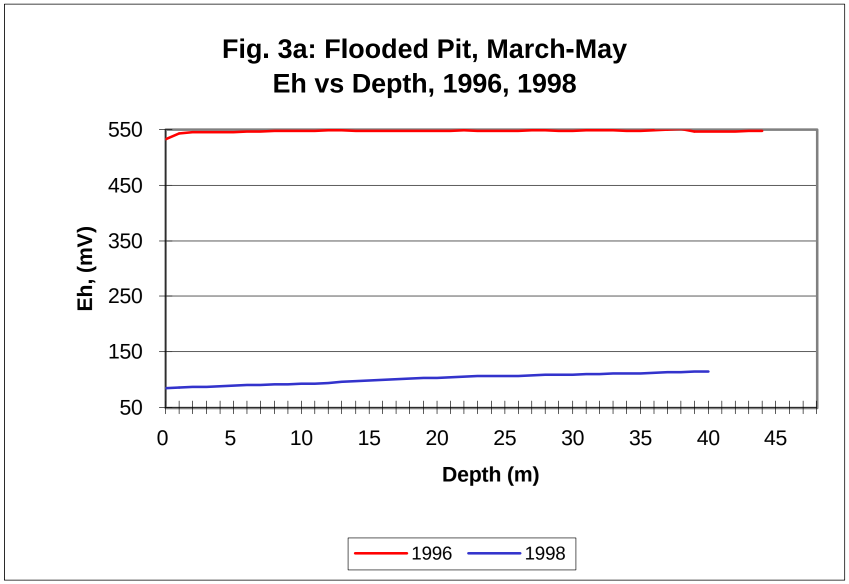


Fig. 3a: Flooded Pit, March-May
Eh vs Depth, 1996, 1998

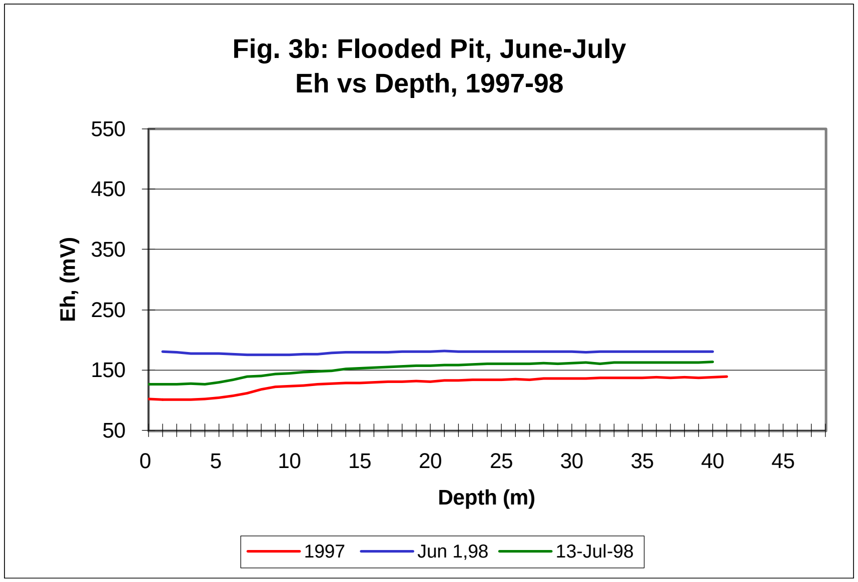


Fig. 3b: Flooded Pit, June-July
Eh vs Depth, 1997-98

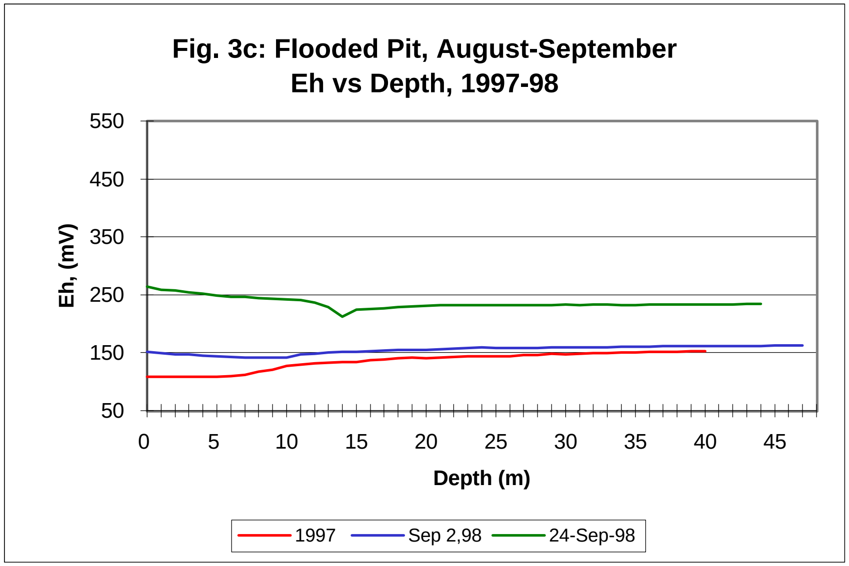


Fig. 3c: Flooded Pit, August-September
Eh vs Depth, 1997-98

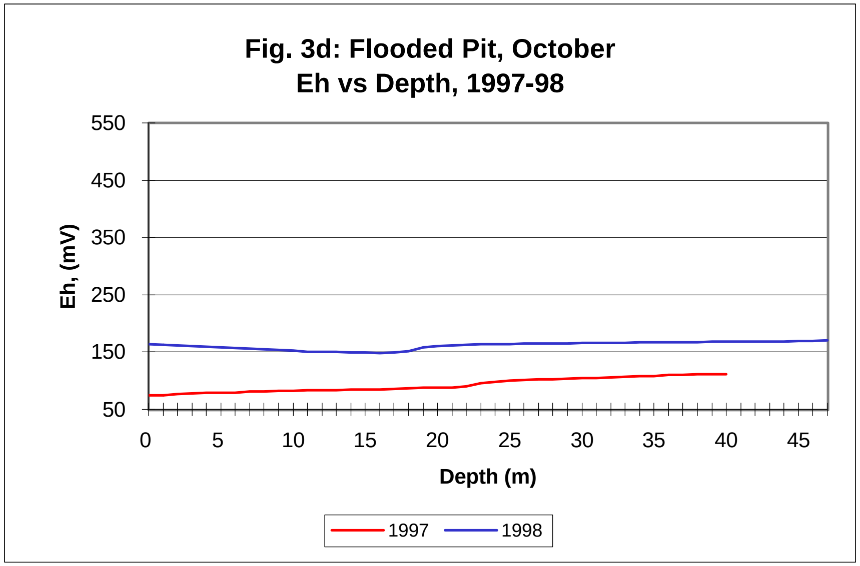


Fig. 3d: Flooded Pit, October
Eh vs Depth, 1997-98

Since oxygen and Eh affect microbial activity, it is not surprising to see a slight increase in pH during the growing season in 1997 (Figures 4a to 4d Appendix 1). By 1998, pH increased to around 7 with depth, and reached 7.5 by the end of the growing season. Such levels cannot be attributed to primary productivity alone (Figures 4a to 4c, page 15), and indicate that other biological activities (such as microbial utilisation of nitrate) have to be involved.

Conductivity in the pit did not change in 1997, compared to the slight annual increases that were evident in previous years (Figures 5a to 5d, Appendix 1). By 1998, the freeze-out effect of the ice cover was very clearly expressed underneath the ice (Figure 5a, page 16), but since no elements which are affected by freeze-out remained in the water, no reduction in conductivity took place. Neither did conductivity increases occur in the summer season, and electrolytes (contributing to conductivity) appeared to increase only slightly during the summer months (Figures 5b to 5d).

Since conductivity levels are quite stable, since no permanent chemocline exists, since the surface drainage basin of the pit is relatively small, and the since hydraulic head between the regional groundwater table and the lake level is minimal, it can be assumed that the water body in the B-Zone Pit is not currently receiving any significant input of major ions or other elements. Given this, then only elements which are concentrated by biota would be expected to change slightly with depth, due to decay and growth. The concentrations of elements in aquatic biota are generally more than 1000 times higher than those found in the water. P, for example, can be 80,000 times more concentrated, N, 30,000 times, C about 5000 times, and Si 2,000 times more highly concentrated than in the host water (J.R. Vallentyne, 1974, *The Algal Bowl - Lakes and Man*, Miscellaneous Special Publication 22, Ottawa, Department of Environment).

This means that, if the dynamics of the B-Zone Pit have been affected by decreasing biological activity, the pit should be moving towards a "steady state", and major elements should be beginning to show a more constant pattern, in comparison to the previous years, 1992-1996.

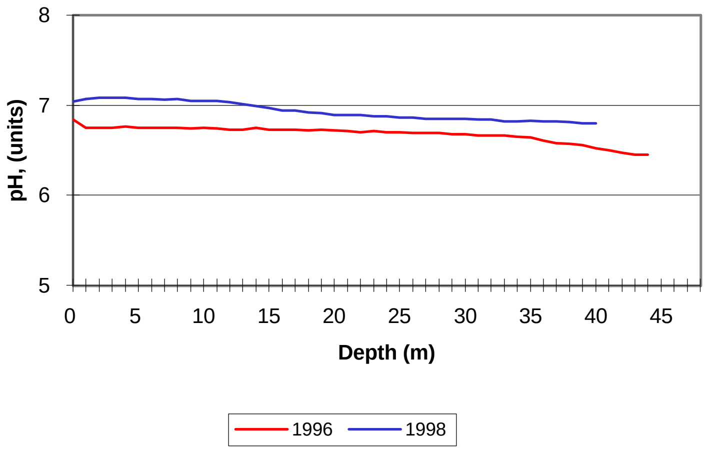


Fig. 4a: Flooded Pit, March-May
pH vs Depth, 1996, 1998

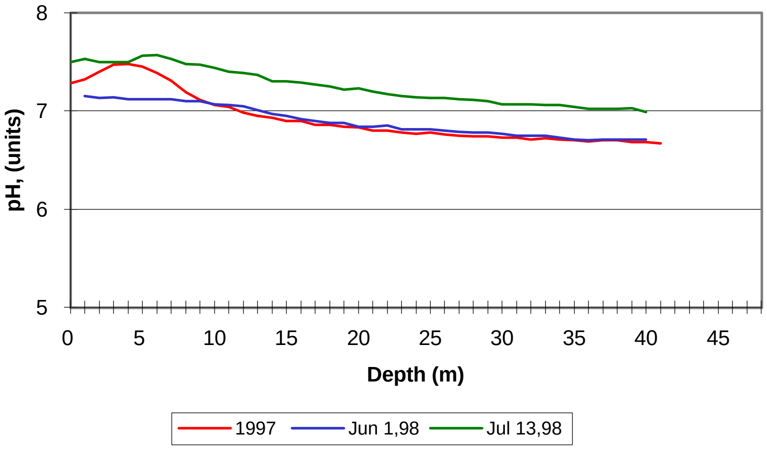


Fig. 4b: Flooded Pit, June-July
pH vs Depth, 1997-98

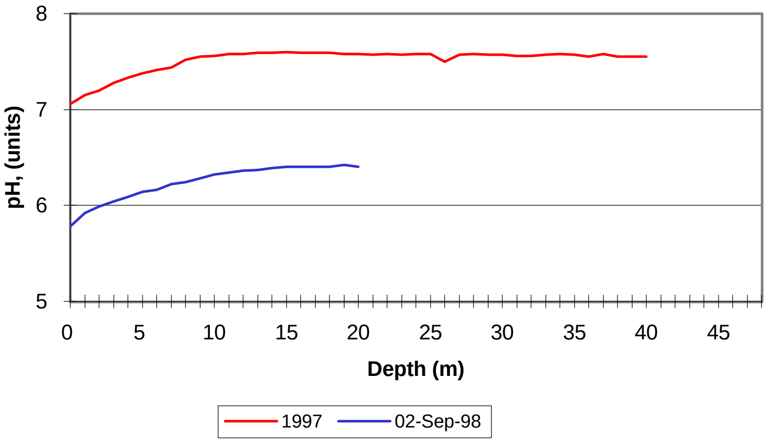


Fig. 4c: Flooded Pit, August-September
pH vs Depth, 1997-98

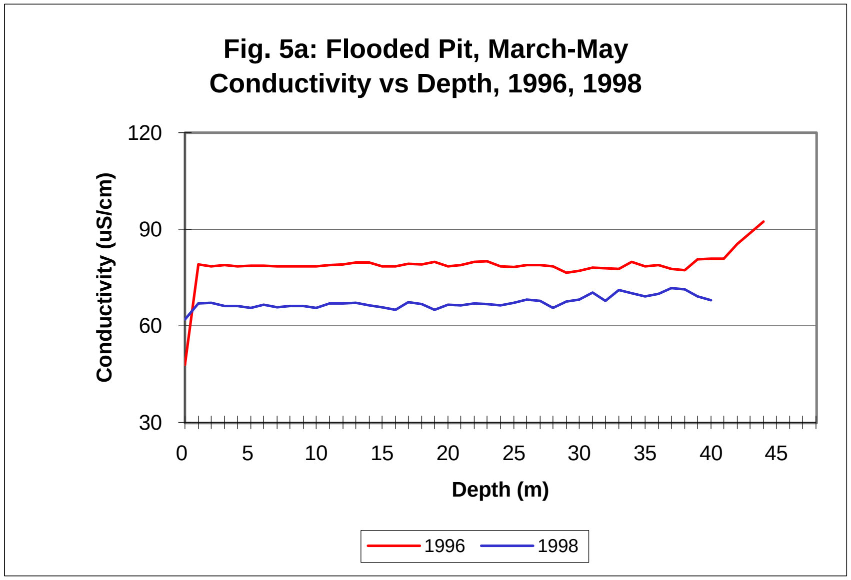


Fig. 5a: Flooded Pit, March-May
Conductivity vs Depth, 1996, 1998

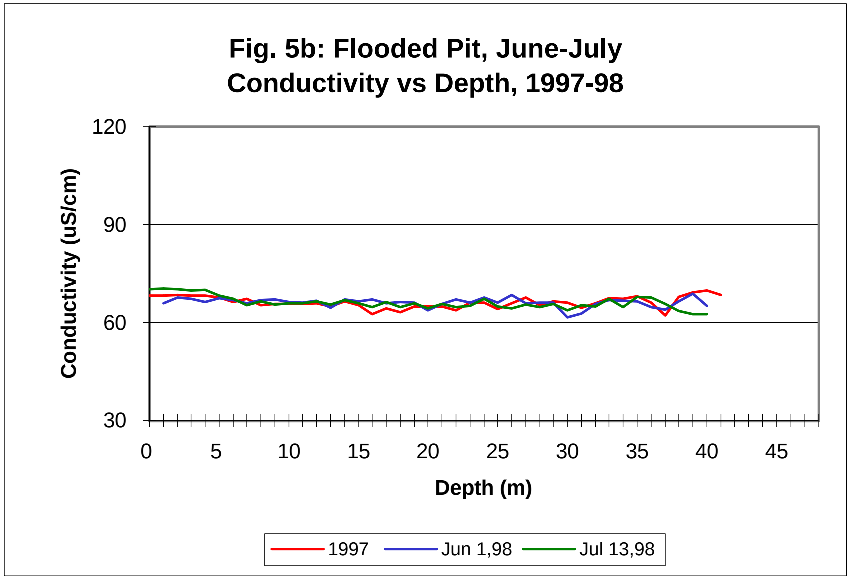


Fig. 5b: Flooded Pit, June-July
Conductivity vs Depth, 1997-98

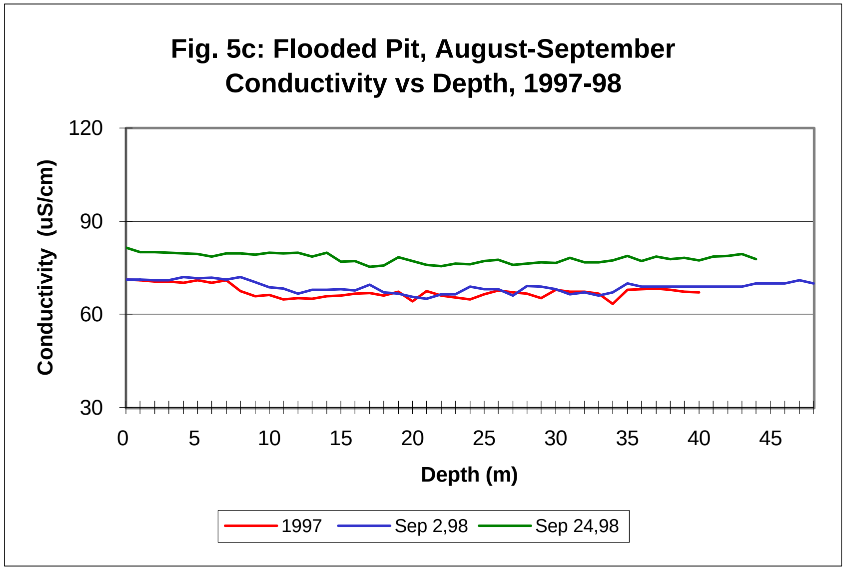


Fig. 5c: Flooded Pit, August-September
Conductivity vs Depth, 1997-98

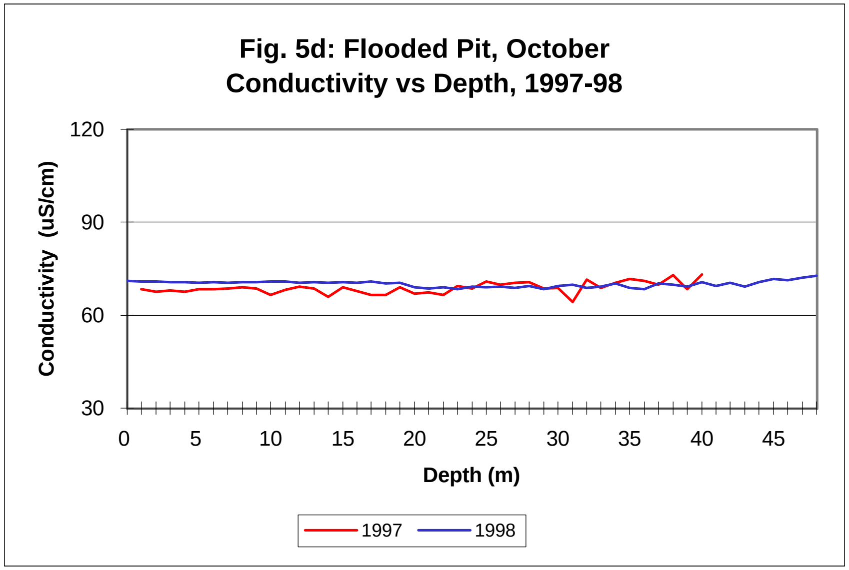


Fig. 5d: Flooded Pit, October
Conductivity vs Depth, 1997-98

At the very bottom of the pit, when it is ice-covered, increases in concentrations are evident for the elements sodium (Figures 6a to 6d, Appendix 1), potassium (Figures 7a to 7d, Appendix 1), magnesium (Figures 8a to 8d, Appendix 1), and calcium (Figures 9a to 9d, Appendix 1). These increases were still evident in 1997, although the fluctuations in concentrations with depth were becoming less pronounced. A comparison of the years 1997 and 1998, however, is striking, in that it shows essentially no fluctuations in the concentrations with depth, and minimal differences in concentrations for sodium (Figures 6a to 6c) potassium (Figures 7a to 7c), magnesium (Figures 8a to 8c) and calcium (Figures 9a to 9c). The Figures appear on pages 18 to 21.

Sulphate has exhibited one very distinct pattern since 1993, suggesting some release from bottom sediments, but this was evident only under ice cover (Figures 10a to 10 d, Appendix 1). In 1993, concentrations at the bottom increased from 10 to 28 mg/L, Thereafter, increases diminished annually until, since 1996, they are completely absent (Figures 10a to 10c, page 22).

Figures 11a to 11d, in Appendix 1, show steady increases in bicarbonate concentrations between 1993 and 1997. These increases, from less than 14 mg/L in early 1993 to about 23 mg/L by the end of 1997, are explained by increased biological productivity and greater light penetration as the surface water became clearer. Water clarity had further improved by 1998, resulting in even higher concentrations. These concentration levels also exhibited greater stability throughout the growing season than those recorded in previous years. Only in the early part of 1998 (Figure 11a, page 23), when the concentration level peaked to above 25 mg/L (the highest value ever reported for the pit), did any change occur. For the remainder of the growing season, concentrations decreased only slightly and remained stable (Figures 11a to 11c). It is clear from the major ions and physical parameters, that the pit is in a steady state - its dynamics being driven by physics and biology.

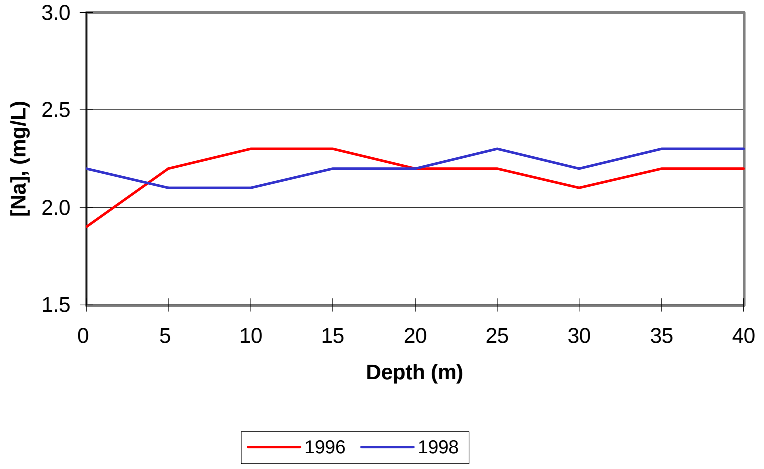


Fig. 6a: Flooded Pit, March-May
Sodium Concentration, 1996, 1998

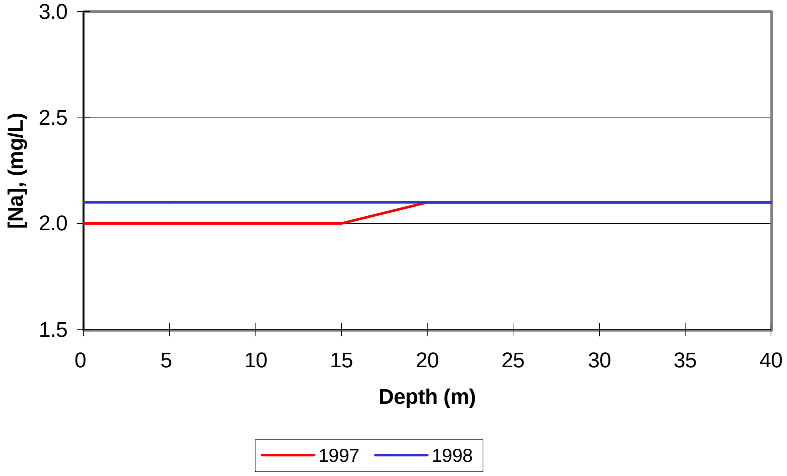


Fig. 6b: Flooded Pit, June
Sodium Concentration, 1997-98

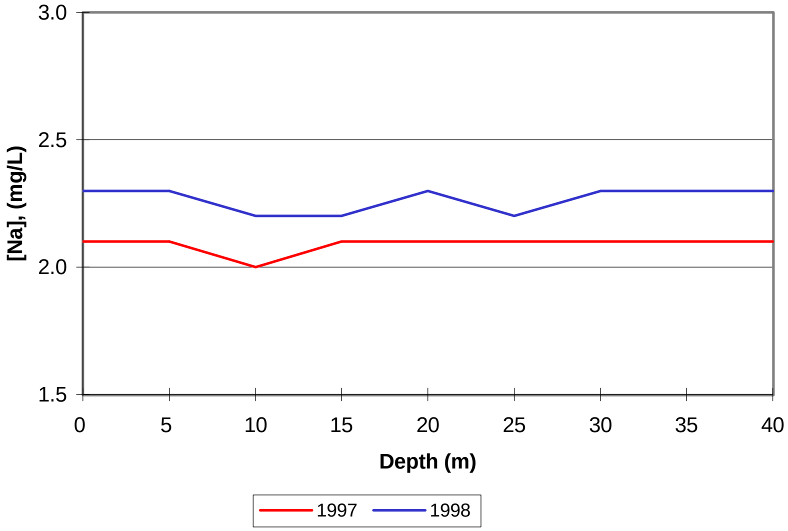


Fig. 6c: Flooded Pit, August-September
Sodium Concentration, 1997-98

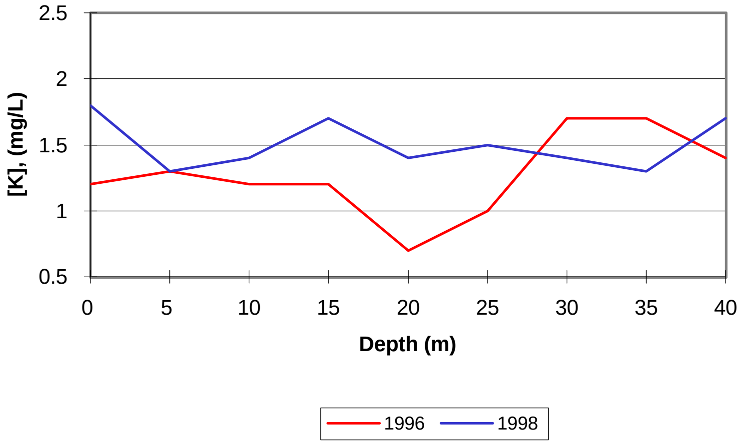


Fig. 7a: Flooded Pit, March-May
Potassium Concentration, 1996, 1998

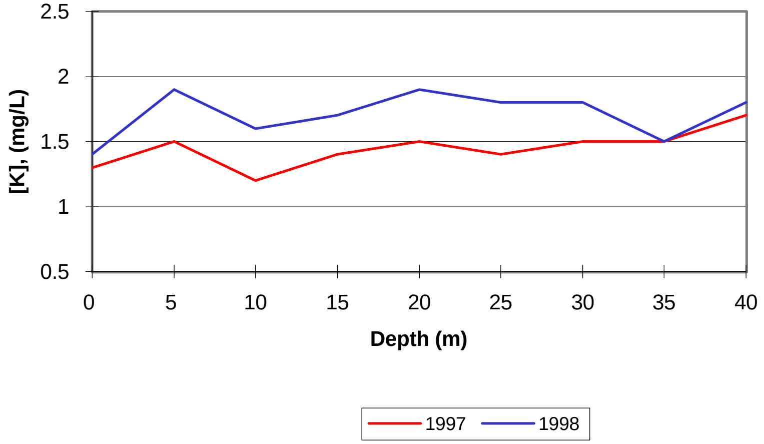


Fig. 7b: Flooded Pit, June
Potassium Concentration, 1997-98

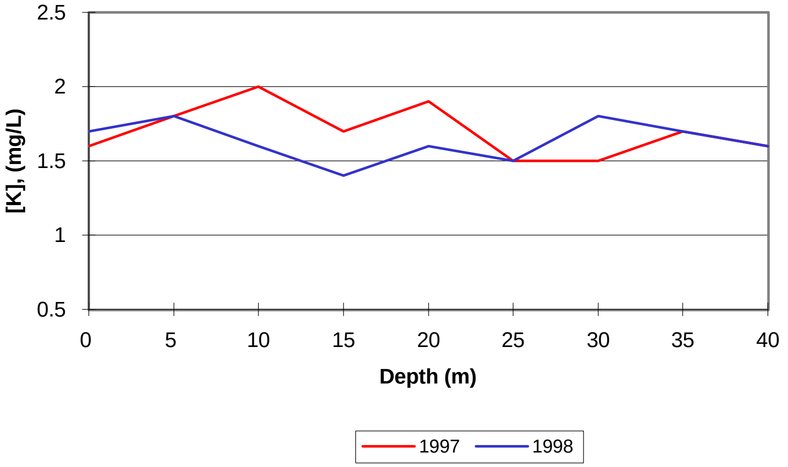


Fig. 7c: Flooded Pit, August-September
Potassium Concentration, 1997-98

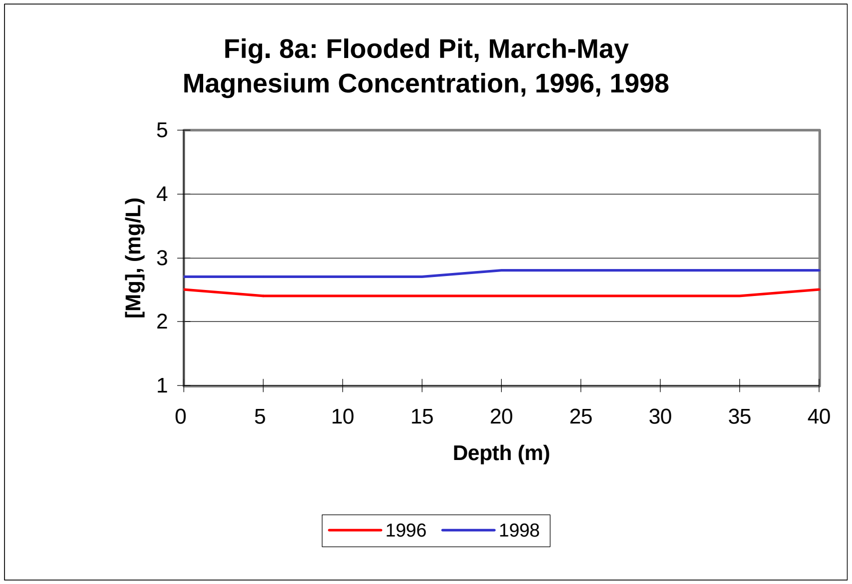


Fig. 8a: Flooded Pit, March-May
Magnesium Concentration, 1996, 1998

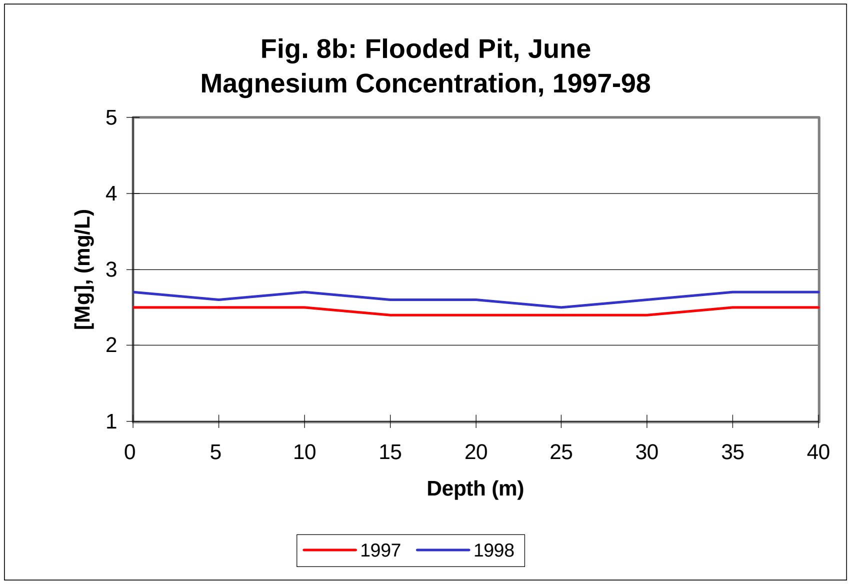


Fig. 8b: Flooded Pit, June
Magnesium Concentration, 1997-98

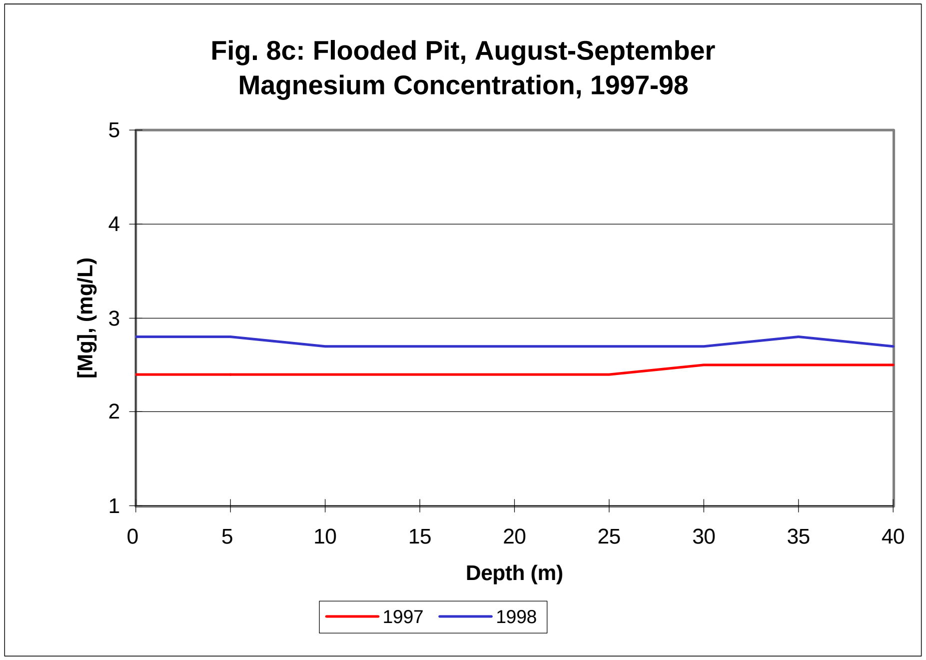


Fig. 8c: Flooded Pit, August-September
Magnesium Concentration, 1997-98

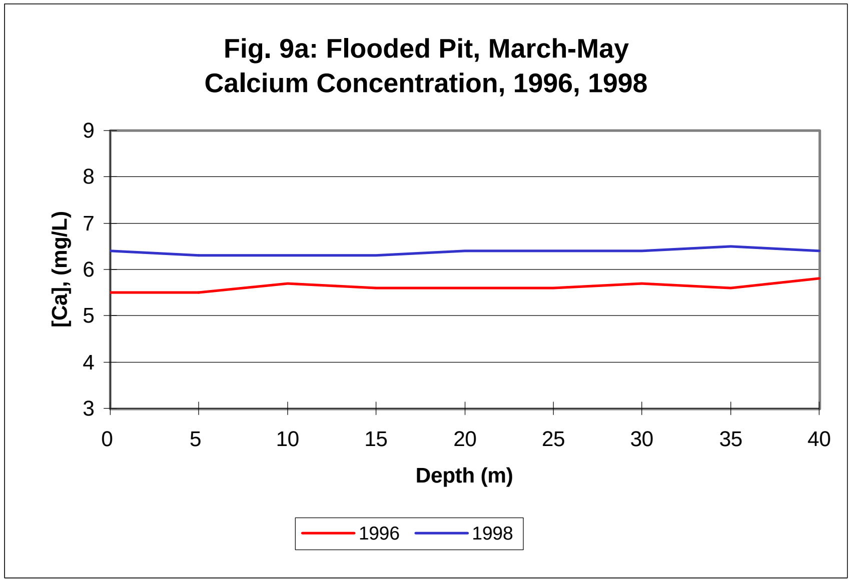


Fig. 9a: Flooded Pit, March-May Calcium Concentration, 1996, 1998

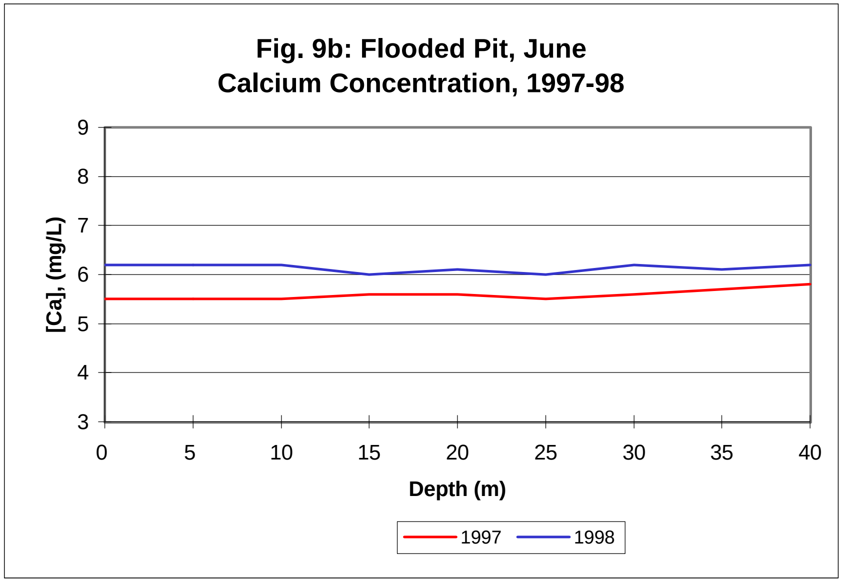


Fig. 9b: Flooded Pit, June Calcium Concentration, 1997-98

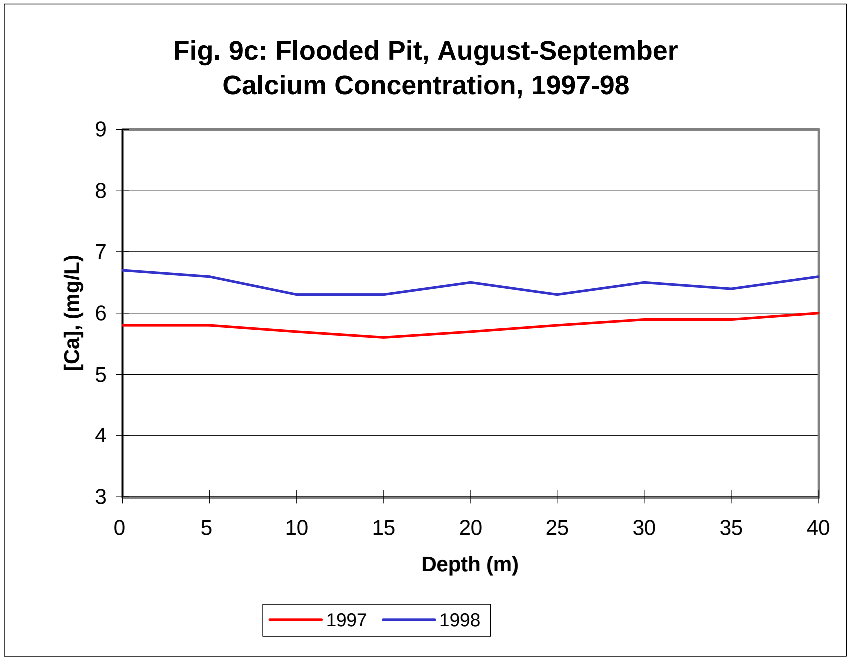


Fig. 9c: Flooded Pit, August-September Calcium Concentration, 1997-98

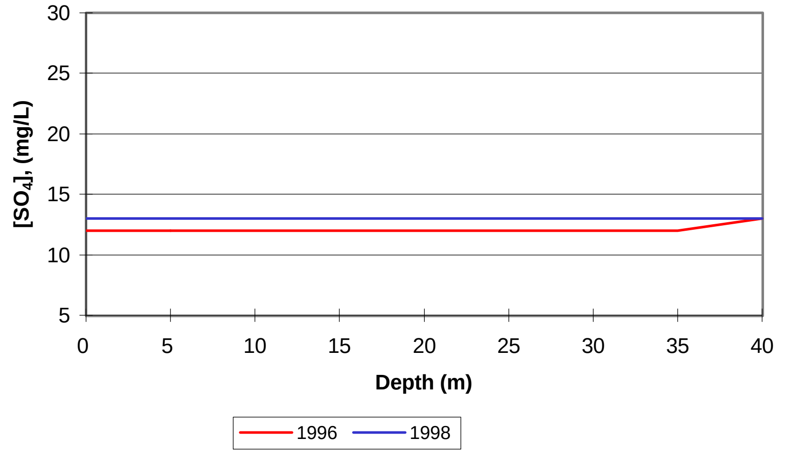


Fig. 10a: Flooded Pit, March-May
Sulphate Concentration, 1996, 1998

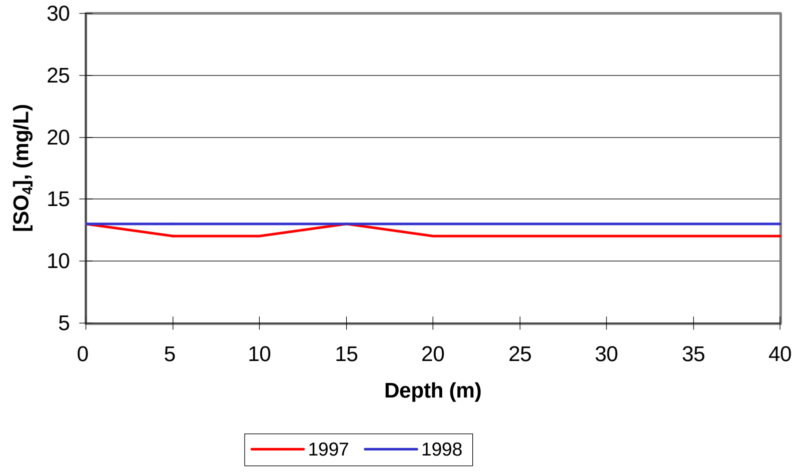


Fig. 10b: Flooded Pit, June
Sulphate Concentration, 1997-98

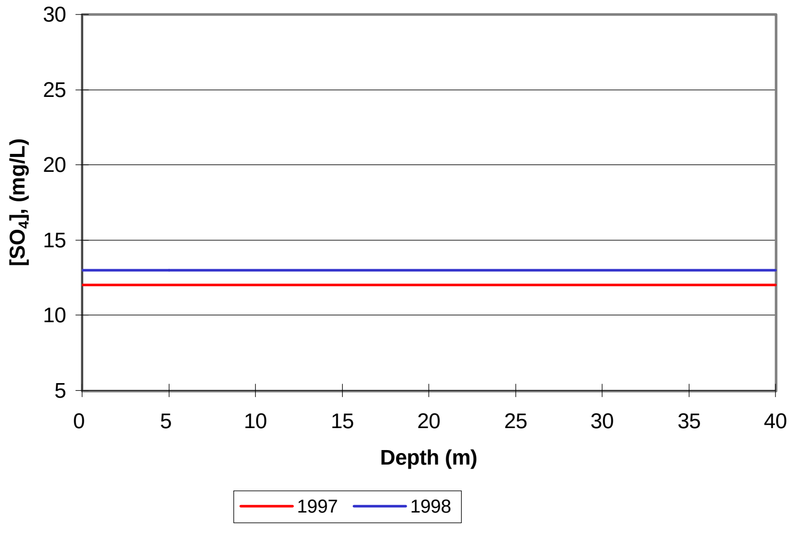


Fig. 10c: Flooded Pit, August-September
Sulphate Concentration, 1997-98

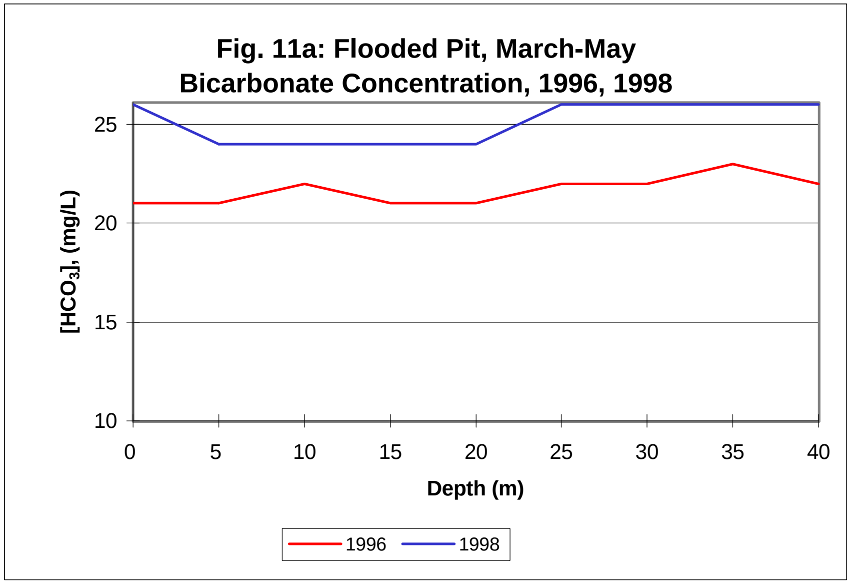


Fig. 11a: Flooded Pit, March-May Bicarbonate Concentration, 1996, 1998

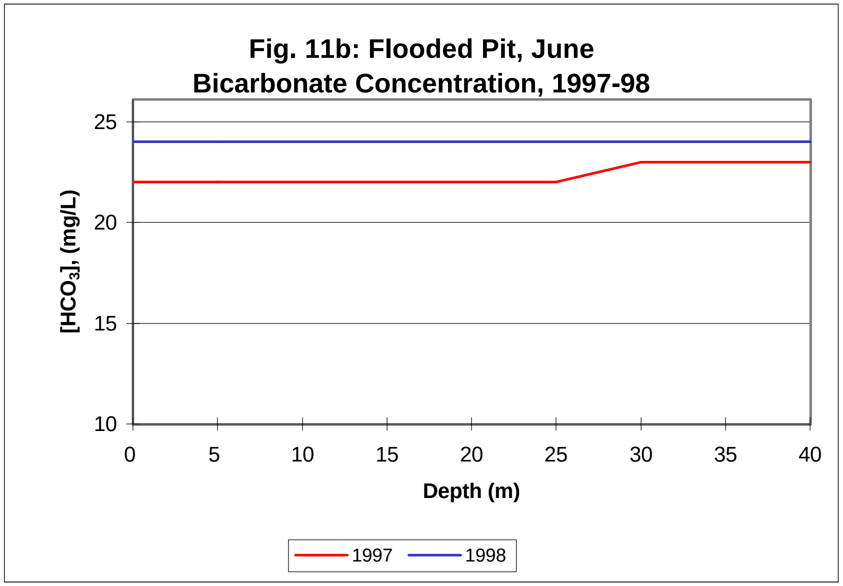


Fig. 11b: Flooded Pit, June Bicarbonate Concentration, 1997-98

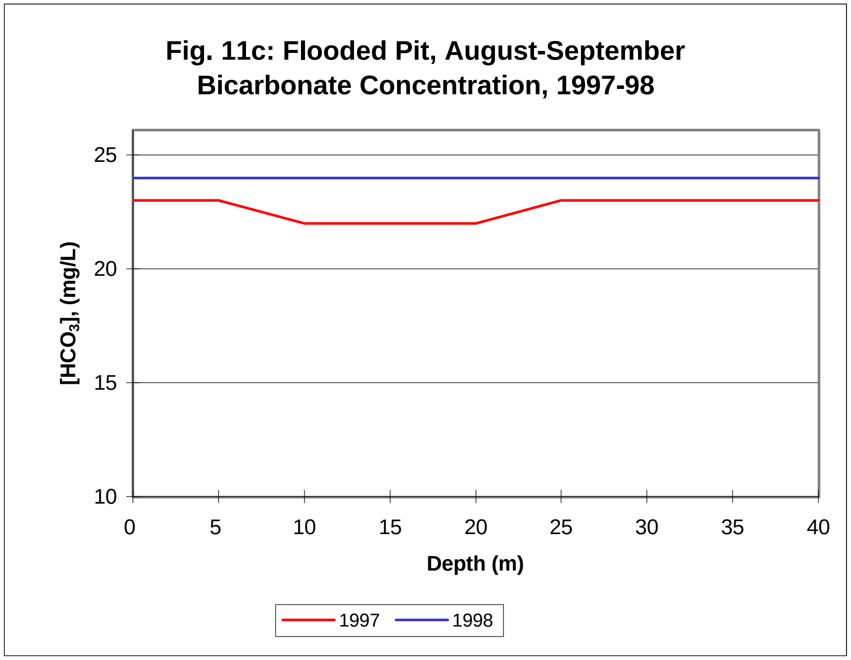


Fig. 11c: Flooded Pit, August-September Bicarbonate Concentration, 1997-98

2.1 Nutrient Concentrations

There have been several changes in the conditions of the B-Zone Pit since the flooding in early 1992. These became especially pronounced over the last couple of years, as it became apparent that nutrients were being limited. The nutrient limitations were discussed in detail in the May 1997 report: *"B-Zone pit: Limnology 1993 to 1996 and the Fate of Arsenic and Nickel"*.

In that report, inorganic and organic particulates were identified as key factors in determining the dynamics of the movement of elements with respect to depth in the B-Zone pit. Algal biomass, one of the major components of those particulates which control the dynamics of the movement in the pit, is controllable by nutrients. In order to demonstrate the role of the biomass in pit dynamics, the 1997 nutrient concentrations were used to determine the expected growth rate, or doubling rate, of the algal biomass, with the pit being considered a closed ecological system. In such a system, nutrient concentrations must reflect the expected growth and decay processes. The 1996 and 1997 data were interpreted from the perspective of nutrient cycling, and then used to project the 1998 nutrient levels.

The main objective of this work is to demonstrate that biochemical processes are involved in contaminant removal mechanisms. The reporting of the data was deferred until the 1998 sampling was complete, in order to demonstrate conclusively the role of biology in the pit, along with its effects. If, as predicted, there is a lower production of algae over time, then that component of the contaminant removal process that is controlled by algal growth should also decrease.

The turbidity of the pit water has been decreasing significantly since 1995, reflected both in decreased amounts of sediments in the sediment traps, and increases in recorded Secchi Disk depths (from about 1 m in 1995, to about 2 m in 1996/97). The resulting increase in the volume of biologically active water may, therefore, offset the reduction in standing crop biomass. The Secchi disk depths were reported in July 1998 as 2.3 m, in

September as 3.9 m and, by October, as 3.6 m. The increased light penetration created improved conditions for algal growth, which increased the utilization of nutrients. Increases in productivity are balanced by decreases in standing crop biomass production.

The concentrations of phosphorus have fluctuated over the years (Figure 12, Appendix 1), but their increase at the bottom of the pit relative to the main body of water has been fairly consistent. Since biomass concentrates phosphorus to about 80,000 times the level found in the host water, those increases noted at the bottom of the pit in 1993 and 1994, might well be related to the biomass having reached the bottom. With the decrease in biomass productivity over the past three years, however, the changes in concentrations in the profiles with depth are decreasing, and are noticeable only at the beginning of the year, under the ice (Figure 12).

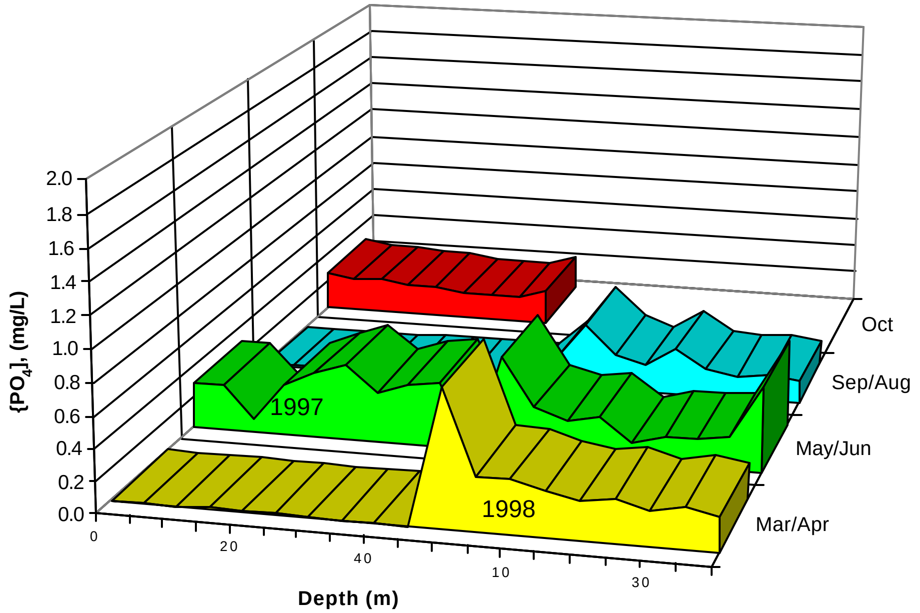


Fig. 12: Flooded Pit, 1997-1998 Data
PO_4 vs Depth

While phosphorus concentration is generally very high in the pit, it has nevertheless decreased from about 0. 4 mg/L, during the entire growing season in 1995 (Table 2a), to 0.3 mg/L and 0.2 mg/L by the end of the growing seasons in 1996 and 1997, respectively

Table 2a: Nutrient concentration in the flooded pit, 1995.

1995		Depth	Nutrients, mg/L			
			PO_4	NO_3	NH_4	N,TKN
		0	0.46	0.44	0.01	
April 12		5	0.43	0.44	0.03	
		10	0.40	0.40	0.01	
		15	0.40	0.35	0.03	
		20	0.40	0.44	0.03	
		25	0.40	0.57	0.03	
No Thermocline		30	0.37	0.44	0.01	
		35	0.37	0.53	0.03	
		40	0.49	0.70	0.01	
		45			0.04	
	Average		**0.41**	**0.48**	**0.02**	
	Above	0	0.40	0.13	0.05	0.24
June 14	Below Thermo-cline	5		0.53		
		10	1.38	0.35	0.05	0.14
		15	0.28	0.40	0.08	0.31
		20	0.21	0.35	0.03	0.16
		25	0.28	0.40	0.12	0.24
Thermocline 3 m		30	0.40	0.40	0.10	0.63
		35	0.46	0.35	0.03	0.8
		40	0.49	0.44	0.07	0.27
	Average	**Above**	**0.40**	**0.13**	**0.05**	**0.24**
		Below	**0.50**	**0.40**	**0.07**	**0.36**
		0	0.37	0.04	0.10	
Aug 17		5	0.46	0.04	0.05	
	Above	10	0.77	0.35	0.05	
	Below Thermo-cline	15	0.37	0.31	0.04	
		20	0.40	0.35	0.05	
		25	0.52	0.44	0.18	
		30	0.52	0.48	0.09	
Thermocline 10 m		35	0.61	0.40	0.13	
		40	0.64	0.62	0.22	
		45	0.77	0.40	0.04	
	Average	**Above**	**0.53**	**0.14**	**0.07**	
		Below	**0.57**	**0.42**	**0.10**	
		0	0.37	0.13	0.05	
Oct 14		5	0.43	0.09	0.03	
		10	0.31	0.09	0.05	
		15	0.28	0.18	0.03	
	Above	20	0.43	0.09	0.03	
	Below Thermo-cline	25	0.18	0.31	0.08	
		30	0.31	0.48	0.03	
		35	0.43	0.48	0.03	
Thermocline 20 m		40	0.49	0.44	0.03	
	Average	**Above**	**0.36**	**0.11**	**0.04**	
		Below	**0.37**	**0.36**	**0.04**	

Table 2b: Nutrient concentration in the flooded pit, 1996.

1996		Depth	Nutrients, mg/L			
			PO_4	NO_3	NH_4	N,TKN
		0	0.40	0.66	0.03	
May 9		5	0.40	0.75	0.01	
		10	0.37	0.75	0.03	
		15	0.40	0.48	0.03	
		20	0.40	0.48	0.03	
		25	0.40	0.53	0.03	
No Thermocline		30	0.31	0.57	0.04	
		35	0.37	0.35	0.04	
		40	0.40	0.18	0.04	
	Average		**0.38**	**0.53**	**0.03**	
		0	0.24	0.04	0.05	
Aug 26	Above	5	0.21	0.04	0.03	
	Below Thermo-cline	10	0.21	0.04	0.02	
		15	0.21	0.04	0.01	
		20	0.24	0.04	0.05	
		25	0.21	0.04	0.10	
Thermocline 9 m		30	0.21	0.04	0.04	
		35	0.31	0.09	0.03	
		40	0.37	0.13	0.04	
	Average	**Above**	**0.22**	**0.04**	**0.03**	
		Below	**0.25**	**0.06**	**0.04**	
		0	0.34	0.13	0.01	
Oct 28		5	0.31	0.18	0.04	
		10	0.31	0.13	0.01	
		15	0.31	0.09	0.05	
		20	0.31	0.22	0.03	
		25	0.31	0.13	0.01	
No Thermocline		30	0.31	0.18	0.01	
		35	0.37	0.13	0.01	
		40	0.64	0.04	0.05	
	Average		**0.35**	**0.14**	**0.03**	

Table 2c: Nutrient concentration in the flooded pit, 1997.

1997		Depth	Nutrients, mg/L			
			PO_4	NO_3	NH_4	N,TKN
		0	0.30	0.04	0.10	
29-Jun	Above	5	0.30	0.04	0.10	
	Below	10	0.09	0.04	0.10	
	Thermo-	15	0.33	0.04	0.12	
	cline	20	0.42	0.04	0.10	
		25	0.48	0.04	0.09	
Thermocline 6 m		30	0.33	0.04	0.08	
		35	0.39	0.04	0.09	
		40	0.42	0.04	0.10	
	Average	**Above**	**0.30**	**0.04**	**0.10**	
		Below	**0.35**	**0.04**	**0.10**	
		0		0.04	0.05	
12-Aug	Above	5		0.04	0.05	
	Below	10		0.04	0.04	
	Thermo-	15		0.04	0.04	
	cline	20		0.04	0.03	
		25		0.04	0.04	
Thermocline 8 m		30		0.04	0.03	
		35		0.04	0.03	
		40		0.18	0.05	
	Average	**Above**		**0.04**	**0.05**	
		Below		**0.06**	**0.04**	
		0	0.27	0.22	0.08	
6-Oct		5	0.24	0.18	0.08	
	Above	10	0.24	0.18	0.10	
	Thermo-	15	0.21	0.18	0.09	
	cline	20	0.21	0.22	0.21	
	Below	25	0.18	0.31	0.13	
Thermocline 23 m		30	0.18	0.26	0.16	
		35	0.18	0.31	0.16	
		40	0.24	0.35	0.18	
	Average	**Above**	**0.23**	**0.19**	**0.11**	
		Below	**0.20**	**0.31**	**0.16**	

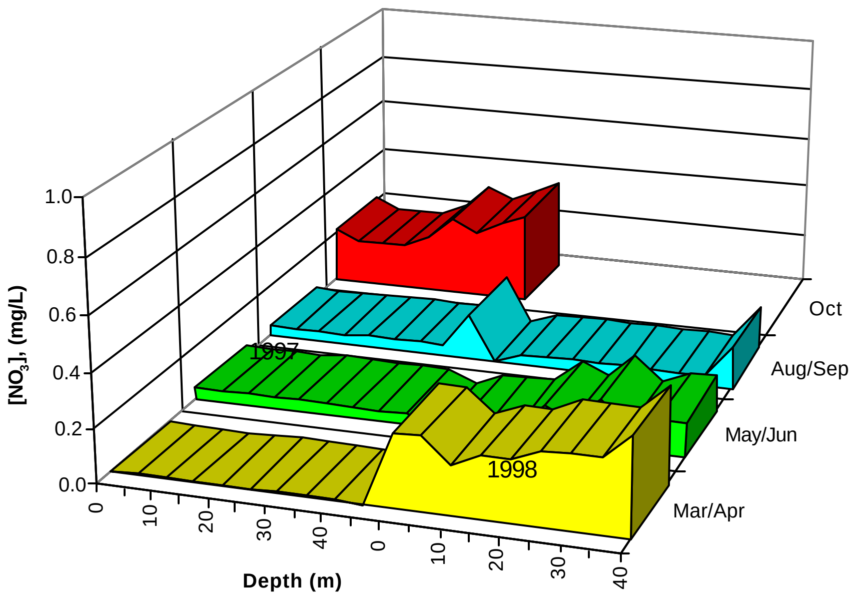
Table 2d: Nutrient concentration in the flooded pit, 1998.

1998		Depth	Nutrients, mg/L			
			PO_4	NO_3	NH_4	N,TKN
		0	0.86	0.26	0.04	
18-Apr		5	0.34	0.26	0.04	
		10	0.34	0.18	0.03	
		15	0.28	0.22	0.03	
		20	0.24	0.22	0.04	
		25	0.28	0.26	0.04	
No Thermocline		30	0.21	0.26	0.05	
		35	0.24	0.26	0.05	
		40	0.21	0.35	0.05	
	Average		**0.33**	**0.25**	**0.04**	
		0	0.61	0.04	0.07	
1-Jun		5	0.31	0.04	0.08	
		10	0.24	0.04	0.08	
		15	0.28	0.13	0.07	
		20	0.12	0.09	0.04	
		25	0.18	0.18	0.05	
No Thermocline		30	0.18	0.09	0.05	
		35	0.21	0.13	0.04	
		40	0.55	0.13	0.07	
	Average		**0.30**	**0.10**	**0.06**	
		0	0.18	0.04	0.05	
2-Sep	Above	5	0.43	0.04	0.04	
	Below Thermocline	10	0.24	0.04	0.04	
		15	0.18	0.04	0.04	
		20	0.31	0.04	0.01	
		25	0.18	0.04	0.03	
Thermocline 10 m		30	0.15	0.04	0.05	
		35	0.18	0.04	0.07	
		40	0.15	0.16	0.05	
	Average	**Above**	**0.31**	**0.04**	**0.05**	
		Below	**0.20**	**0.06**	**0.04**	

(Table 2b and Table 2c). This decrease continued throughout the growing season in 1998, both with depth and with time (Table 2d).

Nitrate levels decreased much more severely during the 1996 and 1997 growing seasons, so that by 1997, the level was clearly a major limiting factor for phytoplankton growth. Tables 2a to 2c show the nutrient concentrations for 1995 to 1997, respectively. In Table 2d, which reports the same concentrations for 1998, only a very small change in concentrations over the growing season is noticeable. This was predicted, since it was estimated that there would be only sufficient nitrogen by the beginning of the 1998 season to allow the biomass to replicate once. (This is discussed in more detail, later.) Nitrate concentrations are also summarized for the years 1993 to 1997 in Figure 13, in Appendix 1, which clearly shows an overall decline over time and higher concentrations at depth.

Fig. 13: Flooded Pit, 1997-1998 Data
NO_3 vs Depth



A comparison of the 1997 and 1998 data (Figure 13) demonstrates that the effects of the turnover of higher concentrations at the bottom of the pit at the end of 1997, are brought to the surface by March/April 1998, and have disappeared into the biomass by May/June.

In previous years, when only one alga dominated, the pit water did not quite reach this near-perfect cycling between biological activity and its chemical expression in the water parameters.

The 1996/97 data also indicated that, based on the amount of nitrogen available in the pit, and with no additions, biomass productivity would be limited to one doubling of the biomass early in the year. Primary productivity in the zone where light penetrates is balanced by the loss of biomass due to grazing by zooplankton and decomposition by heterotrophs in the lower parts of the pit.

The gradually increasing levels of ammonium-N in the pit towards the end of the growing season (October 1997, Table 2c) reflect both the degradation of biomass, and the changes in the rate of some of the ammonia to nitrate by bacteria. This conversion was completed over the winter, resulting in higher levels of nitrate in the spring of 1998; throughout the pit, concentrations were around 0.26 mg/L in April, 1998 (Table 2c and Table 2d).

The very low levels of nitrate in the water column in June 1997 (0.7 :M or 0.04 mg/L), indicate that nitrate rapidly becomes a limiting factor for algal productivity early in the growing season. The shallow piezometer water quality was examined and was often found to contain high, although quite variable levels of ammonium concentrations (1 to 100 :M) in the bog. This suggests that under anaerobic conditions, peat can produce ammonium. One source of ammonium could be decomposition of peat which eroded from the edges of the pit after flooding. On the other hand, increased ammonium could be produced by the biomass generated by the *Dyctiospherium* blooms, tolerant to the conditions of the pit, decaying more rapidly as conditions change.

The nitrogen cycle is complex, especially when the pit thermocline is taken into account, since de-nitrification and nitrification are controlled by the presence or absence of oxygen, which also, of course, exhibit dynamic seasonal change. Based on the years 1993 to 1997 (Figure 14, Appendix 1), it appears that ammonia has increased in the pit. While this suggests an inhibition of denitrification by bacteria, it has not been substantiated specifically for the B-Zone Pit. The 1997/1998 data (Figure 14), demonstrate, however, that some change has occurred, since ammonia concentrations are no longer increasing, either with depth or over the season. The reasons for this are not well defined.

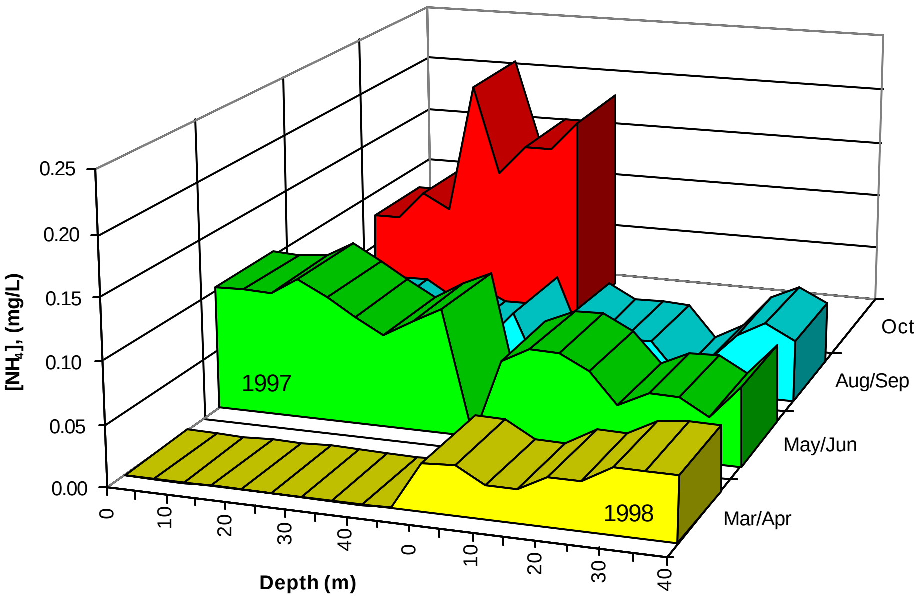


Fig. 14: Flooded Pit, 1997-1998 Data
NH_4 vs Depth

2.2 Primary Productivity

In spite of improved light conditions in the B-Zone Pit in the past 3 years, the standing crop of algae appears to have decreased, rather than increased. There has been an almost complete replacement of the very high concentrations of the green alga, *Dictyosphaerium pulchellum*, evident in 1994 and 1995, by a more diverse algal community with a lower standing biomass, in 1996 and 1997. In Figures 15a and 15b, the main groups of algae are shown. A shift from the group *Chlorophyta*, which includes *Dictyosphaerium pulchellum*, is evident, along with increases in the *Chrysophyta* and *Pyrrohphyta* groups. This trend continued into 1998, when diversity increased and *Cryptophyta* started to contribute to the biomass. In 1998, *Dictyosphaerium pulchellum* was essentially absent, along with other forms of *Chlorophyta*, expressing the pioneering nature of this species.

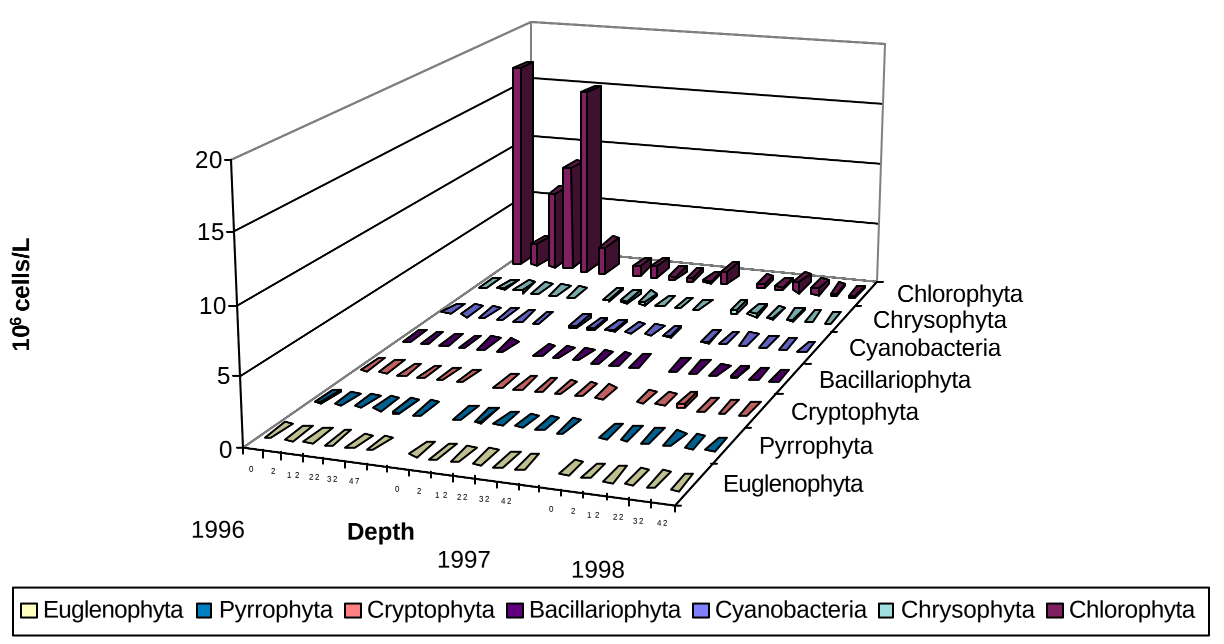


Fig. 15: Comparison of Phytoplankton 1996-1998

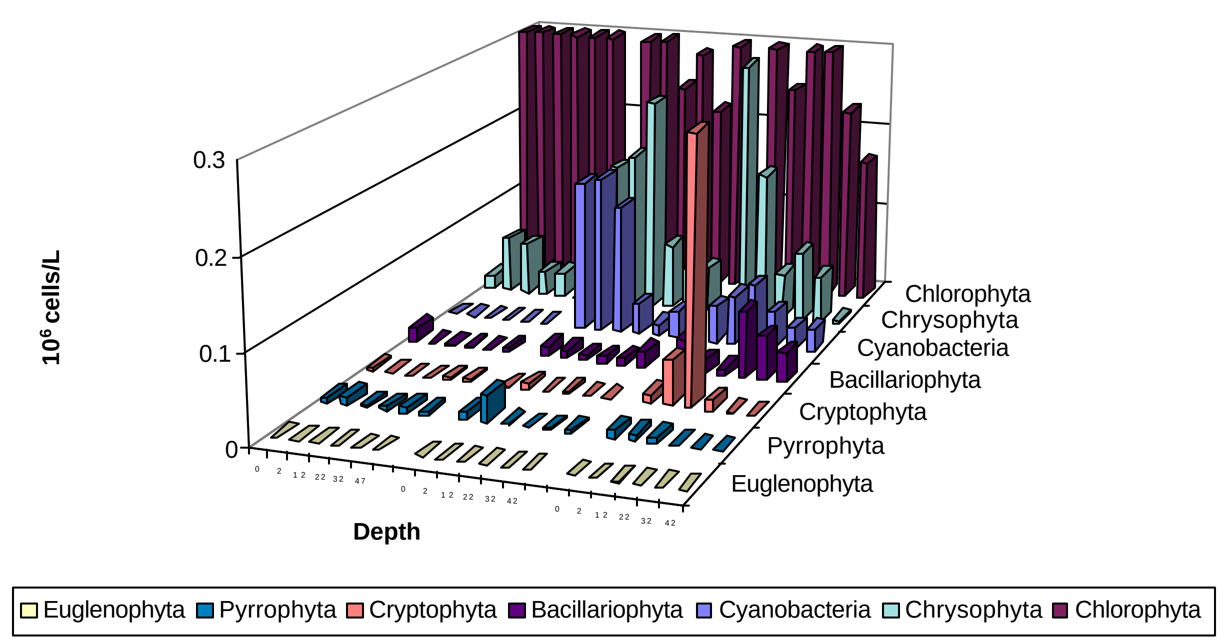


Fig. 15b: Comparison of Phytoplankton 1996-1998

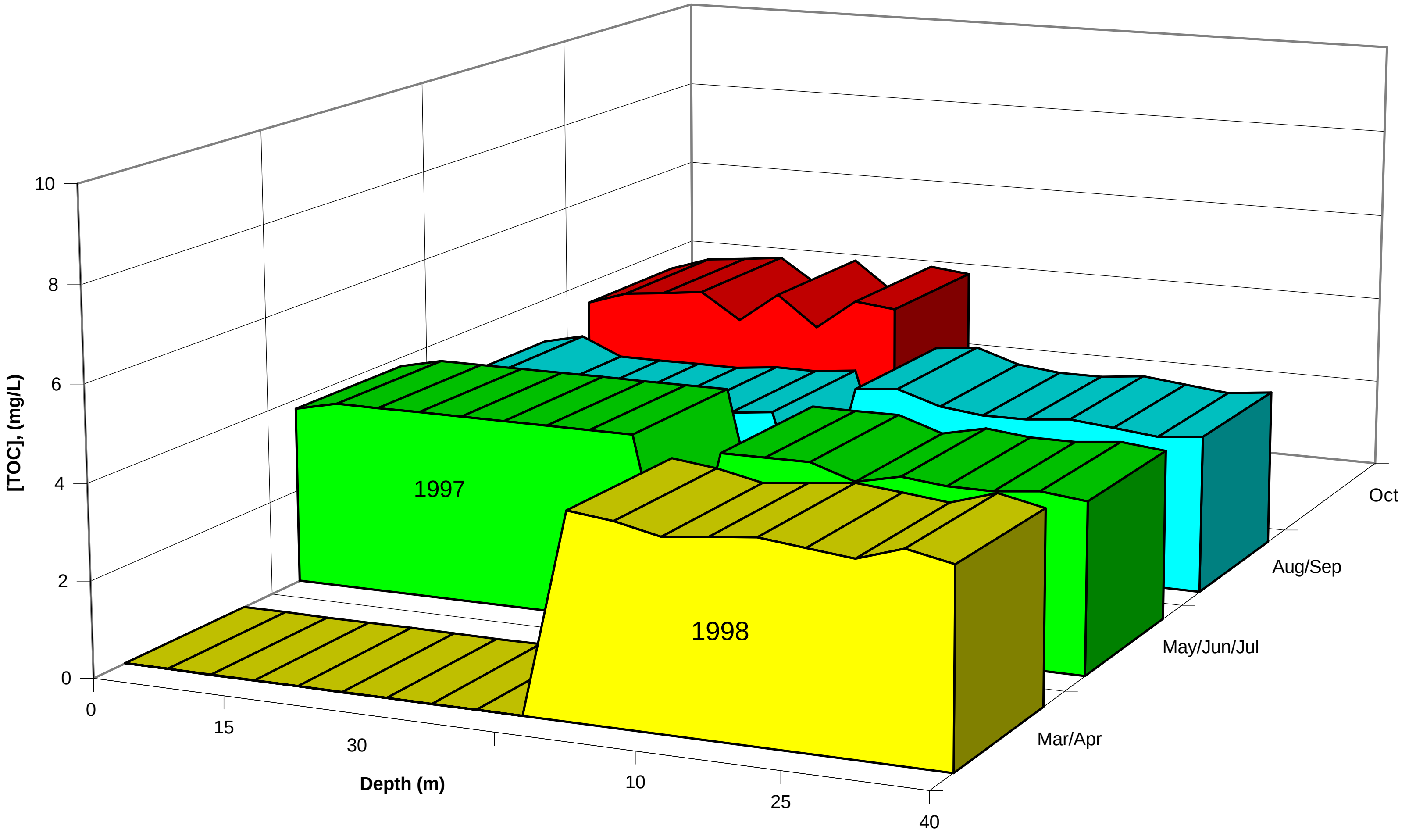
Overall, primary productivity in the pit has likely increased in 1998, as expressed by a more diverse structure, accompanied by a lower standing crop. A more diverse phytoplankton community suggests higher turnover rates, while the lower standing crop probably reflects more active grazing rates, as yet undetermined. This would result in a higher turnover rate of organic carbon in the food chain. Organic carbon levels have remained constant since 1993 (Figure 15, Appendix 1), and have, for the first time, maintained the same concentration range throughout 1998 (Figure 16, on the following page). This is to be expected from an ecosystem in dynamic equilibrium, since decay and growth are balanced.

2.3 Primary productivity and consumption

Astute readers might argue that decreases in phytoplankton standing biomass, along with the heterotrophs (held responsible for changes in the parameters in the pit profiles), can now be discounted, since the ecology of the pit could not account for the increased pH noted in 1998. Alone, however, standing crop biomass or productivity are not an indication of active ecology. Ecosystems are very dynamic, as expressed by the shift in composition of genera in the pit. If light penetration increased, which should result in improved primary productivity, zooplankton would be expected to be present and grazing would occur.

Throughout the years of studying the pit, some information on zooplankton was collected. In 1992, the population of rotifers was small and was reported along with the phytoplankton results. These rotifers were likely transported into the pit either from Wollaston Lake, or from Grenier pond which became incorporated into the pit as the water level rose. No rotifers or other grazers were reported in 1993 or 1994. As zooplankton is an important component of ecosystem development and contributes 14.8% carbon output (estimated based on Mirror Lake, discussed later), an extensive effort to find zooplankton was made in 1995. Three different mesh sizes were used to sample a large volume of water, and no evidence of zooplankton was found. The effort continued in 1996 and, again, 60 L of water strained through a fine 30 :m screen, produced no zooplankton. Finally, in August of 1997, when 100 L of water were sampled, 18 *Keratella*, the most common species of rotifer, and 6 larger Rotifers were recovered.

Fig. 16: Flooded Pit, 1997-1998 Data
Total Organic Carbon vs Depth



In 1998, unfortunately, zooplankton samples were not taken, due to the weather conditions at the time of the field trip. However, phytoplankton data analysis reported some new developments. *Ciliates*, a form of zooplankton never reported before, were present throughout the pit at all depths, and *Keratella* was absent above a depth of 22 m. Only two one-litre samples, taken from depths of 32 m and 42 m, contained a density of 8 and 16 specimens of *Keratella*. Caution has to be exercised, however, since zooplankton populations are extremely dynamic, as Figures 17a and 17b on the following page demonstrate. As such, it is possible that zooplankton were not detected in the single sampling events of previous years. (The data in Figures 17a and 17b were taken from pages 440 and 700 of Wetzel's classic text “Limnology” (1983), and from page 297 of the 1961 article by G.K. Reid, "Ecology of Inland Waters and Estuaries".)

Further evidence to corroborate the arrival of a new ecosystem component, zooplankton, could be gained by examining the carbon flux, since zooplankton would contribute to the organic carbon load in the pit, thereby replacing the lost primary productivity. Table 3 (page 38) summarizes the annual organic carbon fluxes of the inputs and outputs of each component of a lake reported in the limnology text by Wetzel (p. 700). Clearly, in this balanced ecosystem, the inputs and outputs are equal. The Mirror Lake values of only those components present in the B-Zone Pit are also shown in Table 3 and, as expected of a developing ecosystem, the carbon budget does not balance - although it is remarkably close.

These values, when converted to be representative of the total surface area of the B-Zone Pit, fall within the range recorded in 1997 and the range given for Mirror Lake. If the inputs and outputs of the B-Zone Pit had in fact balanced, no sediment would be accumulating in the pit bottom. It is the imbalance, about 2t C@y^{-1}, that is going to the pit bottom.

In the 1997 report, primary productivity was evaluated utilizing nutrient concentration changes in the pit, values of TOC, and sedimentation trap material. The C flux in lakes, which were considered mesotrophic (comparable to the B-Zone Pit), were used. Although the definitions oligotrophic, mesotrophic and eutrophic are based on nutrient inputs, lake

Fig. 17a: Seasonal variation of Keratella

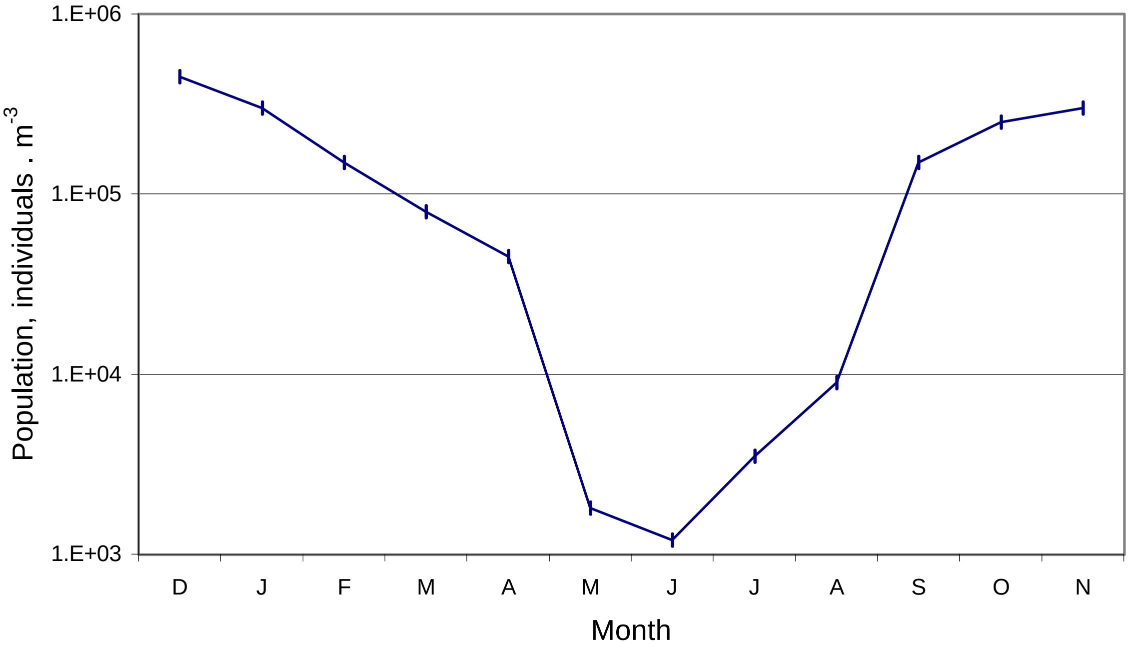


Fig. 17b: Seasonal Variations of Rotifers

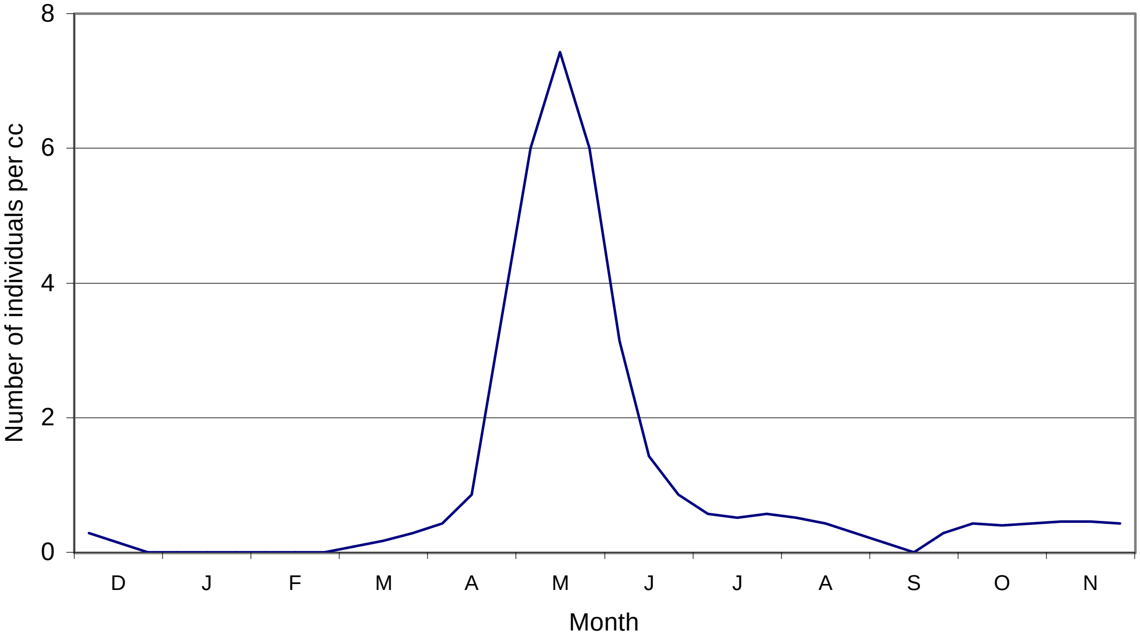


Table 3: Annual Organic Carbon Fluxes in B-Zone Pit compared to Mirror Lake, New Hampshire (after Wetzel,Limnology, p.700)

Organic Carbon Source/Sink	Mirror Lake New Hampshir g C.m^{-2}.y^{-1}	Process in B-Zone Pit	B-Zone Pit Estimated Value g C.m^{-2}.y^{-1}	B-Zone Pit Surface Area Organic Carbon t C.y^{-1}	B-Zone Pit Surface Area Organic Carbon t C.y^{-1}
Inputs					
Autochthonous					
Phytoplankton	56.5	yes	56.5	321.9	321.9
Epilithic algae	2.2	no	0.0		
Epipelic Algae	0.6	no	0.0		
Epiphytic Algae	0.06	no	0.0		
Macrophytes	2.5	no	0.0		
Dark CO$_2$ Fixation	2.1	yes	2.1	12.00	12.0
Allochthonous					
With Precipitation	1.4	yes	1.4	8.0	8.0
Shoreline Litter	4.3	yes	4.3	24.5	24.5
Stream DOC	10.5	no	0.0		
Stream POC	1.2	no	0.0		
SUM OF INPUTS	**81.31**		**64.3**	**366.4**	**366.4**
Outputs					
Respiration					
Phytoplankton	19.1	yes	19.1	108.8	108.8
Zooplankton	12.0	yes	12.0	68.4	68.4
Macrophytes	1.0	no	0.0		
Attached Algae	1.16	no	0.0		
Benthic Invertebrates	2.8	no	0.0		
Fish	0.2	no	0.0		
Sediment Bacteria	17.3	yes	17.3	98.6	98.6
Planktonic Bacteria	4.9	yes	4.9	27.9	27.9
manent Sedimentation	10.7	yes	10.7	61.0	61.0
Outflow					
Dissolved OC	10.87	no	0.0		
Particulate OC	0.78	no	0.0		
Insect Emergence	0.5	no	0.0		
SUM OF OUTPUTS	**81.31**		**64.0**	**364.7**	**364.7**
Balance	**0.0**		0.3	1.7	1.7

dimensions and retention times, one can also classify lakes based on their carbon flux and primary productivity. The estimators (TOC, nutrient changes and sedimentation trap material) for carbon flux, were taken from Table 7 in the 1997 report (page 53), and were based on: a) NO_3 = 6.6 g C/m^{-2}/y^{1}; b) TOC concentrations = 79.3 g C/m^{-2}/y^{1} ; and c) sedimentation trap material with algae which ranged from 7.3-131 g C/m^{-2}/y^{1}. The carbon flux recorded in Mirror Lake (56.6 g C/m^{-2}/y^{1}), which has a carbon budget comparable to the pit, falls in the middle of this range. The contribution to carbon flux from zooplankton is of the same order of magnitude as that from phytoplankton. Zooplankton may, therefore, be balancing the noted reduction in phytoplankton primary productivity.

Although direct confirmation that both phytoplankton and zooplankton are alive and interacting cannot be given, the microscopic observations made during the phytoplankton observations indicated that living cells, containing chlorophyll, are present in the pit waters.

Table 4a: Chlorophyll Content in B-Zone Pit Samples, August 26, 1997

Depth (m)	Chlorophyll (ug/L)		Total (ug/L)
	a	b	
0	1.6	0.8	2.4
2	1.8	0.7	2.5
12	1.3	0.4	1.7
22	1.3	0.6	1.9
32	0.4	0.3	0.7
42	1.0	0.6	1.6

Total chlorophyll levels for pit water samples from different depths taken in August 1997, were determined to be in the range of about 2.5 :g/L near the surface, to about 0.7 to 1.9 :g/l at lower depths (Table 4). These levels are similar to those obtained from a mesotrophic site in Lake Ontario (Evans et al., 1996), where algae are nutrient limited and, probably, also actively grazed. The presence of chlorophyll with depth also indicates that algal biomass is sinking down through the water column, and not all of it is being decomposed at the thermocline, as was suggested by the optical observations of *Dictyosphaerium*, which seems to deteriorate. If the cells are degrading, chlorophyll would decay very rapidly. All this further supports the role of biomass in transporting contaminants to the pit bottom. As it is proposed to increase biomass through fertilization, chlorophyll values for the D-Zone Pit and Collins Bay were obtained at the same time (Table 4b). These values are clearly considerably higher than those of the B-Zone Pit, evidence of the low biomass or standing crop of phytoplankton, and demonstrate room for improvement.

Table 4b: Chlorophyll Content in D-Zone Pit and Collins Bay Samples

September 2, 1997

Depth (m)	Chlorophyll (ug/L)		Total (ug/L)
	a	b	
D-Zone Pit			
surface	5.8	3.8	9.6
Collins Bay Shore Surface			
surface	4.1	2.8	6.9

It can be assumed that total chlorophyll represents 1% of the (dry) algal biomass, the generally accepted average level for light-limited phytoplankton. The observed 2.5 :g chlorophyll/L that

was observed in the top water mass of the pit in August 1997, would, therefore, correspond to 250 :g dry weight algal biomass/L, or about 100 :g cell-C. Given the C:N ratios of healthy algal cells, this corresponds to about 20 :g cell-N/L, or about 1.5 :mol cell-N/L. With only 0.7 :mol/L of nitrate and 2 :mo/L of ammonium in the pit water in August of 1997, there would be sufficient nitrogen available for only a little more than one doubling of the algal biomass.

The algal standing biomass is likely in a dynamic equilibrium, with increases from primary productivity being balanced by losses due to grazing and/or sinking out of the euphotic zone. The same conclusion is reached when the carbon budget of the pit is considered: an estimated 2 t/y^{1} are relegated to the sediment as carbon (Table 3, page 38), if the B-Zone Pit behaves like other studied lakes.

2.4 Biomass accumulation

2.4.1 Particulates

Sediment traps that were placed in the pit at depths of 2, 12, 22 and 32 metres and left for three months were collected on August 26, 1997. Sediment composition is discussed in more detail later. The sedimentation trap particulate was analysed here to evaluate its nutrient ratios, in order to confirm what was previously only an educated guess - that P was biological. That material contained 2.4 - 4.6% organic carbon, and the calculated C:P atomic ratio in these materials was close to the 100:1, adequately reflecting the Redfield ratio expected for phytoplankton biomass (Table 5a). The analytical values used to arrive at :mol/g of material are given in Appendix 2.

Table 5a: Molar amount and atomic ratios of selected elements in Sediment Traps in B-Zone Pit, Station 6.72, August 26, 1997

MOLAR AMOUNT				
	Depth			
Element	2 m	12 m	22 m	32 m
As (:mol/g sediment)	24	48	67	101
Ni (:mol/g sediment)	39	27	14	22
P (:mol/g sediment)	25	27	30	32
TOC (:mol/g sediment)	3480	1990	2330	3790
% TOC in sediment	4.2	2.4	2.8	4.6
ATOMIC RATIOS				
P : As	1.0 : 1	0.6 : 1	0.4 : 1	0.3 : 1
N : P*	6.8 : 1	4.8 : 1	5.5 : 1	4.7 : 1
C : N*	20 : 1	15 : 1	14 : 1	25 : 1
C : P*	139 : 1	74 : 1	78 : 1	118 : 1

* Redfield ratios (for typical algal biomass)

C : N : P = 100 : 18 : 1 C : N = 6 : 1

N : P = 18 : 1 C : P = 100 : 1

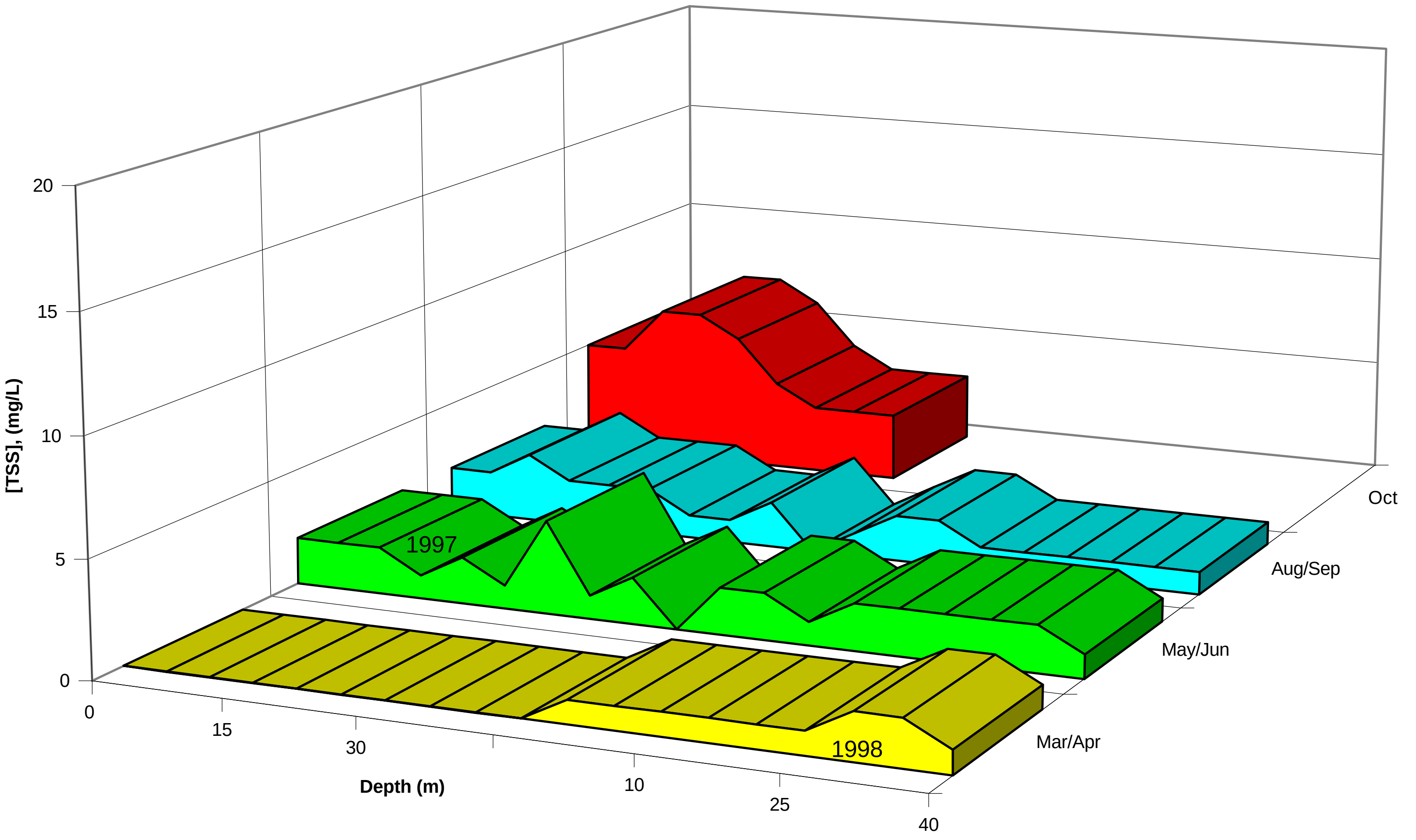
Below Table 5a, the Redfield ratio typical for algal biomass based on the literature is given. The Redfield ratios for C:P in the particle material (Table 5a) range from 74:1 at 12m, to 139:1 at the surface. Both materials reflect their origin from algal biomass. In the early years of the study, it was argued that the carbon could also originate from peat eroding from the pit's edges, but if this were the case, it would not be expected to display a Redfield ratio reflecting phytoplankton.

To further demonstrate the development of an equilibrium of growth, decay and grazing, the TSS distribution was examined to see whether it showed a relatively smooth pattern from the top to the bottom (as seen in Figure 18, on the following page), in comparison to previous years (Figure16, Appendix 1). The smoother profile in 1998 gives further credence to the idea that the TSS is primarily biologically generated.

In summary, phytoplankton productivity (and the standing biomass) at present appears to be strongly limited by nitrogen availability during the growing season, while the concentrations of the other major nutrient - phosphorus, are able to support much higher productivity. An increase in inorganic nitrogen (ammonium and nitrate) by 10 :M, or to concentrations of 0.364 mg/L, would more than double the existing nitrogen available. This would increase the N:P ratios existing in the surface water (about 2:1-5:1) to the ideal Redfield ratio of 18:1. It would require an increase in inorganic nitrogen to about 50 :M in order to take full advantage of the existing high phosphorus levels in the pit.

An increase to 10 :mol of N/L for the entire pit would require about 4,300 kg of sodium nitrate, or 2000 kg ammonium nitrate. Adding ammonium nitrate has a distinct advantage, as the non-simultaneous assimilation (uptake) of ammonium and nitrate nitrogen by algae, would result in no pH change. On the other hand, the assimilation of nitrate by biota from sodium nitrate would cause an increase in pH, which could be as high as 9. This may have some advantages for Ni removal, but it would not be beneficial for the longer-term ecology of the pit, since it might drive it to a state of carbon limitation. Ammonium and sulphate additions should also be considered as possible fertilizers. Extrapolating from the results

Fig. 18: Flooded Pit, 1997-1998 Data
Total Suspended Solids vs Depth



of the 1996 analysis with the help of data gained more recently, it would appear that the water chemistry of the B-Zone Pit is being controlled more and more by its ecological processes.

2.4.2 Sediment

Bottom sediment was collected from the centre of the B-Zone Pit (45 m depth) with an Eckman grab sampler on August 26, 1997. The sample could be separated visually into three distinct layers for station 6.72, and into two layers for station 6.71. The data from these sediments are displayed in Table 5b in the same fashion as the data in Table 5a, so that the origin of the material can be examined. The top layer of the sediment contained about 3% organic carbon.

Table 5b: Molar amount and atomic ratios of selected elements in bottom sediment in B-Zone Pit, Stations 6.71, 6.72, August 26, 1997

MOLAR AMOUNT					
Element	Station 6.71		Station 6.72		
	surface	middle	surface	middle	bottom
As (:mol/g sediment)	15	1.5	20	6	3
Ni (:mol/g sediment)	9	3	14	7	4
P (:mol/g sediment)	18	18	21	20	18
TOC (:mol/g sediment)	2020	925	2580	990	630
% TOC in sediment	2.4	1.1	3.1	1.2	0.8
% inorganic carbon	19	30	13	18	23
ATOMIC RATIOS					
P : As	1.2 : 1	12 : 1	1.1 : 1	3 : 1	6 : 1
N : P	6.3 : 1	2.2 : 1	6.5 : 1	2.7 : 1	1.4 : 1
C : N	18 : 1	24 : 1	19 : 1	18 : 1	25 : 1
C : P	112 : 1	51 : 1	123 : 1	50 : 1	35 : 1

The same Redfield ratio (and percent organic content) decreased considerably at the lower levels of the bottom sediments, further reflecting the decomposition of biomass expressed in the loss of carbon (Table 3). The arsenic content of the sediments showed much higher levels at the surface, while phosphorus remained at almost the same level with depth. This is to be expected, since phosphorus, unlike organic material, is not transformed to CO_2 and water. In summary, the sediment in the pit is originating largely from the material in the sedimentation traps generated within the pit by the biomass.

2.5 The Contaminants and the Thermocline

It has been stressed that the main objective of this work is to better understand the contaminant transport mechanisms in the B-Zone Pit, rather than the developing aquatic ecosystem. In-situ treatment methods must be based on a sound understanding of these mechanisms; only then can fertilization of the pit be targeted. The key physical parameter controlling water movement in the pit is the thermocline, which breaks down over the winter, when the entire water body turns over. As a result, all the contaminants that have not been relegated to the pit sediment get re-suspended.

In Appendix 1, Figures 17a-17d present the As and Ni concentrations in the pit in 1995, by depth, for four measurement periods. The 1996 data are presented for three measuring periods (Figures 18a-18c, Appendix 1), and the 1997 data, (Figures 19a-19d, Appendix 1) again show four measuring periods. In June of 1997, the usual decreases in the concentrations of As and Ni were evident in the surface water, and by the end of that year, both As and Ni showed slightly increased concentrations at the bottom of the pit.
Figures 19a-19c on the following page of the main text, show the 1998 data. Arsenic deceases are evident at all depths and, by the end of the year, this is pronounced. The thermocline formed in the normal manner, but Ni concentrations at a depth of 35 m dropped to levels found at the surface. The adsorption of Ni onto the zooplankton cannot be ruled out as a contributing factor. All but the 40 m water sample showed Ni concentrations at levels recorded at the beginning of the year (0.26 mg/L).

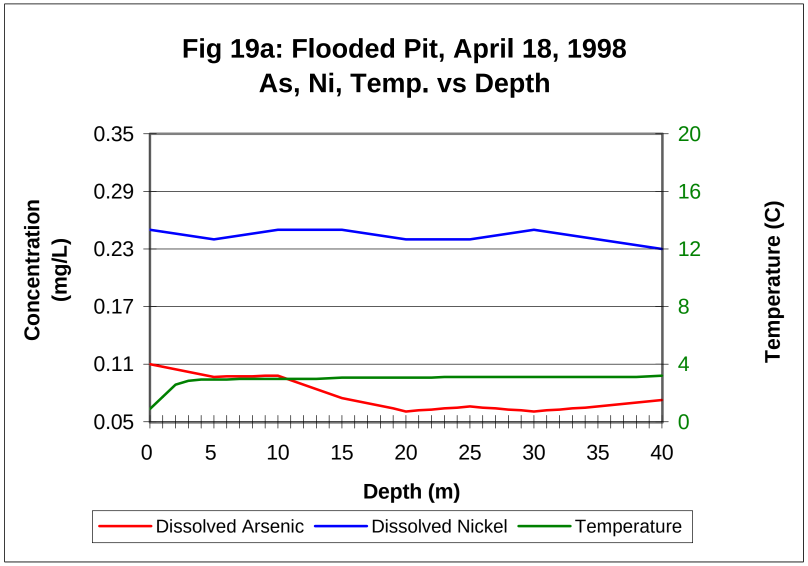


Fig 19a: Flooded Pit, April 18, 1998
As, Ni, Temp. vs Depth

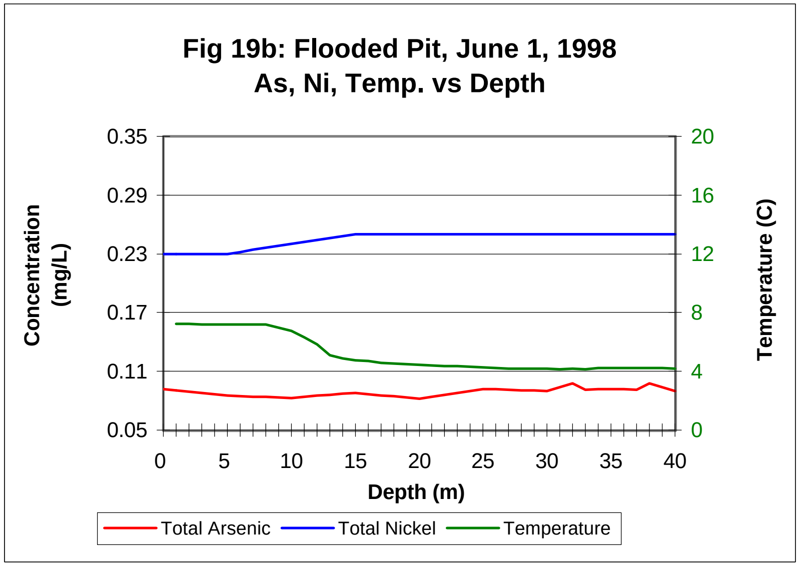


Fig 19b: Flooded Pit, June 1, 1998
As, Ni, Temp. vs Depth

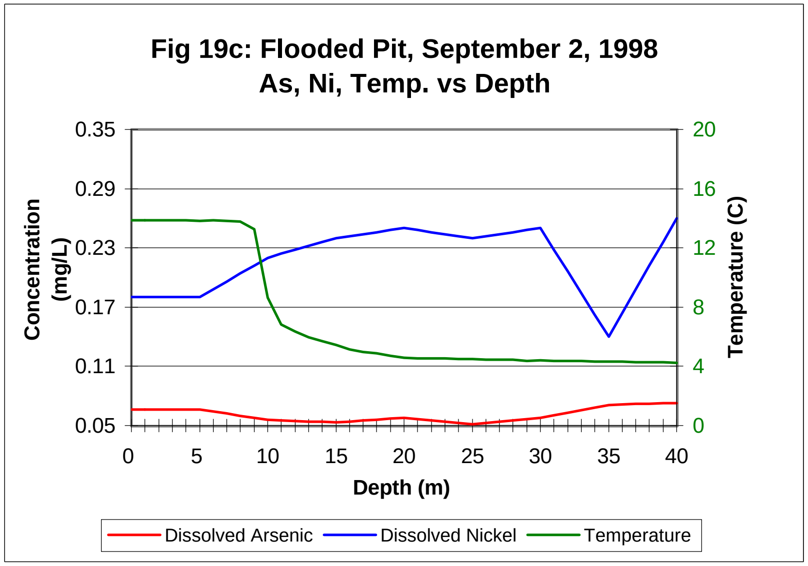


Fig 19c: Flooded Pit, September 2, 1998
As, Ni, Temp. vs Depth

The difference in the behaviour of As and Ni was attributed to the different adsorption and aggregation behaviours of the two elements, along with differences in the material they associate with - organic compounds or inorganic particles, such as iron hydroxides. It was postulated that As associates with Fe, whereas Ni binds to the algal cell wall surface and particles are aggregated by polysaccharides. If correct, then decreases in As concentrations would correspond to decreases in Fe concentrations, or potentially an iron input source would have to be identified in the pit. Iron does appear to have decreased slightly between 1995 and 1998 (from 0.55 mg/L to 0.40 mg/L). In earlier years, increases in iron concentrations were noticeable quite regularly, particularly at depth towards the end of the growing season. Over time, this trend in the depth profile of iron concentrations became less pronounced, until by April, 1998, iron at the surface was at its lowest level ever recorded in spring (0.18 mg/L) and dropped slightly more by September,1998. These trends in iron seem to support the relegation of As to the sediment (Figures 20a-20c, page 48).

If the mechanism for the removal of Ni is correctly identified - i.e., dependent mainly on algal growth and adsorption to be relegated to the sediment - then only a small fraction of Ni can be removed, due to algal decay and microbial respiration. This would account for the relatively constant concentrations of Ni in the water from year to year.

Using the water quality data which were summarized in the previous sections, it can be demonstrated that Ni concentrations in the water cannot be changed quickly only by the mechanism whereby the algal biomass relegates Ni to the sediment. The following considerations show that there is simply not enough biomass in the pit.

For the surface water, the annual summer decrease in Ni concentrations can be attributed to the actively growing algal biomass, with cell surfaces adsorbing the Ni. This mechanism produced a reduction from 0.25 mg/L in April, underneath the ice, to 0.18 mg/L by the end of the growing season (Figures 19a to 19c, page 46). Using this reduction, the algae in one litre of surface water from the pit would have to account for the removal of 0.07 mg/L of Ni to the deeper portions of the pit.

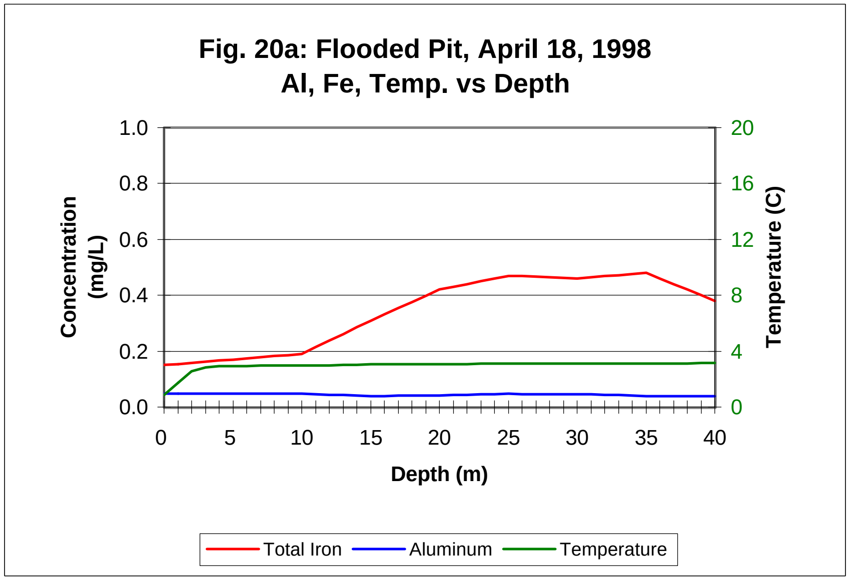


Fig. 20a: Flooded Pit, April 18, 1998
Al, Fe, Temp. vs Depth

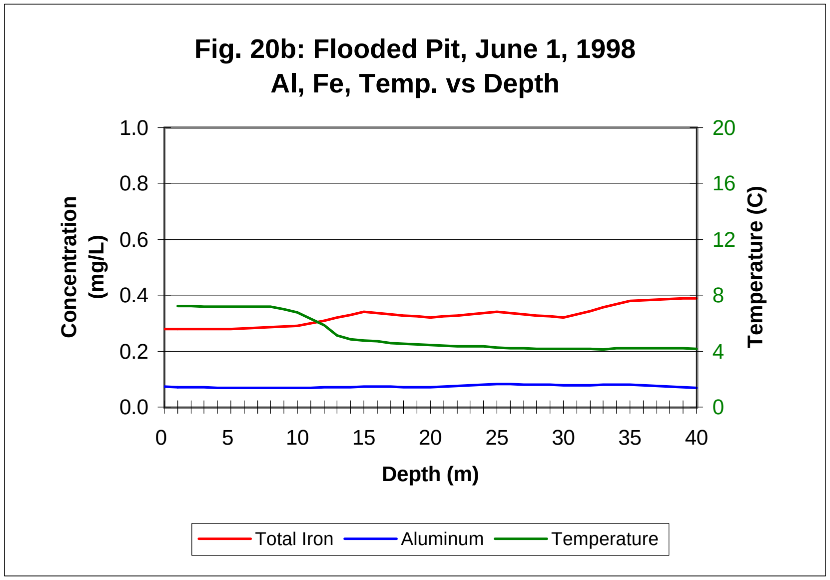


Fig. 20b: Flooded Pit, June 1, 1998
Al, Fe, Temp. vs Depth

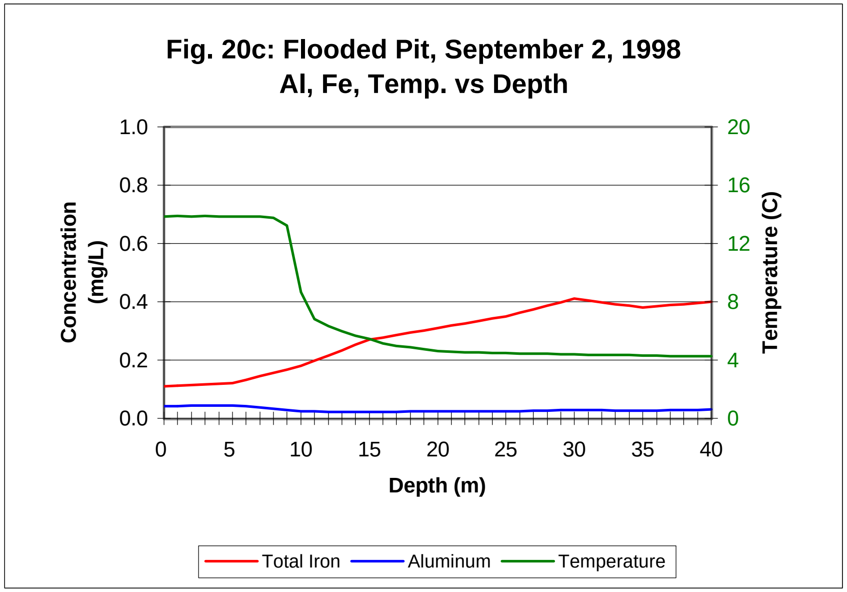


Fig. 20c: Flooded Pit, September 2, 1998
Al, Fe, Temp. vs Depth

Using the chlorophyll concentrations, this quantity (0.07 mg Ni/L) would have to be adsorbed to 250 :g of (dry weight) biomass per litre. Based on the carbon flux in the pit, which was estimated using the 1997/1998 data, only 0.6% of the total phytoplankton productivity is relegated to the sediment (Table 3, page 38). The reduction in Ni due to 0.6 % of the biomass being relegated to sediment, therefore, could only be 4.2 x 10^{-4} mg/L, i.e., much less than 0.07 mg Ni/L, and not detectable as a water quality change.

The same calculations carried out for As showed a reduction in the concentrations at the surface of 0.044 mg/L, falling from 0.11 mg/L to 0.066 mg/L. The 0.6% of biomass involved in the transport would relegate about 2.6 x 10^{-4} mg/L to the bottom, an equally undetectable amount in the water concentrations.

These extremely low amounts indicate that changes in the water chemistry are not an appropriate medium to evaluate the removal process for Ni. The transport mechanism for As may still be, in part, related to the biology, but the particle formation and the relegation of As to the sediment differs from that of Ni, as previous data interpretations demonstrated. An assessment of the characteristics of the particles themselves, some of which are of algal in origin, is an appropriate way to identify the pathway that the contaminants from the water column take, to reach the sediments in the bottom of the pit. To substantiate the role of biology in relegating Ni to the bottom sediment, only the particle and sediment composition and particle characteristics could provide indirect evidence, as discussed previously, since the dynamics of growth and decay in the pit appear to control the overall Ni concentration in the water.

2.5.1 Contaminants in sedimentation trap particulates

In Figures 21a to 21d, on the following page, the concentrations of As, Ni, Fe and P in 1998 are compared to those in 1996 and 1997. The concentrations of the same elements for the previous years are summarized in Figures 23a to 23d in Appendix 1, covering the entire period since the pit was flooded in 1992. Over this period, the concentrations of As, Ni , Fe and P in the sedimentation trap material were determined, since it was suspected that a relationship between Fe and As should be apparent, due to the adsorption of As onto iron

Fig. 21a: Flooded Pit, 1996-1998
Arsenic Concentration in Sed.Traps

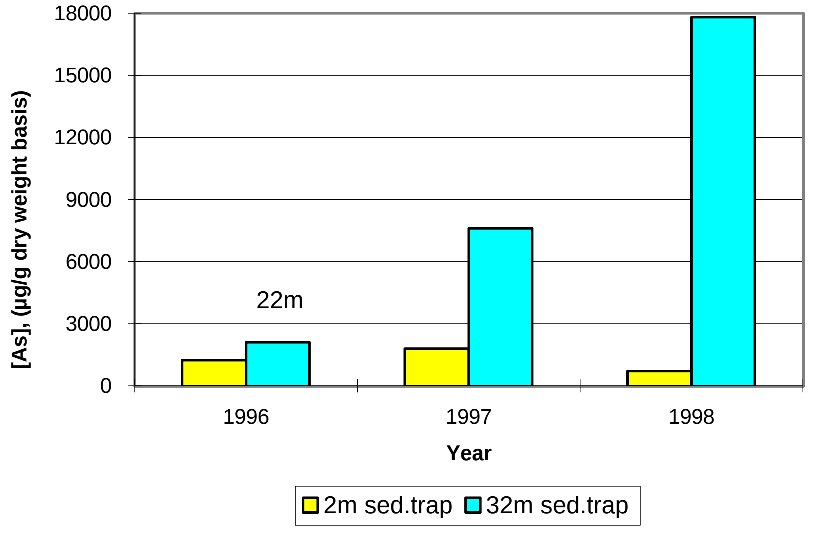


Fig. 21b: Flooded Pit, 1996-1998
Nickel Concentration in Sed.Traps

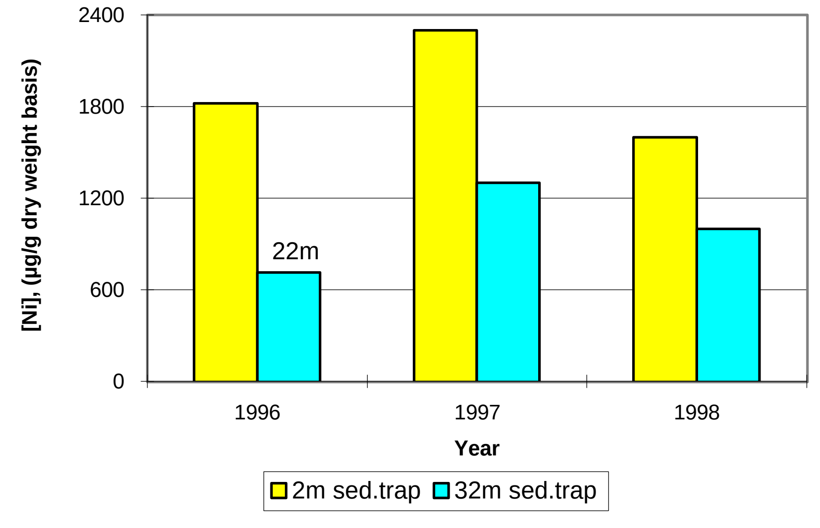


Fig. 21c: Flooded Pit, 1996-1998
Iron Concentration in Sed.Traps

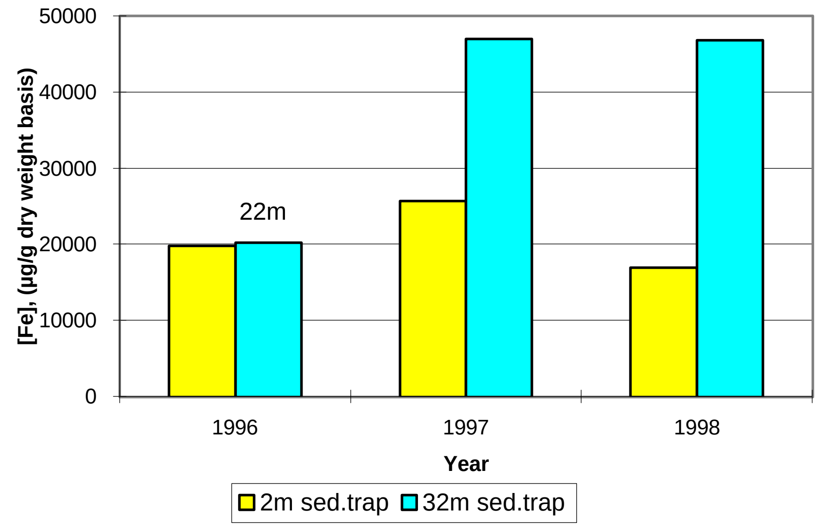
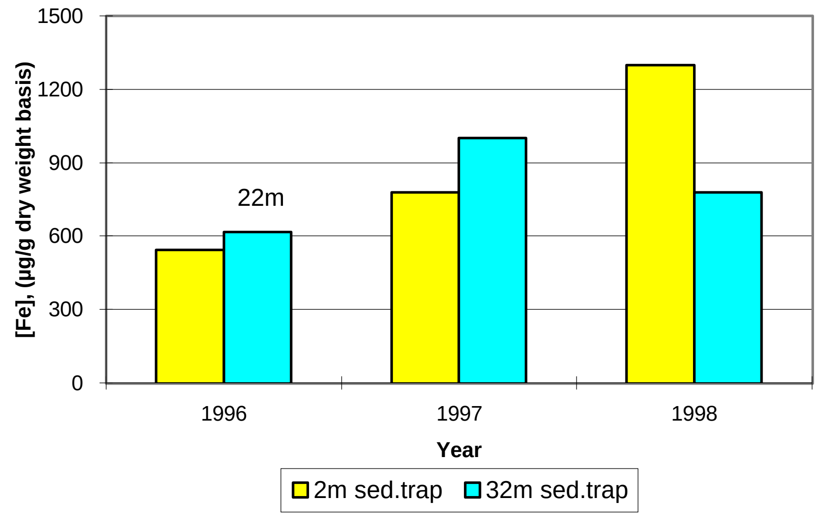


Fig. 21d: Flooded Pit, 1996-1998
Phosphorus Concent. in Sed.Traps



hydroxide.

For the 1997 sedimentation trap material, a complete chemical analysis (including N and total organic carbon) was carried out. The 1997 analysis of nutrient ratios in both sedimentation trap material and sediments in the bottom of the pit, confirmed that biomass was reaching the bottom and accumulating there. The Redfield nutrient ratios were used to identify the origin of the phosphate (Tables 5a and 5b, pages 41 and 42), confirming that
it was largely organic in nature. In 1998 it was confirmed that the surface and bottom samples had similar concentrations of phosphate (Figure 21d).

Comparing concentration of Ni and P, in the surface and bottom material in the sedimentation traps, revealed similarities in the distributions of concentration of Ni and P, both between years and between the bottom and surface. As expected, the concentrations of Ni in the surface material were higher than at the bottom. For As and Fe, the concentration differences clearly indicate a similar pattern over the years and with depth.

3.0 TRENDS IN SEDIMENTATION RATES

The TSS concentrations were discussed previously and found to be in part composed of biomass. If biomass is increased, it may lead to increases in particle sizes, as aggregation of particles might occur with a higher probability. Although more biomass may be produced it may not alter the sedimentation rate. The rates have not been examined with respect to changes with depth, and hence a brief examination of the existing data set was carried out.

Since 1993, sedimentation traps set at four depths in the pit - 2m, 12m, 22m, and 32m - have been sampled seven times annually (Table 6, on the next page). In 1992, a single sample from the 32m sedimentation trap was taken. In 1998, an effort was also made to ascertain sedimentation rates for shorter time intervals, and for control locations in Collins Bay and Ivison Bay, to obtain a reference point comparing the pit to the surrounding water bodies.

The sedimentation rates in the B-Zone Pit for the 1998 1-month interval were very similar to the values that were recorded for the longer 1998 sampling interval. The value of 1.6 $g/m^2/d$ was similar to those values recorded earlier in the year and in the control water bodies. It does suggest, that the sedimentation rates in the pit are comparable and representative of the waters in the region.

While there are some differences in sedimentation rates among the four depths where samples were collected (2, 12, 22 and 32 m), no clear pattern can be observed (Figure 22 on page 54), and the Wilcoxon Signed Ranks Test reveals no significant differences. In other mining waste management areas, this has not been the case; the sedimentation rates at different depths in a pit in Newfoundland and an acidified lake in northern Ontario were found to be significantly different (higher in deeper sedimentation traps). In comparison to these mining lakes, however, the B-Zone Pit is hydrologically and geochemically very stable.

The time-trend in the sedimentation rates in the B-Zone Pit is very pronounced, however,

Table 6: Sedimentation rates in the B-Zone Area

Station	Depth m	Sample total DW (g)	Sedimentation rate (g/m^2/day)
B-Zone Pit 6.72	**From 11-Jun-93 to 13-Aug-93, 63 days**		
	2	14.71	23.79
	12	16.64	26.91
	22	14.24	23.02
	32	17.74	28.68
	From 26-Jun-94 to 8-Sept-94, 74 days		
	2	4.49	6.20
	12	10.58	14.60
	22	12.61	17.35
	32	8.41	11.58
	From 26-Jun-95 to 10-Aug-95, 45 days		
	2	6.37	14.42
	12	3.83	8.66
	22	5.30	12.00
	32	4.49	10.17
	From 10-Aug-95 to 16-Sept-95, 37 days		
	2	6.12	21.00
	12	4.69	12.91
	22	5.52	15.20
	32	5.78	15.90
	From 5-Jul-96 to 30-Aug-96, 56 days		
	2	0.90	1.64
	12	2.91	5.29
	22	1.94	3.52
	32	no sample	
	From 17-Jun-97 to 26-Aug-97, 70 days		
	2	0.80	1.20
	12	1.65	2.40
	22	1.65	2.40
	32	no sample	
	From 25-Jun-98 to 1-Sept-98, 68 days		
	2	1.25	1.87
	12	1.75	2.62
	22	1.90	2.84
	32	1.70	2.54
B-Zone Pit 6.73	**From 31-Aug-98 to 29-Sept-98, 29 days**		
	4	0.45	1.6
Collins Bay 6.12	**From 31-Aug-98 to 29-Sept-98, 29 days**		
	9	1.6	5.6
Ivison Bay 6.10	**From 31-Aug-98 to 29-Sept-98, 29 days**		
	9	0.5	1.8

Fig. 22: Depth versus Sedimentation Rate in B-Zone Pit

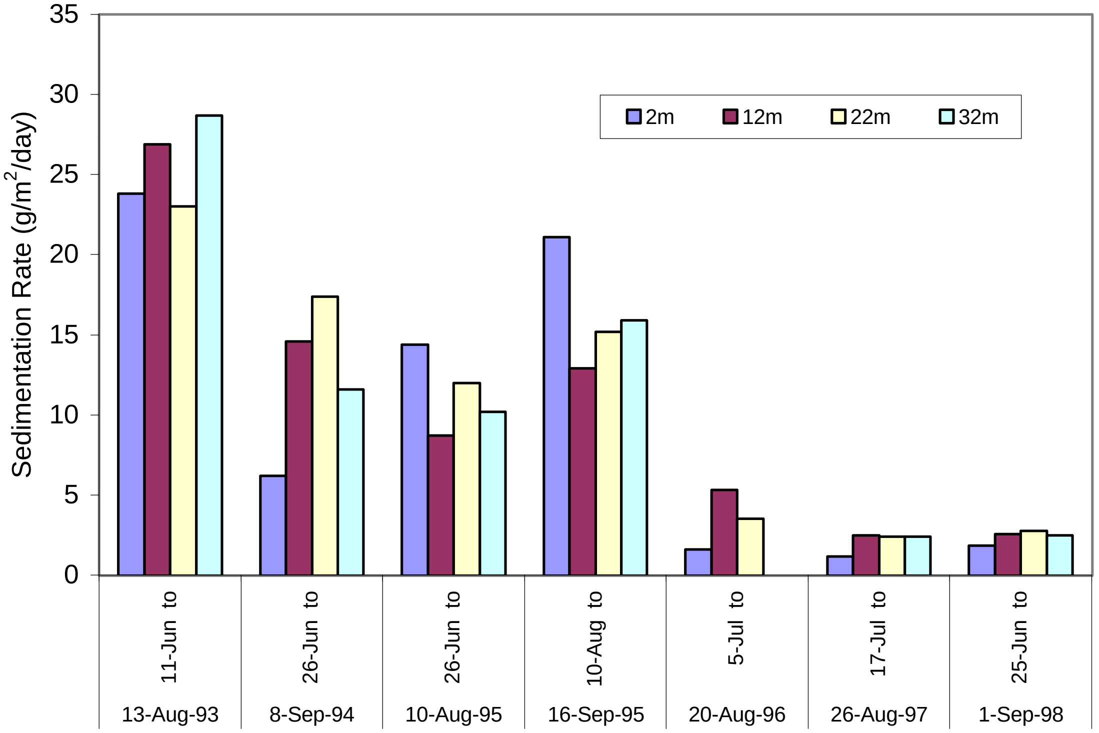
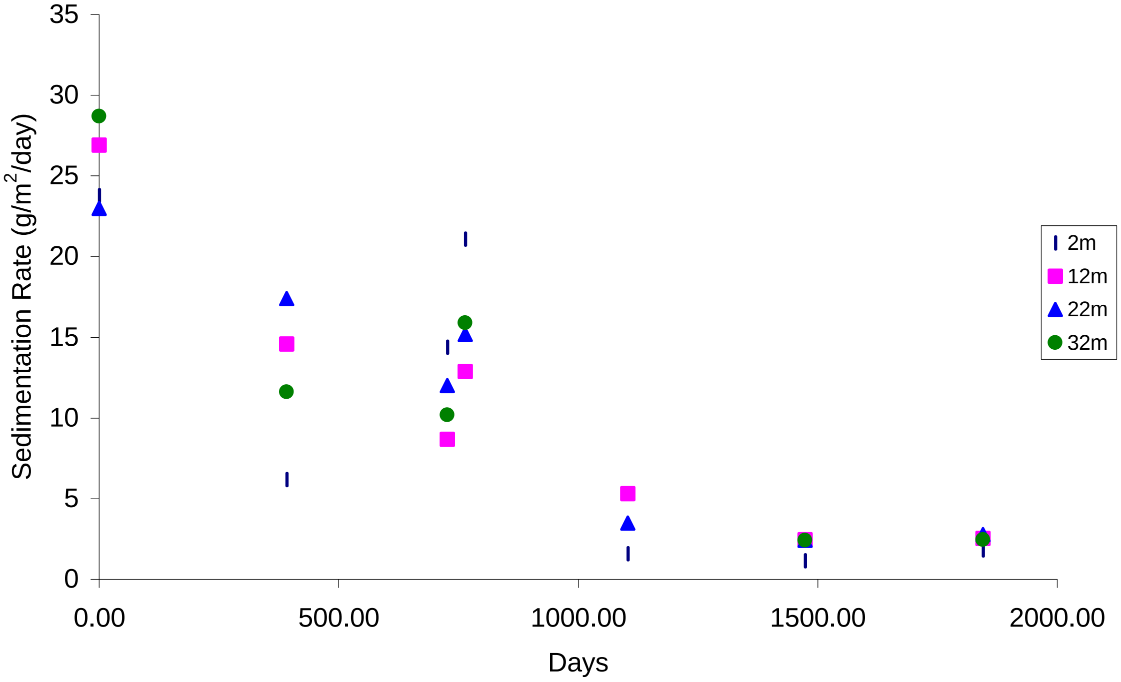


Fig. 23: Time-trend of Sedimentation Rates



showing the rate of sedimentation decreasing over the period, particularly after 1995. Setting the first sampling date (August 13 1993) equal to Day 0, the sedimentation rates were plotted against time - in days. Figure 23 (page 54) shows the trend of decline is statistically significant at all depths (Pearson r=-0.76, -0.92, -0.97 and –0.88 respectively, $P<0.05$).

As these rates form the basis of the mass balance of the contaminant transport to the sediments, they are important. A literature review on sedimentation rates, their use and the general methodology was carried out.

3.1 Literature review of sedimentation rates

The literature on sedimentation rates in natural systems indicates that rates can be affected by the length of time a trap is suspended, and be influenced greatly by the type of water body it is in. The reported rates for natural lakes range widely. For example, Hakanson (1995) deployed sedimentation traps to investigate sedimentation rates in 25 shallow lakes in Sweden. He recorded rates ranging from 0.28 to 6.73 g/m^2/day In his work, Hakanson related sedimentation rates to catchment area, vegetation type, retention time of the water in the lakes, and their depth. He concluded that no single factor could explain a very large proportion of the variance of sedimentation rates.

In another study, by Kozerski (1994), sedimentation rates in a number of German lakes were found to vary between 6.8 and 66 g/m^2/day Although the rates recorded at the B-Zone Pit fall well within these published ranges, the natural lakes, which are highly dynamic hydrologically, involve much higher sedimentation rates. Hornbach et al., (1991), for example, recorded sedimentation rates of 190 - 310 g/m^2/day in a Minnesota channel lake. In such types of lake, sediment is largely allochthonous (input from outside the lake) and its sedimentation rate is strongly controlled by the velocity and size of suspended matter in the inflow.

Another important source of sediments in natural lakes is the biological production within the system (autochthonous, Table 3, page 38), including algae, animal remains and aquatic shoreline plants - the later 2 components not being present in the B-Zone Pit. The B-Zone Pit differs from natural lakes in its physical shape, absence of shoreline and drainage basin, as well as any pronounced input or outflow of rivers or streams. In natural lakes, sediments consist largely of inorganic substances, and biological communities represent a smaller fraction of the total sedimenting mass of material.

Another approach to estimating sedimentation rates is reported in the literature. Instead of measuring the sedimentation rate, the mass balances derived from productivity measurements are calculated. Ideally, the two methods should give similar results but, unfortunately, that is not always the case, due to re-suspension in sedimentation traps. It has frequently been reported that sedimentation traps are subject to re-suspension (Rathke et al., 1981, Rosa et al., 1991, Kozerski, 1994). Bloesch (1994) wrote a critical review of the re-suspension problem. Kozerski (1994) found that traps reached 3 g dry weight (DW)/m^2/day in a slow flowing river, but only 1 g DW/m^2/day could be accounted for by mass balance. At another location in the same study, 35 g DW/m^2/day was estimated from trapping, but only 8.8 g DW/m^2/day was estimated from the mass balance using productivity measurements.

The differences between the two methods are as high as a factor of 4. Mothes (cited by Kozerski, 1994) reported that the rate of phosphorus in sedimentation material exceeded the loss rate derived from the calculated phosphorus balance by a factor of 5 on average. In some cases, the difference even reached a factor of 30 (Kozerski, personal communication). Natural systems, however, display considerably higher dynamics than the B-Zone Pit, which is a deep, narrow water body where wind-induced waves are unlikely to disturb the sediments at the bottom. For these reasons, the sedimentation rates in the pit should match the mass balances reasonably well. Turnover in fall and spring may lead to some re-suspension of particles, which would result in an overestimation of sedimentation rates but, in general, the sedimentation rate measurements should more accurately reflect productivity estimates in the B-Zone Pit than in natural water bodies.

3.2 Chemical composition of particulates

The vertical distribution and time-trend data for both sedimentation rates and chemical composition were analysed, using correlation and regression, in order to determine the relationship of the elements with depth and time. As well, to test the statistically significant differences in non-normally distributed parameters, the Wilcoxon test was carried out.

The chemical composition of trap sediment was analysed for the 7 sets of samples, representing 27 data points. Thirty-one elements/compounds were identified in the material, the type of chemical tests requested only partial elemental analysis was carried out and here the material was used up, some elements were not represented as pairs (time, depth and element) and could not be used in the statistical data interpretation.

The elements Ca, K, Mg, Na, S, Total–N, and TOC had to be excluded from the trend analysis because they had not been analysed consistently over time. The elements in another group, Ag, Be, Bi, and Mo, although present at all sampling intervals and at all depths, were also excluded because they were reported in concentrations at or near the detection limit. The remaining data set consisted of concentrations of the major contaminants As and Ni, and several other major elements Zn, Fe, Mn, Al, Cd, and Cu were present in the particulate matter collected in the sedimentation traps consistently.

The concentrations of these eight important elements in the trap sediments were examined for changes over time and with depth. The results are shown in Figures 24a to 24h (page 58-60). The behaviour of each element, as it moves with the particulate matter down through the pit, is described below.

Ni concentrations, at a depth of 2 m, are significantly higher than at the other depths (Wilcoxon Test, $P<0.05$), but the differences between 12 m, 22 m and 32 m are not significant. The concentration rates were regressed against number of days where, as mentioned earlier, Day 0 was the first day of sampling. The changes in Ni concentrations over time are not significant at any depth (Figure 24a, page 58).

Fig. 24a: Ni Change over Depths and Time

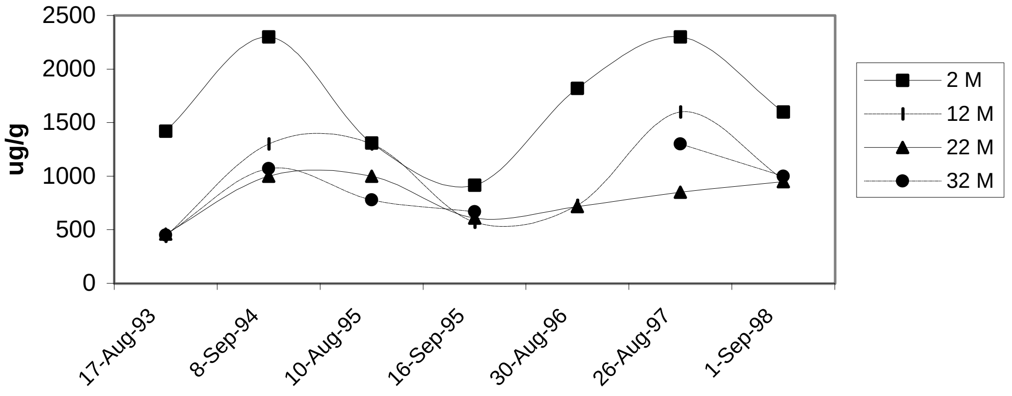


Fig. 24b: As Change over Depths and Time

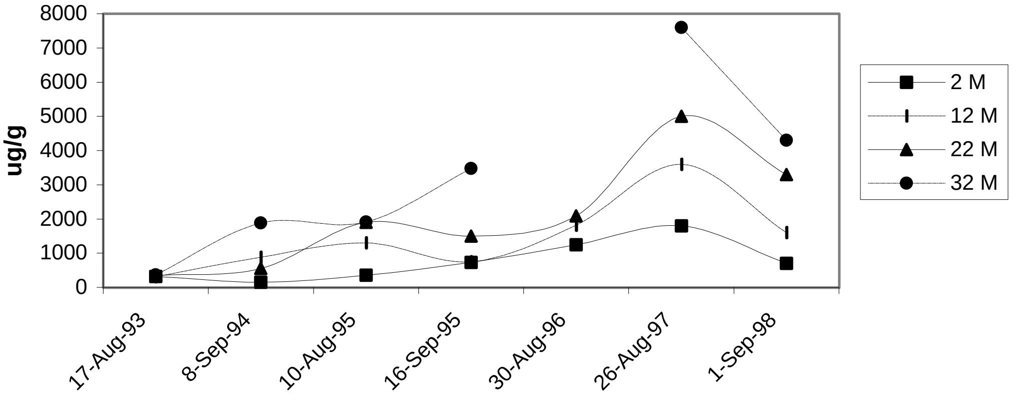


Fig. 24c: Fe Change over Depths and Time

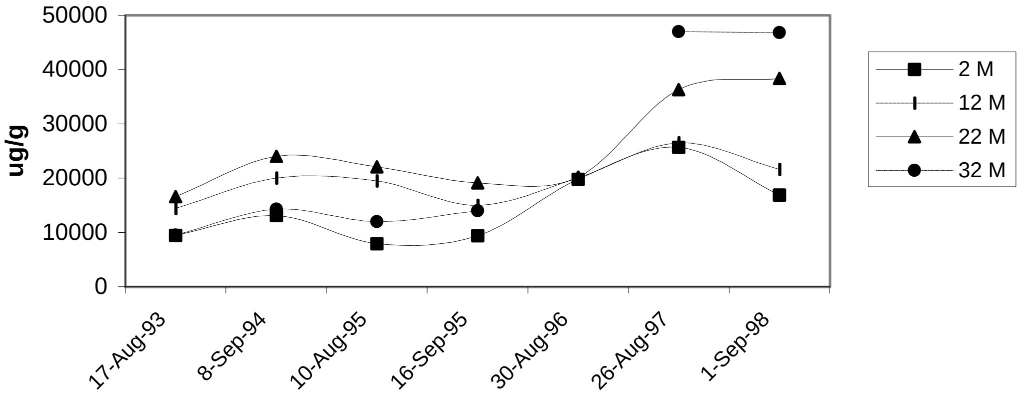


Fig. 24d: Mn Change over Depths and Time

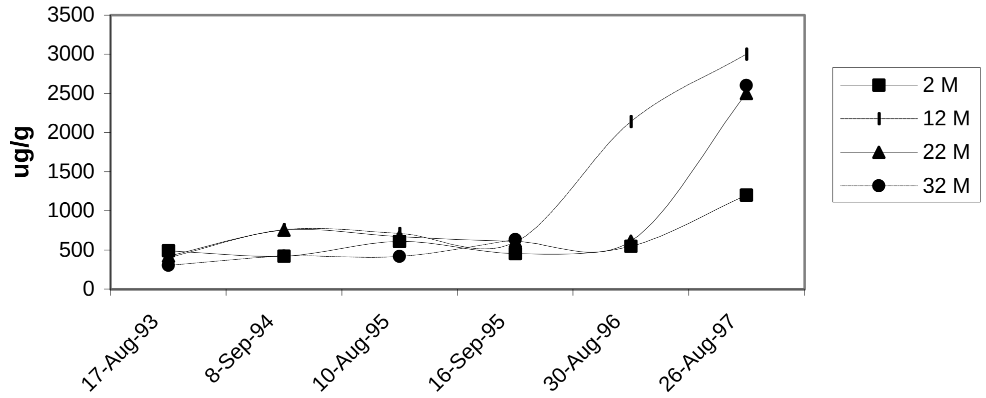


Fig. 24e: Zn Change over Depths and Time

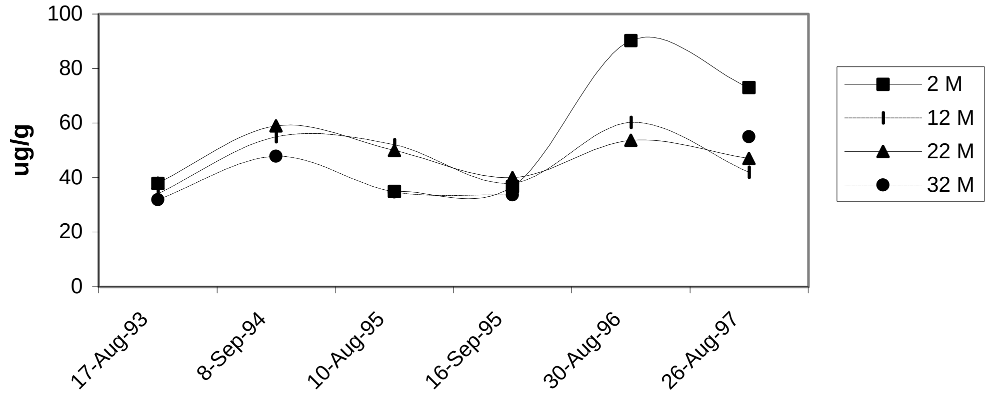


Fig. 24f: Al Change over Depths and Time

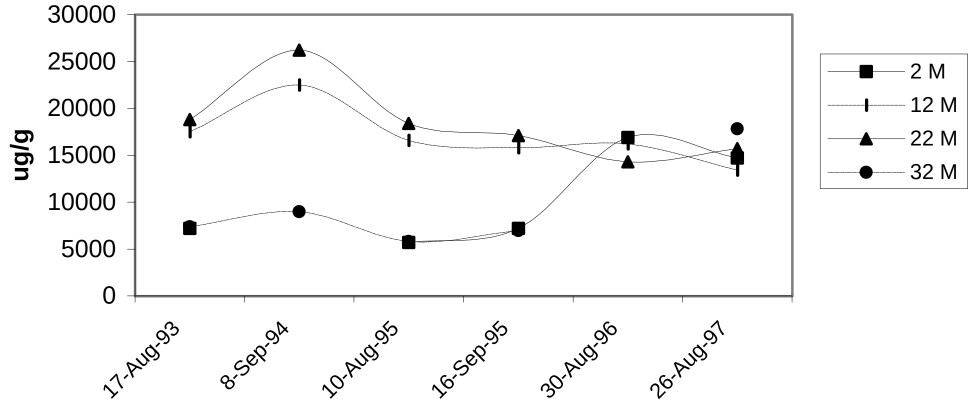


Fig. 24g: Cu Change over Depths and Time

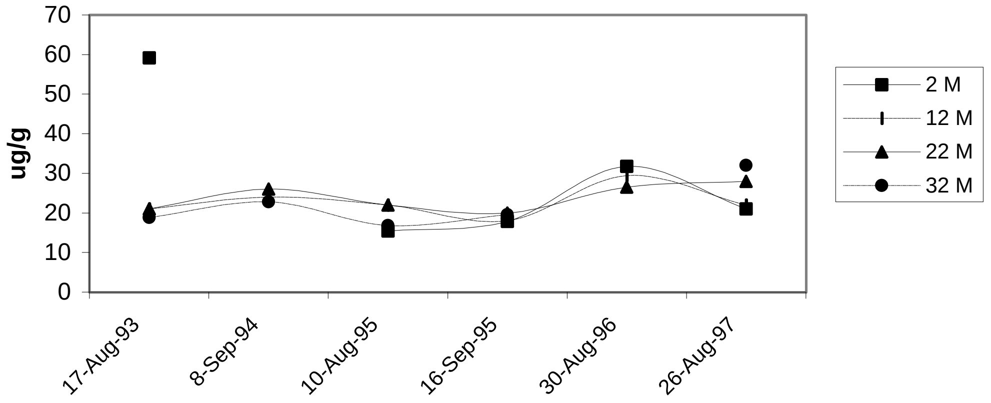
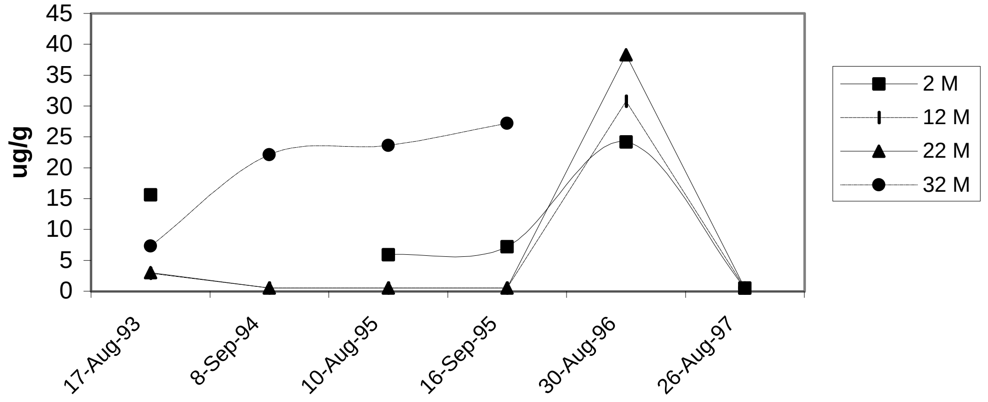


Fig. 24h: Cd Change over Depths and Time



As concentrations are higher at the bottom than in shallow water. A Wilcoxon Test showed As levels are consistently significantly higher in deeper traps ($P<0.05$), with the exception of the traps at 12 m and 22 m; there is no significant difference in the concentration of As in these two traps. Over the study period, the As concentrations at depths 22 m and 32 m significantly increased (linear regression $r^2 = 0.74, 0.65$, respectively, $P<0.05$). See Figure 24b, page 58).

Fe concentrations exhibit similar patterns to As - higher at the bottom than in shallow water, significant at $P<0.05$) with the Wilcoxon Test - but show no significant differences between the concentrations at depths 12 m, 22 m and 32m. Again very similar to As, the concentrations significantly increased over the study period at 22 m and 32 m (linear regression $r^2 = 0.713, 0.847$ respectively, $P<0.05$). See Figure 24c on page 58.

Mn concentrations are significantly lower at the 2 m level than at 12 m, but all other differences are not significant. Over time, however, the concentrations of Mn showed significant increases at all but the 2 m depth (Figure 24d, page 59).

Zn, Al, Cu and Cd concentrations do not show significant changes with depth and, similarly, they display no obvious time trends. The metals Cu, Cd and Zn do not show an adsorption pattern similar to either As or Ni. The fact that Al does not show a similar trend to iron is likely due to the fact that its chemistry is sufficiently different (see Figures 24e to 24h, page 59-60).

These results suggest that different precipitation adsorption processes are involved with different elements. Ni may be re-dissolved, as the particles settle through the water column, whereas As either continues to combine with particles, or the high-As particles are formed in deep water.

The changes in chemical composition of the particulate matter with depth, indicate that different processes take place with As and Ni. In summary, As and Fe attain significantly higher concentration in deeper traps, with significant increases also taking place over time

(1993 and 1998). Ni concentrations are higher in shallow water (2 m), but show no time-trend. All the other five elements show no consistent changes, either with depth or time.

3.3 Particle size of particulates

To determine with which of the particulate size fraction the contaminants move through the pit, water was filtered through different sizes of filter that would trap particles in the range of 0.1 to 1.0 :m on the filter paper. The filter papers and the filtrate was subjected to chemical analysis for the relevant elements. As discussed in detail in the 1997 report, the definition of ‘dissolved’ and ‘total’, based on 0.45 :m filtration needs further consideration. The results of the fractionated filtrations and the solids analysis is presented in Fig 25 a to 25 d on the following page for Fe, As , Ni and P, expressed as percentage particulates of total concentration in the water.

In Figure 25a, the fractions of Fe which are retained on the filter papers are presented as a percentage of the total Fe concentrations in the water, at different depths in the pit. Iron particles form in different sizes.

In Figure 25b, the As that is retained on the filter papers is reported in the same fashion, indicating that slightly larger particles are formed at depth, but that all particles contain some As. For Ni (see Figure 25c), as would be expected, filtration does not capture significant amounts, but the filtered surface water shows the highest concentrations, and the fraction of total Ni concentration diminishes with depth of water sampled. Either the nickel is truly dissolved, or the filtration process breaks down its adsorption bond to the algae. Phosphorus (see Figure 25d), being the main indicator of the biology, should decrease with depth, and it does so, although ever so slightly. This fractionated filtration does demonstrate clearly 0.45 um filtration does not define dissolved for Ni as not even 0.1 um filter paper retain a significant fraction of the Ni. This is quite different for Fe and As which segregates with depth and particle size.

Fig. 25a: Suspended Iron from filter papers

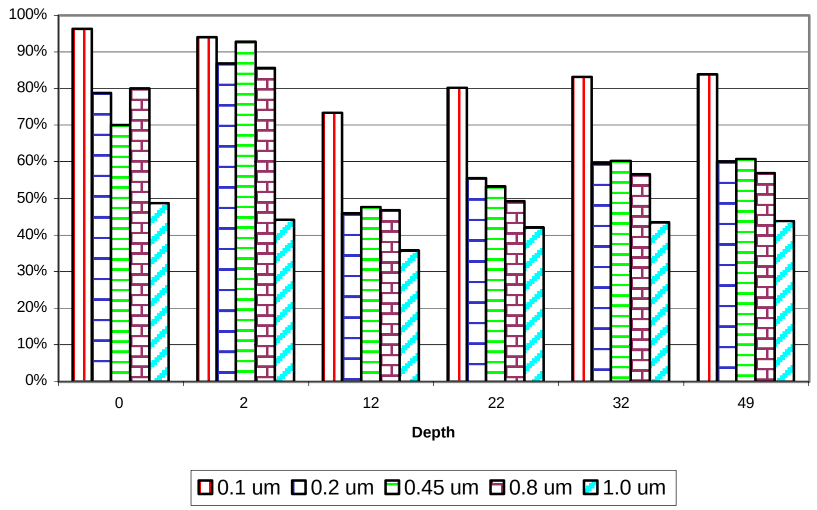


Fig. 25 b: Suspended Arsenic from filter papers

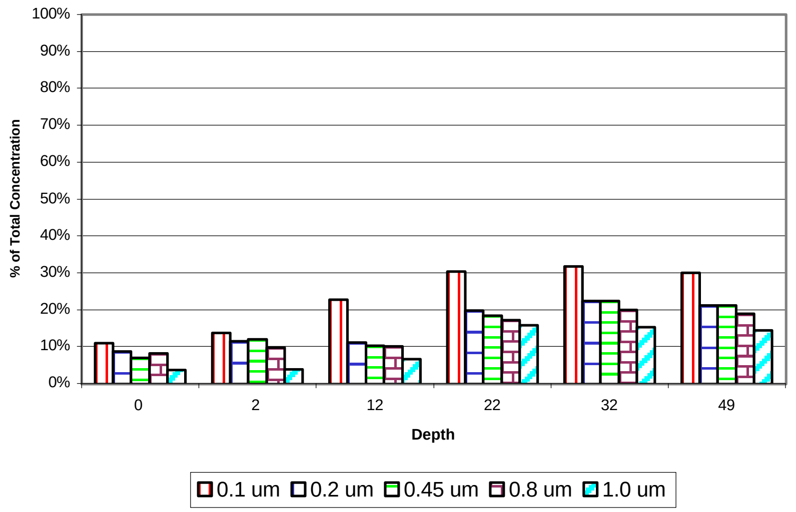


Fig. 25c: Suspended Nickel from filter papers

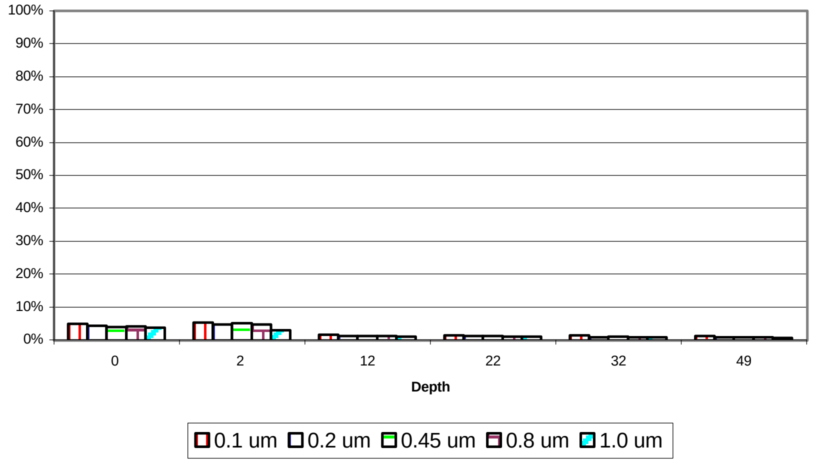
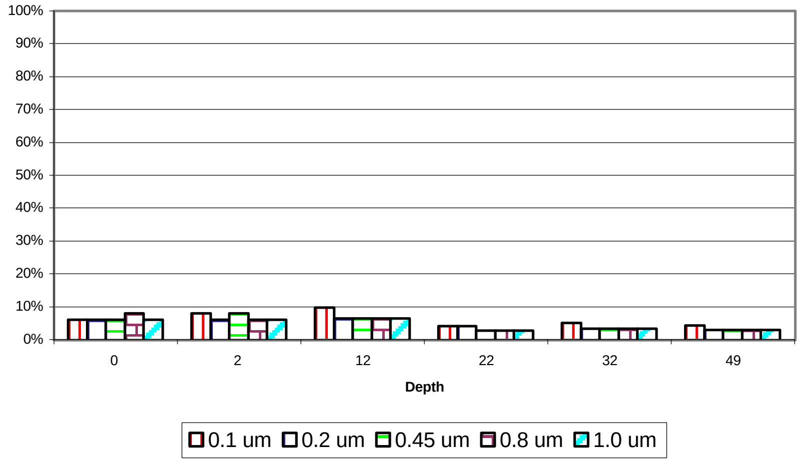


Fig. 25d: Suspended Phosphorus from filter papers



3. 4. Accumulation of As and Ni in the sediment

Collection of sediment material from the bottom of the pit could not yield meaningful results until a reasonable time had passed to allow for the formation of layers which, when brought to the surface, would not disintegrate. On August 26 1997, sediment material which had accumulated at the bottom of the pit was sampled for the first time at two locations (Stations 6.71 and 6.72) with an Eckman dredge. The sampled sediment was divided into different layers, which are described in detail in Table 7, on the next page. The quantity of sediment in each stratum could then be expressed as g(DW)/m^2 and, for the As and Ni concentrations in each layer, a mass per m^2 could be derived.

The concentrations of both As and Ni vary both between the different layers (Table7, page 57), and between the two locations. The concentrations in the sediment, however, are all within the range of the concentrations in the sedimentation trap material (Figures 24a and 24b). In particular, the average concentration estimated from trap data is in close agreement with those from the upper layers of natural sediment: 1070 :g As/g are in the trap sediment, compared to 1100 and 1500 :g/g at Station 6.71 and 6.72, respectively; 975 :g Ni/g are in trap sediment, compared with 550 and 820 :g/g at the two stations (all are expressed as dry weight). The total weight of As and Ni in the surface layer at the bottom of the pit that has accumulated since the pit was flooded was estimated as follows:

[Sediment Layer (:g/g)] × Sediment volume (g/m^2) × Effective Surface Area (m^2)

At station 6.71, the concentration of As was 8.6 g/m^2 in the surface layer, compared to 4.1 g/m^2 at station 6.72. For Ni, the mass per m^2 was lower, as expected, with 4.3 g/m^2 in the surface stratum at station 6.71 and 2.2 g/m^2 at station 6.72. The deeper strata of the sediments had similar or higher masses of both As and Ni per m^2, but generally lower moisture contents with higher wet volumes, suggesting that more inorganic material was contained in the sample.

In order to determine the pit bottom surface area, SURFER was used to estimate

Table 7. Ekman Dredge Sediment Analysis

	Stn 6.71 26-Aug-97 Upper Layer	Stn 6.71 Middle Layer		Stn 6.72 24-Aug-97 Layer 1	Stn 6.72 24-Aug-97 Layer 2	Stn 6.72 24-Aug-97 Layer 3	Stn 6.72 24-Aug-97 Layer 4
Field Description				Fine black-olive	Gelatenous olive sediment	Loose gray clay	Fine white sand
Lab Description	Very moist yellow to gray very fine silt	Very moist tan brown very fine		Very moist light brown sediment	Very moist light brown fine silt and	Very moist light brown fine silt and	
Stratum (cm)	0 - 3 cm	3 - 8 cm		0-1.5 cm	1.5-3 cm	3-8 cm	> 8 cm
Subsample Wet Vol., mL	60	60		60	60	60	
Wet Wt., g	66	89		65	87	90	
Dry wt., g	16	55		11	36	57	
Moisture Content, %	76	38		83	59	37	
Dry sediment [As] ug.g^{-1}	1,100	110		1,500	440	210	
Dry sediment [Ni] ug.g^{-1}	550	180		820	420	230	
m3 sediment.m^{-2}	0.030	0.050		0.015	0.015	0.050	
g dry sediment.m^{-2}	7,800	45,917		2,725	8,875	47,167	
g As.m^{-2} sediment	8.6	5.1		4.1	3.9	9.9	
g Ni.m^{-2} sediment	4.3	8.3		2.2	3.7	11	
Sediment surface area, m^2	333,557	333,557		333,557	333,557	333,557	
50 % Sediment surface area, m^2	166,779	166,779		166,779	166,779	166,779	
			SUM				**SUM**
kg As in sediment layer	1,431	842	**2,273**	682	651	1,652	**2,985**
kg Ni in sediment layer	715	1,378	**2,094**	373	622	1,809	**2,804**

the surface areas of zones at different depths. The whole pit is divided into six depth-zones and 50% of their total surface area is assumed to be horizontal/effective, i.e., where sedimentation material can be expected to settle out. The values of the surface areas of the pit walls for each depth and the pit bottom are given in Table 8, below.

Table 8: Pit Wall Area Estimated for Setting Particulate Matter in B-Zone Pit

Zones	Total Surface m^2	Horizon Surface m^2
0-2 m	82,065	41,033
2-12m	72,658	36,329
12-22m	42,805	21,403
22-32m	39,814	19,907
32-42m	41,806	20,903
>42m	54,409	27,205

:

To calculate the total amount of particulates potentially having reached the bottom of the pit, the sedimentation rates are integrated as in previous evaluations of volume of pit sections. As and Ni in particulates in the 2 m trap are used to represent the 0-2 m zone. For all other zones, however, the averages of the sedimentation rates from above and and below are used, i.e., the rates from 2 m and 12 m are averaged to represent the 2-12 m zone. This applies to the 12-22 m and 22-32 m zones. While no trap was set below 32 m, the 32 m rate was extrapolated to the 32-42 m, and the below 42 m zones. For 1995, two sedimentation rates were determined, and hence their average is used.

Table 9, on page 67, gives the estimates of the total amount of sediment in the different depth-zones. An estimated total of *1773 tonnes* (dry weight) has been deposited on the pit bottom, taking into consideration the trend in decreasing sedimentation rates. The estimations of the total As removed are shown in Table10, on page 67, and the total Ni removed are given in Table 11, on page 67.

Table 9. Estimation of Sedimentation Rate (kg/day) and Warm-season Total (kg).

	2m	12m	22m	32m	42m	below 42m	**185 Days-Total(kg)**
13 Aug. 1993	976585	920940	534005	514596	599916	780784	**800463**
8-Sep-94	254405	377822	342448	288652	242475	315578	**336955**
1995 (average)	728131	308797	261117	265261	272784	355025	**405356**
20-Aug-96	65653	125335	94173	69675	73161	95218	**96795**
26-Aug-97	47769	66083	52169	47798	50190	65321	**60926**
1-Sep-98	76732	81559	58430	53550	53094	69101	**72606**
Total of Depth-zon	2149274	1880534	1342342	1239531	1291619	1681026	**1773100**

Table 10. Estimation of As Removal Rate (kg/day) and Total (kg)

As (kg/day)	2m	12m	22m	32m	42m	below 42m	**185 day total (kg)**
13 Aug. 1993	0.3154	0.2915	0.1762	0.1835	0.2178	0.2834	**271.54**
8-Sep-94	0.0382	0.1946	0.2449	0.3507	0.4559	0.5933	**347.33**
1995 (average)	0.3965	0.2423	0.3558	0.5829	0.7352	0.9568	**604.84**
20-Aug-96	0.0821	0.1924	0.1841	0.1456	0.1529	0.1990	**176.88**
08/26/97	0.0860	0.1784	0.2243	0.3011	0.3814	0.4964	**308.53**
1-Sep-98	0.0537	0.0938	0.1432	0.2035	0.2283	0.2971	**188.62**
Total of Depth-zo	0.9718	1.1930	1.3284	1.7673	2.1714	2.8261	**1897.74**

Table 11. Estimation of Ni Removal Rate (kg/day) and Total.

	2m	12m	22m	32m	42m	below 42m	**185 day total (kg)**
13-Aug-93	1.3868	0.8565	0.2456	0.2316	0.2700	0.3514	**618.22**
8-Sep-94	0.5851	0.6801	0.3424	0.3089	0.2594	0.3377	**465.02**
1995 (average)	0.8104	0.3162	0.2272	0.2027	0.1972	0.2567	**371.92**
20-Aug-96	0.1195	0.1597	0.0680	0.0498	0.0523	0.0681	**95.72**
26-Aug-97	0.1099	0.1289	0.0639	0.0514	0.0652	0.0849	**93.27**
1-Sep-98	0.1228	0.1048	0.0561	0.0522	0.0531	0.0691	**84.74**
Total of Depth-zo	3.1344	2.2462	1.0033	0.8965	0.8973	1.1678	**1728.90**

A total of *1898 kg* As has been removed from the water column, with the maximum amount (605 kg) occurring in 1995. The average sediment trap material concentration of As over the whole pit was estimated at *1,068 :g/g* (1,898 kg As in 1,773,100 kg sediment). The total amount of Ni removed since 1993 was estimated at *1,729 kg*, with the highest yearly rates being in 1993 and 1994. The removal rates have decreased each year since then. The average concentration registered in trap sediment was estimated to be 975 *:g/g*. With these numbers in hand, it is possible to determine a mass balance for the contaminants in the B-Zone pit.

The total amount of both As and Ni that was removed is the sum of the different layers, given in Table 12. The comparison of the mass of As and Ni in the bottom and trap sediments shows that the estimate based on sedimentation of particulates is higher then in the surface layer of the pit , collected with the Eckman grab sampler.

Table 12: Comparison of As and Ni Mass Bottom Sediment vs Trap Sediment

Elememt	Trap Sediment	Bottom Sediment			
		Station 6.71		Station 6.72	
		0-3cm	Total	0-3cm	Total
As (kg)	1898	1431	2273	1333	2985
Ni (kg)	1729	715	2094	995	2804

This might be expected if one considers the following aspects.

Firstly, the sedimentation trap data that are used cover only 1993 to 1998, while the dredged samples contained sediment which had accumulated since the pit was flooded, in 1992. Secondly, the assumption has been made that sedimentation is taking place for only 185 days, based on the fact that the major fraction of particles is generated only during the summer, and not underneath the ice-cover. This period could be shorter and hence would lower the total mass expected to reach the sediment. Thirdly, and most importantly, the lower layer of the sediment (>3cm) contains inorganic matter, which is likely adding nickel which did not arise from sedimentation to the inventory.

In summary, the amount of Ni and As in the top layer of the sediment is remarkably close to the amount estimated from the particles collected - clearly they are in the same order of magnitude. It is also worthy to note the estimates of arsenic removal from sediment trap data and from bottom sediment in relation to arsenic concentrations in the water column. Average pit water arsenic concentration at its peak in June 1994 was 046 mg/L of As. By 1998, the average pit water arsenic concentration had fallen to around 0.10 mg/L of As, resulting in a net difference is 0.36 mg/L of As. Since the pit water volume is 5.7x10^6 m^3, this represents a net removal of 2,052 kg of As. Although the arsenic water balance agrees very closely with the solid mass balance, this approach does not work for nickel. Despite clear evidence of nickel removal in sedimentation trap and bottom sediment data, that level of removal is not evident in changes in pit water quality.

Nevertheless, these results confirm the proposed ecological engineering principles for controlling contaminant removal mechanisms, in that contaminants in the water are relegated to the sediment, where they become an environmentally acceptable component of the ecosystem.

4.0 CONCLUSIONS

The purpose of this report, as described in Section 1.0 Introduction, was to present and interpret the 1997 and 1998 data. In doing so, our fundamental understanding of the pit's behaviour has not been altered. It has been refined and the basic premiss of the ecological engineering with natural contaminant removal processes has been confirmed.

- The case is particularly good for As. The evident drop in water column As concentration is strongly associated with Fe, and As is present in both sedimentation traps and bottom sediments. In fact, there is a relatively good consistency between the various estimates.

- In the case of Ni, there is a good association with P, which has its origin in biomass, and Ni is present in sedimentation traps and in bottom sediments. However, this has not been seen to translate into significant changes in water column concentrations. It is believed that significant cycling of Ni is taking place, but the picture is still not completely clear.

- What is clearly different over the past 3 years is the rate of sedimentation, which has decreased. Reduced sedimentation rates, along with increased water transparency and increased phytoplankton diversity, suggest that the pit may be becoming become more nutrient limited.

- Arsenic removal, however, is either not significantly affected by the biology, or is benefiting indirectly from the biochemial changes in the water characteristics of the pit , since the pit is well on its way to meeting SSWQ objectives for As.

- It would seem that, if the Ni removal process is to be accelerated, the promotion of more biomass remains a logical approach, since the Ni captured in the sedimentation traps and the sediments are of biological origin.

C These developments are very good from an ecological perspective, but they do not assist in removing Ni to the pit bottom. If the removal rate of Ni by biomass is such that it balances an incoming source of Ni, as yet undetermined, then reductions in phytoplankton productivity and biomass would be expected to result in Ni concentration increases.

It could be suggested that, in order to further determine the role of phytoplankton and other sources of Ni in the restoration of the pit, it might by instrumental to maintain the status quo for a further year. Alternatively, it could be argued that it would be important to intervene in a process which is driving pit water arsenic concentrations towards the SSWQO. Although multivariate analysis of the phytoplankton community structure indicates that the ecosystem has not stabilized, predicting what might happen to the biology in the pit is extremely difficult. Considering the nutrient ratios, the system is on a course of reduction in both productivity and biomass. On the other hand, species diversity, which might induce a bloom of a yet unknown species similar to the dominance of the early colonizer, *Dictyosphaerium pulchellum*, is up. We believe that, at some point in time, nitrogen should be added to the pit in order to encourage the biological removal of nickel from the pit water.

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APPENDIX 1

B-ZONE PIT
LIMNOLOGY
1993-1997

LIST OF FIGURES

Fig. 1a: Flooded Pit, March-May
Temperature vs Depth, 1993-97

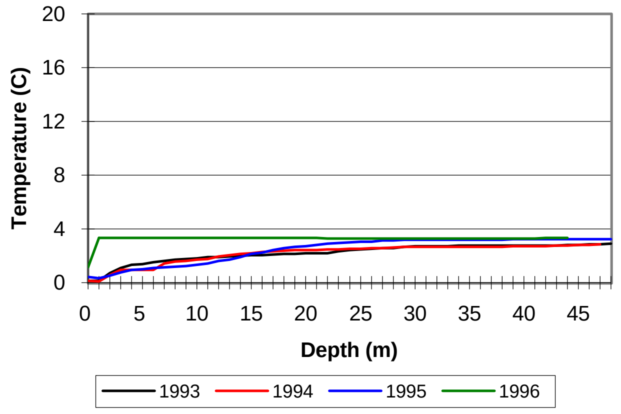


Fig. 1b: Flooded Pit, June-July
Temperature vs Depth, 1993-97

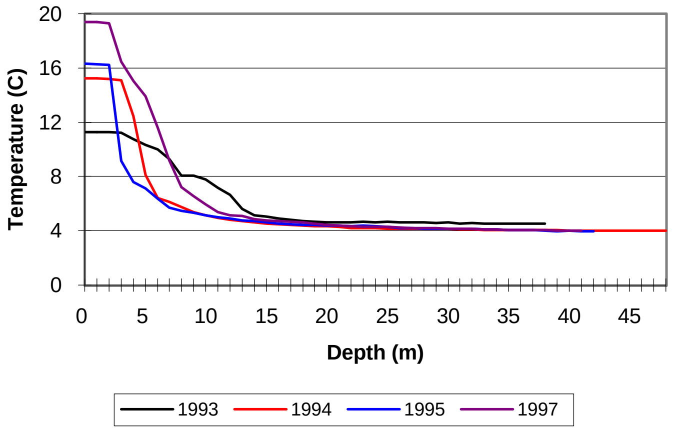


Fig. 1c: Flooded Pit, August
Temperature vs Depth, 1993-97

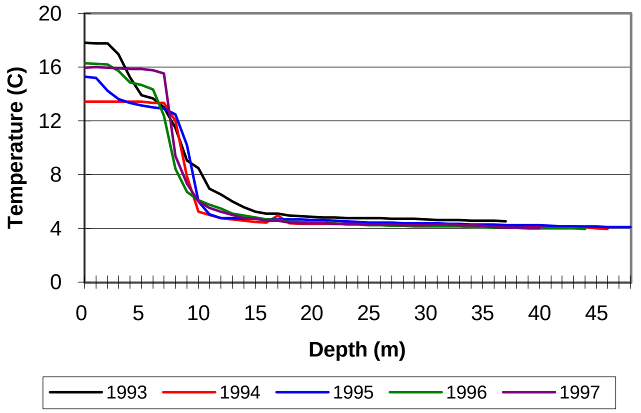
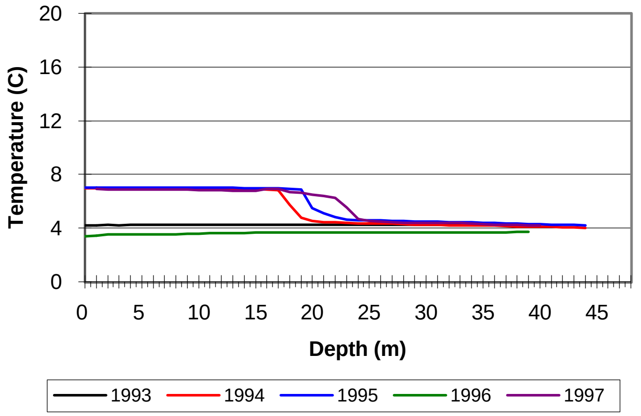


Fig. 1d: Flooded Pit, October
Temperature vs Depth, 1993-97



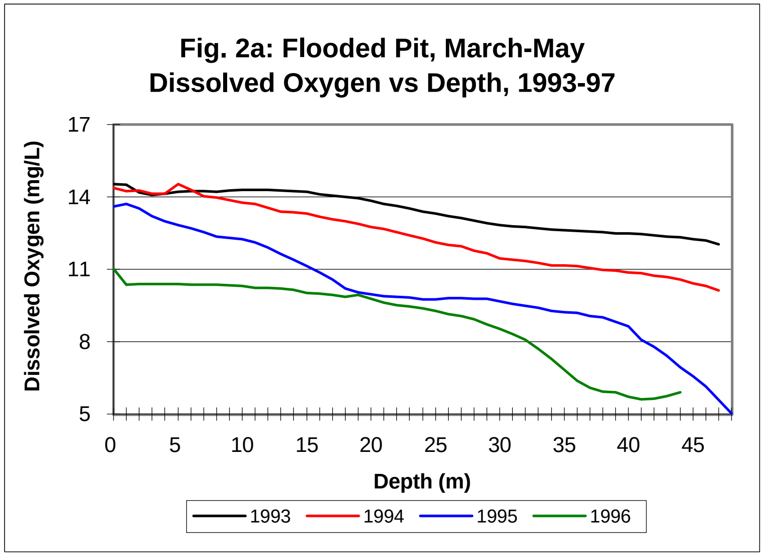


Fig. 2a: Flooded Pit, March-May
Dissolved Oxygen vs Depth, 1993-97

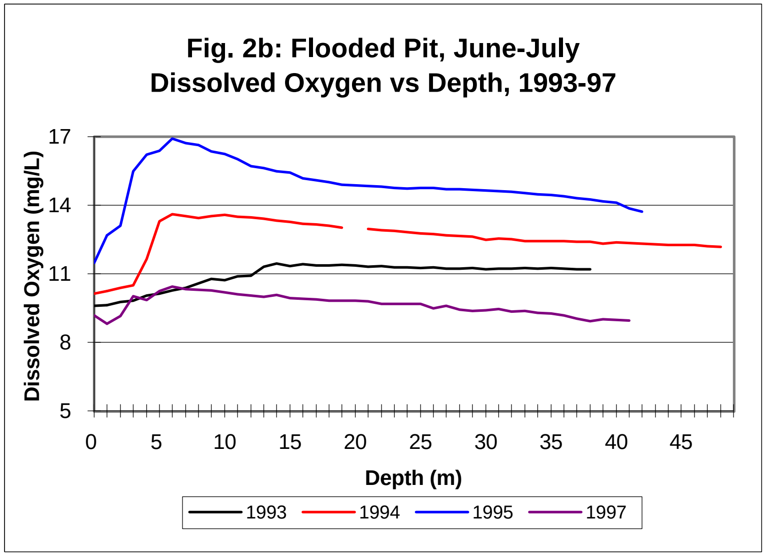


Fig. 2b: Flooded Pit, June-July
Dissolved Oxygen vs Depth, 1993-97

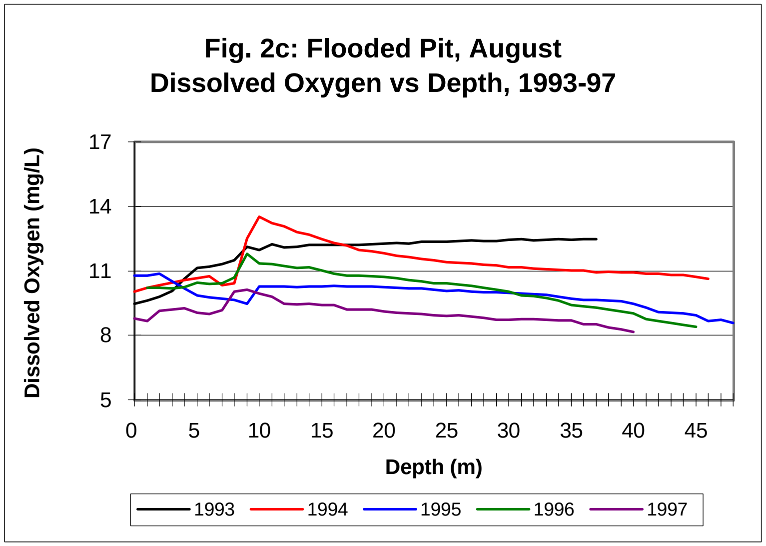


Fig. 2c: Flooded Pit, August
Dissolved Oxygen vs Depth, 1993-97

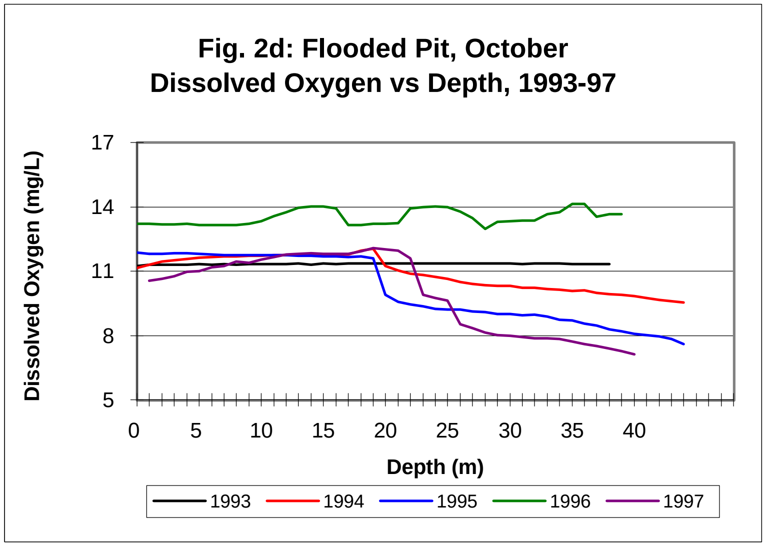


Fig. 2d: Flooded Pit, October
Dissolved Oxygen vs Depth, 1993-97

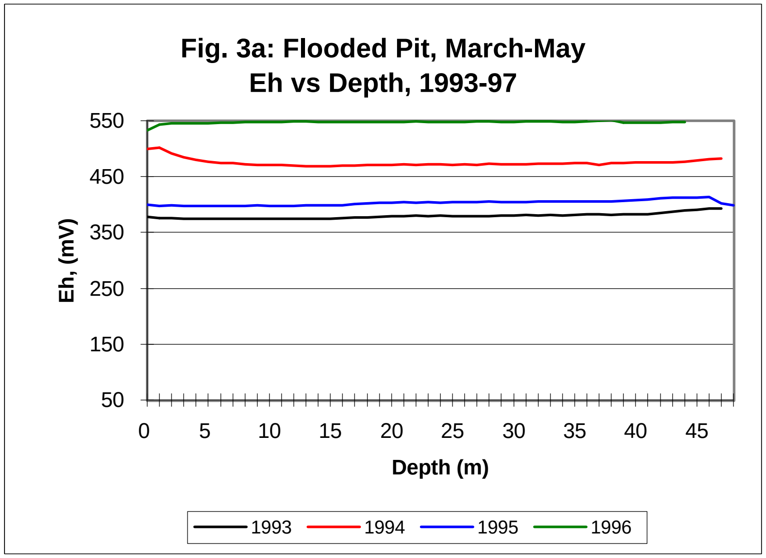


Fig. 3a: Flooded Pit, March-May
Eh vs Depth, 1993-97

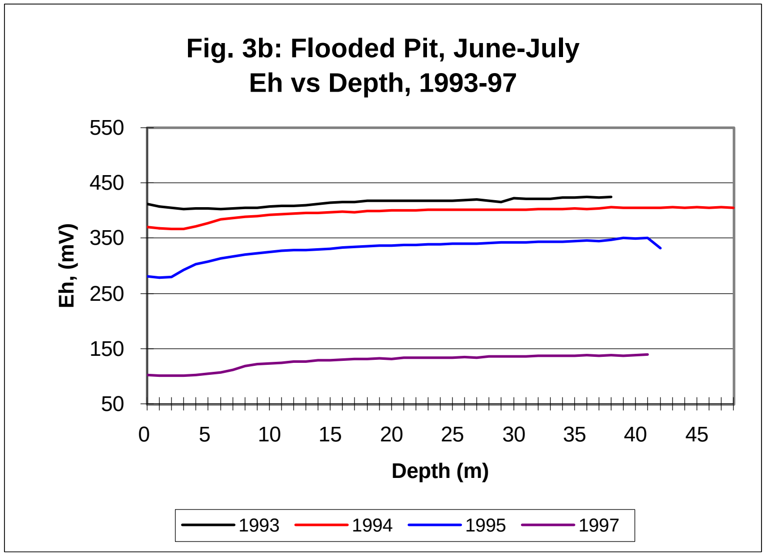


Fig. 3b: Flooded Pit, June-July
Eh vs Depth, 1993-97

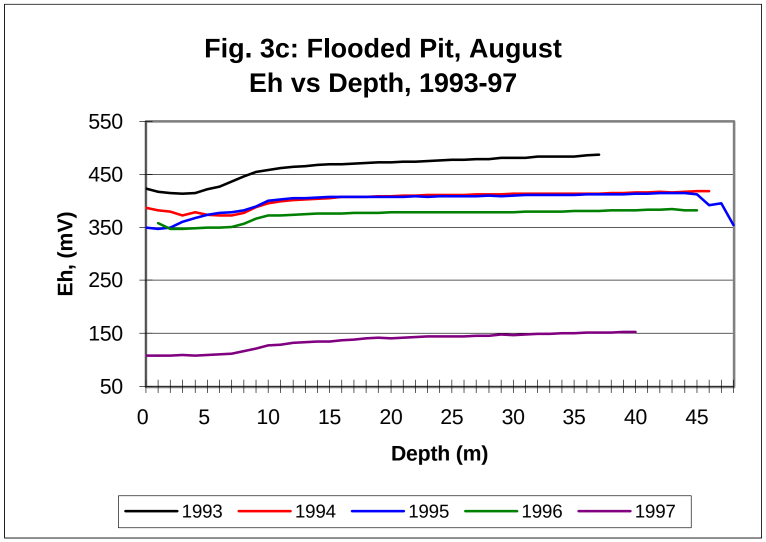


Fig. 3c: Flooded Pit, August
Eh vs Depth, 1993-97

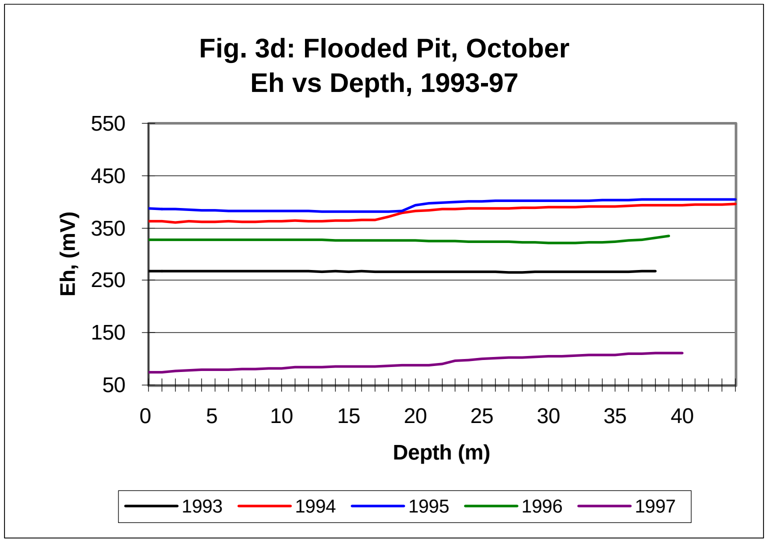


Fig. 3d: Flooded Pit, October
Eh vs Depth, 1993-97

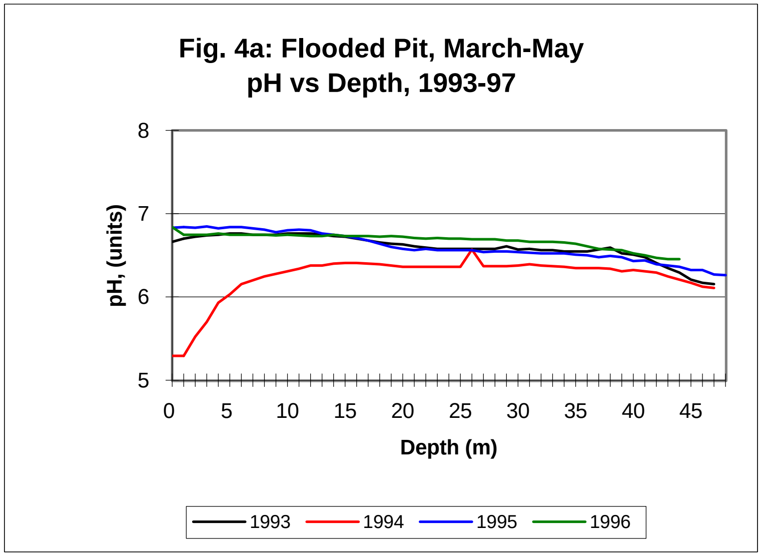


Fig. 4a: Flooded Pit, March-May
pH vs Depth, 1993-97

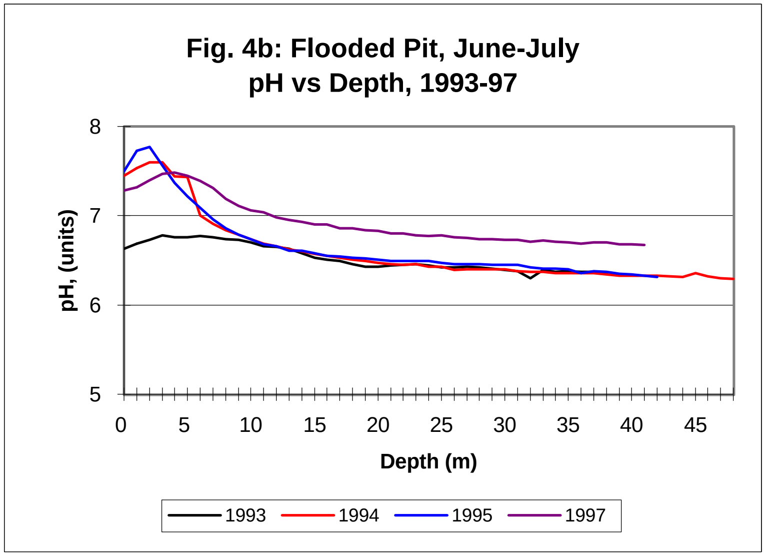


Fig. 4b: Flooded Pit, June-July
pH vs Depth, 1993-97

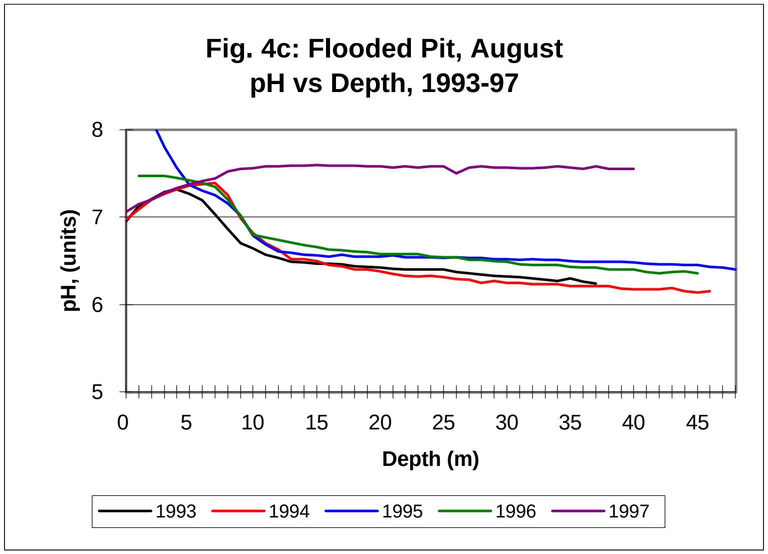


Fig. 4c: Flooded Pit, August
pH vs Depth, 1993-97

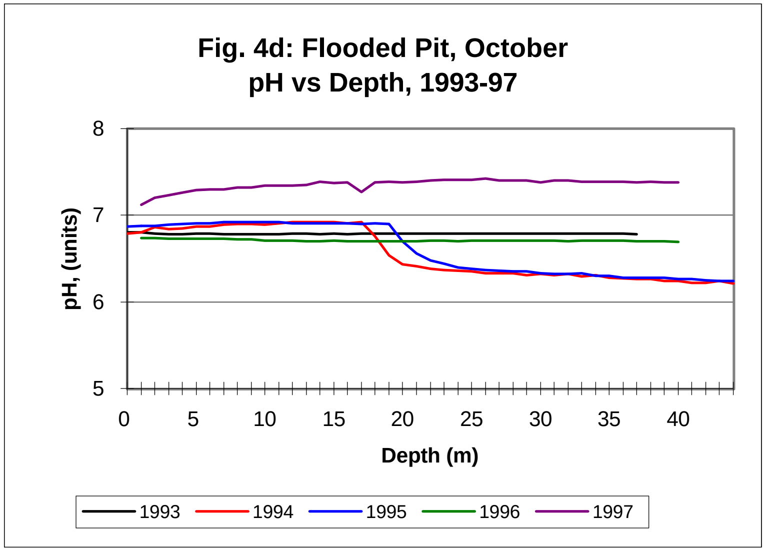


Fig. 4d: Flooded Pit, October
pH vs Depth, 1993-97

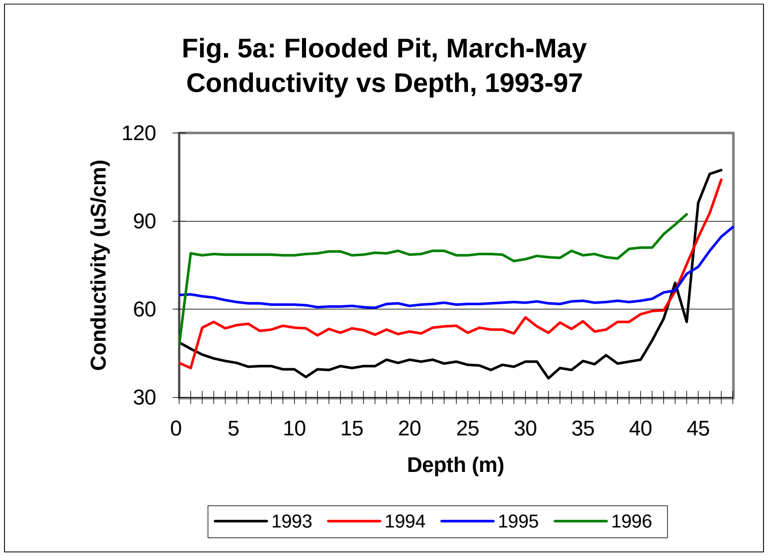


Fig. 5a: Flooded Pit, March-May Conductivity vs Depth, 1993-97

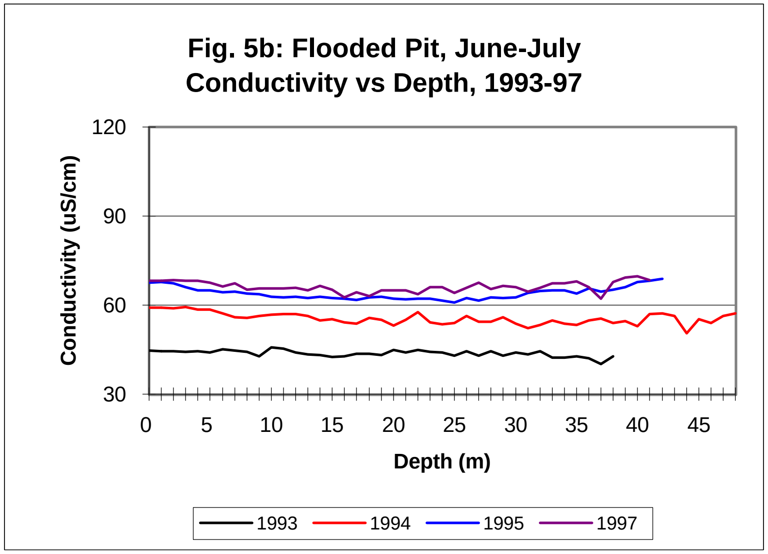


Fig. 5b: Flooded Pit, June-July Conductivity vs Depth, 1993-97

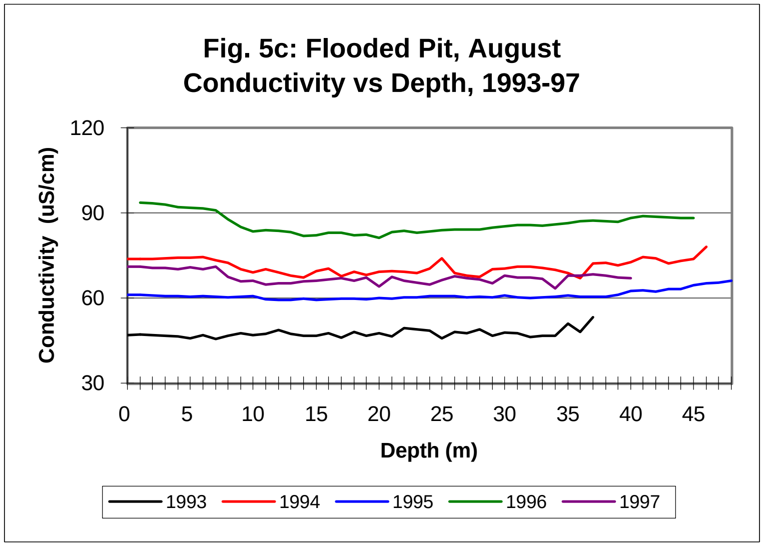


Fig. 5c: Flooded Pit, August Conductivity vs Depth, 1993-97

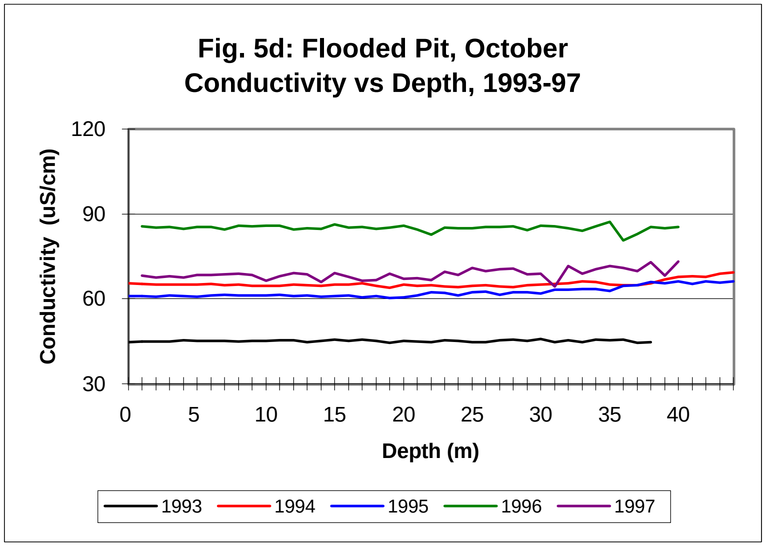


Fig. 5d: Flooded Pit, October Conductivity vs Depth, 1993-97

Fig. 6a: Flooded Pit, March-May Sodium Concentration, 1993-97

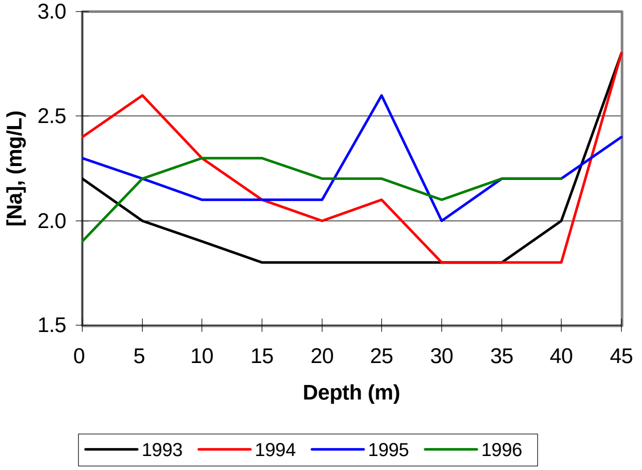


Fig. 6b: Flooded Pit, June Sodium Concentration, 1993-97

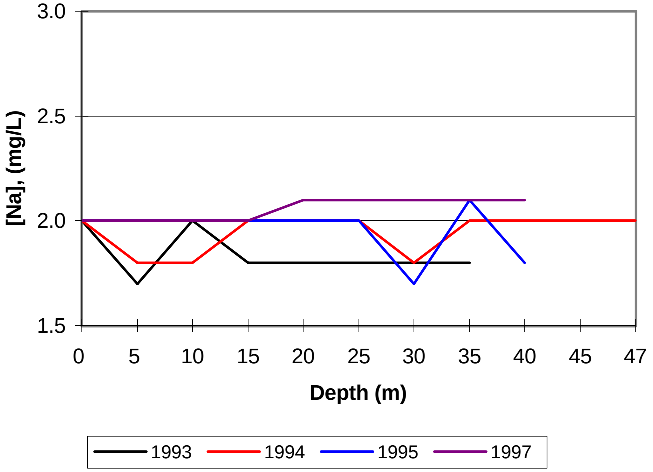


Fig. 6c: Flooded Pit, August Sodium Concentration, 1993-97

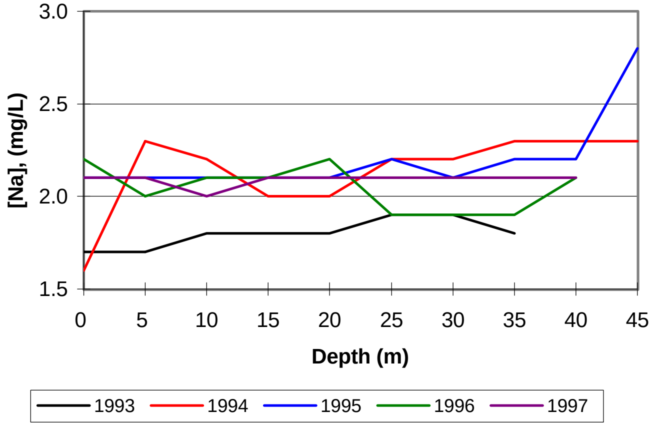
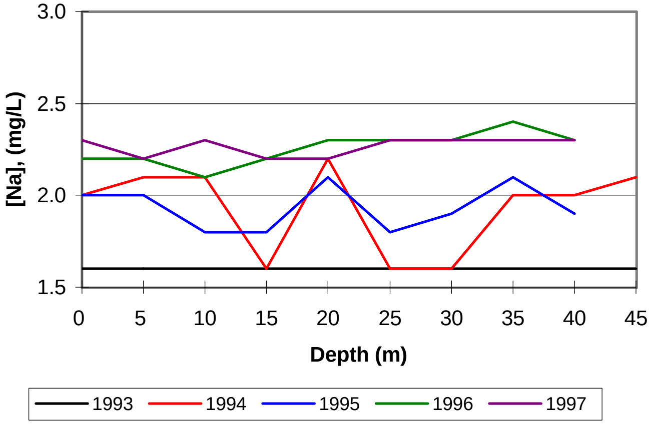


Fig. 6d: Flooded Pit, October Sodium Concentration, 1993-97



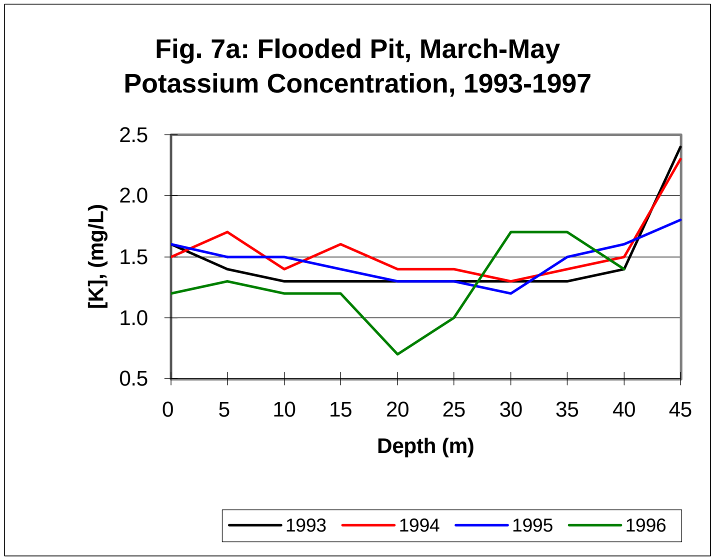


Fig. 7a: Flooded Pit, March-May Potassium Concentration, 1993-1997

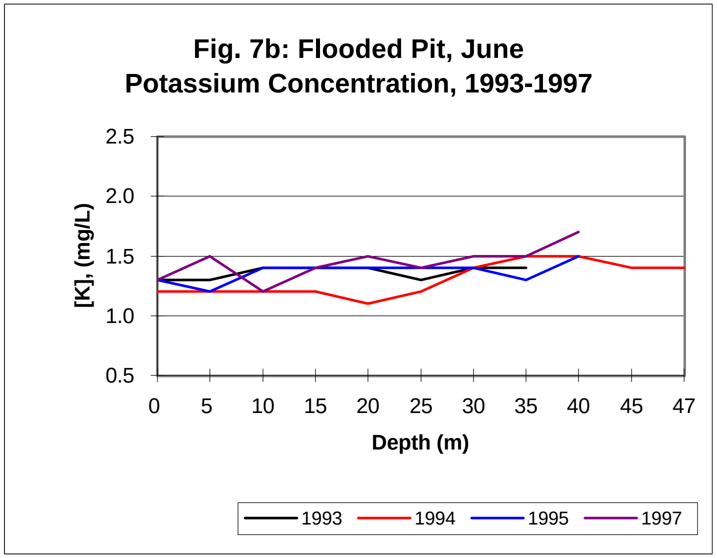


Fig. 7b: Flooded Pit, June Potassium Concentration, 1993-1997

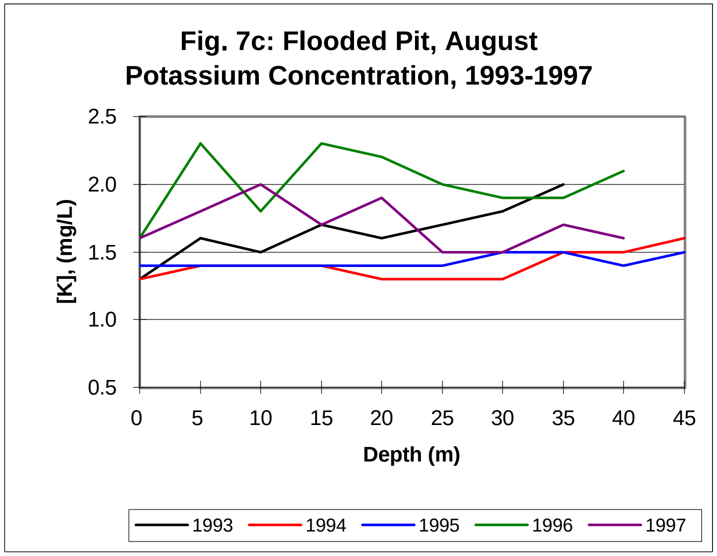


Fig. 7c: Flooded Pit, August Potassium Concentration, 1993-1997

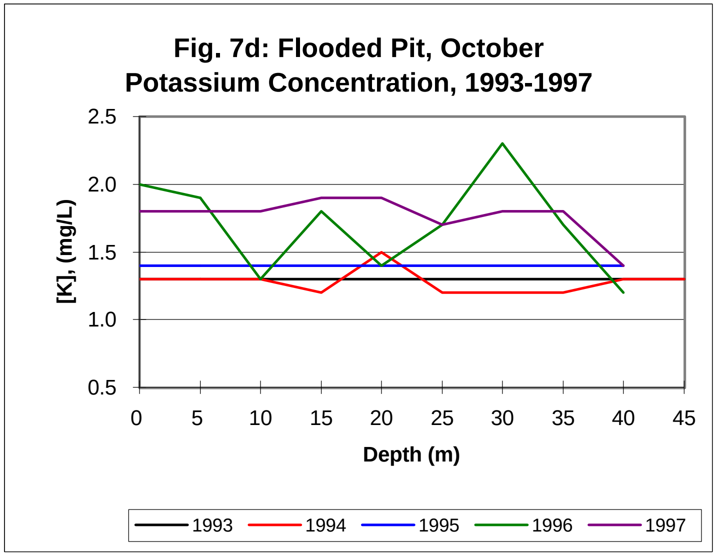


Fig. 7d: Flooded Pit, October Potassium Concentration, 1993-1997

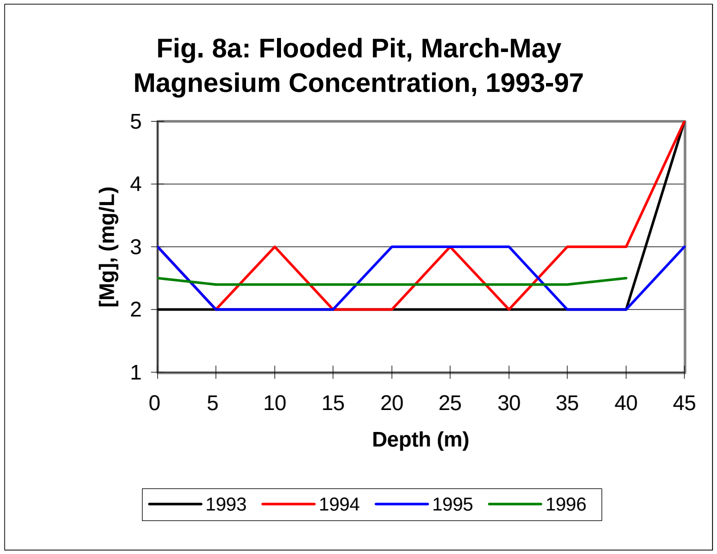


Fig. 8a: Flooded Pit, March-May
Magnesium Concentration, 1993-97

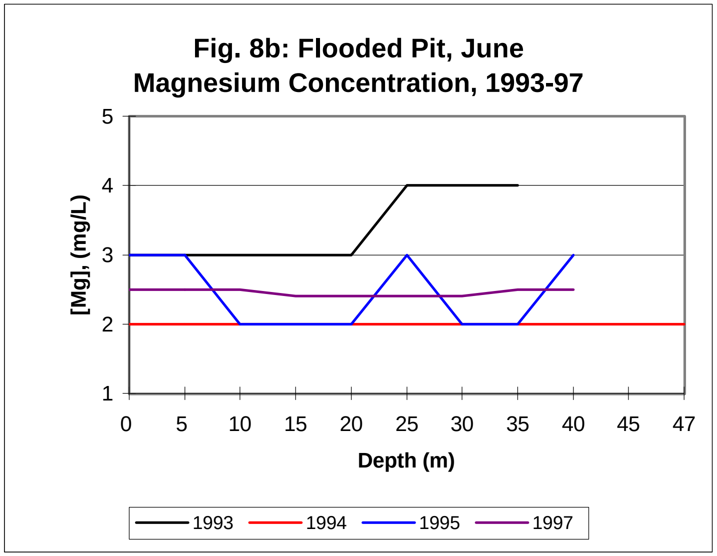


Fig. 8b: Flooded Pit, June
Magnesium Concentration, 1993-97

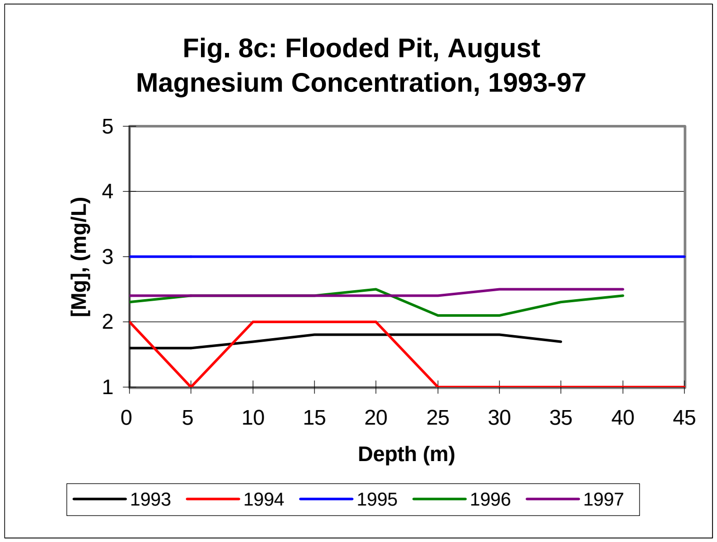


Fig. 8c: Flooded Pit, August
Magnesium Concentration, 1993-97

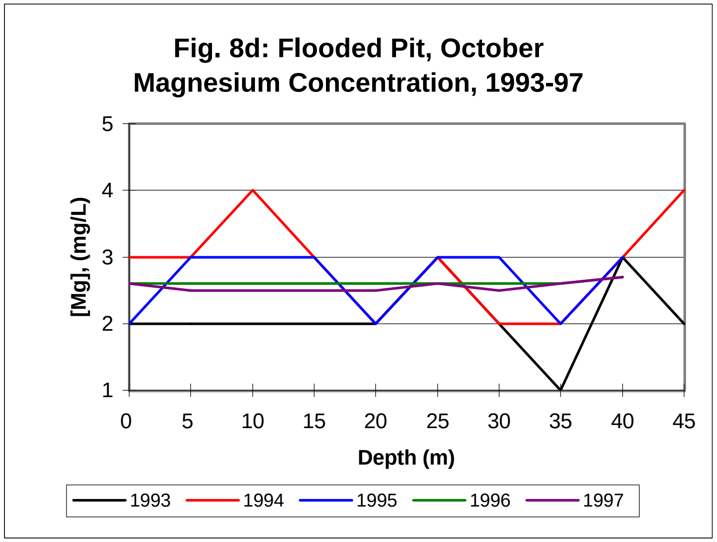


Fig. 8d: Flooded Pit, October
Magnesium Concentration, 1993-97

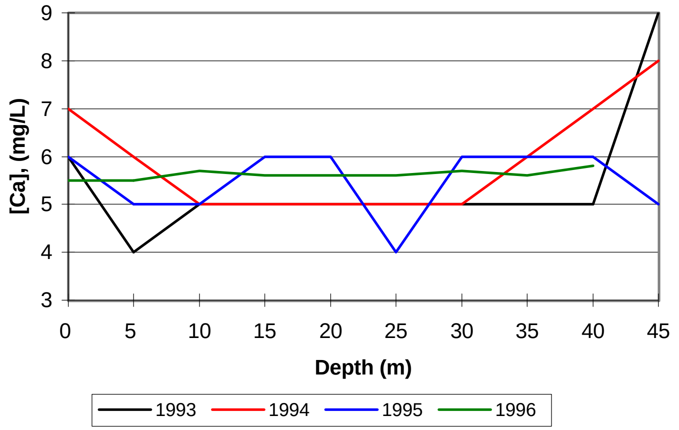


Fig. 9a: Flooded Pit, March-May
Calcium Concentration, 1993-97

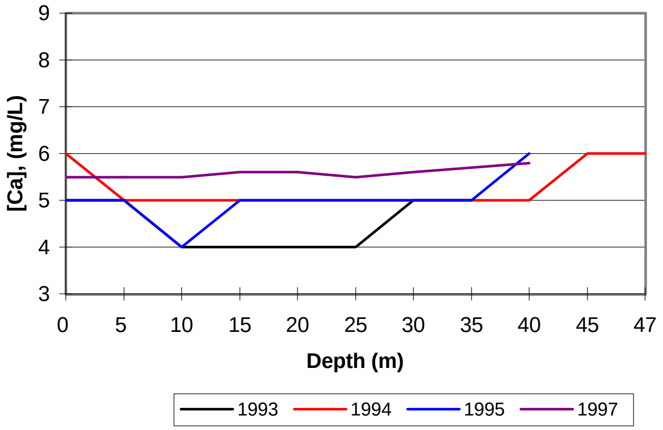


Fig. 9b: Flooded Pit, June
Calcium Concentration, 1993-97

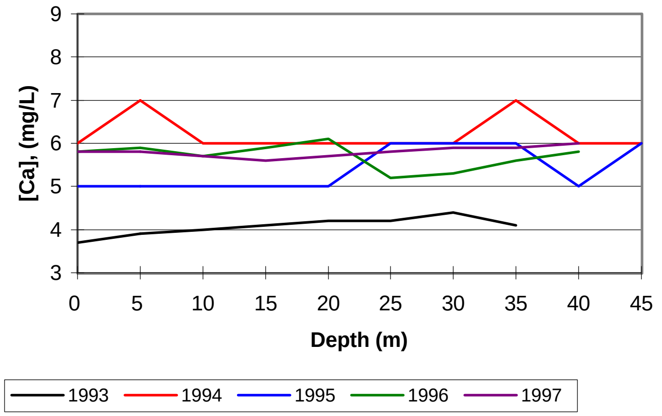


Fig. 9c: Flooded Pit, August
Calcium Concentration, 1993-97

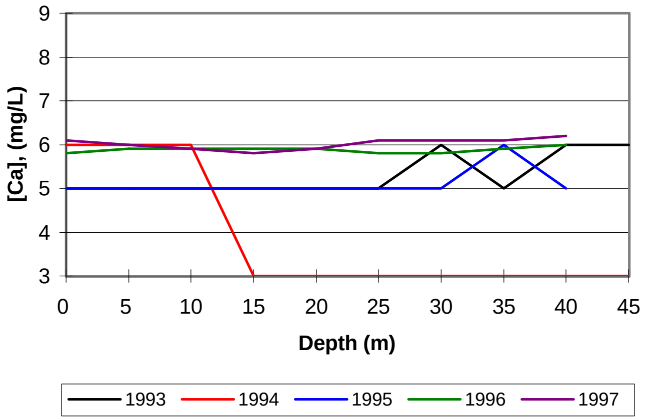


Fig. 9d: Flooded Pit, October
Calcium Concentration, 1993-97

Fig. 10a: Flooded Pit, March-May
Sulphate Concentration, 1993-97

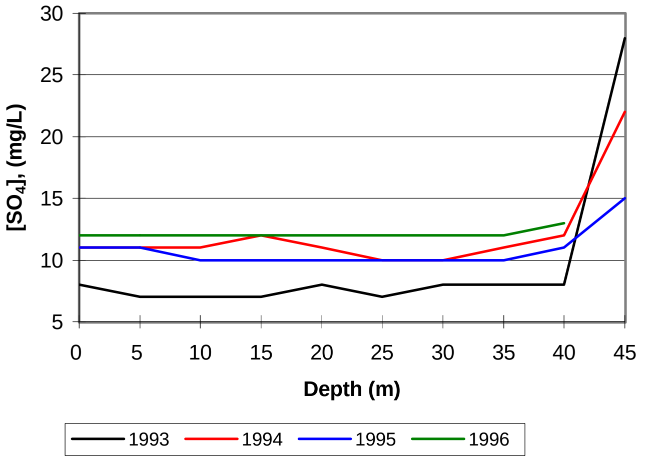


Fig. 10b: Flooded Pit, June
Sulphate Concentration, 1993-97

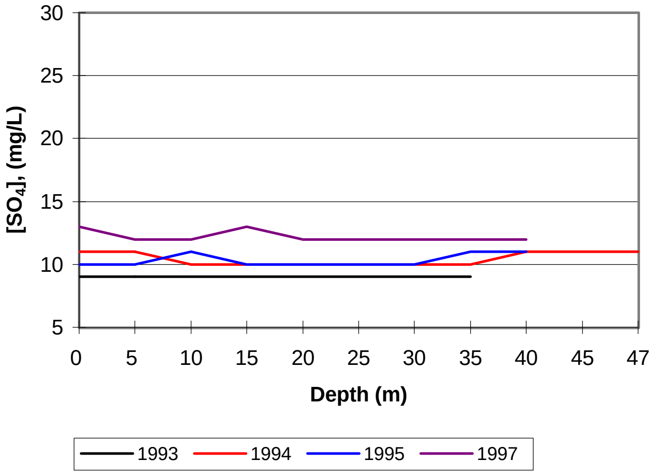


Fig. 10c: Flooded Pit, August
Sulphate Concentration, 1993-97

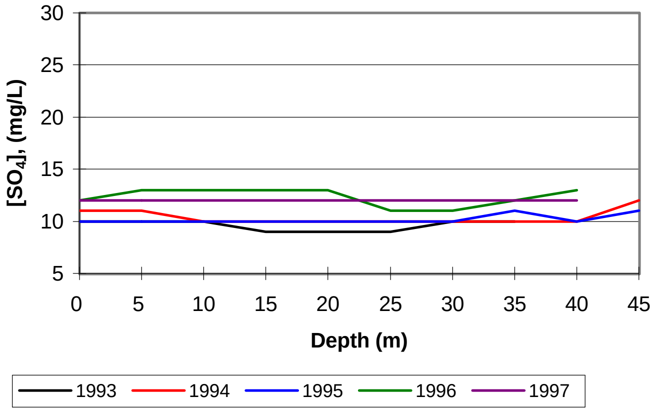
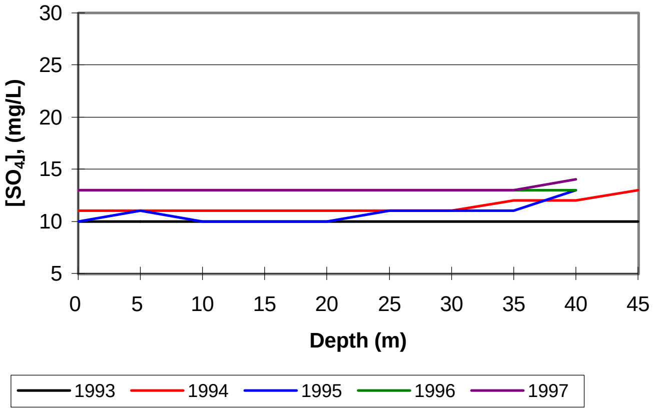


Fig. 10d: Flooded Pit, October
Sulphate Concentration, 1993-97



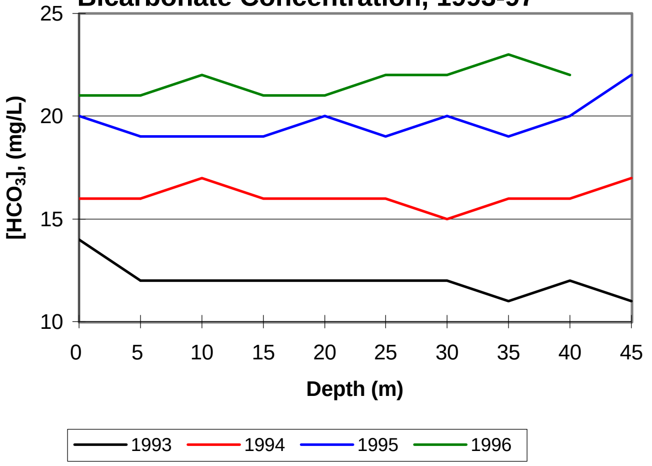


Fig. 11a: Flooded Pit, March-May Bicarbonate Concentration, 1993-97

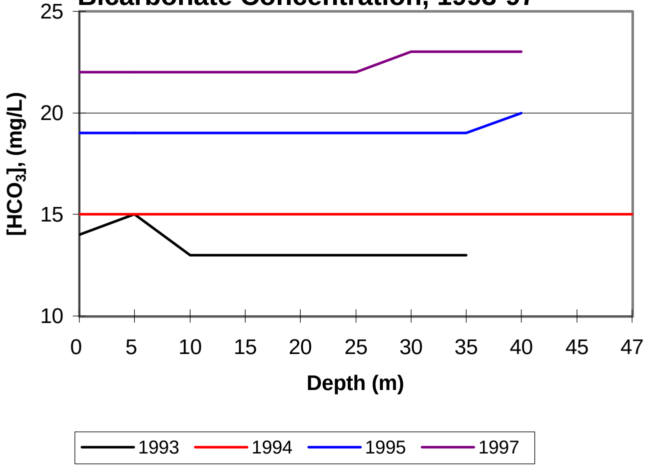


Fig. 11b: Flooded Pit, June Bicarbonate Concentration, 1993-97

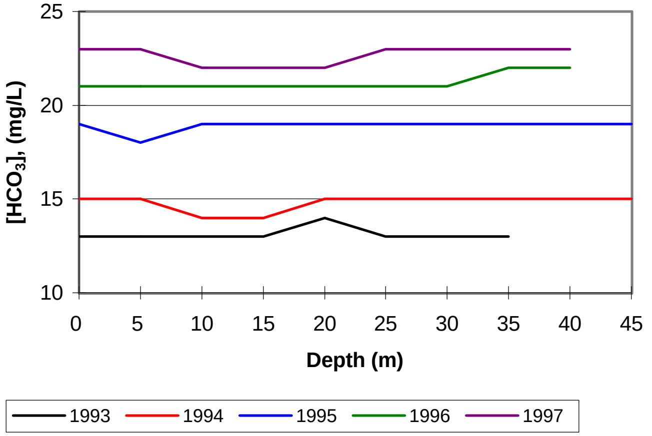


Fig. 11c: Flooded Pit, August Bicarbonate Concentration, 1993-97

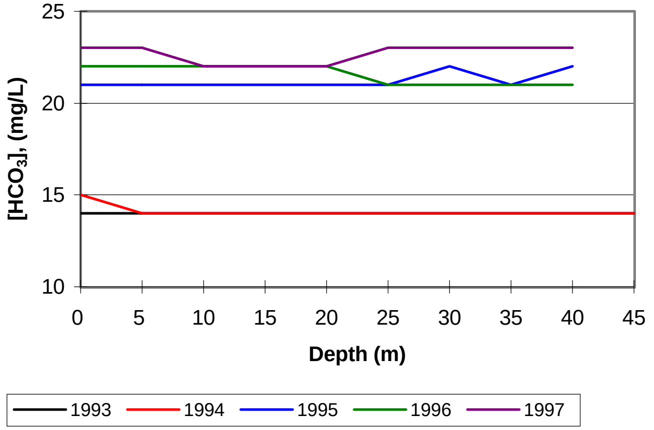


Fig. 11d: Flooded Pit, October Bicarbonate Concentration, 1993-97

Fig. 12: Flooded Pit, 1993-1997 Data
PO_4 vs Depth

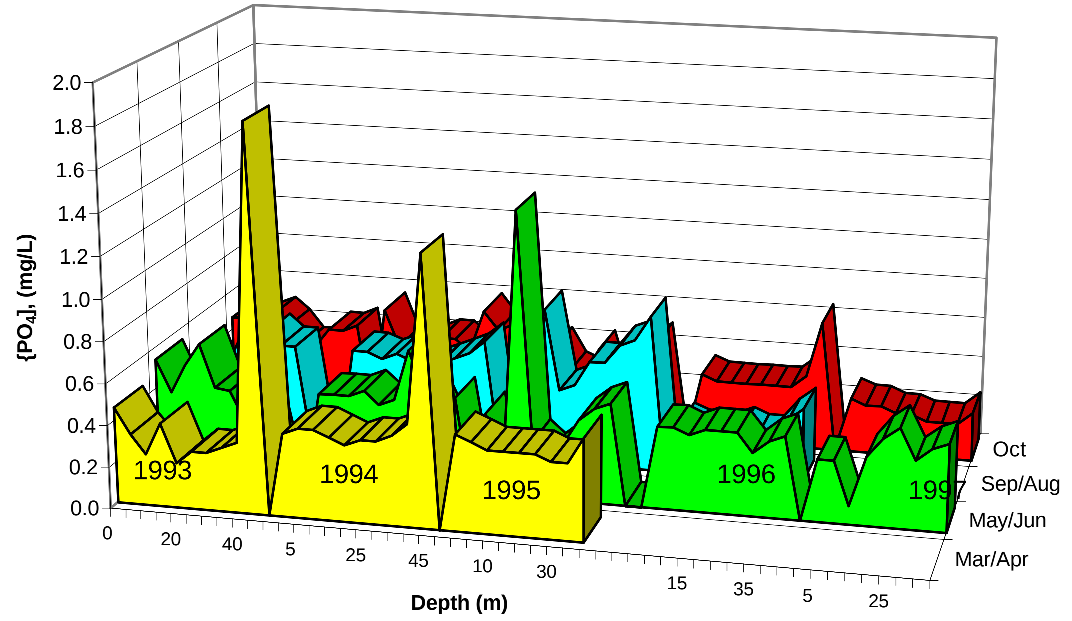


Fig. 13: Flooded Pit, 1993-1997 Data
NO_3 vs Depth

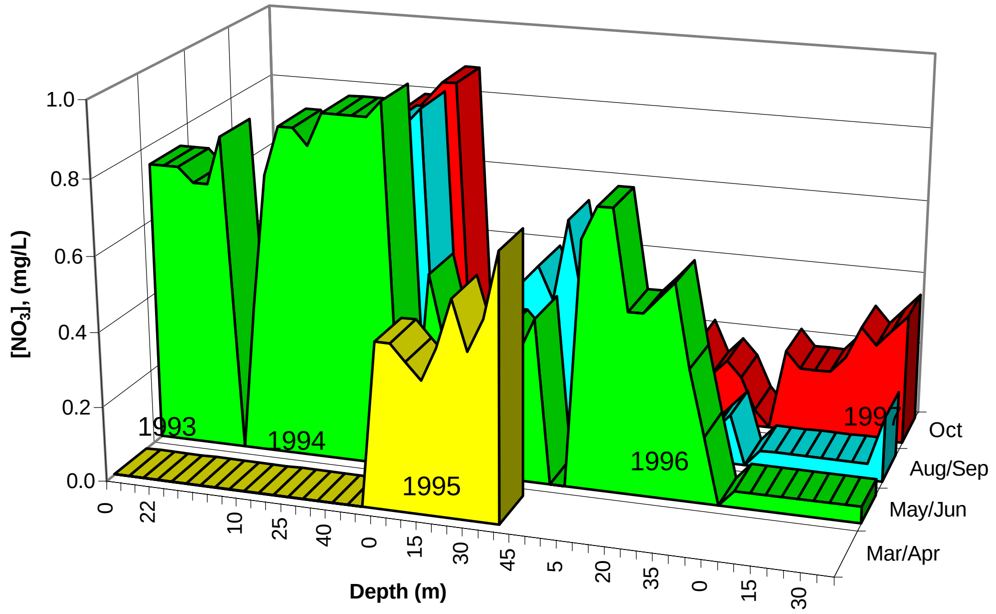


Fig. 14: Flooded Pit, 1993-1997 Data
NH_4 vs Depth

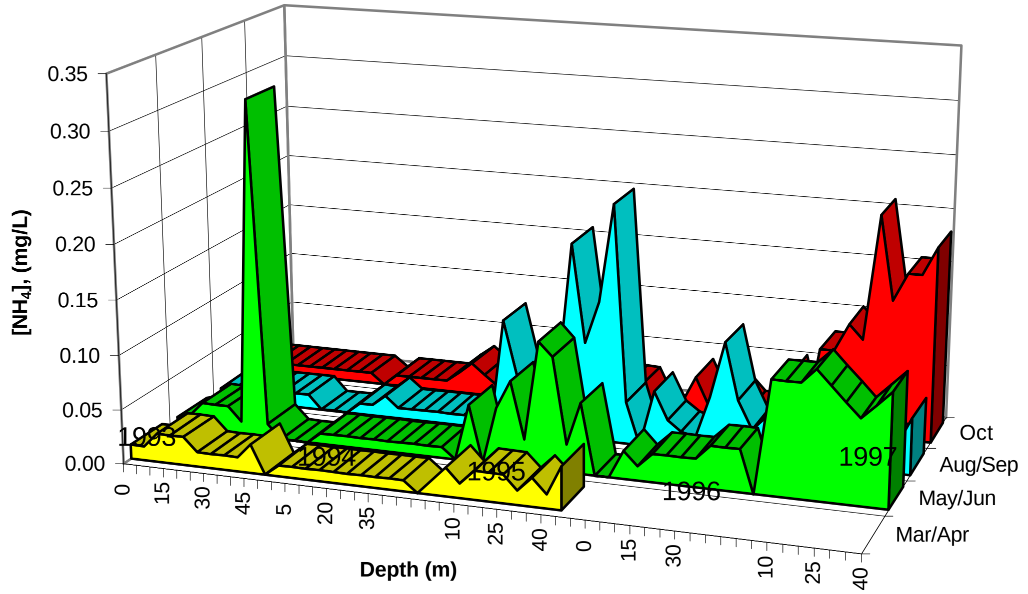


Fig. 15: Flooded Pit, 1993-1997 Data
Total Organic Carbon vs Depth

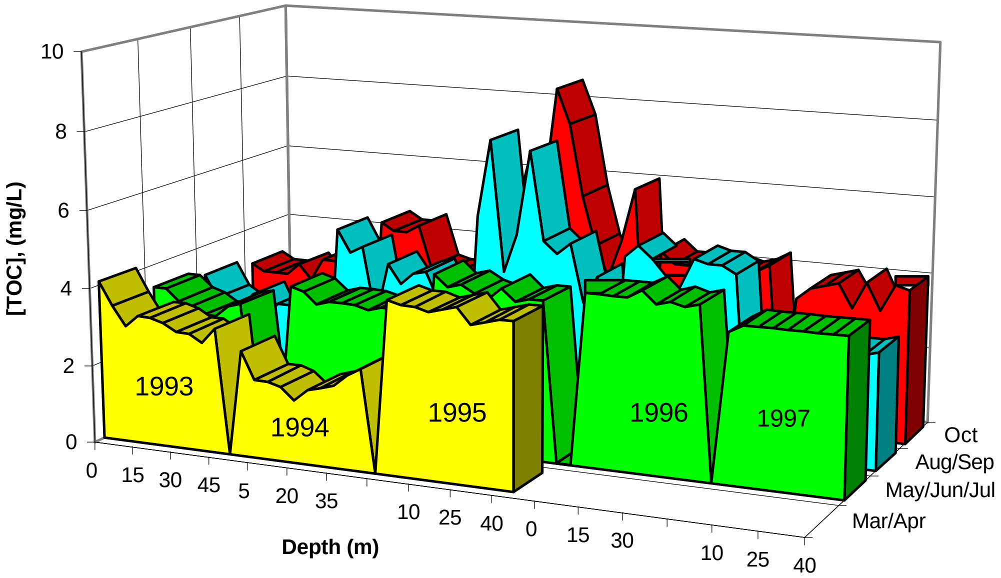
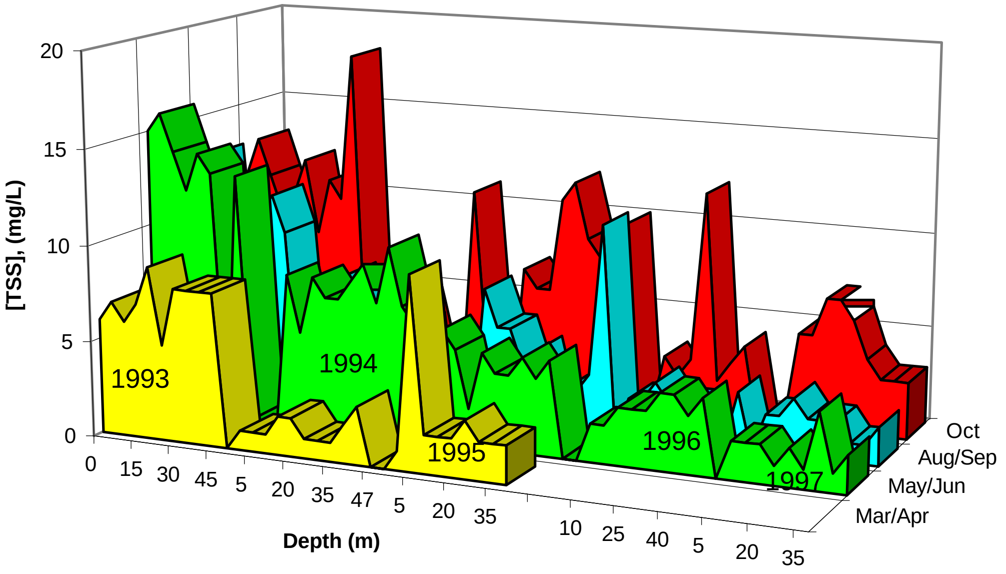


Fig. 16: Flooded Pit, 1993-1997 Data
Total Suspended Solids vs Depth



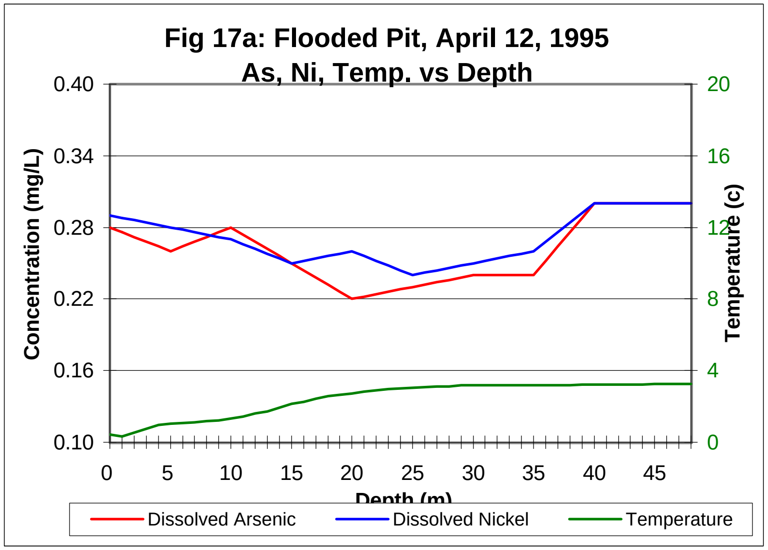


Fig 17a: Flooded Pit, April 12, 1995
As, Ni, Temp. vs Depth

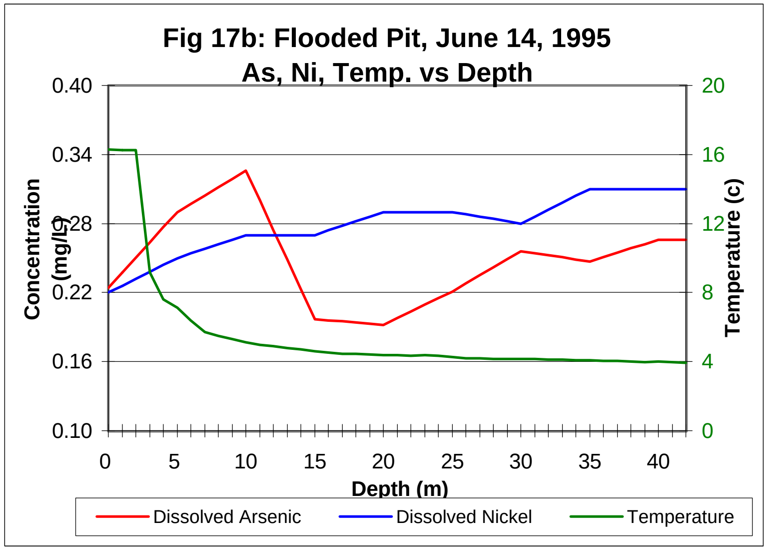


Fig 17b: Flooded Pit, June 14, 1995
As, Ni, Temp. vs Depth

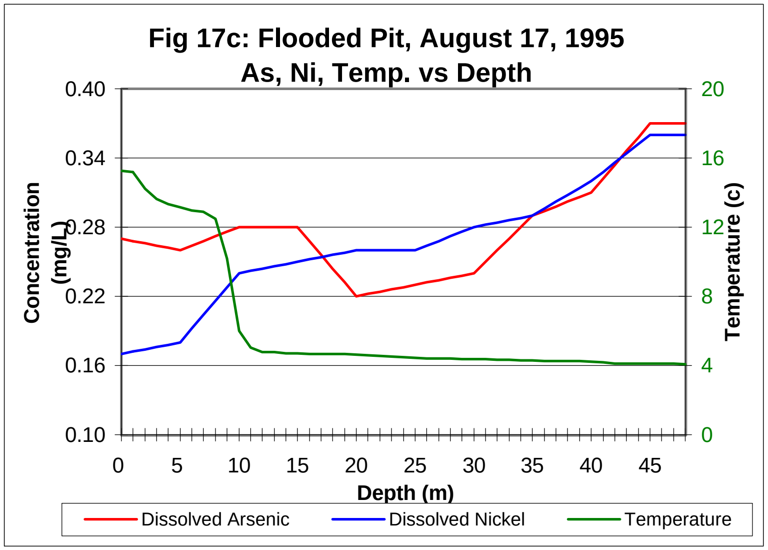


Fig 17c: Flooded Pit, August 17, 1995
As, Ni, Temp. vs Depth

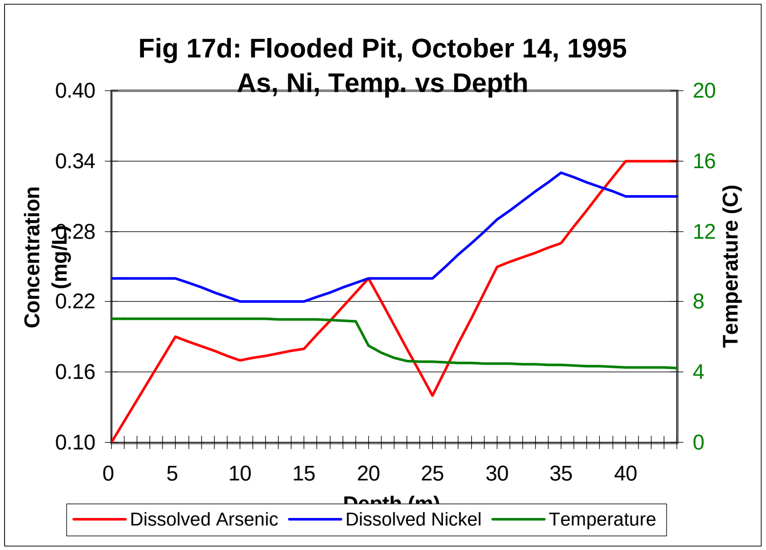


Fig 17d: Flooded Pit, October 14, 1995
As, Ni, Temp. vs Depth

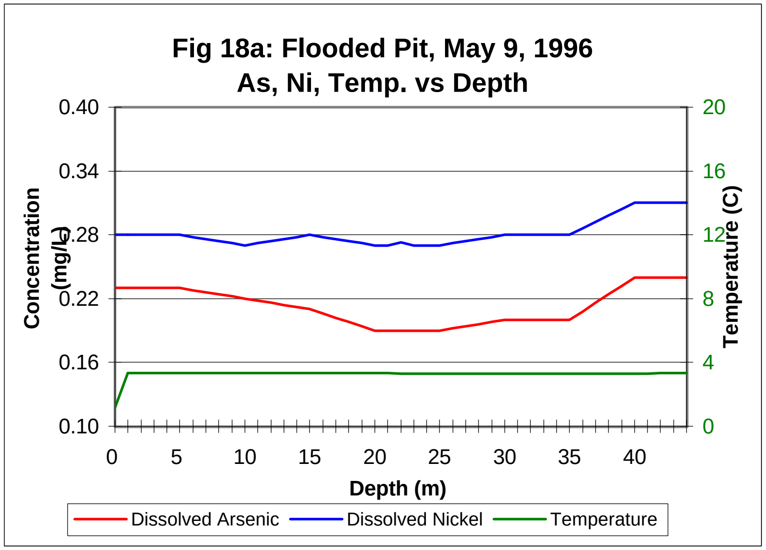


Fig 18a: Flooded Pit, May 9, 1996
As, Ni, Temp. vs Depth

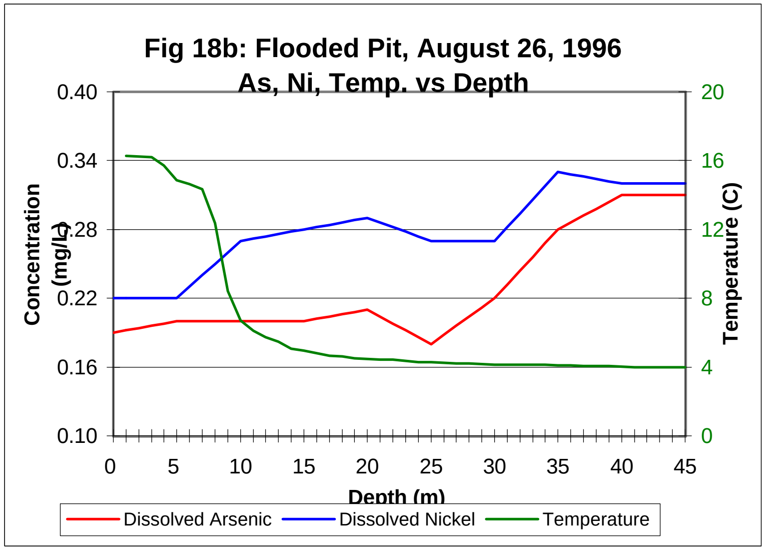


Fig 18b: Flooded Pit, August 26, 1996
As, Ni, Temp. vs Depth

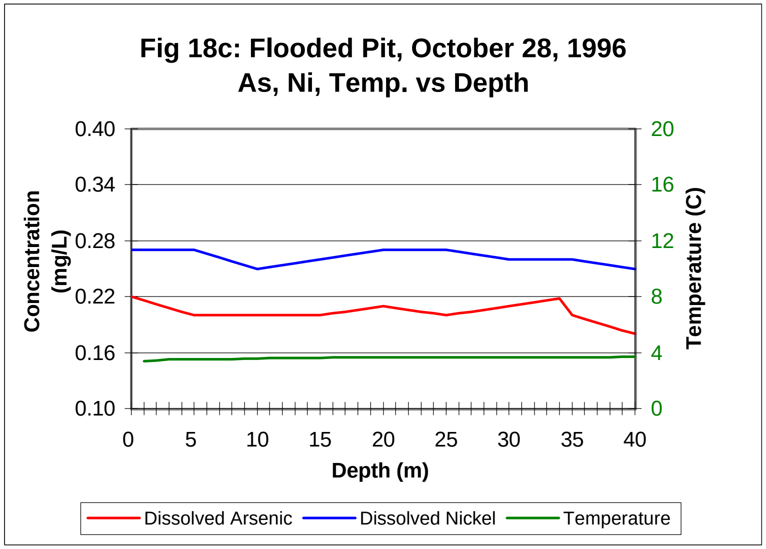


Fig 18c: Flooded Pit, October 28, 1996
As, Ni, Temp. vs Depth

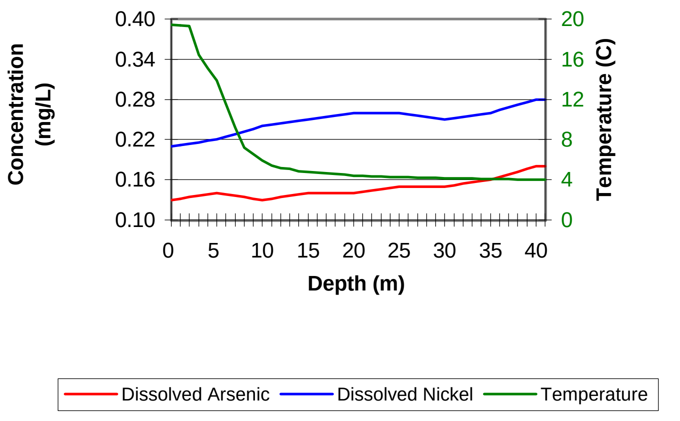


Fig 19a: Flooded Pit, June 29, 1997
As, Ni, Temp. vs Depth

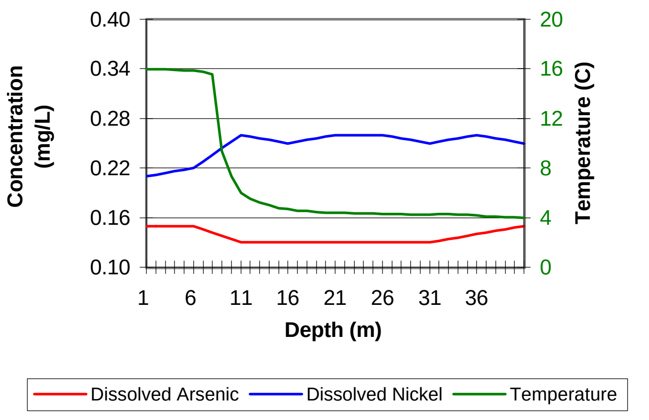


Fig 19b: Flooded Pit, August 12, 1997
As, Ni, Temp. vs Depth

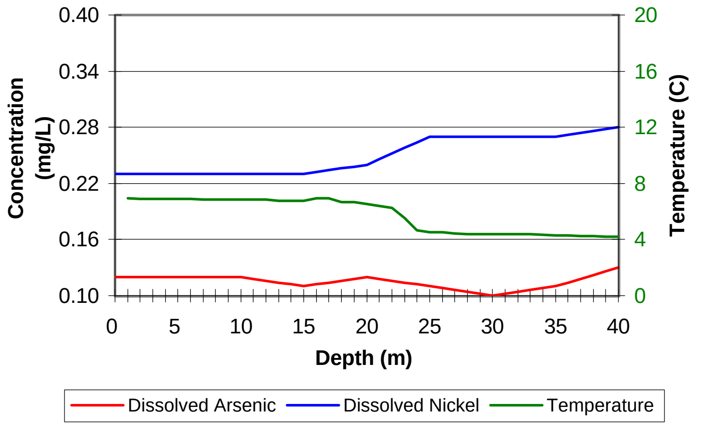


Fig 19c: Flooded Pit, October 6, 1997
As, Ni, Temp. vs Depth

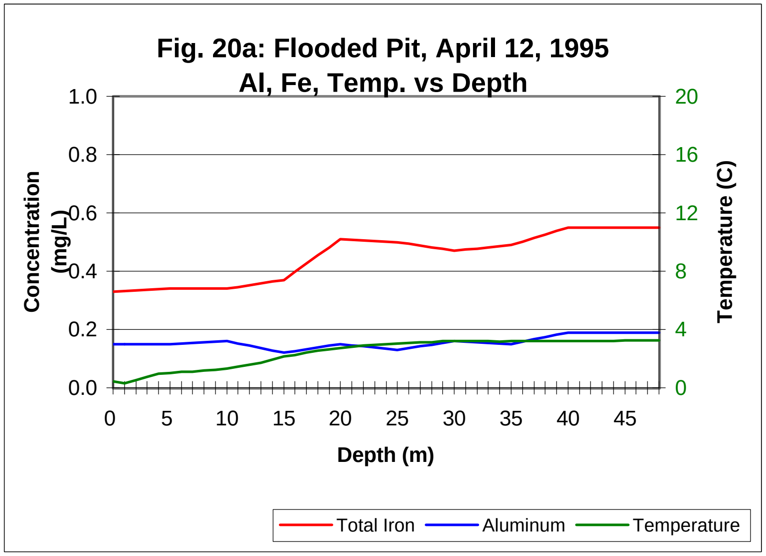


Fig. 20a: Flooded Pit, April 12, 1995
Al, Fe, Temp. vs Depth

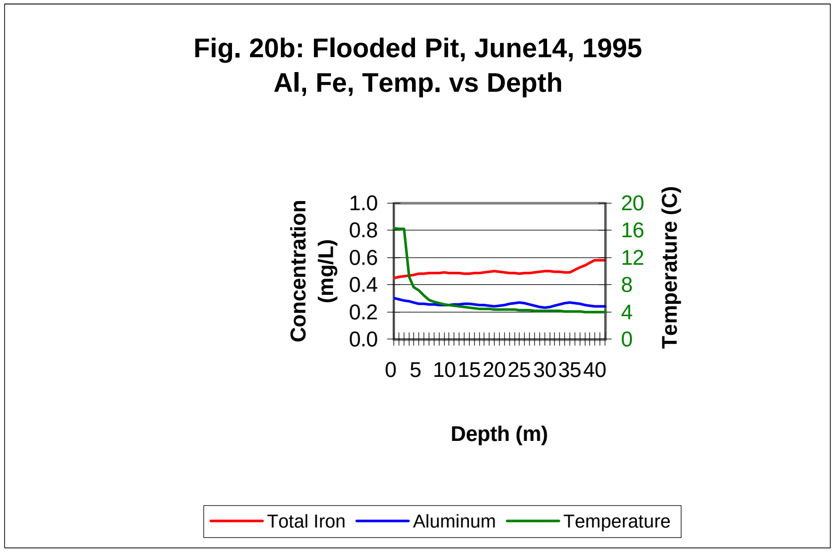


Fig. 20b: Flooded Pit, June14, 1995
Al, Fe, Temp. vs Depth

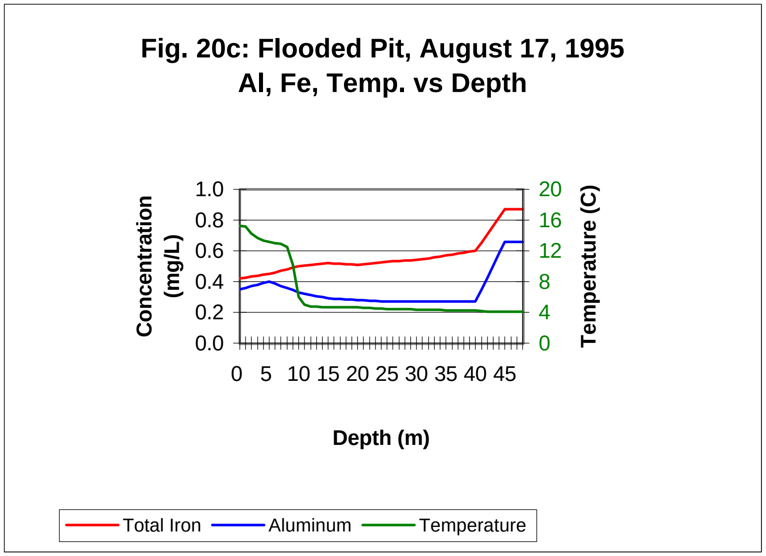


Fig. 20c: Flooded Pit, August 17, 1995
Al, Fe, Temp. vs Depth

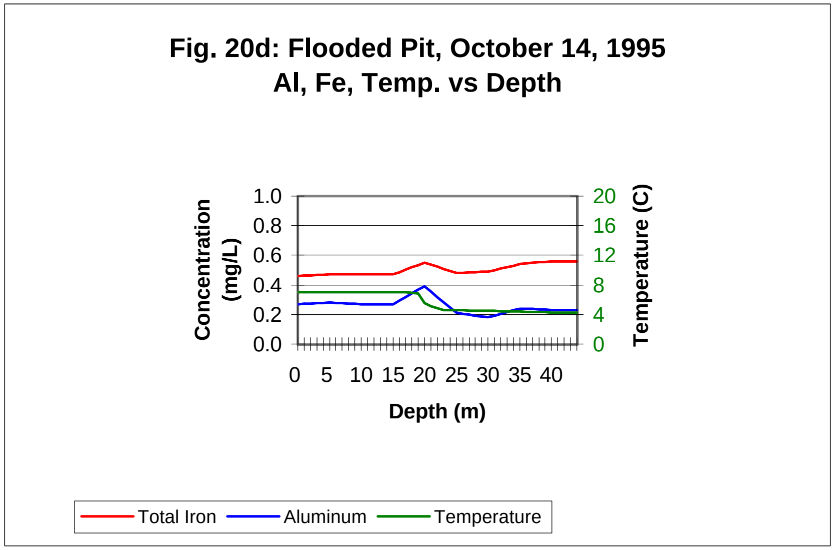


Fig. 20d: Flooded Pit, October 14, 1995
Al, Fe, Temp. vs Depth

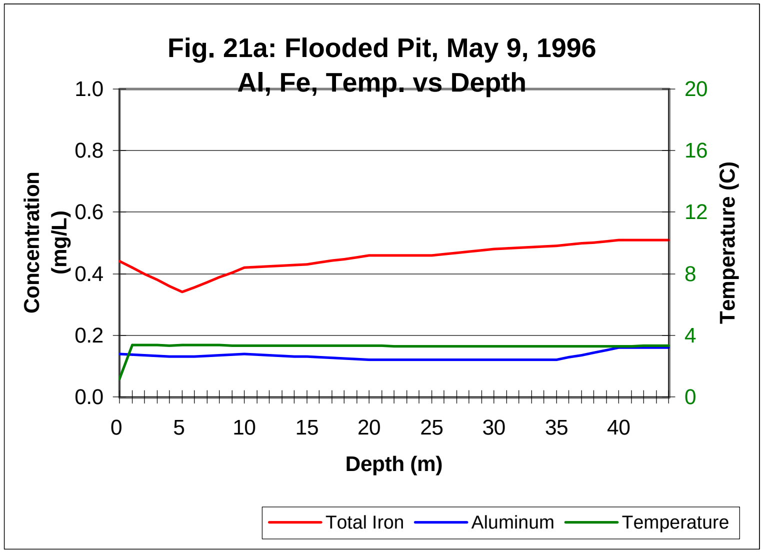


Fig. 21a: Flooded Pit, May 9, 1996
Al, Fe, Temp. vs Depth

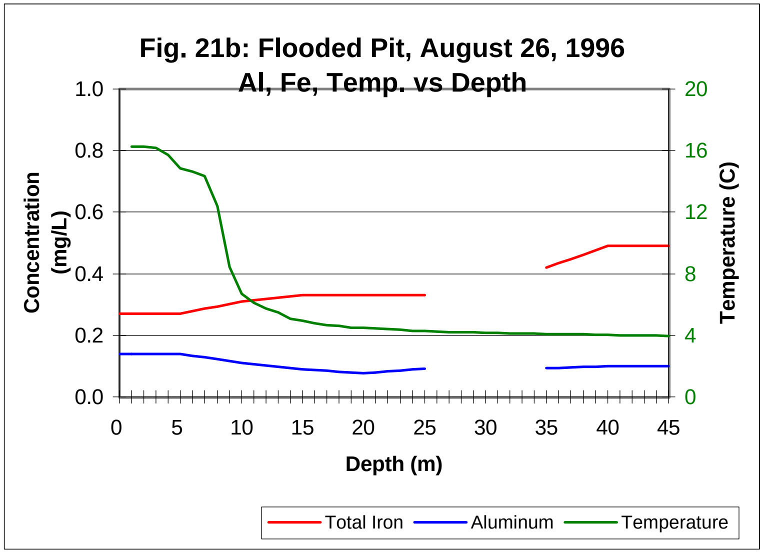


Fig. 21b: Flooded Pit, August 26, 1996
Al, Fe, Temp. vs Depth

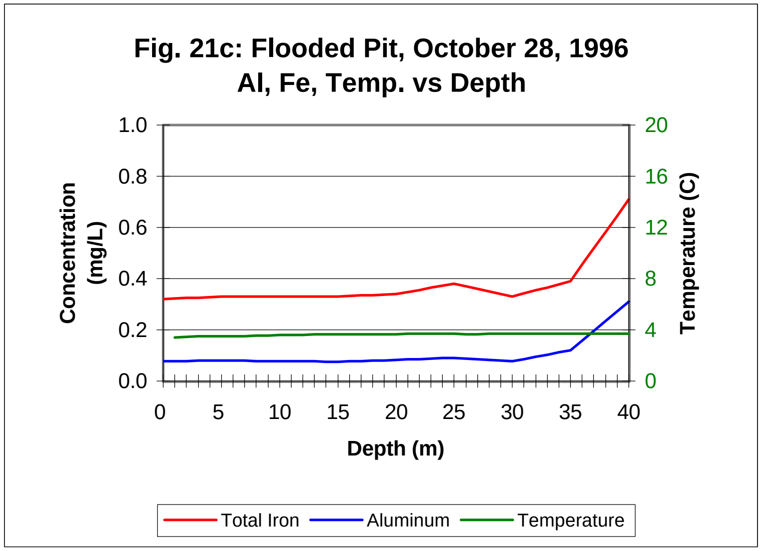


Fig. 21c: Flooded Pit, October 28, 1996
Al, Fe, Temp. vs Depth

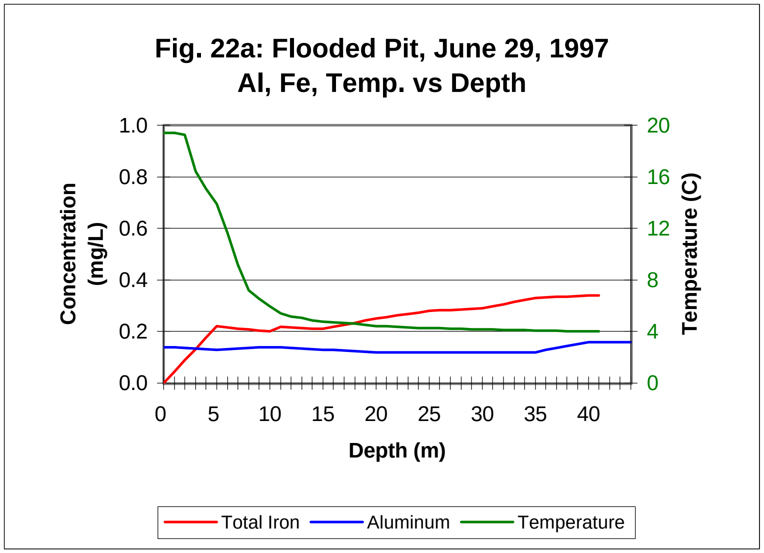


Fig. 22a: Flooded Pit, June 29, 1997
Al, Fe, Temp. vs Depth

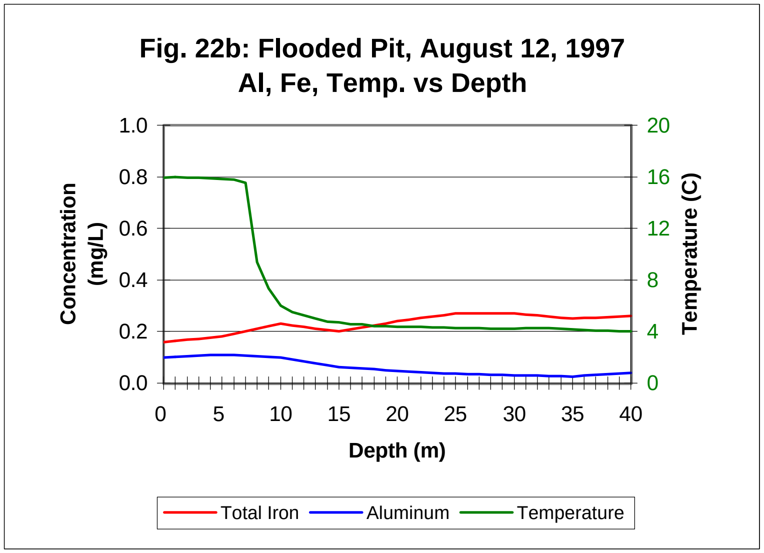


Fig. 22b: Flooded Pit, August 12, 1997
Al, Fe, Temp. vs Depth

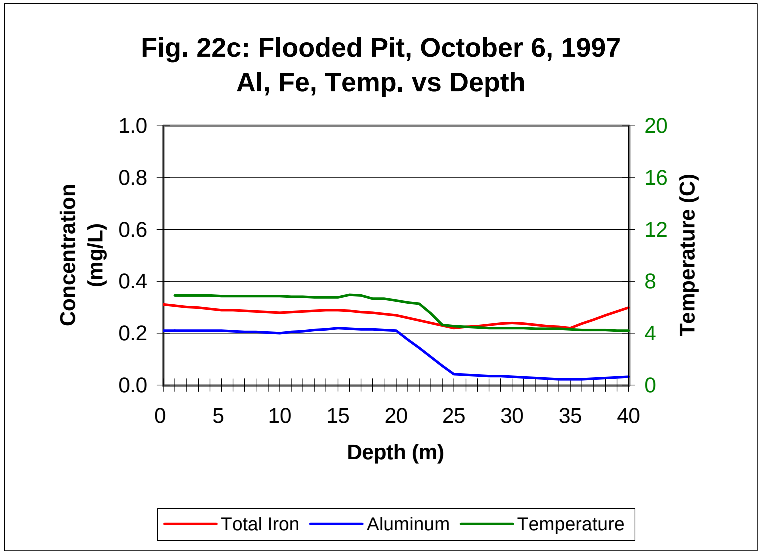


Fig. 22c: Flooded Pit, October 6, 1997
Al, Fe, Temp. vs Depth

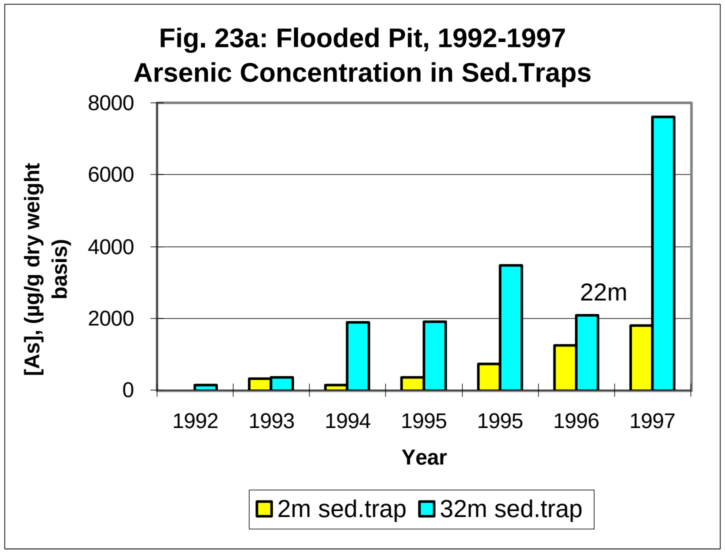


Fig. 23a: Flooded Pit, 1992-1997
Arsenic Concentration in Sed.Traps

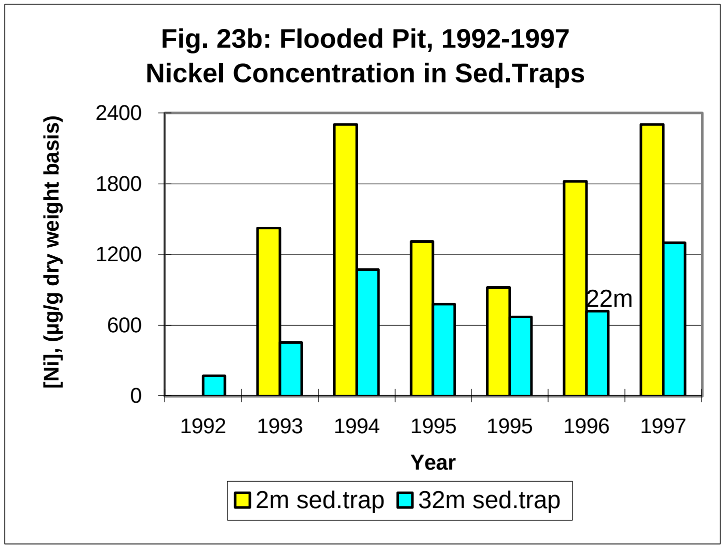


Fig. 23b: Flooded Pit, 1992-1997
Nickel Concentration in Sed.Traps

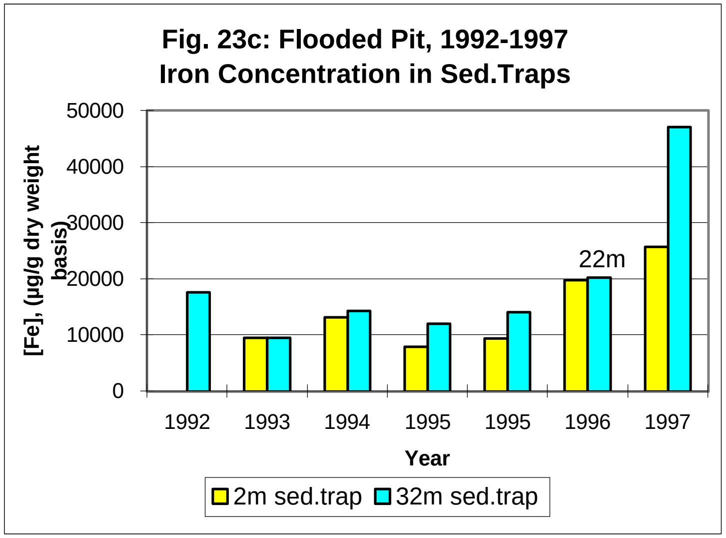


Fig. 23c: Flooded Pit, 1992-1997
Iron Concentration in Sed.Traps

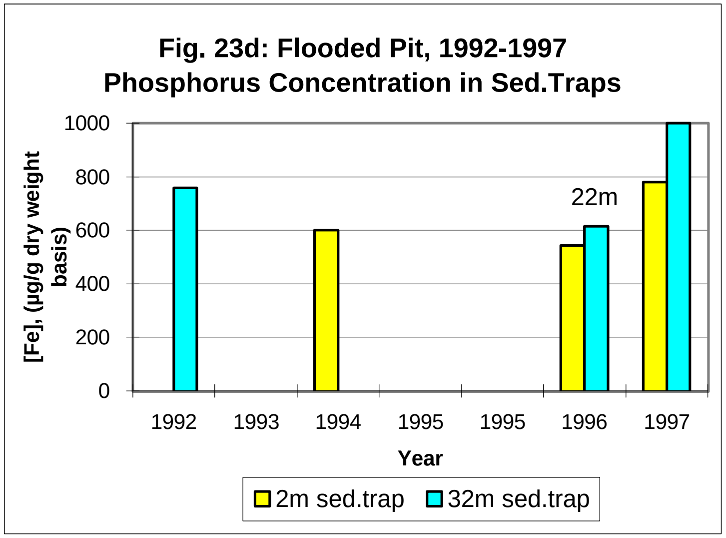


Fig. 23d: Flooded Pit, 1992-1997
Phosphorus Concentration in Sed.Traps

APPENDEIX 2

SUPPORTING DATA

Cameco: B-Zone Flooded Pit Surface Area and Volume, 1997 (hand) vs 1998 (Surfer) Calculations.

Depth	Elevation		Volume Beneath Interval m^3	Planar Area Beneath Interval m^2	Surface Area Beneath Interval m^2	Interval	Planar Area at/of Upper Layer m^2	Planar Area at/of Upper Layer m^2	Pit Wall Area Area in Layer m^2	Volume of Layer m^3	Volume of Layer m^3
	1997[1]	1998[2]	Oct-98	Oct-98	Oct-98		1997	1998	1998	1997	1998
Whole Pit	398	399.5	5,698,140	304,842	333,557	whole pit	240,000	304,842	333,557		5,698,140
0 m	398.0	399.5	5,698,140	304,842	333,557	**0 m - 2 m**	240,000	304,842	82,065	480,000	510,160
2 m	396.0	397.5	5,187,980	223,317	251,492	**2 m - 12 m**	168,000	223,317	72,658	1,680,000	1,858,760
12 m	386.0	387.5	3,329,220	155,743	178,834	**12 m - 22 m**	131,000	155,743	42,805	1,310,000	1,352,610
22 m	376.0	377.5	1,976,610	120,102	136,029	**22 m - 32 m**	100,000	120,102	39,814	1,000,000	1,051,468
32 m	366.0	367.5	925,142	87,774	96,215	**32 m - 42 m**	43,000	87,774	41,806	430,000	721,753
42 m	356.0	357.5	203,389	52,340	54,409	**42 m - bottom**	43,000	52,340	54,409	344,000	203,389
Total Check									333,557	5,244,000	5,698,140

1997[1] Bathymetry based on December, 1992 Boojum interpretation of topo map of pit prior to flooding.

1998[2] Bathymetry based on December, 1992 Boojum interpretation, corrected using 1991, 1995 aerial photographs, and using October 1995 pit water elevation.

Comparison of selected elements in Sediment Traps

B-Zone Pit, Station 6.72, August 26, 1997

Element	Unit	2 m µg/g	12 m µg/g	22 m µg/g	32 m µg/g
As	µg/g	1800	3600	5000	7600
Fe	µg/g	25700	26500	36300	47000
Ni	µg/g	2300	1600	850	1300
P	µg/g	780	840	920	1000
TOC	µg/g	41700	23900	27900	45500
Nitrite+Nitrate nitrogen	µg/g	6	130	46	56
TKN	µg/g	2400	1800	2300	2000
Total Nitrogen	µg/g	2400	1800	2300	2100

Table xx: Comparison of selected elements in bottom sediment
B-Zone Pit, Stations 6.71, 6.72, August 26, 1997

Element	Unit	Stn 6.71		Stn 6.72		
		surface	middle	surface	middle	bottom
Al	µg/g	15000	16700	17800	19500	17900
As	µg/g	1100	110	1500	440	210
B	µg/g	20	22	29	26	29
Ba	µg/g	59	75	68	83	73
Be	µg/g	0.6	0.8	0.8	0.8	0.8
Ca	µg/g	2400	2400	2500	2700	2100
Co	µg/g	29	16	49	25	17
Cr	µg/g	18	17	18	19	17
Cu	µg/g	17	13	17	15	15
Fe	µg/g	13700	14300	17000	15600	13800
K	µg/g	2900	3700	3800	3900	4000
Mg	µg/g	3000	3300	3100	3500	3100
Mn	µg/g	140	140	190	190	150
Mo	µg/g	3.9	-0.5	20	8.3	6.8
Ni	µg/g	550	180	820	420	230
P	µg/g	570	550	650	610	560
Pb	µg/g	19	21	23	20	24
Sr	µg/g	65	130	98	98	170
Ti	µg/g	740	760	740	850	590
V	µg/g	46	45	49	43	42
Zn	µg/g	28	24	30	28	23
Zr	µg/g	29	38	35	37	29
L.O.I.	%	6.26	3.52	6.61	3.36	3.08
Sulphate	mg/g	1100	210	3200	540	260
TOC	µg/g	24200	11100	30900	11900	7600
TKN	µg/g	1600	550	1900	750	350
Tot. Nitrogen	µg/g	1600	550	1900	750	350
Carbon	µg/g	29700	15800	35700	14500	9900
Pb-210	Bq/g	2.8	2.2	3.9	2.5	2
Po-210	Bq/g	2.9	2.2	3.4	2.1	2.2
Ra-226	Bq/g	1.4	1.8	2.6	2.1	2.4
U	µg/g	207	132	207	146	144

Table : Comparison of Suspended Element Concentrations Captured on Filter Papers with Total Element Concentrations in Water Samples from B-Zone Pit

ARSENIC

Filter Paper Pore Size	0 m		2 m		12 m		22 m		32 m		49 m	
	$mg.L^{-1}$	% of Total	$mg.L^{-1}$	% of Total	$mg.L^{-1}$	% of Total	$mg.L^{-1}$	% of Total	$mg.L^{-1}$	% of Total	$mg.L^{-1}$	% of Total
0.1 um	0.018	11	0.022	14	0.034	23	0.046	30	0.054	32	0.054	30
0.2 um	0.014	8.6	0.018	11	0.017	11	0.030	20	0.038	22	0.038	21
0.45 um	0.011	6.9	0.019	12	0.015	10	0.028	18	0.038	22	0.038	21
0.8 um	0.013	8.1	0.016	9.8	0.015	10	0.026	17	0.034	20	0.034	19
1.0 um	0.006	3.6	0.006	3.8	0.010	6.5	0.024	16	0.026	15	0.026	14
Diss.As, 0.45 um	0.120		0.140		0.130		0.120		0.120		0.170	
Diss.As (CAM)	0.150		0.150		0.130		0.130		0.134		0.150	
Total As (CAM)	**0.16**		**0.16**		**0.15**		**0.15**		**0.17**		**0.18**	

NICKEL

Filter Paper Pore Size	0 m		2 m		12 m		22 m		32 m		49 m	
	$mg.L^{-1}$	% of Total	$mg.L^{-1}$	% of Total	$mg.L^{-1}$	% of Total	$mg.L^{-1}$	% of Total	$mg.L^{-1}$	% of Total	$mg.L^{-1}$	% of Total
0.1 um	0.011	4.9	0.012	5.2	0.004	1.6	0.004	1.4	0.004	1	0.004	1.5
0.2 um	0.009	4.3	0.011	4.7	0.003	1.2	0.003	1.1	0.002	0.9	0.002	1.0
0.45 um	0.009	3.9	0.011	5.1	0.003	1.3	0.003	1.1	0.003	1.0	0.003	1.0
0.8 um	0.009	4.2	0.010	4.6	0.003	1.2	0.003	1.0	0.002	0.9	0.002	1.0
1.0 um	0.008	3.6	0.006	2.9	0.003	1.0	0.003	1.0	0.002	0.9	0.002	0.9
Diss.Ni, 0.45 um	0.180		0.220		0.270		0.280		0.280		0.340	
Diss.Ni (CAM)	0.210		0.214		0.256		0.260		0.254		0.250	
Total Ni (CAM)	**0.22**		**0.22**		**0.27**		**0.26**		**0.26**		**0.25**	

IRON

Filter Paper Pore Size	0 m		2 m		12 m		22 m		32 m		49 m	
	$mg.L^{-1}$	% of Total	$mg.L^{-1}$	% of Total	$mg.L^{-1}$	% of Total	$mg.L^{-1}$	% of Total	$mg.L^{-1}$	% of Total	$mg.L^{-1}$	% of Total
0.1 um	0.154	96	0.158	94	0.160	73	0.202	80	0.218	83	0.218	84
0.2 um	0.126	79	0.146	87	0.100	46	0.140	56	0.156	59.5	0.156	60
0.45 um	0.112	70	0.156	93	0.104	48	0.134	53	0.158	60.3	0.158	61
0.8 um	0.128	80	0.144	86	0.102	47	0.124	49	0.148	56.5	0.148	57
1.0 um	0.078	49	0.074	44	0.078	36	0.106	42	0.114	43.5	0.114	44
Diss.Fe, 0.45 um												
Diss.Fe (CAM)												
Total Fe(CAM)	**0.16**		**0.17**		**0.22**		**0.25**		**0.26**		**0.26**	

PHOSPHORUS

Filter Paper Pore Size	0 m		2 m		12 m		22 m		32 m		49 m	
	$mg.L^{-1}$	% of Total	$mg.L^{-1}$	% of Total	$mg.L^{-1}$	% of Total	$mg.L^{-1}$	% of Total	$mg.L^{-1}$	% of Total	$mg.L^{-1}$	% of Total
0.1 um	0.006	6.0	0.008	8.0	0.006	9.7	0.006	4.1	0.006	5.1	0.006	4.3
0.2 um	0.006	6.0	0.006	6.0	0.004	6.5	0.006	4.1	0.004	3.4	0.004	2.9
0.45 um	0.006	6.0	0.008	8.0	0.004	6.5	0.004	2.7	0.004	3.4	0.004	2.9
0.8 um	0.008	8.0	0.006	6.0	0.004	6.5	0.004	2.7	0.004	3.4	0.004	2.9
1.0 um	0.006	6.0	0.006	6.0	0.004	6.5	0.004	2.7	0.004	3.4	0.004	2.9
Diss.P, 0.45 um	0.080		0.090		0.080		0.100		0.100		0.150	
Diss.P (CAM)												
Total P (Cam)	**0.10**		**0.10**		**0.06**		**0.15**		**0.12**		**0.14**	

Summary of Cameco B-Zone Pit Phytoplankton Data

- 6 samples collected in September 1998

Cameco B-Zone Pit (surface) 2/09/98 Sample File A98-14

DATE ANALYSED… 10/27/1998

PHYLUM	Total Density (cells / L)	Total Biomass (µg / L)
CYANOBACTERIA	42278	4.277
CHLOROPHYTA	373927	30.262
EUGLENOPHYTA	0	0
CHRYSOPHYTA	315677	22.978
CRYPTOPHYTA	9630	6.046
PYRROPHYTA	7986	15.541
DIATOMS	36171	10.764
RHODOPHYTA	0	0
TOTAL	**785669**	**89.869**

- Considerable number of empty Dinobryon loricae present
- Numerous rod-like bacteria also present
- A few ciliates evident; no Keratella in this sample

B-Zone Pit **(Surface)** **2/9/98** (File Code A98-14)

Subsample Volume Counted: 126.0 mLs

Original Sample Volume: 1200 mLs

TAXON	CODE	DENSITY (cells/L)	BIOMASS (µg/L)	Colonies	Cells	Length (µm)	Width (µm)	Depth (µm)	# Cells measured	Transects counted	Biovolume (μm^3)	Correction factor
Cyanobacteria												
Oscillatoria limnetica	OS lim 1R	23958	4.2337	0	51	100	1.5	0	1	1	176.71	59.19
Unidentified bluegreen spp.	UN blg 1E	18321	0.0432	0	39	2	1.5	0	1	1	2.36	59.19
Chlorophyta												
Sphaerellopsis sp.	SP spp 2E	470	0.0729	0	2	9.8	5.5	0	1	1	155.22	29.59
Gonatozygon sp.	GN spp 2R	1644	4.1794	0	7	134.8	4.9	0	1	1	2541.98	29.59
Temnogametum sp.	TM spp 2R	1174	1.7104	0	5	61.3	5.5	0	1	1	1456.38	29.59
Dictyosphaerium pulchellum	DT pul 2E	6577	0.4735	0	14	5.5	5	0	1	1	71.99	59.19
Chlamydomonas spp.	CH spp 2E	265883	14.4958	0	566	8.5	3.5	0	1	1	54.52	59.19
Unidentified green spp.	UN chl 2E	98179	9.3303	0	209	6	5.5	0	1	1	95.03	59.19
Chrysophyta												
Dinobryon sertularia	DI ser 4E	13153	2.0339	0	56	12.3	4.9	0	1	1	154.63	29.59
Unidentified chrysophyte spp.	UN chr 4E	218437	9.079	0	465	4.5	4.2	0	1	1	41.56	59.19
Dinobryon spp. (monads)	DI mon 4E	33823	5.23	0	72	12.3	4.9	0	1	1	154.63	59.19
Dinobryon spp. (monads)	DI spp 4E	50264	6.6349	0	107	10.5	4.9	0	1	1	132	59.19
Cryptophyta												
Cryptomonas erosa	CR ero 5F	2584	3.0764	0	11	22.1	14.7	7	1	1	1190.71	29.59
Cryptomonas spp.	CR spp 5E	7046	2.9699	0	15	14.7	7.4	0	1	1	421.48	59.19
Pyrrhophyta												
Peridinium inconspicuum	PE inc 6E	7986	15.5412	0	34	17.2	14.7	0	1	1	1946.08	29.59
Bacillariophyta												
Nitzschia spp.	NZ spp 7R	1409	0.3902	0	6	56.4	2.5	0	1	1	276.85	29.59
Achnanthes sp.	AH spp 7R	26776	7.4225	0	57	14.7	4.9	0	1	1	277.2	59.19
Unidentified diatom spp.	UN dia 7R	7986	2.9516	0	17	19.6	4.9	0	1	1	369.61	59.19
Total		785669	89.8687		1733							

Cameco B-Zone Pit (2 M) 2/09/98 Sample File A98-13

DATE ANALYSED… 10/26/1998

PHYLUM	Total Density (cells / L)	Total Biomass (µg / L)
CYANOBACTERIA	57310	6.851
CHLOROPHYTA	251398	19.367
EUGLENOPHYTA	0	0
CHRYSOPHYTA	171618	23.593
CRYPTOPHYTA	50186	20.775
PYRROPHYTA	8064	15.694
DIATOMS	14328	2.349
RHODOPHYTA	0	0
TOTAL	**552904**	**88.628**

- Considerable number of empty Dinobryon loricae present
- Numerous rod-like bacteria also present
- A few ciliates evident; no Keratella in this sample

B-Zone Pit **(2 M)** **2/9/98** (File Code A98-13)

Subsample Volume Counted: 126.0 mLs

Original Sample Volume: 1200 mLs

TAXON	CODE	DENSITY (cells/L)	BIOMASS (µg/L)	Colonies	Cells	Length (µm)	Width (µm)	Depth (µm)	# Cells measured	Transects counted	Biovolume (µm³)	Correction factor
Cyanobacteria												
Oscillatoria limnetica	OS lim 1R	38520	6.8071	0 82 1		0	1.5	0	1	1	176.71	59.19
Unidentified bluegreen spp.	UN blg 1E	18790	0.0443	0	40	2	1.5	0	1	1	2.36	59.19
Chlorophyta												
Oedogonium sp.	OE sps 2R	391	0.3255	0	5	44.1	4.9	0	1	3	831.61	29.59
Temnogametum sp.	TM spp 2R	861	1.2543	0	11	61.3	5.5	0	1	3	1456.38	29.59
Gonatozygon sp.	GN spp 2R	1174	2.9797	0 10 1		34.6	4.9	0	5	2	2537.26	29.59
Chlamydomonas spp.	CH spp 2E	216088	11.7811	0	460	8.5	3.5	0	1	1	54.52	59.19
Unidentified green spp.	UN chl 2E	32883	3.0261	0	70	6.5	5.2	0	1	1	92.03	59.19
Chrysophyta												
Dinobryon sertularia	DI ser 4E	12840	1.9855	0	164	12.3	4.9	0	1	3	154.63	29.59
Unidentified chrysophyte spp.	UN chr 4E	130123	17.1765	0	277	10.5	4.9	0	1	1	132	59.19
Dinobryon spp. (monads)	DI mon 4E	28655	4.431	0	61	12.3	4.9	0	1	1	154.63	59.19
Cryptophyta												
Cryptomonas erosa	CR ero 5F	2270	2.7035	0	29	22.1	14.7	7	1	3	1190.71	29.59
Cryptomonas spp.	CR spp 5E	47915	18.0711	0	102	14.7	7	0	1	1	377.15	59.19
Pyrrhophyta												
Peridinium inconspicuum	PE inc 6E	8064	15.6936	0	103	17.2	14.7	0	1	3	1946.08	29.59
Bacillariophyta												
Nitzschia spp.	NZ spp 7R	1644	0.4552	0	21	56.4	2.5	0	1	3	276.85	29.59
Achnanthes sp.	AH spp 7R	9395	0.6779	0	20	14.7	2.5	0	1	1	72.16	59.19
Unidentified diatom spp.	UN dia 7R	3288	1.2154	0	7	19.6	4.9	0	1	1	369.61	59.19
Total		552904	88.6277		1462							

A2-9

Cameco B-Zone Pit (12 M) 2/09/98 Sample File A98-11

DATE ANALYSED… 10/25/1998

PHYLUM	Total Density (cells / L)	Total Biomass (µg / L)
CYANOBACTERIA	72343	5.822
CHLOROPHYTA	899468	66.954
EUGLENOPHYTA	235	0.742
CHRYSOPHYTA	54374	4.956
CRYPTOPHYTA	323076	140.778
PYRROPHYTA	6107	11.884
DIATOMS	7986	1.747
RHODOPHYTA	0	0
TOTAL	**1363588**	**232.883**

- Numerous empty Dinobryon loricae present
- Fewer rod-like bacteria than in surface samples
- Numerous ciliates evident; no Keratella in this sample

B-Zone Pit **(12 M)** **2/9/98** (File Code A98-11)

Subsample Volume Counted: 126.0 mLs Original Sample Volume: 1200 mLs

TAXON	CODE	DENSITY (cells/L)	BIOMASS (µg/L)	Colonies	Cells	Length (µm)	Width (µm)	Depth (µm)	# Cells measured	Transects counted	Biovolume (μm^3)	Correction factor
Cyanobacteria												
Oscillatoria limnetica	OS lim 1R	32413	5.7279	0	69	100	1.5	0	1	1	176.71	59.19
Unidentified bluegreen spp.	UN blg 1E	39929	0.0941	0	85	2	1.5	0	1	1	2.36	59.19
Chlorophyta												
Sphaerellopsis sp.	SP spp 2E	1409	0.2187	0	6	9.8	5.5	0	1	1	155.22	29.59
Gonatozygon sp.	GN spp 2R	2466	5.6413	0	21	121.3	4.9	0	2	2	2287.4	29.59
Oedogonium sp.	OE sps 2R	2584	2.0073	0	11	41.2	4.9	0	1	1	776.93	29.59
Chlamydomonas spp.	CH spp 2E	694301	37.8531	0	1478	8.5	3.5	0	1	1	54.52	59.19
Unidentified green spp.	UN chl 2E	198707	21.2336	0	423	8.5	4.9	0	1	1	106.86	59.19
Euglenophyta												
Euglena sp.	EG sp1 3R	235	0.7425	0	2	73.5	7.4	0	1	2	3161.12	29.59
Chrysophyta												
Dinobryon sertularia	DI ser 4E	4580	0.7082	0	39	12.3	4.9	0	1	2	154.63	29.59
Unidentified chrysophyte spp.	UN chr 4E	30534	1.2691	0	65	4.5	4.2	0	1	1	41.56	59.19
Dinobryon spp. (monads)	DI mon 4E	19260	2.9782	0	41	12.3	4.9	0	1	1	154.63	59.19
Cryptophyta												
Cryptomonas erosa	CR ero 5F	5989	7.1317	0	51	22.1	14.7	7	1	2	1190.71	29.59
Cryptomonas spp.	CR sps 5E	317086	133.6463	0	675	14.7	7.4	0	1	1	421.48	59.19
Pyrrhophyta												
Peridinium inconspicuum	PE inc 6E	6107	11.8844	0	52	17.2	14.7	0	1	2	1946.08	29.59
Bacillariophyta												
Nitzschia spp.	NZ spp 7R	940	0.2601	0	8	56.4	2.5	0	1	2	276.85	29.59
Achnanthes sp.	AH spp 7R	3758	0.2712	0	8	14.7	2.5	0	1	1	72.16	59.19
Unidentified diatom spp.	UN dia 7R	3288	1.2154	0	7	19.6	4.9	0	1	1	369.61	59.19
Total		1363588	232.883		3041							

Cameco B-Zone Pit (22 M) 2/09/98 Sample File A98-15

DATE ANALYSED… 10/28/1998

PHYLUM	Total Density (cells / L)	Total Biomass (µg / L)
CYANOBACTERIA	42278	4.686
CHLOROPHYTA	447679	32.191
EUGLENOPHYTA	0	0
CHRYSOPHYTA	81894	3.634
CRYPTOPHYTA	11431	7.106
PYRROPHYTA	705	1.371
DIATOMS	75788	21.527
RHODOPHYTA	0	0
TOTAL	**659774**	**70.516**

- Few empty Dinobryon loricae present
- Fewer rod-like bacteria than in surface samples
- A few ciliates evident; no Keratella in this sample

B-Zone Pit **(22 M)** **2/9/98** (File Code A98-15)

Subsample Volume Counted: 63.0 mLs

Original Sample Volume: 1200 mLs

TAXON	CODE	DENSITY (cells/L)	BIOMASS (µg/L)	Colonies	Cells	Length (µm)	Width (µm)	Depth (µm)	# Cells measured	Transects counted	Biovolume (μm^3)	Correction factor
Cyanobacteria												
Oscillatoria limnetica	OS lim 1R	26306	4.6487	0	28	100	1.5	0	1	1	176.71	59.19
Unidentified bluegreen spp.	UN blg 1E	15972	0.0376	0	17	2	1.5	0	1	1	2.36	59.19
Chlorophyta												
Gonatozygon sp.	GN spp 2R	2349	5.9706	0	15	134.8	4.9	0	1	3	2541.98	29.59
Temnogametum sp.	TM spp 2R	940	1.3683	0	2	61.3	5.5	0	1	1	1456.38	29.59
Chlamydomonas spp.	CH spp 2E	408689	22.2816	0	435	8.5	3.5	0	1	1	54.52	59.19
Unidentified green spp.	UN chl 2E	35702	2.5703	0	38	5.5	5	0	1	1	71.99	59.19
Chrysophyta												
Dinobryon sertularia	DI ser 4E	2036	0.3148	0	13	12.3	4.9	0	1	3	154.63	29.59
Unidentified chrysophyte spp.	UN chr 4E	79859	3.3192	0	85	4.5	4.2	0	1	1	41.56	59.19
Cryptophyta												
Cryptomonas erosa	CR ero 5F	2975	3.5425	0	19	22.1	14.7	7	1	3	1190.71	29.59
Cryptomonas spp.	CR spp 5E	8456	3.5639	0	9	14.7	7.4	0	1	1	421.48	59.19
Pyrrhophyta												
Peridinium inconspicuum	PE inc 6E	705	1.3713	0	3	17.2	14.7	0	1	2	1946.08	29.59
Bacillariophyta												
Nitzschia spp.	NZ spp 7R	6263	1.734	0	40	56.4	2.5	0	1	3	276.85	29.59
Achnanthes sp.	AH spp 7R	63887	17.7097	0	68	14.7	4.9	0	1	1	277.2	59.19
Unidentified diatom spp.	UN dia 7R	5637	2.0835	0	6	19.6	4.9	0	1	1	369.61	59.19
Total		659774	70.5161		778							

Cameco B-Zone Pit (32 M) 2/09/98 Sample File A98-16

DATE ANALYSED… 10/26/1998

PHYLUM	Total Density (cells / L)	Total Biomass (µg / L)
CYANOBACTERIA	26306	2.437
CHLOROPHYTA	229007	18.052
EUGLENOPHYTA	0	0
CHRYSOPHYTA	54962	4.09
CRYPTOPHYTA	1331	1.585
PYRROPHYTA	0	0
DIATOMS	50186	4.689
RHODOPHYTA	0	0
TOTAL	**361791**	**30.853**

- Few empty Dinobryon loricae present
- Very few rod-like bacteria evident
- A few ciliates evident
- Only 1 Keratella in sample giving approximate density of about 8 Keratella / L

B-Zone Pit **(32 M)** **2/9/98** (File Code A98-16)

Original Sample Volume: 1200 mLs

Subsample Volume Counted: 126.0 mLs

TAXON	CODE	DENSITY (cells/L)	BIOMASS (µg/L)	Colonies	Cells	Length (µm)	Width (µm)	Depth (µm)	# Cells measured	Transects counted	Biovolume (μm^3)	Correction factor
Cyanobacteria												
Oscillatoria limnetica	OS lim 1R	13623	2.4074	0	29	100	1.5	0	1	1	176.71	59.19
Unidentified bluegreen spp.	UN blg 1E	12683	0.0299	0	27	2	1.5	0	1	1	2.36	59.19
Chlorophyta												
Temnogametum sp.	TM spp 2R	2114	2.5443	0	27	61.3	5	0	1	3	1203.62	29.59
Sphaerellopsis sp.	SP spp 2E	1174	0.1823	0	15	9.8	5.5	0	1	3	155.22	29.59
Gonatozygon sp.	GN spp 2R	470	1.9037	0	6	214.9	4.9	0	2	3	4052.46	29.59
Oedogonium sp.	OE sps 2R	235	0.1953	0	3	44.1	4.9	0	1	3	831.61	29.59
Chlamydomonas spp.	CH spp 2E	185084	10.0907	0	394	8.5	3.5	0	1	1	54.52	59.19
Unidentified green spp.	UN chl 2E	39929	3.136	0	85	6	5	0	1	1	78.54	59.19
Chrysophyta												
Dinobryon sertularia	DI ser 4E	940	0.1453	0	12	12.3	4.9	0	1	3	154.63	29.59
Unidentified chrysophyte spp.	UN chr 4E	38990	1.6205	0	83	4.5	4.2	0	1	1	41.56	59.19
Dinobryon spp. (monads)	DI mon 4E	15032	2.3244	0	32	12.3	4.9	0	1	1	154.63	59.19
Cryptophyta												
Cryptomonas erosa	CR ero 5F	1331	1.5848	0	17	22.1	14.7	7	1	3	1190.71	29.59
Bacillariophyta												
Nitzschia spp.	NZ spp 7R	1801	0.4985	0	23	56.4	2.5	0	1	3	276.85	29.59
Achnanthes sp.	AH spp 7R	46036	3.3219	0	98	14.7	2.5	0	1	1	72.16	59.19
Unidentified diatom spp.	UN dia 7R	2349	0.8681	0	5	19.6	4.9	0	1	1	369.61	59.19
Total		361791	30.8533		856							

A2-15

Cameco B-Zone Pit (42 M) 2/09/98 Sample File A98-12

DATE ANALYSED… 10/25/1998

PHYLUM	Total Density (cells / L)	Total Biomass (µg / L)
CYANOBACTERIA	26776	2.684
CHLOROPHYTA	169191	11.888
EUGLENOPHYTA	0	0
CHRYSOPHYTA	4580	0.283
CRYPTOPHYTA	391	0.466
PYRROPHYTA	235	0.457
DIATOMS	34057	4.191
RHODOPHYTA	0	0
TOTAL	**235231**	**19.97**

- More sediment than in surface samples
- Few empty Dinobryon loricae present
- Very few rod-like bacteria evident
- A few ciliates evident
- Only 2 Keratella in sample giving approximate density of about 16 Keratella / L

B-Zone Pit **(42 M)** **2/9/98** (File Code A98-12)

Subsample Volume Counted: 126.0 mLs

Original Sample Volume: 1200 mLs

TAXON	CODE	DENSITY (cells/L)	BIOMASS (µg/L)	Colonies	Cells	Length (µm)	Width (µm)	Depth (µm)	# Cells measured	Transects counted	Biovolume (µm³)	Correction factor
Cyanobacteria												
Oscillatoria limnetica	OS lim 1R	15032	2.6564	0	32	100	1.5	0	1	1	176.71	59.19
Unidentified bluegreen spp.	UN blg 1E	11744	0.0277	0	25	2	1.5	0	1	1	2.36	59.19
Chlorophyta												
Gonatozygon sp.	GN spp 2R	548	1.1141	0	7	107.8	4.9	0	1	3	2032.83	29.59
Chlamydomonas spp.	CH spp 2E	134351	7.3248	0	286	8.5	3.5	0	1	1	54.52	59.19
Unidentified green spp.	UN chl 2E	34292	3.4489	0	73	8	4.9	1	1	1	100.57	59.19
Chrysophyta												
Dinobryon sertularia	DI ser 4E	822	0.1271	0	7	12.3	4.9	0	1	2	154.63	29.59
Unidentified chrysophyte spp.	UN chr 4E	3758	0.1562	0	8	4.5	4.2	0	1	1	41.56	59.19
Cryptophyta												
Cryptomonas erosa	CR ero 5F	391	0.4661	0	5	22.1	14.7	7	1	3	1190.71	29.59
Pyrrhophyta												
Peridinium inconspicuum	PE inc 6E	235	0.4571	0	1	17.2	14.7	0	1	1	1946.08	29.59
Bacillariophyta												
Nitzschia spp.	NZ spp 7R	1644	0.4552	0	21	56.4	2.5	0	1	3	276.85	29.59
Achnanthes sp.	AH spp 7R	27716	1.9999	0	59	14.7	2.5	0	1	1	72.16	59.19
Unidentified diatom spp.	UN dia 7R	4698	1.7362	0	10	19.6	4.9	0	1	1	369.61	59.19
Total		235231	19.9697		534							

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