THE DECOMMISSIONING
OF
BUCHANS UNIT, ASARCO

ZINC REMOVAL STRATEGY

1996 FINAL REPORT

Prepared For

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ASARCO Inc. - Abitibi-Price Inc.

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BUCHANS 1996 FINAL REPORT

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Summary

The 1996 objectives, addressing the winter problem, represented collectively one of the most complex years spent addressing decommissioning of the Buchans unit. The approach taken to solving the winter problem was two fold. One avenue was to define and quantify the pathway of zinc during the summer. The second avenue was to review the entire site with the knowledge gained during the years of investigation. Had we missed something, or were some aspects of the process misinterpreted?

In Schematic 3 (Section 9), an overview of the different aspects of science are given, including all players which can interfere or contribute to the winter problem, a phenomenon overall controlled by temperature. Firstly, the monitoring data were reviewed for Buchans with respect to seasonal trends relating to temperature (Section 1). It was evident that carbon dioxide-bicarbonate-~~bi~~carbonate chemistry is producing changes in pH in all monitoring data which result in changes in zinc concentration.

Secondly, a mass balance of the groundwater distribution using chloride for the Drainage Tunnel - OEP - OWP suggests that clean groundwater is entering the OEP, contrary to what was previously postulated (Section 2). These findings suggested that the proposed gradual decrease in zinc concentrations in the OEP had to be due to additional causes other than the depletion of zinc released from the sludge in the underground workings.

The iron mass balance in the system suggested that more iron is being collected in the sedimentation traps than could be accounted for in the ground water. The iron mass balance for the polishing ponds also suggested iron cycling. Iron oxidation and reduction have therefore set up a recycling of iron, increasing the material collected in the sedimentation traps. This was further supported by the results of the iron oxidation experiments carried out this year (Section 3.2). While iron oxidation is controlled by the temperature and oxygen supply, it is not related to the removal of

zinc from the solution. Zinc removal is independent of the iron oxidation process and, contrary to the earlier proposal, not directly related to the formation of iron hydroxide, a reportedly very good adsorbent of zinc.

The SEM-EDX investigations of the particles collected in the sedimentation traps and the biological material supported further the elusive nature of the iron III hydroxide adsorption process. Zinc was not associated with the surface of the sedimentation trap material at magnifications of 200 - 2000 x. It was found predominantly in the biological material in Polishing Pond 17, where particle surfaces reporting up to 40 % zinc, likely a zinc carbonate. Magnification of the sedimentation material at 20,000 x revealed that crystals are surrounding the iron particles, and up to 3 % zinc was found on these surfaces. If the proposed zinc adsorption was indeed taking place, these findings did not support this zinc removal process. Connecting this with the oxidation experimental results, which suggested that iron precipitation and zinc removal was not related, further refutes the importance of the process of zinc adsorption onto iron hydroxide at this specific site.

Through a review of the old work (for example, the inorganic chemistry section in the 1991 report and the field data prior to construction of the polishing ponds), it was evident that zinc removal and iron III hydroxide formation were not related. Where did all the iron in the algae/ moss in the polishing ponds originate, given that most iron remained in the OEP during the ice-free season? On the other hand, during the summer, zinc was effectively removed by the polishing ponds (Section 3.0).

The laboratory and field fertilization experiments, the latter carefully planned according to flow and retention time, did not result in increased zinc removal. However, in the small-scale field experiment, zinc did drop out along with the phosphate added in fertilizer. Because the experiment was conducted for less than 24 hours, the large-scale field application of fertilizer in the polishing ponds for zinc removal produced negative results (Section 3.7).

The large scale experiment was also carefully planned. The flow in the ponds was modelled, along with the dosage of fertilizer related to the growth rates of the algae derived from the laboratory experiments. No zinc removal was noted. A filter paper collecting the particles from the small scale field experiment (mini limnocorral), carried out in July preceding the scaled up fertilization effort, was submitted for chemical analysis. There indeed was phosphate, as well as iron, zinc and, in addition, reasonable amounts of Mg. Zinc was precipitating in some other form, but not adsorbed onto iron- hydroxide.

The answer had to be found in the areas of particle formation, surface charges of particles and colloid formation. This was definitely supported by the experiments where bentonite and sand (rich in iron oxide) did not result in zinc removal. Thus, the surface charges of the zinc were not positive, as would be predicted if zinc has actually adsorbed onto the negatively charged bentonite. The literature on formation of environmental particles reports that iron hydroxides are smaller than 0.45 μm (Section 3.8). These smaller particles have difficulties settling, and must aggregate into particles large enough for gravity to overcome hydrodynamic forces. The major difference between the large scale fertilization experiment and the mini-limnocorral experiment was that the latter provided less turbulent conditions, allowing smaller particles to settle.

The formation of particles in winter in OEP is hindered, since the larger particles of Fe III hydroxide do not form, and no nucleation sites are provided to collect the zinc precipitates. Interesting support for the strong hydrodynamic forces on the particles was obtained from the phytoplankton enumerations (Section 3.5). Phytoplankton productivity in OEP is virtually nil, despite apparently suitable chemical and nutritional conditions for periphyton. Physical factors, such as light limitation, the presence of the thermocline associated with a chemocline and a change in redox, may collectively prevent the growth of algae with a free-floating growth habit. While the hydrodynamic conditions of OEP are only slightly different from OWP, these differences result in relatively sterile pit water. The picoplankton results, when available, will indicate whether living organisms smaller than 2 μm are present in OEP; these organisms may have lower light requirements than phytoplankton. If these minute organisms are present, this may indicate that organisms in this size range are too small to aggregate precipitates and settle.

All evidence suggests that particle formation in the OEP is hindered by the hydrodynamics of the OEP water column, rather than its chemistry. The question, then, is what could be done to overcome the difference in hydrodynamics in the OEP between summer and winter, a classical problem of flotation, or possibly microflotation. The degassing of the CO_2 in the open bottle treatments of the oxidation experiments is the most likely explanation for the observed decreases in the zinc at 20° C, since a precipitate could form as a result of CO_2 leaving the bottle.

The current strategy for solving the winter problem is to form a zinc precipitate particles which are relatively independent of the carbon dioxide-bicarbonate-carbonate chemical reactions and are large enough to effectively settle in OEP. Phosphate was an old candidate, discussed in detail in the 1991 report in connection with the Long Harbour sand. The 1996 fertilization experiments suggested some involvement of zinc removal with phosphate. Since iron is predominantly in the reduced form in pit bottom water, it should not complete with cations, such as zinc, calcium and magnesium, for phosphate if added to the <u>bottom</u> of OEP in molar proportions which promote the formation of calcium, magnesium and zinc phosphate. Competition for phosphate by iron was observed when fertilizer was added to the ponds to increase biological production of particle formation.

In January, 1997, George Neary performed an experiment using water collected from beneath the ice of the OEP. The best zinc removal occurred in the treatment where enough phosphate was provided to combine with all zinc and magnesium present in OEP water. Upon addition of smaller or larger amounts of phosphate, less zinc was removed. Inadequate phosphate for zinc removal may have been provided in the low treatment, while interference by nitrate in the larger fertilizer treatment may explain lower zinc removal in the high application treatment.

Since phosphate can interact with magnesium, this may in part affect the fraction of the zinc which precipitates in the pit and contributes to the annual zinc reductions at the outflow. The fraction of the settled zinc carbonate solids likely recycles each year, due to changes in solubility of this compound due to seasonal changes in inorganic carbon forms and concentrations present in the pit water column. To remove the zinc, clearly a particulate needs to be formed which can settle out, and remain as a solid at the pit bottom under the prevailing conditions.

It is were assumed that no new zinc is currently being added to the pit, and zinc remobilization from precipitate deposits is responsible for the current zinc load at the outflow, the observed annual decrease could be due to dilution of the remobilized zinc by fresh water, and the slope of such a decrease should be quite even. It could, however, also be that a precipitate is formed which is stable and settles out in the bottom of the pit. If this is the case, magnesium concentrations for OEP should decrease similarly to those for zinc. The slope of both magnesium and zinc concentration decreases in the OEP pit (Figure 1; Section 3.8) for the years 1989 to 1996 are convincingly similar, suggesting a similar removal process.

If these observations can be confirmed, then practically it provides the following options. The zinc carbonate is recycling between shifts of carbonate and bicarbonate and only removed through formation of a more stable forms such as zinc phosphate. As fertilizer added more than just phosphate (e.g., nitrate, ammonia), the precipitates have to be analyzed and further experiments conducted to ascertain the possibility of forming a zinc precipitate other than the carbonate.

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Through changes in the hydrodynamics, we can bring about particle formation which should settle to the sediment. We could therefore form a stable zinc precipitate with a one-time application, as long as the application consists of the correct chemical addition. The formed precipitate will be collected by biological polishing . The same approach can be taken for the Lucky Strike, resulting in reductions of zinc in the Valley Seeps, the Drainage Tunnel; essentially, the problem could be solved. The precipitation with hydroxide should also be evaluated in relation to the stability of the zinc precipitate formed. It is likely that, if the zinc is precipitated in the carbonate form, it will eventually remobilize from the sludge.

In summary, the key breakthroughs from the investigation of the winter problem in 1996 were:

- Zinc is precipitating independently from iron III hydroxide; iron is likely recycled in the pit.

- Zinc phosphates can be formed in the winter conditions of the OEP.

- The hydrodynamics of OEP hinder particle formation which are sufficiently large to settle in the pit.

- It is likely that a significant flow of clean groundwater enters OEP, in addition to the zinc and iron-contaminated groundwater emerging from the underground workings.

- The Old Buchans Valley seeps receive water from the Lucky Strike.

- The Lucky Strike is in many ways similar to the OWP, which raises concerns regarding the buffering capacity of the groundwater entering the pit, presently not suggested, as water is leaving the gloryhole, rather then entering it, which was a similar situation in the OWP, prior to Drainage Tunnel additions.

- Biomass production in the OEP is limited hydrodynamics and light, but not in the OWP and the Polishing ponds.

●● **The below data report now needs to be interpreted, using all the newly assembled data, to confirm or refute tentative conclusions reached to date. A large amount of data accumulated since 1988 can be utilized to ascertain a firm understanding of the site.**

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1.0 MONITORING DATA

The main objective in 1996 was to address the winter problems with the absence of zinc removal in the polishing ponds. The approach taken to view the monitoring data was different then in the years prior. Data were plotted with respect to seasonal variations in zinc concentrations. The zinc removal in the polishing ponds appeared to display curves which seasonally reflected the temperature, pH and to some degree also to conductivity changes, like being opposed or similar.

The 1991 report (Section 3) dealt with the inorganic chemistry of Buchans waters on a non-site specific basis. It was concluded that Buchans waters are dominated by carbonate - bicarbonate couple. Therefore, the temperature would affect all formation of carbonaceous zinc species, due to the solubility of carbon dioxide. Zinc carbonate and zinc bicarbonate posess different behaviours, shifting from precipitating and settling to remaining dissolved. If this is the case, then pH should show similar trends seasonally in all monitoring points, which are relatively close to contaminant sources, such as the pits and the tailings. Higher concentrations should be evident both in the beginning and at the end of the year, and the lowest concentrations should be found in the summer time. The pH should be lower in the winter months and increasing slightly in the summer months.

This pattern would suggest that the carbonate-bicarbonate couple dominates in the zinc removal process related to CO_2 solubility, which is related to the temperature. If this is the case in the monitoring data, then the behaviour of OEP is more pronounced, solely due to the degassing of CO_2 from the ground water.

From this perspective, it also would follow that seasonal fluctuations should be essentially eliminated as the water is further away from the zinc source, i.e. either tailings or pits. Zinc removal through a precipitate would have settled out of the water column resulting in lower zinc concentrations and very flat shaped curves.

In Schematic 1, the sequence of water entering the Buchans River is given. The monitoring point, Buchans River at Highway Bridge should be flat, i.e. show not seasonal trends. In Figure 1a and Figure 1b, the zinc concentrations and the pH values are plotted. Essentially, since 1992, which was a year with large fluctuations, the zinc concentrations are around 0.1 mg/L and the pH displays a slight trend of lower pH with lower temperatures and high pH in the summer, generally ranging from 6.2 to 7.4. The same applies for the station below the Hydro Plant (Figures 2a and 2b).

In Figures 3a and 3b, the zinc concentrations for Simms Brook show a trend with lower concentrations in the winter month increasing over the summer, but the pH values do not show a seasonal trend.

In Figures 4a and 4b, the concentrations of zinc in TP1 show an increase after the ice melts and climbing over the summer month from less than 1 mg/L to about 2 mg/L and the pH depression in the beginning of the year is pronounced. In Figures 5a and 5b, the data from TP2, show that the ice cover releases some zinc from the beaches, but the pronounced drop in zinc at the end of the season is evident.
The dramatic increase from about 1.5 mg/L to 4 mg/L in 1996 is due to raising the water level in TP2. The origin of zinc in this pond was identified previously as pore water in beach tailings, which is exemplified by the 1996 data (Figure 5a). The pH of TP2 decreases in winter and remains around neutral pH over the remainder of the year (Figure 5b). This would be expected, given that the solubility of carbon dioxide in the pond water is lower during the warm summer months.

These trends are not new, and were previously interpreted as solely due to dilution taking place during spring run off, followed by concentration of zinc due to evaporation. Although this can not be excluded, the corresponding trends in pH values are more difficult to explain due to spring run-off dilution, and are likely related to the dominant bicarbonate couple.

The Drainage Tunnel should not show any seasonal trends, given that it is measured at the outflow, and is essentially degassed ground water. Figure 6a shows essentially a steady concentrations along with a steady pH value (Figure 6b). Average zinc concentrations for the year have increased for the Drainage Tunnel, particularly in 1996 (Figure 6c) and the flow is higher in the last two years (Figure 6d). This was suggested in previous evaluations of the Lucky Strike flooding.

The seasonal trends in the OWP are given in Figure 7a for the zinc concentrations. The trend was very evident in the years prior to Drainage Tunnel discharge to the OWP. Since 1995, seasonal variations in the Drainage Tunnel loading has diminished. However, the 1996 pH values (Figure 7b) increased by about 1 unit, when the system had stabilized. Overall, the OWP zinc concentrations are increasing as expected, reflecting input from the Drainage Tunnel (Figure 7c).

In the OEP, the 1996 annual decrease in zinc concentration is lower than the year before (Figure 8a). In Figure 8b, the seasonal variation in the water are displayed and magnified by changing the scale on the graph in Figure 8c.

Finally, the Lucky Strike annual average zinc concentration continues to increase, but appears to level out with respect to the magnitude (Figure 9a). In 1996, the increase was only about 2 mg/L, in comparison to the previous year with a 6 mg/L increase. The seasonal behaviour of the Lucky Strike resembles that of the OWP with dilution or ground water input producing a significant decrease in the spring and increasing steadily as the water warms up and the pH decreases by typically 1 unit (Figure 9b and 9c). Given the similarity to the Orientals, it is therefore not surprising that the Lucky Strike also stratifies during the summer. Since an anchor was placed into the pit, the pit can be monitored and sampled also during the summer months (Figure 10).

The water was sampled during the last field trip for titration (Table 1). The acidities are much lower than the OEP suggesting that there are very few metals in the water up to about 25 m, where the values then approach those of the OEP (Figure 11a). The acidities in the summer time in the OEP are below 50 mg/L and rise to about 160 mg/L in September, when the iron starts to remain in solution. This suggests that only the lower portion of the Lucky Strike pit receives or remains ground water containing iron. Comparing the alkalinities of the Lucky Strike and the OEP (Figure 11b), little ground water appears to be added to Lucky Strike, since the alkalinities are very low at 20 mg/L, compared to the OEP with alkalinities ranging from 200 to 300 mg/L. At present, the Lucky Strike water resembles more that of the old OWP with respect to buffer capacity, expressed by acidity/alkalinity values (Table 2).

Table 1: Lucky Strike Pit Water Chemistry With Depth, September 27, 1996.

Depth (m)	Field O_2 $mg.L^{-1}$	Field Temp °C	Field pH	Lab pH	Field Cond $uS.cm^{-1}$	Lab Cond $uS.cm^{-1}$	Field Em mV	Lab Em mV	Lab Acidity $mg.L^{-1}$	Lab Alkalinity $mg.L^{-1}$	Lab Temp °C
Surface	12.5	10.6	6.64	6.61	520	295	139	69	59	22	6.2
5	10.1	10.6	6.64	6.8	520	325	140	123	53	20	10.4
10	10	10.5	6.64	6.81	510	350	145	126	52	21	12.1
15	10.3	6.4	6.64	6.79	560	360	158	133	66	24	11.9
20	9.3	5	6.77	6.76	670	390	171	145	81	32	12
25	5.8	5.1	6.31	6.57	960	530	185	152	122	49	13
33		5.6	6.29	6.4	770	580		129	138	52	7.8

Table 2: Concentrations of Selected Elements in Oriental West Pit, 1988-1996

Date	pH	Acidity,mg/L CaCO3		Iron, mg/L		Aluminum, mg/L		Zinc, mg/L		Sulphur, mg/L	
	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
Jul-88				1.3	3.6	3.8	4.9	53	75	170	230
Jul-88				1.4	2.7	3.9	4.7	54	70	176	220
Dec-88					0.05		<0.01		55		195
Mar-89				0.1		3.6		48		169	
Jun-89				1.2		4.4		>10			
Aug-89					0.7		4.1		53		291
Sep-89				1.2		4.7		58		362	
Jul-90				1.2		3.8		39		120	
May-91	3.55	67	167	1.3	2.1	2.44	4.96	23.5	52.3	73.3	146
Aug-91	3.94	118	122	<1	1	7	6	33	33	107	107
Oct-91	3.72			1.5	1.3	7.4	7.2	39	37.3	119	105
May-92	3.55	38	138	0.9	3.2	1.6	4.2	15.4	50	52.4	144
May-92	3.7	37	110	0.8	1.4	1.45	6.35	12.4	35.1	47.3	114
Jul-92	4.13		57		<1		2.15		21.7		73.1
Jul-92	3.92	61.5	70	0.07	0.03	2.17	1.62	20.9	23.6	75.3	76.8
Sep-92	3.62		70.5	<1	<1	3	3	31.3	31.6	98	97
Feb-93	3.76	87.8	105	0.95	1.03			26.9	30		
Mar-93	3.77	97.9	110.7	0.95	1.1			34.6	33.8		
Apr-93	3.84	81.4	94.3	0.15	0.202	2.72	3.07	30.7	33.8	94.9	106
May-93	4.04	40.3	101.5	0.069	0.205	1.29	3.15	11.5	33.6	43.4	107
Jul-94	6.07	35.0	226.0	0.308	21.1	0.032	0.076	17.4	26.6	172	204
Jul-94	6.05	47.0	235.0	0.786	8.59	0.06	0.112	16.6	24.8	151	196
Aug-96	5.80	32.9	171.3	<0.02	<0.02	<0.025	<0.025	16.3	29.9		

Fig. 1a: River at Highway Bridge
Zinc Concentration, 1992-1996

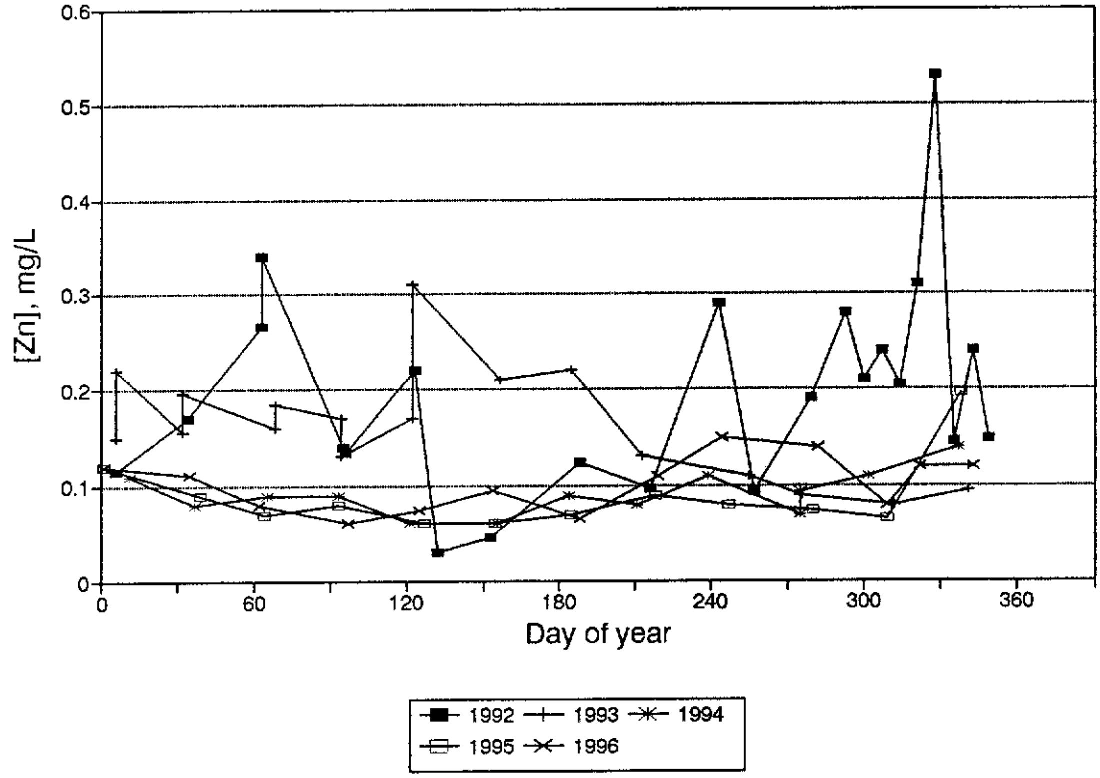


Fig. 1b: River at Highway Bridge
pH, 1992-1996

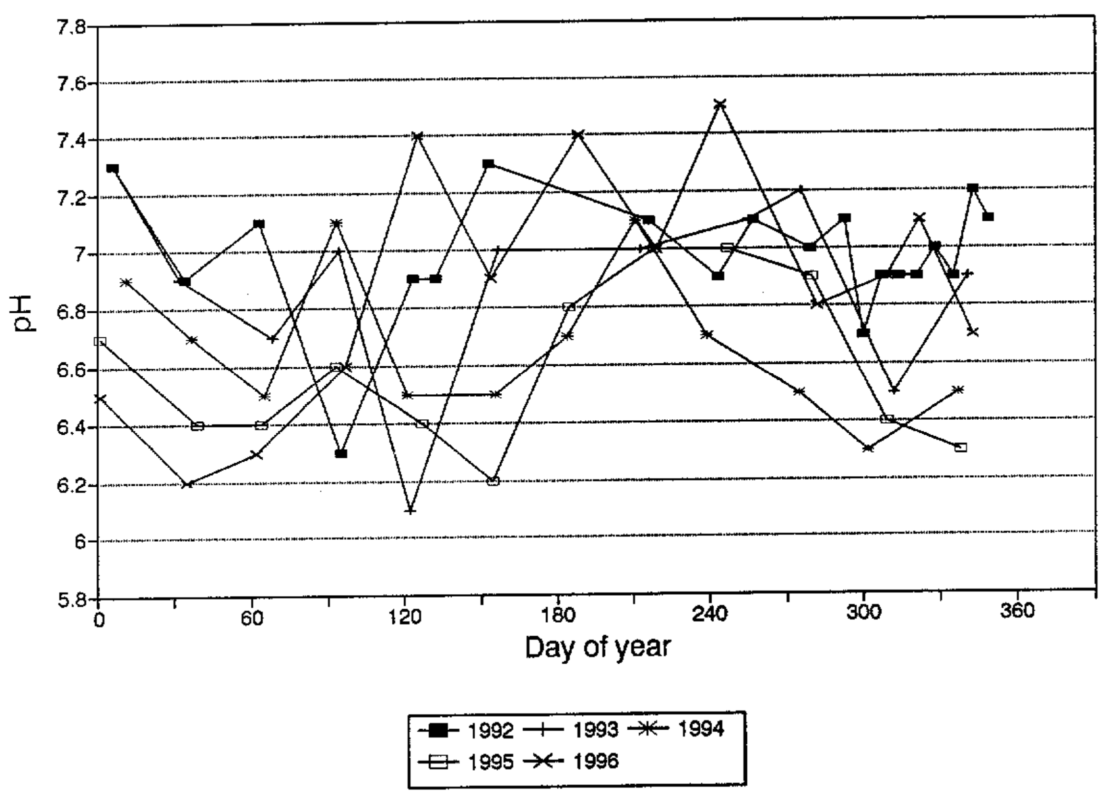


Fig. 2a: River below Hydro Plant
Zinc Concentration, 1992-1996

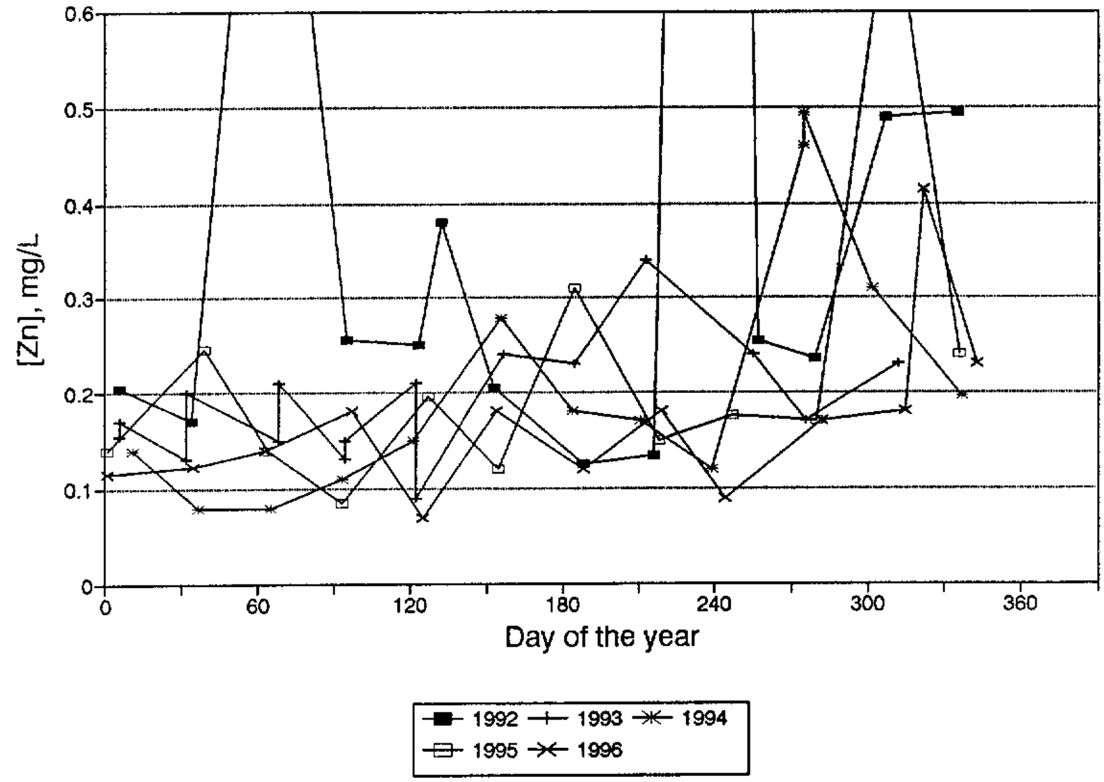


Fig. 2b: River below Hydro Plant
pH, 1992-1996

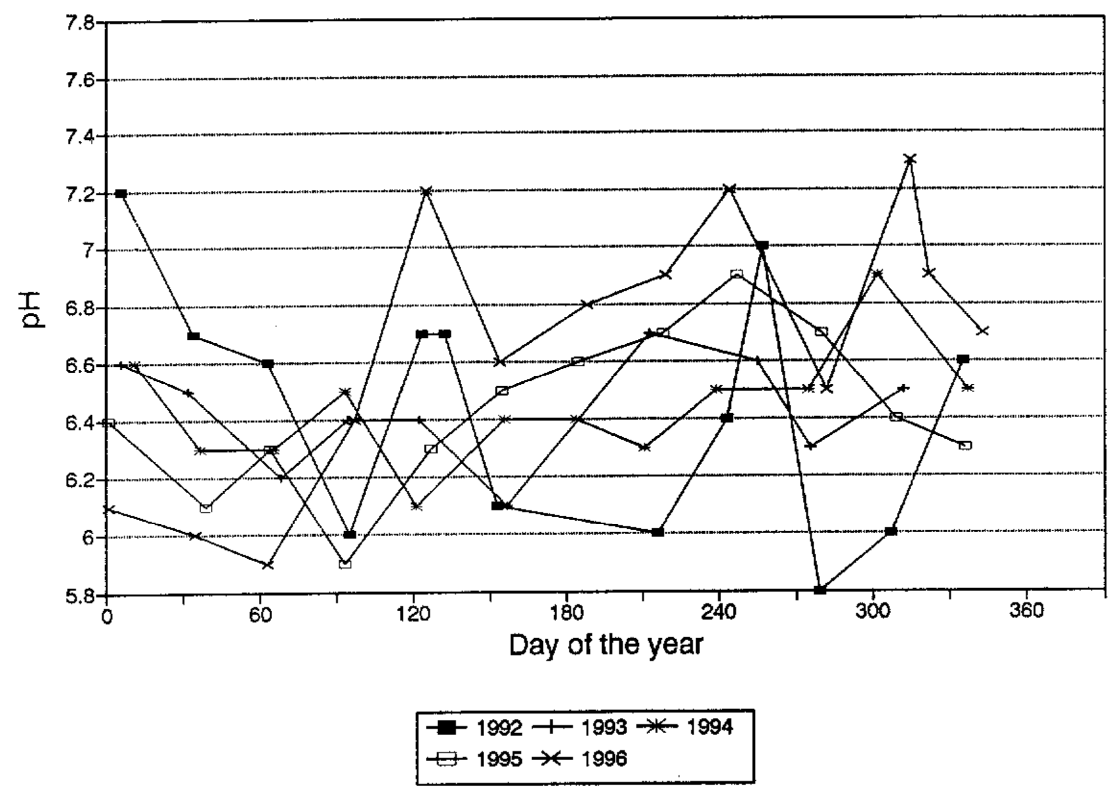


Fig. 3a: Simms Brook
Zinc Concentration, 1992-1996

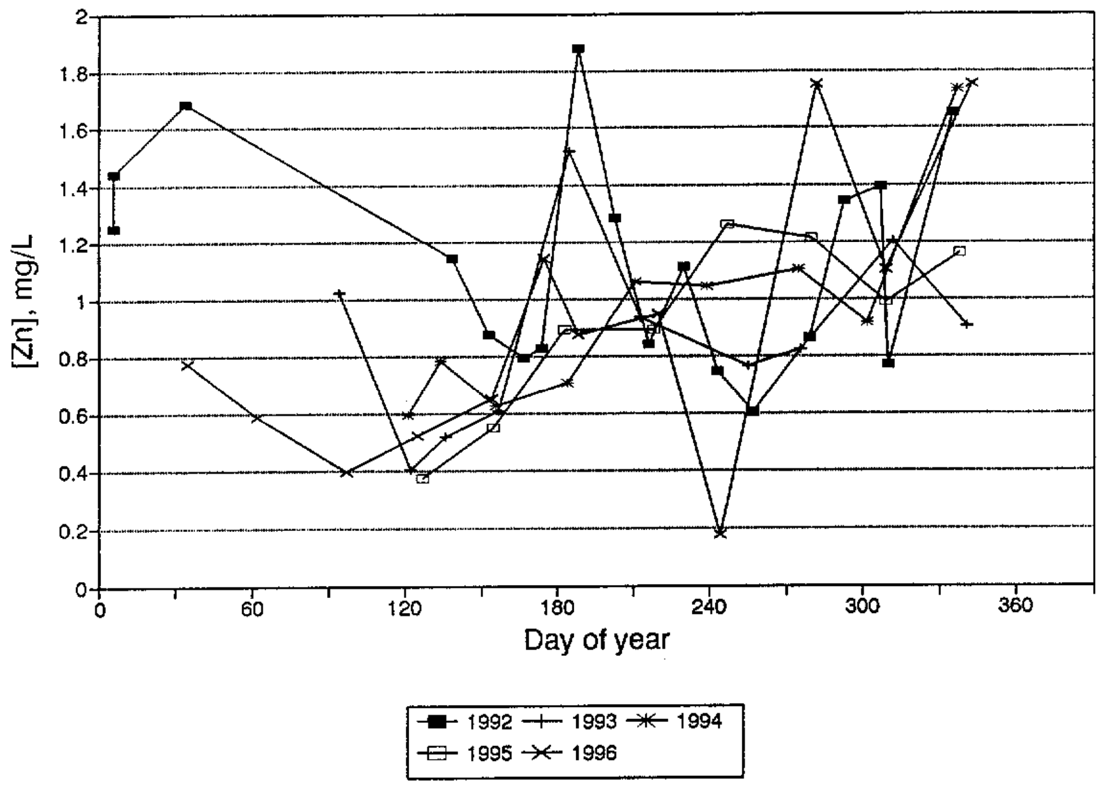


Fig. 3b: Simms Brook
pH, 1992-1996

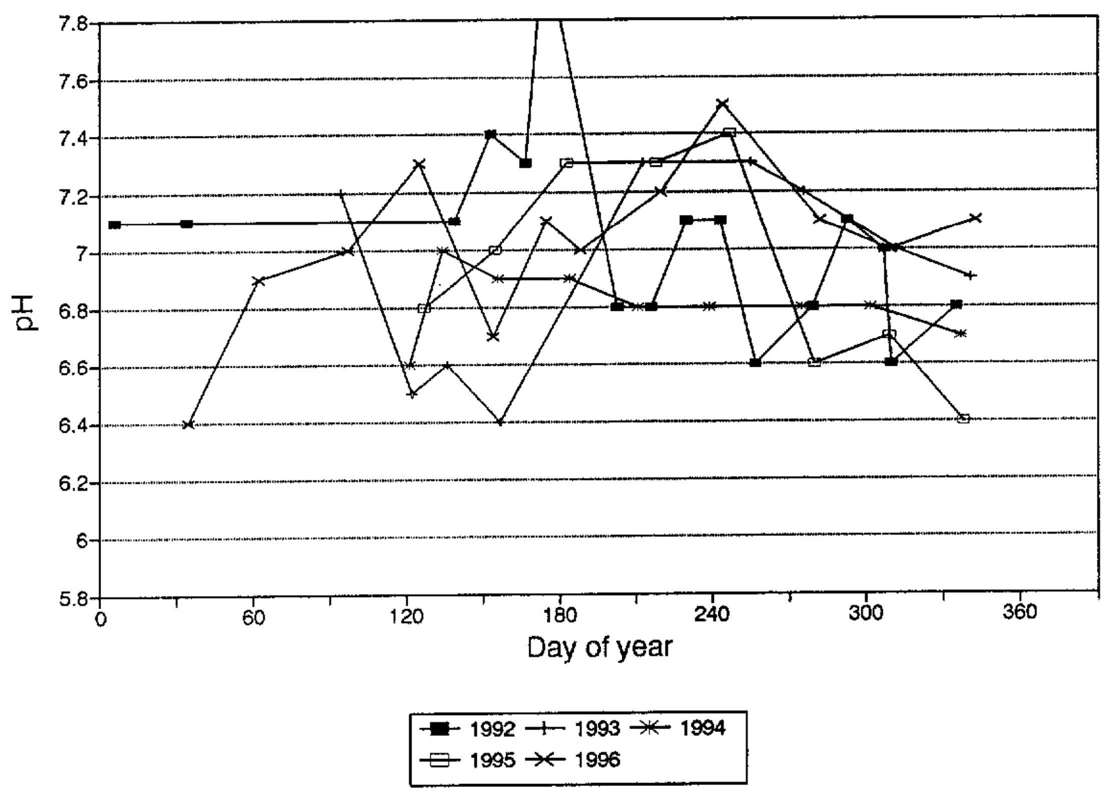


Fig. 4a: Tailing Pond 1
Zinc Concentration, 1992-1996

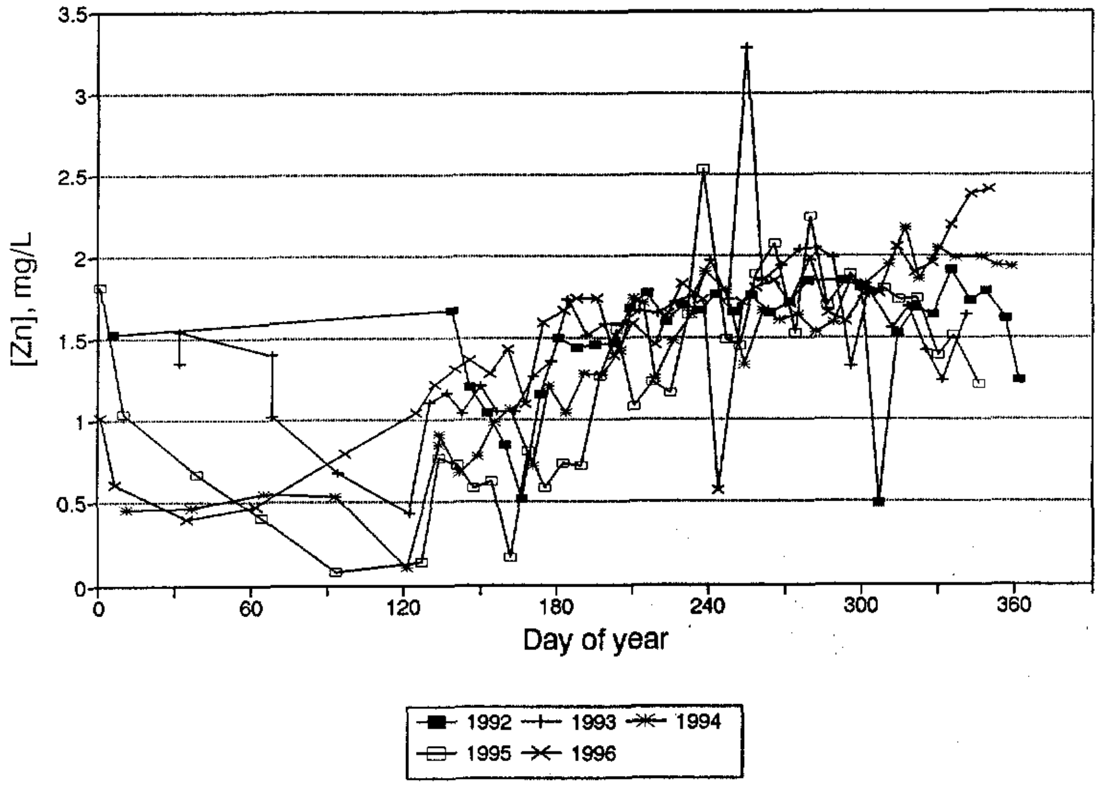
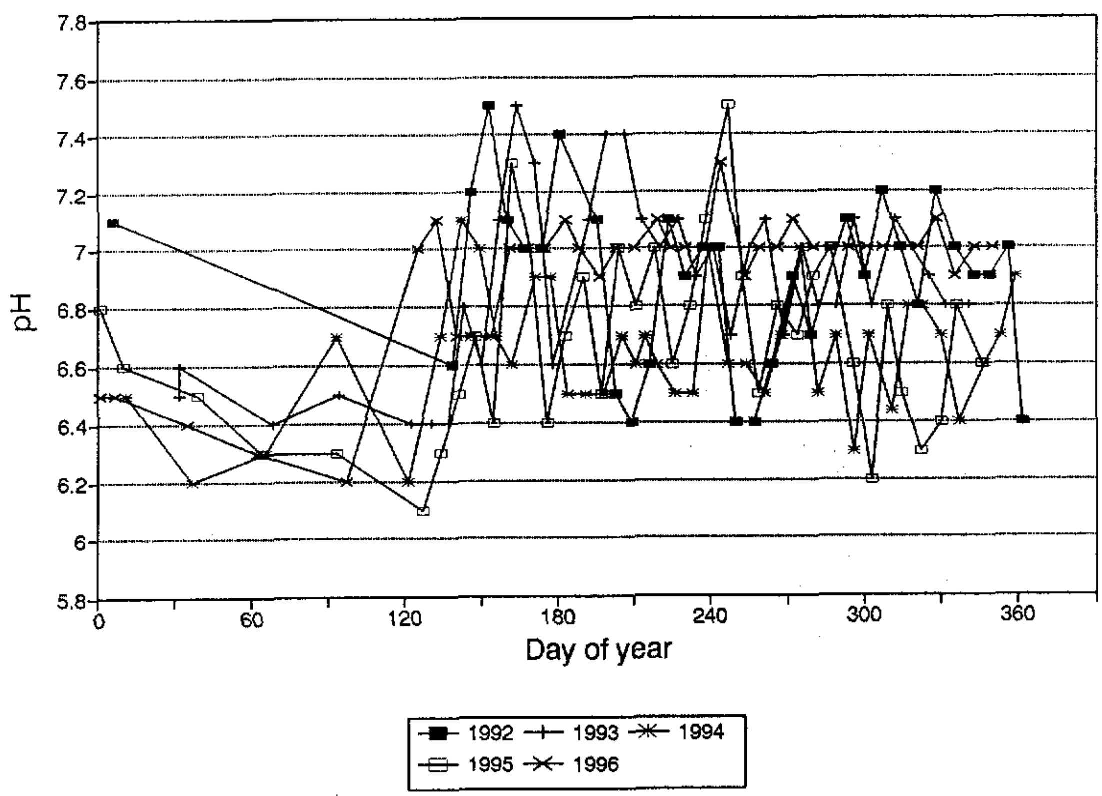


Fig. 4b:Tailing Pond 1
pH, 1992-1996



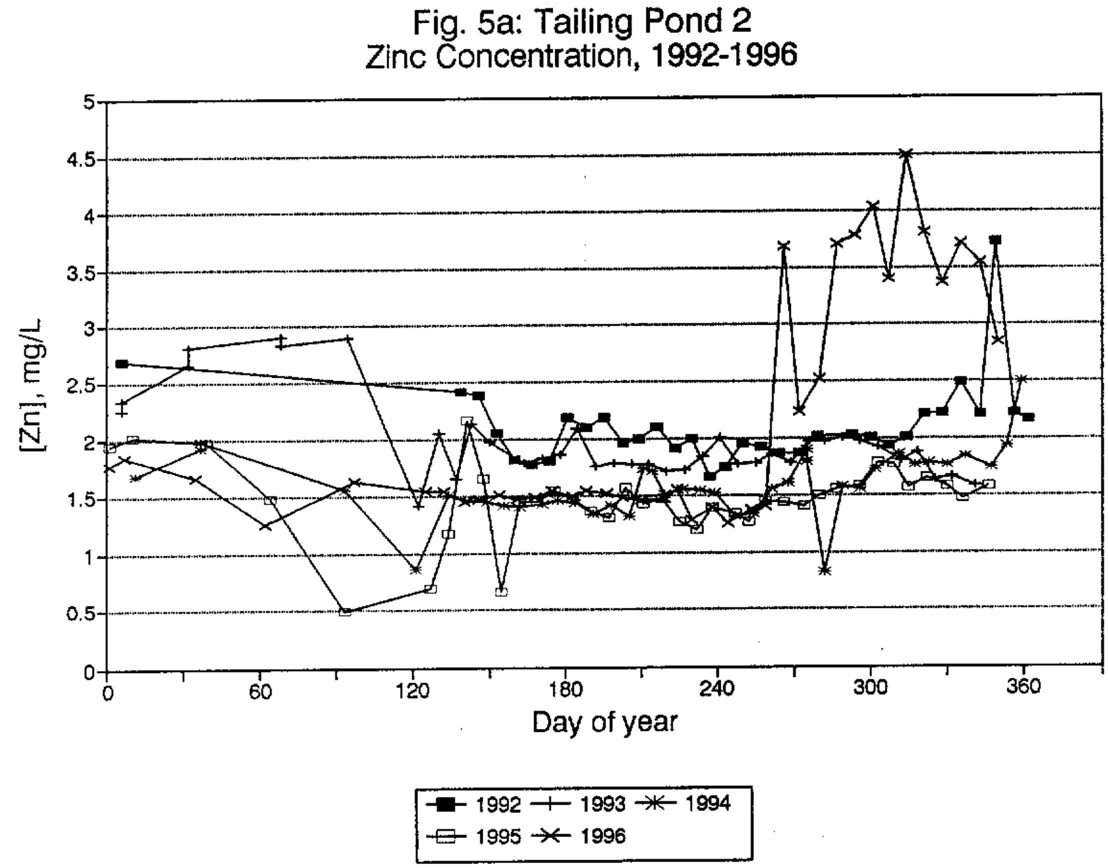


Fig. 5a: Tailing Pond 2
Zinc Concentration, 1992-1996
[Zn], mg/L
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
60
120
180
240
300
360
Day of year
1992
1993
1994
1995
1996

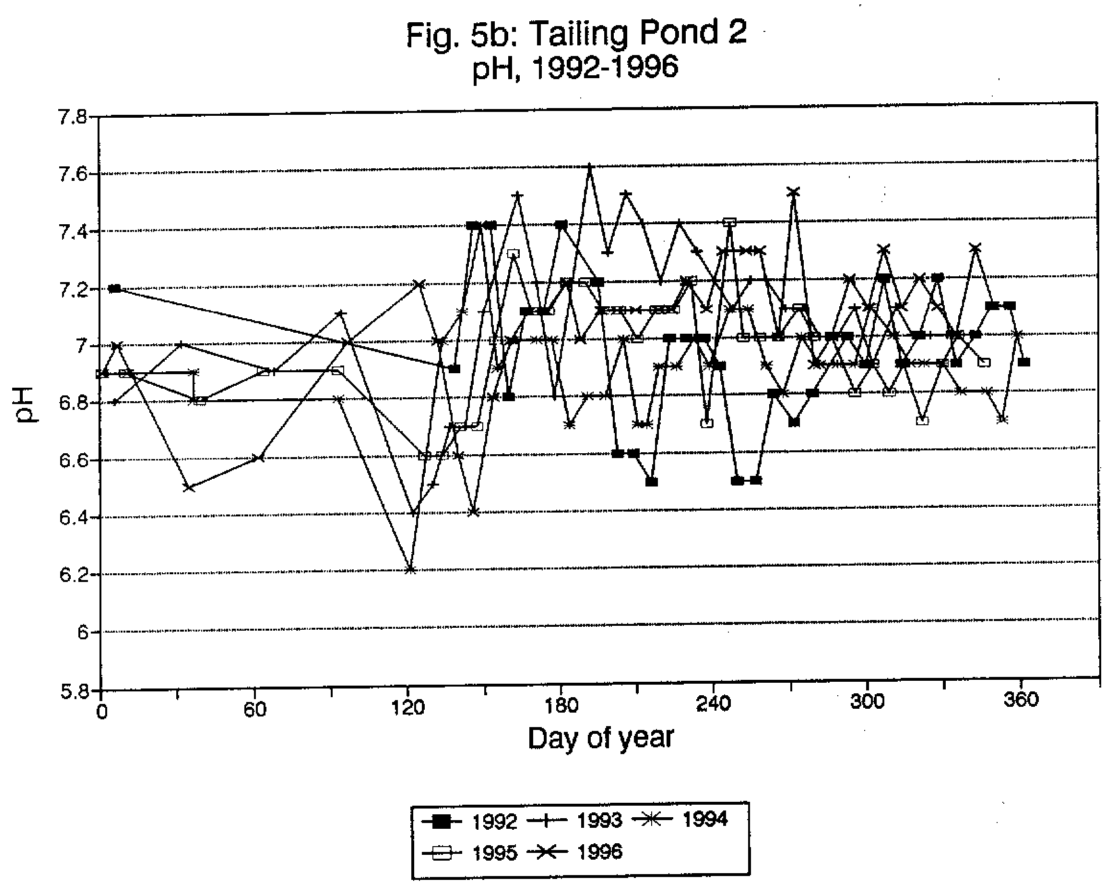


Fig. 5b: Tailing Pond 2
pH, 1992-1996
pH
5.8
6
6.2
6.4
6.6
6.8
7
7.2
7.4
7.6
7.8
0
60
120
180
240
300
360
Day of year
1992
1993
1994
1995
1996

Fig. 6a: Drainage Tunnel
Zinc Concentration, 1992-1996

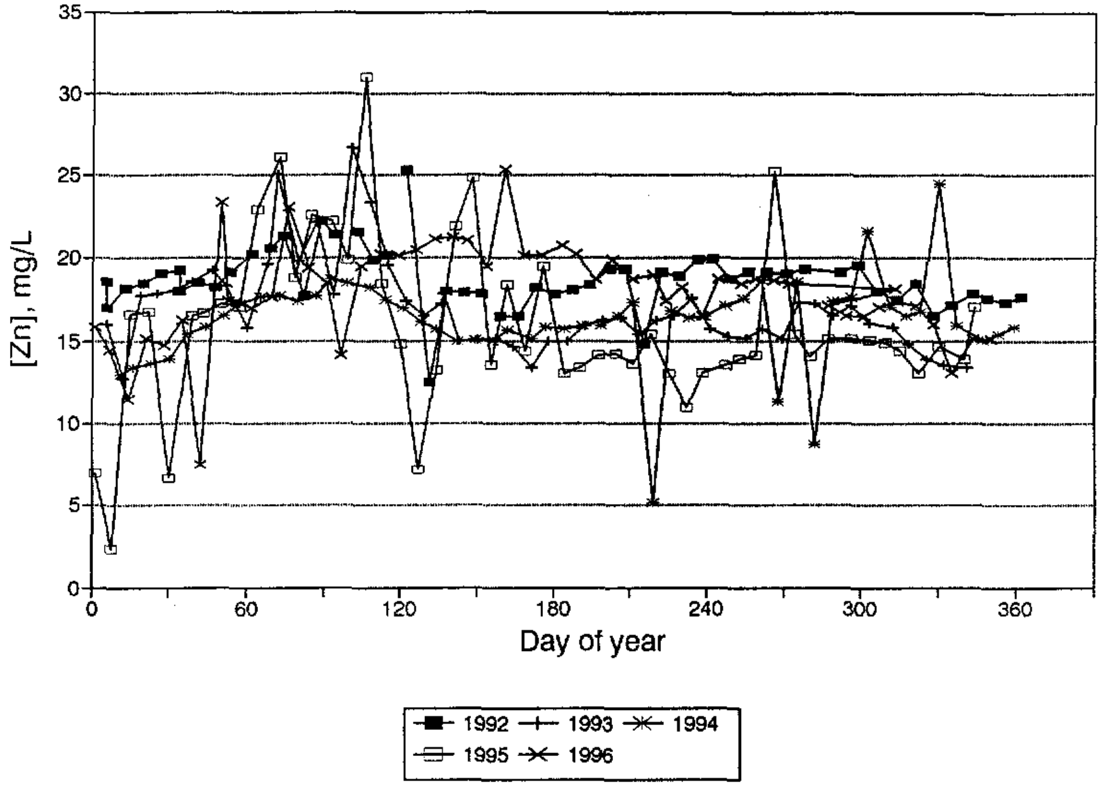


Fig. 6b: Drainage Tunnel
pH, 1992-1996

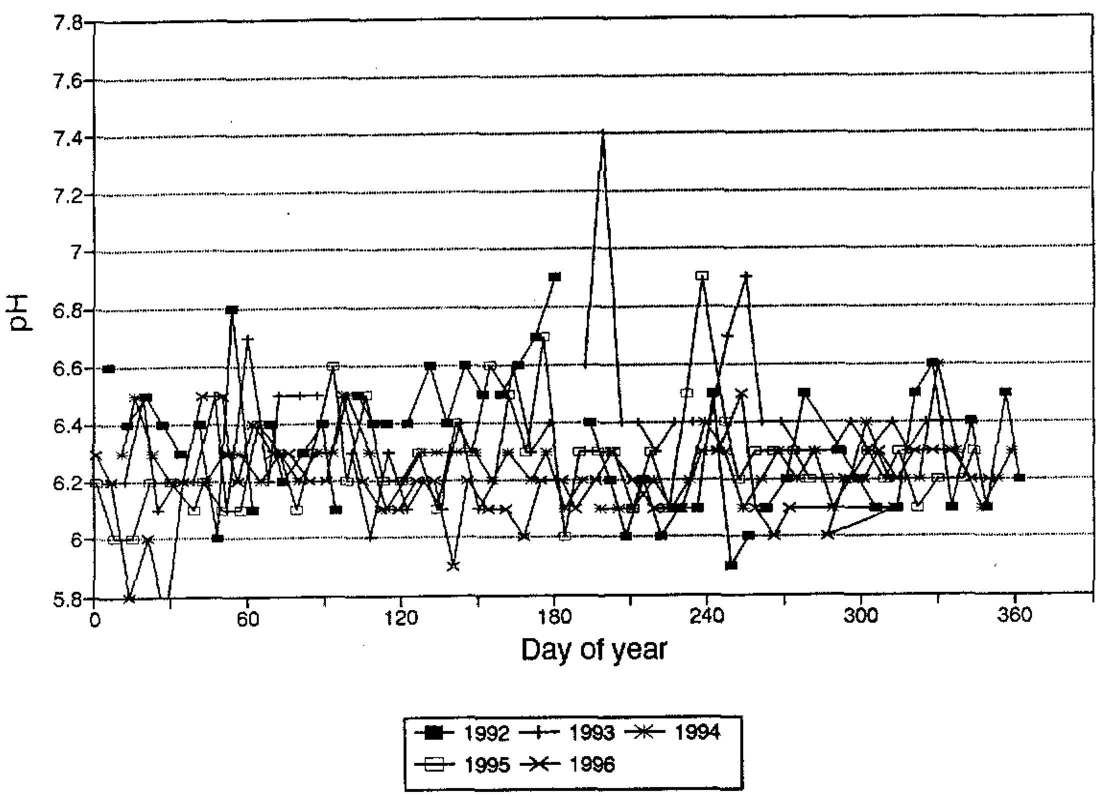


Fig. 6c: Drainage Tunnel
Average [Zn], 1990-1996

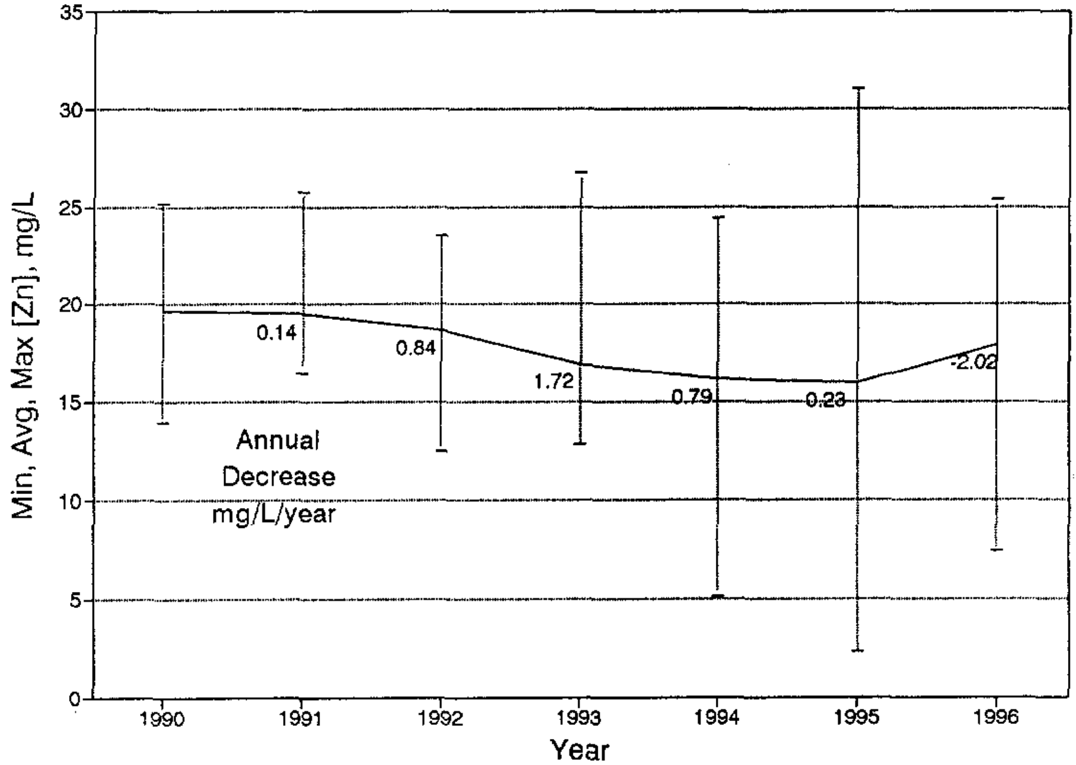


Fig. 6d: Drainage Tunnel
Flow, 1992-1996

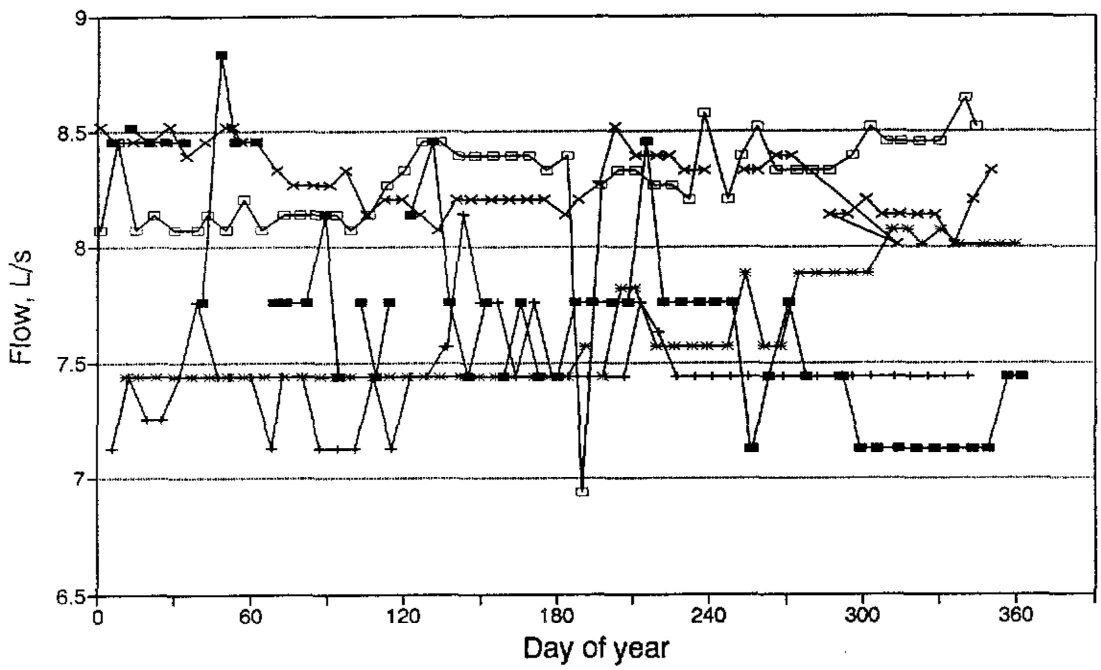


Fig. 7a: Oriental West Pit
Zinc Concentration, 1992-1996

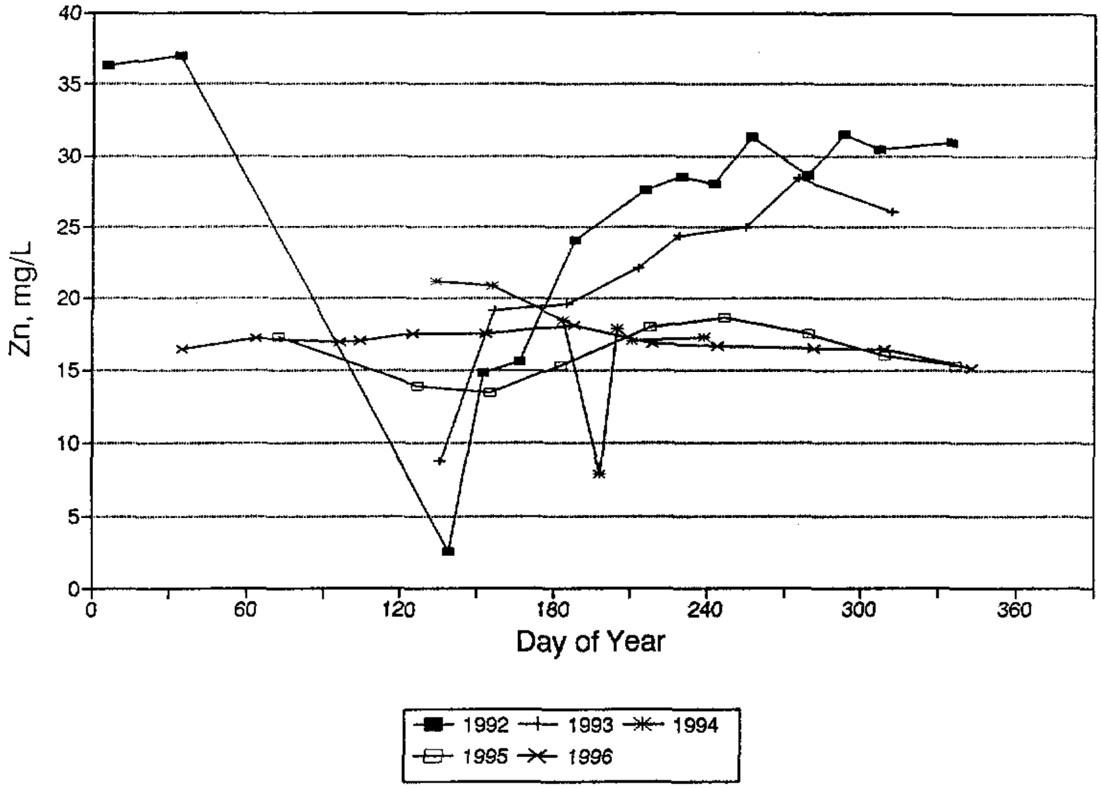


Fig. 7b: Oriental West Pit
pH, 1992-1996

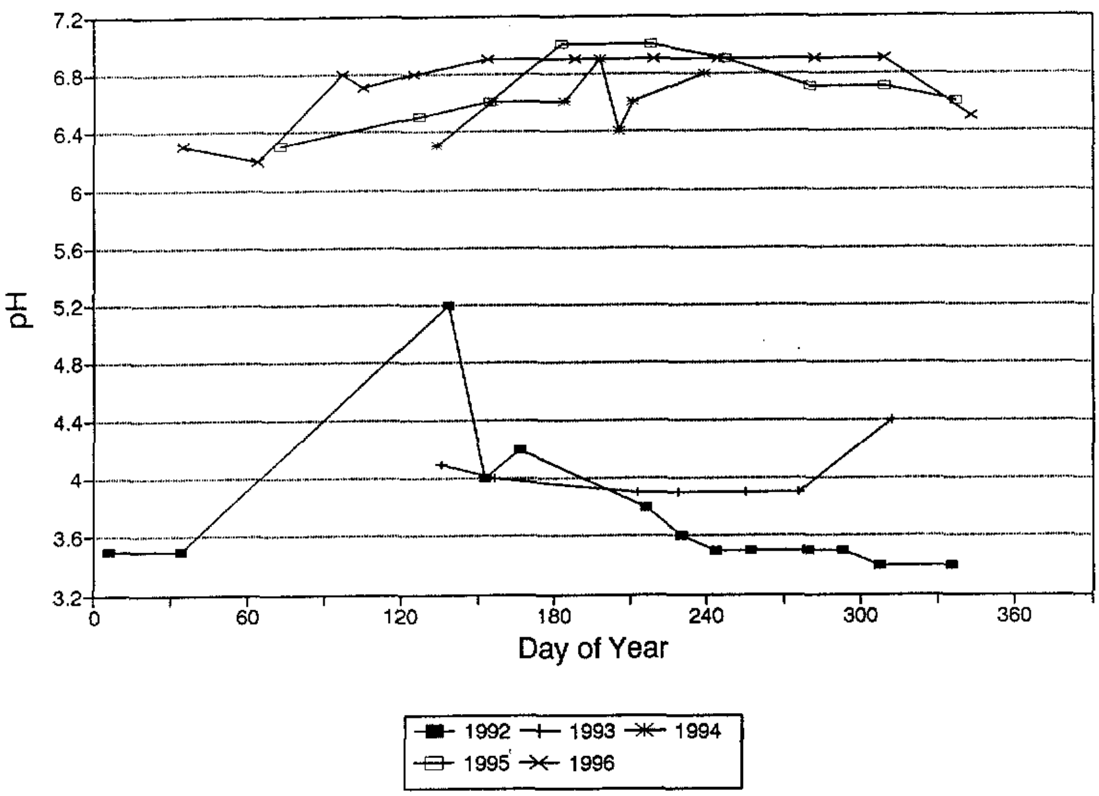


Fig. 7c: Oriental West Pit
Average [Zn], 1989-1996

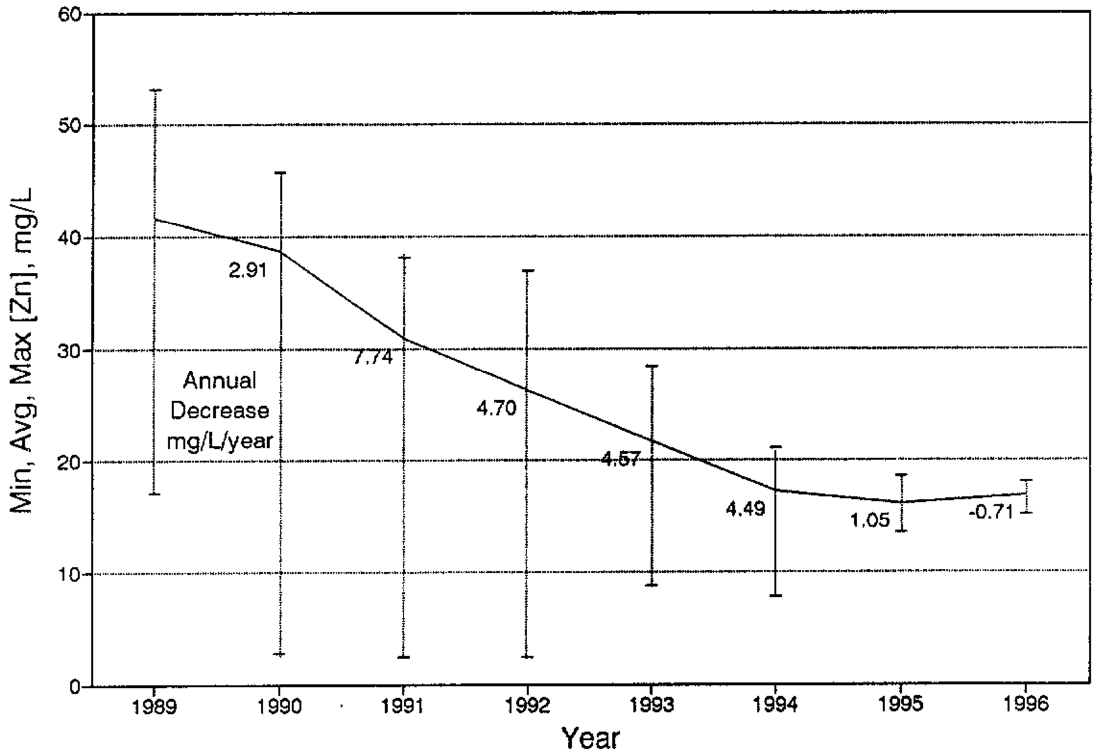


Fig. 8a: Oriental East Pit
Average [Zn], 1989-1996

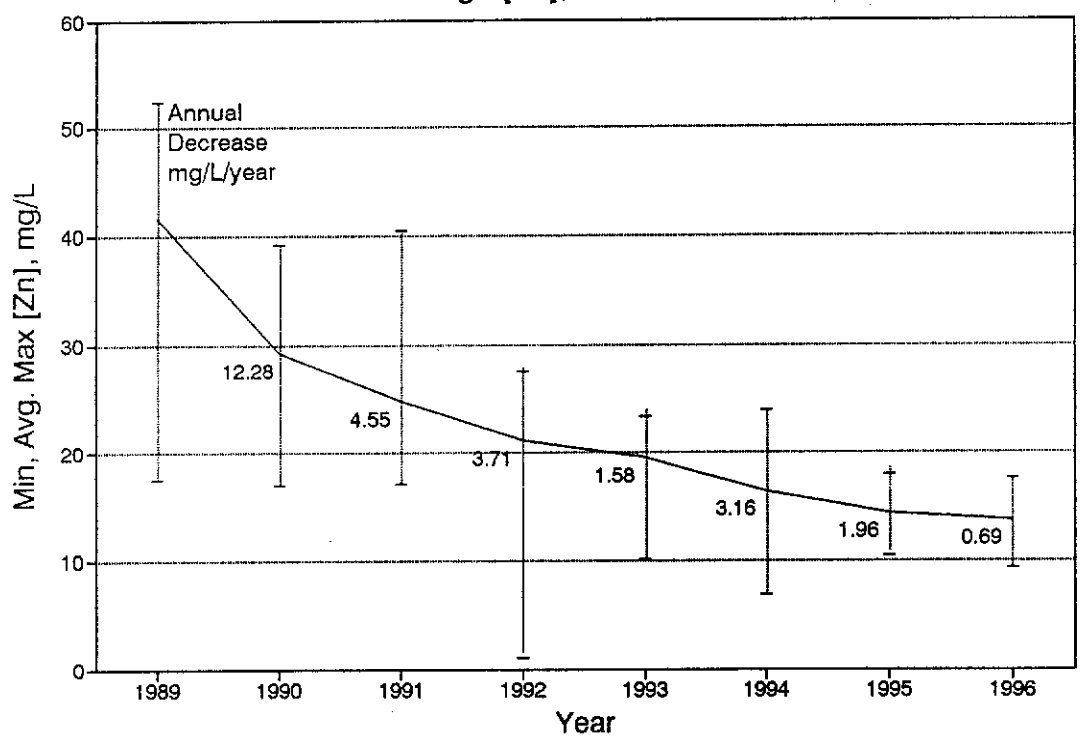


Fig. 8b: Oriental East Pit
Zinc Concentration, 1995-1996

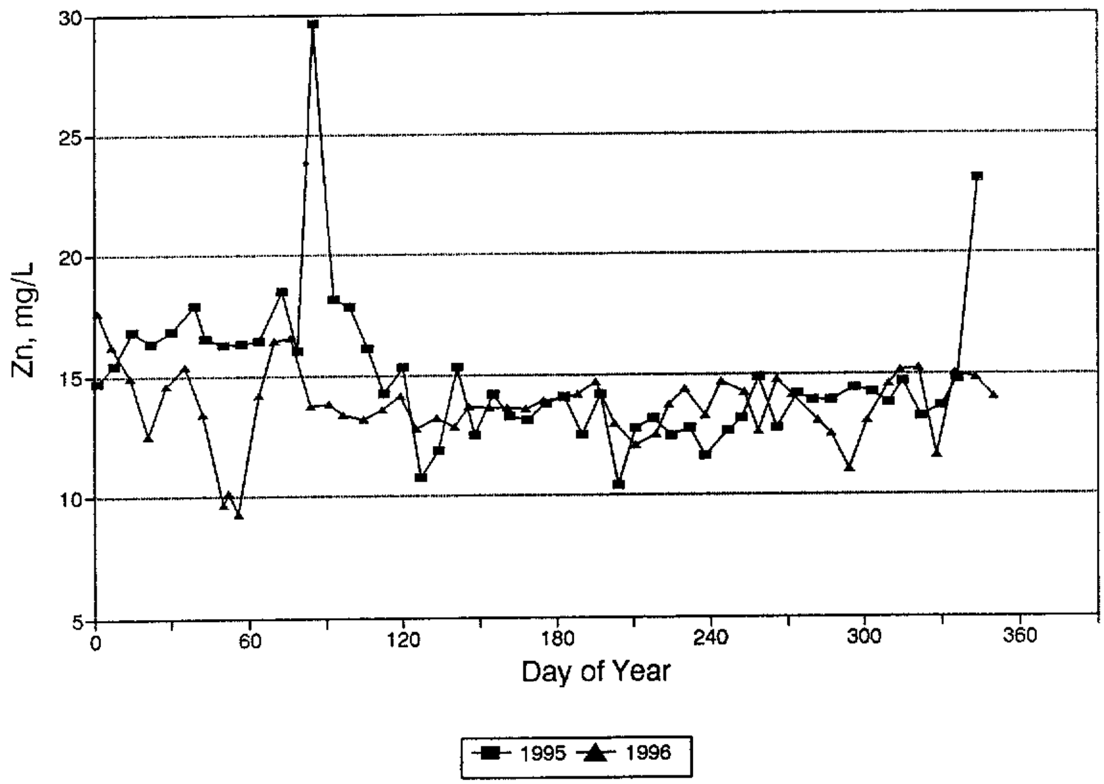


Fig. 8c: Oriental East Pit
Zinc Concentration, 1995-1996

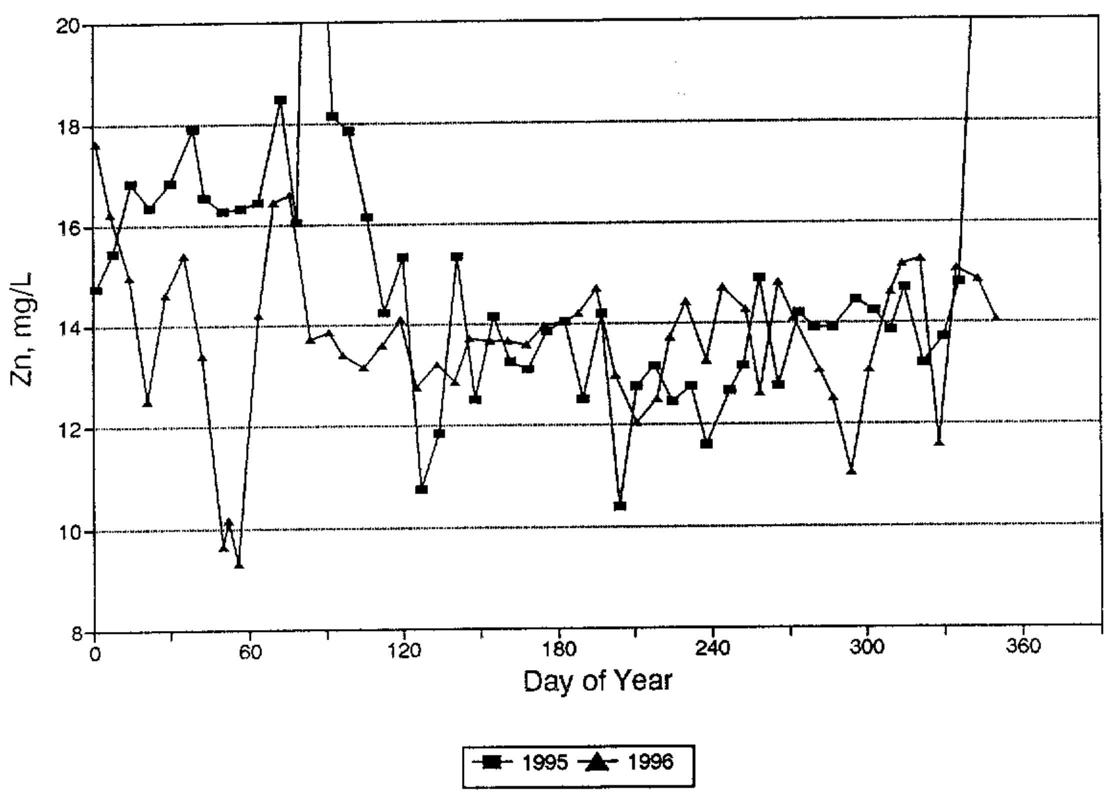


Fig. 9a: Lucky Strike Glory Hole
Average [Zn], 1991-1996

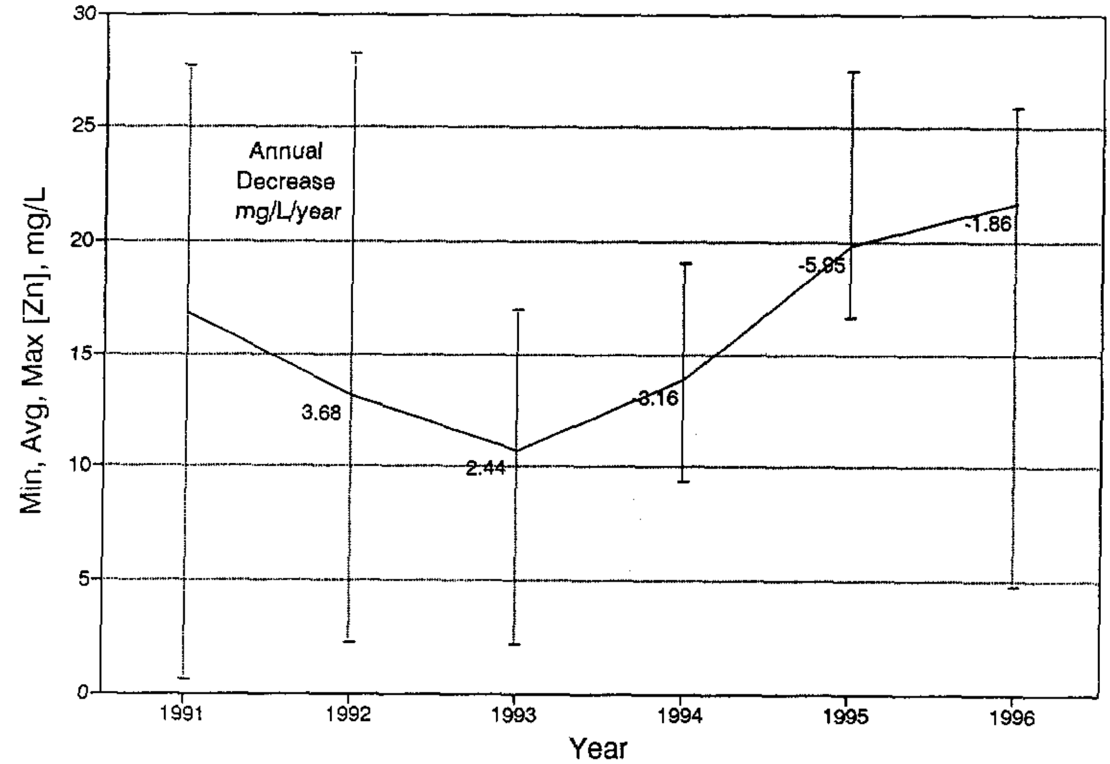


Fig. 9b: Lucky Strike Glory Hole
Zinc Concentration, 1992-1996

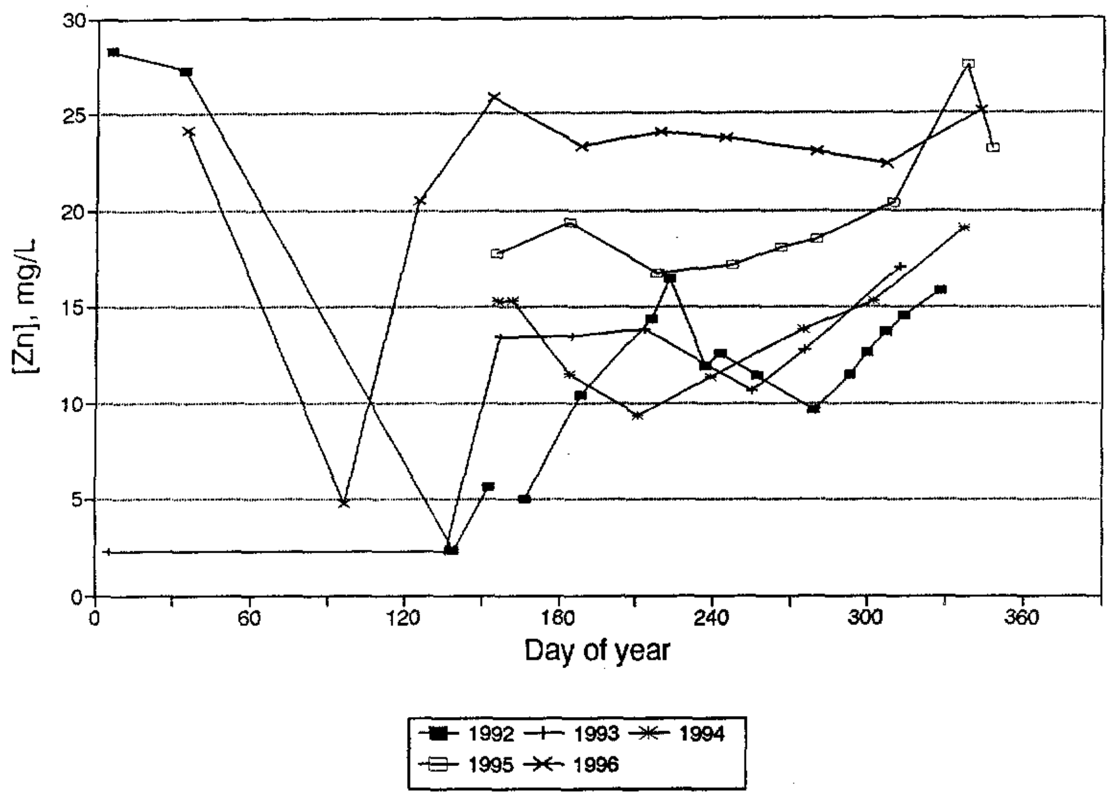


Fig. 9c: Lucky Strike Glory Hole
pH, 1992-1996

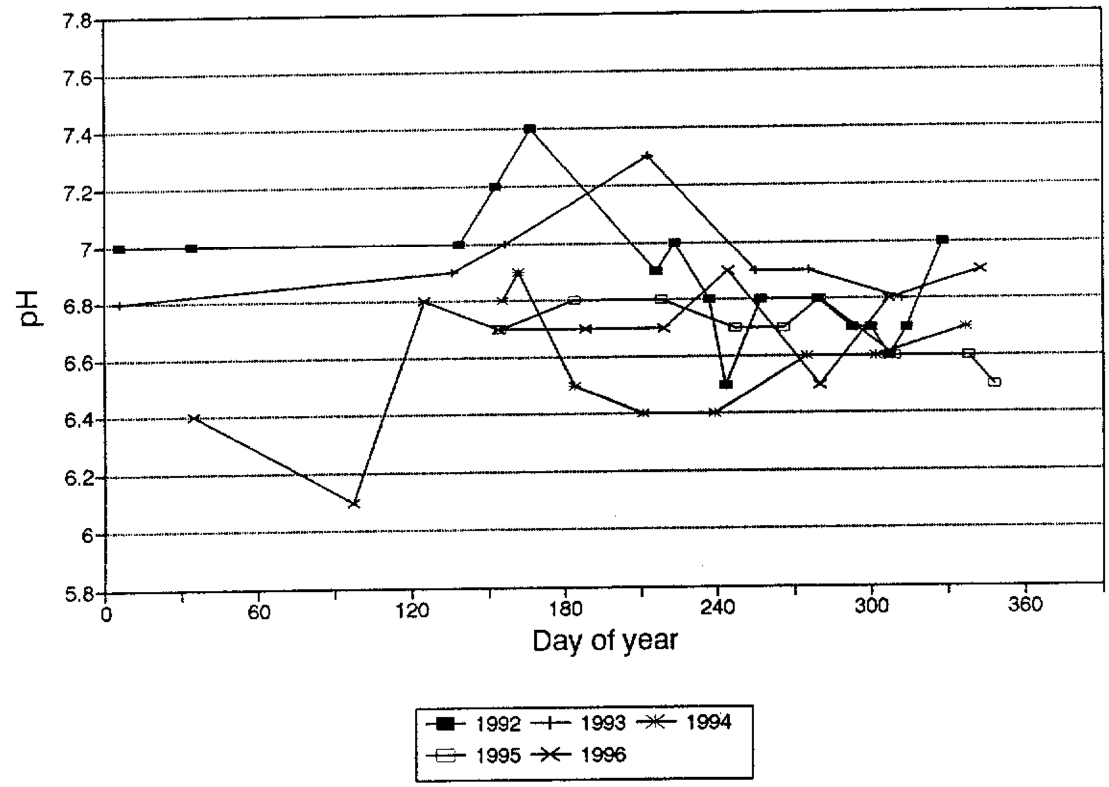


Fig. 10: Lucky Strike Glory Hole
Limnology, September 27, 1996

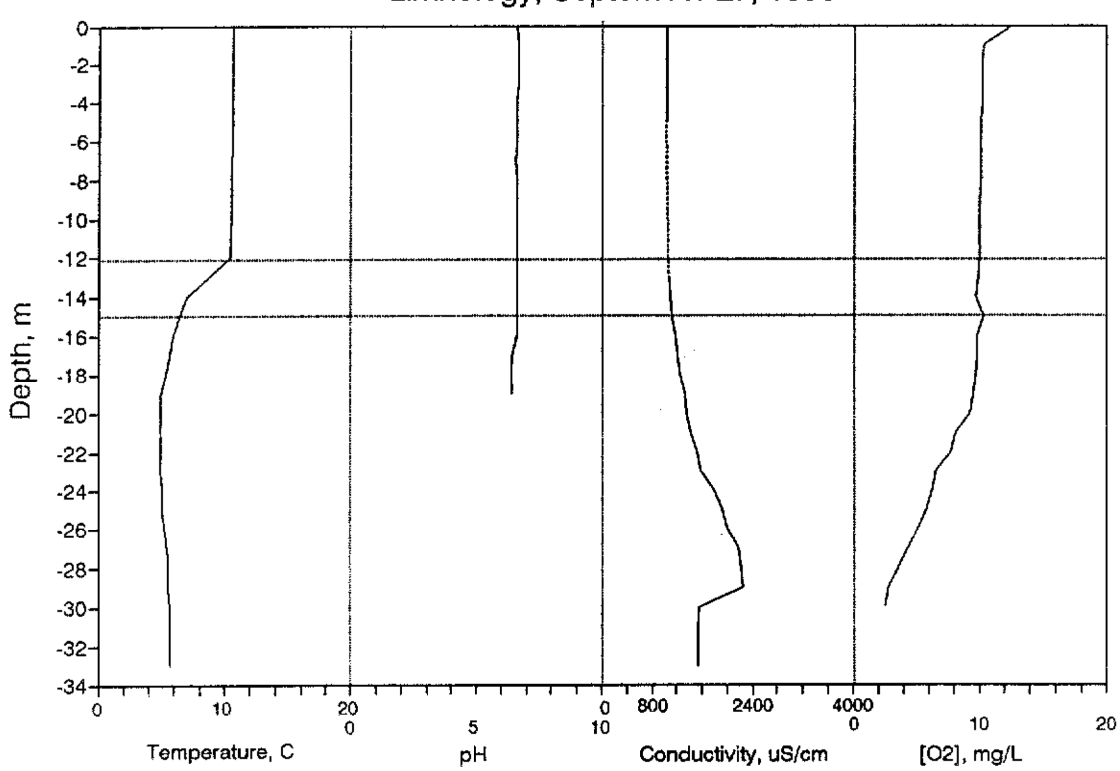


Fig. 11a: Oriental East Pit
Acidity by Depth, 1993-1996

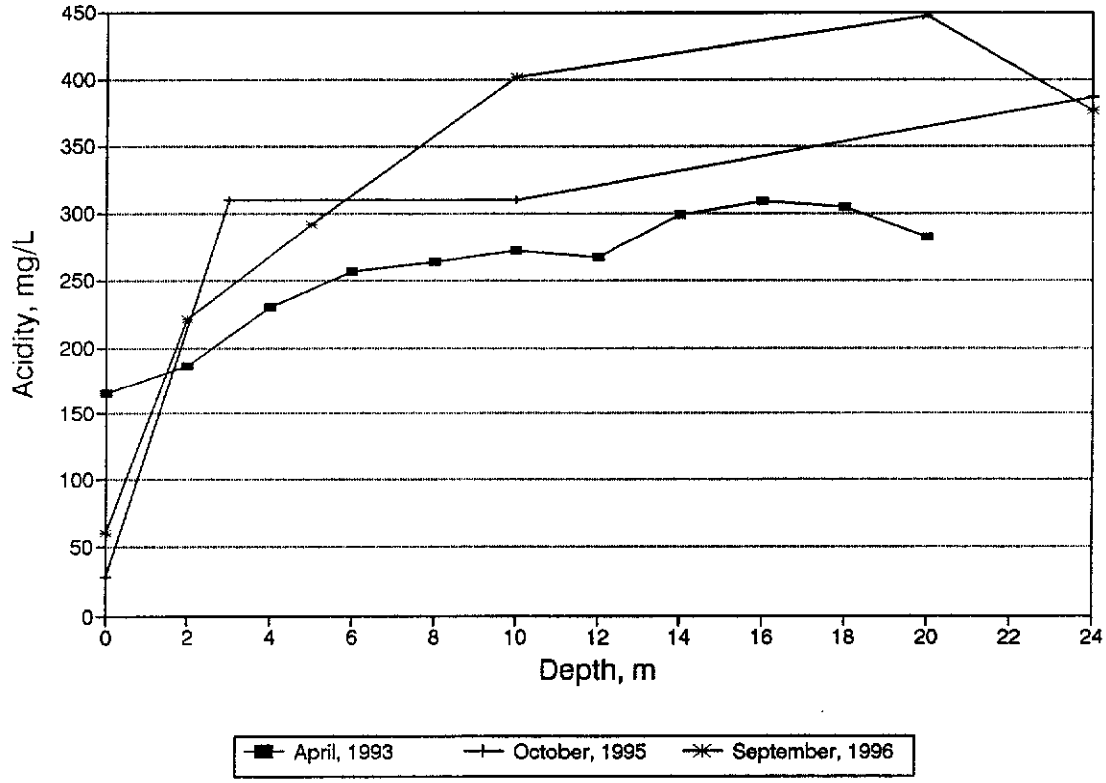
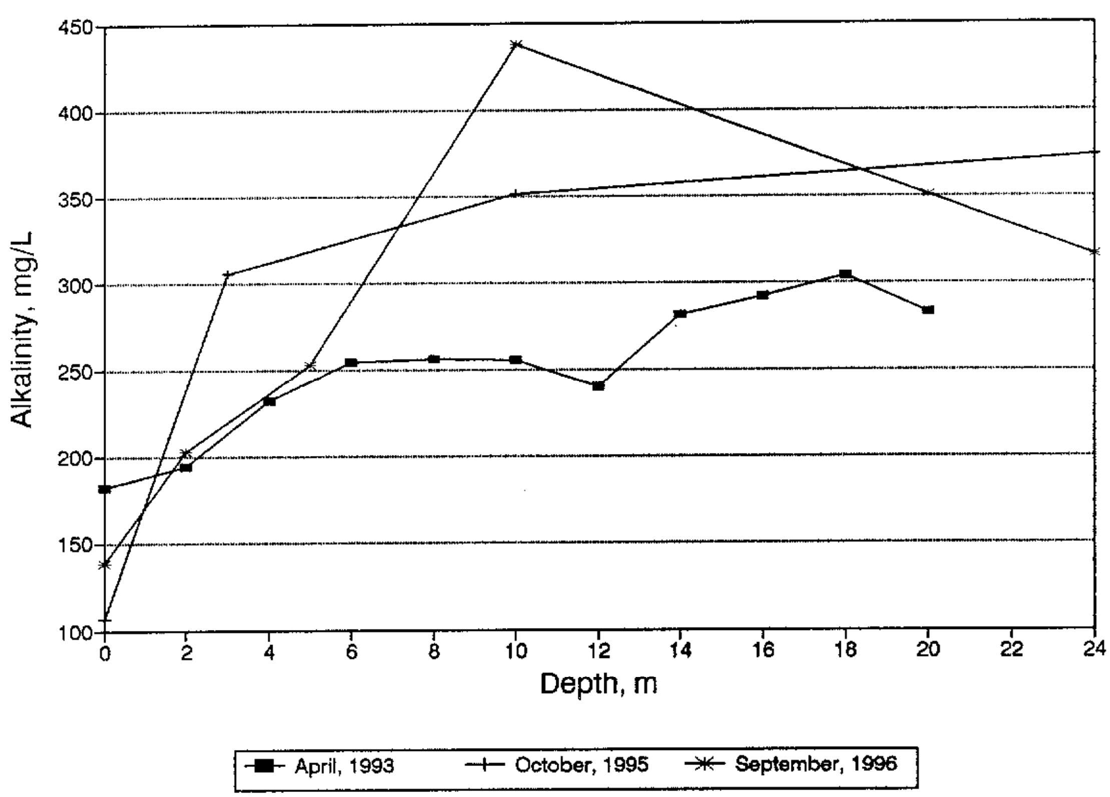
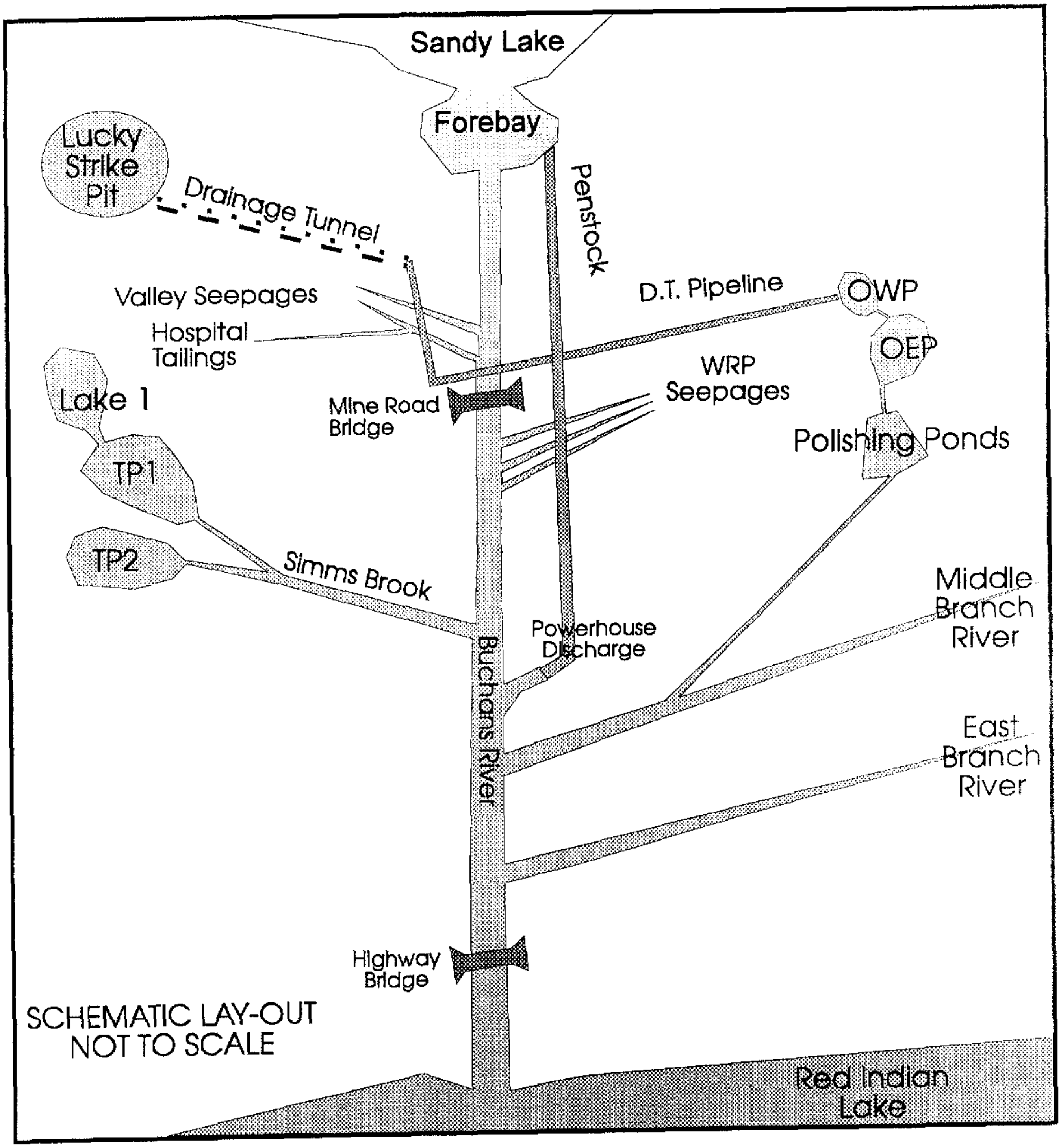


Fig. 11b: Oriental East Pit
Alkalinity by Depth, 1993-1996





Schematic 1: Generalized lay-out of sources of drainage to the Buchans River

2.0 GROUND WATER DISTRIBUTION IN THE SYSTEM

2.1 Introduction

- Until recently, the contributions of various surface and ground water flows to the OEP and OWP which make up the flow at OEP weir could not be confirmed, due to the lay-out of the system and the lack of appropriate monitoring data.

- Sufficient information is now available to estimate the contributions of these various flows.

2.2 Brief History

- Following completion of flooding of the OEP and OWP (August, 1987), the flow volume at the outflow was approximately 10 L/s, with slight variation due to high spring run-off and lower base flows during mid winter.

- No surface water inflow, other than local run-off during precipitation events, contributed to the flow volume at the OEP weir.

- Ground water containing elevated zinc and ferrous iron concentrations was essentially the only source of flow.

- The pH of OEP water was near neutral.

- Following flooding of the OWP, no surface inflow or outflow could be seen, while the water level remained relatively constant year-round. However, variation in zinc concentrations, particularly during spring run-off when surface water zinc concentrations temporarily decreases, suggested that clean water entered the

OWP and OWP water must have been displaced from the pit in spring in order to maintain the water levels at a constant elevation. This phenomenon is depicted in Figure 12 for 1995. This phenomenon did not occur in 1996, as shown in Figure 12.

- Between 1987 and 1993, the pH of the OWP water column was low (pH 3.5), and the water column was clear and contained little suspended solids. Due to its high clarity, light penetrated the water column and thermal stratification did not establish during the ice-free season. This is shown for September 27,1992 in Figure 13.

- The surface water of the OWP was joined to the OEP's surface water by a culvert in September, 1993. Pumping of Drainage Tunnel water to the surface of OWP commenced in August, 1994.

- Following joining of the two pits and lowering of the OWP water level by approximately 0.3 to 0.6 m, major changes in the OWP's water column occurred and have since remained. The pH of the OWP water column increased to near neutral pH, while the OWP pit became and remains thermally stratified, as shown in Figure 13. OWP's stratification is similar to that which has existed in OEP since flooding (Figure 14).

- There is now a ground water source of ferrous iron source to the OWP, and ferrous iron oxidation and ferric hydroxide precipitation occurs in near surface strata of the pit.

- Drainage tunnel water entering the OWP oxygenates the surface water.

2.3 Flow Distribution Using Chloride Data

- A summary of flows, chloride concentrations and mass balance is provided in Table 3.

2.3.1 Oriental West Pit

- Prior to the joining of OWP and OEP surface waters, chloride concentrations in the OWP were low, ranging from 0.8 to 1.5 mg/L.

- Drainage Tunnel water, now pumped to the OWP, contains on average 12.7 mg/L chloride.

- However, OWP water now contains 35 mg/L Cl on average, a higher concentration than the Drainage Tunnel.

- Ground water entering OWP containing an elevated Cl concentration is likely the source of this extra chloride.

- Assuming that the ground water is from the same source as that entering OEP, then the Cl concentration in OEP 7 m samples (similar to the depth of the bottom of OWP) can be used to estimate the flow of ground water required to contribute that extra chloride present in OWP in addition to the Cl contributed by the Drainage Tunnel flow.

(D.T. [Cl] × D.T. Flow) + (GW [Cl] × GW Flow) = (OWP [Cl] × OWP Out Flow)

(12.7 mg/L × 8.3 L/s) + (144 mg/L × **X** L/s) = 35 mg/L × (**X** L/s + 8.3 L/s)

Solving for **X**: Ground water flow is 1.7 L/s.

- According to the chloride concentrations, approximately 10 L/s (8.3 + 1.7 L/s) of water leaves OWP and joins OEP surface water.

2.3.2 Oriental East Pit

- The contribution of ground waters to the OEP can be estimated based on the estimated flow and chloride load from OWP and the measured flow and chloride load leaving OEP at the weir.

- The OWP contributes 354 mg of Cl per second, in 10 L/s of water, to the OEP via the culvert joining the two pits.

- Based on monitoring data, approximately 1231 mg Cl leave OEP per second in a flow of 19.2 L/s. Therefore, by difference, the ground water is contributing 9.2 L/s of water, and a Cl load of 877 mg/s.

- OEP bottom waters contain 149 mg/L chloride (1996 average). If all ground water entering the OEP contained this concentration of chloride, then the ground water chloride contribution to the chloride loading at OEP outflow would be 1371 mg/s, a load exceeding the above estimate (877 mg/s) by 494 mg/s.

  A high chloride ground water flow of only 5.8 L/s is required to add the 870 mg/s to the chloride load at OEP outflow. The remaining 3.4 L/s (6.7 mg/s Cl) likely originates from a low chloride (2 mg/L: DDH 2367 groundwater sample) groundwater flow, perhaps emerging at the overburden-bedrock interface along the pit walls.

2.4 Verification of Estimates Using Sodium Concentration Data

- A mass balance for sodium in the OWP-OEP system is provided in Table 4. In this table, flows determined using chloride as a tracer were used, and sodium concentrations determined for equivalent locations from the same data set were used.

- Chloride is typically the element of choice as a natural tracer of surface and ground water mass balance estimates, such as that performed above, since chloride compounds rarely form and chloride is not precipitating.

- While more opportunities may exist for loss of sodium mass from a system, such as in jarosites, this element can be used to evaluated the assumption that NaCl is the source of chloride, as used in the geochemical simulations presented in Section 4.

- The estimated Na load at OWP outflow from Drainage Tunnel and groundwater is 22 % less than the measured Na load estimated by multiplying the OWP outflow by the OWP surface sodium concentration. For OEP outflow, the estimated Na load is only 1 % less than the measured Na load (Table 4).

- These comparisons provide confidence that the flow volume estimates derived from the chloride mass balance exercise may adequately represent field conditions. Therefore, it can be assumed that clean ground water contributes about 3.4 L/s to OEP.

2.5 Application of Mass Balance Model to Zinc, Iron and Sulphate Loads

2.5.1 Zinc

- A mass balance for zinc in the OWP-OEP system is provided in Table 5. In this table, flows determined using chloride as a tracer were used, and zinc concentrations determined for equivalent locations from the same data set were used.

- The estimated zinc load leaving OWP (162 mg/s) is 3% less than the measured zinc load leaving OWP (166 mg/s). This indicates that zinc removal in OWP may be negligible. However, sedimentation of zinc-bearing compounds and algal uptake of zinc have been measured in the OWP.

- The estimated zinc load leaving OEP is 10 % greater than the measured zinc load exiting OEP at the weir. This suggests that processes in OEP remove zinc prior to discharge here but not in the OWP.

- According to these estimates, the Drainage Tunnel Input (135 mg/s) is a larger contributor of zinc (166 mg/s) to the OWP-OEP system than OEP (255-162=93 mg/s).

2.5.2 Iron

- A mass balance for iron in the OWP-OEP system is presented in Table 6.

- According to this mass balance, 99 % of iron entering OWP remains in the pit as sedimented particles, while 91 % of the iron entering OEP remains in the pit as sedimented particles. While this is consistent with summer water quality data and observations, significantly less iron removal occurs in the winter, when an ice layer covers OEP, blocking oxygen transport into OEP surface waters, which in turn slows ferrous iron oxidation and ferric hydroxide precipitation.

2.5.3 Sulphate

- A mass balance for sulphate is presented on Table 7.

- Using flows estimated from the chloride mass balance, 11 % of the sulphate entering OWP remains in the pit, while 2 % of the sulphate entering OEP remains in the pit. Sulphate removal in the pits appears to be minor. Some gypsum formation could be occurring.

2.6 Areas, Volumes and Residence Times in OWP, OEP and Polishing Ponds

- In Table 8, the areas, water volumes and flows are used to estimate residence time of water in these water bodies.

- The theoretical residence of OWP is 77 days. However, Drainage Tunnel water (8.3 L/s) joins the top 1 m of surface water of OWP, and likely exits OWP without mixing with the entire water volume. The 1.7 L/s groundwater flow also enters the top 1 m of surface water. Therefore, the residence time of the top 1 m of water may only be 5.4 days.

- The theoretical residence of OEP is 126 days. However, as in OWP, water enters OEP from OWP (10 L/s) joining OEP surface water, and does not likely mix with the entire OEP volume before exiting OEP via the weir. Meanwhile, another 9.2 L/s of groundwater joins the top 1 m of OEP surface water, and the flow through this layer totals 19.2 L/s. Therefore, the residence time of the top 1 m of OEP surface water may be only 11.8 days.

- The Polishing Ponds are relatively shallow, averaging only 0.46 m deep. The theoretical residence times of the PP10-PP13 and PP14-PP17 series of ponds are 9 and 6 days, respectively. However, a large fraction of these ponds' areas are virtually stagnant or above water, and actual residence times in these ponds are likely much shorter.

2.7 Sedimentation Rates in OWP, OEP and the Polishing Ponds

2.7.1 Sedimentation Data

- Measurements of sedimentation rates in OEP and OWP have been measured since 1990 and 1994, respectively. These data, in $g{\cdot}m^{-2}{\cdot}d^{-1}$, are presented in Table 9.

- Generally, the rates are consistent from year to year, with two exceptions where very high rates were determined: OEP 20 m and OWP 7 m, but in place between October 12, 1995 to July 10, 1996. These two data were not used in calculations, as they may have been due to improper placement of the traps or erosion of iron hydroxide into the traps from the pit walls into the traps.

- The sedimentation rate data were used to estimate the total weight of sediment settling to the bottom of OWP and OEP each year (Table 10). Since many sedimentation trap incubation periods span two chronological years (e.g., October 18, 1991 to September 29, 1992), a proportional fraction of the measured sedimentation spanning two different years was allocated to the each of the two years (e.g. 21 % of the measured amount of sediment for October 18 to

December 31, 1991 and 79 % for January 1 to September 29, 1992).

- Using OEP sedimentation rates, the estimated sedimentation in OEP ranges from 41 t per year (1995) to 113 t per year (1992). The 1996 weight (27 t) is that amount up to September 26, and does not represent a full year.

- Sedimentation in OWP ranges from 4 t to 9 t per year. Sedimentation traps were not installed in OWP until 1993, following joining of the two pits when it was observed that iron hydroxide was forming due to changes in OWP's limnology.

2.7.2 Comparison of Sedimentation Rate Data With Iron Load Estimates

2.7.2.1 Oriental West Pit

- In Table 11, estimated loads of iron to OWP is presented for the ice-free season (May 1 to November 1), based on iron mass balance presented in Table 6. The estimated Fe load for the 183 day ice-free period is 1,700 kg.

- The elemental composition of particulates captured by the sedimentation traps in the OEP and OWP sedimentation traps are presented in Table 13.

- Estimates of total kg of iron sedimenting in OWP over the ice-free season, based on sedimentation rates and sediment iron assay data for 1994, 1995 and 1996 are 1,163 kg, 817 kg and 439 kg, respectively. In 1995 and 1996, iron settling rates, based on sedimentation trap data, are lower than estimates of the iron load to OWP during the ice-free season. It is possible that the actual mass of iron entering the OWP is diminishing with time. Another possibility is that smaller particles are being formed in more recent years, and settling rates have diminished.

2.7.2.2 Oriental East Pit

- Estimated loads of iron to OEP are presented in Table 12 for the ice-free season, for comparison to measured sedimentation of iron in particles according to sedimentation trap data.

- The estimated iron load to OEP between May 1 and October 31 is 4,759 kg for the 183 day period. In 1995 and 1996, the sedimentation traps collected a similar amount of iron (7,758 and 8,038 kg) in this period.

- Using sedimentation trap data and sediment sample analytical data, between 7 and 8 t of iron settle in OEP during the ice-free season. The iron load estimates are about half the mass of iron collected by the sedimentation traps for the same period. Re-suspension of settled iron may account for higher Fe load captured by the sedimentation traps than indicated by the iron mass balance.

2.7.3 Iron Loads to Polishing Ponds

- An estimate of the accumulation of iron by new algal biomass grown over the 183 day ice-free season is given in Table 14. Data on pond areas, alder substrate surface areas, algal growth rates and iron content of algal biomass are available in the 1995 Report (Tables 1b, 2b and 5b).

- It is estimated that new algal biomass grown over 183 days captures 772 kg of iron. This suggests that the algal biomass may capture iron settled from previous periods which has been resuspended from the pond sediments. In other words, iron is being recycled in the ponds.

- There is direct visual evidence of this process in the ponds. Slabs of algal biomass covering the sediment and substrates periodically buoy to the surface due to an accumulation of air bubbles in the biomass. These floating slabs of algae are broken up by wave agitation or upon being carried over the weirs where they are smashed into smaller particles. Resuspended iron particles are likely recaptured by sieving by algal biomass.

- The iron load to OEP was estimated in the Fe mass balance. A mass of 4,733 kg of Fe enters the OEP in the 182 day ice-covered season. High iron concentrations in PP17 discharge water in winter suggest that little iron is removed from the Polishing Pond system, and that a large fraction of the discharge iron remains in the ferrous form.

- The ice covers over the pits and polishing ponds serve to prevent ferrous iron oxidation and ferric hydroxide precipitation.

Table 3: Chloride Mass Balance for OWP, OEP System.

CHLORIDE	Flow L/s	[Cl] mg/L	Cl Load mg/s		Removal %
Drainage Tunnel	8.3	12.7	105		
OWP Contaminated Groundwater	1.7	144	249		
OWP Surface Outflow	10	35.3	354		
OEP Surface Inflow	~~9.2~~ 6	35.3	206		
OEP Contaminated Groundwater	5.84	149	870		
OEP Clean Groundwater	3.36	2	6.7		
OEP Outflow	19.2	64.1	1231	877	

Table 4: Sodium Mass Balance for OWP, OEP System Based on Flows Derived from Chloride Mass Balance

SODIUM	Flow L/s	[Na] mg/L	Na Load mg/s		Removal %
Drainage Tunnel	8.3	10.2	85		
OWP Contaminated Groundwater	1.7	114	197		
OWP Surface Outflow	10	22	221	281	22%
OEP Surface Inflow	10	22	221		
OEP Contaminated Groundwater	5.8	120	701		
OEP Clean Groundwater	3.4	8	26.9		
OEP Outflow	19.2	49	941	948	1%

Table 5: Zinc Mass Balance for OWP, OEP System Based on Flows Derived from Chloride Mass Balance

ZINC	Flow L/s	[Zn] mg/L	Zn Load mg/s		Removal %
Drainage Tunnel	8.3	16.3	135		
OWP Contaminated Groundwater	1.7	15.5	27		
OWP Surface Outflow	10	16.6	166	162	-3%
OEP Surface Inflow	10	16.6	166		
OEP Contaminated Groundwater	5.8	15.2	89		
OEP Clean Groundwater	3.4	0.01	0.03		
OEP Outflow	19.2	11.9	228	255	10%

Table 6: Iron Mass Balance for OWP, OEP System Based on Flows Derived from Chloride Mass Balance

IRON	Flow L/s	[Fe] mg/L	Fe Load mg/s		Removal %
Drainage Tunnel	8.3	0.131	1.1		
OWP Contaminated Groundwater	1.7	63.2	109		
OWP Surface Outflow	10	0.1065	1.1	110 (3,469 kg)	99%
OEP Surface Inflow	10	0.1065	1.1		
OEP Contaminated Groundwater	5.8	51.27	300		
OEP Clean Groundwater	3.4	0.01	0.03		
OEP Outflow	19.2	1.46	28	301	91%

Table 7: Sulphate Mass Balance for OWP, OEP System Based on Flows Derived from Chloride Mass Balance

SULPHATE	Flow L/s	$[SO_4]$ mg/L	SO_4 Load mg/s		Removal %
Drainage Tunnel	8.3	120	998		
OWP Contaminated Groundwater	1.7	1080	1863		
OWP Surface Outflow	10	255	2552	2861	11%
OEP Surface Inflow	10	255	2552		
OEP Contaminated Groundwater	5.8	1166	6812		
OEP Clean Groundwater	3.4	10	34		
OEP Outflow	19.2	479	9197	9397	2%

Table 8: Areas, Volumes and Residence Times of Water in OWP, OEP and Polishing Ponds

	Area m^2	Whole Volume m^3	Top 1 m Volume m^3	Flow L/s	Theoretical Residence Time days	Top 1 m Residence Time days
Drainage Tunnel				8.3		
OWP	4,645	66,245	4,645	10.0	77	5.4
OEP	19,510	208,197	19,510	19.2	126	11.8
PP10-13 (40% of OEP flow)	13016	5951		7.7	9.0	
PP14-17 (60 % of OEP flow)	13142	6009		11.5	6.0	

Table 9: Summary of Sedimentation Trap Data for OEP and OWP.

				Sedimentation Rate, $g.m^{-2}.d^{-1}$						
			Summer	OEP Outflow		4 m	11 m	20 m		OWP 7 m
From	To	Days	Period?	A	B			A	B	
20-Sep-90	22-Oct-90	32	Yes	0.62				2.1		
20-Sep-90	28-May-91	250			2.1				5.4	
22-Oct-90	28-May-91	218		4.57				4.6		
28-May-91	18-Oct-91	143	Yes	1.87				5.3		
18-Oct-91	29-Sep-92	347		3.84				19		
14-Jun-93	30-Aug-93	77	Yes			5.9	9.9			
30-Aug-93	11-Jul-94	315				5.1	4.5			
11-Jul-94	07-Sep-94	58	Yes							6.22
07-Sep-94	07-Jul-95	303				3.9	3.2	12		4.89
07-Jul-95	12-Oct-95	97	Yes			5.3	4.9	6		6.16
12-Oct-95	10-Jul-96	272				4.5	4.5	60		42.7
10-Jul-96	29-Sep-96	81	Yes			4.8	5.5	9.3		7

Table 10: Sedimentation Rate Data and Calculations for OEP and OWP, 1990 to 1996.

Sedimentation Traps		No. of Days in	Oriental East Pit (OEP)											Oriental West Pit (OWP)				
			Sed. rate, $kg.d^{-1}.pit^{-1}$			Average Sedimentation		Sediment in period	Cumulative to date	Proportions for years *** (current, prev/next)			Estimate for year (to date)	10 m S.T.		Sediment in period	Cumulative to date	Estimated for year
Placed	Retrieved	Period	20 m	4 m	11 m	$kg.d^{-1}.pit^{-1}$	$kg.m^{-2}.d^{-1}$	kg in period	kg			Year	$kg.y^{-1}$	$kg.d^{-1}.pit^{-1}$	$kg.m^{-2}.d^{-1}$	kg	kg	$kg.y^{-1}$
20-Sep-90	22-Oct-90	32	40			40.1	2.06	1,283	1,283	1.00								
22-Oct-90	28-May-91	218	89			89.2	4.57	19,446	20,729	0.32	0.68	1991	54,775					
28-May-91	18-Oct-91	143	104			103.5	5.30	14,801	35,529	1.00								
18-Oct-91	29-Sep-92	347	362			361.8	18.54	125,545	161,074	0.21	0.79	1992	113,144					
29-Sep-92	14-Jun-93	258				154.5 **		39,873	200,947	0.36	0.64	1993	48,816					
14-Jun-93	30-Aug-93	77	6,904 *	115	193	153.8	7.88	11,839	212,786	1.00								
30-Aug-93	11-Jul-94	315	2,006 *	99	88	93.3	4.78	29,393	242,179	0.39	0.61	1994	56,229					4,287
11-Jul-94	07-Sep-94	58	415			414.6	21.25	24,047	266,226	1.00				28.9	6.22	1,676	1,676	
07-Sep-94	07-Jul-95	303	233	77	62	124.1	6.36	37,589	303,815	0.38	0.62	1995	40,513	22.7	4.89	6,878	8,554	9,298
07-Jul-95	12-Oct-95	97	116	103	95	104.6	5.36	10,143	313,958	1.00				28.6	6.16	2,774	11,329	
12-Oct-95	10-Jul-96	272	1,162 *	88	88	88.1	4.52	23,963	337,921	0.29	0.71	1996	27,205	198.3 *	6.07 @	7,670	65,266	8,055
10-Jul-96	29-Sep-96	81	181	93	107	127.0	6.51	10,290	348,211	1.00				32.6	7.00	2,641	67,907	
	equiv. to	6.0	years		Avg =	154.5	(avg used for ** above)							28.2	(avg used in @ above)			

* High values likely due to sediment subsidence; Values not used in calculations

*** proportion of total kg of sediment collected in sed trap for a period which spanned more than one year

Table 11: Ice-free season (May 1 - Oct 31) Iron Load to OWP versus Measured Ice-free Season Sedimentation Rate.

OWP IRON	1994 kg in 183 days	1995 kg in 183 days	1996 kg in 183 days
OWP Fe Load in 183 days, based on Fe Mass Balance (Table 6)	1,739	1,739	1,739
Sed Trap Captured Iron Mass, May 1-Nov 1, kg Using summer sedimentation rates; Fe content of sediment	1,163	817	439

Table 12: Ice-free season (May 1 - Oct 31) Iron Load to OEP versus Measured Ice-free Season Sedimentation Rate.

OEP IRON	1994 kg in 183 days	1995 kg in 183 days	1996 kg in 183 days
OEP Fe Load in 183 days, based on Fe Mass Balance (Table 6)	4,759	4,759	4,759
Sed Trap Captured Iron Mass, May 1-Nov 1, kg Using summer sedimentation rates; Fe content of sediment		7,758	8,038

Table 13: Elemental Composition of Periphyton Grown on Alder Branches or Nylon Netting and Sedimentation Traps in OWP and OEP, 1994, 1995 and 1996.

		OWP, % of dry weight			OEP, % of dry weight		
		Branches	Netting	Sed Trap	Branches	Netting	Sed Trap
	Assay No.	5735	5736	5733	5729	5730	5725
1994	ug/g, Al	0.72	0.61	0.97	0.24	0.34	0.45
	Ba	0.15	0.13	0.12	0.05	0.04	0.065
	Cd	0.003	0.005	0.003	0.005	0.005	0.003
	Cu	0.08	0.11	0.18	0.03	0.04	0.026
	Fe	8.5	15	22	29	29	17
	Mn	0.04	0.06	0.06	0.09	0.09	0.056
	Pb	0.19	0.19	0.36	0.04	0.04	0.19
	Zn	0.93	1.9	1.2	4.3	4.4	1.1
	Assay No.	5737	5738	5734	5731	5732	5726
1995	ug/g, Al	0.54	0.48	0.38	0.17	0.16	0.10
	Ba	0.073	0.064	0.077	0.021	0.062	0.021
	Cd	0.010	0.012	0.003	0.012	0.013	0.003
	Cu	0.26	0.31	0.11	0.05	0.06	0.03
	Fe	24	28	16	38	38	41
	Mn	0.08	0.03	0.02	0.14	0.09	0.11
	Pb	0.16	0.17	0.17	0.02	0.03	0.02
	Zn	1.6	2.5	0.6	5.1	5.8	2.5
1996	Assay No.	Fil Algae Bulk 5993	Fil Algae 5989	5990			5988
	ug/g, Al	0.29	0.18	1.15			0.18
	Ba	0.013	0.007	0.068			0.016
	Cd	0.006	0.003	0.001			0.003
	Cu	0.16	0.11	0.04			0.03
	Fe	7.4	4	7			47
	Mn	0.02	0.01	0.02			0.10
	Pb	0.07	0.04	0.16			0.03
	Zn	1.1	0.6	0.2			1.8
	N, total	3.1					
	P, total	0.16					
	Organic C	39					
	Inorganic C	0.020					

Table 14: Iron accumulation in polishing ponds algal biomass over 183 d ice-free season. May 1 - Oct 31

	Pond Area, m^2 (a)	Substrate Area, m^2 (b)	Alga Biomass In Period @ 1.8 $g.m^{-2}.d^{-}$ kg (c)	[Fe] in Biomass kg $Fe.kg^{-1}$ (d)	Fe Accum in Algae in 183 d, kg
PP10	595	1153	386	0.157	61
PP11	2490	4824	1615	0.040	64
PP12	4041	7828	2620	0.021	54
PP13	5890	11410	3819	0.050	190
					368

	Pond Area, m^2 (a)	Substrate Area, m^2 (b)	Alga Biomass In Period @ 1.8 $g.m^{-2}.d^{-}$ kg (c)	[Fe] in Biomass kg $Fe.kg^{-1}$ (d)	Fe Mass in Algae kg
PP14	1867	3617	1211	0.067	81
PP15	3465	6713	2247	0.04	90
PP16	4038	7823	2618	0.0423	111
PP17	3772.0	7307	2446	0.050	122
					403

	772	kg Fe accumulated by new algae over 193 ice-free season.
Fe Load from OEP in ice-free season (183 d)	443	kg Fe (Fe Mass Balance, Fe Load at OEP Weir).
Fe Load from OEP in winter (1982 d)	4733	kg Fe (Fe Mass Balance, Input to OEP from D.T. and GW)

(a) Pond areas from Table 1b, 1995 Report.

(b) Alder substrate surface area of 50,430 m2 (Table 2b, 1995 Report) split among ponds proportional to pond areas.

(c) Growth rate of 1.829 g.m-2.d-1 for fertilized ponds from Table 2b of 1995 Report.

(d) Iron content (ICAP) of branch and netting algae collected in 1994 and 1995 used, from Table 5b of 1995 report.

Fig. 12: Oriental West Pit
Zinc Concentration, 1995-1996

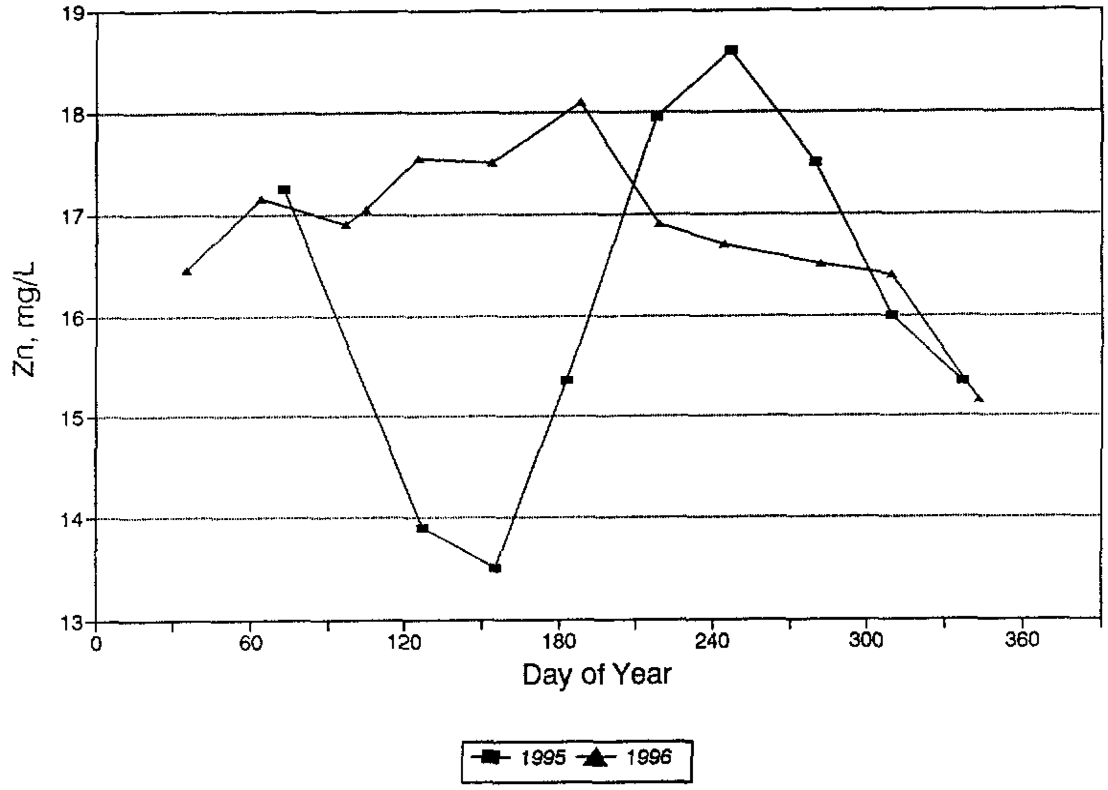


Fig. 13: Oriental West Pit Centre
Limnology, 1992-1996

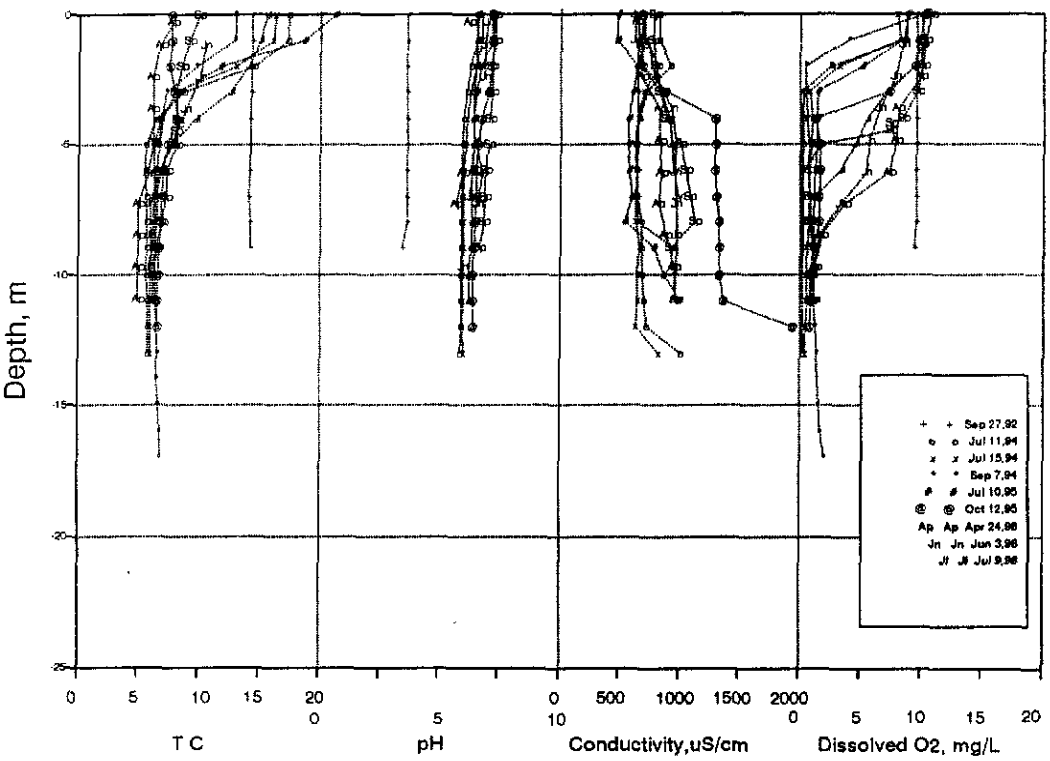
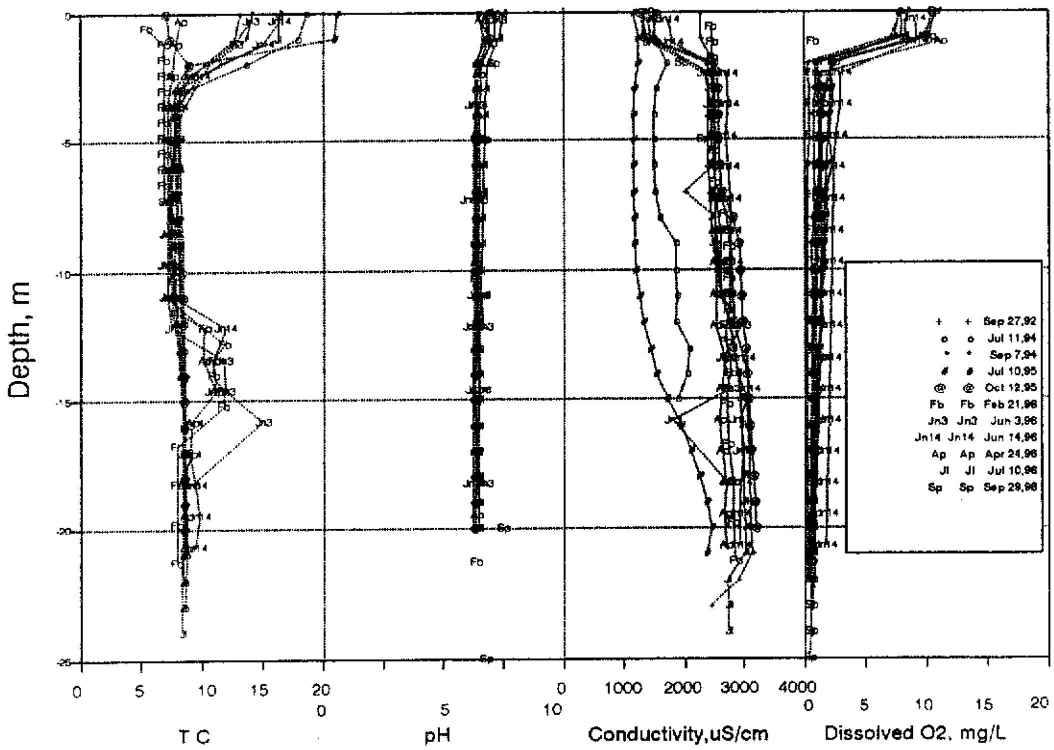


Fig. 14: Oriental East Pit Centre
Limnology, 1992-1996



3.0 IRON AND ZINC REMOVAL MECHANISMS

3.1 Review of Zinc Removal Processes

In the evaluation presented in the 1995 report, it is suggested that virtually no zinc is removed from the system during winter months. Adsorption of zinc on the iron oxides and hydroxides formed during the ice-free season was previously proposed as the removal mechanism. This mechanism is well known from the literature (M.Langen; Hobert and B.Hamacher; B.Muller and L.Sigg, 1990). It was therefore a natural choice for explaining the process of zinc removal in the OEP.

This adsorption mechanism would include a significant role for oxygen in the process of zinc adsorption to the iron oxides and hydroxides. Therefore, a significant quantity of oxygen is required in the pit to oxidise ferrous iron dissolved in solution, which is followed by precipitation as ferric iron hydroxide/oxide.

The process of iron oxidation is slow. The kinetics of oxidation were described by J.L.Liu and M.Kalin (1990) as an exponential curve with the varying coefficients, depending on the conditions of the AMD in which the oxidation takes place. The limitation of oxygen when the pits and ponds are covered by ice was used to explain the increase of the concentration of zinc in the outflow; there was not enough oxygen in the water to oxidize iron, preventing iron hydroxide formation and zinc adsorption. This was also a plausible explanation for observed zinc removal patterns.

However, other experimental facts were collected and have to be examined. The scanning electron microscopy and X-ray microanalyses of sedimentation trap samples have shown that the samples from the OEP itself consist largely of Fe-rich grains with high oxygen signal. This means that there was enough oxygen to form iron oxides/hydroxides and, if the proposed zinc adsorption mechanism was adequate, zinc should have been detected in the samples. The SEM-EDX work showed that zinc could only be detected at 20,000 x magnification. This suggested that the zinc removal mechanism may not be based on adsorption to iron precipitates.

The SEM-EDX analyses detected microzones within polishing pond solid samples with very high concentrations of zinc, but comparatively little iron. This must be considered in light of 1991 observations; a lot of zinc was present in the upper part of the "meadows" close to the outflow of OEP. In this area, large amounts of ferrous iron were detected, while ferric iron was present in large quantities only in the lower part of the "meadows". The fact that zinc was concentrated in areas with little ferric iron, while lower concentrations were present in areas with higher concentrations of ferric iron, contradicts the expected distribution of iron and zinc if zinc adsorption was the primary removal mechanism. However, the pattern of zinc removal can be explained in terms of zinc carbonate precipitation, suggested from the oxidation experiments discussed in Section 3.2 below.

The ferrous iron oxidation-ferric hydroxide precipitation process and the zinc removal process do not appear to be directly related. The process of iron oxidation is not important for the removal of zinc, since this element was not adsorbed in large quantities when iron oxide/hydroxide particles are abundant, such as in OEP. The zinc removal process and iron oxidation/precipitation process take place simultaneously, but are likely independent.

Another observation was presented in the 1995 Final Report (page 13); the zinc concentration dropped rapidly in April (ice melting) but increased again starting in August, when water temperatures began to decrease. The solubility of oxygen in water was therefore increasing as the water temperature decreased. Contrary to the observed zinc concentration increase, higher dissolved oxygen concentrations should have enhanced ferric iron oxidation, and zinc adsorption, if this were the major zinc removal mechanism.

This analysis of old data leads to the conclusion that it is necessary to examine whether the proposed mechanism of zinc adsorption on iron oxides, suggested in the literature, is a significant process removing this metal from OEP water. In the 1991 report, it was determined that both zinc and iron enter the pit through the bottom primarily in the forms of soluble $Zn(HCO_3)_2$ (zinc bicarbonate) and $Fe(HCO_3)_2$ (ferrous bicarbonate). Ferrous bicarbonate hydrolyse to produce ferrous hydroxide and release carbon dioxide.

$$Fe(HCO_3)_2 + 2H_2O = Fe(OH)_2 + 2H_2O + 2CO_2$$

Taking this equation, it is possible than iron precipitates can form in the absence of oxygen, if carbon dioxide is removed from water (e.g. degassing). With zinc, the situation seems more difficult. There is the possibility that zinc bicarbonate decomposes to zinc carbonate, which in turn precipitates. This reaction is favoured if carbon dioxide were removed from solution by, for instance degassing as ground water rises to the pit surface.

$$Zn(HCO_3)_2 = ZnCO_3 + H_2O + CO_2$$

However, zinc carbonate settling through the water column and entering pit bottom water, supersaturated with carbon dioxide and bicarbonate (with respect to surface water), may redissolved into solution as zinc bicarbonate.

$$ZnCO_3 + H_2O + CO_2 = Zn(HCO_3)_2$$

The production of carbon dioxide by the formation of ferrous hydroxide may maintain high carbon dioxide concentrations in water, and suppress the formation of zinc carbonates. This may explain why relatively little zinc removal takes place in the pit. Zinc carbonate formation and precipitation may take place only after the removal of significant amounts of iron and loss of carbon dioxide from the system. This analysis suggests that the presence of oxygen may not be necessary for the removal of zinc.

However another factor(s), as yet not described, may also be very important, which is a reaction which is producing precipitating forms of zinc, a process which takes place only in the upper part of the pit (< 2 m) but not at depth. Some zinc removal occurs in the top layer of the OEP during the summer when surface water temperatures are high and exposed to sunlight. Sunlight could assist in iron oxidation and may also assist zinc removal. An experiment examining the effects of aeration and temperature upon zinc removal from OEP and OWP surface and bottom water samples is described in Section 3.2.

3.2 The Precipitation of Iron and Zinc: The OWP, OEP Oxidation Experiments

- An experiment was conducted examining changes in dissolved zinc and iron concentrations in samples collected from OWP and OEP surface and at depth according to time following collection and storage conditions (open bottles versus closed; 5° C, 15° C or 20° C storage temperatures).

- All zinc and iron analyses presented were performed on whole samples using the Buchans Asarco AAS equipment. The results of these two experiment are presented in Figure 15 a-f (OEP Surface), 16 a-f (OEP Bottom), 17 a-f (OWP Surface) and 18 a-f (OWP Bottom).

3.2.1 OEP Surface Water Samples

- OEP surface samples were collected and analyzed for iron and zinc within 24 hours of collection. Three identical pairs of samples (open, closed bottle) were stored at room temperature (20° C), in the Asarco vault (~ 12° C) and in a fridge (5° C). These samples' zinc and iron concentrations were determined 4 and 14 days after collection (Figure 15 a - f).

- The dissolved iron concentration in these samples was less than 0.1 mg/L at the time of collection, and remained so over the 14 day experiment. The zinc concentration was 14.1 mg/L.

- After 4 days of storage, zinc concentrations remained virtually the same in all treatments. A slight decrease in the zinc concentration in the 20° C bottle stored open was observed.

- After 14 days, zinc concentrations decreased in the open bottle treatment stored at 20° C, but remained near original zinc concentrations in the remaining five treatments.

- In summary, zinc was removed from OEP surface water if the sample was stored at 20° C and open to aeration. Dissolved or suspended iron was not required for this process.

3.2.2 OEP Bottom Water Samples

- Six OEP bottom water samples were collected, stored and analyzed for zinc and iron in an identical manner as the OEP surface water samples (Figure 16 a - f).

- The iron concentration in the OEP bottom water was 64 mg/L. The initial zinc concentration was 16.9 mg/L.

- After 4 days, the zinc concentration diminished in the sample stored at 20° C open to aeration. By 14 days, most of the zinc was removed from the solution. Zinc removal was not observed in the remaining five treatments by day 14.

- Upon storage for 4 days, iron concentrations decreased in samples stored at

20° and 12° C. Larger decreases in iron concentrations occurred at 20° C temperature, compared to 12° C.

- By day 14, iron concentrations had dropped to undetectable concentrations at 12° and 20° C in both open and closed bottles. Iron concentrations had also decreased in samples stored at 5° C, but to a lesser degree than at higher temperatures.

- In summary, zinc was removed from OEP bottom water if the sample was stored at 20° C and open to aeration, as observed for the OEP surface water sample treatment stored open at 20° C. Iron oxidation, precipitation and settling did not enhance zinc removal in the remaining five treatments. Based on the observations of iron and zinc removal in OEP surface and bottom water in this experiment, zinc removal appears to be independent of iron removal.

3.2.3 OWP Surface Water Samples

- Six OWP surface water samples were collected, stored and analyzed for zinc and iron in an identical manner as the OEP surface and bottom water samples (Figure 17 a - f).

- The iron concentration in these samples was less than detection limit. The zinc concentration at collection 16.9 mg/L.

- As observed for OEP samples, the zinc concentration in OWP surface water declined in the open sample stored at 20° C, but not in the remainder of treatments. Over 14 days, the zinc concentration diminished from 16.9 mg/L to 12.4 mg/L, a smaller decline than observed for OEP surface and bottom water samples.

3.2.4 OWP Bottom Water Samples

- Six OWP bottom water samples were collected, stored and analyzed for zinc and iron in an identical manner as the other three sets of samples (Figure 18a-f).

- The iron concentration in these samples was less than detection limit. The zinc concentration at collection 18 mg/L.

- The zinc concentration declined from 18 mg/L to 7 mg/L in the OWP bottom water sample open to aeration and stored at 20° C. This decline was much greater than observed in the same treatment of OWP surface water.

In summary, zinc removal was observed in OEP and OWP surface and bottom water samples only if the samples were stored at 20° C and were left open to the atmosphere. Zinc removal appears to be unrelated to iron removal. Instead, zinc may be present in OEP and OWP bottom water a soluble zinc bicarbonate, coexisting with high bicarbonate and dissolved carbon dioxide. When these waters flow to the surface, the water warm in the epilimnion, and carbon dioxide solubility decreases. As CO_2 is degassed from solution, soluble zinc bicarbonate decomposes to zinc carbonate, CO_2 and water.
In the equation below, CO_2 degassing from the right side of the equation favours the reaction from left to right.

$$\underset{\text{(dissolved)}}{Zn(HCO_3)_2} \rightarrow \underset{\text{(precipitate)}}{ZnCO_3} + H_2O + CO_2 \nearrow$$

- In the experiment, high temperatures reduced the solubility of CO_2. The open bottles favoured degassing, while the closed bottles prevented degassing. In the 12° C and 5° C treatments, enough dissolved CO_2 remained in solution, and zinc bicarbonate was not decomposed. This process was originally described in the December 1991 Final Boojum Report to Asarco (Section 3, pgs 3-3 to 3-10).

3.3 Zinc Precipitation With Phosphate

- Permanent removal of zinc, presently in the form of bicarbonates and carbonates, from OEP water could be achieved by adding phosphate to form zinc phosphates.

- A precipitation experiment consisting of the addition of 10-52-10 fertilizer to four samples, 4 L in volume, of OEP water collected from a depth of 0.6 m below the ice cover. The experiment was set up on January 7, 1997 and run until January 20, 1997.

- Fertilizer was added to three samples, and the fourth was left as a control. To Treatment 1, 45 g were added, while to Treatment 2, 6.3 g, and to Treatment 3, 0.87 g were added. Treatment 4 was the control. The samples were stored in the laboratory at 20 °C. The amounts of fertilizer added were based on the molar phosphate equivalent of zinc, magnesium and calcium concentrations present in OEP bottom water. For instance, 45 g of 10-52-10 fertilizer added to 4 US gallons of OEP water contains the equivalent number of moles of phosphate as the sum of the moles of calcium, magnesium and zinc present in 4 US gallons of OEP bottom water (Tables 15 - 17).

- Zinc concentrations were monitored regularly over the first 50 hours, then again after 190 and 320 hours (Figure 19 a - d).

- The zinc concentration in Treatment 1, the control, remained relatively constant over the first 50 hours of the experiment. Zinc concentrations declined over the first 50 hours in Treatments 1 through 3 where fertilizer was added.

- The greatest zinc removal was measured in Treatment 2, where 6.3 g of 10-52-10 fertilizer was added. After 13 days, the zinc concentration had declined by 87 %, compared to the concentration 1 hour after set-up (Table 18). The high fertilizer addition, Treatment 1 (45 g/4 USG), removed less zinc (57 %), comparable to Treatment 3 (73 %: 0.87 g/4 USG) after 13 days.

- Unlike the earlier oxidation experiment, appreciable zinc removal in the control, Treatment 4, was not observed after 8 days, despite the fact this sample was stored open to aeration at room temperature. After 13 days, the control samples's zinc concentration had begun to decrease. At this time, the zinc concentration was 10.6 mg/L, equivalent to a 43 % decrease, compared to the concentration 1 hour after set-up of the experiment.

- The delay in zinc removal in the control sample stored open at 20° C, compared to the previous experiment's 20° C, open treatments, may have been due to the larger sample size in this experiment (4 USG) compared to the previous experiment (0.25 L). Also, for this experiment, water samples were collected from OEP from beneath the ice in January, when any very fine zinc precipitates formed in the ice-free season would have been flushed out of the pit. These fine particles may serve as flocculation nuclei, accelerating the process of zinc removal through promoting larger particle formation and settling.

Table 15: Experimental Design of January 7-15, 1997 Fertilizer Experiment.

	M.W. g	OEP [ ] used mg/L	mM/L	Equiv. PO_4 mg/L	Equiv. mg of 10-52-10 Fert per L	Equiv. g of 10-52-10 Fert per 4 USG	
Ca	40.1	502	12.5	1190	2527	38	
Mg	24.3	44.5	1.8	174	369	5.6	
Zn	65.4	16.2	0.2	24	51	0.76	(0.87 g added to #3)
NO_3	62						
NH_4	18						

Table 16: Composition of Treatments Immediately Following Fertilizer Addition.

	ADDITION g of 10-52-10 Fert per 4 USG	Equiv. mM of PO_4 in 4 USG	Equiv. mM of Ca in 4 USG	Equiv. mM of Mg in 4 USG	Equiv. mM of Zn in 4 USG	Equiv. mM of NO_3 in 4 USG
Treatment 1 for Ca, Mg and Zinc	45	221	190	28	3.8	26
Treatment 2 for Mg and Zinc	6.3	31	190	28	3.8	3.7
Treatment 3 for Zinc only	0.87	4.3	190	28	3.8	0.51
Treatment 4: Control	0	0	190	28	3.8	0

Table 17: Mass Calculations for Elements Present in OEP and K_3PO_4 equivalents.

	M.W. g	OEP Volume L	[ ] mg/L	Mass kg	Mass Moles	Equiv. PO_4 Mass, kg	Equiv. K_3PO_4 Mass, kg
OEP		208,197,000					
Zn	65		14.6	3,047	46,606	4,428	8,636
Fe	56		47.0	9,785	175,212	16,645	32,468
Ca	40		390	81,197	2,025,869	192,458	375,406
Mg	24		34.7	7,217	296,870	28,203	55,012
Mn	55		9.9	2,062	37,530	3,565	6,955
PO_4	95						
K_3PO_4	185						

	For Entire Pit	
Treatment 4: Control		
Treatment 3: Add K_3PO_4 equiv. to Zn Mass in Pit	8,636	kg K_3PO_4
Treatment 2: Add K_3PO_4 equiv. to Zn and Mg Mass in Pit	63,648	kg K_3PO_4
Treatment 1: Add K_3PO_4 equiv. to Zn, Mg and Ca Mass in Pit	439,054	kg K_3PO_4

Table 18: Zinc Concentrations in 4 USG OEP (5') Samples Treated with 10-52-10 Fertilizer.

Treatment	7-Jan-97 [Zn],mg/L 1 hour	7-Jan-97 [Zn],mg/L 314 hours		% Removal
	Whole	Whole	Filtered	
#1: 45 g per 4 USG	17.4	7.4	7.4	57
#2: 6.3 g per 4 USG	17.6	2.8	2.4	87
#3: 0.87 g per 4 USG	17.5	4.8	4.7	73
#4:Control	17.5	10.6	9.9	43

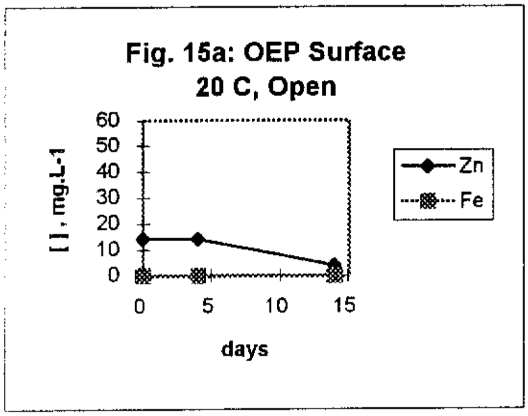


Fig. 15a: OEP Surface
20 C, Open
[ ] , mg.L-1
60
50
40
30
20
10
0
0
5
10
15
days
Zn
Fe

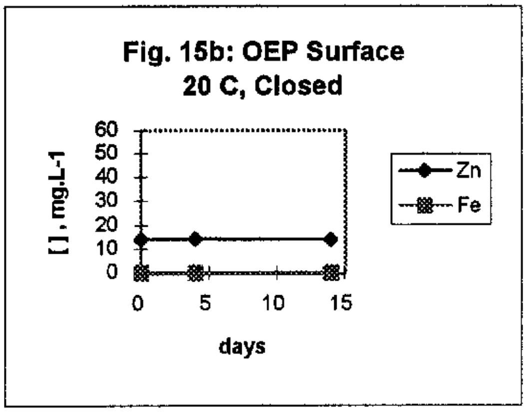


Fig. 15b: OEP Surface
20 C, Closed
[ ] , mg.L-1
60
50
40
30
20
10
0
0
5
10
15
days
Zn
Fe

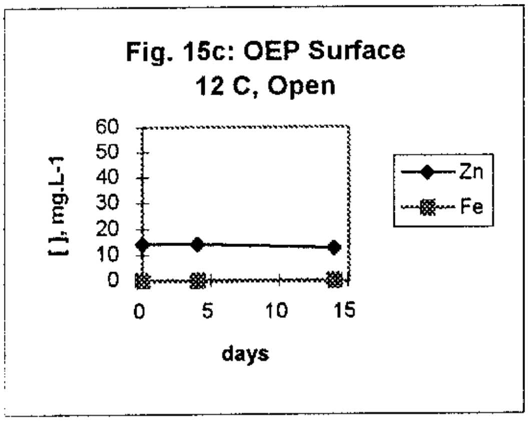


Fig. 15c: OEP Surface
12 C, Open
[ ], mg.L-1
60
50
40
30
20
10
0
0
5
10
15
days
Zn
Fe

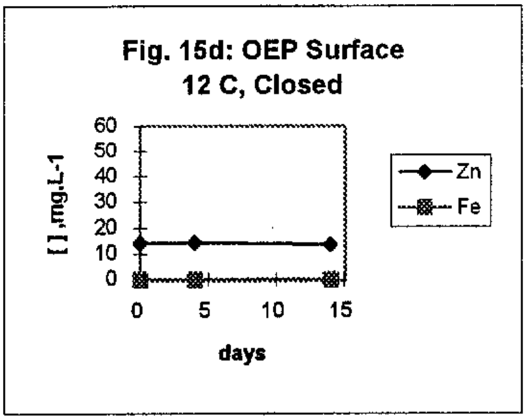


Fig. 15d: OEP Surface
12 C, Closed
[ ] ,mg.L-1
60
50
40
30
20
10
0
0
5
10
15
days
Zn
Fe

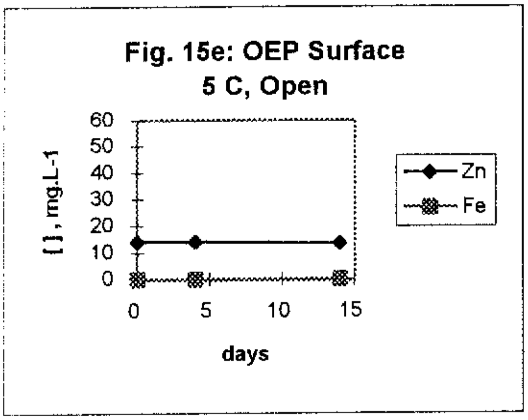


Fig. 15e: OEP Surface
5 C, Open
[ ] , mg.L-1
60
50
40
30
20
10
0
0
5
10
15
days
Zn
Fe

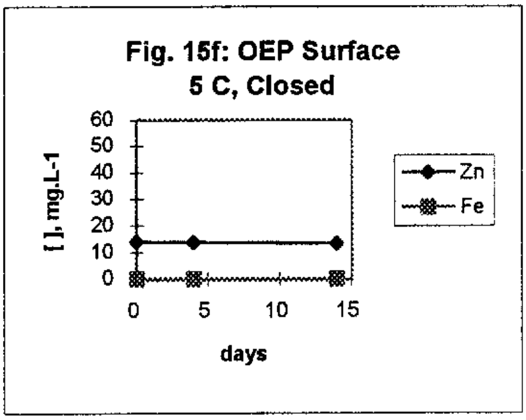


Fig. 15f: OEP Surface
5 C, Closed
[ ], mg.L-1
60
50
40
30
20
10
0
0
5
10
15
days
Zn
Fe

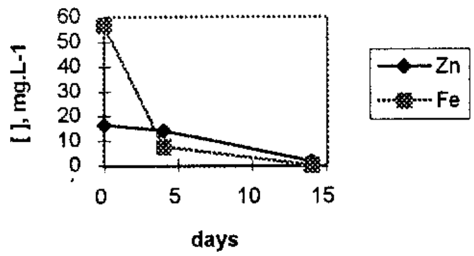


Fig. 16a: OEP Bottom
20 C, Open

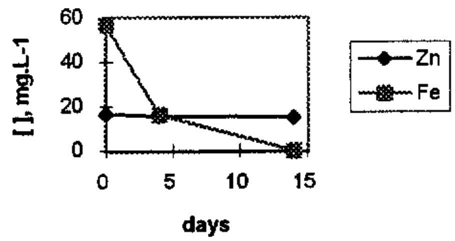


Fig. 16b: OEP Bottom
20 C, Closed

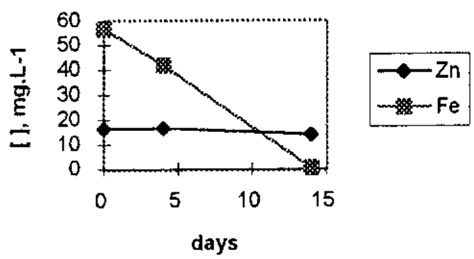


Fig. 16c: OEP Bottom
12 C, Open

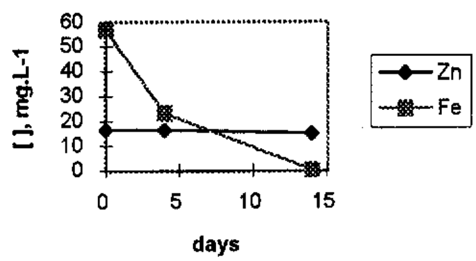


Fig. 16d: OEP Bottom
12 C, Closed

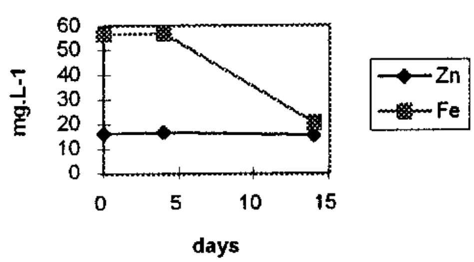


Fig. 16e: OEP Bottom
5 C, Open

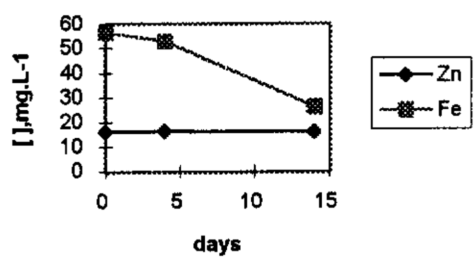


Fig. 16f: OEP Bottom
5 C, Closed

Fig. 17a: OWP Surface 20 C, Open

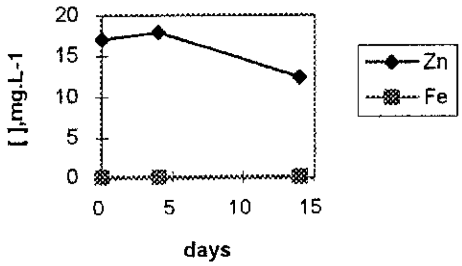


Fig. 17b: OWP Surface 20 C, Closed

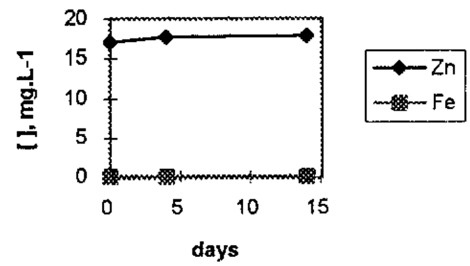


Fig. 17c: OWP Surface 12 C, Open

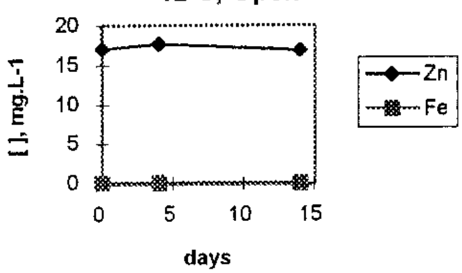


Fig. 17d: OWP Surface 12 C, Closed

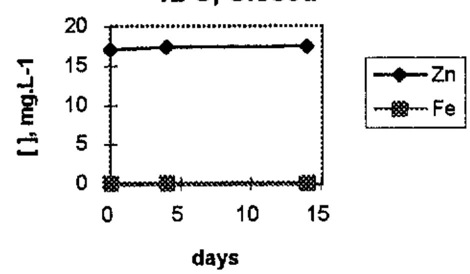


Fig. 17e: OWP Surface 5 C, Open

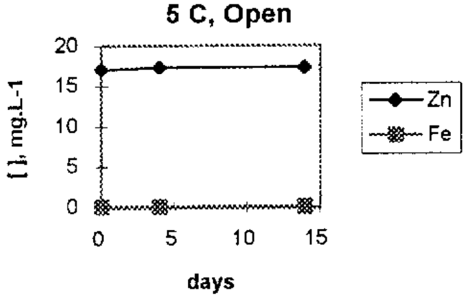


Fig. 17f: OWP Surface 5 C, Closed

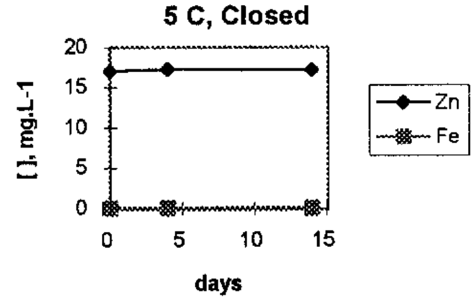


Fig. 18a: OWP Bottom
20 C, Open

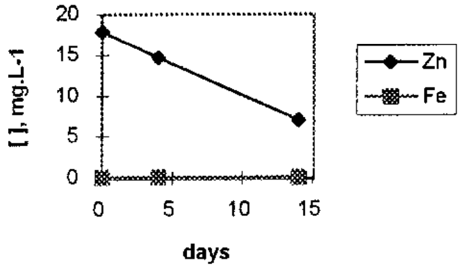


Fig. 18b: OWP Bottom
20 C, Closed

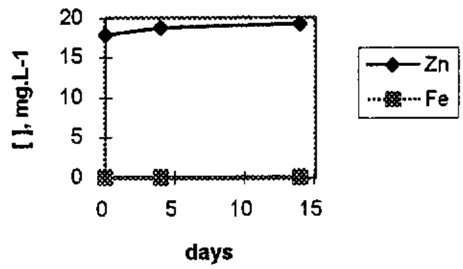


Fig. 18c: OWP Bottom
12 C, Open

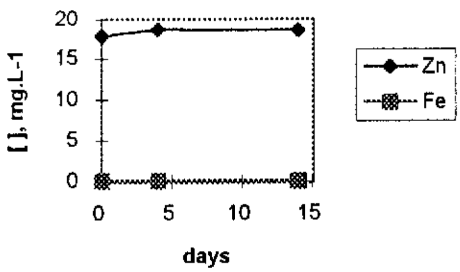


Fig. 18d: OWP Bottom
12 C, Closed

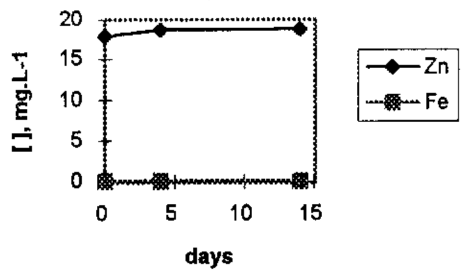


Fig. 18e: OWP Bottom
5 C, Open

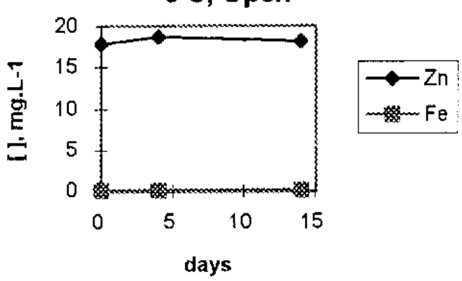


Fig. 18f: OWP Bottom
5 C, Closed

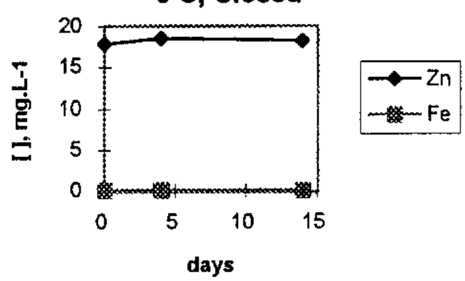


Fig. 19a: OEP Fertilizer Experiment: Control

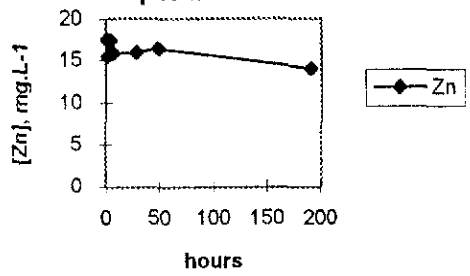


Fig. 19b: OEP Fertilizer Experiment: 0.87 g/4USG

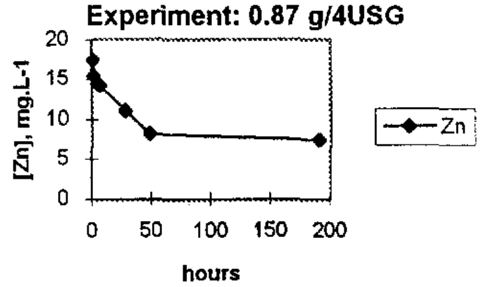


Fig. 19c: OEP Fertilizer Experiment: 6.3 g/4USG

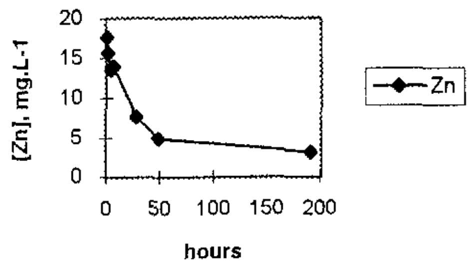
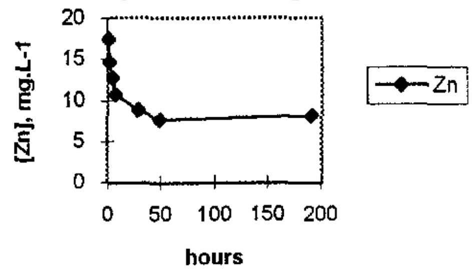


Fig. 19d: OEP Fertilizer Experiment: 45 g/4USG



4.0 SEM-EDX EXAMINATION OF PARTICLES

The purpose of this work is to identify the chemical and physical nature of zinc present on particles formed in the OWP-OEP Polishing Pond system. This was done through SEM-EDX investigations on particles and through sequential extractions using material collected in sedimentation traps (chemical particles).

Variation of concentration of zinc in OEP with depth in the summer shows that there is a zinc removal mechanism operating in the pit, and zinc-containing particles should collect in sedimentation traps. The EDX-SEM surface investigation of the particles in the sedimentation traps did not detect sufficient zinc on the surfaces of the particles to yield a zinc signal (0.1 %) from the surface when investigated at magnifications covering a range of 200 x to 2,000 x. The particle size in these magnifications was identified as submicron (< 1 μm) size.

The bulk samples, however, report, on average, about 1.1 to 2.5% Zn in sedimentation traps (Table 13, Section 2). These two findings suggest that the particles containing zinc which settle in the sedimentation traps are small, but they must be numerous, as the concentrations of zinc accumulated are relatively high. Samples collected in July, 1996 were examined at a magnification of 20,000 x (data presented at the end of this section under SEM-EDX, September 15, 1996 samples). Particles sizes ranged from 0.25 to 1.0 μm. The same samples were previously examined at 200 x to 2,000 x magnification to derive confirmation of the biological accumulation of zinc (data presented at the end of the section under EDX: Samples Collected July 10 & 12, 1995).

At the 20,000 x magnification, it could be confirmed that, indeed, these smaller particles are associated with zinc. It also was determined that there is a distinct layer of precipitate with a thickness of about 100 nm coating the larger particles. The coating was thinner on particles in samples from the bottom of the OEP (25 m deep).

The OWP had particles (at 20,000 x magnification) free of precipitate coatings, which was also the case for the particles in the Polishing Pond samples examined at this magnification.

The observations of the coatings on precipitate particles suggests that a chemical mechanism is involved in the removal of zinc which is associated with the formation of larger particles, governed by colloid formation processes. It is well known from the chemical kinetics that large particles or aggregates can only be formed when small particles are present.

The phytoplankton identified in the Buchans system cover a size range of 2 μm to 100 μm. No populations were detected in the OEP, but they were present in the OWP and the Polishing Ponds. This finding also adds to the conclusion that physical forces must be overwhelming to phytoplankton in the OEP since the nutrient status should support phytoplankton growth, demonstrated by the growth of periphyton (attached algae) and cattails in OEP. Since chemical and biological factors inhibiting phytoplankton growth can be ruled out, the only other factors not considered to date, but relevant to particle formation, are hydrodynamical forces.

The microscopic investigations counting phytoplankton (both in Germany and Canada) reported the presence of needle-like crystals in the single OEP sample collected close to the thermocline in September. Particles experience different hydrodynamical influences when the thermocline is deeper during the summer months. In the September samples, the needle-like form of particles suggests that particles of such shape can be formed only as a result of different hydrodynamic forces, compared to those which lead to round aggregates of colloidal particles. A needle-like crystal can be induced when the hydrodynamical forces are laminar and not turbulent, as would be the case when the thermocline deepens and dissipates towards the end of the ice-free season (Figure 14, Section 2). The gradual decrease in Polishing Pond performance may also be related to particle formation and settling, due to seasonal changes in both temperature and pH.

The observations to date can, in part, be explained in terms of those water flow patterns which influence those processes involved in the formation of zinc-bearing particles and the settling of these precipitates. After the formation of small particles of zinc carbonate, two simultaneous processes are taking place in the OEP to remove zinc via particle formation.

a) the further growth and/or aggregation of particles.

b) once the particle sizes is sufficiently large, then it is possible that they can settle.

Ferric iron oxidation and iron hydroxide formation may provide sufficiently large particles to assist in the aggregation of particles containing zinc.

Some zinc particle formation and settling occurs in OEP during the ice-free season, when ground water must enter and, prior to discharge from the pit, mix with the horizontally and vertically circulating epilimnion (1-2 m thick) covering the entire surface of the pit. Particulates borne in the circulating epilimnion are subjected to both zones of laminar (middle stratum of epilimnion) and turbulent (at epilimnion-thermocline interface) flow, and quiescent zones (pit perimeter). Particle aggregation and settling are possible in these months. However, in winter, gravity and hydrodynamics (dragging of particles with water) are, unfortunately, acting in opposite directions.

For example, while small particles may be forming in winter along the flow paths between ground water input and the OEP outflow, these flow paths may be both relatively laminar and high velocity, such that particles can neither aggregate by turbulent mixing, nor settle out of the rapid flow path. Particles may remain in the moving volume of water until discharged from the pit. The association of zinc with the small particles also explains in part why the polishing ponds, where no dissolved iron is present, still remove zinc at better rates when periphyton growth rates are high, through providing turbulent and quiescent zones for particle aggregation and settling by gravity. The SEM-EDX analyses revealed that a significant amount of zinc in precipitates is associated with algal biomass in the first polishing pond, located very close to the weir of OEP (data presented at the end of this section under EDX, Samples Collected July 10 & 12, 1995; SEM/EDX, February 1996 with 1995 Samples).

The differences between the summer hydrodynamics suggest an opportunity for particle formation and removal of zinc by inducing changes in flow patterns in the OEP. Potentially, changes in the flow pattern may improve the current hydrodynamic conditions. An evaluation of the physical changes which are required can be carried out by evaluating the particles sizes present in the pit, and the orders of magnitude of changes required to augment the particle formation/precipitation process will be estimated.

SEM/EDX

Febuary 1996

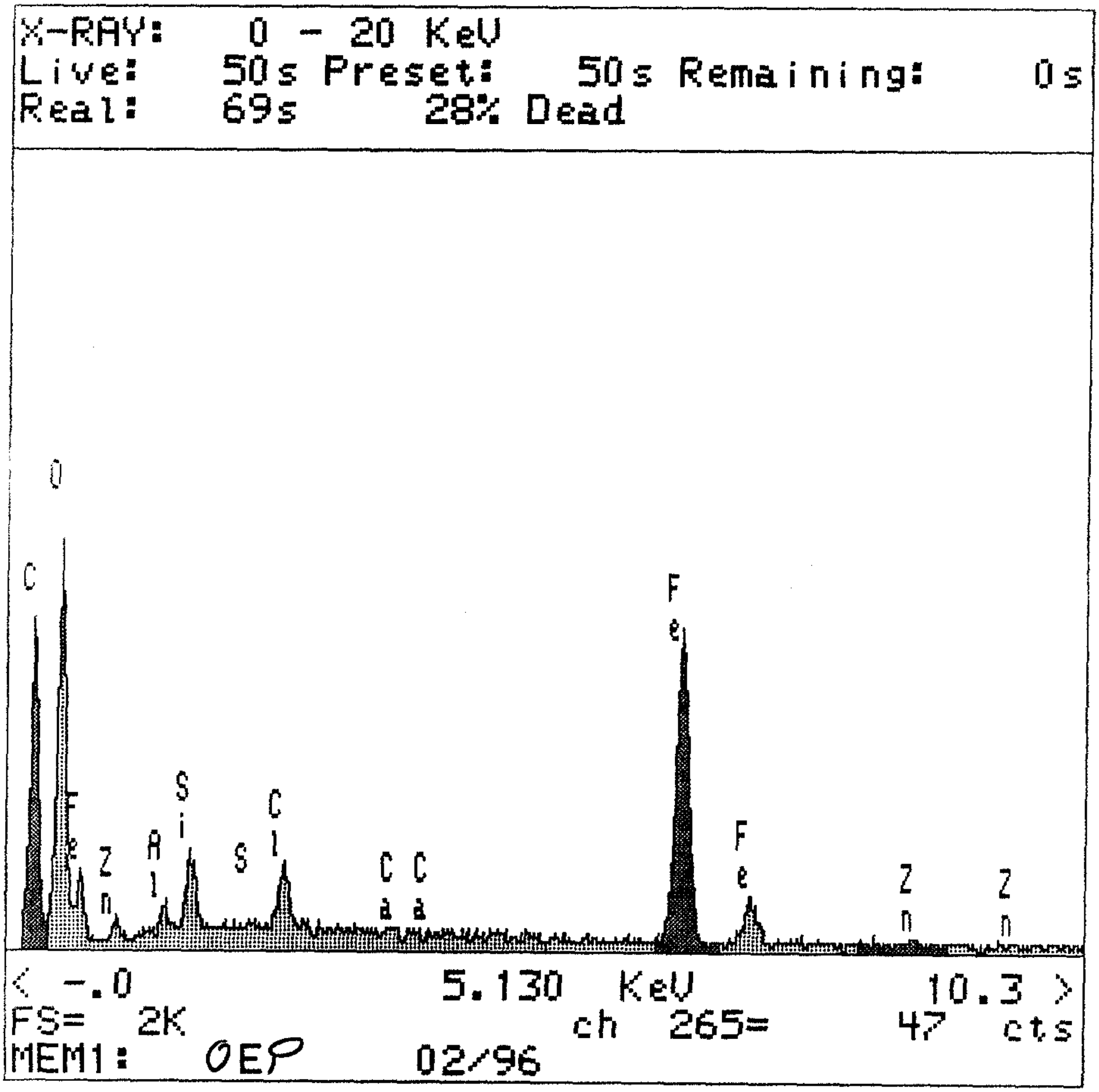
with 1995 Samples

Table of Contents

SEM/EDX

Figure 1

Figure 2


X-RAY: 0 - 20 KeV
Live: 50s Preset: 50s Remaining: 0s
Real: 69s 28% Dead
O
C
Fe
Si
Cl
Fe
Zn
Al
S
Ca Ca
Fe
Zn
Zn
< -.0 5.130 KeV 10.3 >
FS= 2K ch 265= 47 cts
MEM1: OEP 02/96

Spectrum file : NCE
E ؘ02/96 LIVETIME(spec.)= 5Ø

ENERGY	RES	AREA
5.2	79.52	37Ø48

TOTAL AREA= 51491

......
Peak at .5Ø keV omitted?
FIT INDEX= 1.92

ELMT	APP.CONC	ERROR(WT%)
S K : Ø	.Ø76	.Ø74* < 2 Sigma*
CuK : Ø	.146	.236* < 2 Sigma*
SiK : Ø	1.158	.Ø79
NaK : Ø	.415	.Ø55
ClK : Ø	1.144	.Ø95
ZnK : Ø	.669	.331
FeK : Ø	16.Ø97	.392
MnK : Ø	.1Ø6	.125* < 2 Sigma*
AlK : Ø	.4Ø1	.Ø82
CaK : Ø	.Ø22	.Ø76* < 2 Sigma*
K K : Ø	.Ø79	.Ø76* < 2 Sigma*

ZAF CALCULATIONS

...[3 iterations]

2Ø.ØØ kV TILT=15.ØØ ELEV=1Ø.ØØ AZIM=15.ØØ COSINE=1.ØØØ

Spectrum: E Ø2/96 * INITIAL START-UP *

All elmts analysed

ELMT	ZAF	%ELMT	+-	Error	ATOM.%
S K : Ø	.712	< .148	+-	.Ø74	
CuK : Ø	.834	< .471	+-	.236	
SiK : Ø	.542	2.138	+-	.146	14.251
NaK : Ø	.311	1.334	+-	.178	1Ø.863
ClK : Ø	.789	1.449	+-	.121	7.652
ZnK : Ø	.852	.784	+-	.388	2.246
FeK : Ø	.953	16.897	+-	.411	56.636
MnK : Ø	.925	< .25Ø	+-	.125	
AlK : Ø	.439	.914	+-	.188	6.339
CaK : Ø	1.ØØØ	< .152	+-	.Ø76	
K K : Ø	.969	< .152	+-	.Ø76	
TOTAL		23.516			1ØØ.ØØØ

Figure 3

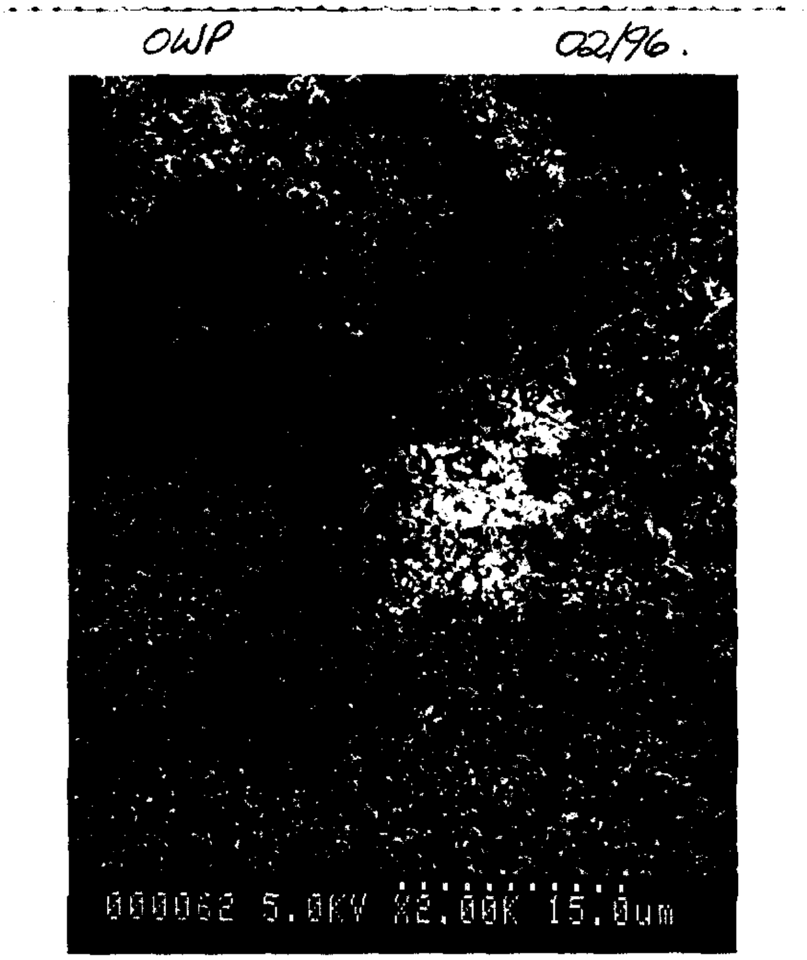
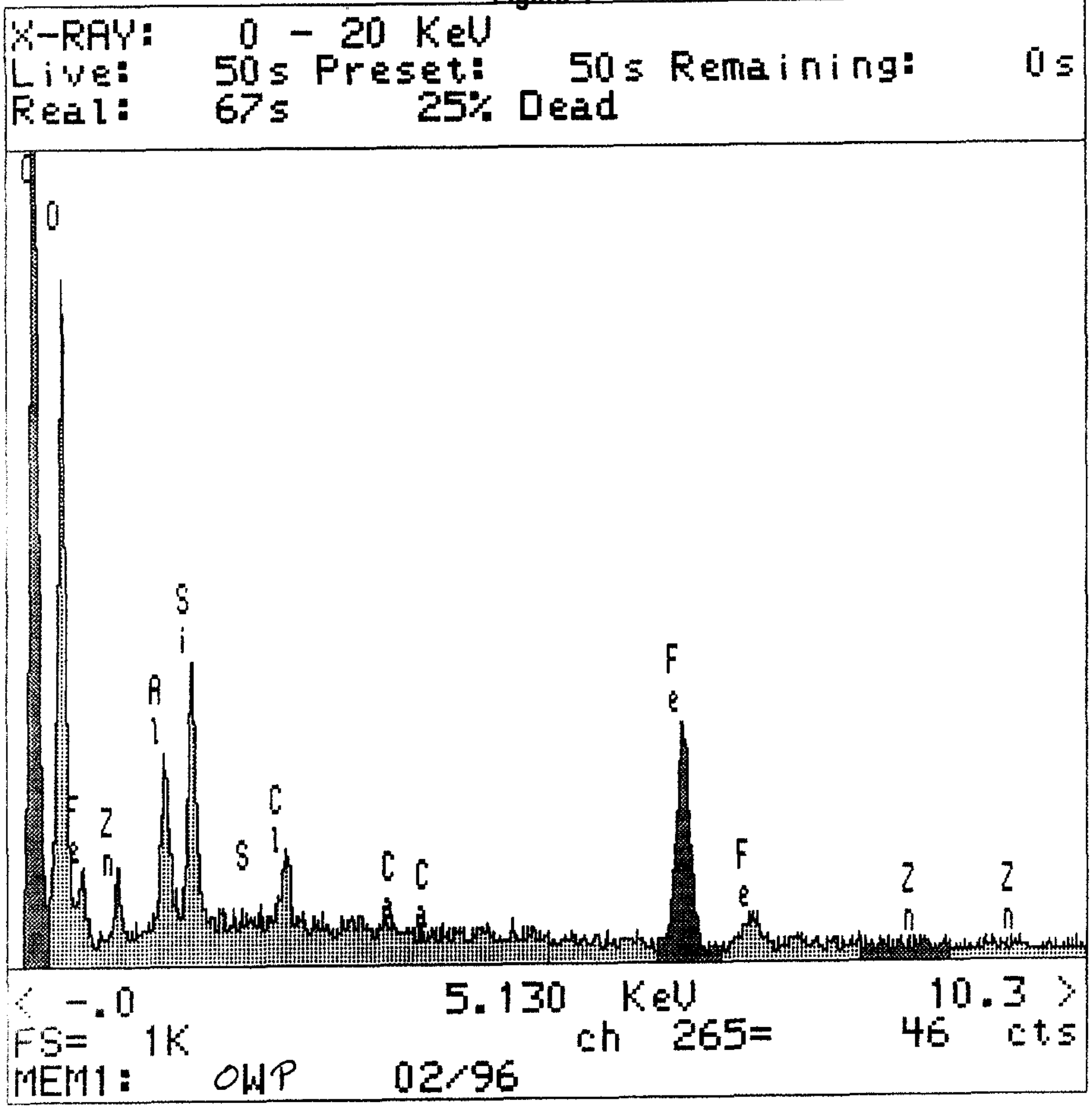


Figure 4


X-RAY: 0 - 20 KeV
Live: 50s Preset: 50s Remaining: 0s
Real: 67s 25% Dead
O
Si
Al
Fe
Zn
S
Cl
Ca
Ca
Fe
Fe
Zn
Zn
< -.0
5.130 KeV
10.3 >
FS= 1K
ch 265=
46 cts
MEM1: OWP 02/96

```
Spectrum file : NCW
    W      Ø2/96                        LIVETIME(spec.)=    5Ø
 ENERGY     RES      AREA
-    5.8   78.21    36464
TOTAL AREA=     421Ø9
......
Peak at    .5Ø keV omitted?
FIT INDEX= 1.48

ELMT          APP.CONC    ERROR(WT%)
S K  :  Ø       .Ø22       .Ø67* < 2 Sigma*
CuK  :  Ø       .173       .2Ø4* < 2 Sigma*
SiK  :  Ø      1.872       .Ø87
NaK  :  Ø       .552       .Ø59
ClK  :  Ø       .617       .Ø78
ZnK  :  Ø       .287       .271* < 2 Sigma*
FeK  :  Ø      5.648       .256
MnK  :  Ø       .1Ø3       .1Ø4* < 2 Sigma*
AlK  :  Ø      1.5Ø2       .1Ø1
CaK  :  Ø      -.Ø58       .Ø69* < 2 Sigma*
K K  :  Ø       .117       .Ø7Ø* < 2 Sigma*

ZAF CALCULATIONS


...[ 3 iterations]

2Ø.ØØ kV  TILT=15.ØØ ELEV=1Ø.ØØ AZIM=15.ØØ COSINE=1.ØØØ

Spectrum:      W      Ø2/96                         * INITIAL START-UP *

All elmts analysed

ELMT         ZAF      %ELMT  +-      Error  ATOM.%
S K  :  Ø   .618    <  .133  +-      .Ø67
CuK  :  Ø   .822    <  .4Ø8  +-      .2Ø4
SiK  :  Ø   .535      3.498  +-      .163   28.628
NaK  :  Ø   .44Ø      1.256  +-      .134   12.563
ClK  :  Ø   .698       .883  +-      .112    5.728
ZnK  :  Ø   .833    <  .542  +-      .271
FeK  :  Ø   .899      6.283  +-      .285   25.866
MnK  :  Ø   .871    <  .2Ø9  +-      .1Ø4
AlK  :  Ø   .541      2.781  +-      .188   23.7Ø3
CaK  :  Ø   .9Ø8    <  .137  +-      .Ø69
K K  :  Ø   .879    <  .141  +-      .Ø7Ø
TOTAL                14.7Ø2                100.ØØØ
```

Figure 5b

Figure 5

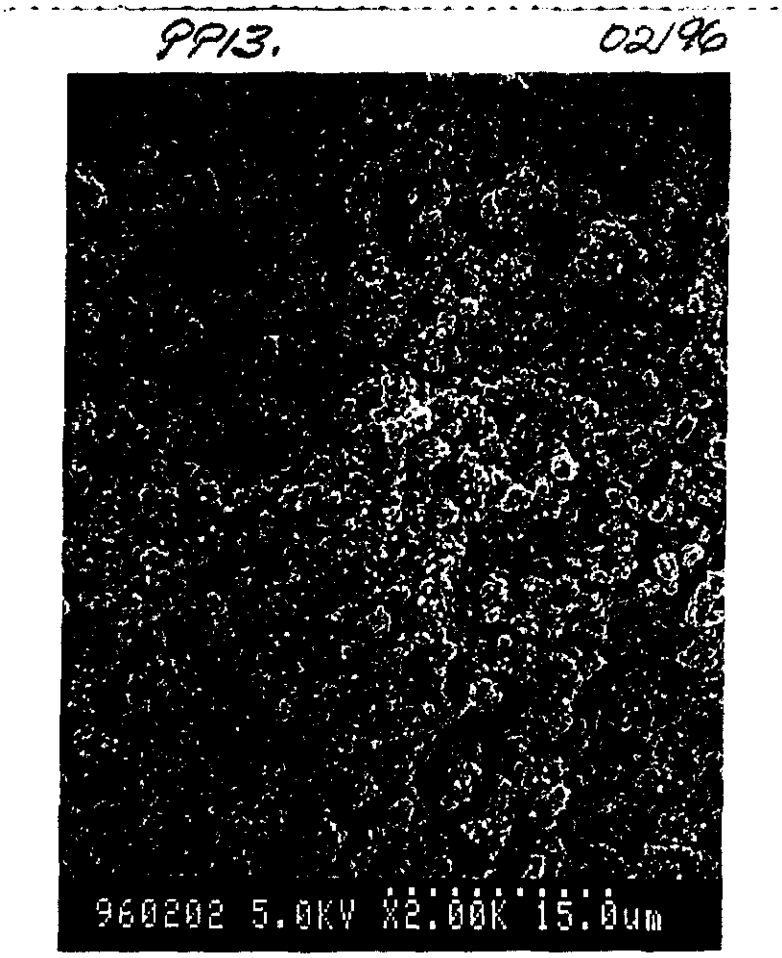
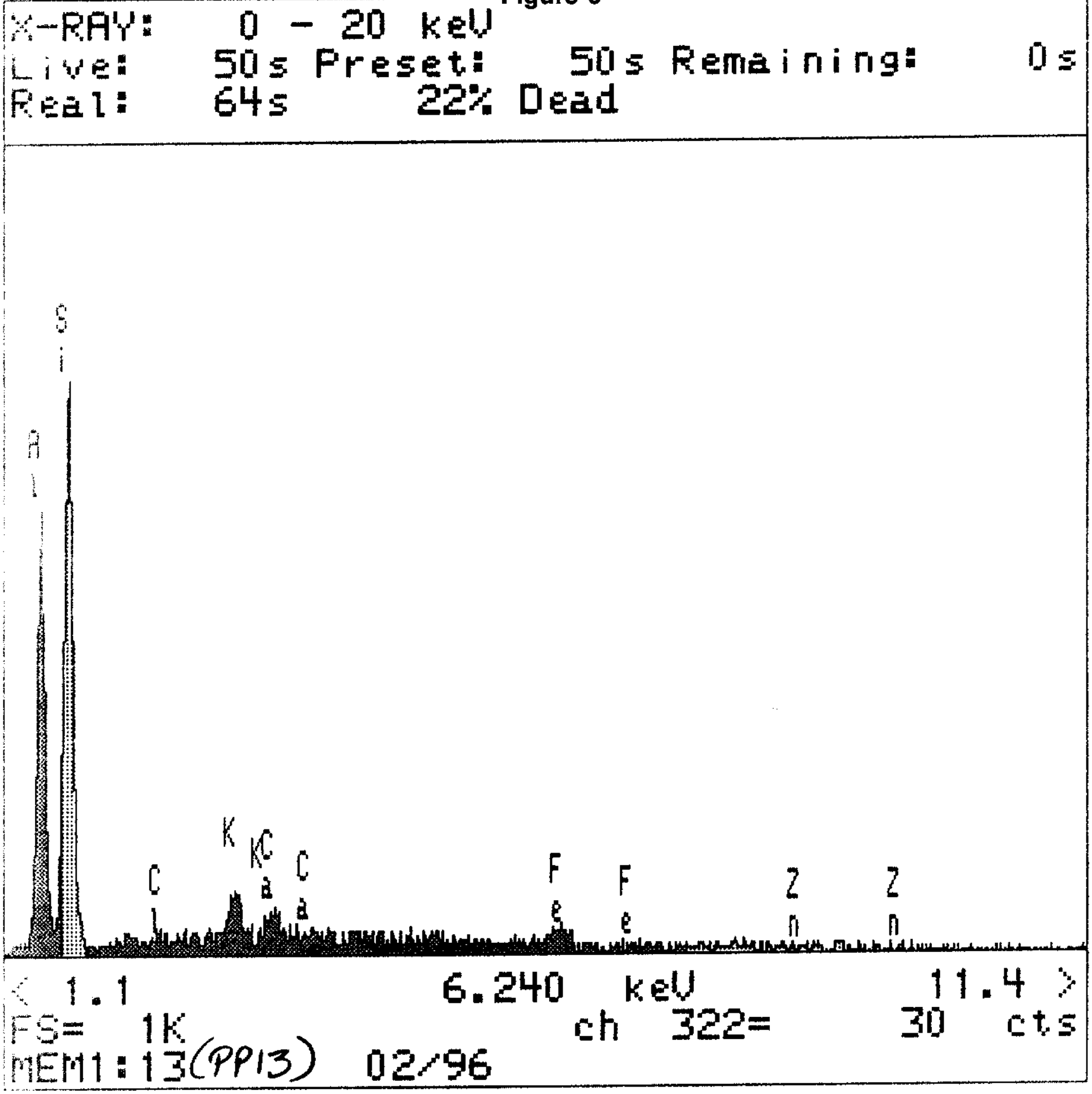


Figure 6


X-RAY: 0 - 20 keV
Live: 50s Preset: 50s Remaining: 0s
Real: 64s 22% Dead
Al
Si
Cl
K
KCa
Ca
Fe
Fe
Zn
Zn
< 1.1 6.240 keV 11.4 >
FS= 1K ch 322= 30 cts
MEM1:13(PP13) 02/96

```
Spectrum file : NC13
13        Ø2/96                         LIVETIME(spec.)=     5Ø
 ENERGY     RES      AREA
-   5.9   77.59    37Ø92
TOTAL AREA=     1989Ø
......
FIT INDEX= 1.58

ELMT         APP.CONC    ERROR(WT%)
S K : Ø        .Ø73        .Ø41* < 2 Sigma*
FeK : Ø        .419        .122
NaK : Ø        .549        .Ø42
CaK : Ø        .252        .Ø64
ClK : Ø        .Ø72        .Ø45* < 2 Sigma*
ZnK : Ø      -.Ø56         .195* < 2 Sigma*
MnK : Ø      -.Ø17         .Ø84* < 2 Sigma*
AlK : Ø      3.813         .124
SiK : Ø      4.147         .1Ø5
K K : Ø        .493        .Ø69

ZAF CALCULATIONS


...[ 3 iterations]

2Ø.ØØ kV  TILT=15.ØØ ELEV=1Ø.ØØ AZIM=15.ØØ COSINE=1.ØØØ

Spectrum: 13        Ø2/96                         * INITIAL START-UP *

All elmts analysed,NORMALISED

ELMT         ZAF    %ELMT +-      Error  ATOM.%
S K : Ø   .5Ø9   <  .Ø82 +-       .Ø41
FeK : Ø   .825     3.855 +-     1.125    1.979
NaK : Ø   .953     4.365 +-      .337    5.444
CaK : Ø   .794     2.4Ø8 +-      .614    1.722
ClK : Ø   .584   <  .Ø89 +-      .Ø45
ZnK : Ø   .8Ø9   <  .39Ø +-      .195
MnK : Ø   .797   <  .168 +-      .Ø84
AlK : Ø   .925    31.248 +-     1.Ø14   33.2Ø4
SiK : Ø   .613    51.364 +-     1.3Ø2   52.423
K K : Ø   .785     4.764 +-      .665    3.493
TOTAL             98.ØØ4                1ØØ.ØØØ
-------------------------------------------------------------------------------
```

Figure 7

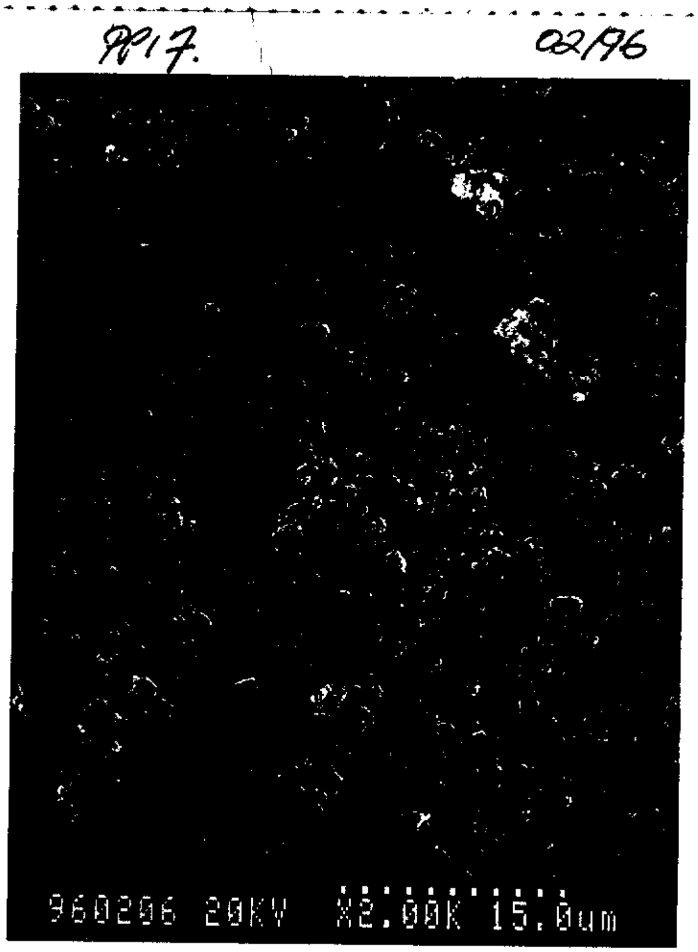
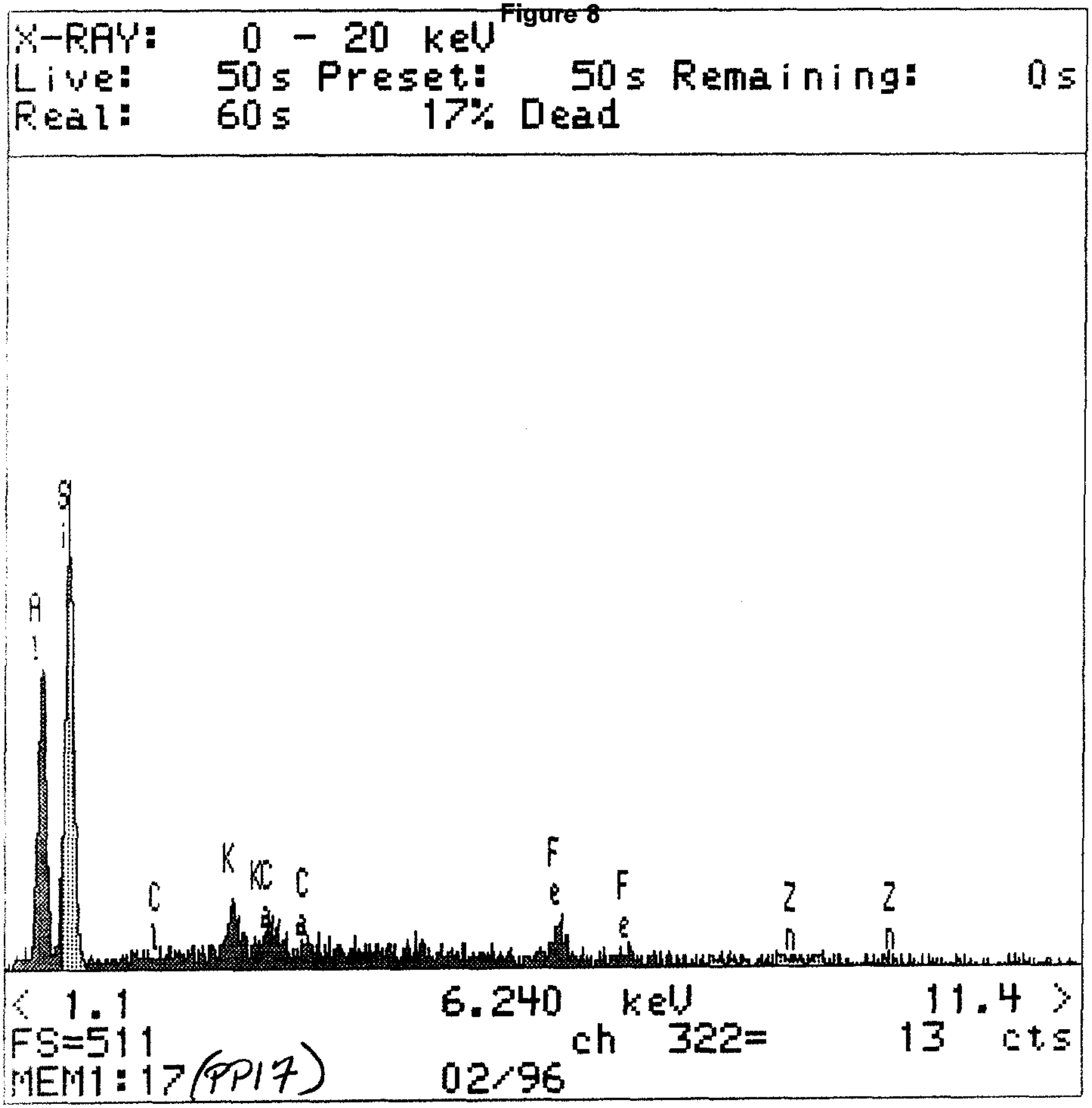


Figure 8


X-RAY: 0 - 20 keV
Live: 50s Preset: 50s Remaining: 0s
Real: 60s 17% Dead
Al
Si
Cl
K
KCa
Ca
Fe
Fe
Zn
Zn
< 1.1 6.240 keV 11.4 >
FS=511 ch 322= 13 cts
MEM1:17 (PP17) 02/96

```
Spectrum file : NC17
17          Ø2/96                   LIVETIME(spec.)=     5Ø
 ENERGY     RES      AREA
-   6.3   75.99    35655
TOTAL AREA=      8843
......
FIT INDEX=  .54

ELMT         APP.CONC    ERROR(WT%)
S K  :  Ø      .ØØ9        .Ø26* < 2 Sigma*
FeK  :  Ø      .391        .Ø95
NaK  :  Ø      .182        .Ø24
CaK  :  Ø      .132        .Ø46
ClK  :  Ø     -.Ø16        .Ø28* < 2 Sigma*
ZnK  :  Ø     -.Ø23        .141* < 2 Sigma*
MnK  :  Ø      .Ø2Ø        .Ø51* < 2 Sigma*
AlK  :  Ø     1.356        .Ø75
SiK  :  Ø     1.631        .Ø66
K K  :  Ø      .22Ø        .Ø47

ZAF CALCULATIONS


..[ 2 iterations]

2Ø.ØØ kV  TILT=15.ØØ ELEV=1Ø.ØØ AZIM=15.ØØ COSINE=1.ØØØ

Spectrum: 17          Ø2/96                    * INITIAL START-UP *

All elmts analysed,NORMALISED

ELMT        ZAF     %ELMT +-      Error  ATOM.%
S K  :  Ø  .516   < .Ø52 +-      .Ø26
FeK  :  Ø  .832    8.616 +-     2.Ø92    4.555
NaK  :  Ø  .833    4.Ø13 +-      .536    5.154
CaK  :  Ø  .81Ø    2.975 +-     1.Ø51    2.191
ClK  :  Ø  .597   < .Ø57 +-      .Ø28
ZnK  :  Ø  .811   < .281 +-      .141
MnK  :  Ø  .8Ø4   < .1Ø1 +-      .Ø51
AlK  :  Ø  .858   29.Ø29 +-     1.6Ø7   31.771
SiK  :  Ø  .6Ø2   49.461 +-     2.ØØ1   51.994
K K  :  Ø  .8Ø3    5.ØØ9 +-     1.Ø76    3.783
TOTAL             99.1Ø2               1ØØ.ØØØ
```

Figure 9

PP17 B. 02/96

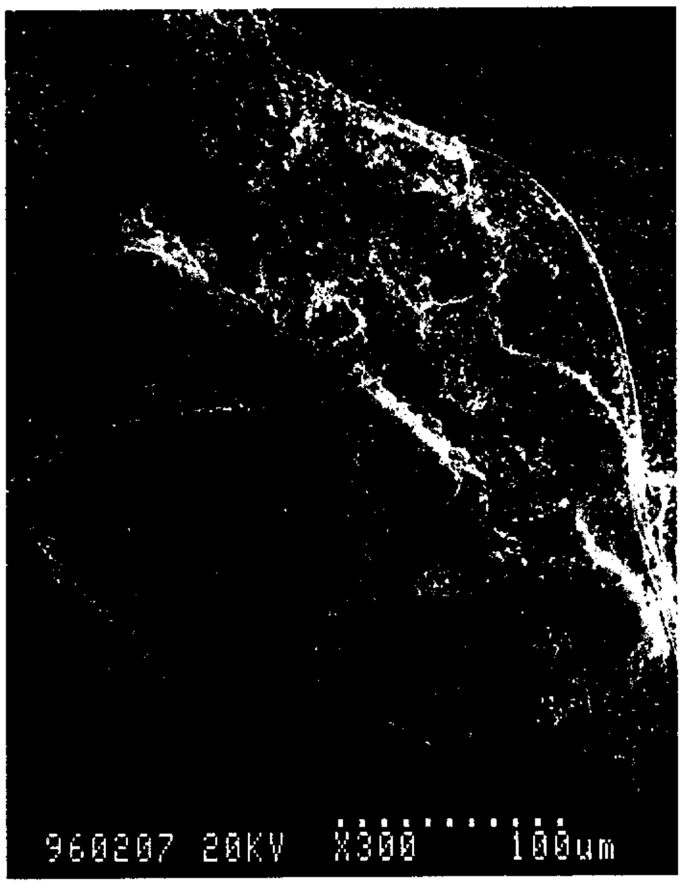
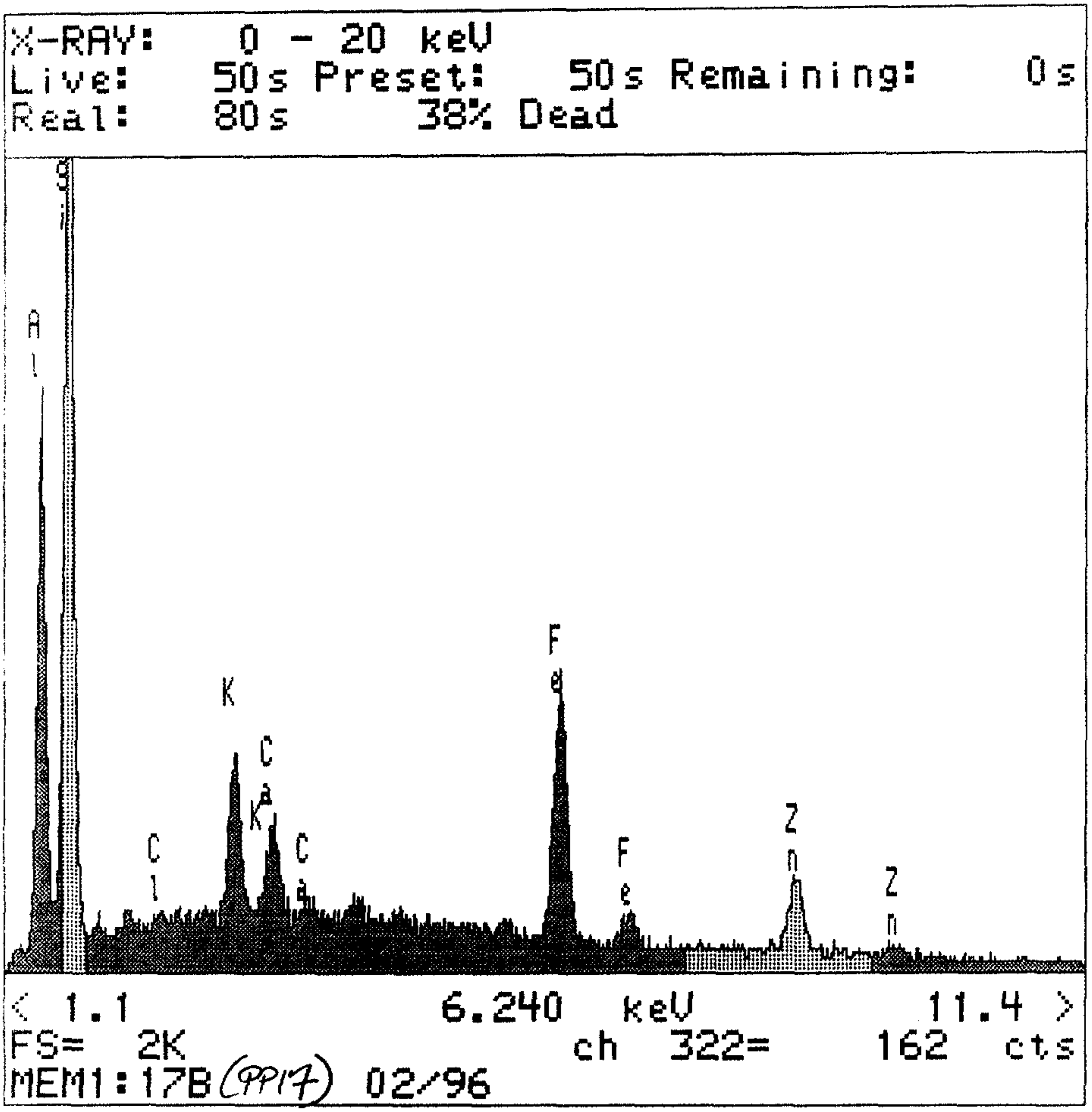


Figure 10



X-RAY: 0 - 20 keV
Live: 50s Preset: 50s Remaining: 0s
Real: 80s 38% Dead
Si
Al
K
Ca
K
Cl
Ca
Fe
Fe
Zn
Zn
< 1.1 6.240 keV 11.4 >
FS= 2K ch 322= 162 cts
MEM1:17B (PP17) 02/96

Spectrum file : NC17B
17B ⌀2/96 LIVETIME(spec.)= 5⌀

ENERGY	RES	AREA
- 5.9	81.⌀5	4⌀698

TOTAL AREA= 94911

......

Peak at 4.46 keV omitted?

FIT INDEX= 4.13

ELMT	APP.CONC	ERROR(WT%)
S K : ⌀	.447	.⌀95
FeK : ⌀	13.173	.412
NaK : ⌀	1.⌀84	.⌀65
CaK : ⌀	1.934	.153
ClK : ⌀	.148	.1⌀⌀* < 2 Sigma*
ZnK : ⌀	7.998	.618
MnK : ⌀	.654	.2⌀⌀
AlK : ⌀	9.751	.2⌀8
SiK : ⌀	15.618	.2⌀5
K K : ⌀	3.72⌀	.165

ZAF CALCULATIONS

....[4 iterations]

2⌀.⌀⌀ kV TILT=15.⌀⌀ ELEV=1⌀.⌀⌀ AZIM=15.⌀⌀ COSINE=1.⌀⌀⌀

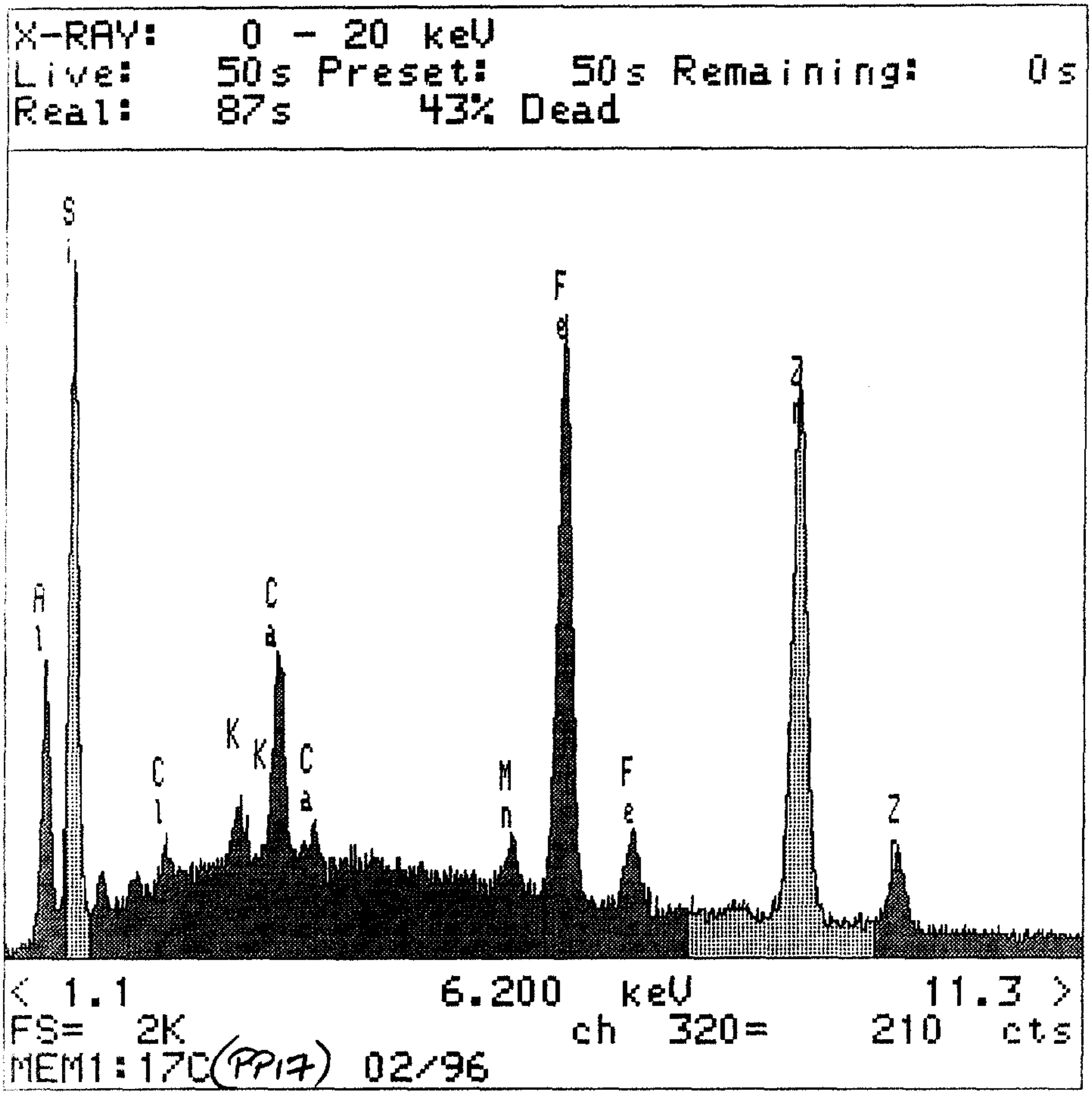
Spectrum: 17B ⌀2/96 * INITIAL START-UP *

All elmts analysed,NORMALISED

ELMT	ZAF	%ELMT	+-	Error	ATOM.%
S K : ⌀	.566	.997	+-	.212	1.⌀64
FeK : ⌀	.878	18.933	+-	.592	11.6⌀6
NaK : ⌀	.52⌀	2.632	+-	.158	3.92⌀
CaK : ⌀	.855	2.854	+-	.225	2.438
ClK : ⌀	.644	< .2⌀⌀	+-	.1⌀⌀	
ZnK : ⌀	.835	12.⌀95	+-	.935	6.334
MnK : ⌀	.846	.976	+-	.299	.6⌀8
AlK : ⌀	.6⌀4	2⌀.361	+-	.434	25.836
SiK : ⌀	.558	35.363	+-	.464	43.⌀99
K K : ⌀	.854	5.499	+-	.244	4.815
TOTAL		99.711			1⌀⌀.⌀⌀⌀

Figure 11

Figure 12


X-RAY: 0 - 20 keV
Live: 50s Preset: 50s Remaining: 0s
Real: 87s 43% Dead
Si
Fe
Zn
Al
Ca
K
K
Ca
Cl
Mn
Fe
Zn
< 1.1 6.200 keV 11.3 >
FS= 2K ch 320= 210 cts
MEM1:17C(PP17) 02/96

Spectrum file : NC17C
17C ∅2/96 LIVETIME(spec.)= 5∅

ENERGY	RES	AREA
- 5.8	8∅.∅6	39993

TOTAL AREA= 13968∅
......
FIT INDEX= 3.95

ELMT	APP.CONC	ERROR(WT%)
S K : ∅	.527	.112
FeK : ∅	29.749	.597
NaK : ∅	.838	.∅57
CaK : ∅	4.834	.2∅5
ClK : ∅	.696	.128
ZnK : ∅	59.544	1.263
MnK : ∅	1.899	.28∅
AlK : ∅	5.1∅3	.159
SiK : ∅	1∅.∅22	.17∅
K K : ∅	1.232	.167

ZAF CALCULATIONS

...[3 iterations]

2∅.∅∅ kV TILT=15.∅∅ ELEV=1∅.∅∅ AZIM=15.∅∅ COSINE=1.∅∅∅

Spectrum: 17C ∅2/96 * INITIAL START-UP *

All elmts analysed,NORMALISED

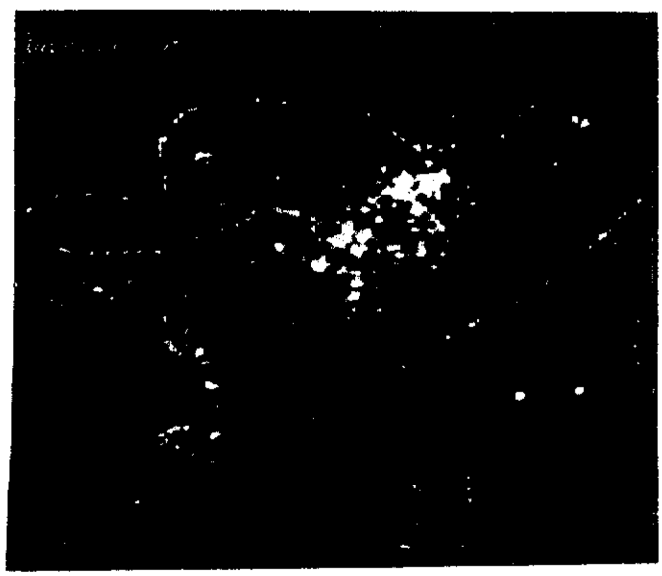
ELMT	ZAF	%ELMT	+-	Error	ATOM.%
S K : ∅	.615	.596	+-	.126	.847
FeK : ∅	.981	21.118	+-	.424	17.214
NaK : ∅	.34∅	1.717	+-	.118	3.4∅∅
CaK : ∅	.949	3.549	+-	.151	4.∅31
ClK : ∅	.7∅∅	.693	+-	.127	.89∅
ZnK : ∅	.898	46.152	+-	.979	32.141
MnK : ∅	.935	1.415	+-	.2∅9	1.172
AlK : ∅	.396	8.975	+-	.28∅	15.144
SiK : ∅	.47∅	14.857	+-	.253	24.∅78
K K : ∅	.922	.931	+-	.126	1.∅84
TOTAL		1∅∅.∅∅2			1∅∅.∅∅∅

Figure 13

PP17 02/96.

Figure 14

SEM Image



Carbon Distribution

Zinc Disribution

EDX

Samples Collected

July 10 &12 1995

Table of Contents

EDX

BUCHAN	Figure 2	Figure 3	Figure 4	Figure 5	Figure 6	Figure 7	Figure8	Figure 9	Figure 10	Figure 11	Figure 12
ELEMENT	OWP BRANCH #2 10/07/95	OEP BRANCH #3 10/07/95	OWP BOTTOM SED TRAP 10/07/95	OEP 32' SED TRAP 10/07/95	PP-10 FLOATING MAT ALGAE 12/07/95	PP-11 MOSS 12/07/95	PP-13 BUBBLE ALGAE 12/07/95	PP-14 FLOATING ALGAE 12/07/95	PP-14 FILAMENTOUS ALGAE 12/07/95	PP-17 FILAMENTOUS ALGAE 12/07/95	PP-17 SEEP ALGAE 12/07/95
Cl						8.232			5.705	2.192	
Na	6.644	13.709		13.964	15.109	10.531	7.126	12.352	7.387	15.428	15.258
S						9.398			11.63		
Zn						12.779	3.505	14.485		6.468	13.898
Fe	15.103	45.946	47.763	46.981	40.401	11.972	20.361	36.768	39.032	17.255	38.503
Cu											
Mn							2.367	2.688			
Al	13.402		11.118				10.672			11.062	
Si	58.421	26.041	24.183	21.705	30.306	19.157	47.06	25.73	24.831	43.705	24.846
Ti											
As											
Cr											
Ca						18.477	3.283	3.594	6.192	2.476	3.078
K						4.065	2.65		3.377		
TOTAL	100	100	100	100	100	100	100	100	100	100	100

Operator: Coombs
Client: coombs
Job: Job number 155
Label: (untitled) (26 Sep 96 13:25:28)

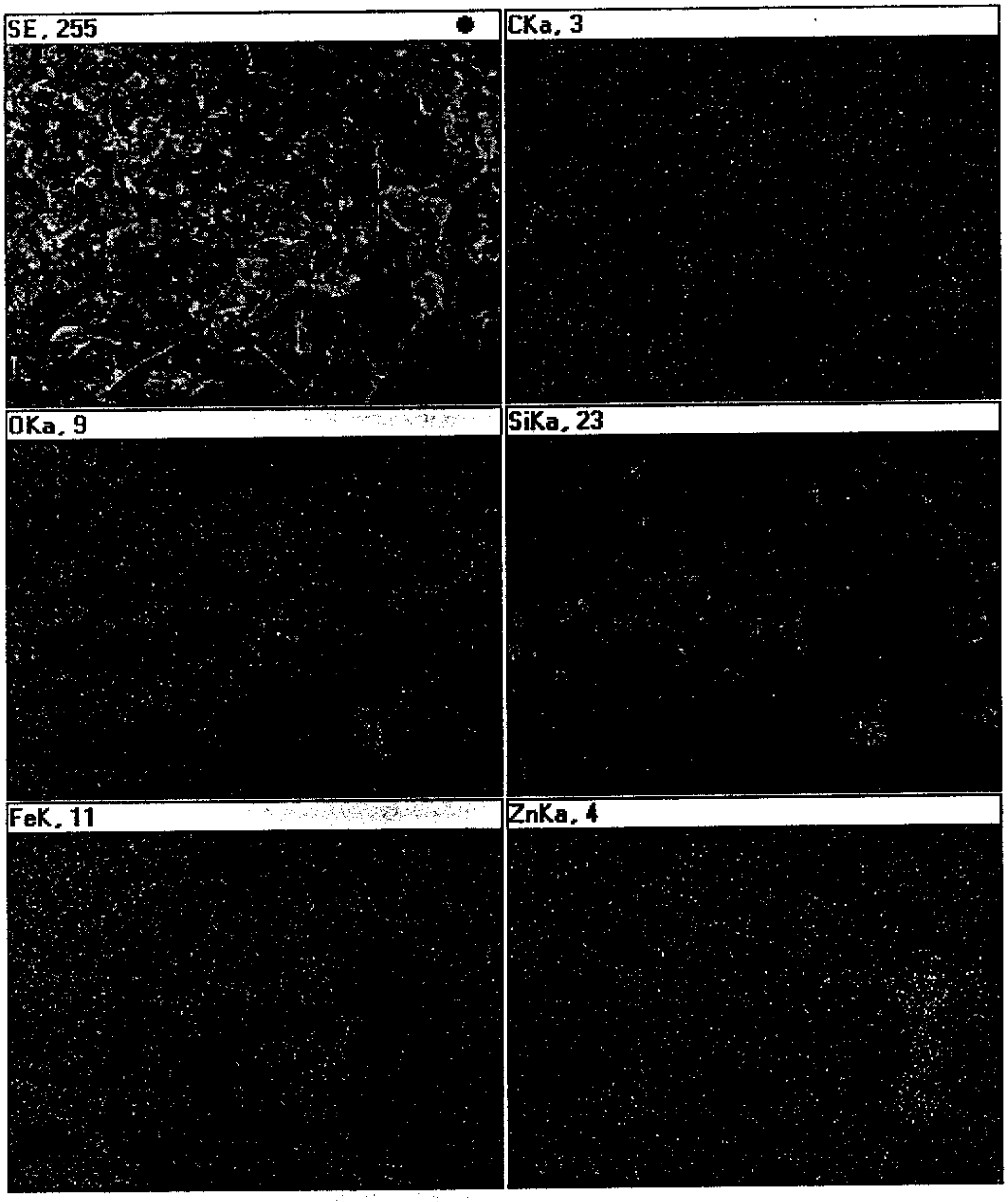


Figure 1

PP13 New Stub 09/96

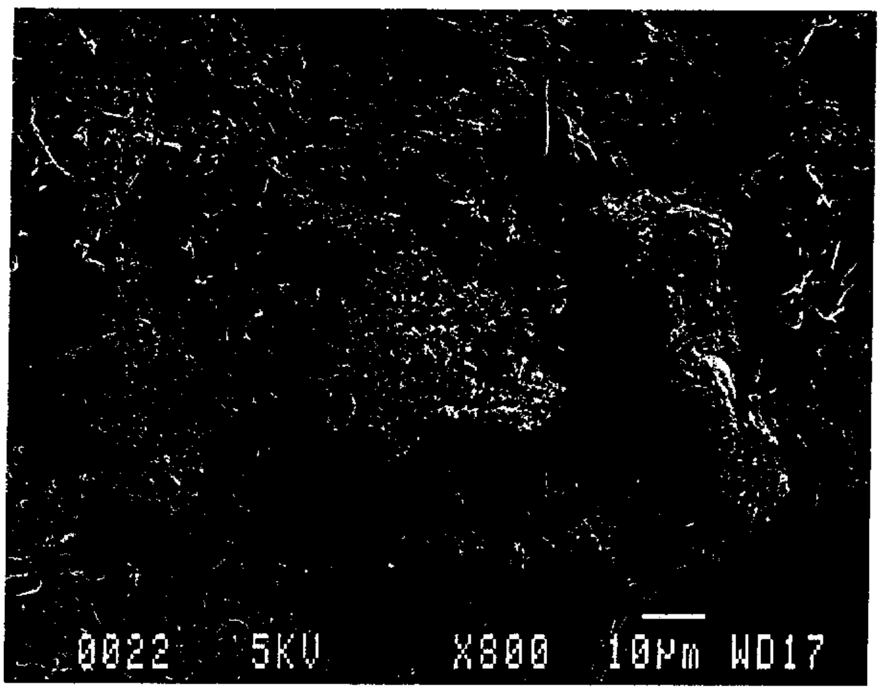
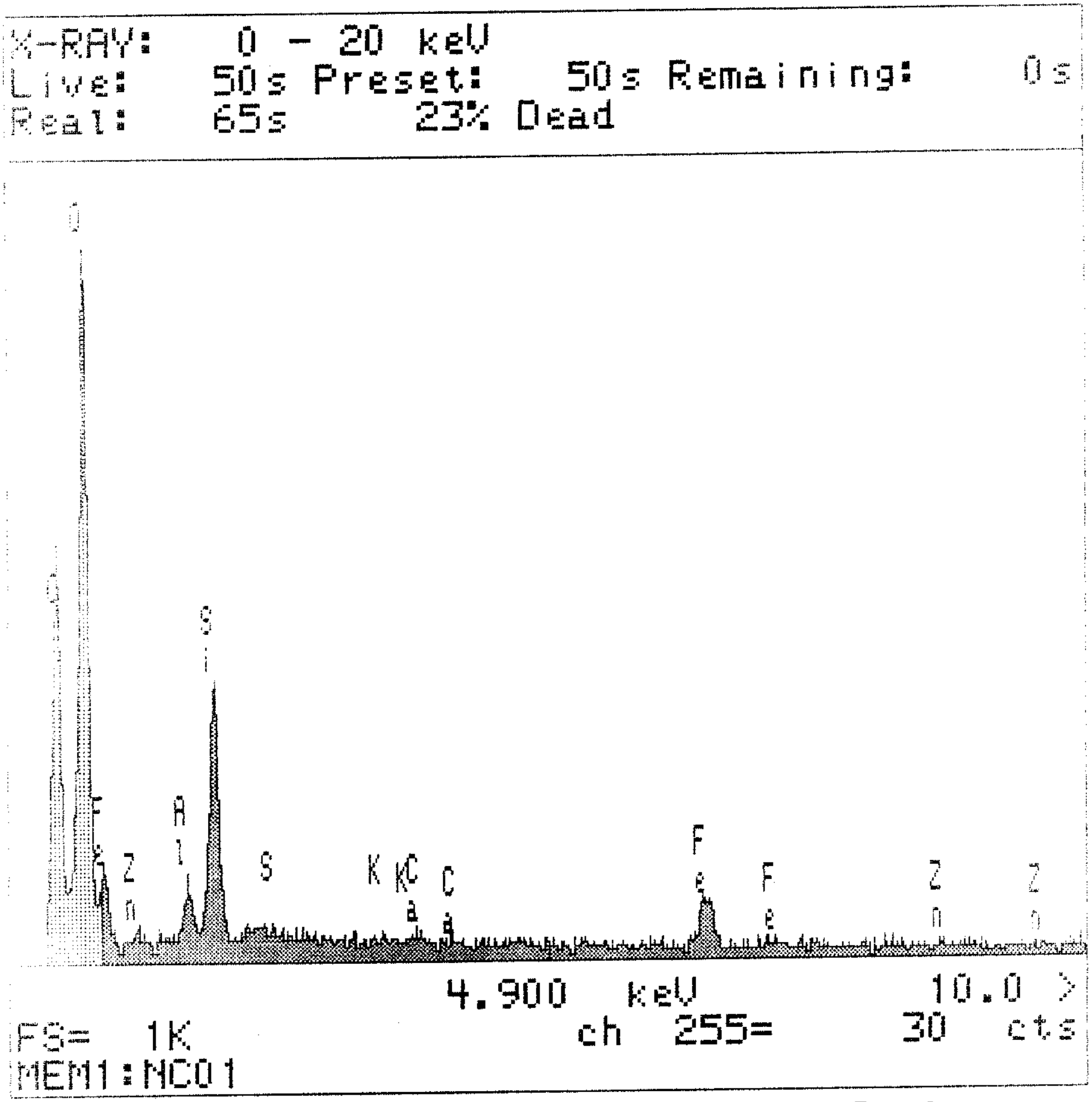


Figure 2

Buchans OWP Branch #2 10/7/95



Spectrum file : NCØ1

NCØ1 LIVETIME(spec.)= 5Ø

ENERGY	RES	AREA
[illegible]	83.98	36438

TOTAL AREA= 31369

Peak at .5Ø keV omitted?

FIT INDEX= 1.37

ELMT	APP.CONC	ERROR(WT%)
[illegible] : Ø	.ØØ5	.Ø58* < 2 Sigma*
NaK : Ø	.173	.Ø5Ø
S K : Ø	-.ØØØ	.Ø79* < 2 Sigma*
[illegible] : Ø	.281	.27Ø* < 2 Sigma*
[illegible] Ø	1.548	.174
[illegible] : Ø	-.174	.2Ø4* < 2 Sigma*
[illegible] : Ø	.Ø89	.1ØØ* < 2 Sigma*
[illegible] : Ø	.465	.Ø82
[illegible] : Ø	2.162	.Ø9Ø
[illegible] : Ø	.Ø13	.Ø68* < 2 Sigma*
[illegible] : Ø	.Ø8Ø	.534* < 2 Sigma*
[illegible] : Ø	-.Ø54	.Ø86* < 2 Sigma*
[illegible] : Ø	.Ø83	.Ø62* < 2 Sigma*
[illegible] : Ø	.Ø67	.Ø6Ø* < 2 Sigma*
[illegible] : Ø	-1.544	.879* < 2 Sigma*Not used for quantitation
[illegible] : Ø	.Ø21	.174* < 2 Sigma*Not used for quantitation

ZAF CALCULATIONS

..[2 iterations]

1Ø.ØØ kV TILT=15.ØØ ELEV=1Ø.ØØ AZIM=15.ØØ COSINE=1.ØØØ

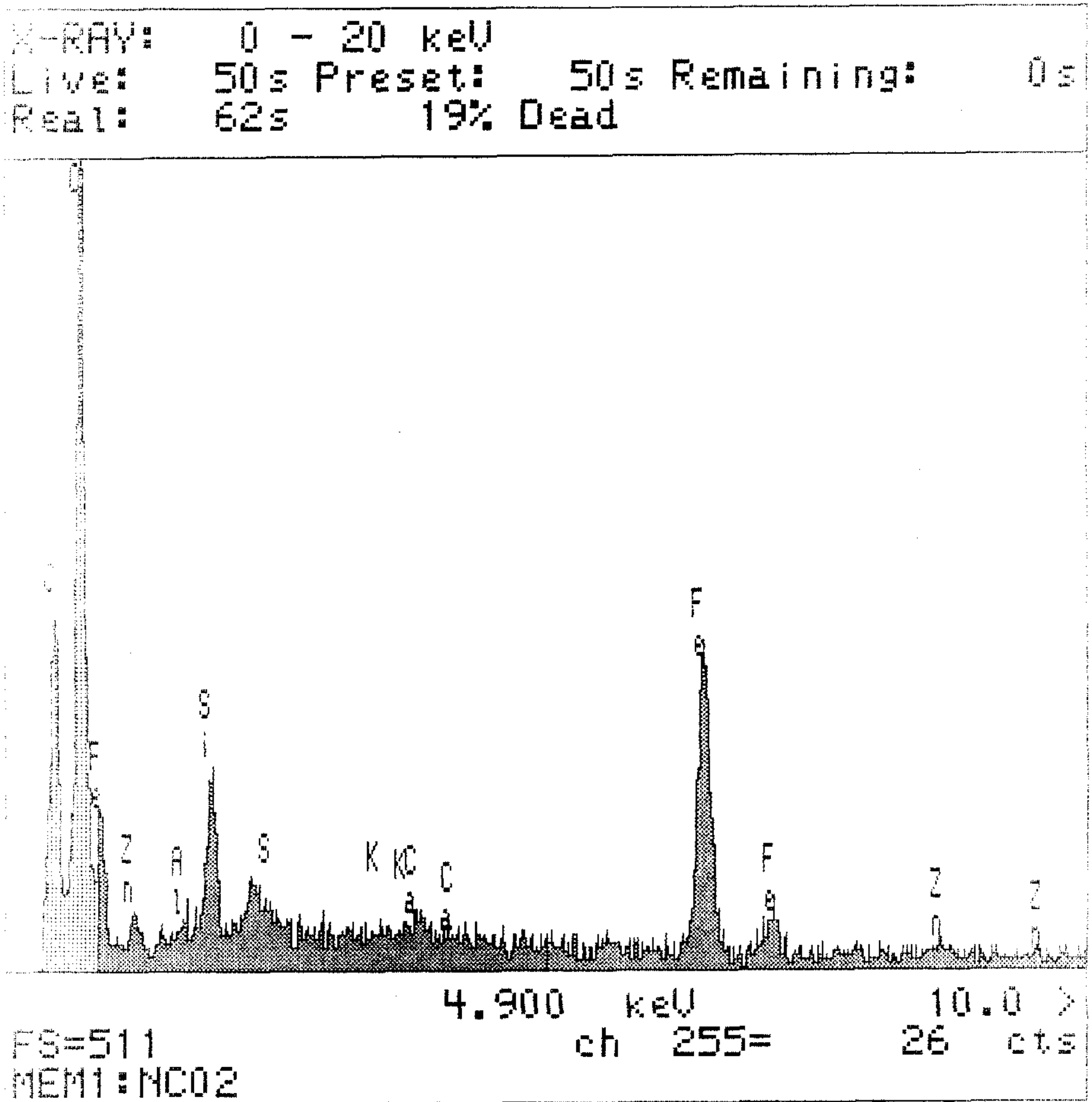
Spectrum: NCØ1 * INITIAL START-UP *

All elmts analysed,NORMALISED

ELMT	ZAF	%ELMT	+-	Error	ATOM.%
[illegible] : Ø	.625	< .116	+-	.Ø58	
[illegible] : Ø	.542	4.541	+-	1.3Ø9	6.644
[illegible] : Ø	.542	< .158	+-	.Ø79	
[illegible] Ø	.827	< .539	+-	.27Ø	
[illegible] : Ø	.872	25.Ø76	+-	2.825	15.1Ø3
[illegible] : Ø	.818	< .4Ø8	+-	.2Ø4	
[illegible] : Ø	.844	< .2Ø1	+-	.1ØØ	
[illegible] : Ø	.614	1Ø.749	+-	1.899	13.4Ø2
SiK : Ø	.623	48.784	+-	2.Ø2Ø	58.421
TiK : Ø	.817	< .136	+-	.Ø68	
AsK : Ø	.753	<1.Ø69	+-	.534	
CrK : Ø	.882	< .173	+-	.Ø86	
[illegible] : Ø	.866	< .124	+-	.Ø62	
[illegible] : Ø	.837	< .121	+-	.Ø6Ø	
TOTAL		89.15Ø			1ØØ.ØØØ

Figure 3

Buchans OWP Branch #3 10/7/95



Spectrum file : NCØ2

NCØ2 LIVETIME(spec.)= 5Ø

ENERGY	RES	AREA
5.8	8Ø.81	35686

TOTAL AREA= 19821

Peak at .5Ø keV omitted?

FIT INDEX= .95

ELMT		APP.CONC	ERROR(WT%)
[illegible]	: Ø	-.Ø15	.Ø49* < 2 Sigma*
[illegible]	: Ø	.179	.Ø42
[illegible]	: Ø	.Ø73	.Ø72* < 2 Sigma*
[illegible]	: Ø	.378	.232* < 2 Sigma*
[illegible]	: Ø	4.Ø33	.223
[illegible]	: Ø	.Ø72	.152* < 2 Sigma*
[illegible]	: Ø	-.Ø1Ø	.Ø79* < 2 Sigma*
[illegible]	: Ø	.ØØ3	.Ø57* < 2 Sigma*
[illegible]	: Ø	.651	.Ø59
[illegible]	: Ø	-.Ø67	.Ø58* < 2 Sigma*
[illegible]	: Ø	.348	.378* < 2 Sigma*
[illegible]	: Ø	.113	.Ø73* < 2 Sigma*
[illegible]	: Ø	.1Ø8	.Ø6Ø* < 2 Sigma*
[illegible]	Ø	.Ø51	.Ø54* < 2 Sigma*
[illegible]	: Ø	-.Ø55	.66Ø* < 2 Sigma*Not used for quantitation
AuM	: Ø	.41Ø	.165Not used for quantitation

ZAF CALCULATIONS

[illegible] 2 iterations)

[illegible] kV TILT=15.ØØ ELEV=1Ø.ØØ AZIM=15.ØØ COSINE=1.ØØØ

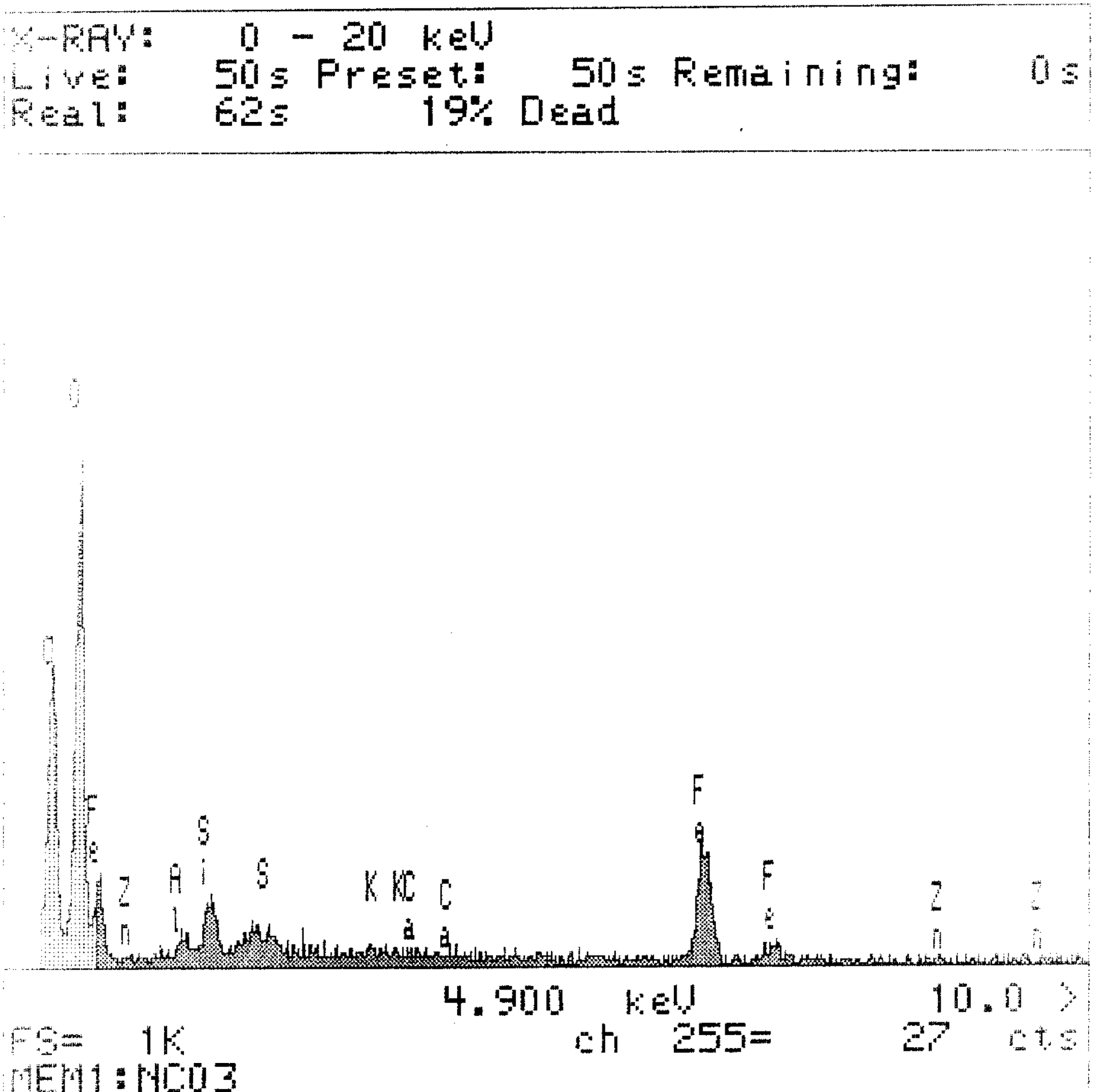
Spectrum: NCØ2 * INITIAL START-UP *

All elmts analysed,NORMALISED

ELMT		ZAF	%ELMT	+-	Error	ATOM.%
[illegible]	: Ø	.738	< .Ø99	+-	.Ø49	
NaK	: Ø	.344	7.124	+-	1.658	13.7Ø9
[illegible]	Ø	.662	< .144	+-	.Ø72	
[illegible]		.864	< .465	+-	.232	
[illegible]	Ø	.947	58.ØØ2	+-	3.2Ø8	45.946
[illegible]	Ø	.847	< .3Ø3	+-	.152	
[illegible]	: Ø	.921	< .158	+-	.Ø79	
[illegible]	: Ø	.422	< .114	+-	.Ø57	
SiK	: Ø	.536	16.534	+-	1.5Ø1	26.Ø41
TiK	: Ø	.93Ø	< .116	+-	.Ø58	
[illegible]	: Ø	.8ØØ	< .756	+-	.378	
[illegible]	: Ø	1.Ø32	< .146	+-	.Ø73	
[illegible]	: Ø	.987	< .12Ø	+-	.Ø6Ø	
[illegible]	Ø	.962	< .1Ø7	+-	.Ø54	
TOTAL			81.66Ø			1ØØ.ØØØ

Figure 4

Buchans OWP Bottom Sed Trap 10/7/95



[illegible]trum file : NCØ3

[illegible] LIVETIME(spec.)= 5Ø

ENERGY	RES	AREA
6.Ø	8Ø.57	35884

TOTAL AREA= 2Ø625

. . . . . .

Peak at .5Ø keV omitted?

FIT INDEX= .86

ELMT		APP.CONC	ERROR(WT%)
[illegible]	: Ø	.Ø66	.Ø52* < 2 Sigma*
[illegible]	: Ø	.Ø47	.Ø38* < 2 Sigma*
[illegible]	: Ø	.11Ø	.Ø74* < 2 Sigma*
ZnK	: Ø	.139	.211* < 2 Sigma*
FeK	: Ø	3.292	.2Ø8
[illegible]	: Ø	.132	.163* < 2 Sigma*
[illegible]	: Ø	-.Ø33	.Ø78* < 2 Sigma*
AlK	: Ø	.184	.Ø59
[illegible]	: Ø	.49Ø	.Ø55
[illegible]	: Ø	.Ø43	.Ø55* < 2 Sigma*
[illegible]	: Ø	-.5Ø2	.4Ø2* < 2 Sigma*
[illegible]	: Ø	.Ø24	.Ø71* < 2 Sigma*
[illegible]	: Ø	.Ø36	.Ø53* < 2 Sigma*
[illegible]	: Ø	.Ø4Ø	.Ø52* < 2 Sigma*
[illegible]	: Ø	.132	.72Ø* < 2 Sigma*Not used for quantitation
[illegible]	: Ø	.364	.169Not used for quantitation

ZAF CALCULATIONS

[illegible] 2 iterations]

2Ø.ØØ kV TILT=15.ØØ ELEV=1Ø.ØØ AZIM=15.ØØ COSINE=1.ØØØ

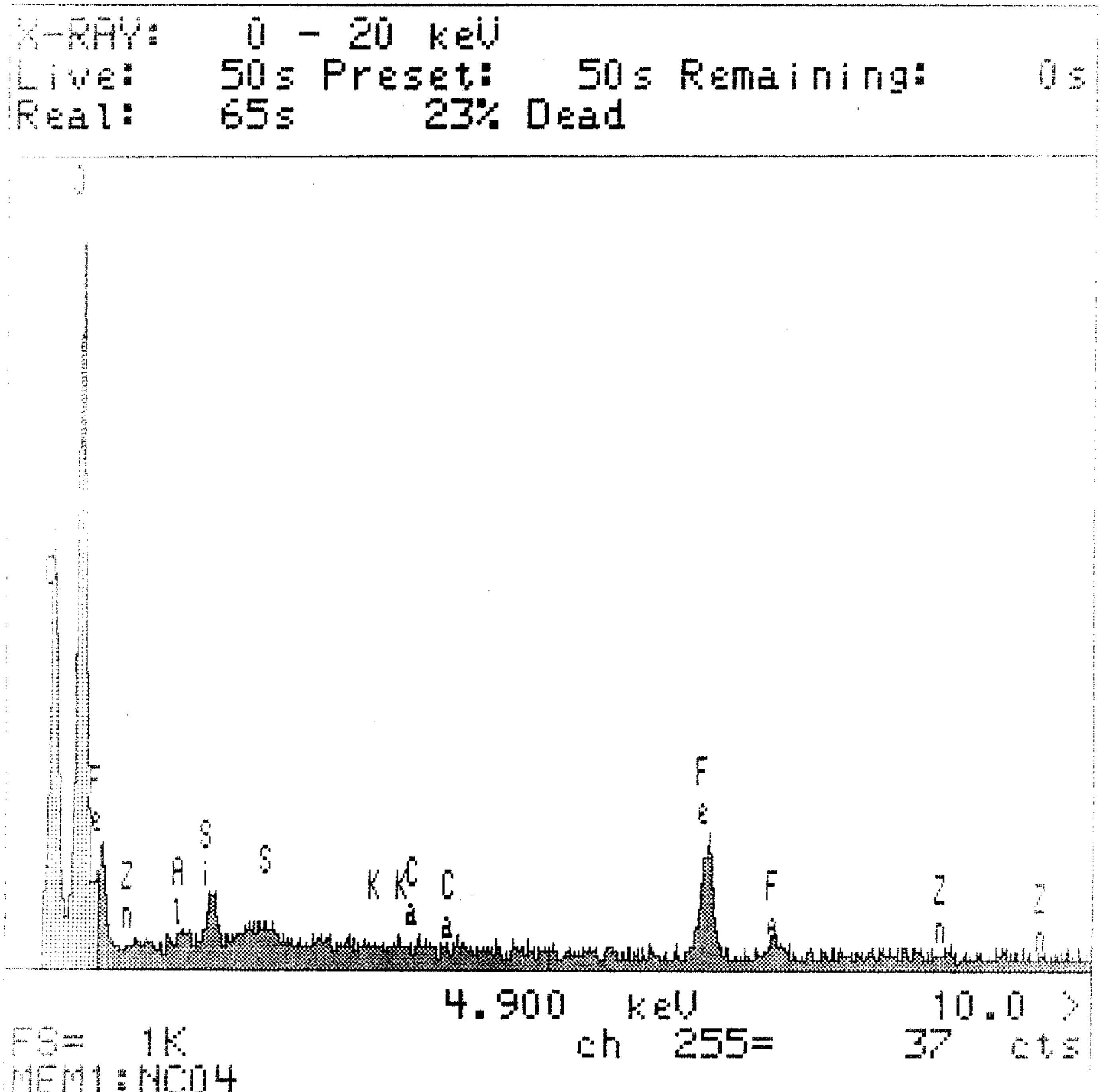
Spectrum: NCØ3 * INITIAL START-UP *

All elmts analysed,NORMALISED

ELMT		ZAF	%ELMT	+-	Error	ATOM.%
[illegible]	: Ø	.739	< .1Ø4	+-	.Ø52	
[illegible]	: Ø	.329	< .Ø76	+-	.Ø38	
[illegible]	: Ø	.674	< .149	+-	.Ø74	
[illegible]	: Ø	.848	< .421	+-	.211	
[illegible]	: Ø	.938	61.942	+-	3.9Ø8	47.763
[illegible]	: Ø	.831	< .325	+-	.163	
[illegible]	: Ø	.91Ø	< .156	+-	.Ø78	
AlK	: Ø	.467	6.965	+-	2.238	11.118
SiK	: Ø	.547	15.773	+-	1.774	24.183
[illegible]	: Ø	.926	< .1Ø9	+-	.Ø55	
[illegible]	: Ø	.791	< .8Ø5	+-	.4Ø2	
[illegible]	: Ø	1.Ø29	< .142	+-	.Ø71	
[illegible]	: Ø	.978	< .1Ø6	+-	.Ø53	
[illegible]	: Ø	.951	< .1Ø5	+-	.Ø52	
TOTAL			84.681			1ØØ.ØØØ

Figure 5

Buchans OWP 32 Sed Trap 10/7/95



Spectrum file : NCØ4

NCØ4 LIVETIME(spec.)= 5Ø

ENERGY	RES	AREA
[illegible].Ø	8Ø.63	35792

[illegible] AREA= 32676

[illegible] at .5Ø keV omitted?

[illegible] INDEX= 1.26

[illegible]	APP.CONC	ERROR(WT%)
[illegible] : Ø	-.Ø49	.Ø59* < 2 Sigma*
[illegible] : Ø	.132	.Ø51
[illegible] : Ø	.125	.Ø84* < 2 Sigma*
[illegible] : Ø	.419	.293* < 2 Sigma*
[illegible] : Ø	3.168	.219
[illegible] : Ø	.Ø23	.222* < 2 Sigma*
[illegible] : Ø	.Ø35	.1Ø4* < 2 Sigma*
[illegible] : Ø	.Ø73	.Ø67* < 2 Sigma*
[illegible] : Ø	.416	.Ø6Ø
[illegible] : Ø	-.Ø95	.Ø7Ø* < 2 Sigma*
[illegible] : Ø	-.445	.547* < 2 Sigma*
[illegible] : Ø	-.Ø43	.Ø92* < 2 Sigma*
[illegible] : Ø	.Ø56	.Ø66* < 2 Sigma*
[illegible] : Ø	-.Ø43	.Ø63* < 2 Sigma*
[illegible] : Ø	.133	.965* < 2 Sigma*Not used for quantitation
[illegible] : Ø	.293	.188* < 2 Sigma*Not used for quantitation

[illegible] CALCULATIONS

[illegible] iterations]

[illegible].ØØ kV TILT=15.ØØ ELEV=1Ø.ØØ AZIM=15.ØØ COSINE=1.ØØØ

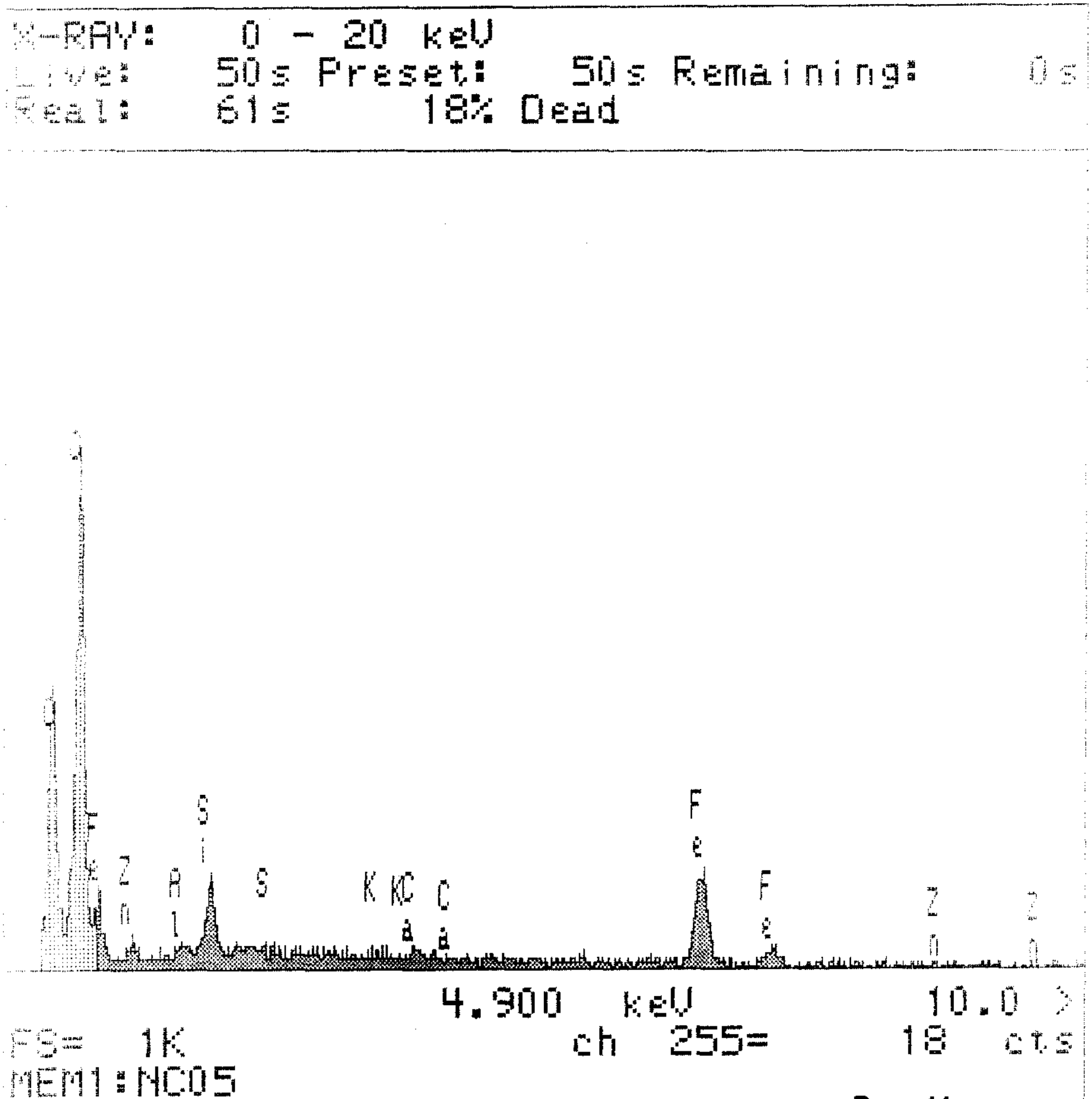
[illegible] NCØ4 * INITIAL START-UP *

All elmts analysed,NORMALISED

ELMT	ZAF	%ELMT	+-	Error	ATOM.%
ClK : Ø	.737	< .117	+-	.Ø59	
NaK : Ø	.325	7.441	+-	2.891	13.964
P K : Ø	.674	< .167	+-	.Ø84	
[illegible] : Ø	.853	< .586	+-	.293	
[illegible] : Ø	.947	6Ø.817	+-	4.211	46.981
[illegible] : Ø	.836	< .444	+-	.222	
[illegible] : Ø	.918	< .2Ø7	+-	.1Ø4	
[illegible] : Ø	.431	< .135	+-	.Ø67	
[illegible] : Ø	.535	14.132	+-	2.Ø48	21.7Ø5
[illegible] : Ø	.934	< .139	+-	.Ø7Ø	
[illegible] : Ø	.792	<1.Ø94	+-	.547	
[illegible] : Ø	1.Ø43	< .183	+-	.Ø92	
[illegible] : Ø	.99Ø	< .131	+-	.Ø66	
[illegible] : Ø	.959	< .127	+-	.Ø63	
TOTAL		82.39Ø			1ØØ.ØØØ

Figure 6

Buchans PP-10 Folating Mat Algae 12/7/95



[illegible] file : NCØ5

LIVETIME(spec.)= 5Ø

ENERGY	RES	AREA
5.8	8Ø.29	35452

[illegible] AREA= 18555

Peak at .5Ø keV omitted?

[illegible] INDEX= 1.Ø2

	APP.CONC	ERROR(WT%)
[illegible] : Ø	.Ø26	.Ø49* < 2 Sigma*
[illegible] : Ø	.152	.Ø42
[illegible] : Ø	.Ø52	.Ø66* < 2 Sigma*
[illegible] : Ø	-.Ø88	.167* < 2 Sigma*
[illegible] : Ø	2.552	.18Ø
[illegible] : Ø	.Ø58	.139* < 2 Sigma*
[illegible] : Ø	.Ø67	.Ø83* < 2 Sigma*
[illegible] : Ø	.Ø86	.Ø57* < 2 Sigma*
[illegible] : Ø	.6ØØ	.Ø57
[illegible] : Ø	-.Ø18	.Ø55* < 2 Sigma*
[illegible] : Ø	-.1Ø5	.311* < 2 Sigma*
[illegible] : Ø	-.Ø56	.Ø66* < 2 Sigma*
[illegible] : Ø	.Ø8Ø	.Ø53* < 2 Sigma*
[illegible] : Ø	.Ø99	.Ø51* < 2 Sigma*
[illegible] : Ø	.5Ø4	.567* < 2 Sigma*Not used for quantitation
[illegible] : Ø	-.ØØ7	.145* < 2 Sigma*Not used for quantitation

[illegible] CALCULATIONS

[illegible] iterations]

[illegible] kV TILT=15.ØØ ELEV=1Ø.ØØ AZIM=15.ØØ COSINE=1.ØØØ

[illegible]: NCØ5

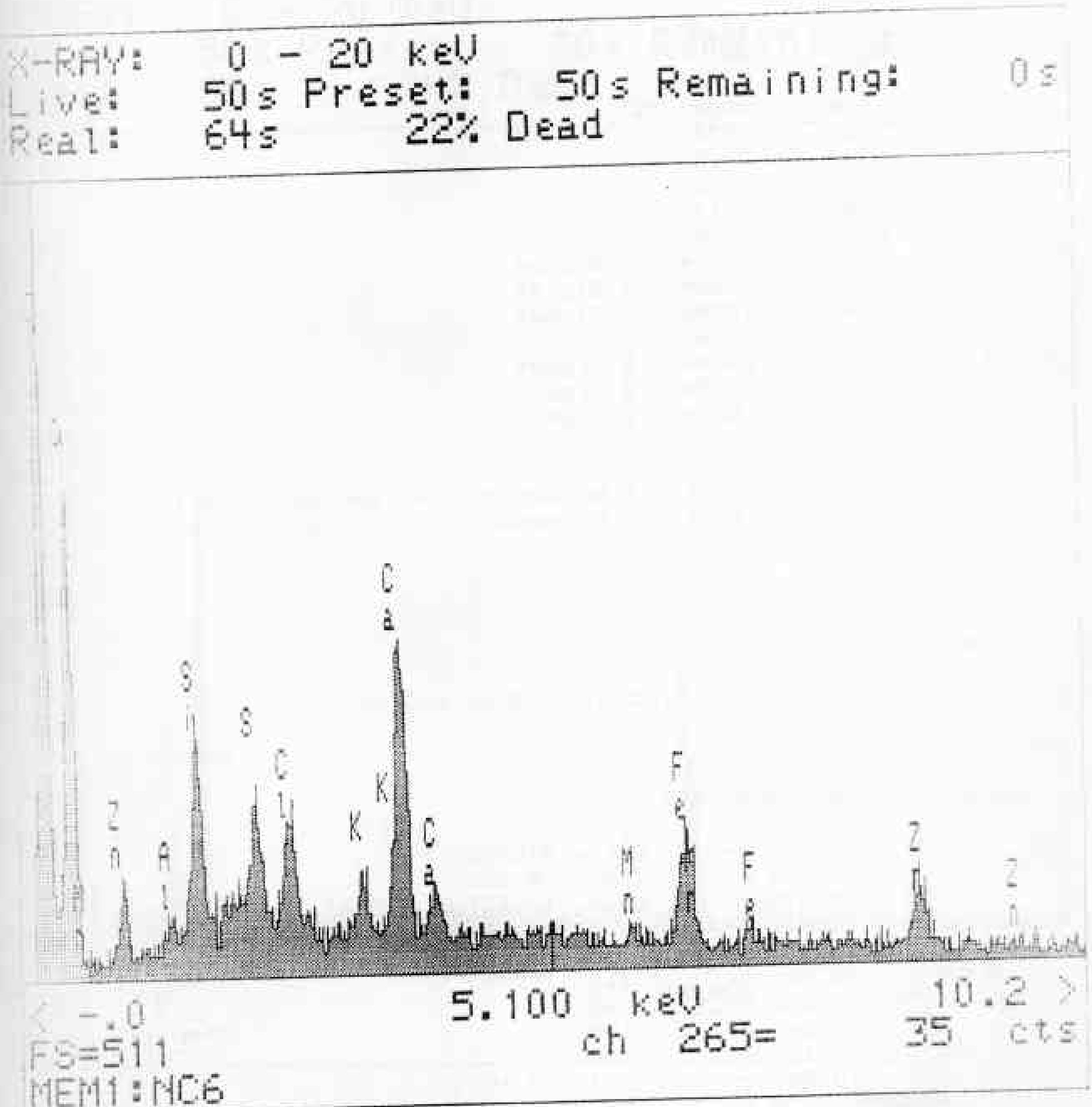
* INITIAL START-UP *

[illegible] elmts analysed,NORMALISED

[illegible]	ZAF	%ELMT	+-	Error	ATOM.%
[illegible] : Ø	.732	< .Ø98	+-	.Ø49	
[illegible] : Ø	.358	8.754	+-	2.428	15.1Ø9
[illegible] : Ø	.659	< .132	+-	.Ø66	
[illegible] : Ø	.837	< .334	+-	.167	
[illegible] : Ø	.919	56.863	+-	4.ØØ8	4Ø.4Ø1
Cu K : Ø	.821	< .279	+-	.139	
Mn K : Ø	.893	< .167	+-	.Ø83	
[illegible] : Ø	.473	< .113	+-	.Ø57	
[illegible] : Ø	.572	21.453	+-	2.Ø21	3Ø.3Ø6
[illegible] : Ø	.9Ø3	< .11Ø	+-	.Ø55	
[illegible] : Ø	.78Ø	< .622	+-	.311	
[illegible] : Ø	1.ØØ2	< .132	+-	.Ø66	
[illegible] : Ø	.959	< .1Ø5	+-	.Ø53	
[illegible] : Ø	.944	< .1Ø2	+-	.Ø51	
[illegible]TAL		87.Ø7Ø			1ØØ.ØØØ

Figure 7

Buchans PP-1Moss 12/7/95



[illegible]ectrum file : NC6
[illegible]
LIVETIME(spec.)= 50

[illegible]ENERGY	RES	AREA
[illegible] 9.5	83.96	35313

[illegible] AREA= 22662

[illegible] at .50 keV omitted?
[illegible] INDEX= 1.45

ELMT	APP.CONC	ERROR(WT%)	
[illegible]	.586	.074	
[illegible]	.279	.045	
[illegible]	.582	.096	
[illegible]	1.968	.314	
[illegible]	1.630	.170	
[illegible]	.015	.166*	< 2 Sigma*
[illegible]	.175	.100*	< 2 Sigma*
[illegible]	.064	.058*	< 2 Sigma*
[illegible]	.854	.066	
[illegible]	-.012	.064*	< 2 Sigma*
[illegible]	.241	.357*	< 2 Sigma*
[illegible]	.067	.085*	< 2 Sigma*
[illegible]	1.832	.104	
[illegible]	.395	.070	
[illegible]	.898	.706*	< 2 Sigma*Not used for quantitation
[illegible]	.118	.194*	< 2 Sigma*Not used for quantitation

ZAF CALCULATIONS

[illegible] 2 iterations)

[illegible] KV TILT=15.00 ELEV=10.00 AZIM=15.00 COSINE=1.000

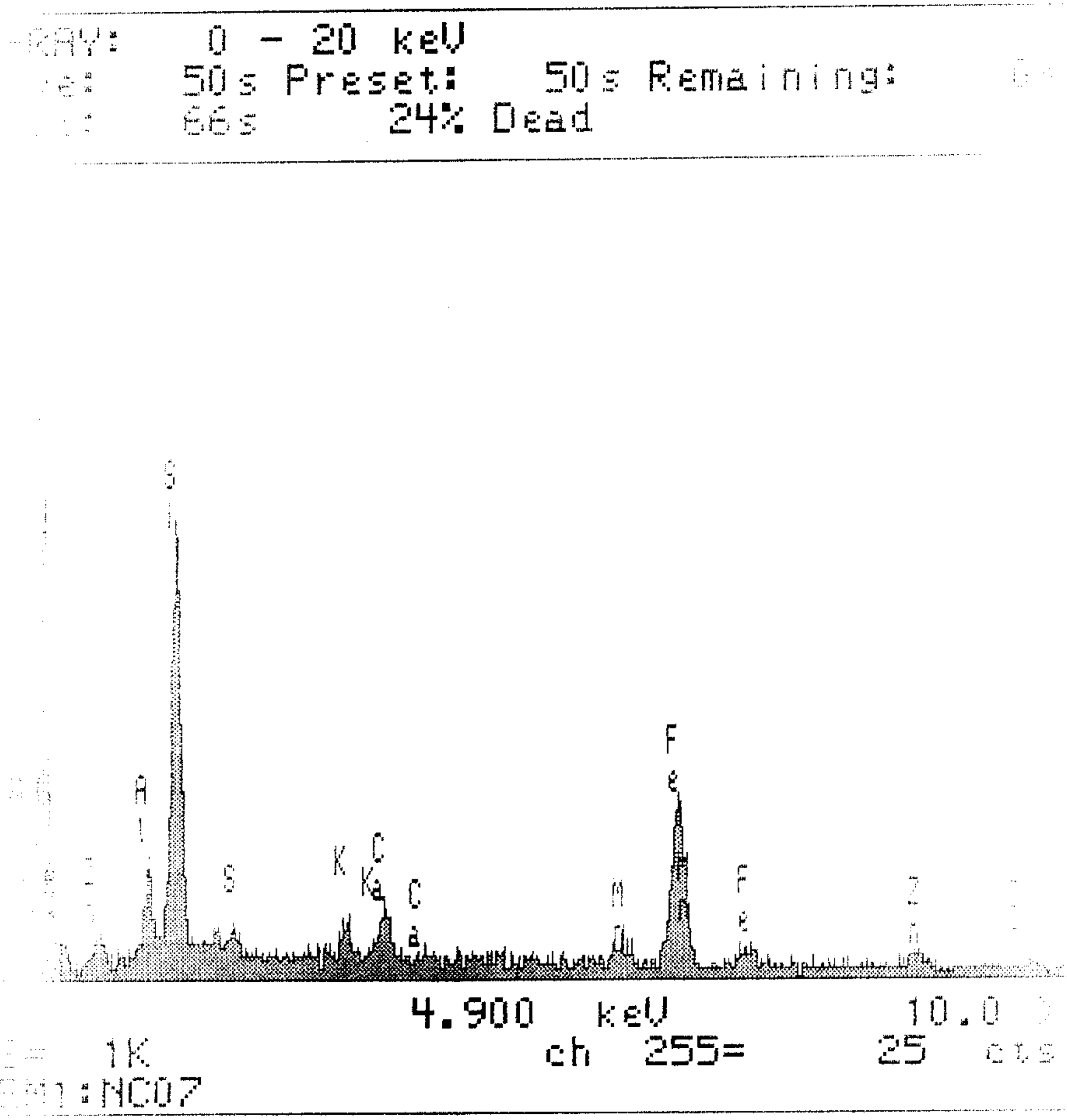
[illegible]trum: NC6 * INITIAL START-UP *

All elmts analysed,NORMALISED

ELMT	ZAF	%ELMT	+-	Error	ATOM.%
[illegible] : 0	.735	7.205	+-	.907	8.232
[illegible] : 0	.423	5.978	+-	.958	10.531
[illegible] : 0	.707	7.440	+-	1.223	9.398
[illegible] : 0	.863	20.625	+-	3.288	12.779*
[illegible] : 0	.893	16.509	+-	1.716	11.972
[illegible] : 0	.852	< .332	+-	.166	
[illegible] : 0	.855	< .200	+-	.100	
[illegible] : 0	.471	< .116	+-	.058	
[illegible] : 0	.581	13.287	+-	1.023	19.157
[illegible] : 0	.788	< .128	+-	.064	
[illegible] : 0	.777	< .714	+-	.357	
[illegible] : 0	.863	< .169	+-	.085	
[illegible] : 0	.906	18.285	+-	1.035	18.477
[illegible] : 0	.911	3.924	+-	.699	4.065
TOTAL		93.254			100.000

Figure 8

Buchans PP-13 Bubble Algae 12/7/95



pectrum file : NCØ7

CØ7 LIVETIME(spec.)= 5Ø

ENERGY	RES	AREA
5.6	83.28	36199

TAL AREA= 32Ø39

ak at .5Ø keV omitted?

T INDEX= 1.75

ELMT		APP.CONC	ERROR(WT%)
[illegible]	: Ø	.Ø22	.Ø56* < 2 Sigma*
[illegible]	: Ø	.337	.Ø53
[illegible]	: Ø	.141	.Ø83* < 2 Sigma*
[illegible]	: Ø	.866	.313
[illegible]	: Ø	4.569	.249
[illegible]	: Ø	-.Ø89	.2Ø2* < 2 Sigma*
[illegible]	[illegible]	.5Ø5	.127
[illegible]	[illegible]	.7Ø8	.Ø93
[illegible]	[illegible]	3.576	.111
[illegible]	[illegible]	-.Ø37	.Ø72* < 2 Sigma*
[illegible]	[illegible]	.29Ø	.485* < 2 Sigma*
[illegible]	: Ø	-.Ø6Ø	.Ø92* < 2 Sigma*
[illegible]	: Ø	.531	.Ø8Ø
[illegible]	: Ø	.411	.Ø74
[illegible]	: Ø	1.Ø62	.9Ø7* < 2 Sigma*Not used for quantitatio
[illegible]	: Ø	.131	.194* < 2 Sigma*Not used for quantitati

F CALCULATIONS

(3 iterations]

.ØØ kV TILT=15.ØØ ELEV=1Ø.ØØ AZIM=15.ØØ COSINE=1.ØØØ

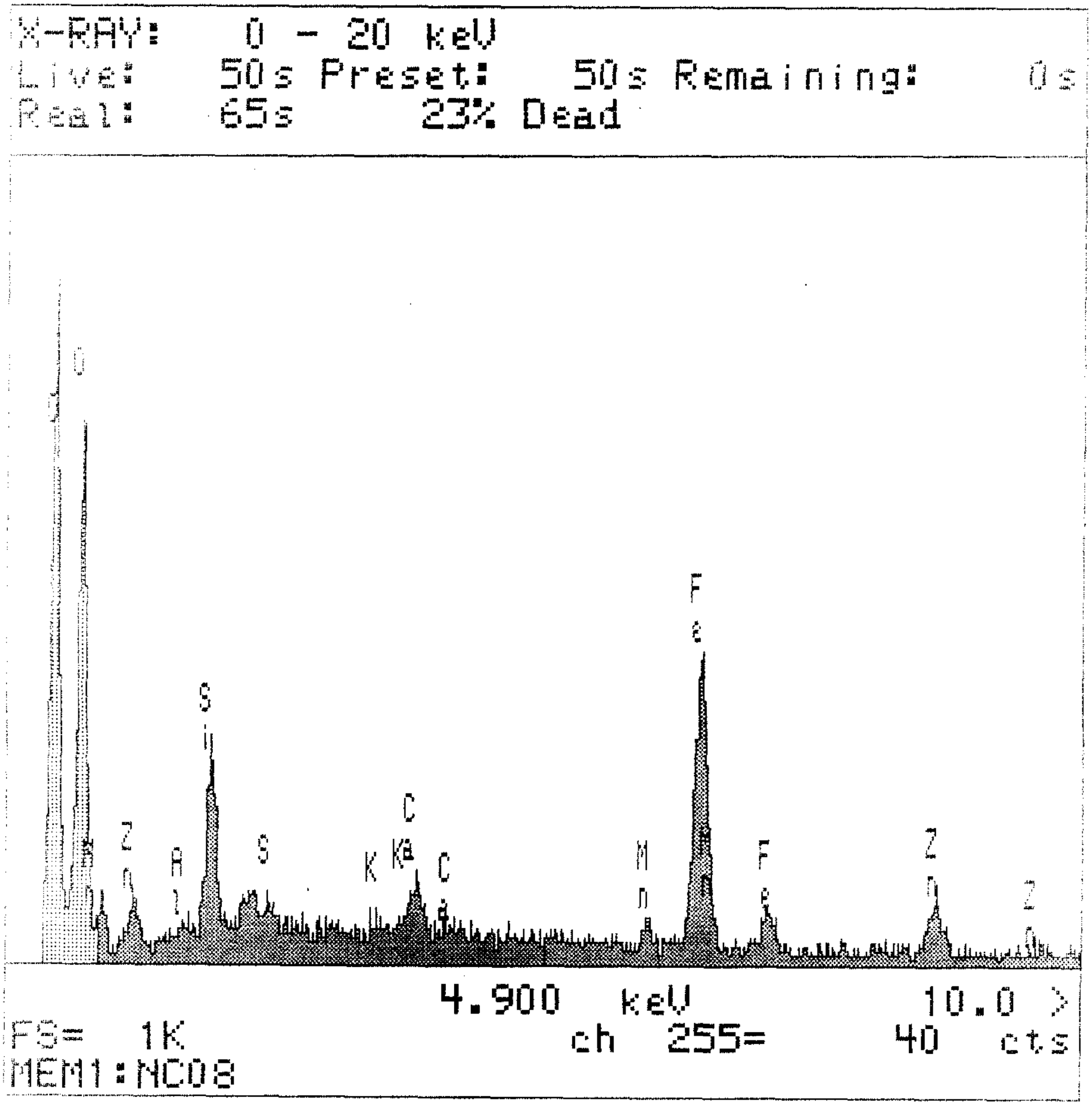
pectrum: NCØ7 * INITIAL START-UP *

elmts analysed,NORMALISED

ELMT		ZAF	%ELMT	+-	Error	ATOM.%
[illegible]	Ø	.666	< .111	+-	.Ø56	
[illegible]	: Ø	.456	4.49Ø	+-	.7Ø2	7.126
[illegible]	: Ø	.59Ø	< .166	+-	.Ø83	
[illegible]	: Ø	.837	6.28Ø	+-	2.274	3.5Ø5 *
[illegible]	[illegible]	.891	31.166	+-	1.7Ø1	2Ø.361
[illegible]	: Ø	.826	< .4Ø4	+-	.2Ø2	
[illegible]	: Ø	.86Ø	3.563	+-	.895	2.367
[illegible]	: Ø	.545	7.892	+-	1.Ø33	1Ø.672
[illegible]	: Ø	.6ØØ	36.23Ø	+-	1.12Ø	47.Ø6Ø
[illegible]	: Ø	.835	< .144	+-	.Ø72	
[illegible]	: Ø	.766	< .969	+-	.485	
[illegible]	: Ø	.9Ø7	< .184	+-	.Ø92	
[illegible]	: Ø	.894	3.6Ø6	+-	.542	3.283
[illegible]	: Ø	.88Ø	2.84Ø	+-	.512	2.65Ø
TAL			96.Ø66			1ØØ.ØØØ

Figure 9

Buchans PP-14 Folating Algae 12/7/95



Spectrum file : NCØ8
NCØ8 LIVETIME(spec.)= 5Ø

ENERGY	RES	AREA
- 5.6	81.5Ø	36ØØØ

TOTAL AREA= 38372
......
Peak at .5Ø keV omitted?
FIT INDEX= 2.Ø6

ELMT	APP.CONC	ERROR(WT%)
ClK : Ø	-.Ø15	.Ø67* < 2 Sigma*
NaK : Ø	.368	.Ø59
S K : Ø	.164	.Ø97* < 2 Sigma*
ZnK : Ø	3.312	.4Ø7
FeK : Ø	7.914	.315
CuK : Ø	.284	.221* < 2 Sigma*
MnK : Ø	.549	.133
AlK : Ø	-.Ø31	.Ø74* < 2 Sigma*
SiK : Ø	1.534	.Ø85
TiK : Ø	.ØØ8	.Ø8Ø* < 2 Sigma*
AsK : Ø	.Ø4Ø	.538* < 2 Sigma*
CrK : Ø	-.Ø85	.1Ø3* < 2 Sigma*
CaK : Ø	.569	.Ø92
K K : Ø	.141	.Ø76* < 2 Sigma*
SnL : Ø	-.Ø97	.949* < 2 Sigma*Not used for quantitation
[illegible] : Ø	.356	.224* < 2 Sigma*Not used for quantitation

ZAF CALCULATIONS

...[3 iterations]

20.ØØ kV TILT=15.ØØ ELEV=1Ø.ØØ AZIM=15.ØØ COSINE=1.ØØØ

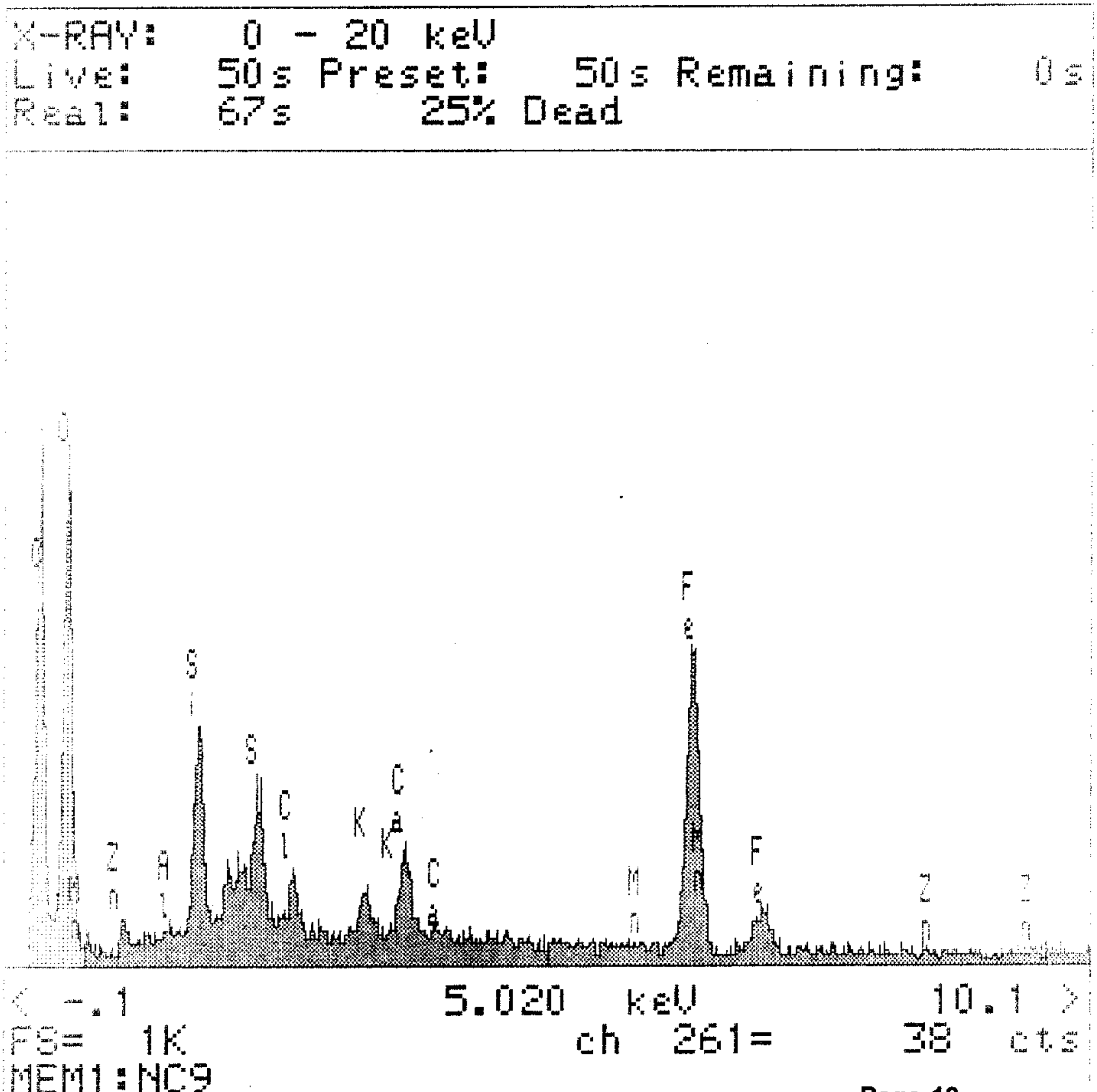
Spectrum: NCØ8 * INITIAL START-UP *

All elmts analysed,NORMALISED

ELMT	ZAF	%ELMT	+-	Error	ATOM.%
ClK : Ø	.736	< .135	+-	.Ø67	
NaK : Ø	.323	6.318	+-	1.ØØ7	12.352
S K : Ø	.659	< .194	+-	.Ø97	
ZnK : Ø	.871	21.Ø67	+-	2.59Ø	14.485 *
FeK : Ø	.96Ø	45.686	+-	1.82Ø	36.768
CuK : Ø	.857	< .442	+-	.221	
MnK : Ø	.925	3.286	+-	.798	2.688
AlK : Ø	.41Ø	< .148	+-	.Ø74	
SiK : Ø	.529	16.Ø8Ø	+-	.89Ø	25.73Ø
TiK : Ø	.916	< .161	+-	.Ø8Ø	
AsK : Ø	.796	<1.Ø77	+-	.538	
CrK : Ø	1.ØØ7	< .2Ø6	+-	.1Ø3	
CaK : Ø	.984	3.2Ø5	+-	.516	3.594
K K : Ø	.96Ø	< .151	+-	.Ø76	
TOTAL		95.641			1ØØ.ØØØ

Figure 10

Buchans PP-14 Filamentous Algae 12/7/95



Spectrum file : NC9

NC9 LIVETIME(spec.)= 50

ENERGY	RES	AREA
6.1	83.57	36585

TOTAL AREA= 37382

......

Peak at .50 keV omitted?

FIT INDEX= 1.96

ELMT	APP.CONC	ERROR(WT%)
ClK : Ø	.639	.Ø83
NaK : Ø	.271	.Ø51
S K : Ø	1.149	.131
[illegible] : Ø	.Ø11	.274* < 2 Sigma*
FeK : Ø	8.5Ø5	.314
[illegible]	.Ø2Ø	.215* < 2 Sigma*
[illegible]	.Ø12	.117* < 2 Sigma*
[illegible]	.Ø29	.Ø73* < 2 Sigma*
SiK : Ø	1.864	.Ø89
[illegible] : Ø	.Ø35	.Ø8Ø* < 2 Sigma*
AsK : Ø	.239	.483* < 2 Sigma*
CrK : Ø	.ØØ2	.Ø98* < 2 Sigma*
CaK : Ø	.995	.Ø99
[illegible] : Ø	.524	.Ø87
[illegible] : Ø	.1Ø2	.934* < 2 Sigma*Not used for quantitation
[illegible] : Ø	.177	.282* < 2 Sigma*Not used for quantitation

ZAF CALCULATIONS

[2 iterations]

10.ØØ kV TILT=15.ØØ ELEV=1Ø.ØØ AZIM=15.ØØ COSINE=1.ØØØ

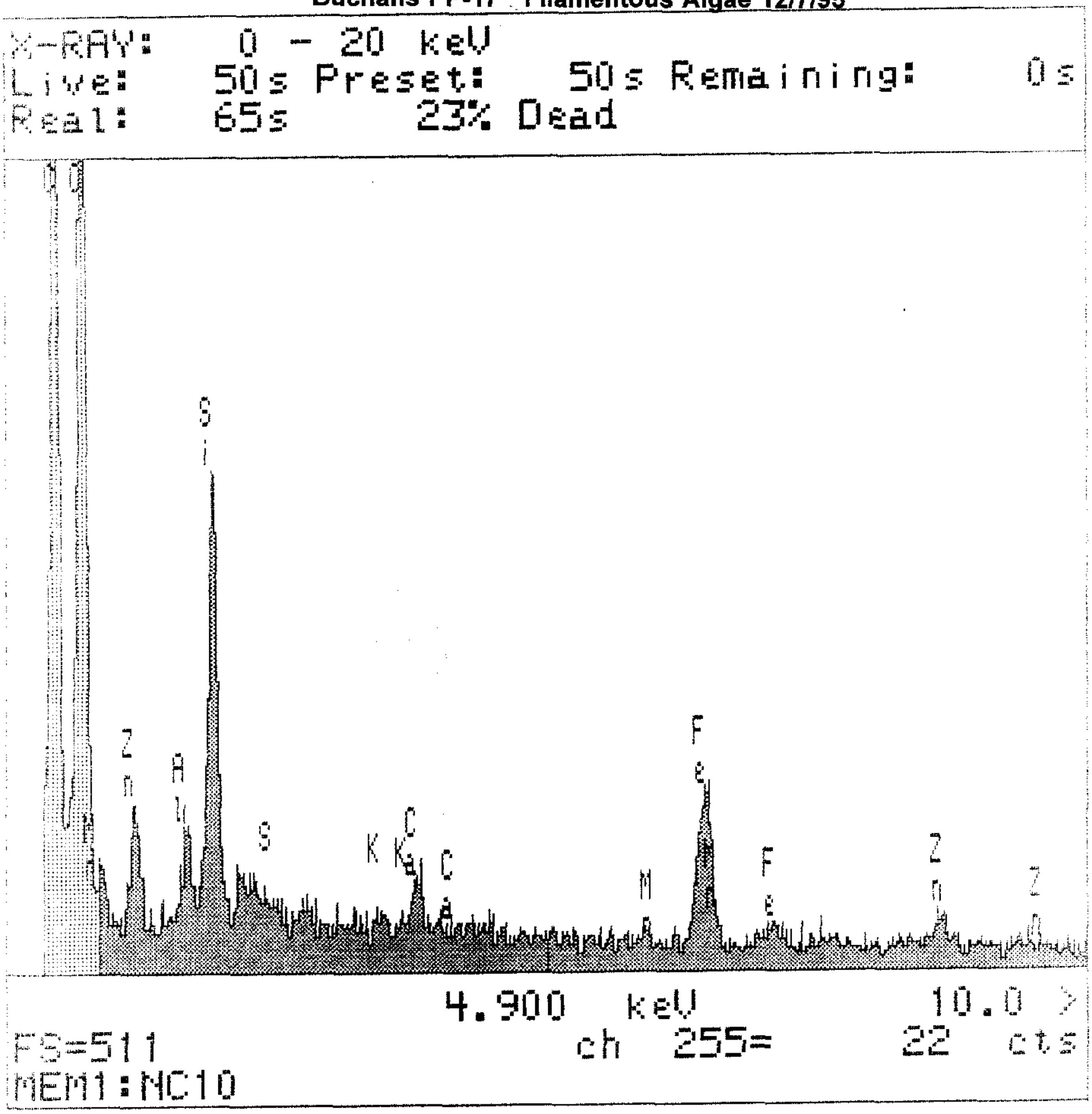
Spectrum: NC9 * INITIAL START-UP *

All elmts analysed,NORMALISED

ELMT	ZAF	%ELMT	+-	Error	ATOM.%
ClK : Ø	.731	4.925	+-	.641	5.7Ø5
NaK : Ø	.371	4.135	+-	.778	7.387
S K : Ø	.714	9.Ø78	+-	1.Ø38	11.63Ø
SnK : Ø	.839	< .547	+-	.274	
FeK : Ø	.9Ø5	53.Ø76	+-	1.962	39.Ø32
CuK : Ø	.823	< .431	+-	.215	
ZnK : Ø	.875	< .234	+-	.117	
P K : Ø	.499	< .147	+-	.Ø73	
SiK : Ø	.619	16.983	+-	.813	24.831
TiK : Ø	.86Ø	< .16Ø	+-	.Ø8Ø	
AsK : Ø	.782	< .965	+-	.483	
CrK : Ø	.953	< .196	+-	.Ø98	
CaK : Ø	.929	6.Ø42	+-	.6Ø2	6.192
K K : Ø	.919	3.215	+-	.535	3.377
TOTAL		97.453			1ØØ.ØØØ

Figure 11

Buchans PP-17 Filamentous Algae 12/7/95



Spectrum file : NC1Ø

NC1Ø LIVETIME(spec.)= 5Ø

ENERGY	RES	AREA
5.5	84.16	36449

TOTAL AREA= 28823

Peak at .5Ø keV omitted?

FIT INDEX= 1.72

ELMT		APP.CONC	ERROR(WT%)
ClK :	Ø	.136	.Ø58
NaK :	Ø	.437	.Ø61
S K :	Ø	-.Ø16	.Ø79* < 2 Sigma*
ZnK :	Ø	.933	.293
FeK :	Ø	2.265	.194
CuK :	Ø	-.Ø75	.184* < 2 Sigma*
MnK :	Ø	.ØØ8	.Ø95* < 2 Sigma*
AlK :	Ø	.4Ø9	.Ø8Ø
SiK :	Ø	1.866	.Ø86
TiK :	Ø	-.Ø56	.Ø66* < 2 Sigma*
AsK :	Ø	-.572	.447* < 2 Sigma*
CrK :	Ø	.Ø29	.Ø8Ø* < 2 Sigma*
CaK :	Ø	.233	.Ø69
K K :	Ø	.Ø99	.Ø6Ø* < 2 Sigma*
[illegible] :	Ø	.Ø68	.759* < 2 Sigma*Not used for quantitation
[illegible] :	Ø	-.133	.184* < 2 Sigma*Not used for quantitation

ZAF CALCULATIONS

...[3 iterations]

2Ø.ØØ kV TILT=15.ØØ ELEV=1Ø.ØØ AZIM=15.ØØ COSINE=1.ØØØ

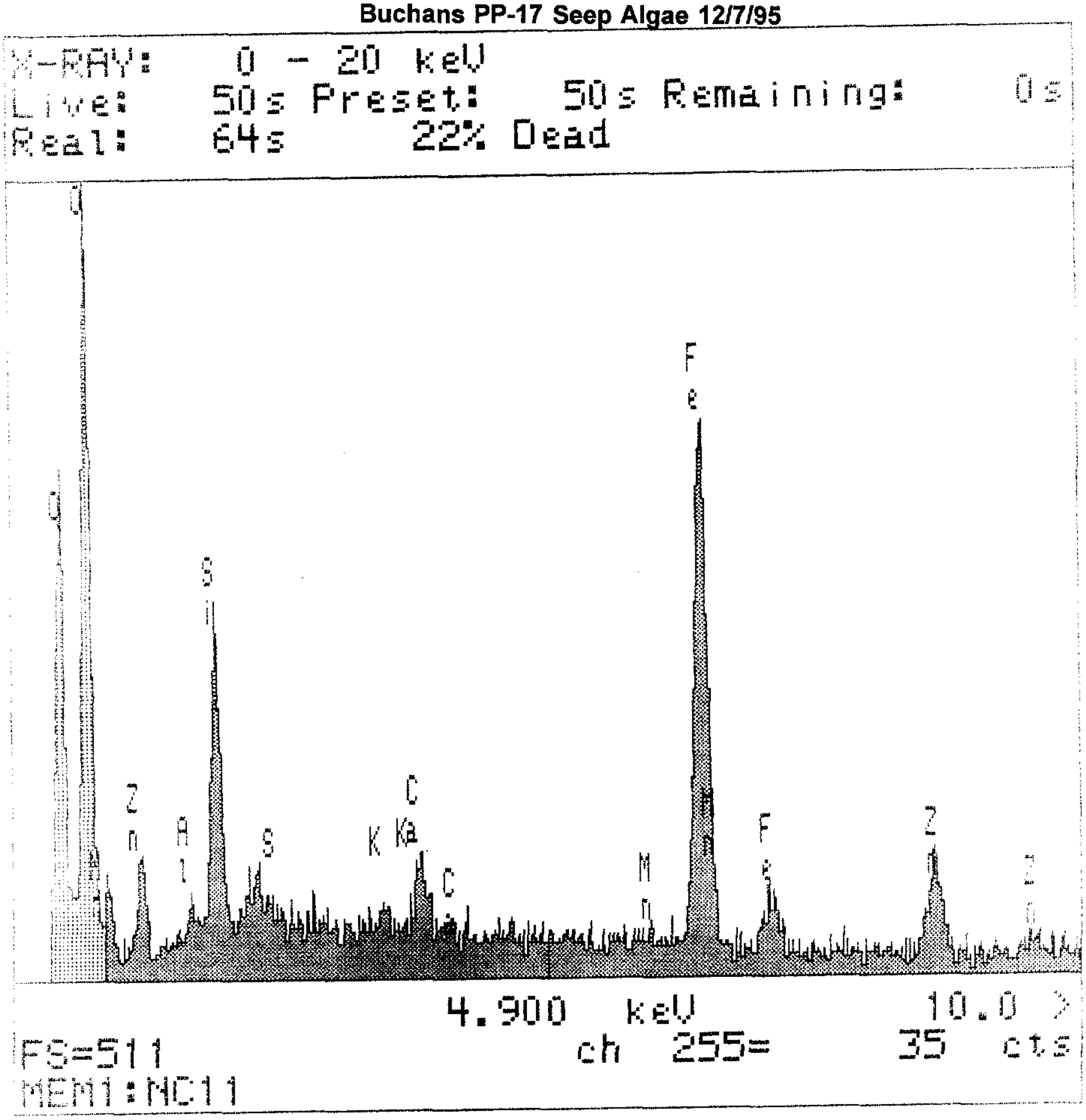
Spectrum: NC1Ø * INITIAL START-UP *

All elmts analysed,NORMALISED

ELMT		ZAF	%ELMT	+-	Error	ATOM.%
ClK :	Ø	.664	2.218	+-	.944	2.192
NaK :	Ø	.467	1Ø.125	+-	1.412	15.428
S K :	Ø	.581	< .157	+-	.Ø79	
ZnK :	Ø	.837	12.Ø7Ø	+-	3.79Ø	6.468*
FeK :	Ø	.892	27.5Ø9	+-	2.351	17.255
CuK :	Ø	.828	< .367	+-	.184	
MnK :	Ø	.861	< .191	+-	.Ø95	
AlK :	Ø	.521	8.519	+-	1.666	11.Ø62
SiK :	Ø	.577	35.Ø45	+-	1.617	43.7Ø5
TiK :	Ø	.832	< .132	+-	.Ø66	
AsK :	Ø	.76Ø	< .895	+-	.447	
CrK :	Ø	.9Ø3	< .16Ø	+-	.Ø8Ø	
CaK :	Ø	.891	2.833	+-	.84Ø	2.476
K K :	Ø	.866	< .121	+-	.Ø6Ø	
TOTAL			98.318			1ØØ.ØØØ

Figure 12

Buchans PP-17 Seep Algae 12/7/95



Spectrum file : NC11

NC11 LIVETIME(spec.)= 50

ENERGY	RES	AREA
5.9	82.1Ø	36595

TOTAL AREA= 26835

Peak at .5Ø keV omitted?

FIT INDEX= 1.56

[illegible]		APP.CONC	ERROR(WT%)
ClK :	Ø	.Ø42	.Ø58* < 2 Sigma*
NaK :	Ø	.4Ø9	.Ø52
S K :	Ø	.ØØ7	.Ø79* < 2 Sigma*
ZnK :	Ø	2.825	.365
FeK :	Ø	7.369	.293
CuK :	Ø	.Ø84	.186* < 2 Sigma*
MnK :	Ø	.Ø8Ø	.1Ø5* < 2 Sigma*
AlK :	Ø	.Ø64	.Ø65* < 2 Sigma*
[illegible] :	Ø	1.3Ø8	.Ø76
[illegible] :	Ø	.Ø75	.Ø71* < 2 Sigma*
AsK :	Ø	-.Ø5Ø	.439* < 2 Sigma*
CrK :	Ø	-.11Ø	.Ø87* < 2 Sigma*
CaK :	Ø	.435	.Ø77
[illegible] K :	Ø	.121	.Ø66* < 2 Sigma*
SeL :	Ø	-.361	.868* < 2 Sigma*Not used for quantitation
AuM :	Ø	.214	.187* < 2 Sigma*Not used for quantitation

[illegible] CALCULATIONS

[illegible] 3 iterations]

[illegible].ØØ kV TILT=15.ØØ ELEV=1Ø.ØØ AZIM=15.ØØ COSINE=1.ØØØ

Spectrum: NC11 * INITIAL START-UP *

All elmts analysed,NORMALISED

ELMT		ZAF	%ELMT	+-	Error	ATOM.%
ClK :	Ø	.74Ø	< .117	+-	.Ø58	
NaK :	Ø	.325	7.966	+-	1.ØØ5	15.258
P K :	Ø	.655	< .159	+-	.Ø79	
ZnK :	Ø	.868	2Ø.631	+-	2.666	13.898 *
FeK :	Ø	.956	48.835	+-	1.944	38.5Ø3
CuK :	Ø	.853	< .371	+-	.186	
MnK :	Ø	.922	< .211	+-	.1Ø5	
AlK :	Ø	.4Ø9	< .13Ø	+-	.Ø65	
SiK :	Ø	.523	15.849	+-	.916	24.846
[illegible] :	Ø	.917	< .142	+-	.Ø71	
AsK :	Ø	.794	< .878	+-	.439	
[illegible] :	Ø	1.Ø11	< .174	+-	.Ø87	
CaK :	Ø	.984	2.8Ø2	+-	.497	3.Ø78
[illegible] :	Ø	.961	< .132	+-	.Ø66	
TOTAL			96.Ø85			1ØØ.ØØØ

SEM/EDX

September 15 1996

with 1996 Samples

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SEM/EDX

Table of Contents

SEM/EDX

September 15, 1996

Report on analysis of Buchans sediment samples (1996)

Sample preparation and analysis

Sediment samples from Buchans (10 in all) were examined by high resolution scanning electron microscopy (SEM) and energy dispersive X-ray microanalysis (EDX). Samples fixed in glutaraldehyde were dehydrated by taking them through an ethanol series. The sediments were then dispersed on filter paper and allowed to air dry. All samples were carbon coated prior to examination. Imaging of the samples was carried out using an Hitachi S-4500 field emission SEM (N.B. All micrographs were recorded at a magnification of 20,000x.). Each sample was also analysed by EDX with an analysed area of approx. 50μm x 50μm. A windowless detector was used allowing for the qualitative detection of light elements including carbon and oxygen. Quantative results were obtained for elements in the range Na - U.

Results & Discussion

High Resolution SEM & EDX:

All three OEP samples (13', middle, bottom) have a grain size in the range 0.25-1.0μm. A close examination of the micrographs (Fig.1a,2a,3a) reveals that the grains are uniformly coated with what appear to be precipitate particles. The particles are largest in the OEP 13' sample (approx. 100nm) and smallest in the OEP Bottom sample (approx. 25nm).
The results from EDX analysis of the three samples are shown in fig.1b,2b,3b. All three of the samples have high Fe (40-70%) and Si (15-30%) content. OEP 13' also showed a significant amount of Zn (approx. 3%).

An example of the morphology of the OWP sample is shown in figure 4a. The sample grain size falls in the range 0.25 -1.0μm. The grains are somewhat faceted and free of any obvious surface coating. EDX of the sample (fig.4b) indicates that the grains are aluminosilicate in composition.

The structure of sample D.T. is illustrated in Fig.5a. Examination of the specimen by SEM revealed that the grain size was finer than the other samples (in the range 0.25 - 0.5μm). Additionally, the grains appear to be coated with a smooth, essentially continuous coating. EDX (fig.5b) showed that the sample was Al/Si rich with significant amounts of Fe (20%) and Zn (4%). The coating is probably a thin adsorbed layer. Determination of the specific chemistry of this layer would require alternate analytical techniques.

SEM images for PP11, PP12, PP14 (branch, float & bubble) are shown in figures 6a - 10a respectively. All samples have a grain size in the range 0.25 - 1.0μm. There are no obvious signs of surface adsorption or precipitation. EDX of the samples (fig.6b - 10b) indicate that the samples are essentially aluminosilicates with traces of Fe and no Zn.

Neil A. Coombs, Ph.D., 32 Manning Ave., Toronto, Canada M6J 2K4
Tel./Fax. 416 504-7127

Figure 1a

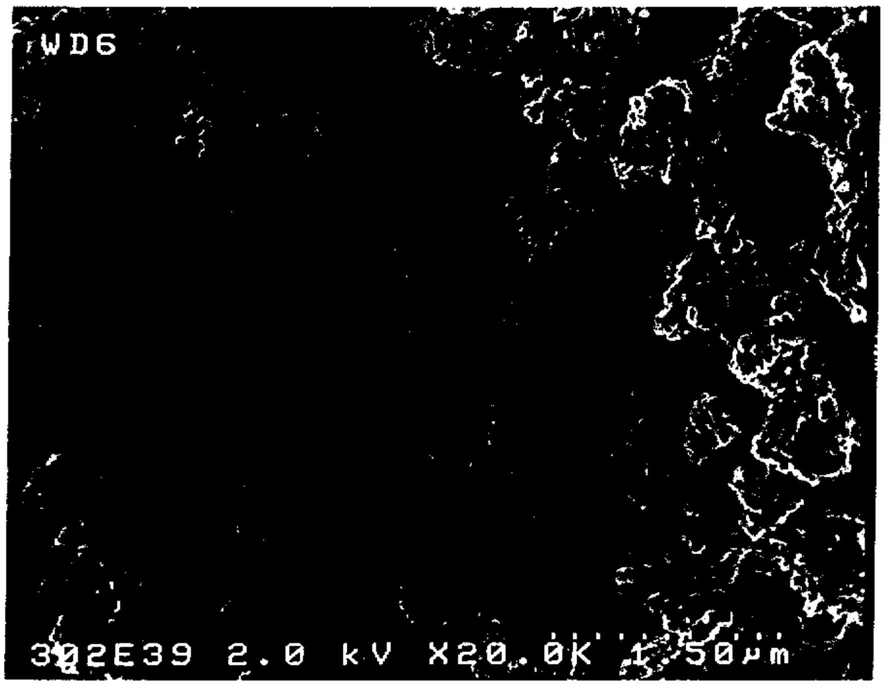
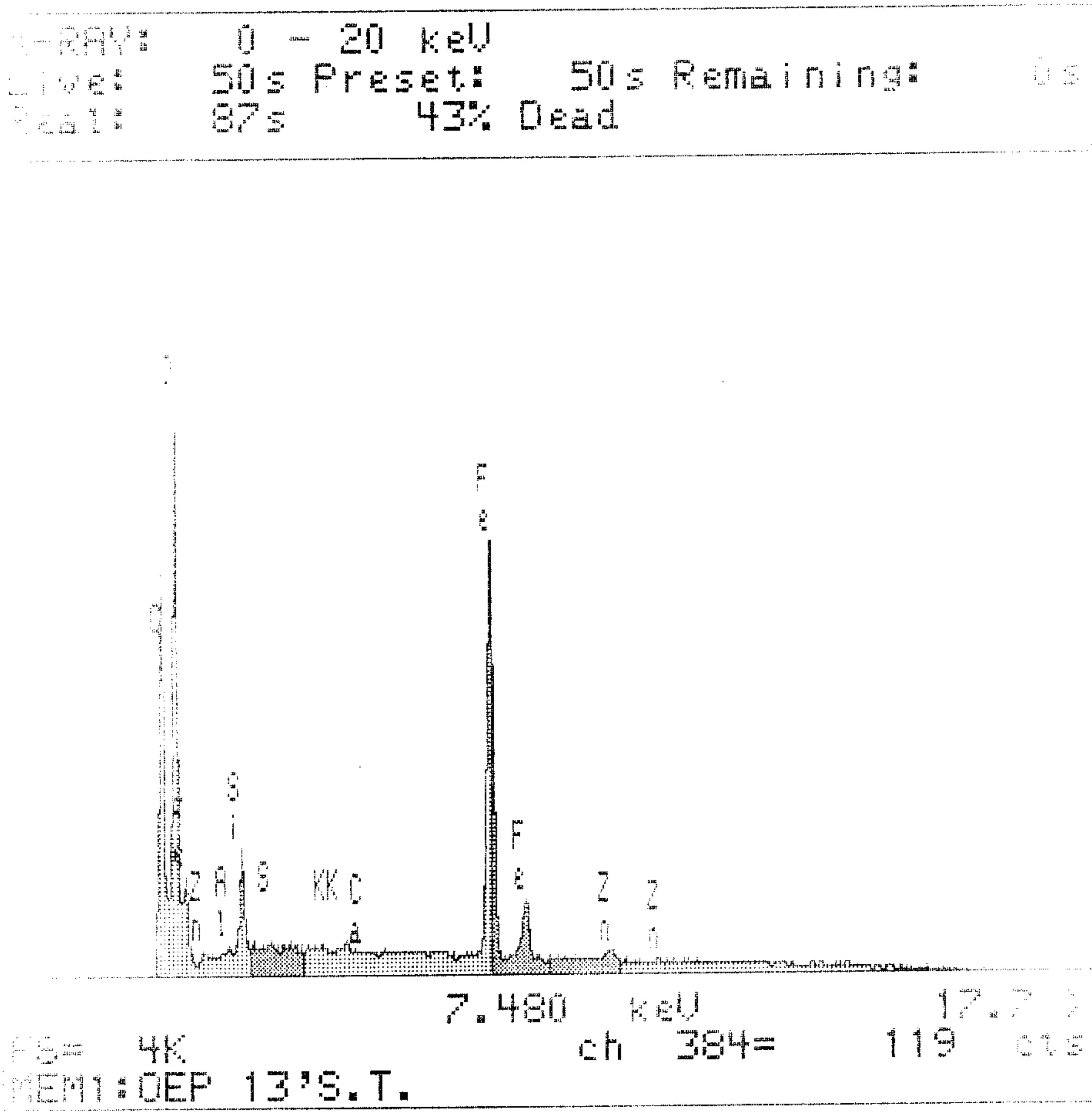


Figure 1b


X-RAY: 0 - 20 keV
Live: 50s Preset: 50s Remaining: 0s
Real: 87s 43% Dead
Fe
Fe
Si
7.480 keV
FS= 4K ch 384= 119 cts
MEM1:DEP 13'S.T.

Spectrum file : NCOEP13
OEP 13'S.T. LIVETIME(spec.)= 5Ø

ENERGY	RES	AREA
4.4	81.97	37621

TOTAL AREA= 1295Ø4

......
Peak at .5Ø keV omitted?
FIT INDEX= 5.49

ELMT	APP.CONC	ERROR(WT%)
NaK : Ø	.61Ø	.Ø92
K K : Ø	-.Ø79	.136* < 2 Sigma*
ClK : Ø	.Ø11	.124* < 2 Sigma*
S K : Ø	-.ØØ4	.123* < 2 Sigma*
CaK : Ø	.427	.142
SiK : Ø	3.372	.136
AlK : Ø	.256	.128
FeK : Ø	5Ø.568	.749
ZnK : Ø	2.312	.637
P K : Ø	.136	.172* < 2 Sigma*

ZAF CALCULATIONS

...[3 iterations]

2Ø.ØØ kV TILT=15.ØØ ELEV=1Ø.ØØ AZIM=15.ØØ COSINE=1.ØØØ

Spectrum: OEP 13'S.T. * INITIAL START-UP *

All elmts analysed,NORMALISED

ELMT	ZAF	%ELMT	+-	Error	ATOM.%
NaK : Ø	.287	3.3Ø6	+-	.5ØØ	6.97Ø
K K : Ø	1.Ø14	< .271	+-	.136	
ClK : Ø	.79Ø	< .248	+-	.124	
S K : Ø	.7Ø5	< .247	+-	.123	
CaK : Ø	1.Ø44	.636	+-	.211	.769
SiK : Ø	.539	9.719	+-	.392	16.771
AlK : Ø	.421	.946	+-	.472	1.699
FeK : Ø	.97Ø	8Ø.9Ø2	+-	1.199	7Ø.216
ZnK : Ø	.857	4.189	+-	1.155	3.1Ø6
P K : Ø	.749	< .344	+-	.172	
TOTAL		99.697			1ØØ.ØØØ

Figure 2a

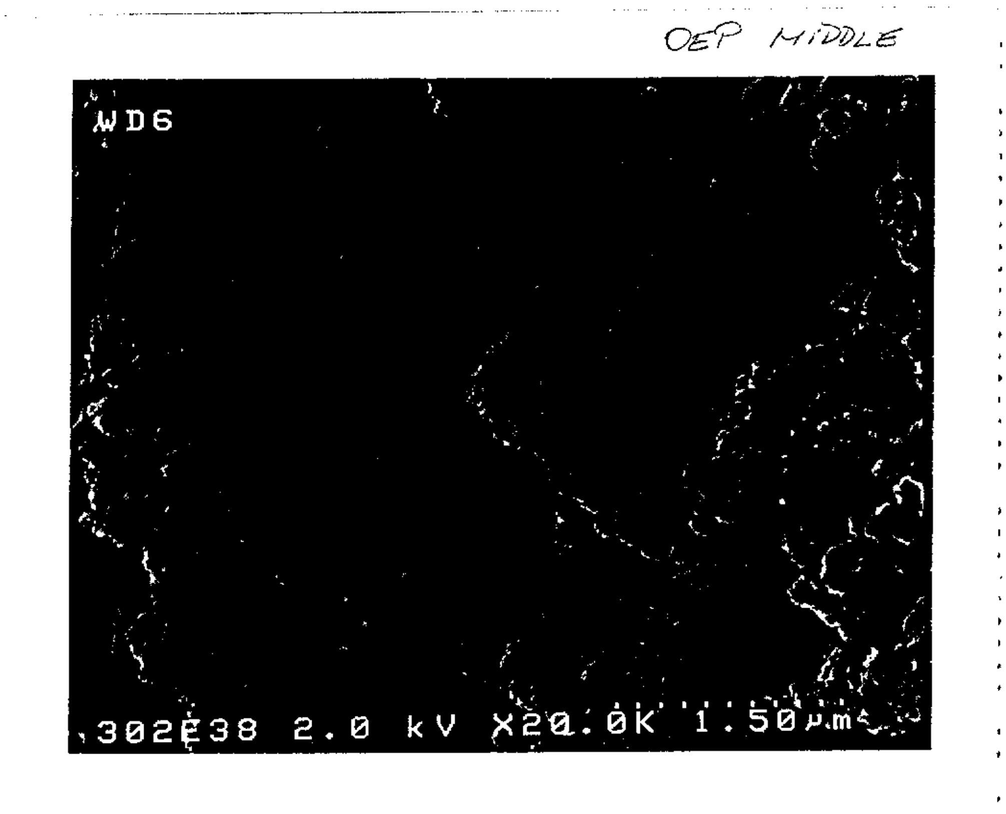
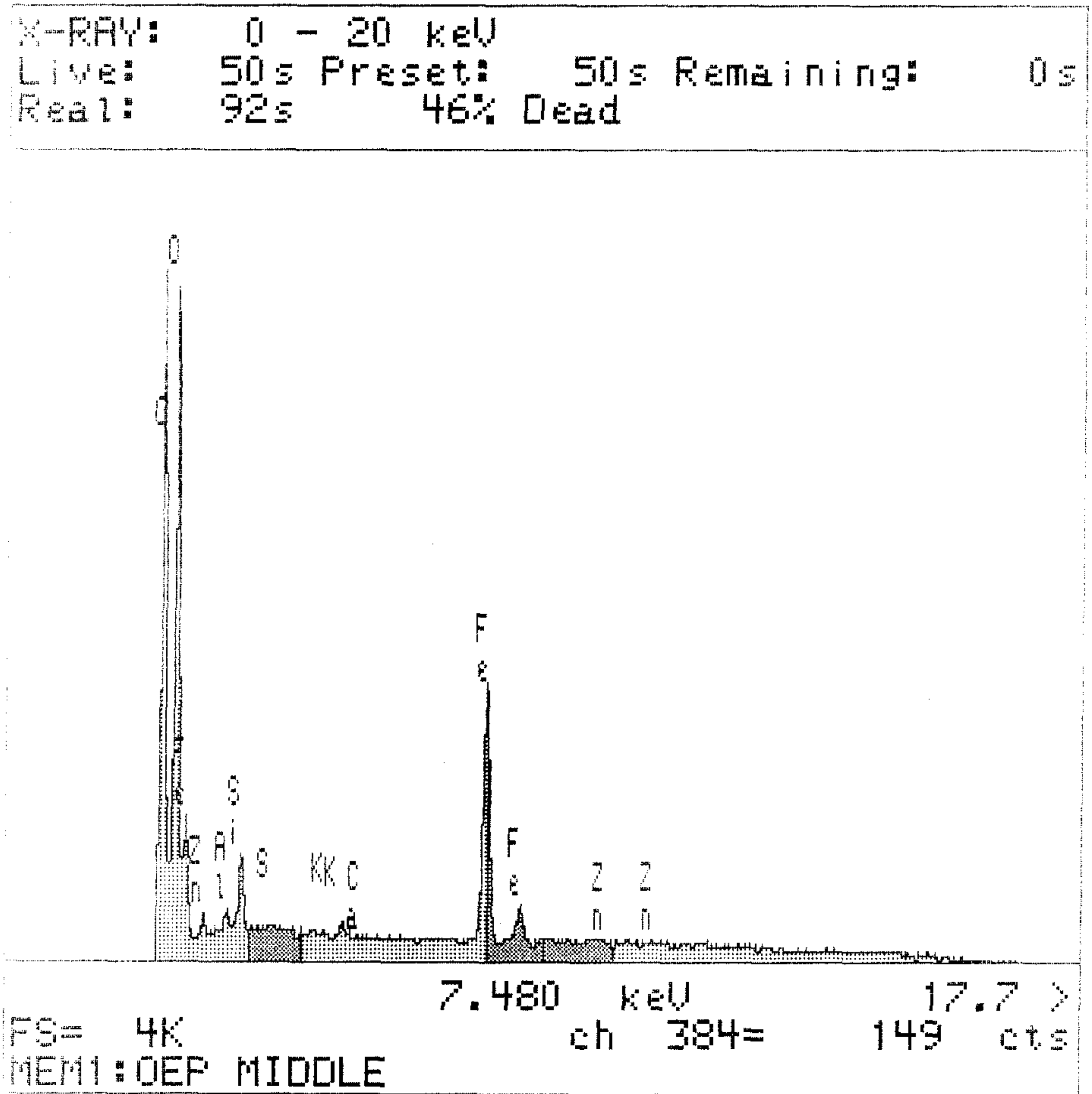


Figure 2b


X-RAY: 0 - 20 keV
Live: 50s Preset: 50s Remaining: 0s
Real: 92s 46% Dead
O
Fe
Si
S
KK
Ca
Zn
Al
Fe
Zn
Zn
7.480 keV
17.7 >
FS= 4K
ch 384= 149 cts
MEM1:OEP MIDDLE

Spectrum file : NCOEPMID

OEP MIDDLE LIVETIME(spec.)= 50

ENERGY	RES	AREA
4.0	81.27	38125

TOTAL AREA= 151830

......

Peak at .50 keV omitted?

FIT INDEX= 5.73

ELMT	APP.CONC	ERROR(WT%)
NaK : 0	1.141	.117
S K : 0	.093	.137* < 2 Sigma*
TiK : 0	-.040	.126* < 2 Sigma*
Cl K : 0	.215	.130* < 2 Sigma*
CaK : 0	.673	.146
SiK : 0	2.729	.140
AlK : 0	.743	.153
FeK : 0	31.181	.637
ZnK : 0	1.042	.669* < 2 Sigma*
P K : 0	.255	.183* < 2 Sigma*

ZAF CALCULATIONS

[... 3 iterations]

20.00 kV TILT=15.00 ELEV=10.00 AZIM=15.00 COSINE=1.000

Spectrum: OEP MIDDLE * INITIAL START-UP *

All elmts analysed,NORMALISED

ELMT	ZAF	%ELMT	+-	Error	ATOM.%
NaK : 0	.313	7.932	+-	.811	15.093
S K : 0	.988	< .275	+-	.137	
TiK : 0	.766	< .251	+-	.126	
Cl K : 0	.687	< .260	+-	.130	
CaK : 0	1.014	1.444	+-	.312	1.576
SiK : 0	.535	11.089	+-	.569	17.269
AlK : 0	.433	3.731	+-	.767	6.049
FeK : 0	.949	71.483	+-	1.460	55.991
ZnK : 0	.848	<1.338	+-	.669	
P K : 0	.732	< .365	+-	.183	
TOTAL		95.678			100.000

Figure 3a

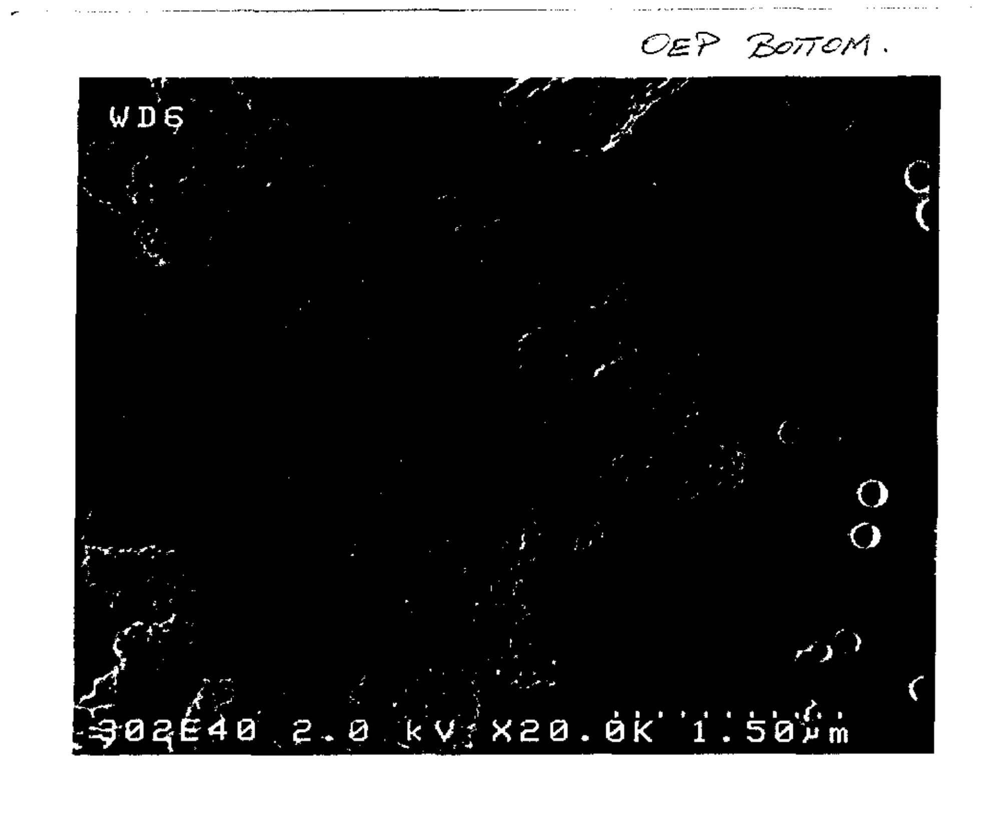
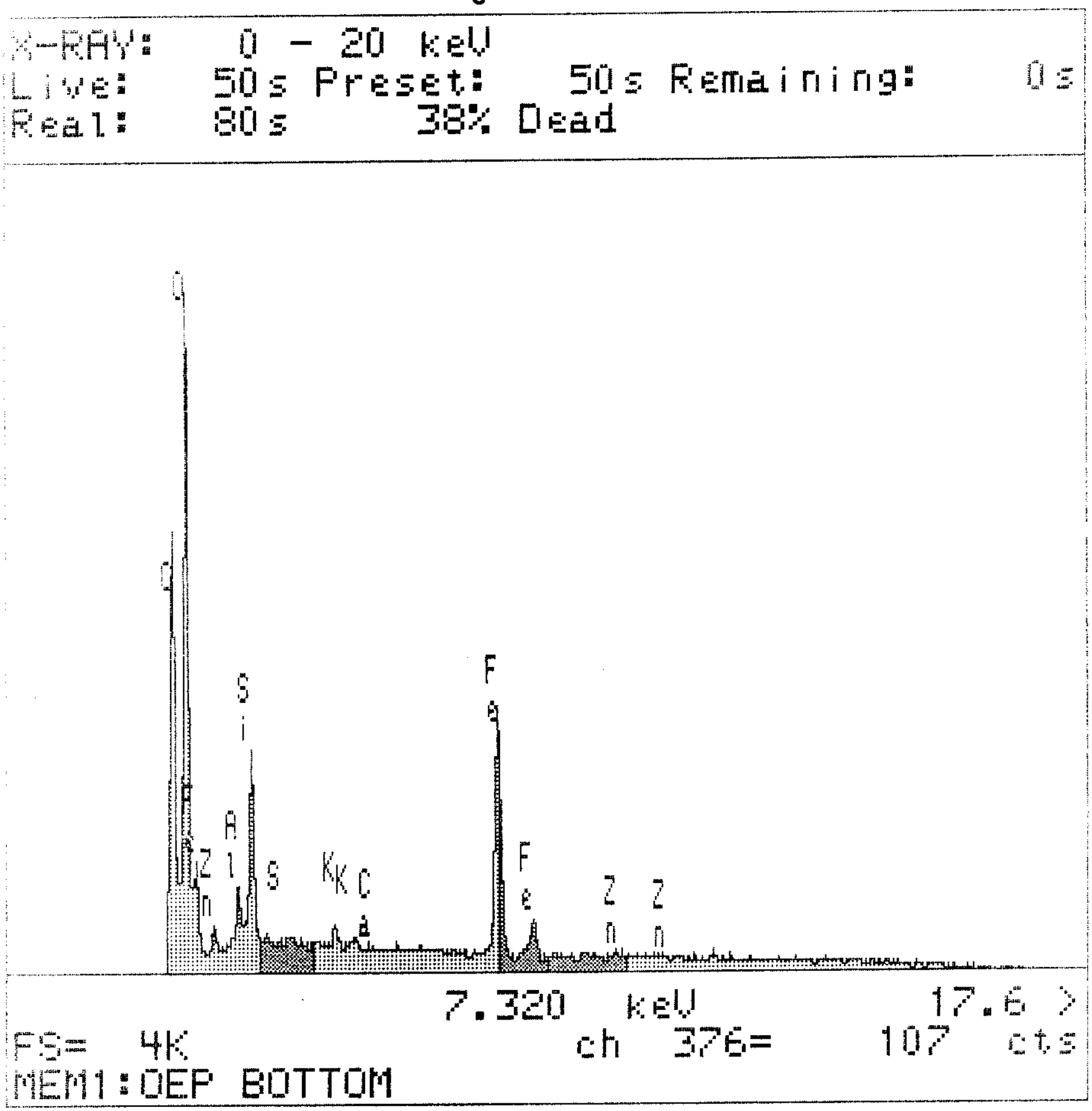


Figure 3b


X-RAY: 0 - 20 keV
Live: 50s Preset: 50s Remaining: 0s
Real: 80s 38% Dead
7.320 keV 17.6 >
FS= 4K ch 376= 107 cts
MEM1:OEP BOTTOM

Spectrum file : NCOEPBOT

OEP BOTTOM LIVETIME(spec.)= 5Ø

ENERGY	RES	AREA
4.2	82.97	36196

TOTAL AREA= 137591

......

Peak at .5Ø keV omitted?

FIT INDEX= 6.16

ELMT		APP.CONC	ERROR(WT%)
NaK	: Ø	1.134	.11Ø
K K	: Ø	.948	.149
ClK	: Ø	.Ø28	.124* < 2 Sigma*
S K	: Ø	-.Ø14	.126* < 2 Sigma*
CaK	: Ø	.377	.144
SiK	: Ø	6.689	.173
AlK	: Ø	2.184	.173
FeK	: Ø	29.Ø1Ø	.6Ø4
ZnK	: Ø	.994	.617* < 2 Sigma*
P K	: Ø	.398	.182

ZAF CALCULATIONS

...[3 iterations]

2Ø.ØØ kV TILT=15.ØØ ELEV=1Ø.ØØ AZIM=15.ØØ COSINE=1.ØØØ

Spectrum: OEP BOTTOM * INITIAL START-UP *

All elmts analysed,NORMALISED

ELMT		ZAF	%ELMT	+-	Error	ATOM.%
NaK	: Ø	.36Ø	5.787	+-	.563	9.999
K K	: Ø	.936	1.861	+-	.292	1.89Ø
ClK	: Ø	.72Ø	< .249	+-	.124	
S K	: Ø	.635	< .252	+-	.126	
CaK	: Ø	.955	.727	+-	.277	.72Ø
SiK	: Ø	.557	22.Ø94	+-	.571	31.244
AlK	: Ø	.488	8.237	+-	.653	12.128
FeK	: Ø	.92Ø	57.95Ø	+-	1.2Ø7	41.216
ZnK	: Ø	.837	<1.234	+-	.617	
P K	: Ø	.672	1.Ø87	+-	.497	1.395
TOTAL			97.743			1ØØ.ØØØ

Figure 4a

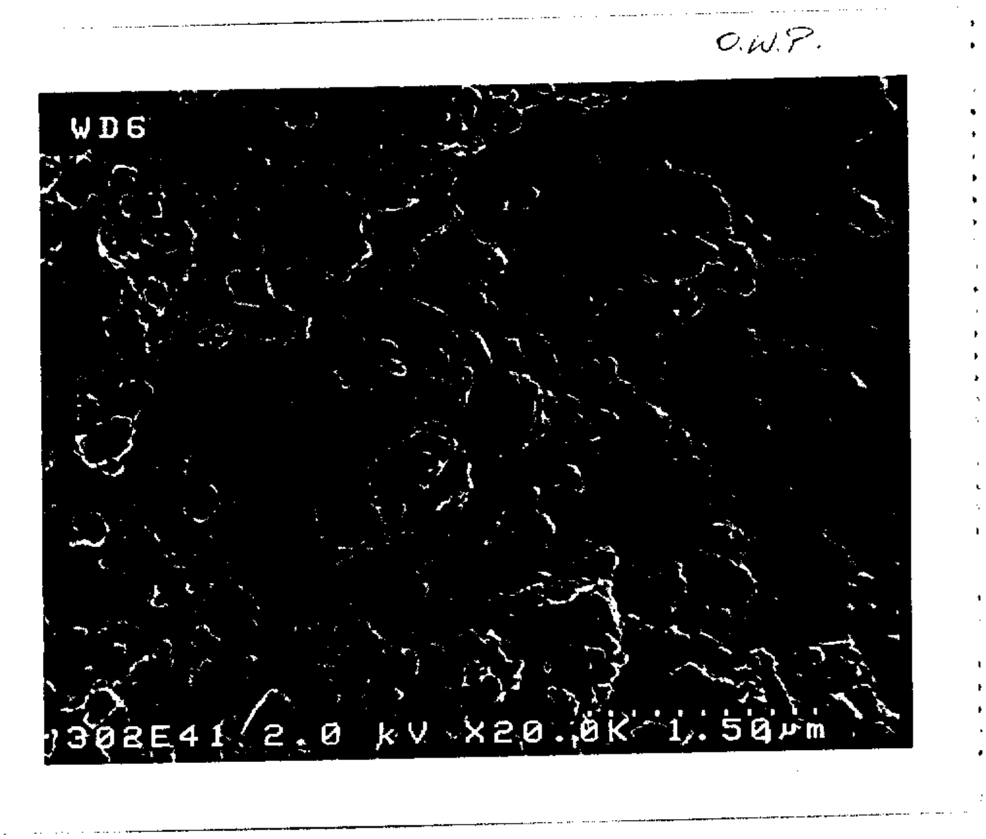
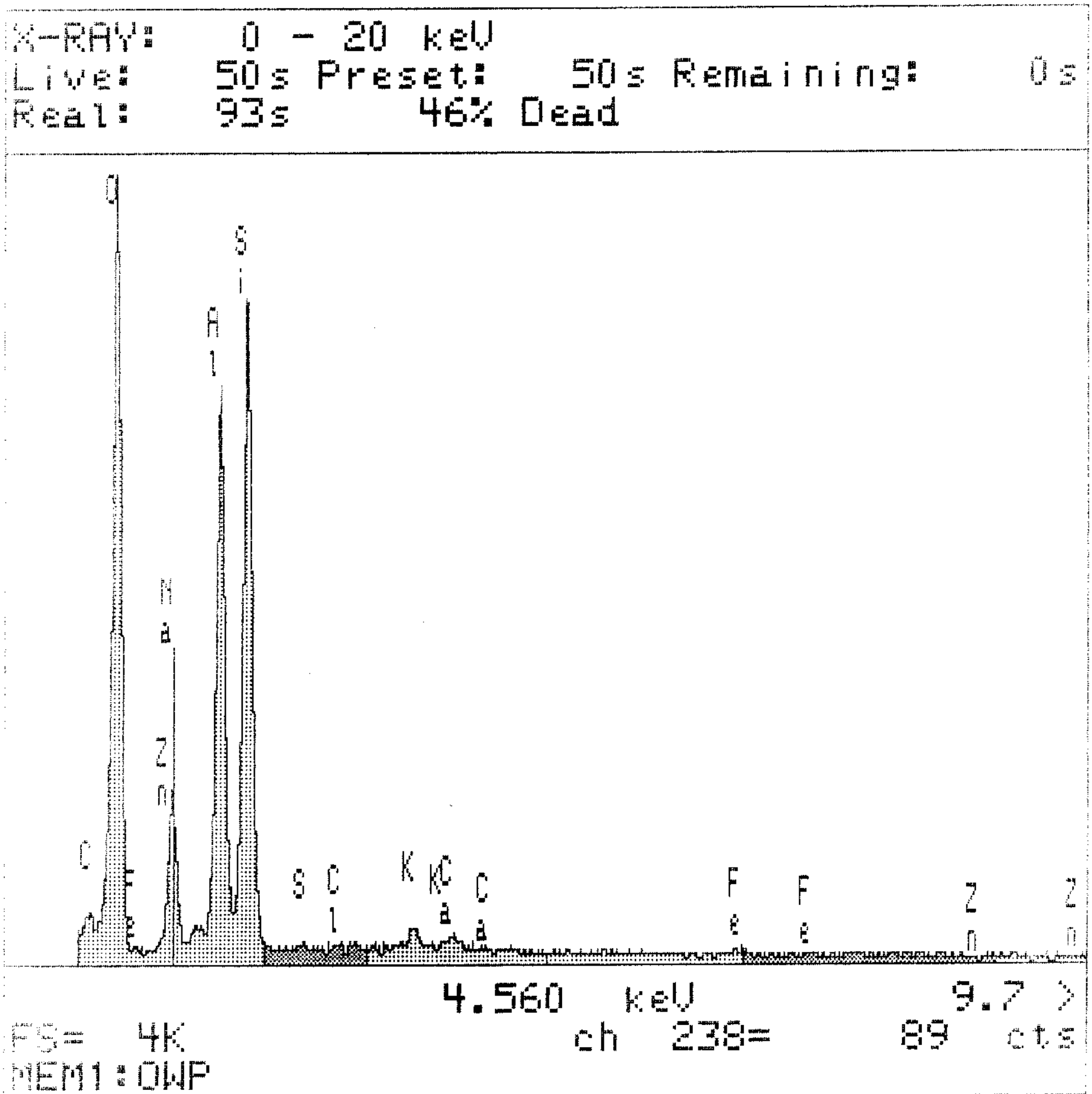


Figure 4b


X-RAY: 0 - 20 keV
Live: 50s Preset: 50s Remaining: 0s
Real: 93s 46% Dead
O
Si
Al
Na
Zn
C
Fe
S
Cl
K
KCa
Ca
Fe
Fe
Zn
Zn
4.560 keV 9.7 >
FS= 4K ch 238= 89 cts
MEM1:OWP

Spectrum file : NCOWP

OWP LIVETIME(spec.)= 50

ENERGY	RES	AREA
- 4.4	83.64	45Ø75

TOTAL AREA= 121535

. . . . . .

Peak at .5Ø keV omitted?

FIT INDEX=27.86

ELMT	APP.CONC	ERROR(WT%)
NaK : Ø	5.957	.161
K K : Ø	.933	.131
ClK : Ø	-.ØØ1	.1Ø3* < 2 Sigma*
S K : Ø	.Ø53	.1Ø1* < 2 Sigma*
CaK : Ø	.631	.13Ø
SiK : Ø	22.828	.27Ø
AlK : Ø	23.518	.341
FeK : Ø	.894	.24Ø
ZnK : Ø	-.663	.464* < 2 Sigma*
P K : Ø	.2Ø8	.156* < 2 Sigma*

ZAF CALCULATIONS

...[3 iterations]

2Ø.ØØ KV TILT=15.ØØ ELEV=1Ø.ØØ AZIM=15.ØØ COSINE=1.ØØØ

Spectrum: OWP * INITIAL START-UP *

All elmts analysed,NORMALISED

ELMT	ZAF	%ELMT	+-	Error	ATOM.%
NaK : Ø	1.Ø92	7.487	+-	.2Ø3	9.Ø12
K K : Ø	.772	1.658	+-	.234	1.173
ClK : Ø	.567	< .2Ø5	+-	.1Ø3	
S K : Ø	.487	< .2Ø2	+-	.1Ø1	
CaK : Ø	.799	1.Ø83	+-	.224	.748
SiK : Ø	.589	53.235	+-	.63Ø	52.443
AlK : Ø	.939	34.36Ø	+-	.499	35.241
FeK : Ø	.825	1.489	+-	.399	.738
ZnK : Ø	.8Ø8	< .928	+-	.464	
P K : Ø	.495	< .311	+-	.156	
TOTAL		99.312			1ØØ.ØØØ

Figure 5a

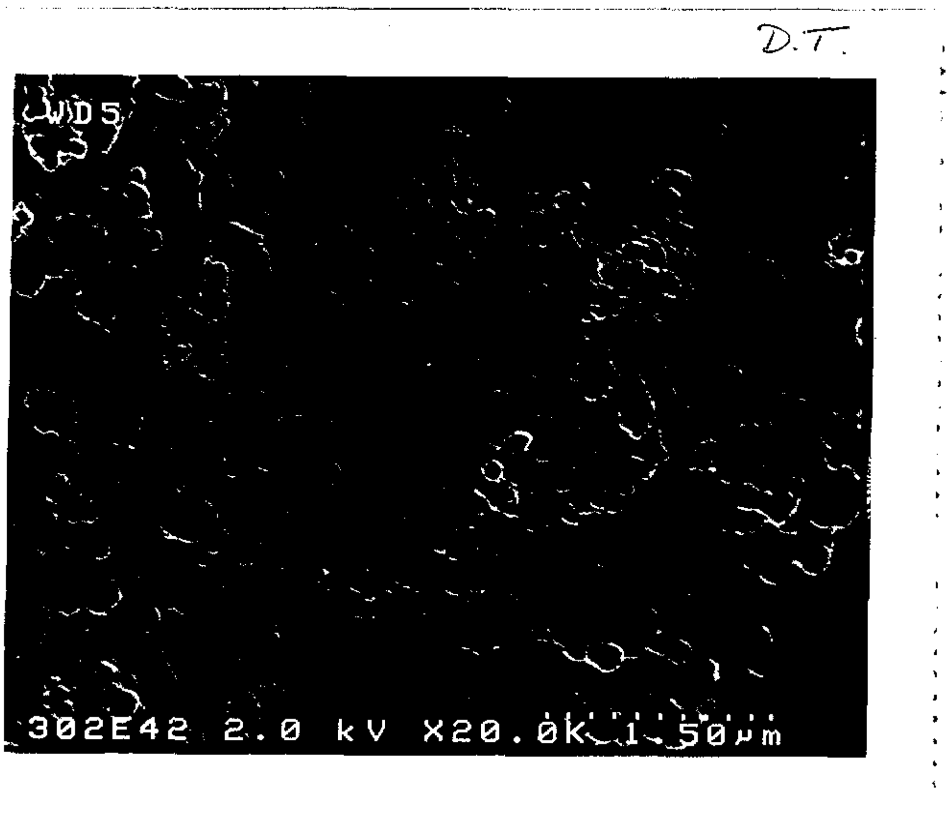
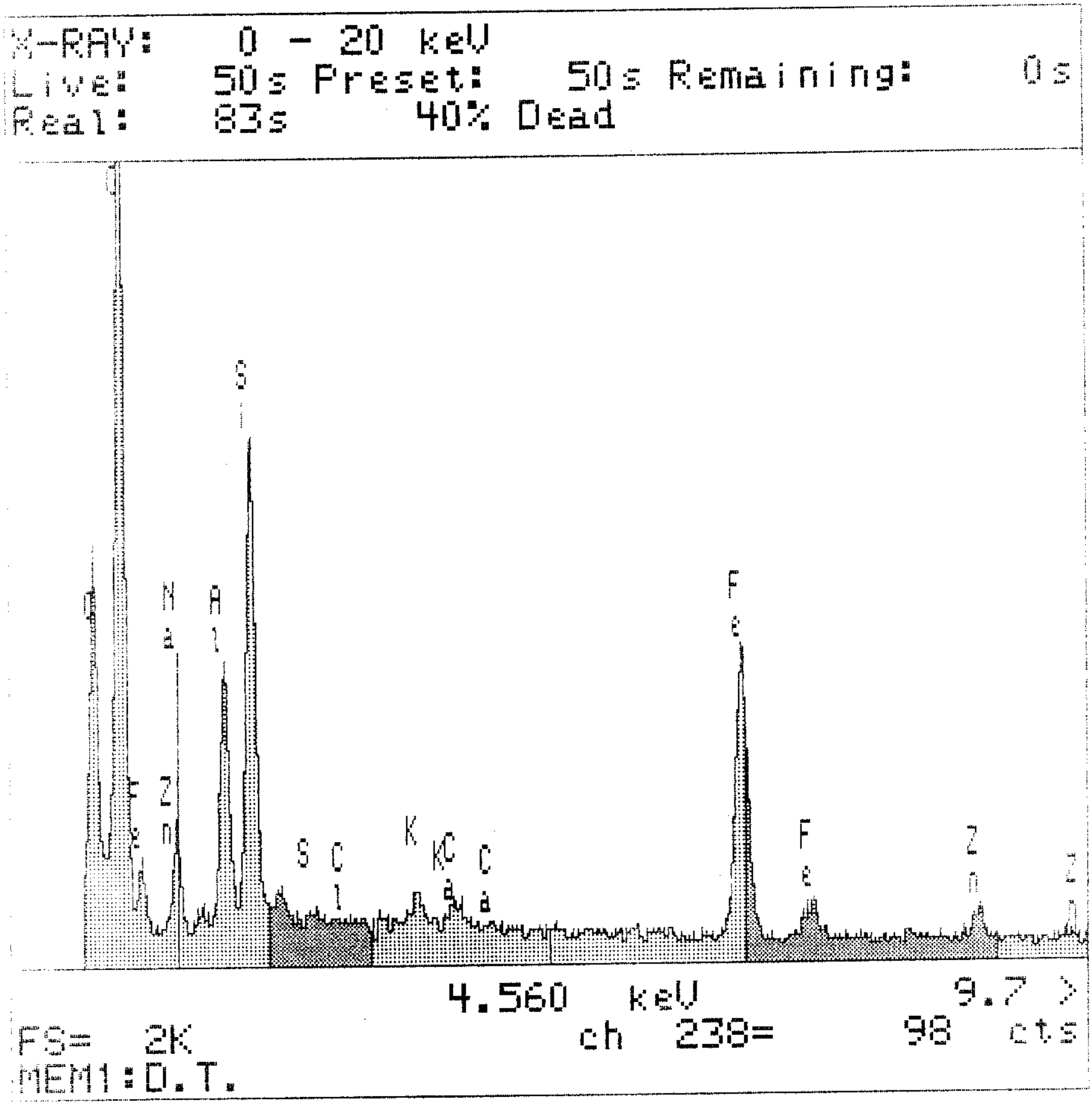


Figure 5b


X-RAY: 0 - 20 keV
Live: 50s Preset: 50s Remaining: 0s
Real: 83s 40% Dead
Si
Na
Al
Fe
Zn
S
Cl
K
Ca
Fe
Zn
4.560 keV
9.7 >
FS= 2K
ch 238= 98 cts
MEM1:D.T.

Spectrum file : NCDT
D.T. LIVETIME(spec.)= 5Ø

ENERGY	RES	AREA
4.4	79.35	37Ø93

TOTAL AREA= 1Ø5243

[illegible]
[illegible] at .5Ø keV omitted?
[illegible] INDEX= 7.21

ELMT			APP.CONC	ERROR(WT%)	
[illegible]	:	Ø	1.863	.116	
[illegible]	:	Ø	.7Ø4	.133	
ClK	:	Ø	.Ø12	.1Ø9*	< 2 Sigma*
[illegible]	:	Ø	.2Ø5	.113*	< 2 Sigma*
[illegible]	:	Ø	.548	.132	
[illegible]	:	Ø	8.379	.185	
[illegible]	:	Ø	5.375	.2ØØ	
[illegible]	:	Ø	16.964	.476	
ZnK	:	Ø	3.682	.588	
[illegible]	:	Ø	.941	.177	

ZAF CALCULATIONS

....[4 iterations]

[illegible].ØØ kV TILT=15.ØØ ELEV=1Ø.ØØ AZIM=15.ØØ COSINE=1.ØØØ

Spectrum: D.T. * INITIAL START-UP *

All elmts analysed,NORMALISED

ELMT			ZAF	%ELMT	+-	Error	ATOM.%
[illegible]	:	Ø	.46Ø	7.211	+-	.449	11.Ø15
[illegible]	:	Ø	.874	1.434	+-	.272	1.288
ClK	:	Ø	.66Ø	< .219	+-	.1Ø9	
[illegible]	:	Ø	.579	< .225	+-	.113	
[illegible]	:	Ø	.998	1.Ø87	+-	.263	.952
[illegible]	:	Ø	.539	27.681	+-	.61Ø	34.6Ø8
AlK	:	Ø	.545	17.566	+-	.652	22.865
CaK	:	Ø	.895	33.774	+-	.948	21.237
ZnK	:	Ø	.834	7.861	+-	1.256	4.223
[illegible]	:	Ø	.615	2.725	+-	.514	3.Ø9Ø
TOTAL				99.339			1ØØ.ØØØ

Figure 6a

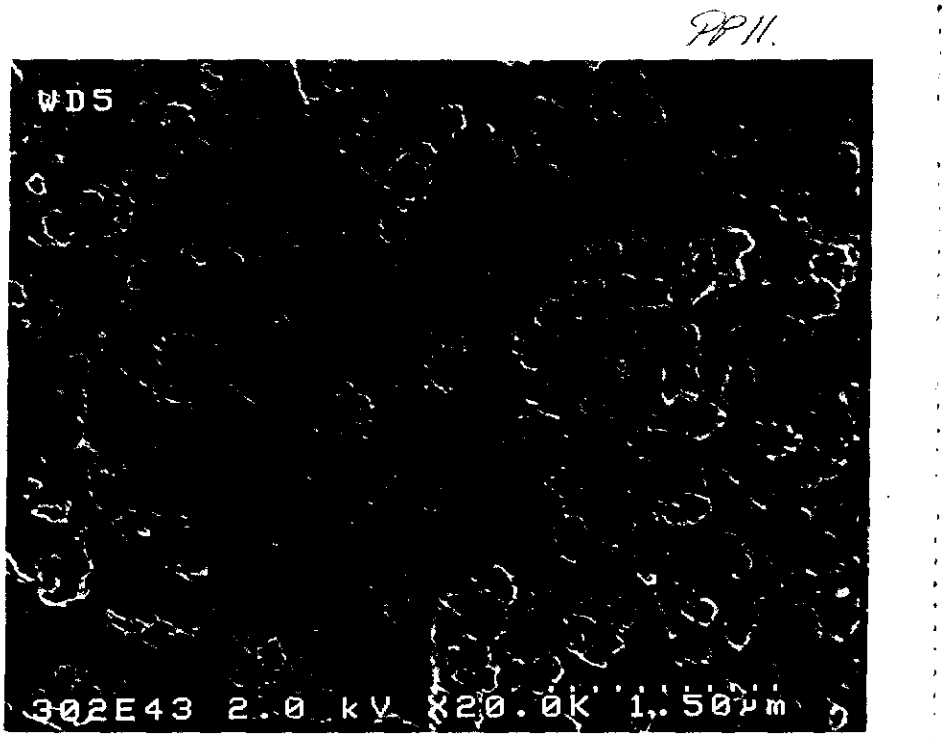
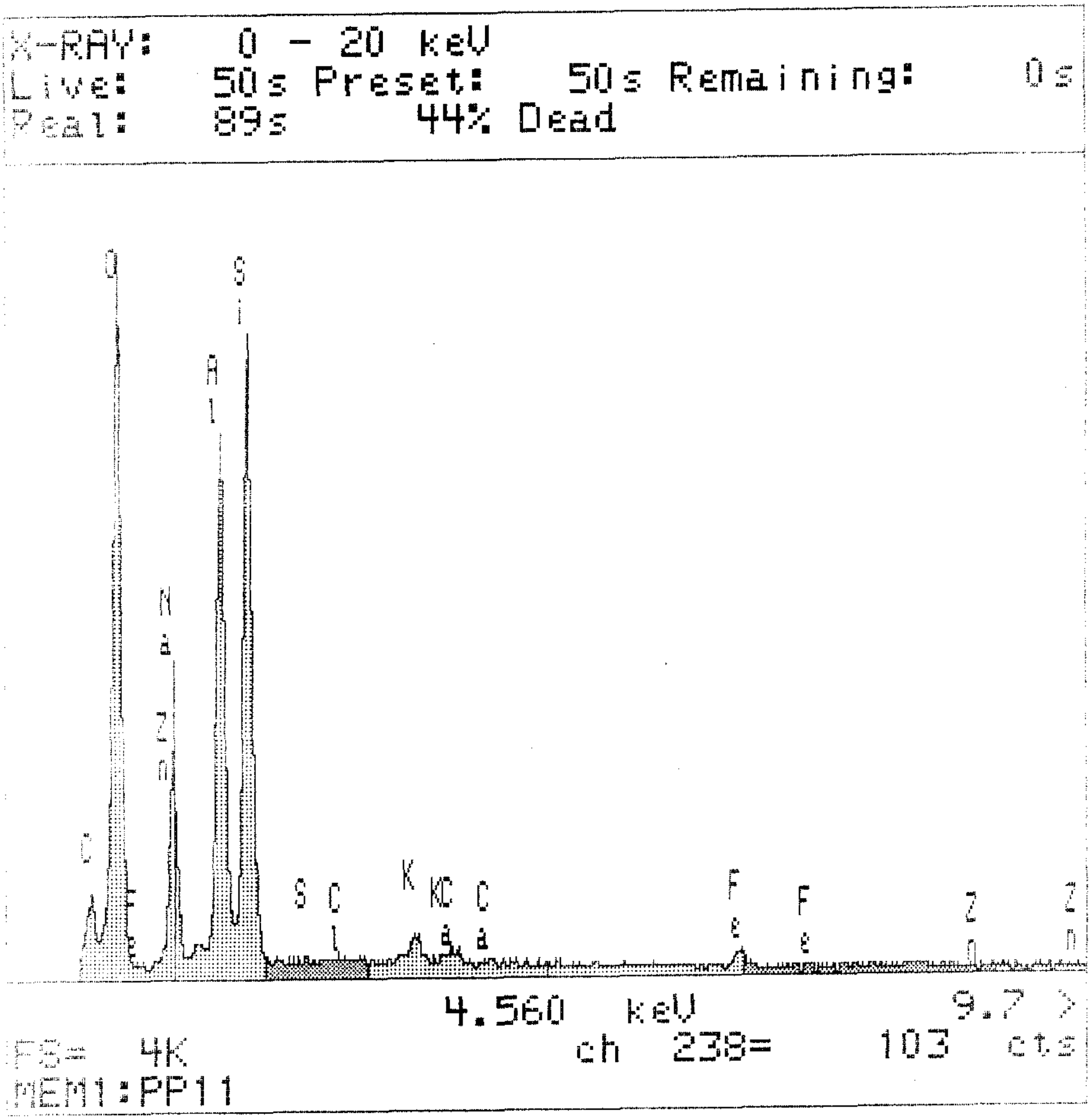


Figure 6b


X-RAY: 0 - 20 keV
Live: 50s Preset: 50s Remaining: 0s
Real: 89s 44% Dead
O
Si
Al
Na
Zn
C
S
Cl
K
K
Ca
Ca
Fe
Fe
Zn
Zn
4.560 keV
9.7 >
FS= 4K
ch 238= 103 cts
MEM1:PP11

Spectrum file : NCPP11

[illegible] LIVETIME(spec.)= 50

ENERGY	RES	AREA
4.5	80.23	43113

TOTAL AREA= 118228

......

Peak at .50 keV omitted?

[illegible] INDEX=23.14

ELMT		APP.CONC	ERROR(WT%)	
[illegible]	: 0	7.705	.173	
[illegible]	: 0	1.217	.138	
[illegible]	: 0	.093	.105*	< 2 Sigma*
[illegible]	: 0	.039	.104*	< 2 Sigma*
[illegible]	: 0	.717	.129	
[illegible]	: 0	20.784	.261	
[illegible]	: 0	21.640	.328	
[illegible]	: 0	1.966	.260	
[illegible]	: 0	-.090	.453*	< 2 Sigma*
[illegible]	: 0	.247	.159*	< 2 Sigma*

[illegible] CALCULATIONS

....[4 iterations]

[illegible].00 kV TILT=15.00 ELEV=10.00 AZIM=15.00 COSINE=1.000

Spectrum: PP11 * INITIAL START-UP *

[illegible] elmts analysed,NORMALISED

[illegible]		ZAF	%ELMT	+-	Error	ATOM.%
[illegible]	: 0	1.037	10.058	+-	.226	12.175
[illegible]	: 0	.783	2.104	+-	.238	1.497
[illegible]	: 0	.579	< .210	+-	.105	
[illegible]	: 0	.498	< .207	+-	.104	
CaK	: 0	.806	1.202	+-	.216	.835
SiK	: 0	.575	48.950	+-	.614	48.492
[illegible]	: 0	.874	33.496	+-	.508	34.548
[illegible]	: 0	.828	3.212	+-	.425	1.600
[illegible]	: 0	.810	< .906	+-	.453	
[illegible]	0	.508	< .318	+-	.159	
TOTAL			99.022			100.000

Figure 7a

PP12

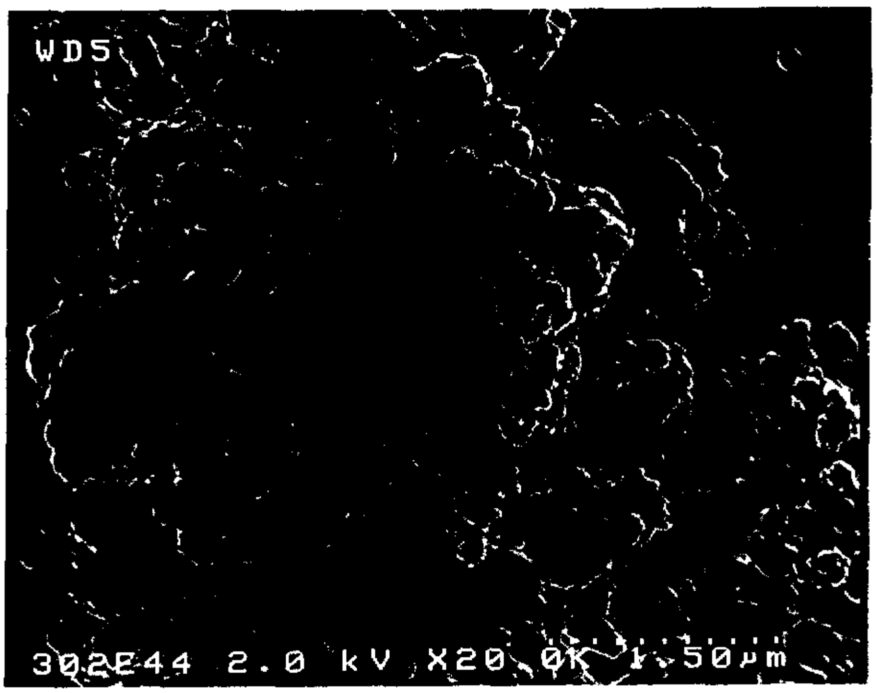
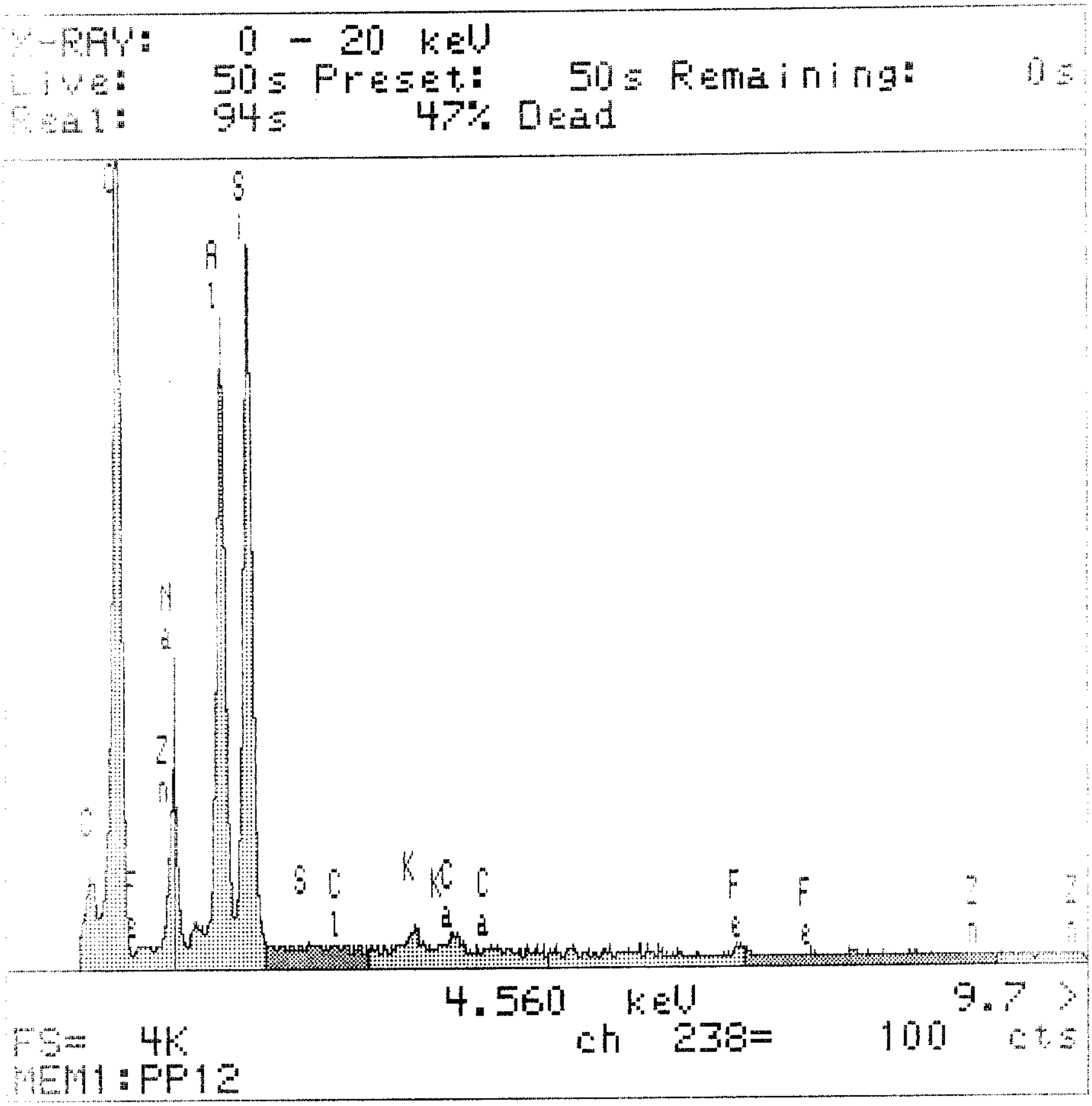


Figure 7b



X-RAY: 0 - 20 keV
Live: 50s Preset: 50s Remaining: 0s
Real: 94s 47% Dead
4.560 keV 9.7 >
FS= 4K ch 238= 100 cts
MEM1:PP12

Spectrum file : NCPP12

[illegible] LIVETIME(spec.)= 5Ø

ENERGY	RES	AREA
[illegible].4	8Ø.64	46698

[illegible]AL AREA= 137688

Peak at .5Ø keV omitted?

[illegible] INDEX=28.15

ELMT	APP.CONC	ERROR(WT%)
NaK : Ø	6.3Ø9	.169
[illegible]K : Ø	1.Ø76	.139
[illegible] : Ø	.Ø13	.1Ø9* < 2 Sigma*
[illegible]	.Ø79	.111* < 2 Sigma*
[illegible] : Ø	.886	.137
[illegible] : Ø	24.176	.281
[illegible]K : Ø	26.Ø83	.358
[illegible]eK : Ø	.973	.267
[illegible] : Ø	.219	.534* < 2 Sigma*
[illegible]K : Ø	.395	.172

[illegible]F CALCULATIONS

[illegible] 3 iterations]

[illegible] kV TILT=15.ØØ ELEV=1Ø.ØØ AZIM=15.ØØ COSINE=1.ØØØ

Spectrum: PP12 * INITIAL START-UP *

[illegible] elmts analysed,NORMALISED

ELMT	ZAF	%ELMT	+-	Error	ATOM.%
[illegible]K : Ø	1.Ø76	7.3Ø9	+-	.196	8.829
[illegible]K : Ø	.774	1.733	+-	.224	1.231
[illegible] : Ø	.569	< .219	+-	.1Ø9	
[illegible]K : Ø	.489	< .222	+-	.111	
CaK : Ø	.8ØØ	1.38Ø	+-	.213	.956
SiK : Ø	.584	51.714	+-	.6Ø1	51.126
AlK : Ø	.932	34.881	+-	.479	35.9Ø3
FeK : Ø	.826	1.47Ø	+-	.4Ø3	.731
ZnK : Ø	.8Ø9	<1.Ø68	+-	.534	
[illegible]K : Ø	.499	.986	+-	.429	.884
[illegible]AL		99.474			1ØØ.ØØØ

Figure 8a

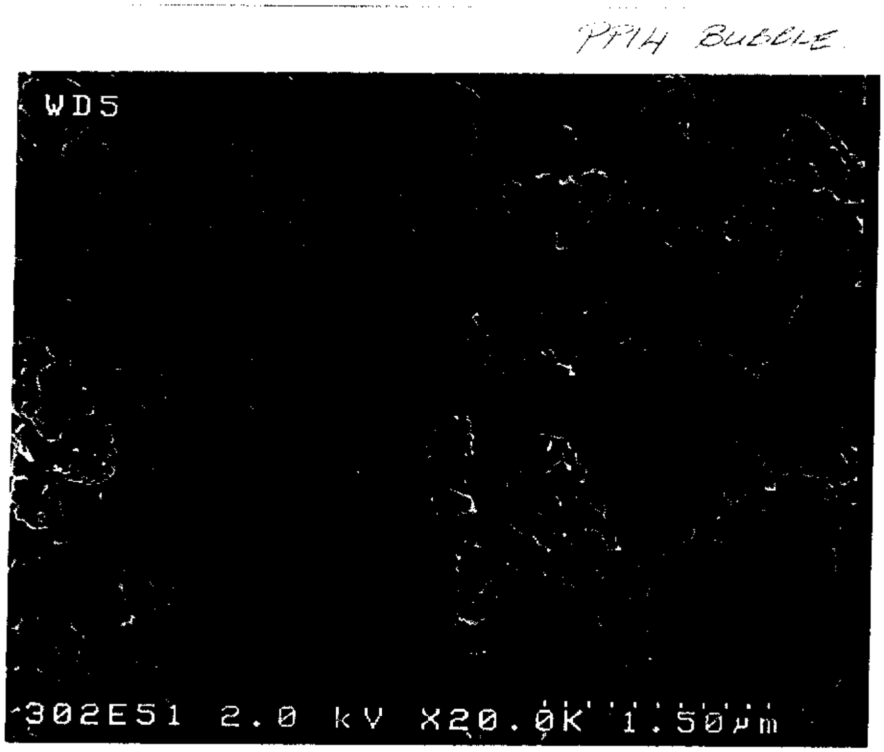
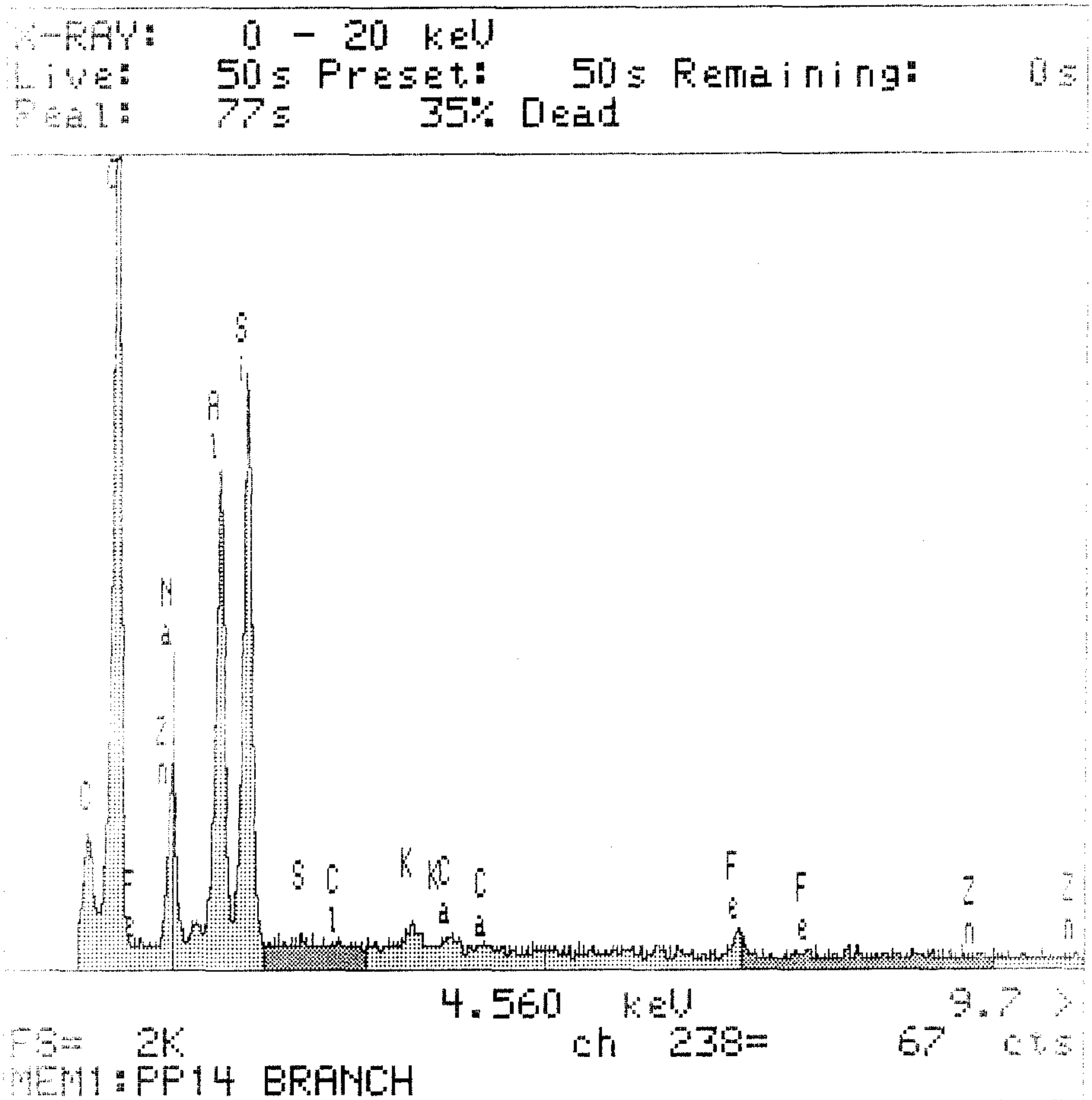


Figure 8b


X-RAY: 0 - 20 keV
Live: 50s Preset: 50s Remaining: 0s
Real: 77s 35% Dead
4.560 keV
9.7 >
FS= 2K
ch 238= 67 cts
MEM1:PP14 BRANCH

[illegible]trum file : NCPP14BRA

PP14 BRANCH LIVETIME(spec.)= 50

[illegible]ERGY	RES	AREA
4.4	79.92	37193

[illegible] AREA= 72050

[illegible] at .50 keV omitted?

[illegible] INDEX=12.74

[illegible]	APP.CONC	ERROR(WT%)
[illegible] : 0	3.375	.124
[illegible] : 0	.531	.104
[illegible] : 0	.039	.084* < 2 Sigma*
[illegible] : 0	.075	.086* < 2 Sigma*
[illegible] : 0	.290	.100
[illegible] : 0	9.841	.184
[illegible] : 0	9.894	.231
[illegible] : 0	1.526	.224
[illegible] : 0	.006	.412* < 2 Sigma*
[illegible] : 0	.159	.130* < 2 Sigma*

[illegible] CALCULATIONS

[illegible] 3 iterations]

[illegible] kV TILT=15.00 ELEV=10.00 AZIM=15.00 COSINE=1.000

[illegible]ctrum: PP14 BRANCH * INITIAL START-UP *

[illegible] elmts analysed,NORMALISED

[illegible]	ZAF	%ELMT	+-	Error	ATOM.%
[illegible] : 0	.979	9.701	+-	.357	11.862
[illegible] : 0	.785	1.904	+-	.373	1.369
[illegible] : 0	.590	< .169	+-	.084	
[illegible] : 0	.501	< .172	+-	.086	
[illegible] : 0	.810	1.007	+-	.347	.706
[illegible] : 0	.576	48.164	+-	.901	48.200
SiK : 0	.855	32.575	+-	.761	33.940
[illegible] : 0	.831	5.170	+-	.758	2.602
ZnK : 0	.810	< .824	+-	.412	
[illegible] K : 0	.513	< .261	+-	.130	
TOTAL		98.521			100.000

Figure 9a

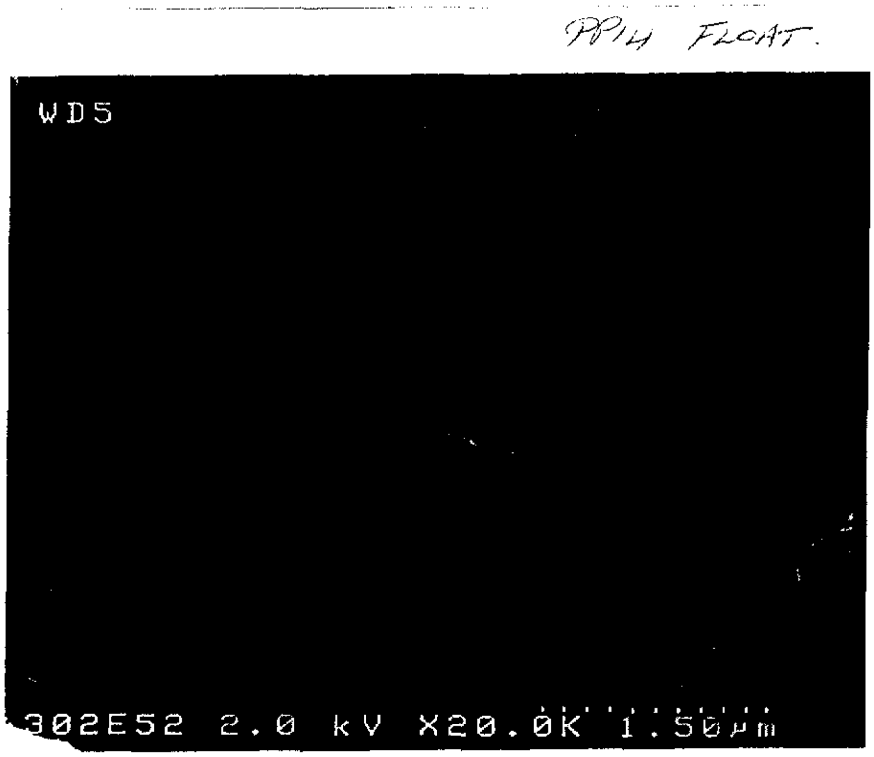
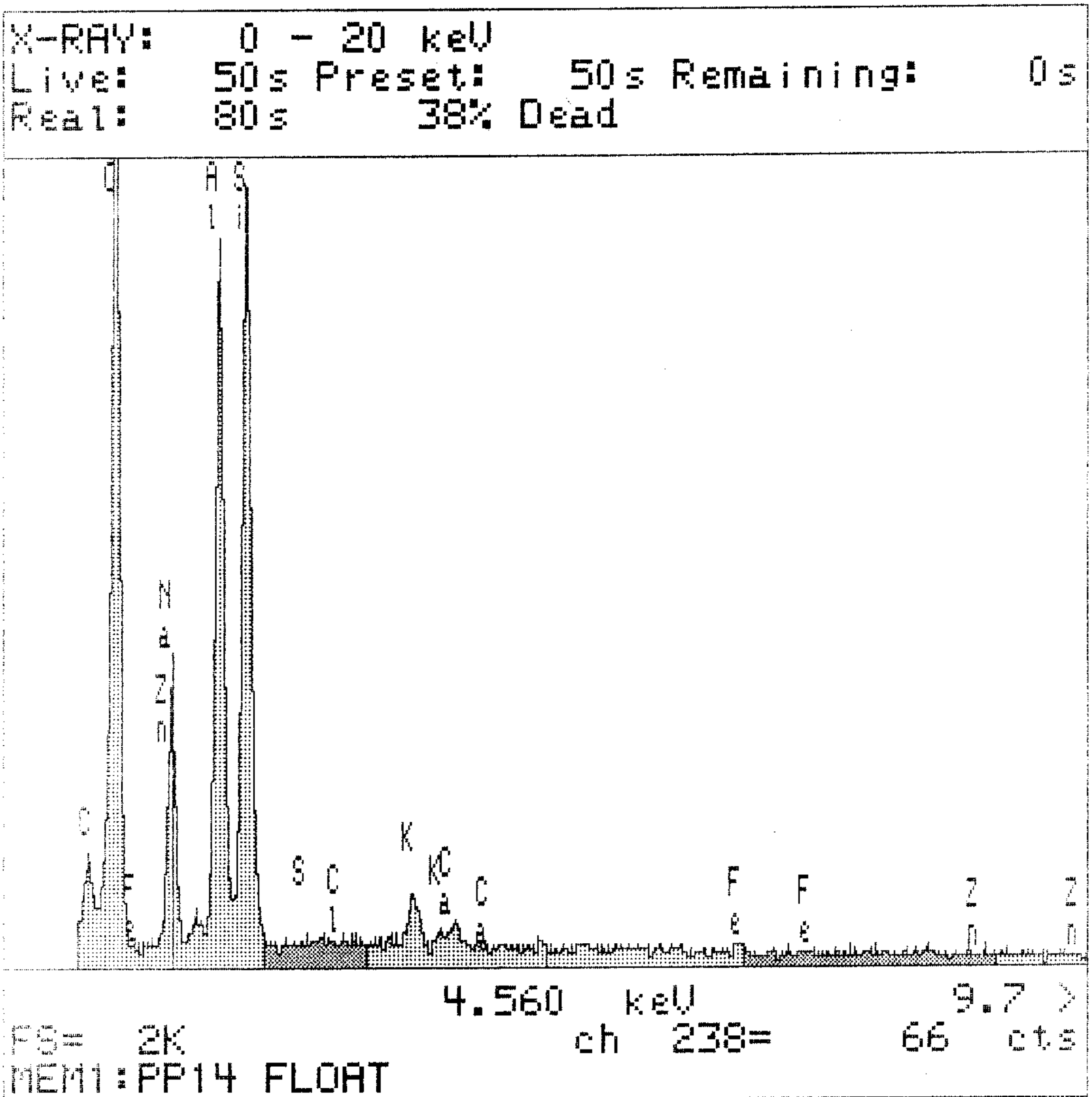


Figure 9b


X-RAY: 0 - 20 keV
Live: 50s Preset: 50s Remaining: 0s
Real: 80s 38% Dead
4.560 keV 9.7 >
FS= 2K ch 238= 66 cts
MEM1:PP14 FLOAT

```
Spectrum file : NCPP14FLO
PP14 FLOAT                                        LIVETIME(spec.)=     50
 ENERGY      RES       AREA
 -    4.6    82.40     38847
TOTAL AREA=     79035
.......
Peak at     .50 keV omitted?
FIT INDEX=15.73

ELMT          APP.CONC     ERROR(WT%)
NaK : 0       4.710         .138
K K : 0       1.219         .119
ClK : 0       -.051         .087* < 2 Sigma*
S K : 0        .008         .085* < 2 Sigma*
CaK : 0        .431         .108
SiK : 0      13.320         .209
AlK : 0      14.653         .267
FeK : 0        .633         .199
ZnK : 0        .307         .408* < 2 Sigma*
P K : 0        .131         .128* < 2 Sigma*

ZAF CALCULATIONS


...[ 3 iterations]

20.00 kV  TILT=15.00 ELEV=10.00 AZIM=15.00 COSINE=1.000

Spectrum: PP14 FLOAT                                   * INITIAL START-UP *

All elmts analysed,NORMALISED

ELMT          ZAF      %ELMT  +-       Error  ATOM.%
NaK : 0 1.054        9.347  +-       .273   11.310
K K : 0   .783       3.256  +-       .317    2.317
ClK : 0   .578     <  .174  +-       .087
S K : 0   .497     <  .169  +-       .085
CaK : 0   .801       1.126  +-       .282     .782
SiK : 0   .571      48.790  +-       .765   48.320
AlK : 0   .887      34.549  +-       .629   35.624
FeK : 0   .828       1.599  +-       .503     .797
ZnK : 0   .810     <  .816  +-       .408
P K : 0   .507     <  .257  +-       .128
TOTAL               98.667                 100.000
```

Figure 10a

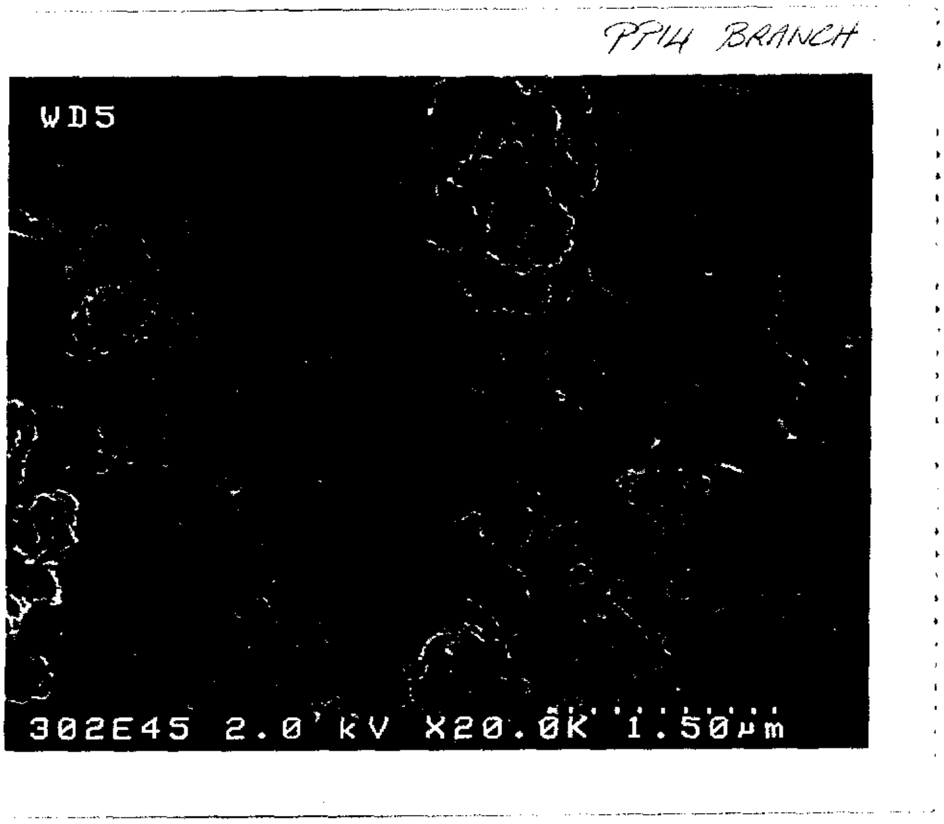
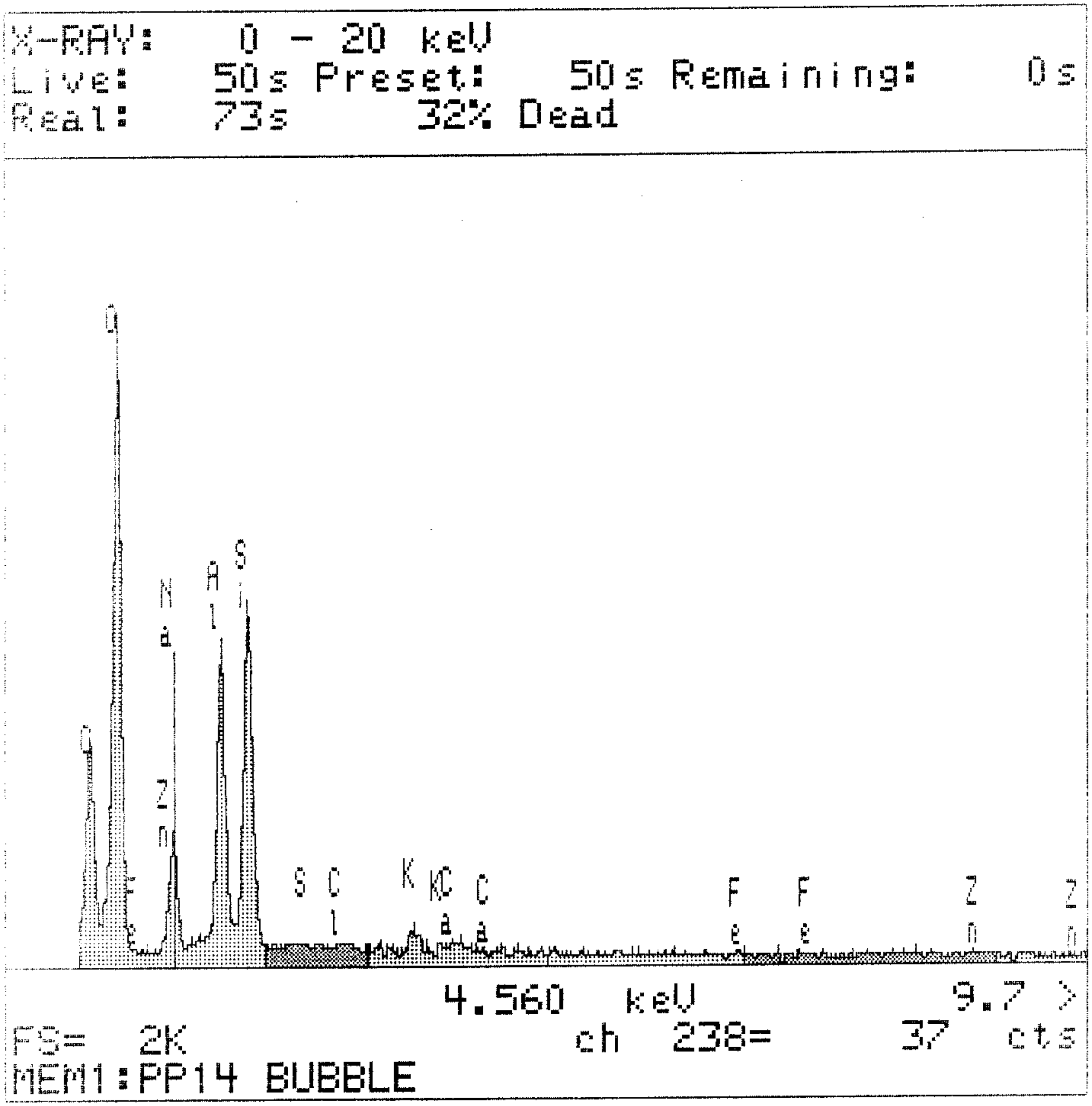


Figure 10b


X-RAY: 0 - 20 keV
Live: 50s Preset: 50s Remaining: 0s
Real: 73s 32% Dead
4.560 keV
9.7 >
FS= 2K
ch 238= 37 cts
MEM1:PP14 BUBBLE

Spectrum file : NCPP14BUB

PP14 BUBBLE LIVETIME(spec.)= 5Ø

ENERGY	RES	AREA
- 4.7	79.Ø3	36117

TOTAL AREA= 53441

......

Peak at .5Ø keV omitted?

FIT INDEX= 8.73

ELMT	APP.CONC	ERROR(WT%)
NaK : Ø	2.2Ø8	.1Ø3
K K : Ø	.572	.Ø93
ClK : Ø	.1ØØ	.Ø77* < 2 Sigma*
S K : Ø	-.Ø37	.Ø78* < 2 Sigma*
CaK : Ø	.115	.Ø89* < 2 Sigma*
SiK : Ø	6.Ø33	.149
AlK : Ø	6.Ø95	.185
FeK : Ø	.351	.172
ZnK : Ø	.3Ø2	.37Ø* < 2 Sigma*
P K : Ø	.Ø9Ø	.117* < 2 Sigma*

ZAF CALCULATIONS

..[3 iterations]

2Ø.ØØ kV TILT=15.ØØ ELEV=1Ø.ØØ AZIM=15.ØØ COSINE=1.ØØØ

Spectrum: PP14 BUBBLE * INITIAL START-UP *

All elmts analysed,NORMALISED

ELMT	ZAF	%ELMT	+-	Error	ATOM.%
NaK : Ø	1.Ø16	9.962	+-	.464	12.139
K K : Ø	.783	3.351	+-	.545	2.4Ø1
ClK : Ø	.582	< .154	+-	.Ø77	
S K : Ø	.5Ø1	< .157	+-	.Ø78	
CaK : Ø	.8Ø1	< .178	+-	.Ø89	
SiK : Ø	.575	48.157	+-	1.192	48.Ø27
AlK : Ø	.856	32.662	+-	.991	33.914
FeK : Ø	.831	1.937	+-	.949	.971
ZnK : Ø	.812	< .739	+-	.37Ø	
P K : Ø	.512	< .234	+-	.117	
TOTAL		96.Ø69			1ØØ.ØØØ

5.0 PARTICLE FORMATION BY PHYTOPLANKTON AND PICOPLANKTON

To purpose of this component is to identify the biological contribution of phytoplankton and picoplankton populations as initiators of particle formation. Picoplankton data we generated out of an independent contract and are arriving in time for the meeting.

The enumeration of small organisms were carried out by flow cytometry and using autofluorescence of pigments in the algal groups. This was done through systematic sampling of phytoplankton (size greater than > 2 μm) and picoplankton (< 2 μm). All phytoplankton and periphyton data are presented at the end of this section ("PHYTOPLANKTON AND PERIPHYTON TAXA IN 1996 BUCHANS SAMPLES AND BUCHANS CULTURING EXPERIMENT").

5.1 Phytoplankton Productivity and Diversity

Samples from different locations at Buchans were analyzed for phytoplankton density, biomass and species diversity into different classes of algae during spring, summer and fall of 1996 (Table 19 and Table 20). As expected, cell density and biomass were very low in early May, and increased in general during the summer and fall. However, one can note very specific differences in these parameters for different locations.

The Drainage Tunnel (DT) water had low cell density, biomass and species diversity at all times sampled. Phytoplankton in OWP increased its cell density, biomass and species diversity during fall and summer, while OEP supported exceptionally low cell densities and biomass at all times of the year (spring, summer and fall) as seen in Table 19. Interestingly, Tailings Pond 2 (TP2) had quite high phytoplankton population and biomass in early May.

As expected, the polishing ponds (PP) supported considerable phytoplankton populations and biomass, and generally had high species diversity both in the spring and the fall. The qualitative assessment of species diversity shows high species diversity for the polishing ponds during the summer (Table 20).

According to nutrient data available for Oriental East Pit (phosphate, nitrate and ammonium), one would have expected significant phytoplankton biomass to have developed. This did not take place at any time of the year. The data indicate that the system behaves as an exceptionally oligotrophic (nutrient-poor) aquatic ecosystem. There may be several reasons for this:

(1) phosphate may not be available for uptake by the algae due to complexing with metals (e.g., zinc);

(2) the low Secchi disc values (around 1.4 m) indicates low water transparency in spite of the very low phytoplankton biomass, indicating that light is rapidly lost due to scattering or absorption by abiotic particles;

(3) the very shallow chemo/thermocline (at about 1.5 m during most of the productive season).

It is very likely that the unfavourable chemistry and establishment of a very shallow epilimnion, coupled with very low water transparency, inhibits development of a significant phytoplankton productivity and biomass. Only the top meter is strongly oxygenated, light is rapidly absorbed in the top 1-2 meters and it appears likely that key nutrients, such as phosphorus, may not be available for algal transport system due to metal complexing. The conditions on Oriental West Pit appear to be much more favourable for phytoplankton productivity in addition to rapid development of aquatic mosses.

The experiments conducted in the laboratory (see Sections 6.1 and 6.2) and in the field suggest that:

a) Results of laboratory experiments examining the effects of nutrients upon primary productivity cannot be related to the Polishing Pond ecosystem, due to interferences by zinc, iron and manganese present in the effluent in the field, but attenuated or eliminated in effluent samples shipped to the laboratory.

b) Geochemical reactions precipitating phosphate in the pits and Polishing Ponds are potentially competing with the algal population for phosphate.

c) N:P ratios in Polishing Pond algal biomass indicate that these plants have access to sufficient P for growth, and are not nutrient-starved. While a large fraction of added phosphate appears to be relegated to the sediments by precipitation reactions, remobilization of P from the sediments could supply adequate phosphate to the Polishing Pond ecosystem. Phosphorus cycling can be addressed in the field in 1997 using a new radioactive isotope of phosphorus, ^{33}P, a compound analogous to ^{14}C in terms of acceptability by agencies regulating the application of this isotope in scientific field work.

Table 19: Phytoplankton density, biomass and percent distribution into different classes. Samples were collected spring, summer and fall of 1996 at different locations at Buchans, Newfoundland.

Date	Location[1]	Cell Density ($x10^6 \cdot L^{-1}$)	Biomass ($\mu g \cdot L^{-1}$)	Diversity (%)[2]			
				G	D	Cy	Chr
May 3	DT	0.02	1.2	80	-	-	20
	OWP	0.01	0.7	38	63	-	-
	OEP	0.06	25	60	40	-	-
	PP13	0.1	10	38	6	48	8
	PP17	0.7	59	54	6	21	16
	TP2	1.8	240	8	25	5	60
Jul 11	OWP	1.9	168	40	26	6	29
	OEP	0.06	4	35	10	-	55
Sep 29	DT	0.3	16	75	22	1	3
	OWP	1.1	127	39	18	27	14
	OEP	0.1	2.5	32	12	-	56
	PP13	1.5	480	60	33	1	1
	PP17	0.6	38	50	18	7	25

1 DT=Drainage Tunnel; OWP=Oriental West Pit; OEP=Oriental East Pit; PP13=Polishing Pond 13; PP17=Polishing Pond 17; TP2=Tailings Pond 2

2 Diversity expresses as percent of total algae identified; G=Green algae; D=diatoms; Cy=cyanobacteria; Chr=chrysophytes

Table 20: Qualitative assessment of diversity of phytoplankton as distribution into different classes. Samples were collected during the summer 1996.

Date	Location[1]	Diversity (%) [2]			
		G	D	Cy	Chr
May 5	OWP	30	70	-	-
Jul 8	PP-In	40	20	20	20
	PP-Out	10	60	10	20
Jul 11	PP-In	30	40	10	25
	PP-Out	45	35	15	5
Jul 12	PP12	70	20	5	-
	PP14	60	25	10	-

[1] OWP = Oriental West Pit; PP-In = intake water for Polishing Ponds; PP-Out = exit water from Polishing Ponds; PP12 = Polishing Pond 12; PP14 = Polishing Pond 14

[2] Diversity expresses as percent of total algae identified; G = Green algae; D = diatoms; Cy = cyanobacteria; Chr = chrysophytes

PHYTOPLANKTON AND PERIPHYTON TAXA PRESENT

IN 1996 BUCHANS SAMPLES

AND

BUCHANS CULTURING EXPERIMENT

LIST OF PHYTOPLANKTON SAMPLES

LIST OF PERIPHYTON SAMPLES

BUCHANS CULTURING EXPERIMENT

List of Algal Taxon Codes for Boojum Research Samples - 1996

Cyanobacteria (Bluegreen Algae)

AN spp 1R	Anabaena spp.
BG fil 1R	Undentified fialmentous bluegreen sp.
ME min 1E	Merismopedia minutus
OS lim 1R	Oscillatoria limnetica
OS sps 1R	Oscillatoria spp. (small spp.)
OS ten 1R	Oscillatoria tenuis
UN bgf 1R	Unidentified bluegreen filament (small)
UN blg 1E	Unidentified small spp. (e.g. Synechococcus, Merismopedia, Chroococcus, etc.)

Chlorophyceae (Green Algae)

AK fal 2R	Ankistrodesmus falcatus
BO bra 2E	Botryococcus braunii
CH spp 2E	Chlamydomonas spp.
CL spp 2R	Chlorogonium sp.
CT spp 2E	Carteria spp.
DT pul 2E	Dictyosphaerium pulchellum
MG spm 2R	Mougeotia sp. (medium width filament)
MG spn 2R	Mougeotia sp. (narrow filaments)
MG spw 2R	Mougeotia sp. (wide filaments)
MT spp 2E	Mesotaenium sp.
OO spp 2E	Oocystis spp.
SC spp 2E	Scenedesmus spp.
SP sub 2E	Sphaerellopsis cylindrica
TM spp 2R	Temnogametum spp.
UL spp 2R	Ulothrix sp.
UN chl 2E	Unidentified small spp. (e.g. Chlorella, Chlamydomonas, Chlorococcum, etc.)

Euglenophyceae (Euglenoids)

EG spp 3E	Euglena spp.
LP spp 3E	Lepocinclis sp.
TR spp 3E	Trachelomonas sp.

Chrysophyceae (Chrysophytes)

CK pla 4E	Chrysolykos planctonicus
CM spp 4E	Chromulina spp.
CS spp 4E	Chrysosphaerella sp.
DI mon 4E	Dinobryon monads
DI ser 4E	Dinobryon sertularia
DI spp 4E	Dinobryon sp.
EP spp 4E	Epipyxis sp.
KP spp 4E	Kephyrion sp.
OM spp 4E	Ochromonas spp.
PK spp 4E	Pseudokephyrion spp.
UN chr 4E	Unidentified small spp. (e.g. Chromulina, Ochromonas, etc.)

Cryptophyceae (Cryptophytes)

CR ero 5F	Cryptomonas erosa
CR ova 5F	Cryptomonas ovata
CR spp 5E	Cryptomonas spp. (small taxa)
RH min 5E	Rhodomonas minutus
UN cry 5E	Unidentified spp. (e.g. Chroomonas, Cryptomonas, Rhodomonas, etc.)

Dinophyceae (Dinoflagellates)

GM spp 6E	Gymnodinium spp.
PE inc 6E	Peridinium inconspicuum

Bacillariophyceae (Diatoms)

MS isl 7R	Melosira islandica
AC spp 7R	Achnanthes spp.
AH spp 7R	Achnanthes spp. (small taxa)
AS for 7R	Asterionella formosa
EU ssp 7R	Eunotia spp. (small)
FR rhm 7D	Frustulia rhomboides
NV spp 7D	Navicula spp.

NZ spp 7R	Nitzschia spp.
PN spm 7R	Pinnularia sp. (medium frustule)
PN spp 7R	Pinnularia spp.
SY spl 7R	Synedra spp. (large frustule)
SY spm 7R	Synedra spp. (medium frustule)
TA flc 7T	Tabellaria flocculosa
TA fen 7T	Tabellaris fenestrata
UN dia 7R	Unidentified spp. (e.g. Achnanthes, Cyclotella, Cymbella, Eunotia, Navicula, Pinnularia, etc.)

Buchans - Drainage Tunnel **3/05/96** **(A96-17)**

Sample File BR9617
DATE ANALYSED...09-12-1996

SUBSAMPLE VOLUME... 500.0 mLs

TAXON	CELLS.L^{-1} (L^{-1})	BIOMASS ($MG.M^{-3}$)	COL	CELLS	LEN (μM)	WID (μM)	D (μM)	#	TRANS	BIOVOL (μM^3)	COR.F
CYANOBACTERIA											
UN blg 1E	11404	0.0038	0	289	1.0	0.8	0	1	3	0.34	59.19
CHLOROPHYTA											
UN chl 2E	3117	0.1480	0	79	7.4	3.5	0	1	3	47.46	59.19
EUGLENOPHYTA											
EG spp 3E	308	1.0167	0	26	41.7	12.3	0	1	5	3303.28	29.59
CHRYSOPHYTA											
UN chr 4E	1184	0.0486	0	30	4.9	4.0	0	1	3	41.05	59.19
CRYPTOPHYTA											
CR spp 5E	252	0.2479	0	17	19.6	9.8	0	1	4	985.61	29.59
TOT CNT	16264	1.4650		441							

Buchans - Drainage Tunnel **3/05/96**

PHYLUM	TOT CELLS.L^{-1}	TOT BIOMASS.M^{-3}
CYANOBACTERIA	11404	0.004
CHLOROPHYTA	3117	0.148
EUGLENOPHYTA	308	1.017
CHRYSOPHYTA	1184	0.049
CRYPTOPHYTA	252	0.248
PYRROPHYTA	0	0.000
DIATOMS	0	0.000
RHODOPHYTA	0	0.000
TOTAL ALGAE	16264	1.465

SUMMARY:

Cell Density: 1.52×10^4 cells/L

Biomass Estimate: 1.47 μg/L

Buchans - OWP (surface) 9/07/96 (A96-30)

(Sample File BR9630)
DATE ANALYSED...09-22-1996

SUBSAMPLE VOLUME... 125.0 mLs

TAXON	CELLS.L^{-1} (L^{-1})	BIOMASS ($MG.M^{-3}$)	COL	CELLS	LEN (μM)	WID (μM)	D (μM)	#	TRANS	BIOVOL (μM^3)	COR.F
CYANOBACTERIA											
OS lim 1R	119799	9.4090	0	253	100.0	1.0	0	1	1	78.54	59.19
UN blg 1E	114117	0.0896	0	241	1.5	1.0	0	1	1	0.79	59.19
CHLOROPHYTA											
UL spp 2R	789	0.1458	0	10	9.8	4.9	0	1	3	184.80	29.59
TM spp 2R	11838	18.0595	0	150	80.9	4.9	0	1	3	1525.56	29.59
CH spp 2E	40722	7.7314	0	86	7.4	7.0	0	1	1	189.86	59.19
UN chl 2E	573427	39.6490	0	1211	5.5	4.9	0	1	1	69.14	59.19
CHRYSOPHYTA											
EP spp 4E	66292	1.0630	0	140	4.9	2.5	0	1	1	16.04	59.19
UN chr 4E	374551	7.0287	0	791	3.5	3.2	0	1	1	18.77	59.19
CM spp 4E	226814	37.1301	0	479	7.4	6.5	0	1	1	163.70	59.19
OM spp 4E	90441	4.6988	0	191	4.9	4.5	0	1	1	51.95	59.19
BACILLARIOPHYTA											
AC spp 7R	304470	43.0614	0	643	14.7	3.5	0	1	1	141.43	59.19
TOT CNT	1923262	168.0664		4195							

Buchans - OWP (surface) 9/07/96 (A96-30)

PHYLUM	TOT CELLS.L^{-1}	TOT BIOMASS.M^{-3}
CYANOBACTERIA	233917	9.499
CHLOROPHYTA	626777	65.586
EUGLENOPHYTA	0	0.000
CHRYSOPHYTA	758098	49.921
CRYPTOPHYTA	0	0.000
PYRROPHYTA	0	0.000
DIATOMS	304470	43.061
RHODOPHYTA	0	0.000
TOTAL ALGAE	1923262	168.066

SUMMARY:

Cell Density: 1.92×10^6 cells/L

Biomass Estimate: 168.01 μg/L

Buchans - OEP - surface 10/07/96 (A96-31)

Sample File BR9631
DATE ANALYSED...09-26-1996

SUBSAMPLE VOLUME... 26.3 mLs

TAXON	CELLS.L^{-1} (L^{-1})	BIOMASS ($MG.M^{-3}$)	COL	CELLS	LEN (μM)	WID (μM)	D (μM)	#	TRANS	BIOVOL (μM^3)	COR.F
CHLOROPHYTA											
UN chl 2E	22548	1.5591	0	10	5.5	4.9	0	1	1	69.14	59.19
CHRYSOPHYTA											
UN chr 4E	38332	1.4451	0	17	4.5	4.0	0	1	1	37.70	59.19
DI spp 4E	6765	0.8334	0	3	9.8	4.9	0	1	1	123.20	59.19
BACILLARIOPHYTA											
AH spp 7D	8268	0.4561	0	22	17.2	3.5	0	1	3	55.16	29.59
TOT CNT	75913	4.2936		52							

Buchans - OEP - surface 10/07/96 (A96-31)

PHYLUM	TOT CELLS.L^{-1}	TOT BIOMASS.M^{-3}
CYANOBACTERIA	0	0.000
CHLOROPHYTA	22548	1.559
EUGLENOPHYTA	0	0.000
CHRYSOPHYTA	45097	2.278
CRYPTOPHYTA	0	0.000
PYRROPHYTA	0	0.000
DIATOMS	8268	0.456
RHODOPHYTA	0	0.000
TOTAL ALGAE	75913	4.294

SUMMARY:

Cell Density: 7.59×10^4 cells/L

Biomass Estimate: 4.29 μg/L

Buchans - OEP 3/05/96 (A96-32)

Sample File BR9632
DATE ANALYSED...09-22-1996

SUBSAMPLE VOLUME... 105.0 mLs

TAXON	CELLS.L^{-1} (L^{-1})	BIOMASS ($MG.M^{-3}$)	COL	CELLS	LEN (μM)	WID (μM)	D (μM)	#	TRANS	BIOVOL (μM^3)	COR.F
CYANOBACTERIA											
UN blg 1E	7892	0.0186	0	14	2.0	1.5	0	1	1	2.36	59.19
CHLOROPHYTA											
MG spw 2R	141	1.3128	0	2	78.4	12.3	0	1	4	9315.72	29.59
MT spp 2E	352	9.6677	0	5	51.5	31.9	0	1	4	27440.20	29.59
MG spn 2R	493	0.1974	0	7	41.6	3.5	0	1	4	400.24	29.59
UL spp 2R	13177	2.4351	0	187	9.8	4.9	0	1	4	184.80	29.59
UN chl 2E	10147	1.6611	0	18	7.4	6.5	0	1	1	163.70	59.19
CHRYSOPHYTA											
UN chr 4E	9583	0.4979	0	17	4.9	4.5	0	1	1	51.95	59.19
BACILLARIOPHYTA											
NV spp 7D	775	0.1651	0	11	26.9	5.5	0	1	4	213.03	29.59
EU spp 7R	6201	3.7301	0	88	31.9	4.9	0	1	4	601.55	29.59
UN dia 7R	11838	5.4692	0	21	24.5	4.9	0	1	1	462.01	59.19
TOT CNT	60599	25.1549		370							

Buchans - OEP 3/05/96 (A96-32)

PHYLUM	TOT CELLS.L^{-1}	TOT BIOMASS.M^{-3}
CYANOBACTERIA	7892	0.019
CHLOROPHYTA	24310	15.274
EUGLENOPHYTA	0	0.000
CHRYSOPHYTA	9583	0.498
CRYPTOPHYTA	0	0.000
PYRROPHYTA	0	0.000
DIATOMS	18814	9.364
RHODOPHYTA	0	0.000
TOTAL ALGAE	60599	25.155

SUMMARY:

Cell Density: 6.06×10^4 cells/L

Biomass Estimate: 25.16 μg/L

Buchans - Drainage Tunnel 3/05/96 (A96-33)

Sample File BR9633
DATE ANALYSED...09-21-1996

SUBSAMPLE VOLUME... 500.0 mLs

TAXON	CELLS.L^{-1} (L^{-1})	BIOMASS ($MG.M^{-3}$)	COL	CELLS	LEN (μM)	WID (μM)	D (μM)	#	TRANS	BIOVOL (μM^3)	COR.F
CYANOBACTERIA											
UN blg 1E	3038	0.0024	0	77	1.5	1.0	0	1	3	0.79	59.19
CHLOROPHYTA											
UN chl 2E	2091	0.1446	0	53	5.5	4.9	0	1	3	69.14	59.19
CHRYSOPHYTA											
UN chr 4E	1539	0.0289	0	39	3.5	3.2	0	1	3	18.77	59.19
TOT CNT	6669	0.1759		169							

Buchans - Drainage Tunnel 3/05/96 (A96-33)

PHYLUM	TOT CELLS.L^{-1}	TOT BIOMASS.M^{-3}
CYANOBACTERIA	3038	0.002
CHLOROPHYTA	2091	0.145
EUGLENOPHYTA	0	0.000
CHRYSOPHYTA	1539	0.029
CRYPTOPHYTA	0	0.000
PYRROPHYTA	0	0.000
DIATOMS	0	0.000
RHODOPHYTA	0	0.000
TOTAL ALGAE	6669	0.176

SUMMARY:

Cell Density: 6.67×10^3 cells/L

Biomass Estimate: 0.18 μg/L

Buchans - Tailings Pond 2 (TP-2)   3/05/96   (A96-34)

Sample File BR9634
DATE ANALYSED...09-22-1996

SUBSAMPLE VOLUME... 105.0 mLs

TAXON	CELLS.L^{-1} (L^{-1})	BIOMASS ($MG.M^{-3}$)	COL	CELLS	LEN (μM)	WID (μM)	D (μM)	#	TRANS	BIOVOL (μM^3)	COR.F
CYANOBACTERIA											
UN bgf 1R	142055	11.1569	0	252	100.0	1.0	0	1	1	78.54	59.19
UN blg 1E	112742	0.0885	0	200	1.5	1.0	0	1	1	0.79	59.19
CHLOROPHYTA											
TM spp 2R	940	0.9124	0	10	51.5	4.9	0	1	3	971.16	29.59
UN chl 2E	133599	16.3688	0	237	6.5	6.0	0	1	1	122.52	59.19
CHRYSOPHYTA											
EP spp 4E	14656	0.2750	0	26	3.5	3.2	0	1	1	18.77	59.19
UN chr 4E	404179	7.5847	0	717	3.5	3.2	0	1	1	18.77	59.19
CM spp 4E	81174	13.2885	0	144	7.4	6.5	0	1	1	163.70	59.19
DI ser 4E	275654	42.6245	0	489	12.3	4.9	0	1	1	154.63	59.19
DI mon 4E	299329	46.2855	0	531	12.3	4.9	0	1	1	154.63	59.19
KP spp 4E	90757	2.3285	0	161	4.0	3.5	0	1	1	25.66	59.19
OM spp 4E	130217	4.9091	0	231	4.5	4.0	0	1	1	37.70	59.19
BACILLARIOPHYTA											
UN dia 7R	27622	10.2091	0	49	19.6	4.9	0	1	1	369.61	59.19
TOT CNT	1712923	156.0317		3048							

Buchans - Tailings Pond 2 (TP-2)   3/05/96   (A96-34)

PHYLUM	TOT CELLS.L^{-1}	TOT BIOMASS.M^{-3}
CYANOBACTERIA	254796	11.245
CHLOROPHYTA	134539	17.281
EUGLENOPHYTA	0	0.000
CHRYSOPHYTA	1295967	117.296
CRYPTOPHYTA	0	0.000
PYRROPHYTA	0	0.000
DIATOMS	27622	10.209
RHODOPHYTA	0	0.000
TOTAL ALGAE	1712923	156.032

SUMMARY:

Cell Density: 1.71×10^6 cells/L

Biomass Estimate: 156.03 μg/L

Buchans - Tailings Pond 2 (TP 2) 3/05/96 (A96-35)

Sample File BR9635
DATE ANALYSED...09-25-1996

SUBSAMPLE VOLUME... 105.0 mLs

TAXON	CELLS.L^{-1} (L^{-1})	BIOMASS ($MG.M^{-3}$)	COL	CELLS	LEN (μM)	WID (μM)	D (μM)	#	TRANS	BIOVOL (μM^3)	COR.F
CYANOBACTERIA											
UN bgf 1R	49606	3.8961	0	88	100.0	1.0	0	1	1	78.54	59.19
UN blg 1E	164603	0.1293	0	292	1.5	1.0	0	1	1	0.79	59.19
CHLOROPHYTA											
MT spp 2R	211	2.3471	0	3	36.8	19.6	0	1	4	11103.24	29.59
TM spp 2R	282	0.3386	0	4	63.7	4.9	0	1	4	1201.22	29.59
UN chl 2E	104286	12.7774	0	185	6.5	6.0	0	1	1	122.52	59.19
CHRYSOPHYTA											
UN chr 4E	315113	8.0847	0	559	4.0	3.5	0	1	1	25.66	59.19
CM spp 4E	98649	16.1492	0	175	7.4	6.5	0	1	1	163.70	59.19
DI ser 4E	220974	51.4496	0	392	14.7	5.5	0	1	1	232.83	59.19
DI mon 4E	312295	57.7129	0	554	14.7	4.9	0	1	1	184.80	59.19
KP spp 4E	103159	3.8890	0	183	4.5	4.0	0	1	1	37.70	59.19
OM spp 4E	153893	5.8016	0	273	4.5	4.0	0	1	1	37.70	59.19
CRYPTOPHYTA											
UN cry 5E	1691	0.0000	0	3	0.0	0.0	0	1	1	0.00	59.19
BACILLARIOPHYTA											
FR rhm 7D	1015	3.3753	0	18	58.8	14.7	0	1	5	3326.45	29.59
TA flc 7T	113	0.1787	0	2	14.7	4.9	22	1	5	1584.66	29.59
PN spp 7R	41714	66.0219	0	74	36.8	7.4	0	1	1	1582.71	59.19
NZ spp 7R	2255	1.3819	0	4	63.7	3.5	0	1	1	612.87	59.19
UN dia 7R	219283	81.0481	0	389	19.6	4.9	0	1	1	369.61	59.19
TOT CNT	1789142	314.5811		3198							

Buchans - Tailings Pond 2 (TP 2) 3/05/96 (A96-35)

PHYLUM	TOT CELLS.L^{-1}	TOT BIOMASS.M^{-3}
CYANOBACTERIA	214209	4.025
CHLOROPHYTA	104779	15.463
EUGLENOPHYTA	0	0.000
CHRYSOPHYTA	1204082	143.087
CRYPTOPHYTA	1691	0.000
PYRROPHYTA	0	0.000
DIATOMS	264379	152.006
RHODOPHYTA	0	0.000
TOTAL ALGAE	1789142	314.581

SUMMARY:

Cell Density: 1.78×10^6 cells/L

Biomass Estimate: 314.58 $\mu g/L$

Buchans - Pool 13   3/05/96   (A96-36)

Sample File BR9636
DATE ANALYSED...09-23-1996

SUBSAMPLE VOLUME... 105.0 mLs

TAXON	CELLS.L^{-1} (L^{-1})	BIOMASS ($MG.M^{-3}$)	COL	CELLS	LEN (μM)	WID (μM)	D (μM)	#	TRANS	BIOVOL (μM^3)	COR.F
CYANOBACTERIA											
OS sps 1R	27058	4.7815	0	48	100.0	1.5	0	1	1	176.71	59.19
UN blg 1E	10147	0.0531	0	18	2.5	2.0	0	1	1	5.24	59.19
CHLOROPHYTA											
TM spp 2R	5543	2.8118	0	59	26.9	4.9	0	1	3	507.26	29.59
UN chl 2E	15220	1.0524	0	27	5.5	4.9	0	1	1	69.14	59.19
CHRYSOPHYTA											
UN chr 4E	21985	0.4126	0	39	3.5	3.2	0	1	1	18.77	59.19
OM spp 4E	7892	0.4100	0	14	4.9	4.5	0	1	1	51.95	59.19
BACILLARIOPHYTA											
UN dia 7R	3946	0.5581	0	7	14.7	3.5	0	1	1	141.43	59.19
TOT CNT	91791	10.0795		212							

Buchans - Pool 13   3/05/96   (A96-36)

PHYLUM	TOT CELLS.L^{-1}	TOT BIOMASS.M^{-3}
CYANOBACTERIA	37205	4.835
CHLOROPHYTA	20763	3.864
EUGLENOPHYTA	0	0.000
CHRYSOPHYTA	29877	0.823
CRYPTOPHYTA	0	0.000
PYRROPHYTA	0	0.000
DIATOMS	3946	0.558
RHODOPHYTA	0	0.000
TOTAL ALGAE	91791	10.080

SUMMARY:

Cell Density: 9.18×10^4 cells/L

Biomass Estimate: 10.08 μg/L

Buchans - Pool 17 3/05/96 (A96-37)

Sample File BR9637
DATE ANALYSED...09-24-1996

SUBSAMPLE VOLUME... 105.0 mLs

TAXON	CELLS.L^{-1} (L^{-1})	BIOMASS ($MG.M^{-3}$)	COL	CELLS	LEN (μM)	WID (μM)	D (μM)	#	TRANS	BIOVOL (μM^3)	COR.F
CYANOBACTERIA											
AN spp 1R	5073	1.5938	0	9	100.0	2.0	0	1	1	314.16	59.19
OS lim 1R	134726	10.5814	0	239	100.0	1.0	0	1	1	78.54	59.19
UN blg 1E	166858	0.3931	0	296	2.0	1.5	0	1	1	2.36	59.19
CHLOROPHYTA											
TM spp 2R	12402	10.8980	0	88	46.6	4.9	0	1	2	878.76	29.59
SP cyl 2E	2819	0.9940	0	5	12.3	7.4	0	1	1	352.67	59.19
OO spp 2E	6201	2.0165	0	11	14.7	6.5	0	1	1	325.19	59.19
SC spp 2E	6201	0.9588	0	11	12.3	4.9	0	1	1	154.63	59.19
UN chl 2E	112742	13.8134	0	200	6.5	6.0	0	1	1	122.52	59.19
EUGLENOPHYTA											
EG spp 3E	1691	3.1295	0	36	36.8	9.8	0	1	3	1850.54	14.80
TR spp 3E	188	1.2057	0	4	31.9	19.6	0	1	3	6416.55	14.80
CHRYSOPHYTA											
UN chr 4E	217028	8.1818	0	385	4.5	4.0	0	1	1	37.70	59.19
OM spp 4E	25931	1.3472	0	46	4.9	4.5	0	1	1	51.95	59.19
CRYPTOPHYTA											
CR ova 5F	141	0.4071	0	3	41.7	14.7	9	1	3	2888.65	14.80
BACILLARIOPHYTA											
PN spm 7R	1550	1.9601	0	11	29.4	7.4	0	1	2	1264.45	29.59
UN dia 7R	4510	1.6668	0	8	19.6	4.9	0	1	1	369.61	59.19
TOT CNT	698059	59.1472		1352							

Buchans - Pool 17 3/05/96 (A96-37)

PHYLUM	TOT CELLS.L^{-1}	TOT BIOMASS.M^{-3}
CYANOBACTERIA	306658	12.568
CHLOROPHYTA	140364	28.681
EUGLENOPHYTA	1879	4.335
CHRYSOPHYTA	242959	9.529
CRYPTOPHYTA	141	0.407
PYRROPHYTA	0	0.000
DIATOMS	6060	3.627
RHODOPHYTA	0	0.000
TOTAL ALGAE	698059	59.147

SUMMARY:

Cell Density: 6.98×10^5 cells/L

Biomass Estimate: 59.15 μg/L

Buchans - OWP 3/05/96 (A96-43)

Sample File BR9643
DATE ANALYSED...01-11-1997

SUBSAMPLE VOLUME... 52.5 mLs

TAXON	CELLS.L^{-1} (L^{-1})	BIOMASS ($MG.M^{-3}$)	COL	CELLS	LEN (μM)	WID (μM)	D (μM)	#	TRANS	BIOVOL (μM^3)	COR.F
CHLOROPHYTA											
UN chl 2E	6765	0.2550	0	6	4.5	4.0	0	1	1	37.70	59.19
BACILLARIOPHYTA											
AH sps 7R	6952	0.4198	0	37	12.3	2.5	0	1	3	60.38	29.59
TOT CNT	13717	0.6748		43							

Buchans - OWP 3/05/96 (A96-43)

PHYLUM	TOT CELLS.L^{-1}	TOT BIOMASS.M^{-3}
CYANOBACTERIA	0	0.000
CHLOROPHYTA	6765	0.255
EUGLENOPHYTA	0	0.000
CHRYSOPHYTA	0	0.000
CRYPTOPHYTA	0	0.000
PYRROPHYTA	0	0.000
DIATOMS	6952	0.420
RHODOPHYTA	0	0.000
TOTAL ALGAE	13717	0.675

SUMMARY:

Cell Density: 1.37×10^4 cells/L

Biomass Estimate: 0.68 μg/L

Buchans - PP13 (regular) 29/09/96 (A96-99)

Sample File BR9699
DATE ANALYSED...11-05-1996

SUBSAMPLE VOLUME... 105.0 mLs

TAXON	CELLS.L^{-1} (L^{-1})	BIOMASS ($MG.M^{-3}$)	COL	CELLS	LEN (μM)	WID (μM)	D (μM)	#	TRANS	BIOVOL (μM^3)	COR.F
CYANOBACTERIA											
AN spp 1R	4651	4.4744	0	33	100.0	3.5	0	1	2	962.11	29.59
BG fil 1R	40023	3.5364	0	71	50.0	1.5	0	1	1	88.36	59.19
RB lin 1R	12402	2.2918	0	22	9.8	4.9	0	1	1	184.80	59.19
UN blg 1E	61444	0.1448	0	109	2.0	1.5	0	1	1	2.36	59.19
CHLOROPHYTA											
TM spp 2R	133035	196.6822	0	944	78.4	4.9	0	1	2	1478.42	29.59
SP cyl 2E	141	0.0458	0	1	14.7	6.5	0	1	2	325.19	29.59
OO spp 2E	153893	54.2731	0	273	12.3	7.4	0	1	1	352.67	59.19
KS spp 2R	636427	13.9958	0	1129	7.0	2.0	0	1	1	21.99	59.19
UN chl 2E	141491	9.7832	0	251	5.5	4.9	0	1	1	69.14	59.19
EUGLENOPHYTA											
EG spp 3E	3100	24.0830	0	22	49.0	17.4	0	1	2	7767.71	29.59
CHRYSOPHYTA											
UN chr 4E	120634	6.2674	0	214	4.9	4.5	0	1	1	51.95	59.19
CM spp 4E	37768	4.6275	0	67	6.5	6.0	0	1	1	122.52	59.19
OM spp 4E	92448	1.7349	0	164	3.5	3.2	0	1	1	18.77	59.19
CRYPTOPHYTA											
CR ero 5F	1973	2.1792	0	14	24.5	12.3	7	1	2	1104.51	29.59
UN cry 5E	6765	1.3178	0	12	12.3	5.5	0	1	1	194.82	59.19
BACILLARIOPHYTA											
PN spm 7R	16207	150.9763	0	115	78.4	12.3	0	1	2	9315.72	29.59
NZ spp 7R	7892	1.3288	0	14	34.3	2.5	0	1	1	168.37	59.19
UN dia 7R	42278	5.9794	0	75	14.7	3.5	0	1	1	141.43	59.19
TOT CNT	1512572	483.7218		3530							

Buchans - PP13 (regular - unconcentrated) 29/09/96 (A96-99)

PHYLUM	TOT CELLS.L^{-1}	TOT BIOMASS.M^{-3}
CYANOBACTERIA	118520	10.447
CHLOROPHYTA	1064987	274.780
EUGLENOPHYTA	3100	24.083
CHRYSOPHYTA	250850	12.630
CRYPTOPHYTA	8737	3.497
PYRROPHYTA	0	0.000
DIATOMS	66377	158.285
RHODOPHYTA	0	0.000
TOTAL ALGAE	1512572	483.722

SUMMARY:

Cell Density: 1.51×10^6 cells/L

Biomass Estimate: 483.72 μg/L

Buchans - Drainage Tunnel (regular) 29/09/96 (A96-101)

Sample File BR96C1
DATE ANALYSED...10-12-1996

SUBSAMPLE VOLUME... 105.0 mLs

TAXON	CELLS.L^{-1} (L^{-1})	BIOMASS ($MG.M^{-3}$)	COL	CELLS	LEN (μM)	WID (μM)	D (μM)	#	TRANS	BIOVOL ($μM^3$)	COR.F
CYANOBACTERIA											
UN blg 1E	15220	0.0359	0	27	2.0	1.5	0	2	1	2.36	59.19
CHLOROPHYTA											
SC spp 2E	165730	10.4175	0	294	9.8	3.5	0	1	1	62.86	59.19
UN chl 2E	23676	1.2301	0	42	4.9	4.5	0	1	1	51.95	59.19
CHRYSOPHYTA											
UN chr 4E	23676	0.4443	0	42	3.5	3.2	0	1	1	18.77	59.19
BACILLARIOPHYTA											
EU sps 7R	20294	0.7842	0	36	12.3	2.0	0	1	1	38.64	59.19
AH sps 7R	42842	2.5867	0	76	12.3	2.5	0	2	1	60.38	59.19
TOT CNT	291437	15.4986		517							

Buchans - Drainage Tunnel (regular-unconcentrated) 29/09/96 (A96-101)

PHYLUM	TOT CELLS.L^{-1}	TOT BIOMASS.M^{-3}
CYANOBACTERIA	15220	0.036
CHLOROPHYTA	189406	11.648
EUGLENOPHYTA	0	0.000
CHRYSOPHYTA	23676	0.444
CRYPTOPHYTA	0	0.000
PYRROPHYTA	0	0.000
DIATOMS	63135	3.371
RHODOPHYTA	0	0.000
TOTAL ALGAE	291437	15.499

SUMMARY:

Cell Density: 2.91×10^5 cells/L

Biomass Estimate: 15.5 μg/L

Buchans - OWP (regular) 29/09/96 (A96-103)

Sample File BR96C3
DATE ANALYSED...12-10-1996

SUBSAMPLE VOLUME... 52.5 mLs

TAXON	CELLS.L^{-1} (L^{-1})	BIOMASS ($MG.M^{-3}$)	COL	CELLS	LEN (μM)	WID (μM)	D (μM)	#	TRANS	BIOVOL (μM^3)	COR.F
CYANOBACTERIA											
OS spl 1R	14469	27.2839	0	77	100.0	4.9	0	1	3	1885.74	29.59
BG fil 1R	80047	7.0727	0	71	50.0	1.5	0	1	1	88.36	59.19
UN blg 1E	138672	0.3267	0	123	2.0	1.5	0	1	1	2.36	59.19
CHLOROPHYTA											
PD spp 2F	451	1.9150	0	8	61.3	44.1	3	1	5	4246.38	14.80
TM spp 2R	1879	2.6044	0	10	73.5	4.9	0	1	3	1386.02	29.59
MC spp 2R	8080	1.1427	0	43	14.7	3.5	0	1	3	141.43	29.59
SC spp 2E	48479	7.4963	0	43	12.3	4.9	0	1	1	154.63	59.19
UN chl 2E	289746	35.5003	0	257	6.5	6.0	0	1	1	122.52	59.19
EUGLENOPHYTA											
EG spp 3E	752	2.6257	0	4	44.1	12.3	0	1	3	3493.39	29.59
CHRYSOPHYTA											
UN chr 4E	224356	11.6562	0	199	4.9	4.5	0	1	1	51.95	59.19
CM spp 4E	27058	3.5399	0	24	6.5	6.2	0	1	1	130.83	59.19
OM spp 4E	135290	2.5388	0	120	3.5	3.2	0	1	1	18.77	59.19
BACILLARIOPHYTA											
AH sps 7R	23676	1.7084	0	21	14.7	2.5	0	1	1	72.16	59.19
NZ sps 7R	4510	0.4339	0	4	19.6	2.5	0	1	1	96.21	59.19
UN dia 7R	65390	21.2092	0	58	17.2	4.9	0	1	1	324.35	59.19
TOT CNT	1062854	127.0542		1062							

Buchans - OWP (regular - unconcentrated) 29/09/96 (A96-103)

PHYLUM	TOT CELLS.L^{-1}	TOT BIOMASS.M^{-3}
CYANOBACTERIA	233188	34.683
CHLOROPHYTA	348635	48.659
EUGLENOPHYTA	752	2.626
CHRYSOPHYTA	386704	17.735
CRYPTOPHYTA	0	0.000
PYRROPHYTA	0	0.000
DIATOMS	93576	23.351
RHODOPHYTA	0	0.000
TOTAL ALGAE	1062854	127.054

SUMMARY:

Cell Density: 1.06×10^6 cells/L

Biomass Estimate: 127.05 $\mu g/L$

Buchans - PP 17 (regular) 29/09/96 (A96-105)

Sample File BR96C5
DATE ANALYSED...11-29-1996

SUBSAMPLE VOLUME... 52.5 mLs

TAXON	CELLS.L^{-1} (L^{-1})	BIOMASS ($MG.M^{-3}$)	COL	CELLS	LEN (μM)	WID (μM)	D (μM)	#	TRANS	BIOVOL (μM^3)	COR.F
CYANOBACTERIA											
BG fil 1R	25179	2.2247	0	134	50.0	1.5	0	1	3	88.36	29.59
UN blg 1E	157838	0.3719	0	140	2.0	1.5	0	1	1	2.36	59.19
CHLOROPHYTA											
KS spp 2R	25931	0.5295	0	23	6.5	2.0	0	1	1	20.42	59.19
OO spp 2E	9019	3.1808	0	8	12.3	7.4	0	1	1	352.67	59.19
UN chl 2E	125143	15.3328	0	111	6.5	6.0	0	1	1	122.52	59.19
CHRYSOPHYTA											
UN chr 4E	131908	4.9728	0	117	4.5	4.0	0	1	1	37.70	59.19
CM spp 4E	29313	3.5915	0	26	6.5	6.0	0	1	1	122.52	59.19
OM spp 4E	55243	1.0367	0	49	3.5	3.2	0	1	1	18.77	59.19
BACILLARIOPHYTA											
PN spm 7R	564	5.0839	0	1	75.9	12.3	0	1	1	9018.66	29.59
AH sps 7R	9019	0.5446	0	8	12.3	2.5	0	1	1	60.38	59.19
UN dia 7R	6765	0.9567	0	6	14.7	3.5	0	1	1	141.43	59.19
TOT CNT	575922	37.8260		623							

Buchans - PP 17 (regular-unconcentrated) 29/09/96 (A96-105)

PHYLUM	TOT CELLS.L^{-1}	TOT BIOMASS.M^{-3}
CYANOBACTERIA	183017	2.597
CHLOROPHYTA	160093	19.043
EUGLENOPHYTA	0	0.000
CHRYSOPHYTA	216464	9.601
CRYPTOPHYTA	0	0.000
PYRROPHYTA	0	0.000
DIATOMS	16348	6.585
RHODOPHYTA	0	0.000
TOTAL ALGAE	575922	37.826

SUMMARY:

Cell Density: 5.76×10^5 cells/L

Biomass Estimate: 37.83 μg/L

Buchans - OEP (regular) 29/09/96 (A96-107)

Sample File BR96C7
DATE ANALYSED...10-27-1996

SUBSAMPLE VOLUME... 105.0 mLs

TAXON	CELLS.L^{-1} (L^{-1})	BIOMASS ($MG.M^{-3}$)	COL	CELLS	LEN (μM)	WID (μM)	D (μM)	#	TRANS	BIOVOL (μM^3)	COR.F
CHLOROPHYTA											
UN chl 2E	1785	0.2922	0	19	7.4	6.5	0	1	3	163.70	29.59
UN chl 2E	12965	0.4888	0	23	4.5	4.0	0	1	1	37.70	59.19
CHRYSOPHYTA											
UN chr 4E	75537	1.4175	0	134	3.5	3.2	0	1	1	18.77	59.19
BACILLARIOPHYTA											
UN dia 7R	1691	0.3189	0	3	19.6	3.5	0	1	1	188.57	59.19
TOT CNT	91978	2.5174		179							

Buchans - OEP (regular-unconcentrated) 29/09/96 (A96-107)

PHYLUM	TOT CELLS.L^{-1}	TOT BIOMASS.M^{-3}
CYANOBACTERIA	0	0.000
CHLOROPHYTA	14750	0.781
EUGLENOPHYTA	0	0.000
CHRYSOPHYTA	75537	1.418
CRYPTOPHYTA	0	0.000
PYRROPHYTA	0	0.000
DIATOMS	1691	0.319
RHODOPHYTA	0	0.000
TOTAL ALGAE	91978	2.517

SUMMARY:

Cell Density: 9.2×10^4 cells/L

Biomass Estimate: 2.52 μg/L

ALGATAX CONSULTING - ALGAL IDENTIFICATION REPORT

SITE: Buchans

Sample # **A96-23**

Location: **Buchans - PP in (00:56)**

Date: **8/07/96**

- 250 mLs concentrated to 20 mLs; settled 2.1 mLs for examination (at 200X and 400X)

- some floc-like material and fine debris present; very little algal matter present

Algal Taxa Present:

CLASS	TAXON	Ranking
Cyanobacteria	Oscillatoria sp. (small filament)	1
Chlorophyceae	Chlamydomonas spp.	1
	Ulothrix sp.	1
	Unidentified small green spp.	2
Euglenophyceae		
Chrysophyceae	Ochromonas spp.	2
	Unidentified small chrysophytes	2
Bacillariophyceae	Achnanthes sp.	2
	Eunotia fallax	2
Cryptophyceae		
Dinophyceae		

Note: - fungal hyphae evident in sample

ALGATAX CONSULTING - ALGAL IDENTIFICATION REPORT

SITE: Buchans

Sample # **A96-24**

Location: **Buchans - PP out (00:36)**

Date: **8/07/96**

- 250 mLs concentrated to 20 mLs; settled 2.1 mLs for examination (at 200X and 400X)

- very dilute sample with very little algal material present; some floc-like precipitate present
- similar to sample A96-23

Algal Taxa Present:

CLASS	TAXON	Ranking
Cyanobacteria	Oscillatoria sp. (small filament)	2
Chlorophyceae	Unidentified small green spp.	3
Euglenophyceae		
Chrysophyceae	Ochromonas spp.	3
	Unidentified small chrysophytes	2
Bacillariophyceae	Achnanthes sp.	1
	Eunotia fallax	2
	Fragilaria sp.	1
	Navicula sp. (small sp.)	1
Cryptophyceae		
Dinophyceae		

Note: - fungal hyphae evident in sample

ALGATAX CONSULTING - ALGAL IDENTIFICATION REPORT

SITE: Buchans

Sample # **A96-38**

Location: **Buchans - MLC - I (16:54)**

Date: **11/07/96**

- 250 mLs concentrated to 20 mLs; concentrated 10 mLs to 2.1 mLs for examination (at 200X and 400X)

- very dilute sample with very little algal material present; also very little debris present

Algal Taxa Present:

CLASS	TAXON	Ranking
Cyanobacteria		
Chlorophyceae	Scenedesmus acuminatus	2
	Selenastrum sp.	2
	Unidentified small green spp.	3
Euglenophyceae		
Chrysophyceae		
Bacillariophyceae		
Cryptophyceae		
Dinophyceae		

ALGATAX CONSULTING - ALGAL IDENTIFICATION REPORT

SITE: Buchans

Sample # **A96-39**

Location: **Buchans - MLC - II (17:21)**

Date: **11/07/96**

- 250 mLs concentrated to 20 mLs; concentrated 10 mLs to 2.1 mLs for examination (at 200X and 400X)

- very dilute sample with very little algal material present; also very little debris present

Algal Taxa Present:

CLASS	TAXON	Ranking
Cyanobacteria		
Chlorophyceae	Selenastrum sp.	1
	Unidentified small green spp.	2
Euglenophyceae		
Chrysophyceae		
Bacillariophyceae	Navicula sp. (small sp.)	1
Cryptophyceae		
Dinophyceae		

ALGATAX CONSULTING - ALGAL IDENTIFICATION REPORT

SITE: Buchans

Sample # **A96-40**

Location: **Buchans - MLC - III (17:41)**

Date: **11/07/96**

- 250 mLs concentrated to 20 mLs; concentrated 10 mLs to 2.1 mLs for examination (at 200X and 400X)

- very dilute sample with very little algal material present; also very little debris present

Algal Taxa Present:

CLASS	TAXON	Ranking
Cyanobacteria	Unidentified bluegreen filament	1
Chlorophyceae	Scenedesmus acuminatus	1
	Selenastrum sp.	1
	Temnogametum sp.	3
	Ulothrix sp.	2
	Unidentified small green spp.	3
Euglenophyceae		
Chrysophyceae		
Bacillariophyceae	Achnanthes sp.	2
	Navicula sp. (small sp.)	3
Cryptophyceae		
Dinophyceae		

ALGATAX CONSULTING - ALGAL IDENTIFICATION REPORT

SITE: Buchans

Sample # **A96-41**

Location: **Buchans - PP - In (18:42)**

Date: **11/07/96**

- 250 mLs concentrated to 20 mLs; concentrated 10 mLs to 2.1 mLs for examination (at 200X and 400X)

- dilute sample with very little debris present

Algal Taxa Present:

CLASS	TAXON	Ranking
Cyanobacteria	Unidentified bluegreen filament	1
	Unidentified bluegreen spp.	2
Chlorophyceae	Chlamydomonas sp.	1
	Unidentified small green spp.	3
Euglenophyceae	Euglena sp.	1
Chrysophyceae	Epipyxis sp.	1
	Ochromonas spp.	3
	Unidentified small chrysophytes	2
Bacillariophyceae	Achnanthes sp.	2
	Navicula spp. (small spp.)	2
	Nitzschia sp.	1
	Pinnularia sp. (small sp.)	1
Cryptophyceae		
Dinophyceae		

Note: - amoeboid species also present

ALGATAX CONSULTING - ALGAL IDENTIFICATION REPORT

SITE: Buchans

Sample # **A96-42**

Location: **Buchans - PP out (18:16)**

Date: **11/07/96**

- 250 mLs concentrated to 20 mLs; concentrated 10 mLs to 2.1 mLs for examination (at 200X and 400X)

- dilute sample with very little algal material present

Algal Taxa Present:

CLASS	TAXON	Ranking
Cyanobacteria	Unidentified bluegreen filament	1
	Unidentified small bluegreens	2
Chlorophyceae	Chlamydomonas spp.	1
	Scenedesmus acuminatus	1
	Selenastrum sp.	1
	Temnogametum sp.	1
	Ulothrix sp.	1
	Unidentified small green spp.	3
Euglenophyceae	Euglena sp.	1
Chrysophyceae	Unidentified small chrysophytes	2
Bacillariophyceae	Achnanthes sp.	1
	Navicula sp. (small sp.)	1
	Nitzschia sp.	1
Cryptophyceae	Chroomonas sp.	1
Dinophyceae		

ALGATAX CONSULTING - ALGAL IDENTIFICATION REPORT

SITE: Buchans

Sample # **A96-43**

Location: **Oriental West Pit (OWP)**

Date: **3/05/96**

- 1000 mLs concentrated to 20 mLs; considerable amount of sediment and floc-like precipitate present

- too much sediment to permit enumeration; very little algae present

Algal Taxa Present:

CLASS	TAXON	Ranking
Cyanobacteria		
Chlorophyceae	Oocystis sp.	1
	Ulothrix sp.	2
Euglenophyceae		
Chrysophyceae		
Bacillariophyceae	Achnanthes sp.	2
	Eunotia fallax	2
	Navicula spp.	1
	Nitzschia spp.	1
	Pinnularia sp.	1
Cryptophyceae		
Dinophyceae		

ALGATAX CONSULTING - ALGAL IDENTIFICATION REPORT

SITE: Buchans

Sample # **A96-44**

Location: **Oriental West Pit (OWP)**

Date: **13/05/96**

- 250 mLs concentrated to 20 mLs; considerable amount of sediment and floc-like precipitate present

- considerable amount of filamentous algae; many filaments coated with precipitate; also many filaments look 'unhealthy' with distorted cell shapes

Algal Taxa Present:

CLASS	TAXON	Ranking
Cyanobacteria		
Chlorophyceae	Microspora spp.	5
	Ulothrix sp.	2
Euglenophyceae		
Chrysophyceae		
Bacillariophyceae		
Cryptophyceae		
Dinophyceae		

ALGATAX CONSULTING - ALGAL IDENTIFICATION REPORT

SITE: Buchans

Sample # **A96-45**

Location: **Oriental East Pit (OEP)**

Date: **13/05/96**

- 250 mLs concentrated to 20 mLs; considerable amount of floc-like precipitate present

- cells appear healthy and greater algal diversity is evident
- considerable amount of moss protonemata present (at least 2 distinct sizes); much of the protonemata is coated with floc-like precipitate
- narrow fungal hyphae also present

Algal Taxa Present:

CLASS	TAXON	Ranking
Cyanobacteria	Bluegreen filament (small sp.)	3
Chlorophyceae	Temnogametum sp.	2
Euglenophyceae		
Chrysophyceae		
Bacillariophyceae	Achnanthes sp.	4
	Nitzschia spp.	3
	Pinnularia sp. (medium)	3
Cryptophyceae		
Dinophyceae		

ALGATAX CONSULTING - ALGAL IDENTIFICATION REPORT

SITE: Buchans

Sample # **A96-46**

Location: **Pool 13 (PP 13)**

Date: **13/05/96**

- 250 mLs concentrated to 20 mLs; relatively little precipitate present

- moss protonemata also common; not coated with precipitate in this sample

Algal Taxa Present:

CLASS	TAXON	Ranking
Cyanobacteria	Bluegreen filament (small spp.) (maybe Phormidium sp.)	4
Chlorophyceae	Temnogametum sp. (very healthy filaments)	5
Euglenophyceae		
Chrysophyceae		
Bacillariophyceae	Pinnularia sp. (medium)	2
Cryptophyceae		
Dinophyceae		

ALGATAX CONSULTING - ALGAL IDENTIFICATION REPORT

SITE: Buchans

Sample # **A96-47**

Location: **Pool 17 (PP 17)**

Date: **13/05/96**

- 250 mLs concentrated to 20 mLs; considerable amount of sediment and floc-like precipitate present

- moss protonemata co-dominant with filamentous algae
- narrow fungal hyphae also common

Algal Taxa Present:

CLASS	TAXON	Ranking
Cyanobacteria	Bluegreen filament (small sp.)	3
Chlorophyceae	Temnogametum sp.	4
Euglenophyceae		
Chrysophyceae		
Bacillariophyceae	Pinnularia sp. (medium)	1
	Pinnularia sp. (small)	1
Cryptophyceae		
Dinophyceae		

ALGATAX CONSULTING - ALGAL IDENTIFICATION REPORT

SITE: Buchans

Sample # **A96-55**

Location: **Buchans - Polishing Pond (PP14) - Mat "Bubble"** (pH 6.93)
(sample labelled A)

Date: **12/07/96**

- 100 mLs "pureed" sample for Culturing Experiment

- considerable amount of floc-like sediment present; let sample settle then examined algae in supernatant

- sample dominated by moss protonemata (wide filament form)

Algal Taxa Present:

CLASS	TAXON	Ranking
Cyanobacteria	Oscillatoria sp. (small sp.)	1
Chlorophyceae	Microthamnion sp.	2
	Oocystis sp.	2
	Ulothrix sp.	3
Euglenophyceae	Euglena gracilis	2
Chrysophyceae		
Bacillariophyceae	Nitzschia spp.	3
Cryptophyceae		
Dinophyceae		

NOTE: - numerous bacteria and heterotrophic flagellates also present

ALGATAX CONSULTING - ALGAL IDENTIFICATION REPORT

SITE: Buchans

Sample # **A96-56**

Location: **Buchans Polishing Pond (PP 12) - Seep Algae** (pH 6.99)
(sample labelled B)

Date: **12/07/96**

- 100 mLs "pureed" sample for Culturing Experiment

- considerable amount of floc-like sediment present; let sample settle then examined algae in supernatant (sample similar to samples A96-55 and A96-58)

- sample dominated by moss protonemata (both wide and narrow filament forms)

Algal Taxa Present:

CLASS	TAXON	Ranking
Cyanobacteria		
Chlorophyceae	Chlamydomonas spp.	2
	Chlorella sp.	1
	Microthamnion sp.	2
	Oocystis sp.	2
	Ulothrix sp.	3
Euglenophyceae	Euglena gracilis	2
Chrysophyceae		
Bacillariophyceae	Nitzschia spp.	2
Cryptophyceae		
Dinophyceae		

ALGATAX CONSULTING - ALGAL IDENTIFICATION REPORT

SITE: Buchans

Sample # **A96-57**

Location: **Oriental West Pit (OWP) - Filamentous Algae** (pH 4.83)
(sample labelled C)

Date: **12/07/96**

- 100 mLs "pureed" sample for Culturing Experiment

- very little debris or sediment present; essentially 'pure' sample of Ulothrix sp.

Algal Taxa Present:

CLASS	TAXON	Ranking
Cyanobacteria		
Chlorophyceae	Ulothrix sp.	5
Euglenophyceae		
Chrysophyceae		
Bacillariophyceae		
Cryptophyceae		
Dinophyceae		

NOTE: - bacteria and fungal hyphae also noted

ALGATAX CONSULTING - ALGAL IDENTIFICATION REPORT

SITE: Buchans

Sample # **A96-58**

Location: **Buchans Polishing Pond (PP 14) - "Floating Bubble"** (pH 6.98)
(sampled labelled D)

Date: **12/07/96**

- 100 mLs "pureed" sample for Culturing Experiment

- considerable amount of floc-like sediment present; let sample settle then examined algae in supernatant (sample similar to A96-55 and A96-56)

- sample dominated by moss protonemata (wide filament form)

Algal Taxa Present:

CLASS	TAXON	Ranking
Cyanobacteria		
Chlorophyceae	Chlamydomonas sp.	2
	Chlorella sp.	2
	Microthamnion sp.	2
	Oocystis sp.	2
	Ulothrix sp.	3
Euglenophyceae	Euglena gracilis	2
Chrysophyceae		
Bacillariophyceae	Nitzschia spp.	2
Cryptophyceae		
Dinophyceae		

NOTE: - fungal hyphae also present in sample

Summary of Macronutrients Present in Media Used for Culturing Buchans Algal Mat Samples and for <u>Dictyosphaerium pulchellum</u>

MEDIA TYPES
(concentrations given in mmolar and mg/L)

Inorganic Macronutrients		Regular and Modified Chu-1 0 Regular (10:1 N to P)		Reduced Silica Content		Field Levels (1:1 N to P)	
		mM	mg/L	mM	mg/L	mM	mg/L
Ammonium	(NH_4^+)	——	——	——	——	——	——
Calcium	(Ca^{2+})	0.17	6.81	0.17	6.81	0.085	3.41
Magnesium	(Mg^{2+})	0.1	2.43	0.1	2.43	0.1	2.43
Potassium	(K^+)	0.11	4.3	0.11	4.3	0.46	4.3
Sodium	(Na^+)	0.55	12.6	0.39	8.97	0.55	12.6
Carbonate	(CO_3^{2-})	0.19	11.4	0.19	11.4	0.19	11.4
Chloride	(Cl^-)	0.0089	0.32	0.0089	0.32	0.0089	0.32
Nitrate	(NO_3^-)	0.34	21.08	0.34	21.08	0.17	10.54
Phosphate	(PO_4^{3-})	0.057	5.41	0.057	5.41	0.23	21.84
Silicate	(SiO_3^{2-})	0.088	6.69	0.0088	0.669	0.0088	0.669
Sulphate	(SO_4^{2-})	0.1	9.6	0.1	9.6	0.1	9.6

Summary of Macronutrients Present in Media Used for Culturing Buchans Algal Mat Samples and for Dictyosphaerium pulchellum

MEDIA TYPES
(concentrations given in mmolar and mg/L)

Inorganic Macronutrients		B.B.M. Bold's Basal Medium mM	B.B.M. Bold's Basal Medium mg/L	B.G.-11 Blue-Green-11 Medium mM	B.G.-11 Blue-Green-11 Medium mg/L
Ammonium	(NH_4^+)	----	----		
Calcium	(Ca^{2+})	0.17	6.81	0.25	10.02
Magnesium	(Mg^{2+})	0.3	7.29	0.3	7.29
Potassium	(K^+)	2.7	105.56	0.34	13.29
Sodium	(Na^+)	3.37	77.48	18.03	414.51
Carbonate	(CO_3^{2-})	----	----	0.19	11.4
Chloride	(Cl^-)	0.77	27.3	0.49	17.37
Nitrate	(NO_3^-)	2.94	182.28	17.65	1094.3
Phosphate	(PO_4^{3-})	1.72	117.27	0.17	16.15
Silicate	(SiO_3^{2-})	----	----	----	----
Sulphate	(SO_4^{2-})	0.34	32.66	0.3	28.82

BUCHAN'S CULTURING EXPERIMENT- Sampling Day 31

Identification of Major Taxa Found in Four Different Types of Freshwater Media

Ranking System Used:

5 = most abundant, found dominating most fields of view
4 = very abundant
3 = common
2 = less common
1 = rare

Innoculum Taken From Sampling Container Marked:
C - **OWP fil.algae from 12/7/96**

REGULAR CHU 10 MEDIA

CATEGORY	GENERA	RANK
Green algae	**Scenedesmus**	5
Filamentous greens	**Mougeotia**	5
Blue-Green filaments	**Phormidium**	4
	Anabaena	1
Diatoms	**Pinnularia**	4
	Navicula	2
	Achnanthes	3
Small Greens		1

CHU 10 WITH LESS SILICA

CATEGORY	GENERA	RANK
Green algae	**Scenedesmus**	5
Filamentous greens	**Mougeotia**	5
Blue-Green filaments	**Lyngbya**	4
	Anabaena	3
	Phormidium	1
Diatoms	**Pinnularia**	3
	Navicula	2
Moss		2
Small Greens		2

BOLD'S BASAL MEDIUM (B.B.M.)

CATEGORY	GENERA	RANK
Green algae	**Scenedesmus**	5
Filamentous greens	**Mougeotia**	3
Blue-Green filaments	**Phormidium**	4
	Lyngbya	2
Diatoms	**Pinnularia**	2
Moss		1

BLUE - GREEN 11 (B.G.11)

CATEGORY	GENERA	RANK
Green algae	**Scenedesmus**	4
Blue-Green filaments	**Phormidium**	4
	Lyngbya	4
	Anabaena	3
Small Greens		2

BUCHAN'S CULTURING EXPERIMENT- Sampling Day 31

Identification of Major Taxa Found in Four Different Types of Freshwater Media

Ranking System Used:

5 = most abundant, found dominating most fields of view
4 = very abundant
3 = common
2 = less common
1 = rare

Innoculum Taken From Sampling Container Marked:
D - PP14 Float Bubble from 11/7/96

REGULAR CHU 10 MEDIA

CATEGORY	GENERA	RANK
Green algae	Scenedesmus	1
Filamentous greens	Mougeotia	1
	Ulothrix	5
Blue-Green filaments	Lyngbya	3
Small Greens		1

CHU 10 WITH LESS SILICA

CATEGORY	GENERA	RANK
Green algae	Scenedesmus	1
Filamentous greens	Mougeotia	3
	Ulothrix	5
Small Greens		4

BOLD'S BASAL MEDIUM (B.B.M.)

CATEGORY	GENERA	RANK
Green algae	Scenedesmus	4
Filamentous greens	Mougeotia	1
	Ulothrix	5
Small Greens		1

BLUE - GREEN 11 (B.G.11)

CATEGORY	GENERA	RANK
Green algae	Scenedesmus	3
Filamentous greens	Mougeotia	4
	Ulothrix	5
Small Greens		2

BUCHAN'S CULTURING EXPERIMENT- Sampling Day 31

Identification of Major Taxa in Preserved Samples

Ranking System Used:

5 = most abundant, found dominating most fields of view
4 = very abundant
3 = common
2 = less common
1 = rare

SAMPLE VIAL	CATEGORY	GENERA	RANK
A1	Diatoms	Pinnularia	4
		Navicula	4
	Blue-Green Filaments	Phormidium	2
	Moss		5
	Small Greens		1
	Rod and Coccoid Bacteria		5
A2	CATEGORY	GENERA	RANK
	Diatoms	Pinnularia	3
		Navicula	3
	Blue-Green Filaments	Phormidium	3
	Moss		5
	Small Greens		1
	Rod and Coccoid Bacteria		5
A3	CATEGORY	GENERA	RANK
	Diatoms	Pinnularia	2
		Navicula	2
	Blue-Green Filaments	Phormidium	4
	Moss		5
	Small Greens		1
	Rod and Coccoid Bacteria		4

CULTURING EXPERIMENT Continued

SAMPLE VIAL	CATEGORY	GENERA	RANK
B1	Filamentous Greens	Microspora	5
		Ulothrix	1
	Diatoms	Pinnularia	1
		Navicula	1
	Blue-Green Filaments	Phormidium	4
	Moss		5
	Small Greens		1
	Rod and Coccoid Bacteria		3

	CATEGORY	GENERA	RANK
B2	Filamentous Greens	Microspora	5
		Ulothrix	1
	Rod and Coccoid Bacteria		4

	CATEGORY	GENERA	RANK
B3	Filamentous Greens	Microspora	5
	Blue-Green Filaments	Phormidium	3
	Rod and Coccoid Bacteria		4

CULTURING EXPERIMENT Continued

SAMPLE VIAL	CATEGORY	GENERA	RANK
C1	CATEGORY	GENERA	RANK
	Green algae	Scenedesmus	1
	Filamentous Greens	Microspora	5
	Blue-Green Filaments	Lyngbya	5
	Diatoms	Achnanthes	3
		Pinnularia	3
		Nitzschia	3
		Navicula	3
	Rod and Coccoid Bacteria		3
C2	CATEGORY	GENERA	RANK
	Green algae	Scenedesmus	1
	Filamentous Greens	Microspora	5
	Blue-Green Filaments	Lyngbya	5
	Diatoms	Achnanthes	3
		Pinnularia	3
		Nitzschia	3
		Navicula	3
	Rod and Coccoid Bacteria		3
C3	CATEGORY	GENERA	RANK
	Green algae	Scenedesmus	2
	Filamentous Greens	Microspora	5
	Blue-Green Filaments	Lyngbya	4
		Phormidium	4
	Diatoms	Achnanthes	3
		Pinnularia	3
		Nitzschia	3
		Navicula	3
	Rod and Coccoid Bacteria		4

CULTURING EXPERIMENT Continued

SAMPLE VIAL	CATEGORY	GENERA	RANK
D1	Blue-Green Filaments	Lyngbya	2
		Phormidium	2
	Diatoms	Navicula	3
		Pinnularia	3
	Rod and Coccoid Bacteria		5
	Moss		5
	Fungal Hyphae		5
	CATEGORY	GENERA	RANK
D2	Blue-Green Filaments	Lyngbya	2
	Diatoms	Navicula	2
		Pinnularia	2
	Rod and Coccoid Bacteria		5
	Moss		5
	Fungal Hyphae		5
	Small Greens		1
D3	CATEGORY	GENERA	RANK
	Green Algae	Scenedesmus	1
	Blue-Green Filaments	Lyngbya	5
	Diatoms	Navicula	3
		Pinnularia	3
	Rod and Coccoid Bacteria		4
	Moss		5
	Fungal Hyphae		5

CULTURING EXPERIMENT Continued

SAMPLE VIAL			
E1	CATEGORY	GENERA	RANK
	Filamentous Greens	Ulothrix	5
	Diatoms	Achnanthes	2
		Pinnularia	2
	Rod and Coccoid Bacteria		3
	Small Greens		1
E2	CATEGORY	GENERA	RANK
	Filamentous Greens	Ulothrix	5
	Diatoms	Achnanthes	2
		Pinnularia	2
	Rod and Coccoid Bacteria		2
	Small Greens		1
E3	CATEGORY	GENERA	RANK
	Filamentous Greens	Ulothrix	5
	Diatoms	Achnanthes	2
		Pinnularia	2
	Rod and Coccoid Bacteria		1
	Small Greens		1
	Fungal Hyphae		4

CULTURING EXPERIMENT Continued

SAMPLE VIAL	CATEGORY	GENERA	RANK
F1	CATEGORY	GENERA	RANK
	Filamentous Greens	Ulothrix	2
		Microspora	2
	Blue-Green Filaments	Lyngbya	4
		Phormidium	2
	Rod and Coccoid Bacteria		2
	Small Greens		1
	Fungal Hyphae		5
	Moss		5
	Diatoms	Achnanthes	3
		Pinnularia	3
		Nitzschia	3
		Navicula	3
F2	CATEGORY	GENERA	RANK
	Filamentous Greens	Ulothrix	4
		Microspora	5
	Diatoms	Achnanthes	4
		Pinnularia	4
		Nitzschia	4
		Navicula	4
	Rod and Coccoid Bacteria		3
	Fungal Hyphae		4
	Moss		5
F3	CATEGORY	GENERA	RANK
	Filamentous Greens	Ulothrix	2
		Microspora	2
	Green algae	Scenedesmus	1
	Blue-Green Filaments	Lyngbya	3
	Diatoms	Achnanthes	4
		Pinnularia	4
		Nitzschia	4
		Navicula	4
		Eunotia	1
	Rod and Coccoid Bacteria		2
	Fungal Hyphae		5
	Moss		5

CULTURING EXPERIMENT Continued

SAMPLE VIAL	CATEGORY	GENERA	RANK
G1	Filamentous Greens	Ulothrix	1
		Microspora	3
	Green algae	Scenedesmus	1
	Blue-Green Filaments	Lyngbya	3
	Diatoms	Achnanthes	2
		Pinnularia	2
		Nitzschia	2
		Navicula	2
		Eunotia	1
	Rod and Coccoid Bacteria		2
	Fungal Hyphae		5
	Moss		5
G2	CATEGORY	GENERA	RANK
	Blue-Green Filaments	Lyngbya	3
	Diatoms	Achnanthes	3
		Pinnularia	3
		Nitzschia	3
		Navicula	3
	Rod and Coccoid Bacteria		3
	Fungal Hyphae		5
	Moss		5
G3	CATEGORY	GENERA	RANK
	Filamentous Greens	Microspora	2
	Green algae	Scenedesmus	4
	Blue-Green Filaments	Lyngbya	4
	Diatoms	Achnanthes	3
		Pinnularia	3
		Nitzschia	3
		Navicula	3
	Rod and Coccoid Bacteria		2
	Fungal Hyphae		5
	Moss		5
	Small Greens		1

6.0 PHOSPHATE: LIMITING NUTRIENT FOR PRIMARY PRODUCTIVITY

Phosphate was identified as the limiting nutrient in the system, based on the water chemistry and previous studies. Fertilization of Polishing Pond water assisted in the productivity and growth of algae. It was inferred that this assisted zinc removal through providing more sites to collect particles. This was addressed through a series of lab and field experiments.

6.1 Nutrient Availability: Lab Experiments

6.1.1 Nitrogen and Phosphorus Solubility in Distilled and Boomerang Lake Water

Laboratory studies were performed to determine the solubility of various fertilizer formulations in distilled water and in OEP and polishing pond water.

A wide range of fertilizer formulations are available for supplying nutrients to plants and bacteria for agriculture and land reclamation. However, few fertilizers are marketed for application as a slow-release source of nutrients for aquatic environmental applications, such as supplying nitrogen and phosphorus to acidic water bodies to enhance primary productivity.

Fertilizers are typically described according to their available nitrogen, phosphorus and potassium (N-P-K) content in percent. However, there is typically ambiguity whether the P content actually refers to, for instance, P, PO_4 or P_2O_5, while the form of nitrogen (e.g., ammonia, nitrate and/or urea) is not specified. 'Slow-release' refers to the dissolution rate in soil conditions; submerged in water, most slow release fertilizers rapidly dissolve.

The section reports on the dissolution behaviour of eleven types of fertilizer, and describes the release of nitrate, ammonia and phosphate to distilled water or acidic lake water in stirred conditions for up to 14 days.

Methods and Materials

Fertilizer Types: In total, eleven types of fertilizer were tested (see Table 21). For many of the types, the N, P and K content is given. However, whether a fertilizer contains 10% P_2O_5 or 10 % P could not always be verified from manufacturers' specifications provided on packaging. In Tables 21 and 22, manufacturers' specifications are given under "Reported N:P:K", while under "Amount of N/P added, mg/L" the best *estimate of the actual amount of* N *or* P *present in the experimental* solution is given.

Types 1, 2 and 3 are resin-coated fertilizer granules, designed to slowly release nutrients even in saturated conditions (Osmocote, Grace; Nutricote, Plant Products).. According to the manufacturer, Type 1 contains potassium nitrate, while Type 3 contains 21%-7%-7% N-P-K. Information on the composition of Type 2 is not available.

Fertilizer Types 4 and 5 are liquid fertilizers containing 14-4-6 and 4-18-6 N-P-K, respectively. These fertilizers were designed as foliar fertilizers for supplementing the nutrient supply to citrus trees. These types are presumed to contain 14% and 4% N as specified. Without additional information, these types are presumed to contain 4% and 18% P.

Type 6 fertilizer is molasses. While this is not specifically a fertilizer, molasses has been use to augment bacterial growth, and may be suitable for initiating remediation processes for AMD and groundwater. Therefore, information regarding the release of nitrate, ammonia and phosphate from molasses may be of utility.

Type 7 is calcium nitrate, in the form of soluble white crystals. The manufacturer specifications indicate that Type 7 is composed of 15.5-0-0 N-P-K. Type 7 is presumed to contain 15.5% N.

Fertilizer types 8 and 9 are two forms of ground natural phosphate rock, used as soil supplements in agriculture as long term sources of phosphate and alkalinity. Type 8 is Code 30 phosphate rock, ground to a fine sand consistency, while Type 9 is Code 31 phosphate rock ground finely to a flour-like powder. Phosphorus content (P) of these materials were determined by ICAP by Boojum.

Fertilizer Types 10 and 11 are water soluble horticultural formulation which, according to the manufacturer, contains 15-30-15 and 10-52-10 N-P_2O_5-K, respectively. Type 11 is exactly the same fertilizer used to supplement the Buchans polishing ponds with nutrients Converting P2O5 to P, Type 10 contains 13.1.7% P and Type 11 contains 22.7 % P.

Experiment Set-up: A 100 mg sample of each solid fertilizer was added to 1 l of distilled water or 1 L water sample from Boomerang Lake (an acidified water body). For fertilizer Type 3, 1000 mg were added, since this type was a blend of several solids types of different colours. For liquid fertilizers, 1 mL was added, and the equivalent dry weight was determined by drying down a 25 mL sample at 75°C.

The 1 L samples were continuously stirred using a magnetic stirrer and stir bar at room temperature. Controls were set up, consisting of distilled water or Boomerang Lake water with no added fertilizer.

The pH, conductivity and temperature were measured 1 hour, 24 hours, 1 week, 11 days and 2 weeks following set up. Nitrate, ammonium and phosphate concentrations were determined at these times using Hach reagents and hand-held colorimeters.

Results

- The results of phosphate concentration determinations are expressed as P in Table 21, and nitrate and ammonium concentrations as N are presented in Table 22.

- Measurable phosphate concentrations were detected in solutions of fertilizer types 1, 2, 3, 4, 5, 6, 8, 9, 10 and 11. as expected, phosphate was not released from type 7 (calcium nitrate).

- For types 1, 2 and 3, phosphate release to distilled water could be compared to release to Boomerang Lake water. More phosphate was measured in distilled water leachates, indicating that phosphate may be precipitated by iron and/or zinc present in Boomerang L. water.

- Actual phosphate release could be compared to the manufacturer's specification on phosphate content for types 3, 4, 5, 8, 9, 10 and 11. With the exception of type 10 (15-13.1-15), all fertilizers released less phosphate than specified.

- Relatively little phosphate was released by types 1 and 2 resin-coated slow release fertilizers. However, up to 70 % of the phosphate content of type 3 (resin coated) was released, indicating that the resin coating did not impede release in the stirred solutions.

- The fertilizer type used to provide nutrients to the Polishing Ponds (type 11) readily dissolved, providing 133 % of the specified phosphate content within 1 hour of dissolving.

- Measurable nitrogen concentrations were detected in solutions of all fertilizer types, including the phosphate rock samples (ammonia: types 8 and 9).

- For types 1, 2 and 3, nitrogen release to distilled water could be compared to release to Boomerang Lake water. Much more nitrogen was measured in Boomerang Lake water than in distilled water leachates, indicating that nitrogen compound dissolution may be enhanced by the low pH of Boomerang L. water.

- Actual nitrogen release could be compared to the manufacturer's specification on nitrogen content for types 3, 4, 5, 7, 10 and 11. In many instances, fertilizers released more nitrogen than specified.

- Relatively little nitrogen was released by type 1 resin-coated slow release fertilizer. Type 2 released up to 93 mg/L N as ammonia in Boomerang L. water. However, up to 38 and 152 % of the nitrogen content of type 3 (resin coated) was released, indicating that the resin coating did not impede release in the stirred solutions.

- The fertilizer type used to provide nutrients to the Polishing Ponds (type 11) readily dissolved, providing 256 % of the specified nitrogen content within 1 hour of dissolving.

Discussion

This experiment was required to determine whether one particular fertilizer was particularly suitable among the types available for experimentation. The type 11 fertilizer, used in Buchans to date, appears to readily dissolved and release nutrients upon addition.

6.1.2 Manipulation of N and P Concentrations and Ratios

Laboratory studies with OWP water and algae were performed to determine a fertilization rate based on the consumption rate of phosphate by the periphyton population in the Polishing Ponds.

Background concentrations of nutrients in OWP water were determined using Hach reagents and a spectrophotometer. Phosphate and nitrate were then added to set up the following type of nutrient status:

1) N:P ratio of 10:1, achieved by adding KNO_3 or K_2HPO_4.
2) N concentration of 10 mg/L, by adding KNO_3.
3) N concentration of 10 mg/L and P concentration of 1 mg/L.

The results indicated that some nitrate was taken up by the algae. Ammonia release occurred in some cultures. Phosphate was rapidly depleted from the solutions, and its concentration was less than detection limits, including control samples without algae Table 23).

It was concluded that phosphate determinations are prone to interference, and meaningful results could not be obtained, unless phosphorus isotopes could be used and monitored.

6.1.3 Periphyton Growth Study in Media

Growth studies with the biological material growing in the ponds in chemically defined growth media to determine which biological group might be the dominant component of the biological activity and what differences are possibly related to the chemical composition, ie. nutrient limitation other than phosphate.

The results of this study indicated that upon transfer to laboratory conditions, those algal species dominant in the periphyton community in the field are replaced by species more suited for growth in the laboratory (see "PHYTOPLANKTON AND PERIPHYTON TAXA IN 1996 BUCHANS SAMPLES AND BUCHANS CULTURING EXPERIMENT", Section 5). Without extensive further work, field conditions cannot be emulated in the lab.

6.2 Periphyton Communities

The periphyton in Polishing Pond system were characterized according to growth form. At the time of observations, periphyton in the polishing ponds consists primarily of aquatic moss, with some algal biomass, growing as 'mat bubble algae' over the bottom and as 'branch algae' on alder branches of the ponds.

- As 'mat bubble algae' accumulate air bubbles (O_2, CO_2), slabs of this mat buoy up from the bottom, and become 'float bubble algae'. Sand and gravel lifted from the bottom sifts out of the mat, while iron hydroxide accumulates on the underside of the floating mat.

- 'Float bubble algae' is found as large mats in the ponds. Portions breaking away and passing over the weirs is pulverized and returns to the pond bottom, probably to reform as 'mat bubble algae'.

- In terms of nutrients, the existing mat and float bubble periphyton in the polishing ponds have nitrogen available primarily as ammonia (0.5 mg/L N as NH_4), with a small amount of N as NO_3 (0.03 to 0.05 mg/L) and trace amounts of phosphate (0.1 mg/L PO_4; see Table 24, PP11 In data).

- Small populations of 'seep algae' remain along the upstream berm of Polishing Pond 12, in areas where water is seeping from the pond bottom from the Pond 11 area. This periphyton is clearly a filamentous species with no moss present. Nutrient concentrations were not measured in the vicinity of the this algae.

- A special interest is the filamentous algae growing on the remaining section of the peribasket in OWP. Large tough ropes of filamentous algae up to 5 m long have grown in the area where the Drainage Tunnel inflow maintains a relatively constant flow pattern. This massive growth of periphyton in OWP is encouraging, as the new perigrid can now be anticipated to be readily colonized by this algae.

- The OWP 'rope periphyton' is growing in the area of the drainage Tunnel input. This flow generally maintains a unidirectional flow, which may favour the growth of this form of periphyton. In addition, the primary form of N is nitrate, present at a concentration of 0.4 mg/L N as NO_3). The ammonia concentration in the D.T. water was less than 0.1 mg/L as N (Hach, determined in field), while trace amounts of PO_4 was measured, as observed in the polishing ponds.

Summary

- The field data on the periphyton biomass produced in the OWP and the results of the perigrid suggest that the OWP is a suitable area to focus on increasing biological productivity (Table 25, Schematic 2, Plates 1 and 2).

6.3 Nutrient Additions in Field

6.3.1 Polishing Pond 11 Small-Scale Study

With fertilizer additions based on the rates determined in the laboratory studies, both mini limnocorrals (96 L) and in Pond 11 with monitoring phosphate concentrations in the field.

The nutrient concentrations and general water chemistry were measured for PP11 in and out on the morning of July 8, 1996. At noon, 3.7 kg of 10-52-10 fertilizer was added in a 20 L slurry. At noon on July 9, 3.7 kg were added, on July 10, 2.8 kg and on July 11, 3.7 kg.

According to Plant Products (G.Neary, p.c.) the 10% N in the 10-52-10 fertilizer is 7.8 ammonia, 0.9 % nitrate and 1.3 % urea.

Phosphate, [N] as nitrate and [N] as ammonia were determined at 2 to 4 hr intervals during daylight hours. Small amounts of precipitates regularly developed during the ammonia tests, while nitrate tests were frequently unsuccessful due to formation of yellow colour, instead of the expected pink colour formation. Overall, phosphate concentrations are likely the most reliable results. All PP11 fertilizer experiment data are presented in Table 24.

The actual flows at PP11 in and out were measured once using a water collection system, a bucket and stopwatch. The water levels over these weirs were also periodically measured. These levels were used to estimate flow, using G. Neary's equation relating head with flow.

The changes in [phosphate], [N] as nitrate and [N] as ammonia in PP11 in and PP11 out are presented in Figures 20, 21 and 22. Water samples were saved in the event that the Hach kit results can be compared to results produced by an analytical lab.

In Figure 22, N concentrations as ammonia at the inflow and outflow of PP11 are presented. As expected, N as ammonia concentrations increased upon addition of ammonia-containing fertilizer just below the inflow of PP11. N as ammonia concentrations reached as high as 1.2 mg/L. The N as ammonia concentrations in the PP11 inflow at a location just upstream of additions remained relatively constant over the course of the experiment, ranging from 0.45 to 0.7 mg/L, and averaging about 0.5 mg/L N.

In Figure 20, phosphate concentrations in PP11 in and out are plotted. As observed for ammonia, measured phosphate concentrations also increased following addition of fertilizer to the PP11 inflow. Phosphate concentrations reached as high as 1.3 mg/L as PO_4. Background (PP11 Inflow) concentrations remained around <1 to 0.3 mg/L, averaging about 0.1 mg/L.

The Hach nitrate tests were very unreliable during the experiment. Typically, following the three minute shaking period with the Nitraver 6 (Cadmium reduction step), transfer to clean tube and addition of the Nitraver 3 reagent, the sample turned a light to deep yellow, masking the pink to red colour indicative of the presence of nitrate. Addition of the Nitraver 3 alone also resulted in the yellow colour. However, occasionally the test worked and detectable nitrate could be measured. The results of the nitrate tests are shown in Figure 21.

Nitrate concentrations, when detected, ranged from 0.03 to 0.1 mg/L $N\text{-}NO_3$ in the PP11 outflow samples. The test worked only once for the PP11 in samples, and a 0.03 mg/L $N\text{-}NO_3$ was recorded. This suggests that upon addition of the 10-52-10 fertilizer, nitrate concentrations increased in PP11.

A model of the polishing ponds has been developed. This model simulates nutrient concentrations in the polishing ponds, taking into account the volumes of the cells, the flow volumes, the background concentrations and the additions of phosphate. The program repeats calculations in iterations of 1 hour. The program assumes complete mixing of a fertilizer addition with the receiving pond's volume within an hour; in reality, the mixing process is probably not this rapid.

The model was run for ammonia and phosphate. The expected $N\text{-}NH_4$ concentrations in PP10, PP11, PP12 and PP13 are shown in Figure 23 upon addition of fertilizer (starting at hour 0) at the rate applied during the experiment, and at the flow volumes measured during the experiment. In addition, the actual concentrations measured in the field are also plotted in the graph.

The model was started 456 hours (19 days) prior to the addition of the first lot of fertilizer, since ammonia was already present in the inflows to PP10 prior to the experiment, and the model needed these 19 days to reach equilibrium with respect to ammonia concentrations throughout the PP10-PP13 system.

The match between predicted ammonia concentrations (red) and the measured ammonia concentrations determined during the field experiment (blue) is remarkable. Both the magnitude of ammonia concentrations match well, as well as undulations in concentrations due to the 24 hour time spans between successive additions of fertilizer. There appears from Figure 23 that the actual ammonia concentration increases were delayed, compared to the modeled concentration increases. This is likely due to actual mixing times exceeding modeled mixing times.

Overall, it appears that PP11's behaviour is closely simulated by the model. Given that similar ammonia concentrations were measured as modeled, it appears that ammonia uptake by algae or ammonia adsorption onto organics during the field experiment may have been negligible. This also indicates that the ammonia was well mixed in the estimated pond volume. Finally, although some doubt remains regarding the accuracy of the Hach ammonia kit (precipitate formation), it appears to be working adequately.

The model was also run for phosphate in the system, for comparison to measured phosphate concentrations in PP11 during the field experiment (Figure 24). The measured phosphate concentrations (blue) were much lower than those predicted by the model (red), although undulations relating to the fertilizer additions, and delays due to mixing, can be seen in the curve. This suggest that a substantial fraction of the phosphate added to PP11 was lost by, for example, adsorption onto algae and/or precipitation with other compounds, such that the Hach phosphate kit did not detect the phosphate present in solution.

Apparent loss of phosphate mass during the field experiment was anticipated. A second static field experiment was performed during the site visit in order to examine apparent losses of nutrients from the system. This results of the Mini-Limnocorral Experiment, is described in the next section.

6.3.2 Fate of Nutrients: Mini-Limnocorral Experiment

Mini-Limnocorrals (MLCs) were set up in PP11. These consisted of plastic bags containing 96 L of PP11 water added prior to addition of the large doses of fertilizer to PP11. All MLC fertilizer experimen data are presented in Table 26.

MLC-i was set up as a control. This container did not receive any fertilizer, nor was periphyton added. A does of 0.797 g of 10-52-10 fertilizer was added to MLC-ii and MLC-iii. A sample of float bubble algae was carefully added to the surface of MLC-iii such that the mat remained afloat over the course of the experiment. Nutrient concentrations were periodically measured in each MLC. The entire algal sample was recovered at the end of the experiment in order that its dry weight could be determined.

The results of ammonia determinations in the MLCs are shown in Figure 25. In the control set-up, MLC-i, ammonia concentrations remained at background (0.5-0.6 mg/L N-NH_4). In MLC-ii, where fertilizer was added, the ammonia concentration stayed relatively constant at 1.7 to 1.8 mg/L N-NH_4 over the course of the experiment. A slight decrease in the ammonia concentration, to 1.4 mg/L N-NH_4 was measured in MLC-iii, the set-up where a clump of float bubble algae was added.

In a separate test ('dose check'), an identical dose of the fertilizer was added to distilled water, and diluted to the correct fertilizer dose:96 L ratio. This sample contained 1.2 mg/L N as ammonia. Since the background N (ammonia) concentration was 0.5 mg/L, the expected N as ammonia concentration in MLC-ii and MLC-iii was 1.7 mg/L, a perfect match with measured concentrations.

These results match the PP11 Fertilizer Experiment. Ammonia added to PP11 and the MLCs remained dissolved in the solutions. Despite formation of precipitates, the Hach ammonia test was functioning well.

The 'dose check' test indicated that the fertilizer dose added to MLC-ii and MLC-iii should yield a final concentration of 3.8 mg/L PO_4. In fact, PO_4 concentrations in MLC-ii and MLC-ii were 3.5 to 3.7 mg/L at the start of the experiment and after 20 hours (Figure 26). However, the phosphate concentration decreased to 1.8 to 1.9 mg/L after 55 hours, both in water only (MLC-ii) or in the presence of periphyton (MLC-iii). This indicates that the phosphate was initially present at the expected dose at the start of the MLC experiment, but was adsorbed by organics and was removed from the system, or had combined with compounds and was not detected by the Hach kit 35 hours later in the experiment (Table 27).

The MLC experiment's phosphate results also match well with the PP11 Fertilizer experiment. A substantial fraction (~70 %) of the phosphate 'disappeared' (no longer detected by Hach test) in the MLC experiment between hours 20 and 55. In the Field Fertilizer experiment, the peak phosphate concentration was 1.3 mg/L, while the modeled (expected) concentration for that fertilizer dose was 4 mg/L, a difference where the measured concentration was 67 % lower than the expected concentration.

Unfortunately, the Hach nitrate test did not function properly for most attempts, including during measurements of the MLC experiment (Figure 27). Only one observation can be made from the very limited results, namely, that the final nitrate concentration in MLC-iii (with periphyton) was lower than the nitrate concentration in MLC-ii (no periphyton), suggesting measurable nitrate uptake by the periphyton in MLC-iii.

Table 21: Dissolution of Phosphorus from Various Fertilizer Types in Distilled Water and Boomerang Lake Water.

Fertilizer Sample	Fertilizer Desription	Reported N:P:K	Medium	Am't Fert. added to 1 L, mg	Amount of P added mg/L	[P] mg/L 1 Hour	[P] mg/L 24 Hours	[P] mg/L 1 Week	[P] mg/L 11 days	[P] mg/L 2 Weeks	% of P Dissolved
1	Dearbom resin coated potassium nitrate pellets	unknown	Distilled Water	108	unknown	0.03	0.24	0.16	0.2	0.13	N.C.
			Boomerang L.	135	unknown	0.03	0.03	0.03	N.R.	N.R.	N.C.
2	Dearborn resin coated pellets	unknown	Distilled Water	109	unknown	0.03	0.1	0.23	0.1	0.13	N.C.
			Boomerang L.	146	unknown	0.03	0.03	0.03	N.R.	N.R.	N.C.
3	Dearborn resin coated pellets	21-7-7	Distilled Water	1044	73	51	29	29	29	29	70
			Boomerang L.	321	22	7	8	8	N.R.	N.R.	36
4	Harvest Plus liquid fertilizer	14-4-6	Distilled Water	462	18	12	12	13	N.R.	N.R.	71
5	Harvest Plus liquid fertilizer	4-18-6	Distilled Water	610	110	88	91	95	N.R.	N.R.	86
6	Liquid molasses	unknown	Distilled Water	1200	unknown	0.75	0.72	0.52	N.R.	N.R.	N.C.
7	Calcium nitrate crystalline	15.5-0-0	Distilled Water	95	0	0.01	0.01	0.012	N.R.	N.R.	N.C.
8	Natural phosphate rock Code 30 fine sand	?-12.8-?	Distilled Water	106	14	0.62	1.2	1.3	1.1	N.R.	10
9	Natural phosphate rock Code 31 powder	?-12.1-?	Distilled Water	89	11	0.85	0.85	0.82	0.78	N.R.	8
10	Plant Products fertilizer, powder	15-13.1-15	Distilled Water	103	14	18	11	12	N.R.	N.R.	133
11	Plant Products fertilizer, powder	10-22.7-10	Distilled Water	104	24	16	16	16	N.R.	N.R.	69
	Distilled Water (Control)		Distilled Water	0	0	0.07	0.1	0.1	N.R.	N.R.	N.A.
	Boomerang Lake (Control)		Boomerang L.	0	0	N.R.	0.03	0.03	N.R.	N.R.	N.A.
	New Boomerang lake (Control)		Boomerang L.	0	0	N.R.	0.03	0.03	N.R.	N.R.	N.A.

Table 22: Dissolution of Nitrogen from Various Fertilizer Types in Distilled Water and Boomerang Lake Water.

Fertilizer Sample	Fertilizer Desription	Reported N:P:K	Medium	Am't Fert. added to 1 L, mg	Amount of N added, mg/L		[N] mg/L 1 Hour	[N] mg/L 24 Hours	[N] mg/L 1 Week	[N] mg/L 11 days	[N] mg/L 2 Weeks	% of N Dissolved
1	Dearborn resin coated potassium nitrate pellets	unknown	Distilled Water	108	unknown	[N] as NO_3	< 0.02	< 0.02	0.90	1.7	1.7	N.C.
						[N] as NH_4	0.19	0.19	0.56	0.37	0.37	
			Boomerang L.	135	unknown	[N] as NO_3	< 0.16	1.8	21			N.C.
						[N] as NH_4	0.93	1.5	1.39			
2	Dearborn resin coated pellets	unknown	Distilled Water	109	unknown	[N] as NO_3	< 0.02	0.045	< 0.02	1.1	1.4	N.C.
						[N] as NH_4	0.19	0.19	0.46	1.6	2.3	
			Boomerang L.	146	unknown	[N] as NO_3	< 0.12	0.14	9			N.C.
						[N] as NH_4	1.3	1.6	93			
3	Dearborn resin coated pellets	21-7-7	Distilled Water	1044	219	[N] as NO_3	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	38
						[N] as NH_4	9	28	37	84	65	
			Boomerang L.	321	67	[N] as NO_3	< 0.12	0.13	0.17			152
						[N] as NH_4	65	102	74			
4	Harvest Plus liquid fertilizer	14-4-6	Distilled Water	462	65	[N] as NO_3	< 0	< 0.02	< 0.02			115
						[N] as NH_4	37	46	74			
5	Harvest Plus liquid fertilizer	4-18-6	Distilled Water	610	24	[N] as NO_3	< 0.02	< 0.02	< 0.02			38
						[N] as NH_4	9	9.3	9.29			
6	Liquid molasses	unknown	Distilled Water	1200	unknown	[N] as NO_3	< 0.02	< 0.02	< 0.02			N.C.
						[N] as NH_4	N.U.	9.3	9.29			
7	Calcium nitrate crystalline	15.5-0-0	Distilled Water	95	15	[N] as NO_3	11	10	13.17			101
						[N] as NH_4	1.58	1.58	1.39			
8	Natural phosphate rock, Code 30, fine sand	?-12.8-?	Distilled Water	106	unknown	[N] as NO_3	< 0.02	< 0.02	< 0.02	< 0.02		N.C.
						[N] as NH_4	0.37	0.6	0.19	0.65		
9	Natural phosphate rock, Code 31, powder	?-12.1-?	Distilled Water	89	unknown	[N] as NO_3	< 0.02	< 0.02	< 0.02	< 0.02		N.C.
						[N] as NH_4	0.19	0.46	0.37	0.46		
10	Plant Products fertilizer, powder	15-13.1-15	Distilled Water	103	15	[N] as NO_3	3.6	3.8	3.70			95
						[N] as NH_4	10	9.3	10.84			
11	Plant Products fertilizer powder	10-22.7-10	Distilled Water	104	10	[N] as NO_3	8.0	2.0	1.00			256
						[N] as NH_4	19	9.3	9.29			
	Distilled Water (Control)		Distilled Water	0	0	[N] as NO_3	0.08	0.10	0.09			N.C.
						[N] as NH_4	0.46	0.37	0.37			
	Boomerang Lake (Control)		Boomerang L.	0	0	[N] as NO_3	< 0.11	0.13	0.08			N.C.
						[N] as NH_4	1.2	1.5	1.11			
	New Boomerang L.(Control)		Boomerang L.	0	0	[N] as NO_3		0.13	0.09			N.C.
						[N] as NH_4		1.6	1.11			

Table 23: Treatments and Nutrient Concentrations in Buchans and South Bay Algal Cultures.

Culture	DATE STARTED: 21/7/96 DESCRIPTION	BEFORE ADDITION OF NUTRIENTS [NO_3 OLD] mg.L^{-1} 1/8/1996	[NH_3 OLD] mg.L^{-1} 1/8/1996	[PO_4 OLD] mg.L^{-1} 1/8/1996	TREATMENT 1: N:P 10:1 2: N, 10 mg.L-1 3: [N],[P],10, 1 mg.L^{-1}	ADDED NUTRIENTS 2/8/1996	TARGETED CONCENTRATIONS [NO_3 NEW] mg.L^{-1}	[PO_4 NEW] mg.L^{-1}	MEASURED CONCENTRATIONS [NO_3 NEW] mg.L^{-1} 7/8/96	[NH_3 NEW] mg.L^{-1} 7/8/96	[PO_4 NEW] mg.L^{-1} 7/8/96
A1	PP14 MAT BUBBLE	0.06	0.12	0.08	N:P 10:1	N-NO_3	0.22		0.05	0.07	0.07
A2	PP14 MAT BUBBLE	0.13	0.13	0.08	N, 10 mg.L-1	N-NO_3	9.86		6.39	0.07	0.09
A3	PP14 MAT BUBBLE	0.05	0.10	0.14	[N],[P],10, 1 mg.L^{-1}	N-NO_3+P-PO_4	9.89	2.21	5.77	0.07	0.12
C1	PP12 SEEP ALGAE	0.05	0.10	0.11	N:P 10:1	N-NO_3	0.39		0.04	0.07	0.07
C2	PP12 SEEP ALGAE	0.06	0.20	0.18	N, 10 mg.L-1	N-NO_3	9.79		8.42	0.08	0.08
C3	PP12 SEEP ALGAE	0.05	0.11	0.14	[N],[P],10, 1 mg.L^{-1}	N-NO_3+P-PO_4	9.89	2.21	5.27	0.08	0.07
D1	PP14 FLOAT BUBBLE	0.22	0.12	0.09	N:P 10:1	N-NO_3	0.29		0.05	0.11	0.07
D2	PP14 FLOAT BUBBLE	0.32	0.12	0.10	N, 10 mg.L-1	N-NO_3	9.88		8.63	0.08	0.08
D3	PP14 FLOAT BUBBLE	0.23	0.11	0.13	[N],[P],10, 1 mg.L^{-1}	N-NO_3+P-PO_4	9.89	2.21	6.55	0.07	0.11
F1	PP14 MAT BUBBLE PUREE	0.05	0.10	0.25	N:P 10:1	N-NO_3	1.04		0.04	0.07	0.07
F2	PP14 MAT BUBBLE PUREE	0.05	0.09	0.25	N, 10 mg.L-1	N-NO_3	9.91		7.81	0.07	0.07
F3	PP14 MAT BUBBLE PUREE	0.05	0.11	0.24	[N],[P],10, 1 mg.L^{-1}	N-NO_3+P-PO_4	9.88	2.21	3.09	0.07	0.10
G1	PP14 FLOAT BUBBLE PUREE	0.53	0.43	0.12	N:P 10:1	P-PO_4	0.53	0.18	0.05	0.08	0.07
G2	PP14 FLOAT BUBBLE PUREE	1.30	0.22	0.13	N, 10 mg.L-1	N-NO_3	9.77		9.09	0.07	0.07
G3	PP14 FLOAT BUBBLE PUREE	0.53	0.37	0.10	[N],[P],10, 1 mg.L^{-1}	N-NO_3+P-PO_4	9.63	2.21	4.43	0.07	0.06
B1	OWP PERI	0.38	0.70	0.14	N:P 10:1	P-PO_4	0.38	0.20	0.36	3.55	0.09
B2	OWP PERI	0.34	0.67	0.13	N, 10 mg.L-1	N-NO_3	9.33		9.20	3.85	0.11
B3	OWP PERI	0.53	0.68	0.29	[N],[P],10, 1 mg.L^{-1}	N-NO_3+P-PO_4	9.32	2.21	10.94	3.65	0.68
E1	BOOMERANG LAKE ALGAE	0.07	2.00	0.08	N:P 10:1	P-PO_4	0.07	0.33	0.07	4.29	0.11
E2	BOOMERANG LAKE ALGAE	0.05	2.00	0.08	N, 10 mg.L-1	N-NO_3	8.00		6.55	5.02	0.08
E3	BOOMERANG LAKE ALGAE	0.05	1.30	0.09	[N],[P],10, 1 mg.L^{-1}	N-NO_3+P-PO_4	8.69	2.21	8.11	4.34	0.11
OWP-1	ORIENTAL WEST PIT	0.47	0.10	0.08	N:P 10:1	P-PO_4	0.47	0.11	0.52	0.09	0.07
OWP-2	ORIENTAL WEST PIT	0.55	0.12	0.08	N, 10 mg.L-1	N-NO_3	9.88		10.22	0.09	0.06
OWP-3	ORIENTAL WEST PIT	0.51	0.11	0.07	[N],[P],10, 1 mg.L^{-1}	N-NO_3+P-PO_4	9.89	2.21	10.22	0.08	0.55
BL1	BOOMERANG LAKE 1	0.24	0.77	0.06	N:P 10:1	P-PO_4	0.24	0.17	0.25	0.56	0.17
BL2	BOOMERANG LAKE 2	0.24	0.78	0.09	N, 10 mg.L-1	N-NO_3	9.22		10.09	0.48	0.07
BL3	BOOMERANG LAKE 3	0.24	0.73	0.07	[N],[P],10, 1 mg.L^{-1}	N-NO_3+P-PO_4	9.27	2.21	7.71	0.52	3.11

Table 24: PP11 Nutrient Exp't Data.

Date	Days	Hr	Min	Hours after start		PP11 In [PO4]		[N] as NO3		[N] as NH4	pH	T C	Cond	Em	[O2]	W.L. (CM)	Flow (l/s)	Kg Fert Added
08-Jul-96	0	9	8	-2.98		0.1												
08-Jul-96	0	9	16	-2.85		0.1	<	0.01	Y	0.6	6.4	18	1365	110	8.04			
08-Jul-96	0	12	7	0														3.7
08-Jul-96	0	12	27	0.33														
08-Jul-96	0	13	15	1.13														
08-Jul-96	0	13	32	1.42														
08-Jul-96	0	15	2	2.92												2.2	6.78	
08-Jul-96	0	16	55	4.80														
08-Jul-96	0	19	14	7.12														
08-Jul-96	0	22	20	10.22														
09-Jul-96	1	8	36	20.48														
09-Jul-96	1	8	53	20.77		0.1			N.M.	0.45								
09-Jul-96	1	9	0	20.88														
09-Jul-96	1	9	15	21.13														
09-Jul-96	1	9	30	21.38												2	5.88	
09-Jul-96	1	11	31	23.40														
09-Jul-96	1	11	43	23.60														3.7
09-Jul-96	1	13	46	25.65														
09-Jul-96	1	16	18	28.18														
09-Jul-96	1	16	48	28.68		0.1			N.M.	0.45	6.7	18	1346	149		2.1	6.33	
09-Jul-96	1	21	35	33.47														
10-Jul-96	2	8	42	44.58														
10-Jul-96	2	11	30	47.38														
10-Jul-96	2	11	50	47.72														2.815
10-Jul-96	2	11	52	47.75		0.1		0.05		0.5	6.9	16	1209	143		2.5	8.22	
10-Jul-96	2	15	18	51.18														
10-Jul-96	2	18	43	54.60	<	0.1		0.1		0.5								
10-Jul-96	2	21	30	57.38														
11-Jul-96	3	8	54	68.78		0.2	<	0.01	Y	0.5						2.4	7.73	
11-Jul-96	3	9	10	69.05														
11-Jul-96	3	9	45	69.63														
11-Jul-96	3	10	5	69.97							6.9	17	1303	138				
11-Jul-96	3	12	11	72.07														3.7
11-Jul-96	3	12	13	72.10		0.1	<	0.01		0.5								
11-Jul-96	3	12	28	72.35														
11-Jul-96	3	15	10	75.05		0.3	<	0.01		0.6								
11-Jul-96	3	15	32	75.42												2.3	7.25	
11-Jul-96	3	16	54	76.78														
11-Jul-96	3	17	22	77.25														
11-Jul-96	3	17	44	77.62														
11-Jul-96	3	18	24	78.28														
11-Jul-96	3	18	45	78.63		0.1		0.03		0.7	7.1	21	1307	109		2.2	6.78	
12-Jul-96	4	11	40	95.55														
12-Jul-96	4	11	40	95.55														
12-Jul-96	4	19	30	103.38														
12-Jul-96	4	19	30	103.38														
12-Jul-96	4	19	30	103.38														
12-Jul-96	4	19	30	103.38														
13-Jul-96	5	12	0	119.88														
13-Jul-96	5	12	0	119.88														
13-Jul-96	5	12	0	119.88														
13-Jul-96	5	12	0	119.88														

Table 24: PP11 Nutrient Exp't Data.

Date	Days	Hr	Min	Hours after start	PP11 Out [PO4]		[N] as NO3		[N] as NH4	pH	T C	Cond	Em	[O2]	W.L (cm)
08-Jul-96	0	9	8	-2.98											
08-Jul-96	0	9	16	-2.85											
08-Jul-96	0	12	7	0											
08-Jul-96	0	12	27	0.33	0.1	<	0.01	Y	0.4	6.64	17.4	1235	102		
08-Jul-96	0	13	15	1.13											
08-Jul-96	0	13	32	1.42											
08-Jul-96	0	15	2	2.92	0.1	<	0.01	Y	0.5						
08-Jul-96	0	16	55	4.80	0.3			N.M.	0.5	6.68	18.6	1264	137		
08-Jul-96	0	19	14	7.12	0.4			N.M.	0.4						
08-Jul-96	0	22	20	10.22	0.6			N.M.	0.6						
09-Jul-96	1	8	36	20.48	0.6	<	0.01	Y	0.7						
09-Jul-96	1	8	53	20.77											
09-Jul-96	1	9	0	20.88											
09-Jul-96	1	9	15	21.13											
09-Jul-96	1	9	30	21.38											
09-Jul-96	1	11	31	23.40	0.6			N.M.	0.6						
09-Jul-96	1	11	43	23.60											
09-Jul-96	1	13	46	25.65	0.6			N.M.	0.7						
09-Jul-96	1	16	18	28.18	0.6			N.M.	0.7	6.6	17.6	1291	122		
09-Jul-96	1	16	48	28.68											
09-Jul-96	1	21	35	33.47	0.9		0.06	tr	0.9						
10-Jul-96	2	8	42	44.58	0.9		0.09		0.75						
10-Jul-96	2	11	30	47.38	0.95		0.03		0.85	6.58	15.6	1264	177		
10-Jul-96	2	11	50	47.72											
10-Jul-96	2	11	52	47.75											
10-Jul-96	2	15	18	51.18	1		0.07		1	7.46	16.4	1327	162		
10-Jul-96	2	18	43	54.60	0.95		0.1		1						
10-Jul-96	2	21	30	57.38	1.3		0.07		0.9						
11-Jul-96	3	8	54	68.78											2.3
11-Jul-96	3	9	10	69.05	0.9	<	0.01	Y	1.2						
11-Jul-96	3	9	45	69.63						6.83	17.1	1289	155		
11-Jul-96	3	10	5	69.97											
11-Jul-96	3	12	11	72.07											
11-Jul-96	3	12	13	72.10											
11-Jul-96	3	12	28	72.35	0.7	<	0.01		0.9						
11-Jul-96	3	15	10	75.05											
11-Jul-96	3	15	32	75.42	1	<	0.01		1.1						
11-Jul-96	3	16	54	76.78											
11-Jul-96	3	17	22	77.25											
11-Jul-96	3	17	44	77.62											
11-Jul-96	3	18	24	78.28	1.05	<	0.01		0.95	6.53	20.4	1333	96		
11-Jul-96	3	18	45	78.63											
12-Jul-96	4	11	40	95.55											
12-Jul-96	4	11	40	95.55											
12-Jul-96	4	19	30	103.38											
12-Jul-96	4	19	30	103.38											
12-Jul-96	4	19	30	103.38											
12-Jul-96	4	19	30	103.38											
13-Jul-96	5	12	0	119.88											
13-Jul-96	5	12	0	119.88											
13-Jul-96	5	12	0	119.88											
13-Jul-96	5	12	0	119.88											

Table 25: OWP Perigrid Zinc Removal Performance and Scale-up.

Days installed (Jul 13-Sep 29)	78	days
Area of perigrid netting	391	m^2
Algal fresh biomass	0.5	cm^3 per cm^2
Wet volume of algae	1.955	m^3
Periphyton dry weight:wet volume	0.1	$g.cm^{-3}$
Dry weight of algae	0.196	t
Growth rate	6.41	$g.m^{-2}$ $netting.d^{-1}$
Zn content in periphyton	10,900	$ug.g^{-1}$ (#5993)
Zn content of periphyton biomass	2.13	kg
If perigrid scaled up 19 x	40.5	kg
Potential Zinc removal rate	0.52	$kg.d^{-1}$
OWP Zinc load from D.T.	11.4	$kg.d^{-1}$
Zinc Removal	4.6	% of load

Table 26: PP11 Nutrient Exp't Data.

Date	Days	Hr	Min	Hours after start	MLC i [PO4]	MLC i [N] as NO3	MLC i [N] as NH4	MLC ii [PO4]	MLC ii [N] as NO3	MLC ii [N] as NH4	MLC iii [PO4]	MLC iii [N] as NO3	MLC iii [N] as NH4
08-Jul-96	0	9	8	-2.98									
08-Jul-96	0	9	16	-2.85	0.1	0.01	0.6						
08-Jul-96	0	12	7	0									
08-Jul-96	0	12	27	0.33									
08-Jul-96	0	13	15	1.13				3.5	0.01 Y	1.8			
08-Jul-96	0	13	32	1.42							3.7	0.01 Y	1.8
08-Jul-96	0	15	2	2.92									
08-Jul-96	0	16	55	4.80									
08-Jul-96	0	19	14	7.12									
08-Jul-96	0	22	20	10.22									
09-Jul-96	1	8	36	20.48									
09-Jul-96	1	8	53	20.77									
09-Jul-96	1	9	0	20.88	0.1	N.M.	0.5						
09-Jul-96	1	9	15	21.13				3.5	N.M	1.7			
09-Jul-96	1	9	30	21.38							3.7	N.M	1.5
09-Jul-96	1	11	31	23.40									
09-Jul-96	1	11	43	23.60									
09-Jul-96	1	13	46	25.65									
09-Jul-96	1	16	18	28.18									
09-Jul-96	1	16	48	28.68									
09-Jul-96	1	21	35	33.47									
10-Jul-96	2	8	42	44.58									
10-Jul-96	2	11	30	47.38									
10-Jul-96	2	11	50	47.72									
10-Jul-96	2	11	52	47.75									
10-Jul-96	2	15	18	51.18									
10-Jul-96	2	18	43	54.60	0.2	0.09	0.5	1.9	0.14	1.7	1.8	0.12	1.4
10-Jul-96	2	21	30	57.38									
11-Jul-96	3	8	54	68.78									
11-Jul-96	3	9	10	69.05									
11-Jul-96	3	9	45	69.63									
11-Jul-96	3	10	5	69.97									
11-Jul-96	3	12	11	72.07									
11-Jul-96	3	12	13	72.10									
11-Jul-96	3	12	28	72.35									
11-Jul-96	3	15	10	75.05									
11-Jul-96	3	15	32	75.42									
11-Jul-96	3	16	54	76.78	0.1		0.6						
11-Jul-96	3	17	22	77.25				1.7		1.9			
11-Jul-96	3	17	44	77.62							1.7		1.55
11-Jul-96	3	18	24	78.28									
11-Jul-96	3	18	45	78.63									
12-Jul-96	4	11	40	95.55									
12-Jul-96	4	11	40	95.55									
12-Jul-96	4	19	30	103.38									
12-Jul-96	4	19	30	103.38									
12-Jul-96	4	19	30	103.38									
12-Jul-96	4	19	30	103.38									
13-Jul-96	5	12	0	119.88									
13-Jul-96	5	12	0	119.88									
13-Jul-96	5	12	0	119.88									
13-Jul-96	5	12	0	119.88									

Table 27: Mini-Limnocorral iii Filter Paper Analysis

Element	M.W., g	# 5999 total ug on F.P. from 0.1 L sample	Equiv. mg/L	Equiv. uM/L
Al	27	2.5	0.025	0.93
Ba	137	2.4	0.024	0.17
Ca	40	339	3.4	85
Cd	112	6.6	0.066	0.59
Co	59	0.3	<0.003	<0.05
Cu	64	3.1	0.031	0.49
Fe	56	55.1	0.55	9.9
Mg	24	4.6	0.046	1.9
Mn	55	28.3	0.28	5.2
Na	23	17.2	0.17	7.5
P	31	544	5.4	176
S	32	2.77	0.028	0.86
Zn	65	2300	23	352

Fig. 20: PP11 Phosphate

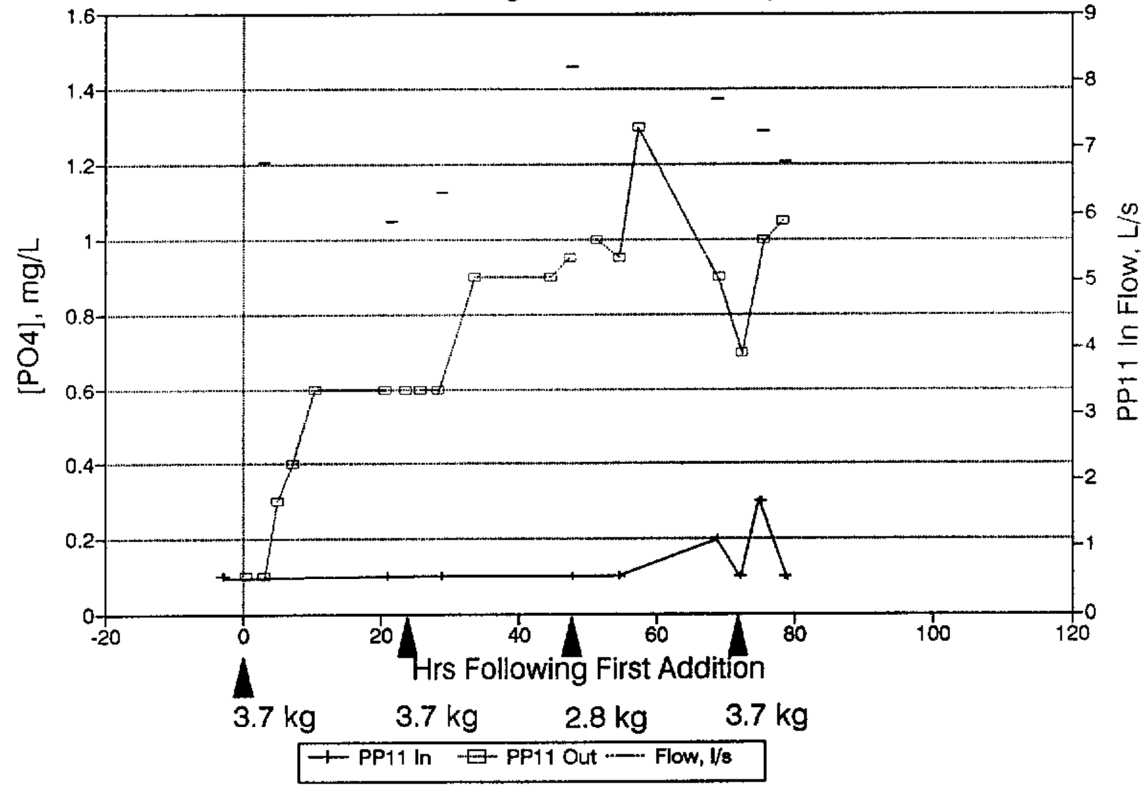


Fig. 21: PP11 N as Nitrate

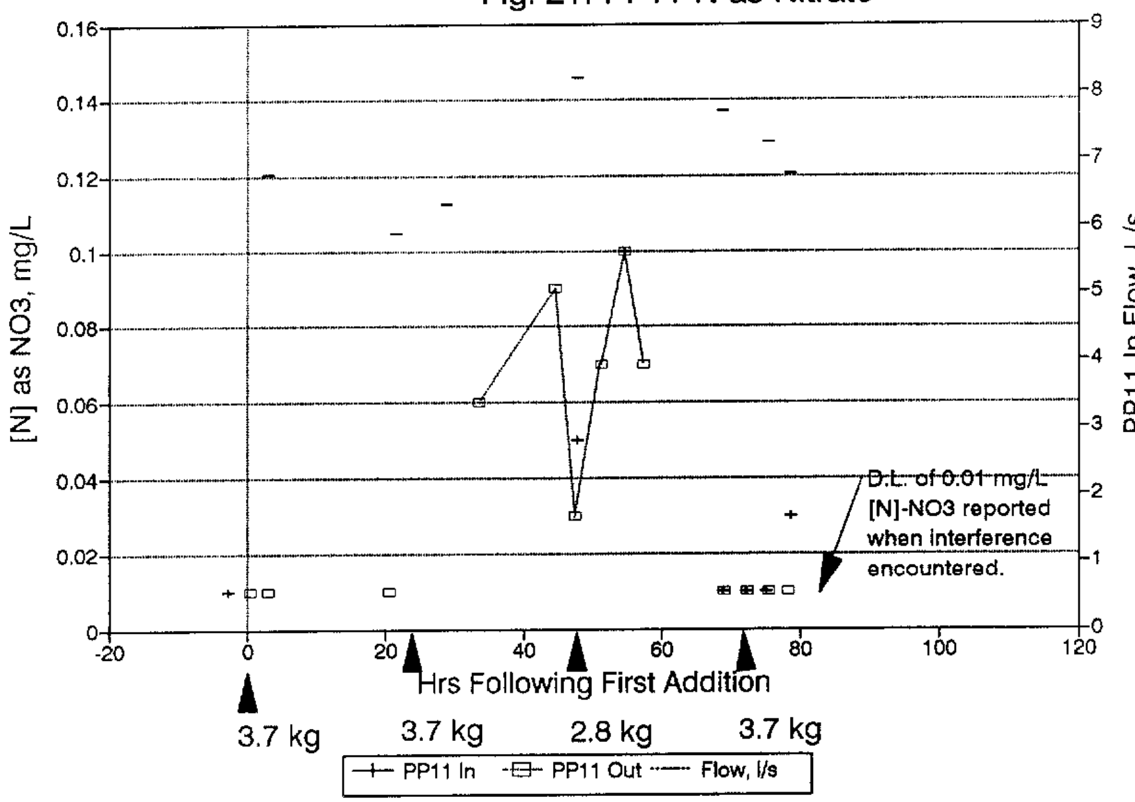


Fig. 22: PP11 N as Ammonia

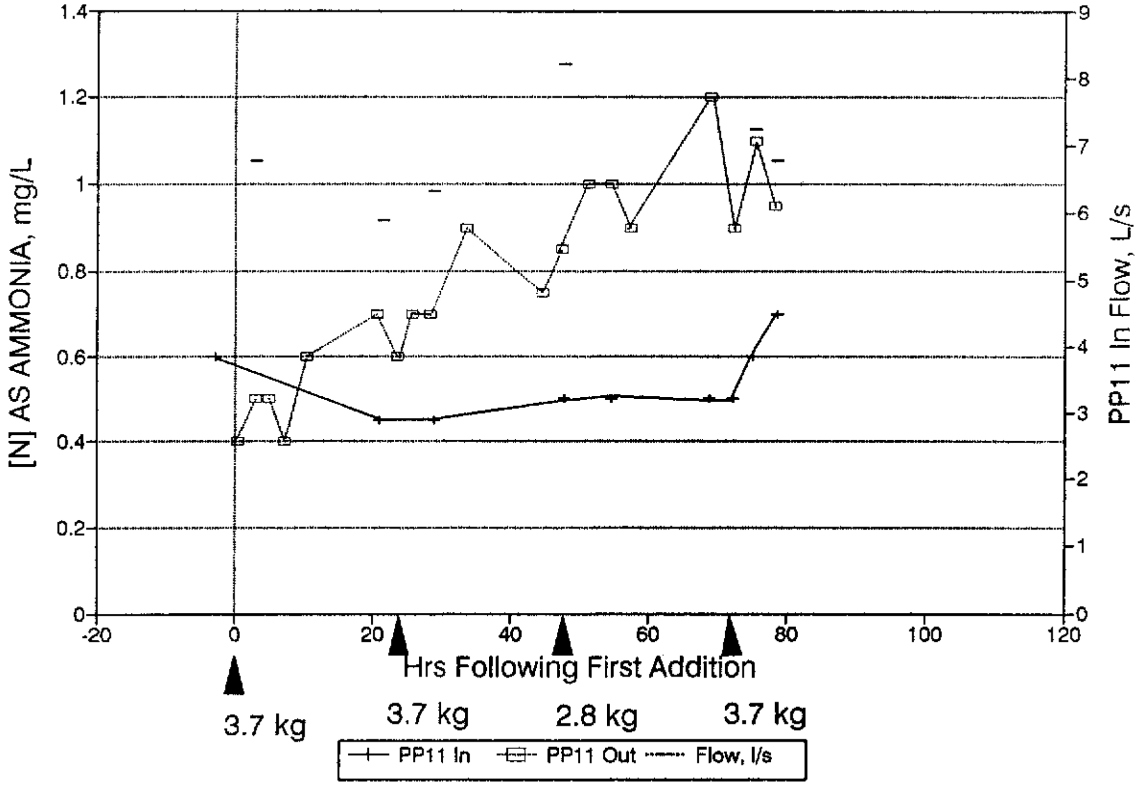


Fig. 23: [N]-NH4 in PP10 - PP13
Modelled vs. Measured

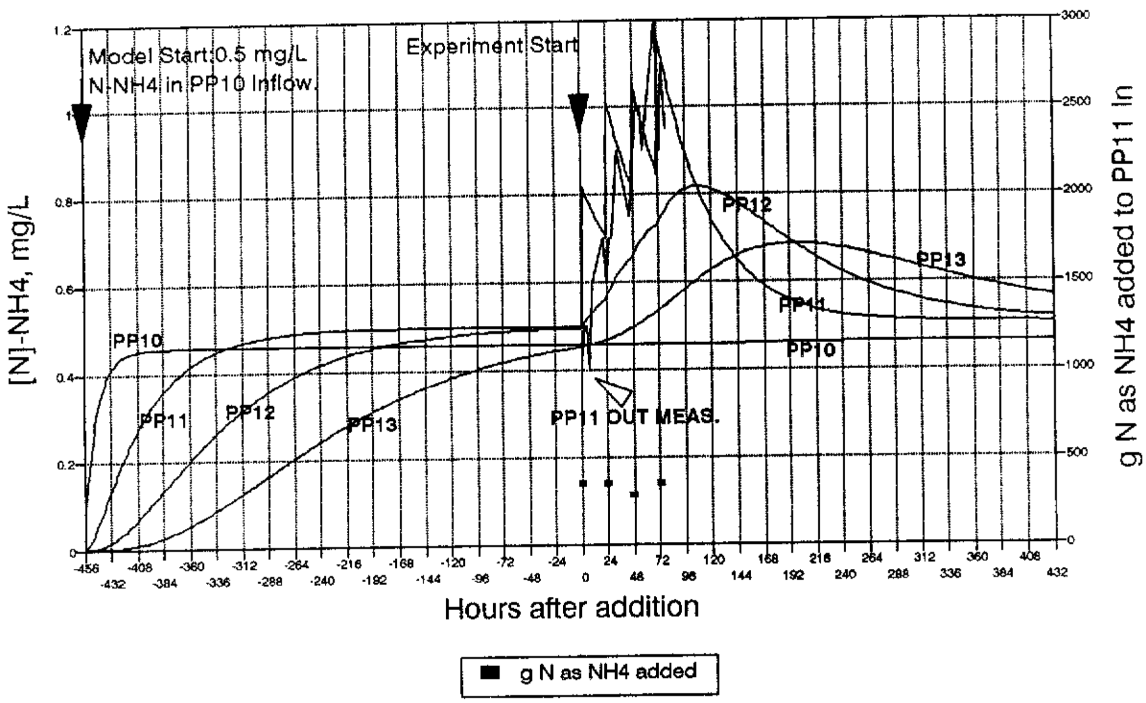


Fig. 24: [PO4] in PP10 - PP13
Modelled vs. Measured

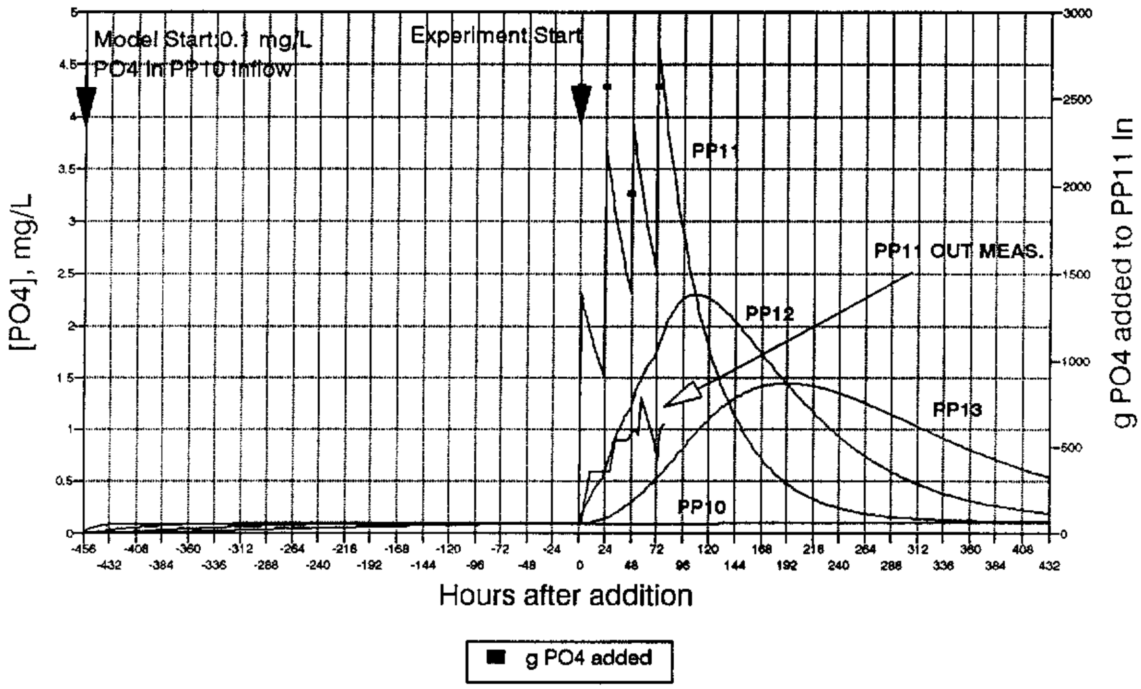
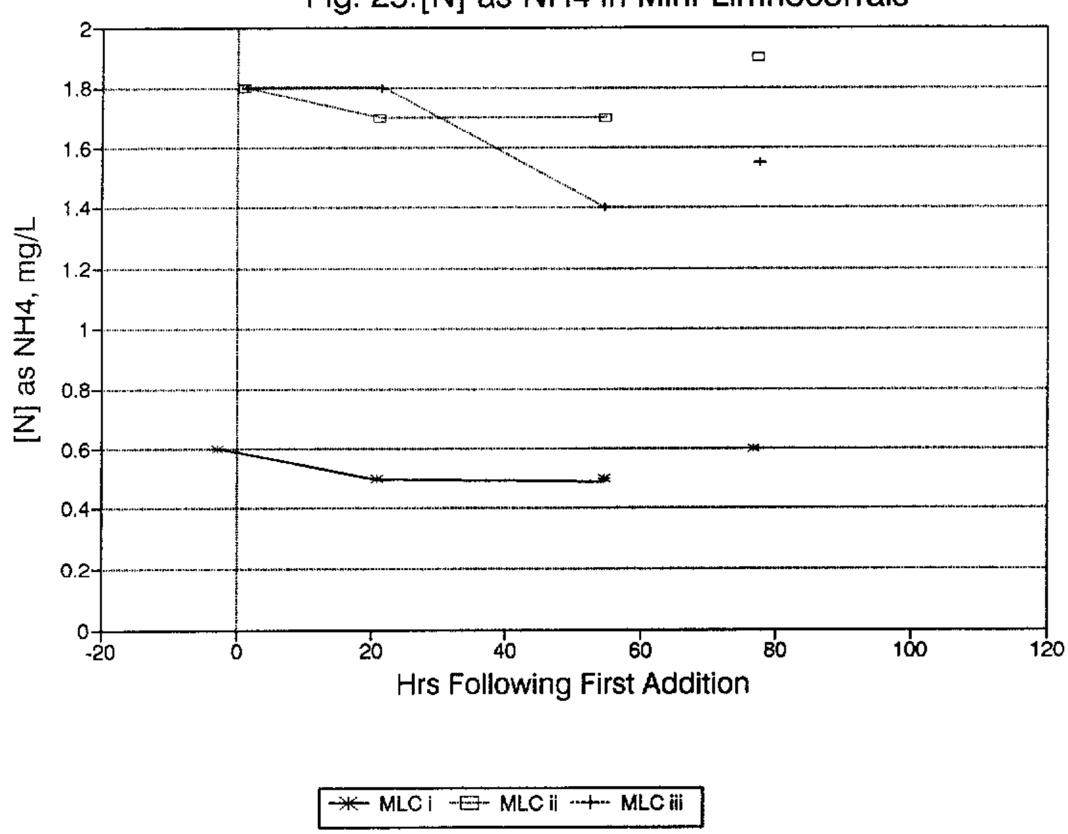


Fig. 25:[N] as NH4 in Mini-Limnocorrals



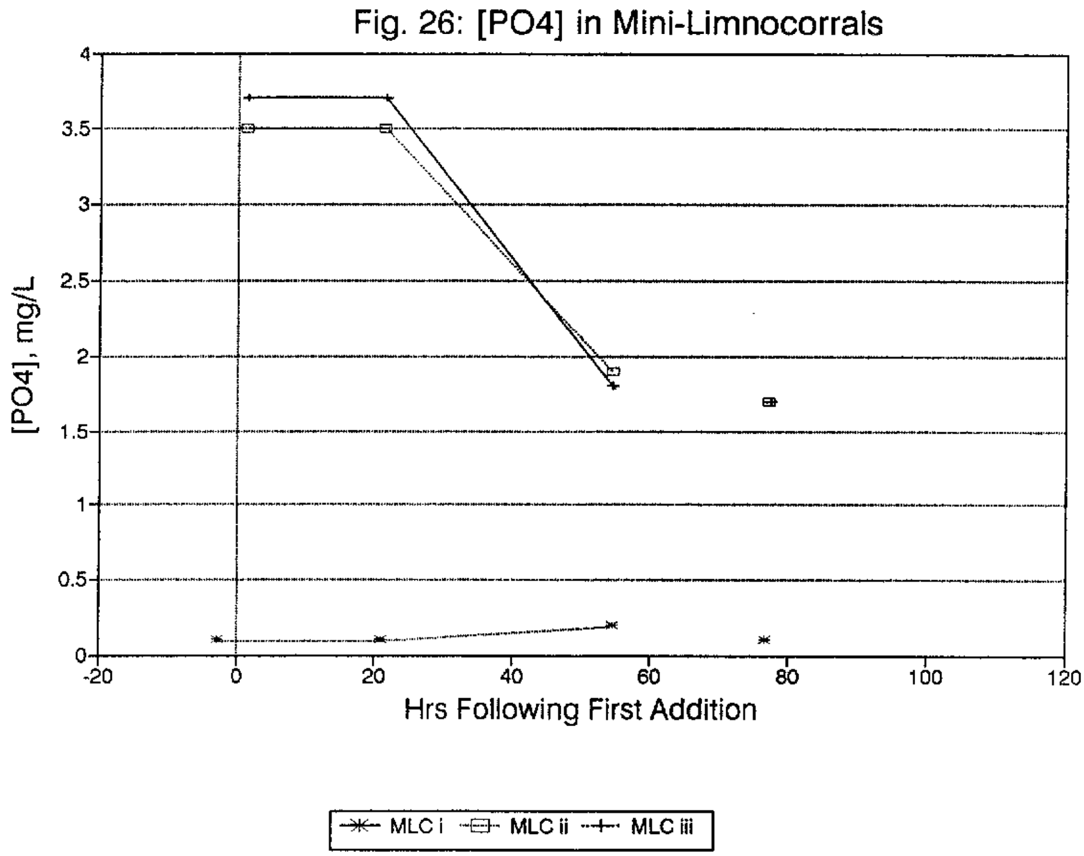


Fig. 26: [PO4] in Mini-Limnocorrals
[PO4], mg/L
4
3.5
3
2.5
2
1.5
1
0.5
0
-20
0
20
40
60
80
100
120
Hrs Following First Addition
MLC i
MLC ii
MLC iii

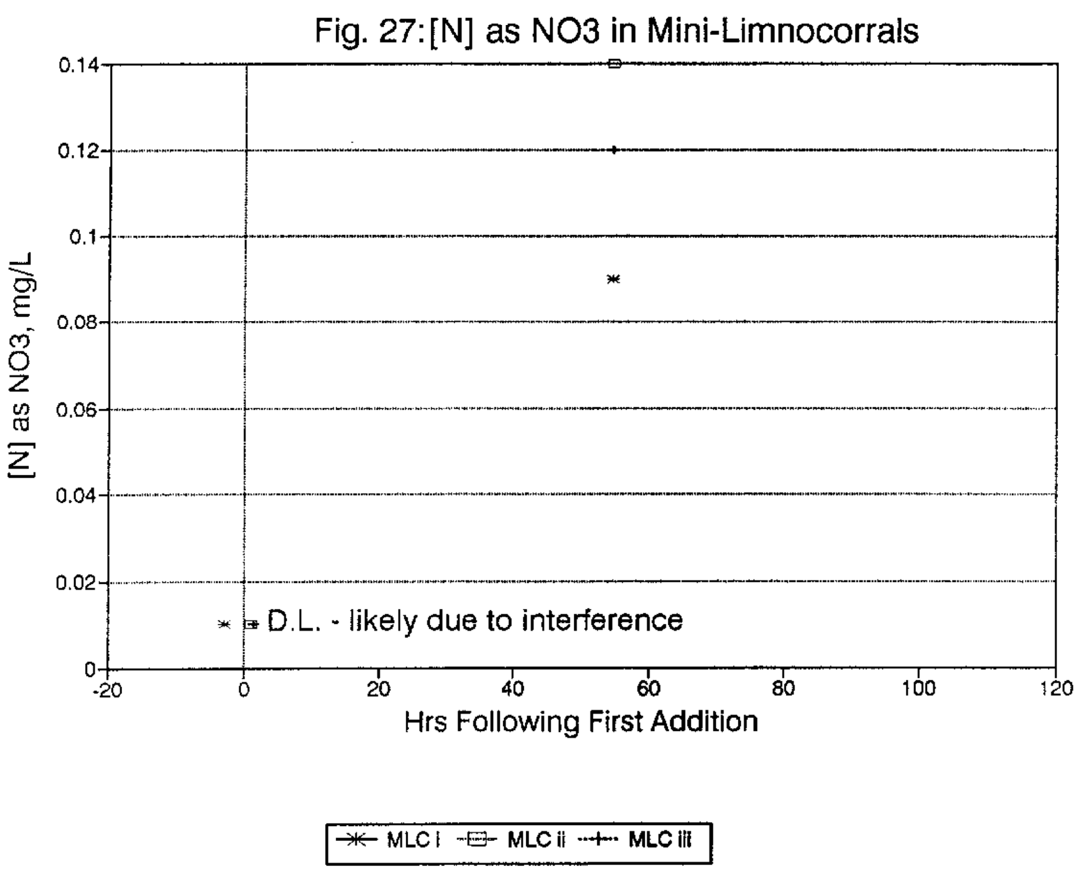
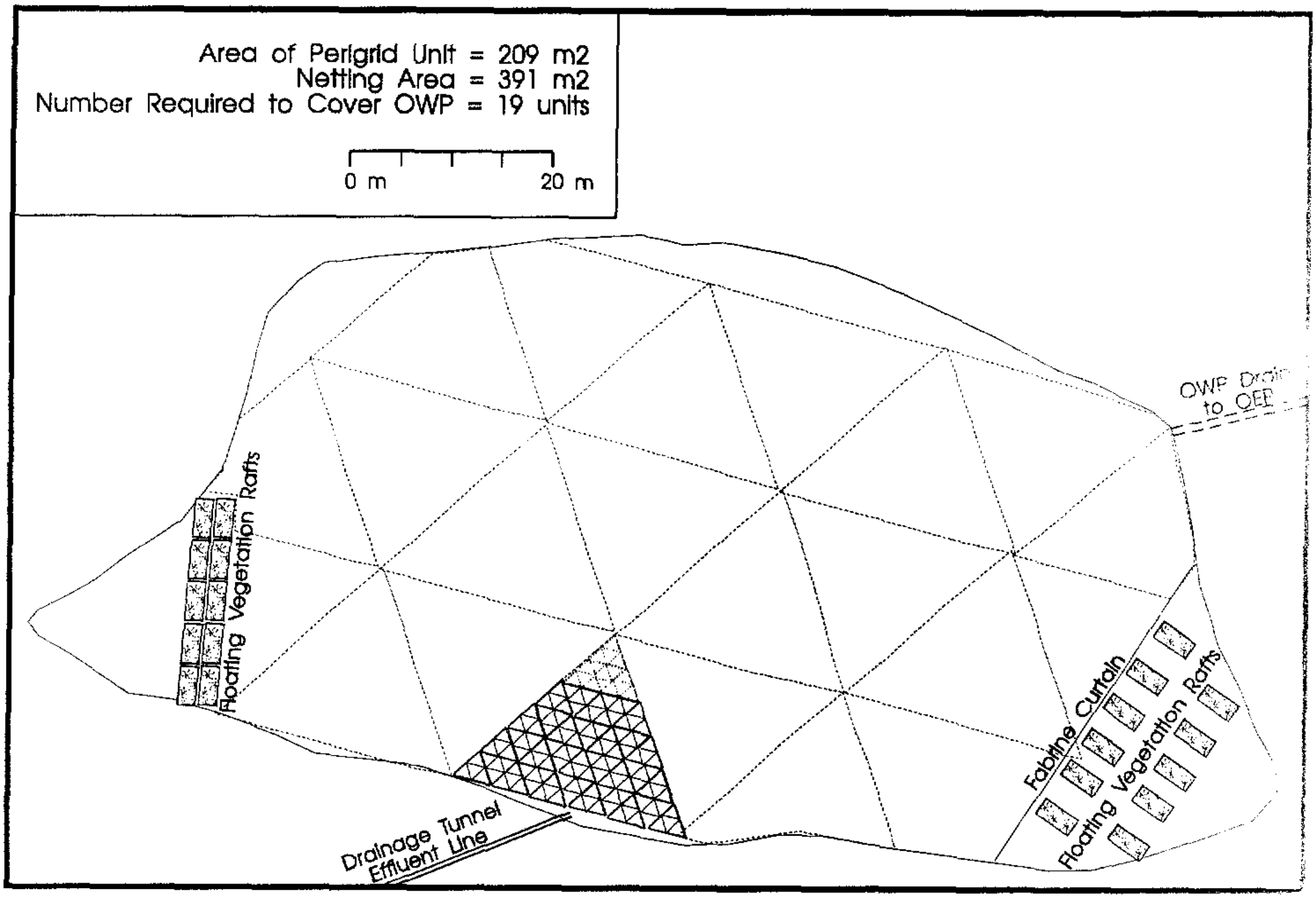


Fig. 27:[N] as NO3 in Mini-Limnocorrals
[N] as NO3, mg/L
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
D.L. - likely due to interference
-20
0
20
40
60
80
100
120
Hrs Following First Addition
MLC i
MLC ii
MLC iii



Schematic 2: OWP Perigrid Construction and Possible Scale-up.

Plate 1: Overview of Perigrid structure during installation in OWP, July 13, 1996.

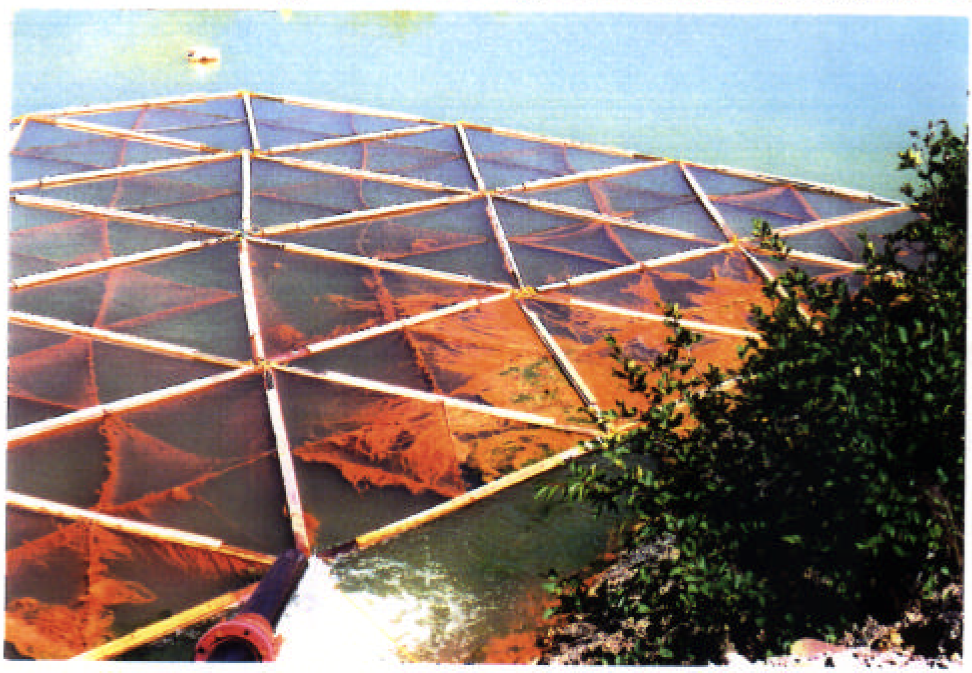


Plate 2: Installed Perigrid supporting periphyton population adjacent to Drainage Tunnel inflow, August 1, 1996.

7.0 POLISHING POND PERFORMANCE AND SCALE-UP

7.1 Fate of Nutrient Additions: Mass Balance Calculations

The ammonia and phosphate data collected during the PP11 Fertilizer Experiment was used to estimate a mass balance of these nutrients during the experiment. Table 27 presents the data and estimates made to perform the mass balance. Data is shaded in grey, while interpolated and calculated values are not shaded.

In Figure 28, a mass balance for ammonia is presented. The cumulative mass of N as ammonia added to PP11 (PP11 In, '+') is plotted versus hours after the experiment was started. The cumulative mass of N as ammonia is constantly increasing, as ammonia was present in PP11 inflow water. Big jumps in the cumulative mass occur every 24 hours when fertilizer was added.

The PP11 out cumulative mass of N as ammonia (squares) is based on measured N as ammonia concentrations at the outflow, multiplied by the flow measured leaving PP11.

Overall, the slope of the expected mass of ammonia entering the pond closely parallels the measured mass of ammonia leaving PP11. The mass of ammonia leaving PP11 is delayed with respect to the mass entering PP11. This is most likely due to the residence time of water in PP11. In 1995, the results of a Rhodamine tracer experiment conducted in PP11 suggested that the residence time of water in PP11 in 18 hours. In Figure 28, the slope of the PP11 out ammonia mass is delayed by approximately 17 hours with respect to the PP11 In ammonia balance, again a very close match between data sets and projections.

In Figure 29, the results of the phosphate mass balance for PP11 are presented. This presentation indicates that either phosphate is remaining in PP11, or that phosphate has reacted with other compounds in PP11 pond water such that the Hach phosphate kit does not detect it.

7.2 Large-Scale Study in Polishing Ponds 14 to 17

A field study was conducted on August 21, 1996, between 8 am and 6 pm, examining zinc concentrations in Polishing Ponds 11 to 13 following addition of a large dose of fertilizer (Figure 30). Unfortunately, given the results of phosphate consumption by algal biomass in the laboratory experiments, the field experiment was not conducted over a sufficiently long period in order to detect zinc concentration changes induced by the phosphate addition.

7.3 Drainage Tunnel-OWP-OEP-Polishing Pond Mass Balance Modelling

The model is based on the mass equation. This model assumes that the added fertilizer dissolves and mixes immediately. For one time step (all simulations were made using 1 hour time step) for each "vessel" (OWP, OEP, PP10, PP11, PP12, PP13), the mass and the new concentration is calculated. The mass consists of the following components:

(1) existing mass = the concentration multiplied by the volume.

(2) mass coming in = flow in multiplied by the concentration and by time step.

(3) mass leaving the "vessel" = flow out multiplied by the concentration and by time step.

(4) mass consumed by algae = rate multiplied by volume and by time step.

Then the new mass is calculated:

new mass = mass existing + mass in - mass out - mass eaten

and new concentration in the "vessel"

new concentration = new mass/volume

The program does this calculation for each "vessel" in this same time step and repeats so many time steps as required by user.

As input data, the following parameters have to be prepared:

- the initial concentration in each "vessel"
- rate of consumption of the nutrient (P or N) by algae
- the volume of each "vessel"
- the flows between the "vessels"
- the time intervals and rates, when and how much fertilizer is added to each "vessel"

The results (mass, concentration) are stored in ASCII format. The examples of the input parameters and output results are given below.

Model#1 - 1994 (Figure 31)

Pool 10 - Pool 13

June 24 - September 8 , PP10 addition of 350 g of fertilizer /day
September 9 - September 26, PP13 addition of 350 g of fertilizer/day
September 27 - October 31, PP12 addition of 350 g of fertilizer/day

Model #5 (Figure 32)

for 4 days addition of 3700 g of fertilizer/day to PP11

According to Boojum's Lab Experiment
100 g of 10-52-10 fertilizer converts to 77.03 g of PO_4 or 25.12 g of P
So:
350 g = 269.6 g of PO_4 or 87.9 g of P
3700 g = 2850 g of PO_4

P MODEL # 1

Calculation time: 1441 hours

Initial concentration:

DT	0.0 mg/L	
GW	0.0	ground water
OWP	0.0	
OEP	0.0	
PP10	0.0	
PP11	0.0	
PP12	0.0	
PP13	0.0	

Rate of P consumption by algae: 0.018 mg/L/hour

Volumes:	OWP	23,225 m^3	(area 4645 m^2 x 5 m thermocline)
	OEP	48,775	(area 19510 x 2.5)
	PP10	272	
	PP11	1,138	
	PP12	1,848	
	PP13	2,693	

Flows:	DT	29.52 m^3/h	= 8.2 L/s
	GW	39.312	= 10.92
	OWP	29.52	= 8.2
	OEP	68.832	= 19.12 (8.2 + 10.92)
	PP10	26.156	38 % of OEP flow, 62% goes to PP14
	PP11	26.156	
	PP12	26.156	
	PP13	26.156	

FROM LAB EXPERIMENT: 15% of 10-52-10 fertilizer converts to P

Addition of P:

OWP	5000 g/day	approx.	30 kg of fertilizer
PP10	50 g/day		0.3
PP11	150 g/day		0.9
PP12	250 g/day		1.5
PP13	400 g/day		2.4

Figure 33 shows the results for one day. All phosphate is used by algae, so the process repeats every day.

P MODEL # 2

Calculation time: 1441 hours

Initial concentration:

DT	0.0 mg/L	
GW	0.0	ground water
OWP	0.0	
OEP	0.0	
PP10	0.0	
PP11	0.0	
PP12	0.0	
PP13	0.0	

Rate of P consumption by algae: 0.009 mg/L/hour

Volumes:	OWP	23225 m^3	(area 4645 m^2 x 5 m thermocline)
	OEP	48775	(area 19510 x 2.5)
	PP10	272	
	PP11	1138	
	PP12	1848	
	PP13	2693	

Flows:	DT	29.52 m^3/h	= 8.2 L/s
	GW	39.312	= 10.92
	OWP	29.52	= 8.2
	OEP	68.832	= 19.12 (8.2 + 10.92)
	PP10	26.156	38 % of OEP flow, 62% goes to PP14
	PP11	26.156	
	PP12	26.156	
	PP13	26.156	

FROM LAB EXPERIMENT: 15% of 10-52-10 fertilizer converts to P

Addition of P:

OWP	5000 g/day	approx.	30 kg of fertilizer
PP10	50 g/day		0.3
PP11	150 g/day		0.9
PP12	250 g/day		1.5
PP13	400 g/day		2.4

Figure 34 shows the results for one day. All phosphate is used by algae, so the process repeats every day.

N MODEL # 1

Calculation time: 1441 hours

Initial concentration:

DT	0.0 mg/L	
GW	0.0	ground water
OWP	0.0	
OEP	0.0	
PP10	0.0	
PP11	0.0	
PP12	0.0	
PP13	0.0	

Rate of N consumption by algae: 0.041 mg/L/hour

Volumes:

OWP	23225 m^3	(area 4645 m^2 x 5 m thermocline)
OEP	48775	(area 19510 x 2.5)
PP10	272	
PP11	1138	
PP12	1848	
PP13	2693	

Flows:

DT	29.52 m^3/h	= 8.2 L/s
GW	39.312	= 10.92
OWP	29.52	= 8.2
OEP	68.832	= 19.12 (8.2 + 10.92)
PP10	26.156	38 % of OEP flow, 62% goes to PP14
PP11	26.156	
PP12	26.156	
PP13	26.156	

FROM LAB EXPERIMENT: 10% of 10-52-10 fertilizer converts to N

Addition of N (Calculated from amount of fertilizer added in P models 1 & 2):

OWP	3000 g/day
PP10	30 g/day
PP11	90 g/day
PP12	150 g/day
PP13	240 g/day

From Figure 35, it can be seen that all N is consumed in about 4-5 hours.

N MODEL # 2

Calculation time: 1441 hours

Initial concentration:

	DT	0.0 mg/L	
	GW	0.0	ground water
	OWP	0.0	
	OEP	0.0	
	PP10	0.0	
	PP11	0.0	
	PP12	0.0	
	PP13	0.0	

Rate of N consumption by algae: 0.002 mg/L/hour

Volumes:	OWP	23225 m^3	(area 4645 m^2 x 5 m thermocline)
	OEP	48775	(area 19510 x 2.5)
	PP10	272	
	PP11	1138	
	PP12	1848	
	PP13	2693	

Flows:	DT	29.52 m^3/h	= 8.2 L/s
	GW	39.312	= 10.92
	OWP	29.52	= 8.2
	OEP	68.832	= 19.12 (8.2 + 10.92)
	PP10	26.156	38 % of OEP flow, 62% goes to PP14
	PP11	26.156	
	PP12	26.156	
	PP13	26.156	

FROM LAB EXPERIMENT: 10% of 10-52-10 fertilizer converts to N

Addition of N (Calculated from amount of fertilizer added in P models 1 & 2):

	OWP	3000 g/day
	PP10	30 g/day
	PP11	90 g/day
	PP12	150 g/day
	PP13	240 g/day

From Figure 36, it can be seen that all N is consumed in about 4-5 hours.

7.4 Polishing Pond System Performance - 1996

Long term monitoring and performance data are presented in Figures 37 - 43 and Table 29 for the following:

- OEP weir and Polishing Pond system effluent seasonal zinc loads.
- PP10 and PP13 seasonal zinc loads.
- PP14 and PP17 seasonal zinc loads.
- Polishing Pond system seasonal zinc removal performance.
- OEP weir and Polishing Pond system final effluent seasonal pH.
- OEP weir and Polishing Pond system final effluent seasonal zinc concentrations.
- OEP weir and Polishing Pond final effluent seasonal zinc concentrations, by year.
- Iron and zinc concentrations in OEP with depth, 1993 to 1996.

Table 28: Mass Balance of Phosphate and Ammonia in PP11 fertilizer Experiment, Buchans.

Date	Days	Hr	Min	Hours after start	PP11 In [PO4]	Data	[N] as NH4	W.L. (CM)	Flow (l/s)	Kg Fert Added	Kg PO4 Added	Kg N-NH4 Added	mg PO4 entering PP11	Cumulative mg PO4 ent.PP11	mg N-NH4 entering PP11	Cumulative mg N-NH4 ent.PP11	PP11 Out [PO4]	Data	[N] as NH4	W.L. (cm)	mg PO4 exiting PP11	Cumulative mg PO4 exit PP11	mg N-NH4 exiting PP11	Cumulative mg N-NH4 exit PP11	PP In In Smoothed
08-Jul-96	0	9	8	-2.98	0.1																				
08-Jul-96	0	9	16	-2.85	0.1	* Y	0.6																		
08-Jul-96	0	12	7	0	0.1		0.525		6.78				0	0	0	0					0	0	0	0	0
08-Jul-96	0	12	27	0.33	0.1		0.525		6.78	3.7	2.57039	0.2886	2571204	2571203.6	292871	292871	0.1	* Y	0.4		814	814	3254	3254	8901
08-Jul-96	0	13	15	1.13	0.1		0.525		6.78				1953	2573156.2	10251	303123	0.1		0.45		1953	2766	8787	12041	30264
08-Jul-96	0	13	32	1.42	0.1		0.525		6.78				692	2573847.8	3631	306753	0.1		0.45		692	3458	3112	15153	37830
08-Jul-96	0	15	2	2.92	0.1		0.525	2.2	6.78				3663	2577510.6	19230	325983	0.1	* Y	0.5		3663	7121	18314	33467	77886
08-Jul-96	0	16	55	4.80	0.1		0.525		6.331				4293	2581803.2	22536	348519	0.3	*	0.5		12878	19998	21463	54930	128178
08-Jul-96	0	19	14	7.12	0.1		0.525		6.331				5280	2587083.5	27721	376241	0.4	*	0.4		21121	41119	21121	76051	190042
08-Jul-96	0	22	20	10.22	0.1		0.525		6.331				7066	2594149.1	37095	413335	0.6	*	0.6		42394	83513	42394	118445	272824
09-Jul-96	1	8	36	20.48	0.1		0.525		6.331				23400	2617549.3	122851	536186	0.6	* Y	0.7		140401	223915	163801	282247	546983
09-Jul-96	1	8	53	20.77	0.1	*	0.45		6.331				646	2618195.1	2906	539092	0.6		0.75		3875	227789	4843	287090	554549
09-Jul-96	1	9	0	20.88	0.1		0.45		6.331				266	2618461	1197	540289	0.6		0.75		1595	229385	1994	289084	557665
09-Jul-96	1	9	15	21.13	0.1		0.45		6.331				570	2619030.8	2564	542853	0.6		0.75		3419	232804	4274	293358	564341
09-Jul-96	1	9	30	21.38	0.1		0.45	2	5.88				529	2619560	2381	545234	0.6		0.75		3175	235978	3969	297327	571017
09-Jul-96	1	11	31	23.40	0.1		0.45		6.103				4431	2623990.5	19937	565172	0.6	*	0.6		26583	262562	26583	323910	624869
09-Jul-96	1	11	43	23.60	0.1		0.45		6.103	3.7	2.57039	0.2886	2570629	5194819.9	290577	855749	0.6		0.65		2636	265198	2856	326766	630210
09-Jul-96	1	13	46	25.65	0.1		0.45		6.103				4504	5199323.6	20267	876016	0.6	*	0.7		27022	292220	31526	358292	684953
09-Jul-96	1	16	18	28.18	0.1		0.45		6.103				5566	5204889.2	25045	901061	0.6	*	0.7		33394	325614	36959	397251	752603
09-Jul-96	1	16	48	28.68	0.1	*	0.46	2.1	6.33				1139	5206027.9	5124	906185	0.75		0.8		8540	334154	9109	406360	765954
09-Jul-96	1	21	35	33.47	0.1		0.475		7.271				12521	5218549	59476	965660	0.9	* Y	0.9		112691	446844	112691	519051	893688
10-Jul-96	2	8	42	44.58	0.1		0.475		7.271				29100	5247648.8	138224	1103884	0.9	*	0.75		261898	708742	218248	737299	1190545
10-Jul-96	2	11	30	47.38	0.1		0.475		7.271				7329	5254978.2	34815	1138699	0.95	*	0.85		69630	778372	62300	799599	1265316
10-Jul-96	2	11	50	47.72	0.1		0.475		7.271	2.815	1.9555805	0.21957	1956453	7211431.3	223715	1362414	0.975		0.925		8507	786879	8071	807670	1274217
10-Jul-96	2	11	52	47.75	0.1	*	0.5	2.5	8.22				99	7211529.9	493	1362907	0.975		0.925		961	787841	912	808582	1275107
10-Jul-96	2	15	18	51.18	0.1		0.5		7.973				9854	7221384.2	49271	1412178	1	*	1		98543	886383	98543	907125	1366790
10-Jul-96	2	18	43	54.60	0.1	*	0.5		7.973				9806	7231190.6	49032	1461210	0.95	*	1		93161	979545	98064	1005190	1458028
10-Jul-96	2	21	30	57.38	0.1		0.5		7.973				7989	7239179.3	39943	1501154	1.3	*	0.9		103853	1083397	71898	1077068	1532354
11-Jul-96	3	8	54	68.78	0.2	* Y	0.5	2.4	7.73				63437	7302616.5	158593	1659747	1.1		1.05	2.3	348905	1432302	333045	1410133	1836777
11-Jul-96	3	9	10	69.05	0.15		0.5		7.49				1079	7303695	3595	1663342	0.9	* Y	1.2		6471	1438773	8628	1418761	1843898
11-Jul-96	3	9	45	69.63	0.15		0.5		7.49				2359	7306054.3	7864	1671206	0.8		1.05		12583	1451356	16515	1435276	1859476
11-Jul-96	3	10	5	69.97	0.15		0.5		7.49				1348	7307402.4	4494	1675700	0.8		1.05		7190	1458546	9437	1444713	1868377
11-Jul-96	3	12	11	72.07	0.15		0.5		7.49	3.7	2.57039	0.2886	2578883	9886285.7	316911	1992611	0.8		1.05		45298	1503844	59453	1504166	1924455
11-Jul-96	3	12	13	72.10	0.1	*	0.6		7.49				90	9886375.6	449	1993060	0.8		1.05		719	1504563	944	1505110	1925345
11-Jul-96	3	12	28	72.35	0.2		0.55		7.49				1348	9887723.8	3707	1996768	0.7	*	0.9		4719	1509281	6067	1511177	1932021
11-Jul-96	3	15	10	75.05	0.3	*	0.6		7.49				21840	9909563.8	43680	2040448	0.85		1		61880	1571161	72800	1583977	2004121
11-Jul-96	3	15	32	75.42	0.2		0.65	2.3	7.25				1914	9911478	6221	2046669	1	*	1.1		9571	1580732	10528	1594505	2013913
11-Jul-96	3	16	54	76.76	0.2		0.65		7.017				6905	9918382.6	22440	2069109	1.025		0.975		35386	1616118	33660	1628165	2050408
11-Jul-96	3	17	22	77.25	0.2		0.65		7.017				2358	9920740.2	7662	2076771	1.025		0.975		12083	1628201	11494	1639659	2062870
11-Jul-96	3	17	44	77.62	0.2		0.65		7.017				1852	9922592.7	6020	2082792	1.025		0.975		9494	1637695	9031	1648689	2072661
11-Jul-96	3	18	24	78.28	0.2		0.65		7.017				3368	9925960.8	10946	2093738	1.05	*	0.95		17683	1655378	15998	1664688	2090464
11-Jul-96	3	18	45	78.63	0.1	*	0.7	2.2	6.78				855	9926815.5	5983	2099721	1.05		0.95		8974	1664352	8119	1672807	2099810

Table 29: Water Quality Data for OEP Profile Water Samples, 1993 - 1996

	Zinc (mg/L)					Iron (mg/L)				
Depth	**Apr 17,93**	**Apr 12,95**	**Oct 10,95**	**May 10,96**	**Jun 18,96**	**Apr-17-93**	**Apr-12-95**	**Oct-10-95**	**May 10,96**	**Jun 18,96**
weir	18.4		13.1	13.5	13.8	45.8		0.1	ND	ND
2m	18.3	15.4				41.0	3.9			
3 m			16.7					1.2		
4m	22.7				15.7	29.2				45.1
6m	23.8					53.6				
8m	24.9				14.3	54.7				51.3
10m	25.7	19.5	17.7	15.4	14.8	49.0	10.6	7.4	43.3	50.9
12m	21.1			15.4	15.9	59.8			49.9	53.1
14m	24.8			16.3	16.6	56.2			51.9	56.4
16m	26.9					70.9				
18m	27.7			16.6	17.6	76.4			53.8	58.4
20m	28.1	20.2	19.2			188.0	6.4	30.8		

Fig. 28: N-NH4 Mass Balance

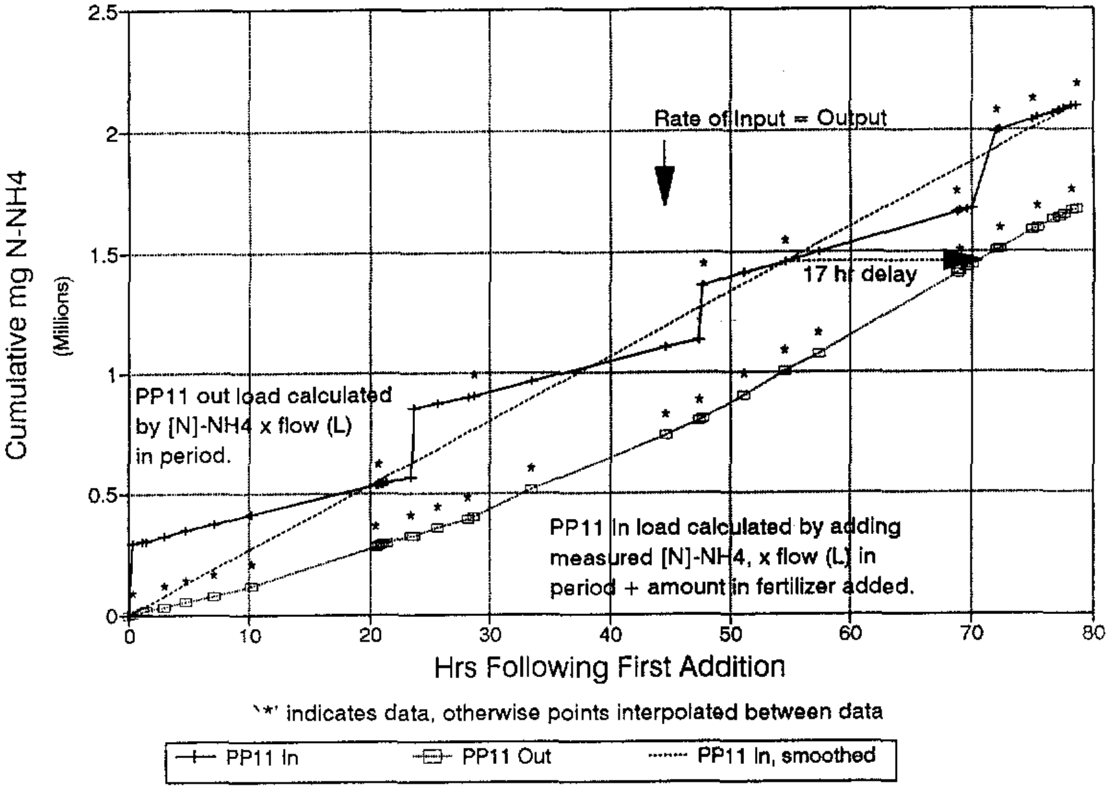


Fig. 29: PO4 Mass Balance

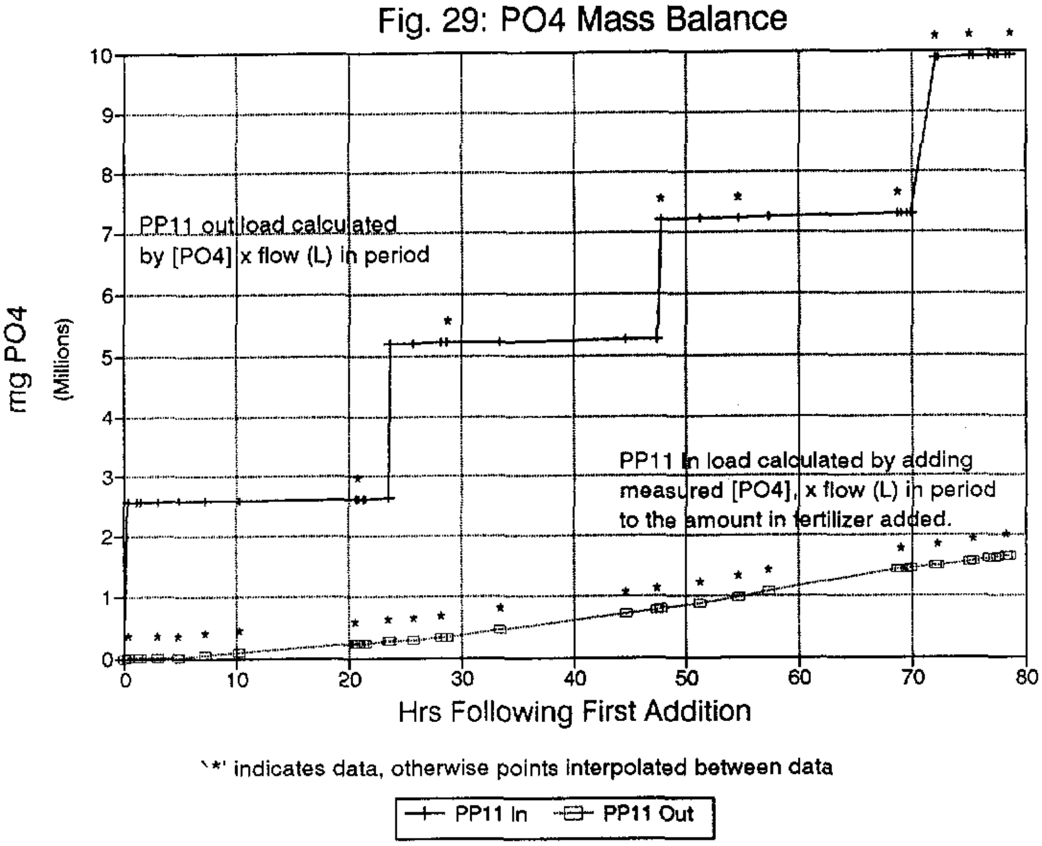


Fig 30: [Zn] - fertilizer experiment
August 21,1996

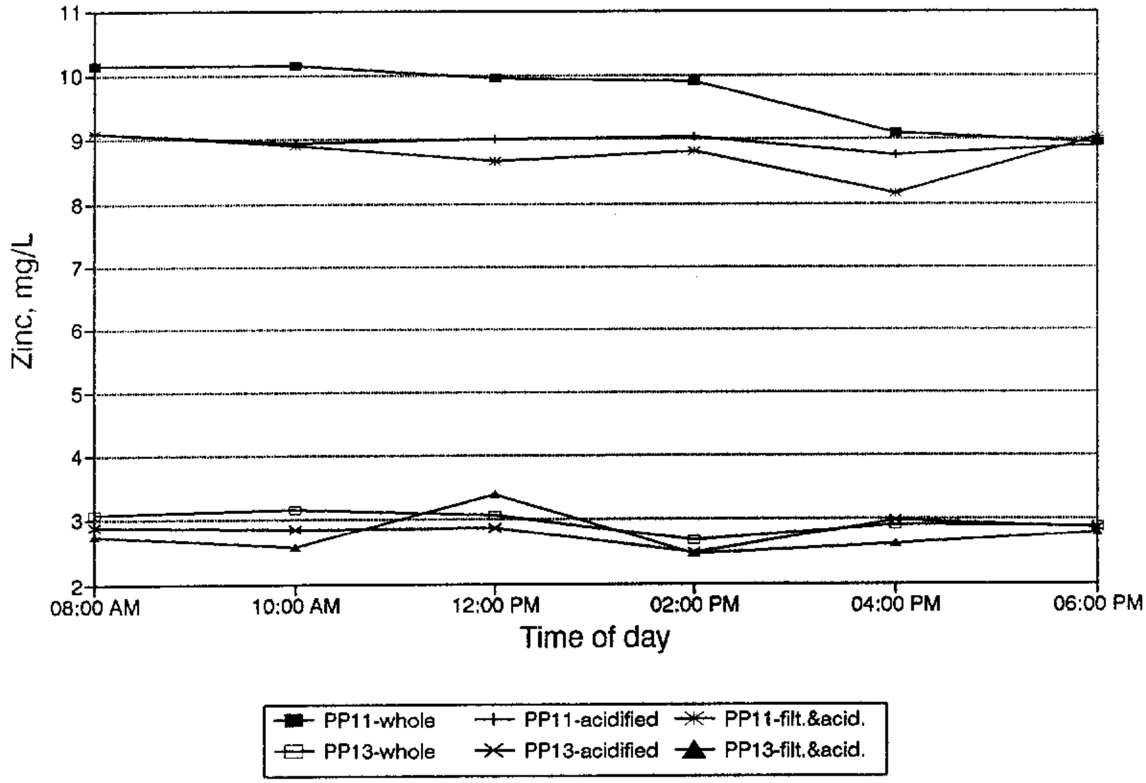


Fig. 31: Model#1
350g of fertilizer=269.6 g of PO4

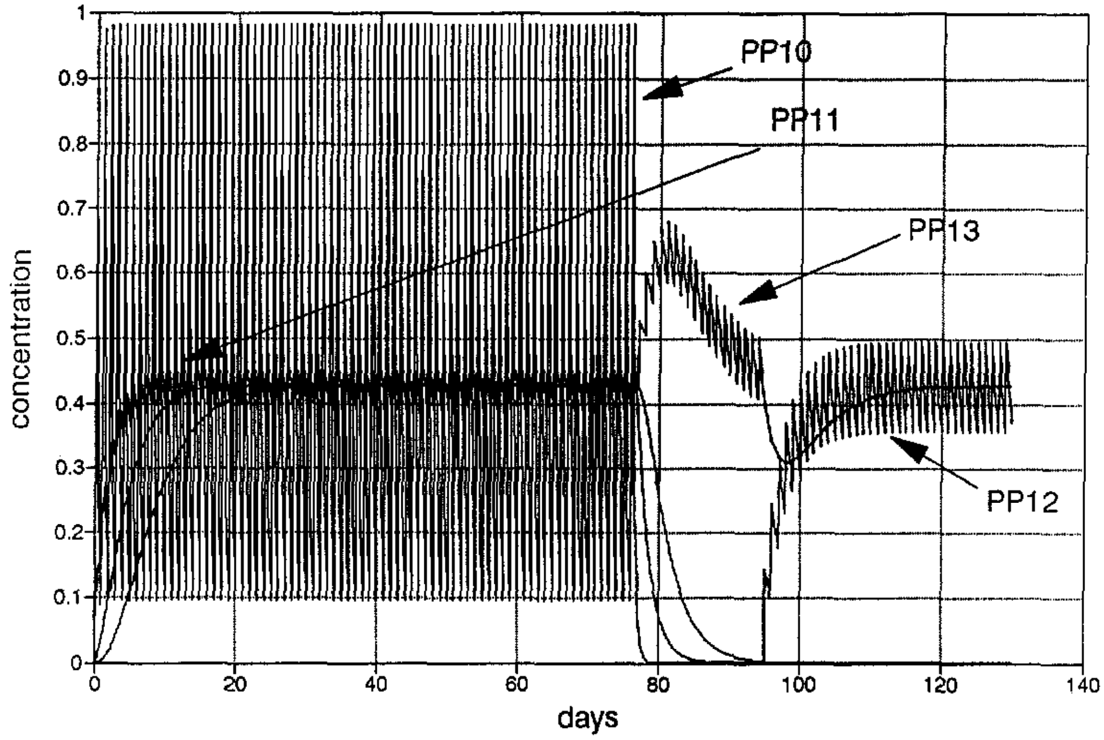


Fig. 32: Model #5
3700g of fertilizer=2850g of PO4

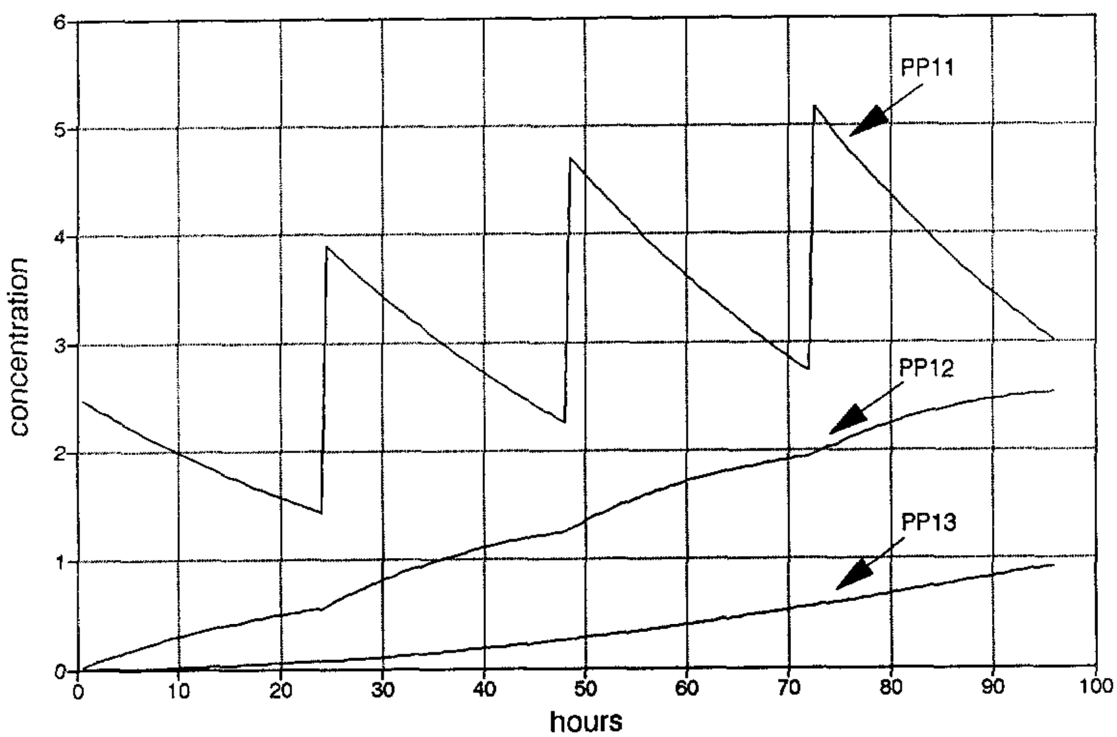


Fig. 33: P Model#1, Concentration of P
OWP, PP10, PP11, PP12, PP13

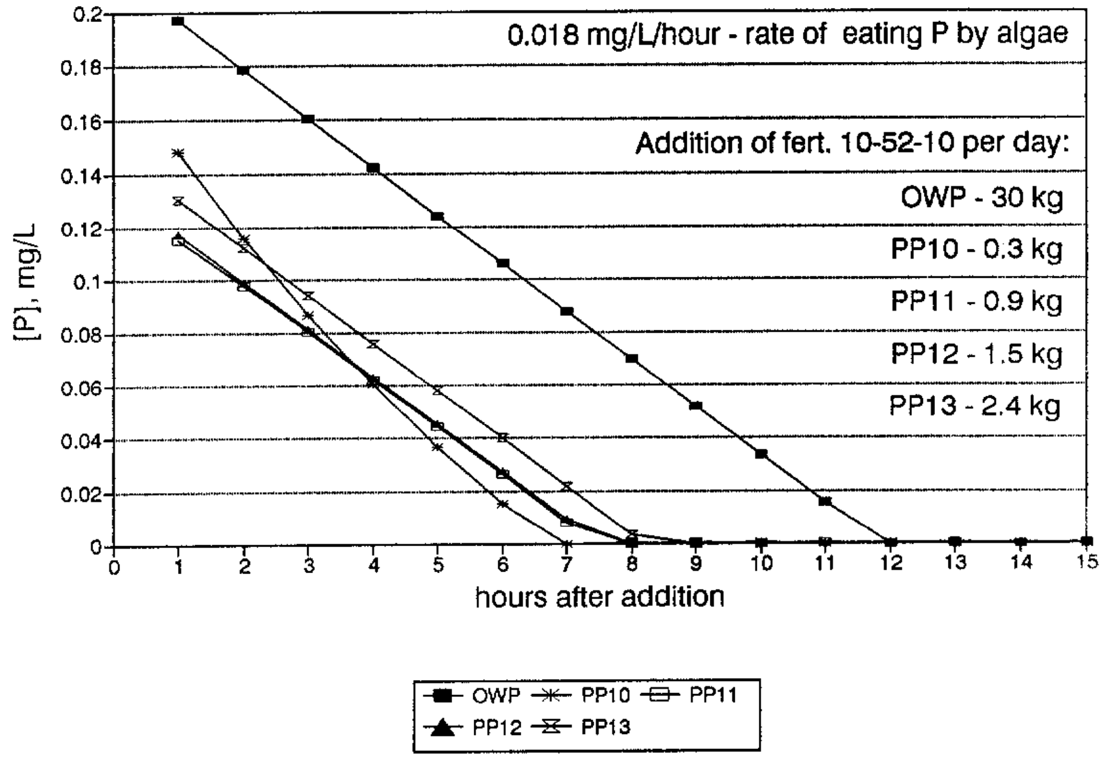


Fig. 34: P Model#2, Concentration of P
OWP, PP10, PP11, PP12, PP13

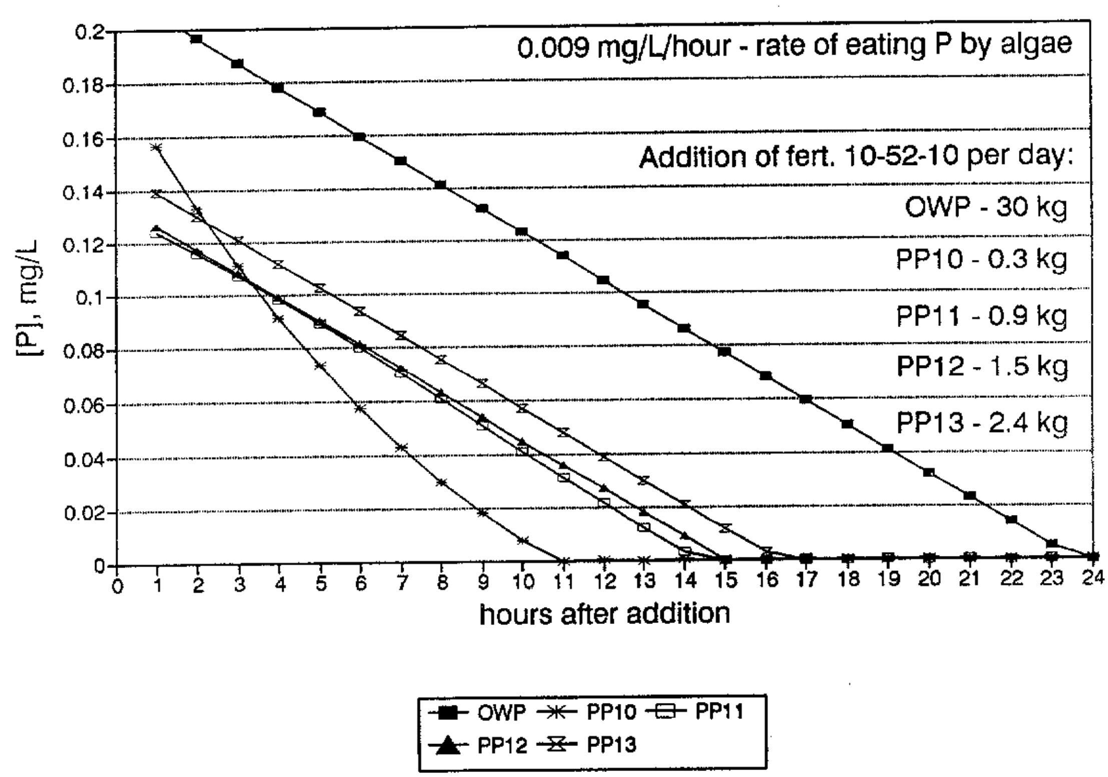


Fig. 35: N Model#1, Concentration of N
OWP, PP10, PP11, PP12, PP13

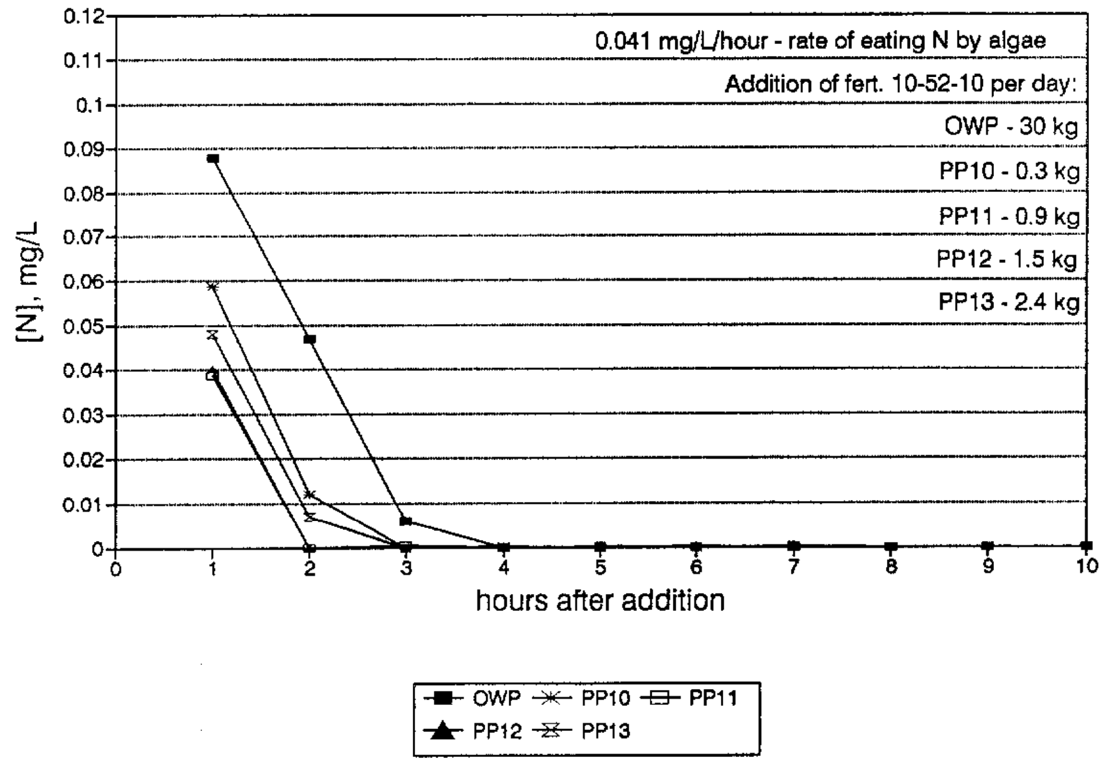


Fig. 36: N Model#2, Concentration of N
OWP, PP10, PP11, PP12, PP13

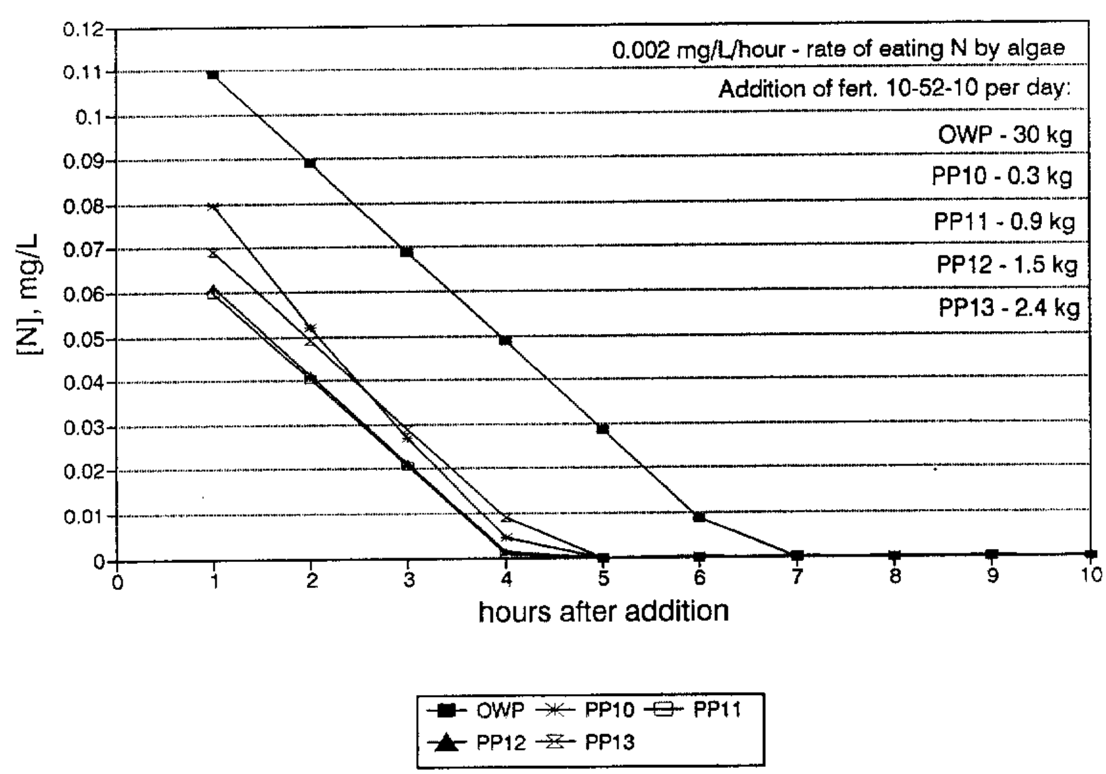


Fig. 37: Zinc Load, 1995-1996
OEP Weir and Final Effluent

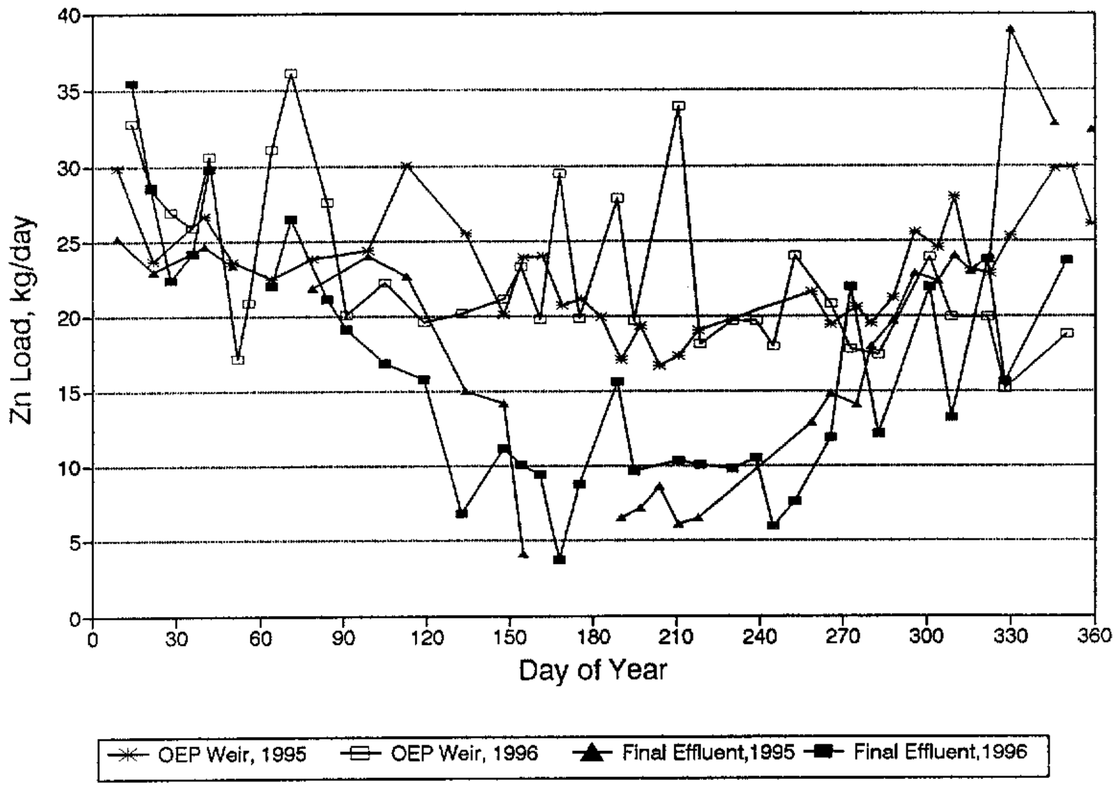


Fig. 38: Zinc Load, 1995-1996
PP10 and PP13

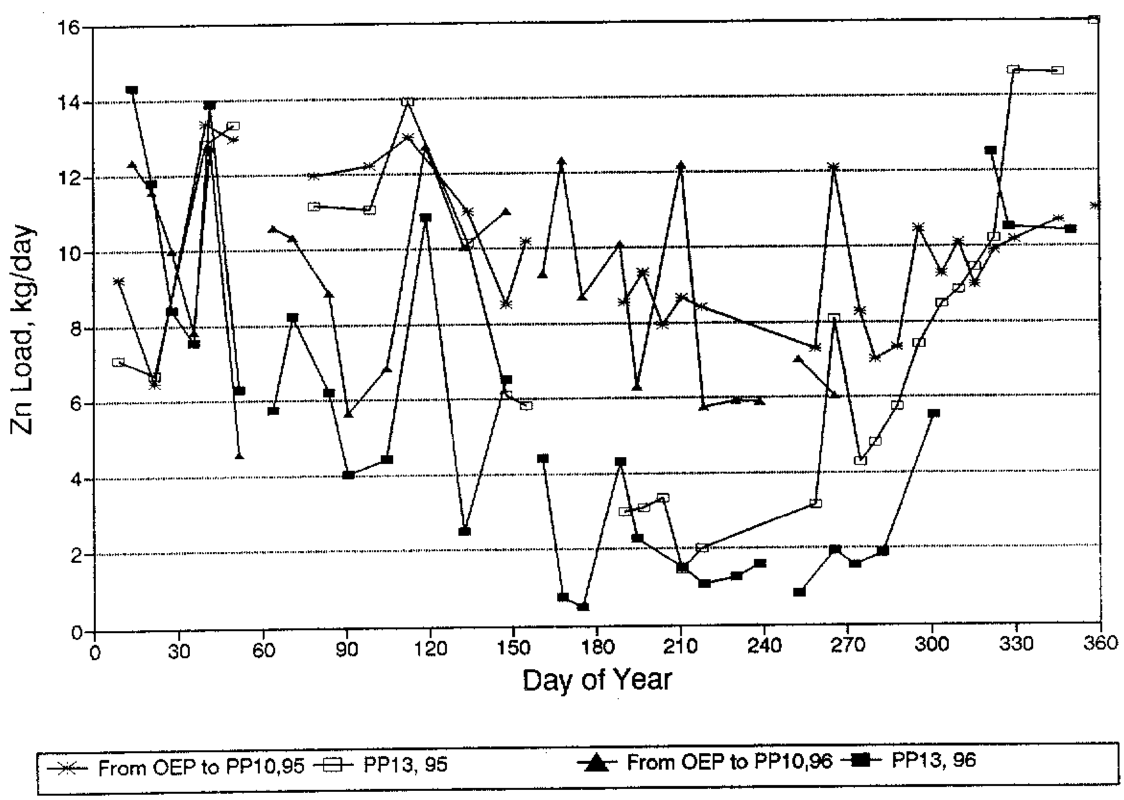


Fig. 39: Zinc Load, 1995-1996
PP14 and PP17

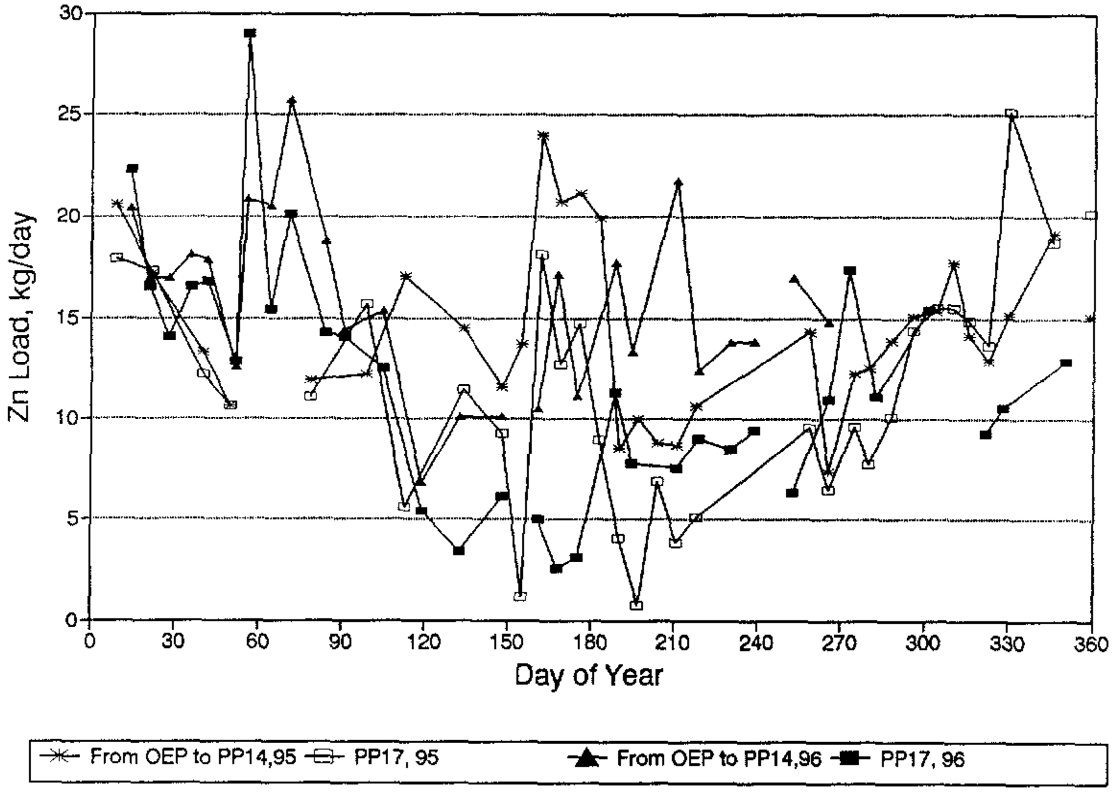


Fig. 40: Pond Performance
1995 - 1996

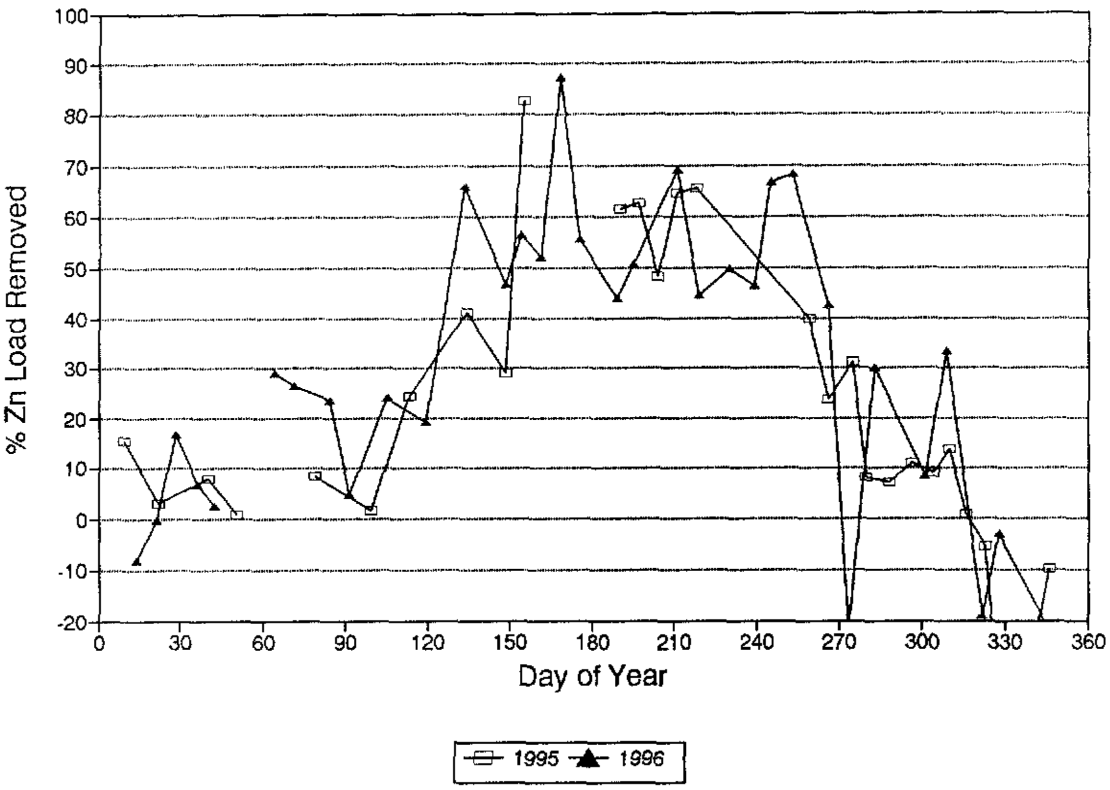


Fig. 41: pH, 1995-1996
OEP Weir, Final Effluent, PP13, PP17

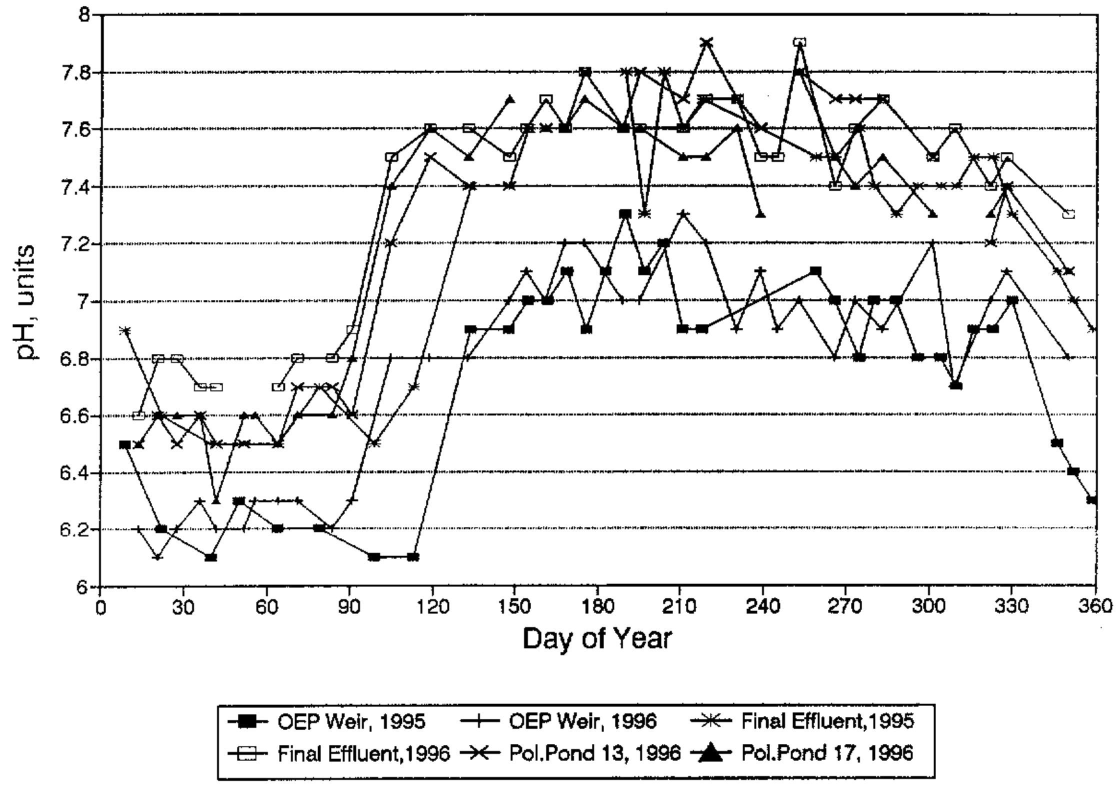


Fig. 42: Zinc Concentration, 1995-1996
OEP Weir and Final Effluent

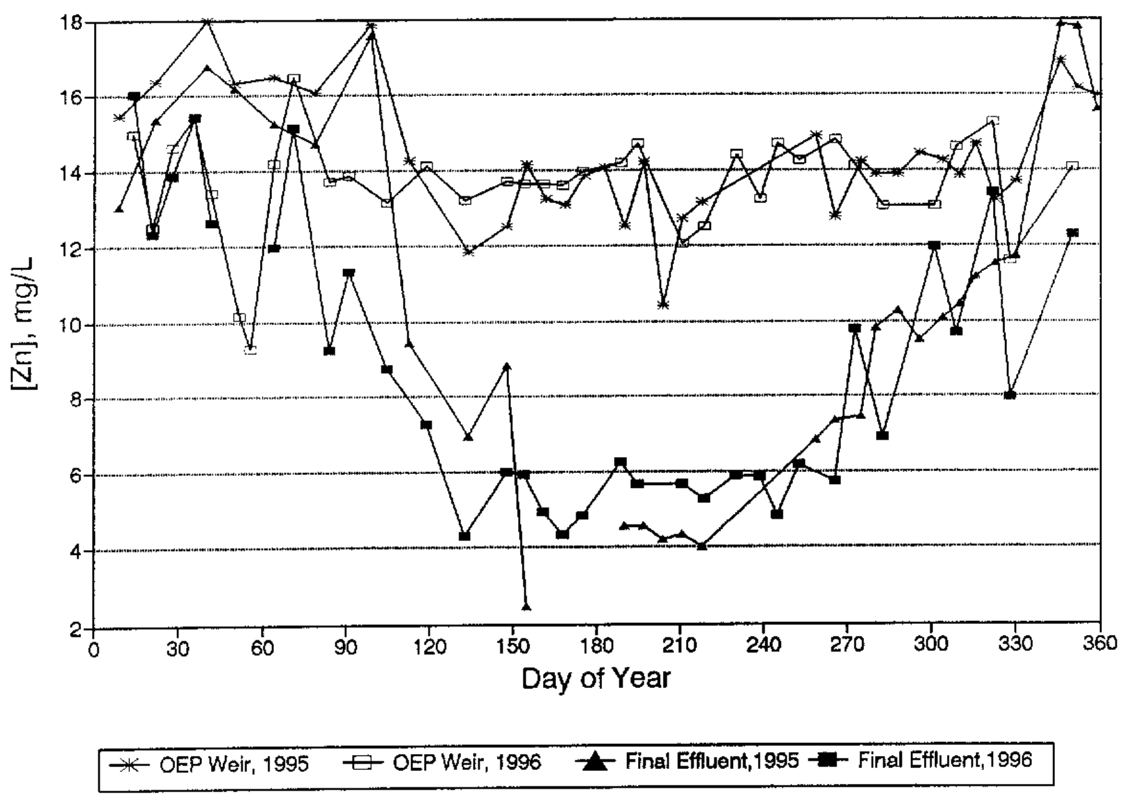
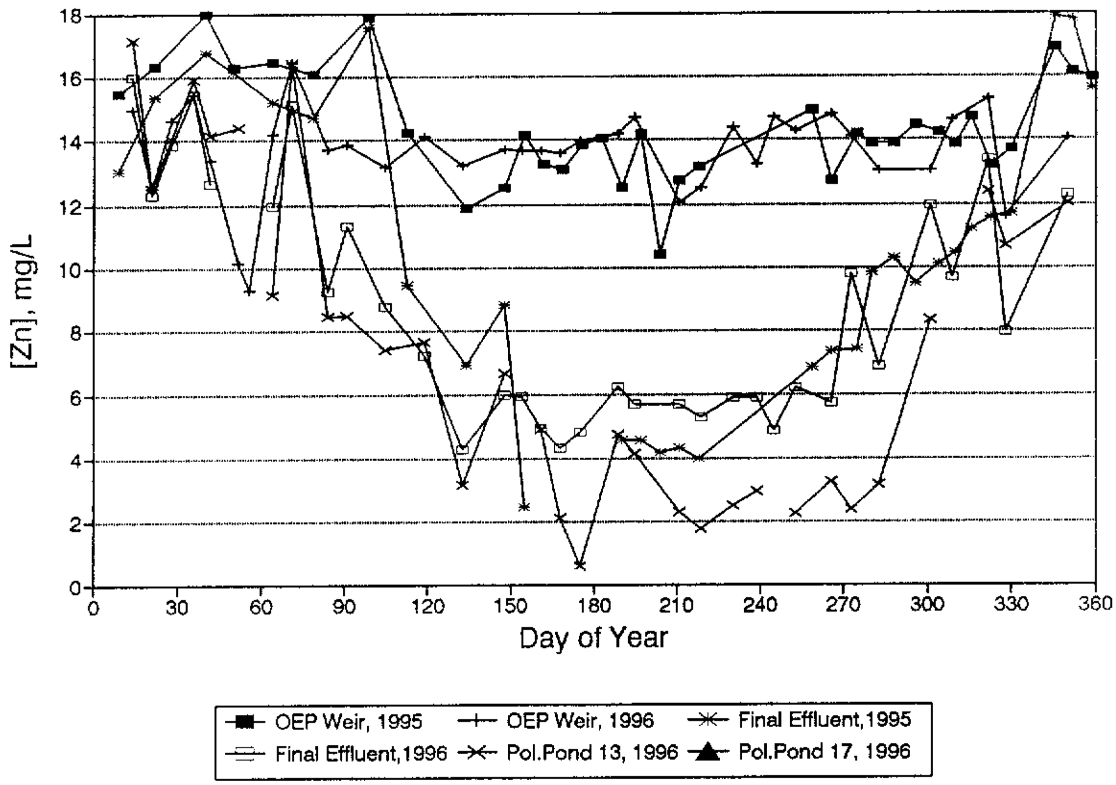


Fig. 43: Zinc Concentration, 1995-1996
OEP Weir,Final Effluent, PP13 and PP17



8.0 GEOCHEMICAL ASSESSMENTS OF OLD BUCHANS VALLEY SEEPAGES

The primary nutrient and chemistry data used in mass balance and nutrient status assessments are presented in the attached tables.

A overview of the Buchans areas is presented in Map 1. Sampling locations in the Old Buchans Valley drainage area are presented in Map 2.

The report by R.O. Van Everdingen (December 28, 1996), "ASARCO-Buchans. The Valley Seeps, 1995/1996" is attached. The report by J. Gerits (January, 1997), "Valley Seepages at Buchans" is also attached.

Table 30: PO_4, N as NO_3 and N as NH_4 Concentrations in OWP, OEP and Polishing Ponds, July 1, 1990 to August 13, 1996.

	PO_4 mg.L^{-1} 01-Jul-90 EPL	PO_4 mg.L^{-1} 05-Jul-91 EPL	PO_4 mg.L^{-1} 06-Apr-93 EPL	PO_4 mg.L^{-1} 16-May-93 EPL	PO_4 mg.L^{-1} 14-Jun-95 MDS	PO_4 mg.L^{-1} 21-Feb-96 MDS	PO_4 mg.L^{-1} 09-Jul-96 Hach Field	PO_4 mg.L^{-1} 15-Jul-96 Hach Lab	PO_4 mg.L^{-1} 09-Jul-96 MDS	PO_4 mg.L^{-1} 13-Aug-96 MDS
Drainage Tunnel		<3.1	<0.18		<0.18	<0.18	0.12	<0.1	<0.18	
OWP Surface		<3.1	<0.18	<0.18			<0.1	<0.1	<0.18	<0.31
OWP Bottom			<0.18	<0.18						<0.31
OEP Surface	<0.03		<0.18					<0.1	<0.18	<0.31
OEP Middle						<0.18				
OEP Bottom	<0.03		0.28			<0.18				<0.31
OEP outflow	<0.03	<3.1			<0.18	<0.18		<0.1	<0.18	
PP11 In						<0.18	0.1	<0.1	<0.18	
PP13 out							0.1	<0.1	<0.18	
PP17 out						<0.18	0.15	<0.1	<0.18	

	N-NO_3 mg.L^{-1} 01-Jul-90 EPL	N-NO_3 mg.L^{-1} 05-Jul-91 EPL	N-NO_3 mg.L^{-1} 06-Apr-93 EPL	N-NO_3 mg.L^{-1} 16-May-93 EPL	N-NO_3 mg.L^{-1} 15-Jun-95 MDS	N-NO_3 mg.L^{-1} 21-Feb-96 MDS	N-NO_3 mg.L^{-1} 09-Jul-96 Hach Field	N-NO_3 mg.L^{-1} 15-Jul-96 Hach Lab	N-NO_3 mg.L^{-1} 13-Aug-96 MDS	N-NH_4 mg.L^{-1} 09-Jul-96 Hach Field	N-NH_4 mg.L^{-1} 15-Jul-96 Hach Lab
Drainage Tunnel		2.27	1.07		0.94	0.8	0.4	0.5		<0.1	0.2
OWP Surface		<0.05	<0.03	0.14			0.12	0.28	0.36	0.3	0.3
OWP Bottom			<0.03	<0.03					<0.05		
OEP Surface	<0.01		<0.03					0.2	0.2		0.4
OEP Middle						<0.03					
OEP Bottom	<0.01		<0.03			<0.03			<0.05		
OEP outflow	<0.01	<0.05			0.35	0.23		0.18			0.2
PP11 In						<0.03	<0.01	0.16		0.6	0.5
PP13 out							<0.01	0.04		0.5	0.2
PP17 out						0.11	0.02	0.04		0.5	0.2

Table 31: Chemistry of OWP, OEP and Polishing Pond System Water Samples Collected July 1, 1990.

	Assay No.	pH	Cond. uS.cm-	Acidity mg.L-1	Alkalinity mg.L-1	Diss. Zn mg.L-1 AAS	mg.L-1 ICAP	Diss .Iron mg.L-1 AAS	mg.L-1 ICAP	Diss. Mn mg.L-1 ICAP	Diss. Ca mg.L-1 ICAP	Diss. Mg mg.L-1 ICAP	Diss. Na mg.L-1 ICAP
Drainage Tunnel													
OWP Surface													
OWP 7 m													
OEP Surface													
OEP 11 m	1822	6.4	1400				20		1.1	6.5	240	30	111
OEP bottom	1824	6.4	1400				24		8.6	8.3	292	37	149
OEP outflow	1825	6.9					15		<0.01	6.3	231	30	116
PP11 In													
PP11 out													
PP13 out													
PP17 out													

	TDS mg.L-1	SO_4 g.L-	SiO_2 mg.L-1 ICAP	HCO_3 mg.L-1	TOC mg.L-1	Cl mg.L-1
Drainage Tunnel						
OWP Surface						
OWP 7 m						
OEP Surface						
OEP 11 m		732	8.1	170		232
OEP bottom		900	9.4	188		256
OEP outflow		726	6.6	157		128
PP11 In						
PP11 out						
PP13 out						
PP17 out						

Table 32: Chemistry of OWP, OEP and Polishing Pond System Water Samples Collected July 5, 1991.

	Assay No	pH	Cond. uS.cm^{-1}	Acidity mg.L^{-1}	Alkalinity mg.L^{-1}	Diss. Zn mg.L^{-1}	mg.L^{-1}	Diss .Fe mg.L^{-1}	mg.L^{-1}	Diss. Mn mg.L^{-1}	Diss. Ca mg.L^{-1}	Diss. Mg mg.L^{-1}	Diss. Na mg.L^{-1}
						AAS	ICAP	AAS	ICAP	ICAP	ICAP	ICAP	ICAP
Drainage Tunnel	2914	5.61	483				17		<1	<1	37	5	13
OWP Surface	2909	3.9	733				35		2	2	85	11	4
OWP 7 m													
OEP Surface													
OEP 11 m													
OEP bottom													
OEP outflow	2910	6.47	2410				23		<1	11	389	40	98
PP11 In													
PP11 out													
PP13 out													
PP17 out													

	TDS mg.L^{-1}	SO_4 mg.L^{-1}	SiO_2 mg.L^{-1}	HCO_3 mg.L^{-1}	TOC mg.L^{-1}	Cl mg.L^{-1}
			ICAP			
Drainage Tunnel		106	17.1	4.88		16
OWP Surface		316	12.8	1.22		1.5
OWP 7 m						
OEP Surface						
OEP 11 m						
OEP bottom						
OEP outflow		907	17.1	25.93		123
PP11 In						
PP11 out						
PP13 out						
PP17 out						

Table 33: Chemistry of OWP, OEP and Polishing Pond System Water Samples Collected April 6, 1993.

	Assay No.	pH	Cond. uS.cm^{-1}	Acidity mg.L^{-1}	Alkalinity mg.L^{-1}	Diss. Zn mg.L^{-1}	mg.L^{-1}	Diss .Iron mg.L^{-1}	mg.L^{-1}	Diss. Mn mg.L^{-1}	Diss. Ca mg.L^{-1}	Diss. Mg mg.L^{-1}	Diss. Na mg.L^{-1}
						AAS	ICAP	AAS	ICAP	ICAP	ICAP	ICAP	ICAP
Drainage Tunnel	4413	5.72	450	54.5	29.5		23.9		0.006	0.267	43.2	5.76	12.6
OWP Surface	4414	3.91	456	81.4			29		0.15	2	71.1	9.61	2.86
OWP 7 m	4415	3.84	495	94.3			33.8		0.202	2.22	79	10.2	2.86
OEP Surface	4416	6.02	1510	248.5	229.7		17.2		0.788	10.3	332	32.6	88.5
OEP 11 m													
OEP bottom	4417	6.09	2040	397.8	340.6		24.2		3.97	14.6	508	45.9	127
OEP outflow													
PP11 In													
PP11 out													
PP13 out													
PP17 out													

	TDS mg.L^{-1}	SO_4 mg.L^{-1}	SiO_2 mg.L^{-1}	HCO_3 mg.L^{-1}	TOC mg.L^{-1}	Cl mg.L^{-1}
			ICAP			
Drainage Tunnel	259	122	19.8	23		20.9
OWP Surface	390	267	12.8	<0.1		1.54
OWP 7 m	447	310	13.8	<0.1		1.54
OEP Surface	1650	861	16.3	170		129
OEP 11 m						
OEP bottom	2410	1260	18.9	220		196
OEP outflow						
PP11 In						
PP11 out						
PP13 out						
PP17 out						

Table 34: Chemistry of OWP, OEP and Polishing Pond System Water Samples Collected May 16, 1993.

	Assay No.	pH	Cond. $uS.cm^{-1}$	Acidity $mg.L^{-1}$	Alkalinity $mg.L^{-1}$	Diss. Zn $mg.L^{-1}$	$mg.L^{-1}$	Diss .Iron $mg.L^{-1}$	$mg.L^{-1}$	Diss. Mn $mg.L^{-1}$	Diss. Ca $mg.L^{-1}$	Diss. Mg $mg.L^{-1}$	Diss. Na $mg.L^{-1}$
						AAS	ICAP	AAS	ICAP	ICAP	ICAP	ICAP	ICAP
Drainage Tunnel													
OWP Surface	4418	4.24	315	40.3			13.2		0.69	0.834	32	4.16	1.36
OWP 7 m	4419	4.04	700	101.5			34.4		0.205	2.14	75.8	9.86	2.78
OEP Surface													
OEP 11 m													
OEP bottom													
OEP outflow													
PP11 In													
PP11 out													
PP13 out													
PP17 out													

	TDS $mg.L^{-1}$	SO_4 $mg.L^{-1}$	SiO_2 $mg.L^{-1}$	HCO_3 $mg.L^{-1}$	TOC $mg.L^{-1}$	Cl $mg.L^{-1}$
			ICAP			
Drainage Tunnel						
OWP Surface	182	125	6.2	<0.1		0.83
OWP 7 m	450	316	13.6	<0.1		1.48
OEP Surface						
OEP 11 m						
OEP bottom						
OEP outflow						
PP11 In						
PP11 out						
PP13 out						
PP17 out						

Table 35: Chemistry of OWP, OEP and Polishing Pond System Water Samples Collected June 14, 1995.

	Assay No.	pH	Cond. uS.cm^{-1}	Acidity mg.L^{-1}	Alkalinity mg.L^{-1}	Diss. Zn mg.L^{-1}	mg.L^{-1}	Diss .Iron mg.L^{-1}	mg.L^{-1}	Diss. Mn mg.L^{-1}	Diss. Ca mg.L^{-1}	Diss. Mg mg.L^{-1}	Diss. Na mg.L^{-1}
						AAS	ICAP	AAS	ICAP	ICAP	ICAP	ICAP	ICAP
Drainage Tunnel	5575	6.4	192				13		0.009	0.172	41.1	3.88	9.41
OWP Surface													
OWP 7 m													
OEP Surface													
OEP 11 m													
OEP bottom													
OEP outflow	5576	7.1	1080				12.2		0.024	6.29	243	21.7	58.3
PP11 In													
PP11 out													
PP13 out													
PP17 out													

	TDS mg.L^{-1}	SO_4 mg.L^{-1}	SiO_2 mg.L^{-1}	HCO_3 mg.L^{-1}	TOC mg.L^{-1}	Cl mg.L^{-1}
			ICAP			
Drainage Tunnel	205	93.6		28		10.9
OWP Surface						
OWP 7 m						
OEP Surface						
OEP 11 m						
OEP bottom						
OEP outflow	1070	535		114		70.5
PP11 In						
PP11 out						
PP13 out						
PP17 out						

Table 36: Chemistry of OWP, OEP and Polishing Pond System Water Samples Collected February 21, 1996.

	Assay No.	pH	Cond. uS.cm^{-1}	Acidity mg.L^{-1}	Alkalinity mg.L^{-1}	Diss. Zn mg.L^{-1}	mg.L^{-1}	Diss .Iron mg.L^{-1}	mg.L^{-1}	Diss. Mn mg.L^{-1}	Diss. Ca mg.L^{-1}	Diss. Mg mg.L^{-1}	Diss. Na mg.L^{-1}
						AAS	ICAP	AAS	ICAP	ICAP	ICAP	ICAP	ICAP
Drainage Tunnel	5857	6.3	215	26.6	21.2		16.3		0.348	0.327	54.2	4.34	9.34
OWP Surface													
OWP 7 m													
OEP Surface													
OEP 11 m	5853	6.4	2050	227	361		16.4		63.7	13.6	489	41.7	116
OEP bottom	5852	6.4	2270	206.2	256.9		16.5		65.6	13.6	492	41.4	116
OEP outflow	5854	6.2	900	43.5	73.6		10.5		4.26	4.21	150	13.3	34.8
PP11 In													
PP11 out	5855	6.5	1292	49.8	132.3		11.9		7.93	9.1	265	23.3	62.8
PP13 out													
PP17 out	5856	6.6	1177	33.8	109.1		10.8		5.33	6.62	226	20	53.5

	TDS mg.L^{-1}	SO_4 mg.L^{-1}	SiO_2 mg.L^{-1}	HCO_3 mg.L^{-1}	TOC mg.L^{-1}	Cl mg.L^{-1}
			ICAP			
Drainage Tunnel	254	125	17.1	26.3	3	11.6
OWP Surface						
OWP 7 m						
OEP Surface						
OEP 11 m	2320	1160	15.8	255	8.9	154
OEP bottom	2320	1160	15	249	16.9	157
OEP outflow	716	363	10.8	84.9	2.8	46.5
PP11 In						
PP11 out	1250	624	12	154	6	86.6
PP13 out						
PP17 out	1060	534	11.4	128	5.3	73

Table 37. Chemistry of OWP, OEP and Polishing Pond System Water Samples Collected July 9, 1996.

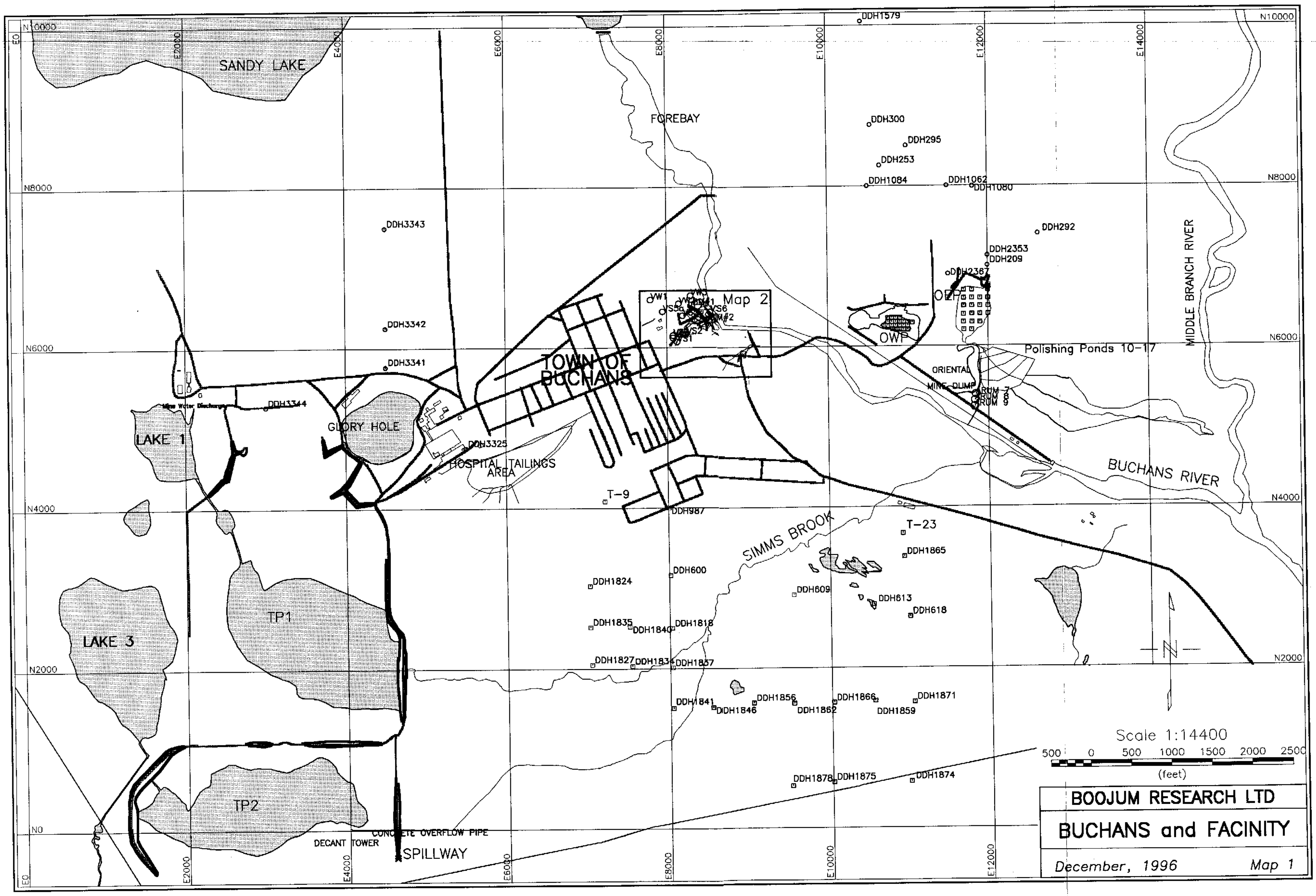
	Assay No.	pH	Cond. uS.cm^{-1}	Acidity mg.L^{-1}	Alkalinity mg.L^{-1}	Diss. Zn mg.L^{-1}	mg.L^{-1}	Diss .Iron mg.L^{-1}	mg.L^{-1}	Diss. Mn mg.L^{-1}	Diss. Ca mg.L^{-1}	Diss. Mg mg.L^{-1}	Diss. Na mg.L^{-1}
						AAS	ICAP	AAS	ICAP	ICAP	ICAP	ICAP	ICAP
Drainage Tunnel	5927	6.26	410	49.4		18.75	19.6	<d.l.	0.036	0.173	47	5.15	11.9
OWP Surface	5928	6.6	624	44.8		16.8	16.8	<d.l.	0.193	1.22	83.4	8.56	19.4
OWP 7 m	5935	6.26	983			18.26	18	<d.l.	0.634	2.43	132	12	24.1
OEP Surface	5929	7.52	1331	49		14.15	13.1	<d.l.	0.197	5.01	224	20.3	52.8
OEP 11 m	5936	6.59	2600	301		15	14.6	45.5	62.7	11.5	444	39.2	109
OEP bottom	5937	6.47	3010			16.55	16.2	55.35	78.1	13.2	502	44.5	123
OEP outflow	5938	7.24	1357	55.5		13.71	13	<d.l.	0.107	4.67	227	20.5	52.6
PP11 In	5932	6.64	1235	22.8		13.35	13.1	0.11	0.194	4.88	226	21.1	54.6
PP11 out	5933,34	6.53	1333			10.5		<d.l.					
PP13 out	5930	7.46	1284	8.6		4.65	3.88	<d.l.	0.044	1.46	222	19.8	50.8
PP17 out	5931	7.22	1295	16.4		7.755	6.79	<d.l.	0.04	2.5	215	19.8	51.3

	SO_4 mg.L^{-1}	TDS mg.L^{-1}	SiO_2 mg.L^{-1}	HCO_3 mg.L^{-1}	TOC mg.L^{-1}	Cl mg.L^{-1}
			ICAP			
Drainage Tunnel	142	300	16.3	24	2.3	15.5
OWP Surface	223	482	14.8	45	4.1	39.4
OWP 7 m	327		14.8			
OEP Surface	527	1080	13.3	113	2.8	76
OEP 11 m	999	2000	18.2	220	5.9	134
OEP bottom	1167		19.4			
OEP outflow	539	1110	13.2	118	2.7	75.4
PP11 In	537	1320	13			163?
PP11 out					5.6,4	
PP13 out	524	1010	10.8	109	4.3	65.1
PP17 out	510	1030	11.2	106	4.2	61

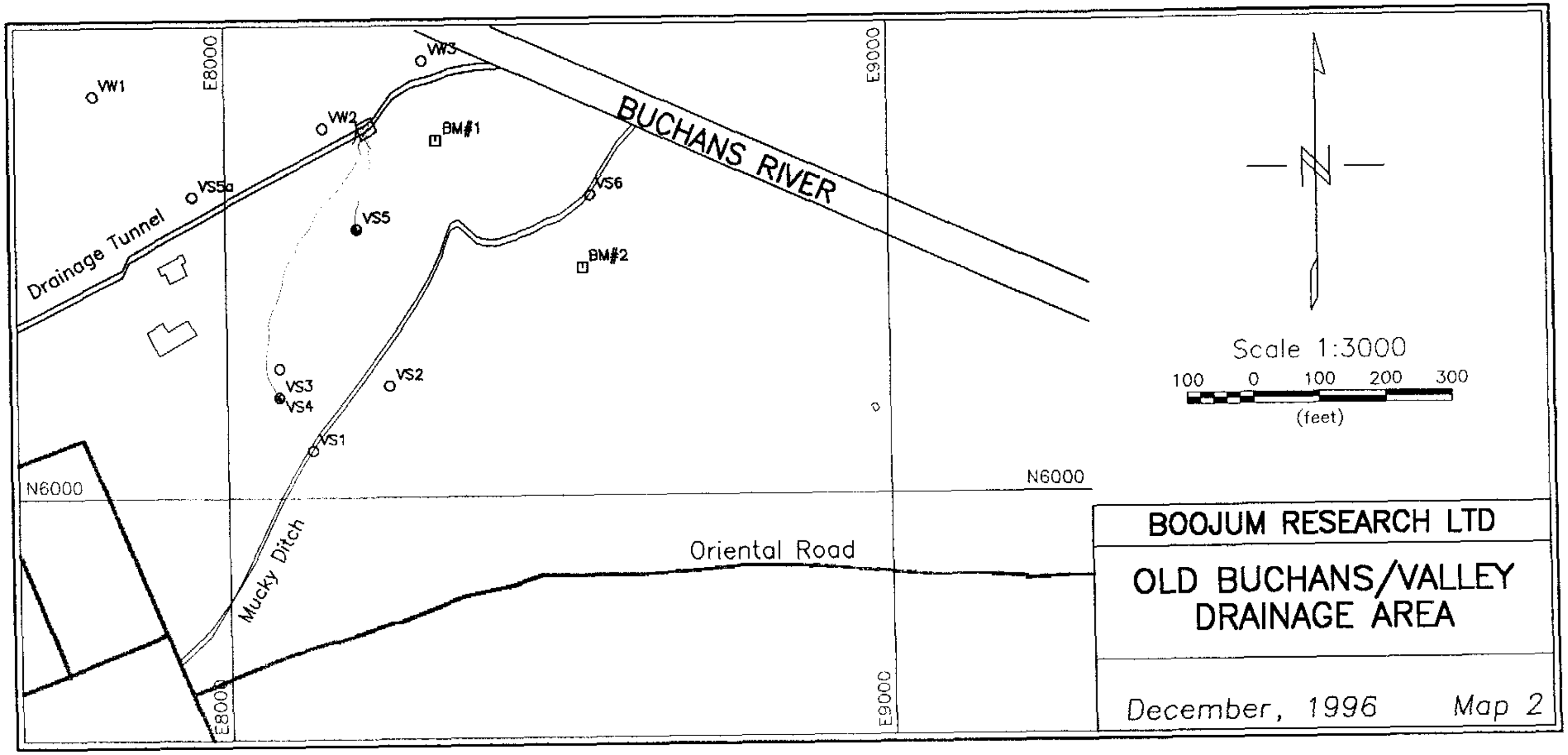
Table 38: Chemistry of OWP, OEP and Polishing Pond System Water Samples Collected August 13, 1996.

	Assay No.	pH	Cond. uS.cm^{-1}	Acidity mg.L^{-1}	Alkalinity mg.L^{-1}	Diss. Zn mg.L^{-1}	mg.L^{-1}	Diss .Iron mg.L^{-1}	mg.L^{-1}	Diss. Mn mg.L^{-1}	Diss. Ca mg.L^{-1}	Diss. Mg mg.L^{-1}	Diss. Na mg.L^{-1}
						AAS	ICAP	AAS	ICAP	ICAP	ICAP	ICAP	ICAP
Drainage Tunnel													
OWP Surface(5')	5977	6.49	748	32.9	63.5		16.3		<0.02	2.03	112	10.3	24.2
OWP 7 m	5978	5.73	962	171.3	42.8		29.9		<0.02	3.88	168	15.2	23.1
OEP Surface (5')	5975	6.89	1235	44.6	112.9		13.4		<0.02	5.15	224	19.6	51.7
OEP 11 m													
OEP bottom	5976	6.3	2410	71.5	301.3		13		10.1	13.2	505	41.2	116
OEP outflow													
PP11 In													
PP11 out													
PP13 out													
PP17 out													

	TDS mg.L^{-1}	SO_4 mg.L^{-1}	SiO_2 mg.L^{-1}	HCO_3 mg.L^{-1}	TOC mg.L^{-1}	Cl mg.L^{-1}
			ICAP			
Drainage Tunnel						
OWP Surface(5')	548	286		61.9		31.1
OWP 7 m	763	452		41.4		25.8
OEP Surface (5')	982	488		125		51.7
OEP 11 m						
OEP bottom	2300	1170		285		141
OEP outflow						
PP11 In						
PP11 out						
PP13 out						
PP17 out						



SANDY LAKE
FOREBAY
MIDDLE BRANCH RIVER
BUCHANS RIVER
SIMMS BROOK
TOWN OF BUCHANS
Map 2
OWP
Polishing Ponds 10-17
ORIENTAL
MINE DUMP
GLORY HOLE
HOSPITAL TAILINGS AREA
LAKE 1
LAKE 3
TP1
TP2
T-9
T-23
DECANT TOWER
CONCRETE OVERFLOW PIPE
SPILLWAY
DDH1579
DDH300
DDH295
DDH253
DDH1084
DDH1062
DDH1080
DDH292
DDH2353
DDH209
DDH3343
DDH3342
DDH3341
DDH3344
DDH3325
DDH987
DDH1865
DDH600
DDH1824
DDH609
DDH613
DDH618
DDH1835
DDH1840
DDH1818
DDH1827
DDH1857
DDH1841
DDH1846
DDH1856
DDH1866
DDH1862
DDH1871
DDH1859
DDH1878
DDH1875
DDH1874
N10000
N8000
N6000
N4000
N2000
N0
E0
E2000
E4000
E6000
E8000
E10000
E12000
E14000
Scale 1:14400
500 0 500 1000 1500 2000 2500
(feet)
BOOJUM RESEARCH LTD
BUCHANS and FACINITY
December, 1996
Map 1


VW1
VW2
VW3
BM#1
BM#2
VS1
VS2
VS3
VS4
VS5
VS5a
VS6
E8000
E9000
N6000
BUCHANS RIVER
Drainage Tunnel
Mucky Ditch
Oriental Road
Scale 1:3000
100 0 100 200 300
(feet)
BOOJUM RESEARCH LTD
OLD BUCHANS/VALLEY DRAINAGE AREA
December, 1996
Map 2

ASARCO - BUCHANS

THE VALLEY SEEPS, 1995/1996

LIST OF FIGURES

ASARCO - BUCHANS

THE VALLEY SEEPS, 1995/1996

INTRODUCTION

Information on discharge rates and chemical composition of the Valley Seeps at Buchans, measured during 1995 and 1996, was used to attempt the determination of a possible relationship between the seeps and the waterlevel in the Lucky Strike Pit. Because of time constraints the extent of the interpretation had to be limited in scope.

BOOJUM has checked the assumptions and uncertainties and presents the answer as bold, italic text.

DATA QUALITY

The available information presented a few uncertainties, as follows (numbers mentioned below are Assayer's numbers).

1 - Sample point VS-3 could not be found on the map of "Old Buchans/Valley Drainage Area", dated 11 September 1996.
Flow through the pipe was discontinued in summer 1996. This flow became part of flow at VS-4. Location VS-3 was added to Map 2.

2 - #5970: the listing of sample numbers and dates indicates this sample came from sample point VS-5; the analysis file BU0595.WQ1 indicated the sample represents "Total Valley S. Drainage at River"; the map suggests that the sample point likely was VS-6.
Yes, this is location VS-6 called Total Valley South Drainage at River

3 - Values for SO_4 (or S) were not provided for three of the seep samples collected in May 1995.
The samples were sent for ICP analysis. S is not a part of standard ICP.

4 - Some of the values for discharge rates were estimated rather than measured; Mr.Neary suggested that some of those values may be too high.

ASSUMPTIONS

Several assumptions had to be made because of inconsistencies in the designations of sample sources.

1 - #5572 and 5966 are from the same place, VS-1 on the map, called "Mucky Ditch at Culvert" (BU0595 and BU0896)

2 - #5574 and 5967 are from the same place, VS-2 on the map, called "4" Swimming Pool Pipe" (BU0595), and "Pipe Disch. Swimm. Pool" (BU0896)

3 - #5573 and 5970 are from the same place, VS-6 on the map, called "Mucky Ditch at River" (BU0595), and "Total Valley S. Drainage at River" (BU0896)

4 - #5569 and 5969 are from the same place, VS-5 on the map, called "Valley Seep 110' S.of Tun. Pumph." (BU0595), and "Valley Lower Seep" (BU0896)

5 - #5571 and 5968 are from the same place, VS-4 on the map, called "Valley Seep 370' S.of Tun. Pumph." (BU0595), and "Valley Combined Upper Seeps" (BU0896)

6 - #5570 is from VS-3, not on the map, called "Valley Seep 220' S. of Tun. Pumph." (BU0595)

If any of the above assumptions is erroneous, you may have to change the X-axis data labels on Figures 17 and 18, showing chemical compositions for these samples.

All of the above assumptions are correct. The seepages VS-1, VS-2, VS-3, VS-4, VS-5, VS-6, VW-1, VW-2, VW-3 are located on Map 2.

DATA GRAPHS and INTERPRETATION

Fig. 1 - amounts of **precipitation** from storms producing 20 mm or more water equivalent, vs. time.
Melting of any snowpack has not been taken into account.

Fig. 2 - **waterlevels** in the Lucky Strike Pit (LSP) and the diamond drill holes (DDH's), vs. time.
The LSP seems to have been "overfilled" by early 1995, and the waterlevel appears to have dropped more or less continuously since June 1995.
Waterlevels in the DDH's that had initially increased during filling of the LSP declined somewhat when the waterlevel in the LSP dropped; they showed minor fluctuations, probably in response to local precipitation. This behaviour can be expected to continue. It is unlikely that complete analyses of further samples from the DDH's will provide any additional useful information.

Fig. 3 - (Zn) and flow rates for the discharge from the **Drainage Tunnel** (DT), vs. time.
No clear correlation between the two parameters.

Fig. 4 - **intervals** between successive measurements of flow rates and (Zn) for sample points VS 1, 2, 3, 4, 5, and 6, vs. time.
The intervals ranged from 7 to more than 110 days. The irregularity of the intervals and the fact that the sample points were not all measured and sampled on the same dates makes the interpretations considerably less reliable than they could have been.

Fig. 5 - (Zn) values and flow rates for **VS-1**, vs. time.
In some instances (Zn) increases with increasing flow rate, in others (Zn) decreases with increasing flow rate. Short-term variations are too large to discern any clear long-term trend (see VS-6).

Fig. 6a - (Zn) values vs. flow rates for **VS-1**
No clear correlation between the two parameters.

Fig. 6b - (Zn) values for **VS-1** vs. LSP waterlevels
No clear correlation between the two parameters.

Fig. 6c - flowrates for **VS-1** vs. LSP waterlevels
No clear correlation between the two parameters.

Fig. 7 - (Zn) values and flow rates for **VS-2**, vs. time.
(Zn) appears to increase with decreasing flow rate and to decrease with increasing flow rate; no long-term trend.

Fig. 8a - (Zn) values vs. flow rates for **VS-2**
No clear correlation between the two parameters.

Fig. 8b - (Zn) values for **VS-2** vs. LSP waterlevels
No clear correlation between the two parameters.

Fig. 8c - flowrates for **VS-2** vs. LSP waterlevels
No clear correlation between the two parameters.

Fig. 9 - (Zn) values and flow rates for **VS-3**, vs. time.
The data record is insufficient to warrant interpretation.

Fig. 10 - (Zn) values and flow rates for **VS-4**, vs. time.
(Zn) appears to have increased somewhat with time (see VS-5).

Fig.11a - (Zn) values vs. flow rates for **VS-4**
No clear correlation between the two parameters.

Fig.11b - (Zn) values for **VS-4** vs. LSP waterlevels
Negative correlation between the two parameters.

Fig.11c - flowrates for **VS-4** vs. LSP waterlevels
No clear correlation between the two parameters.

Fig. 12 - (Zn) values and flow rates for **VS-5**, vs. time.
(Zn) appears to have increased with time (see VS-4).

Fig.13a - (Zn) values vs. flow rates for **VS-5**
Negative correlation between the two parameters.

Fig.13b - (Zn) values for **VS-5** vs. LSP waterlevels
Negative correlation between the two parameters.

Fig.13c - flowrates for **VS-5** vs. LSP waterlevels
Positive correlation between the two parameters.

Fig. 14 - (Zn) values and flow rates for **VS-6**, vs. time.
In some instances (Zn) increases with increasing flow rate, in others (Zn) decreases with increasing flow rate. Short-term variations are too large to discern any clear long-term trend (see VS-1).

Fig.15a - (Zn) values vs. flow rates for **VS-6**

No clear correlation between the two parameters.

Fig.15b - (Zn) values for **VS-6** vs. LSP waterlevels
No clear correlation between the two parameters.

Fig.15c - flowrates for **VS-6** vs. LSP waterlevels
No clear correlation between the two parameters.

Fig. 16 - (Zn) values vs. time for **VS-1, 2, 3, 4, 5, and 6**
VS-1 shows the widest range of variation of (Zn). VS-2 shows both the lowest (Zn) values and the smallest variations in (Zn). VS-3 and VS-4 appear to be related in both (Zn) values and flow rates (VS-3 record is too short to be sure). VS-4 and VS-5 show somewhat similar variations in (Zn) values and flow rates, although (Zn) values in VS-4 are almost double those in VS-5.

Fig. 17 - Concentrations of selected elements (Ca, Cu, Mg, Mn, Zn, S) in samples from **LSP** and **VS-1, 2, 3, 4, 5, and 6** collected on 28 May 1995 and a sample from **DT** collected on 14 June 1995 (see ASSUMPTIONS above).
Metal concentrations in the LSP increased with depth; those in the DT discharge were lower than those in the near-surface LSP sample. Values for (S), (Ca), (Mg), and (Zn) indicate that the samples from the LSP, DT and VS-1, 3, 4, 5, and 6 had a similar origin. Values for (Cu) and (Mn) varied more than those for the other metals (likely due to increased significance of analytical precision at low concentrations). Concentrations for each element in the VS samples were lower than those for the LSP bottom sample and higher than those for the DT sample. The sample from VS-2 appears to have had a different origin.

Fig. 18 - Concentrations of selected elements (Ca, Cu, Mg, Mn, Zn, S) in samples from **LSP, DT, and VS-1, 2, 3, 4, 5, and 6** collected on 13 August 1996 (see ASSUMPTIONS above).
Metal concentrations in the LSP still increased with depth; those in the DT discharge (with the exception of (Cu)) were lower than those in the near-surface LSP sample. Values for (S), (Ca), (Mg), and (Zn) indicate that the samples from the LSP, DT and VS-1, 3, 4, 5, and 6 had a similar origin. Values for (Cu) and (Mn) varied more than those for the other metals (likely due to increased significance of analytical precision at low concentrations). Concentrations for each element in the VS samples were lower than those for the LSP bottom sample and (with the exception of the sample from VS-1) higher than those for the DT sample. The sample from VS-2 again appears to have had a different origin.

Fig. 19 - (Zn) values and flow rates for **VW-1**, vs. time.
(Zn) appears to increase with decreasing flow rate and to decrease with increasing flow rate; record too short to determine long-term trend.

Fig. 20 - (Zn) values and flow rates for **VW-2**, vs. time.
No clear correlation between the two parameters.

Fig. 21 - (Zn) values and flow rates for **VW-3**, vs. time.
In some instances (Zn) increases with increasing flow rate, in others (Zn) decreases with increasing flow rate. Short-term variations are too large to discern any clear long-term trend.

Fig.22a - (Zn) values vs. flow rates for **VW-3**
No clear correlation between the two parameters.

Fig.22b - (Zn) values for **VW-3** vs. LSP waterlevels
No clear correlation between the two parameters.

Fig.22c - flowrates for **VW-3** vs. LSP waterlevels
Minor positive correlation between the two parameters.

Fig. 23 - Zn contents vs. time for **VW-1, 2 and 3**
VW-3 shows the widest range of variation for (Zn). There appears to be some correlation between (Zn) for VW-1 and VW-2, but inconsistent sample dates make the relationship uncertain.

The behaviour of the Zn concentrations in the discharge from the Valley Seeps can probably be explained in principle as follows.

(1) After a prolonged dry period, increased infiltration from precipitation (or snowmelt) may push out water with higher metal concentrations, due to a preceding extended residence time, resulting in increased flow rates and increased metal concentrations.

(2) If infiltration continues, metal concentrations will gradually drop due to dilution.

(3) When infiltration stops, flow rates will gradually decrease, whereas metal concentrations will gradually increase due to lack of dilution, and longer residence times.

It should be noted that the "monitoring data" for the Valley Seeps cannot be used to give a clear indication of the diluting effects of local precipitation, unless the concentration of at least one other metal (e.g. Ca or Mg) is also determined for each sample. If at all possible, discharge rates should be measured rather than estimated.

The magnitude of the metal loadings from some of the Valley Seeps appears to have become sufficiently large to warrant continuing monitoring of the main seepages.

Robert O. van Everdingen
28 December 1996

Fig. 1: BUCHANS
Storm Precipitation > 20mm

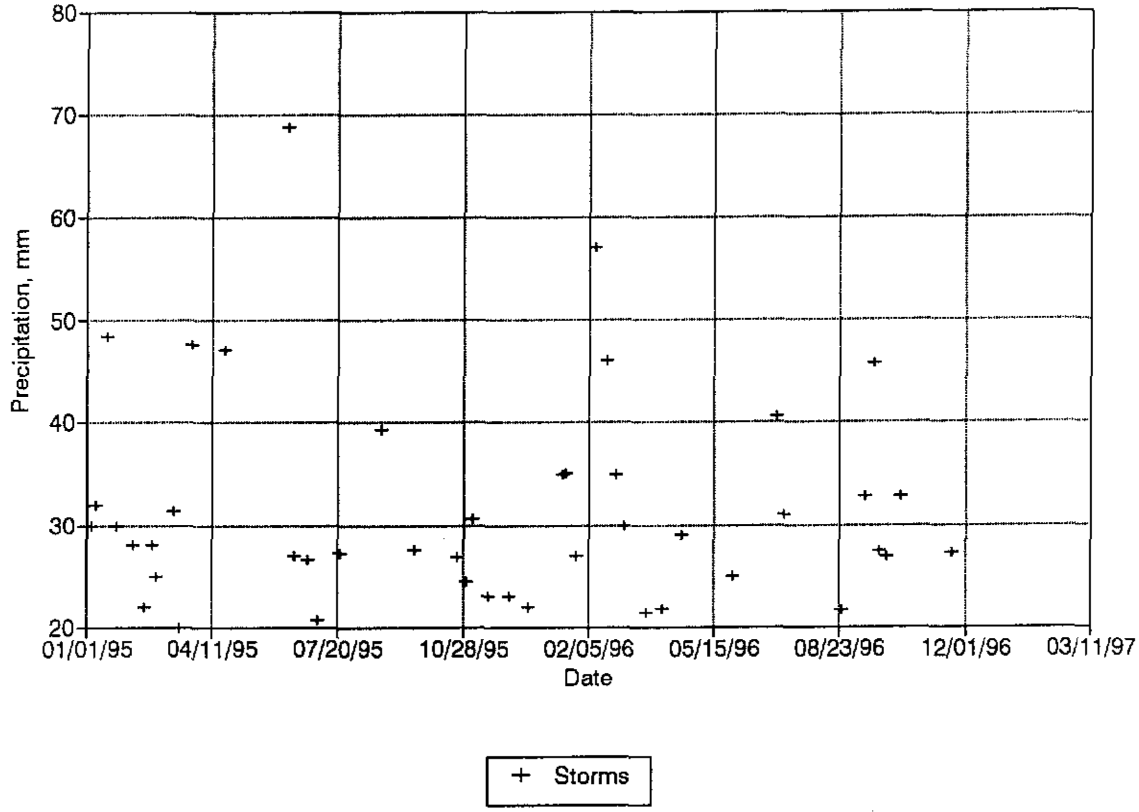


Fig. 2: LUCKY STRIKE PIT and DDH
Water Levels, 1995-1996

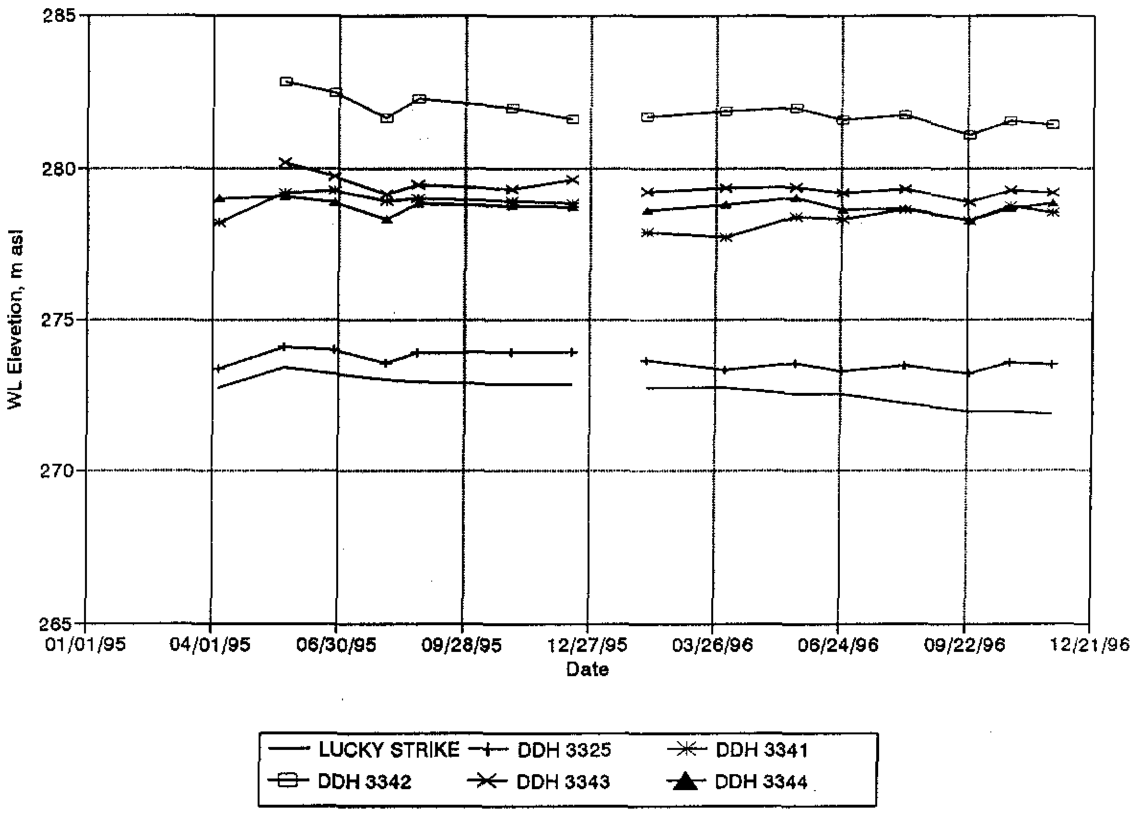


Fig. 3: DRAINAGE TUNNEL
Discharge

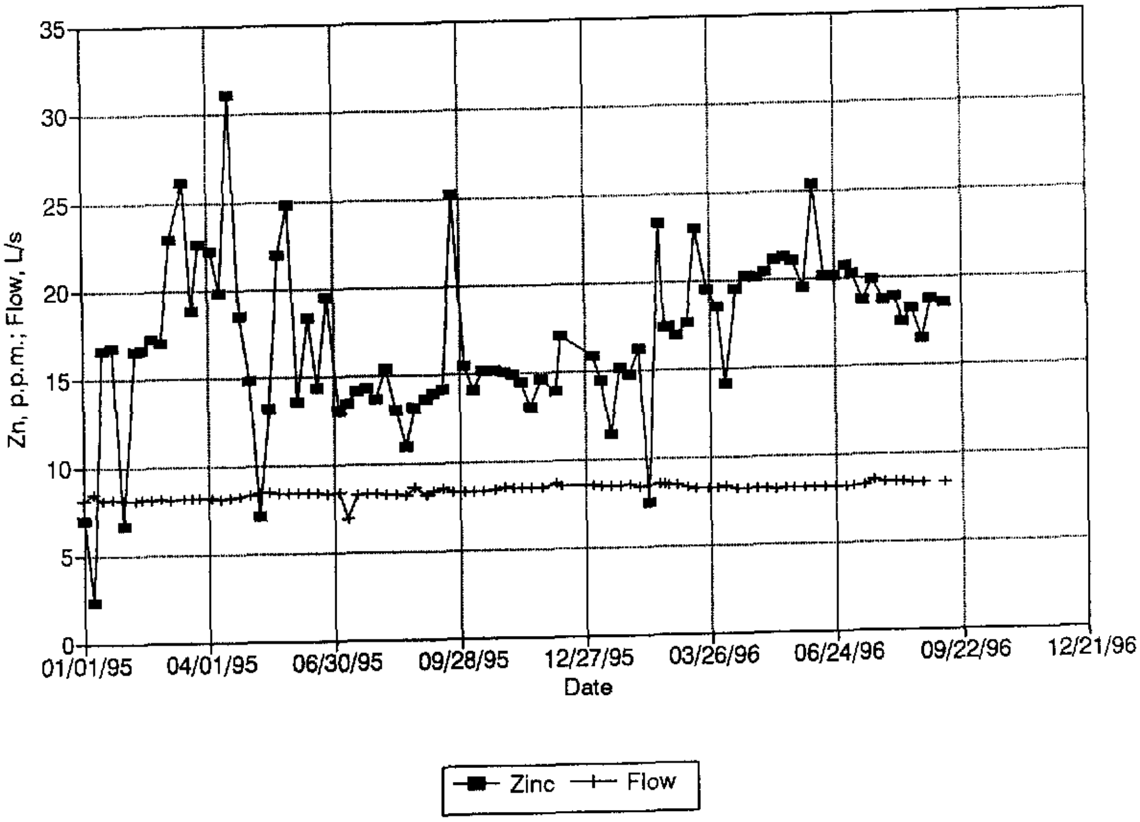


Fig. 4: VALLEY SOUTH
Intervals between measurements

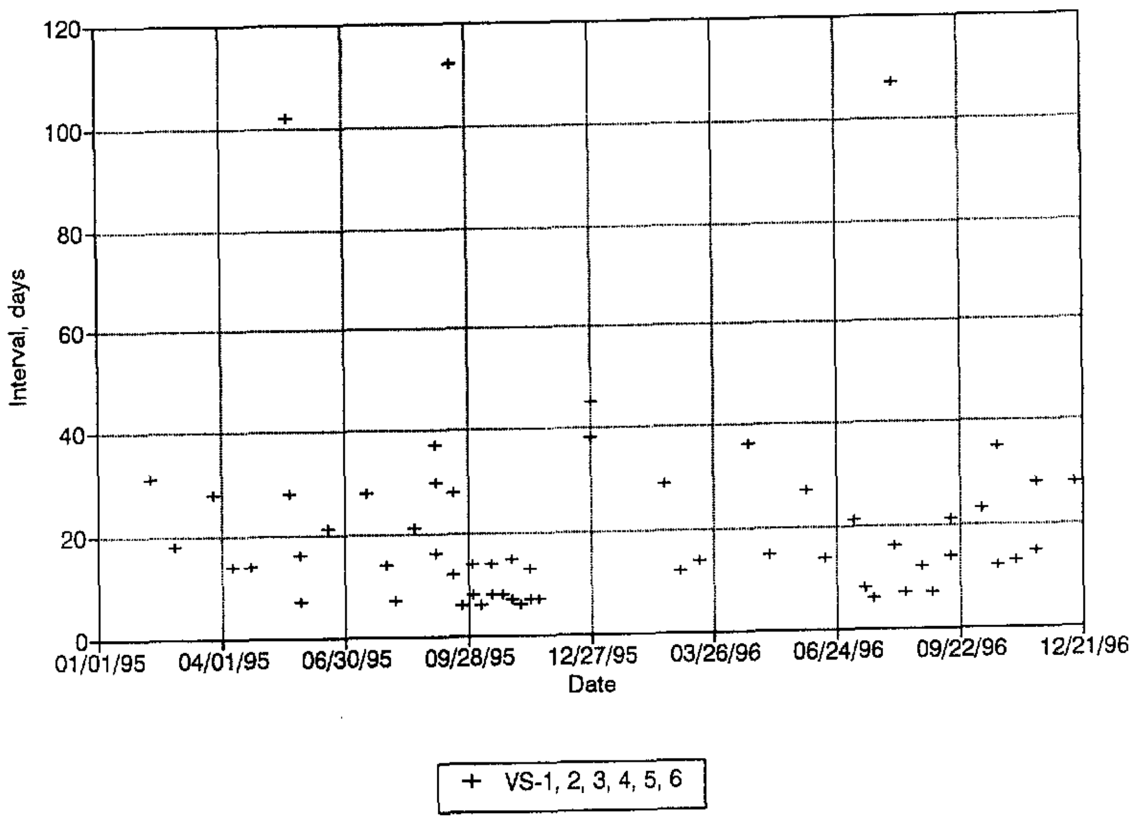


Fig. 5: VALLEY SOUTH, VS-1
[Zn] and Flow versus Time

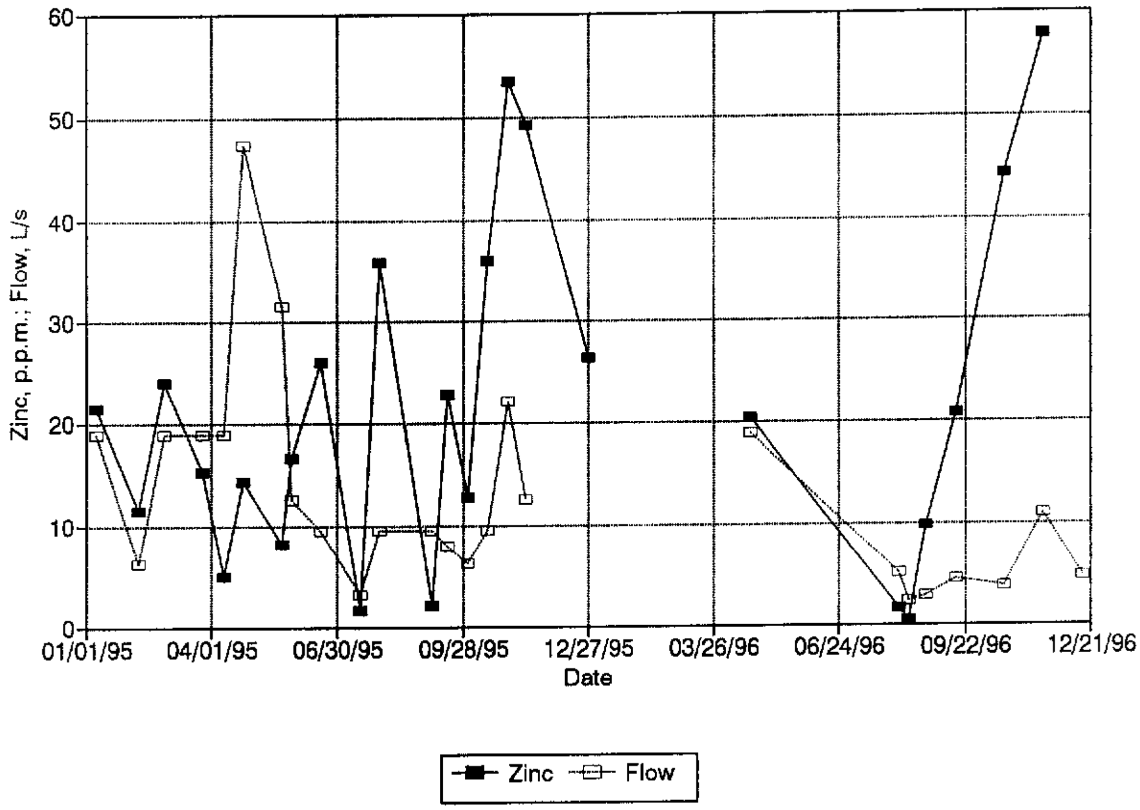


Fig. 6a: VALLEY SOUTH, VS-1
[Zn] versus Flow

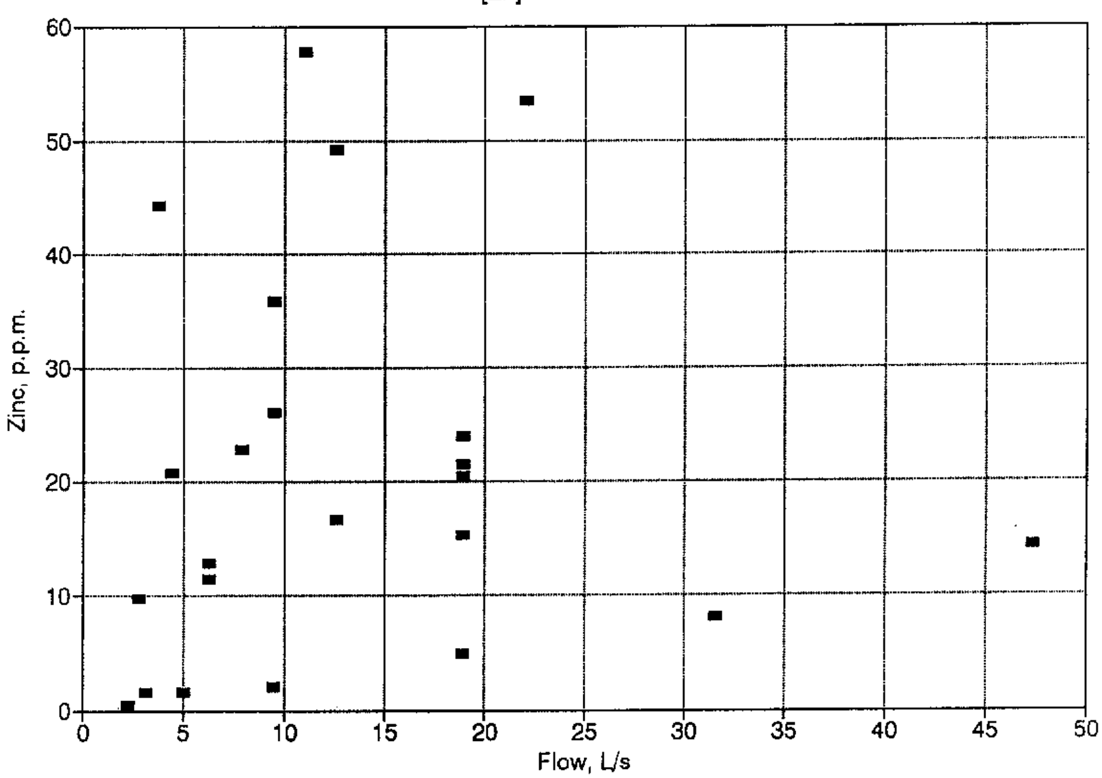


Fig. 6b: VALLEY SOUTH, VS-1
[Zn] versus LS Waterlevel

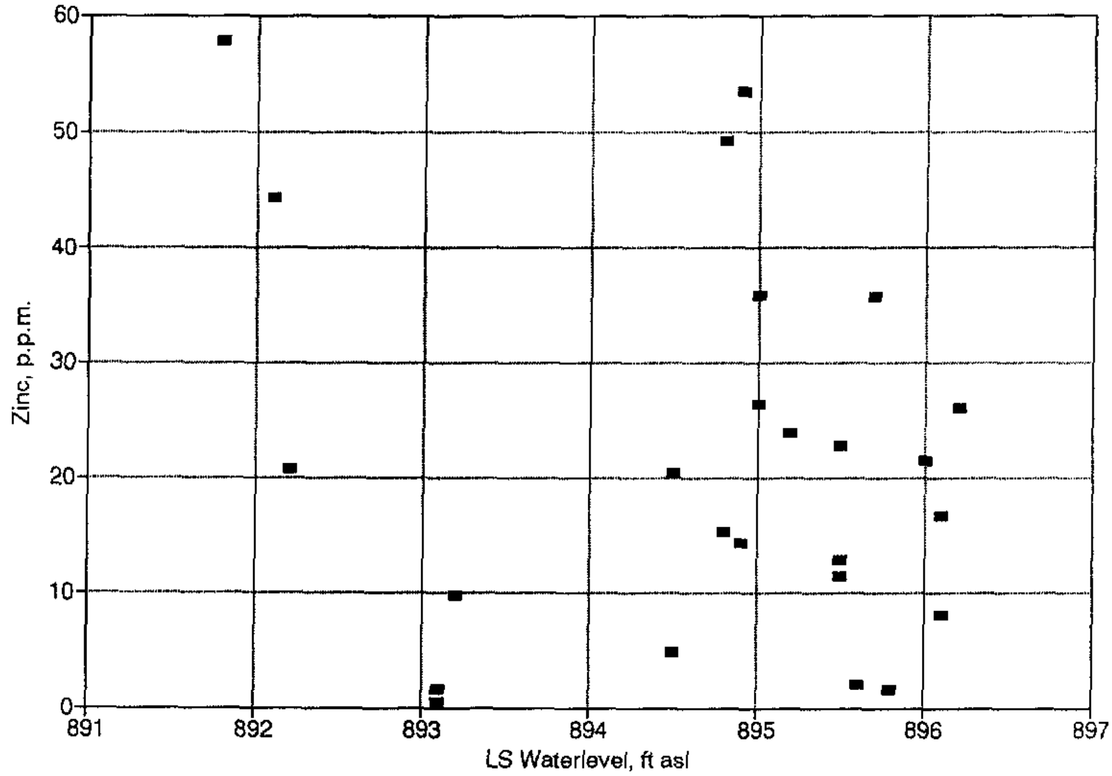


Fig. 6c: VALLEY SOUTH, VS-1
Flow versus LS Waterlevel

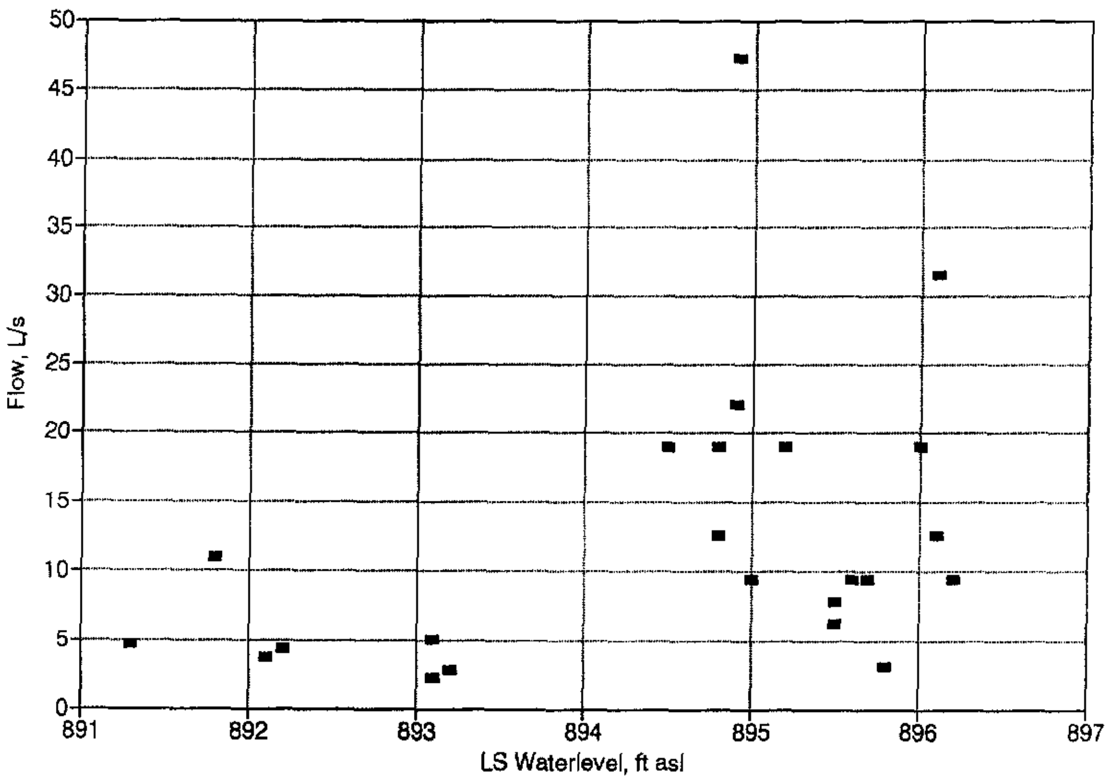


Fig. 7: VALLEY SOUTH, VS-2
[Zn] and Flow versus Time

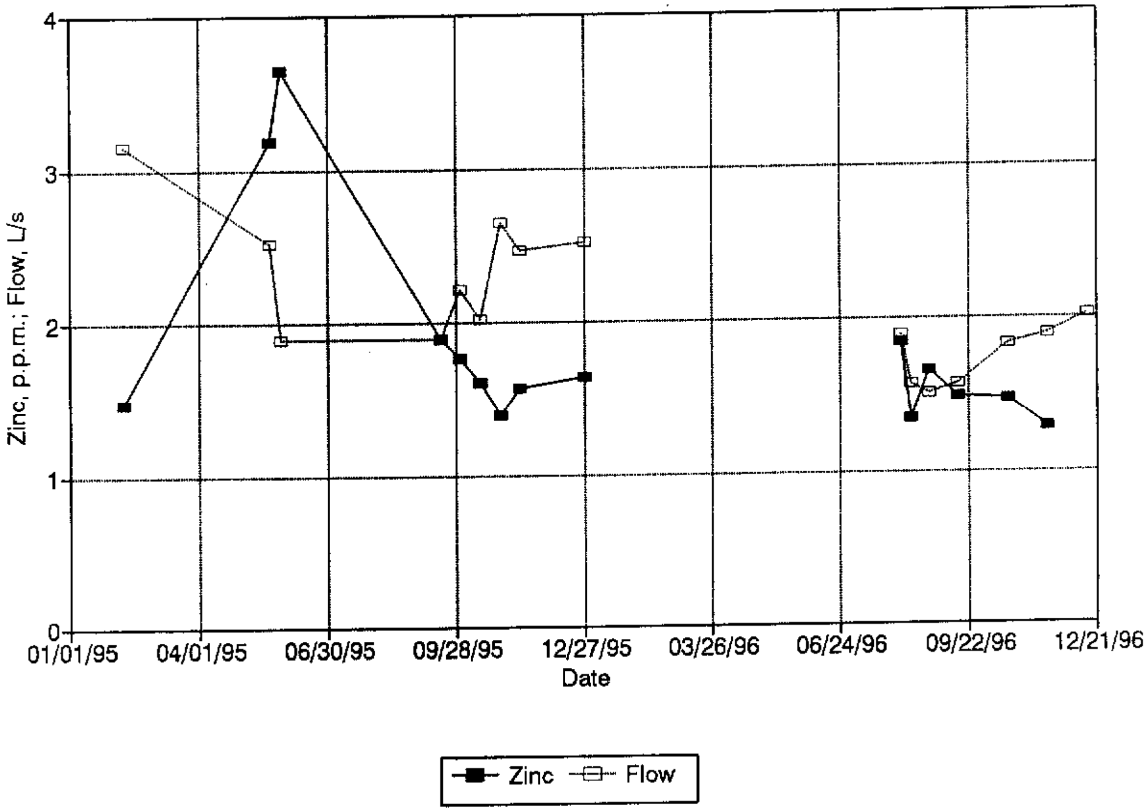


Fig. 8a: VALLEY SOUTH, VS-2
[Zn] versus Flow

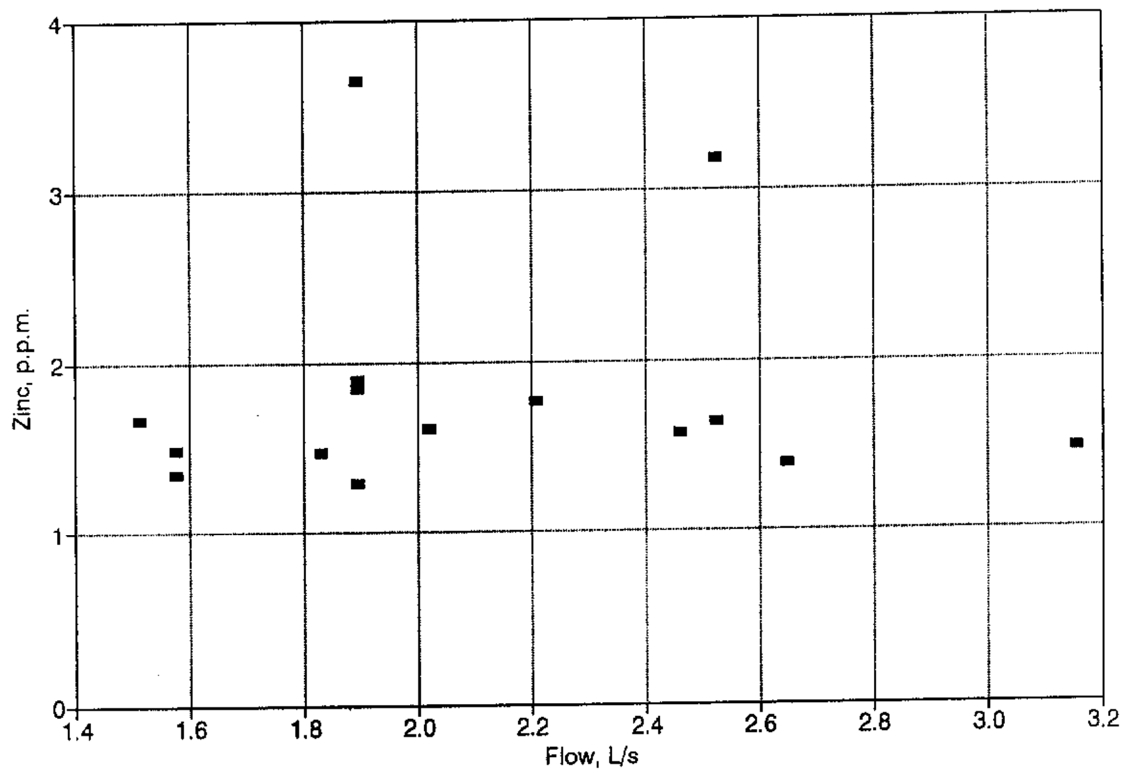


Fig. 8b: VALLEY SOUTH, VS-2
[Zn] versus LS Waterlevel

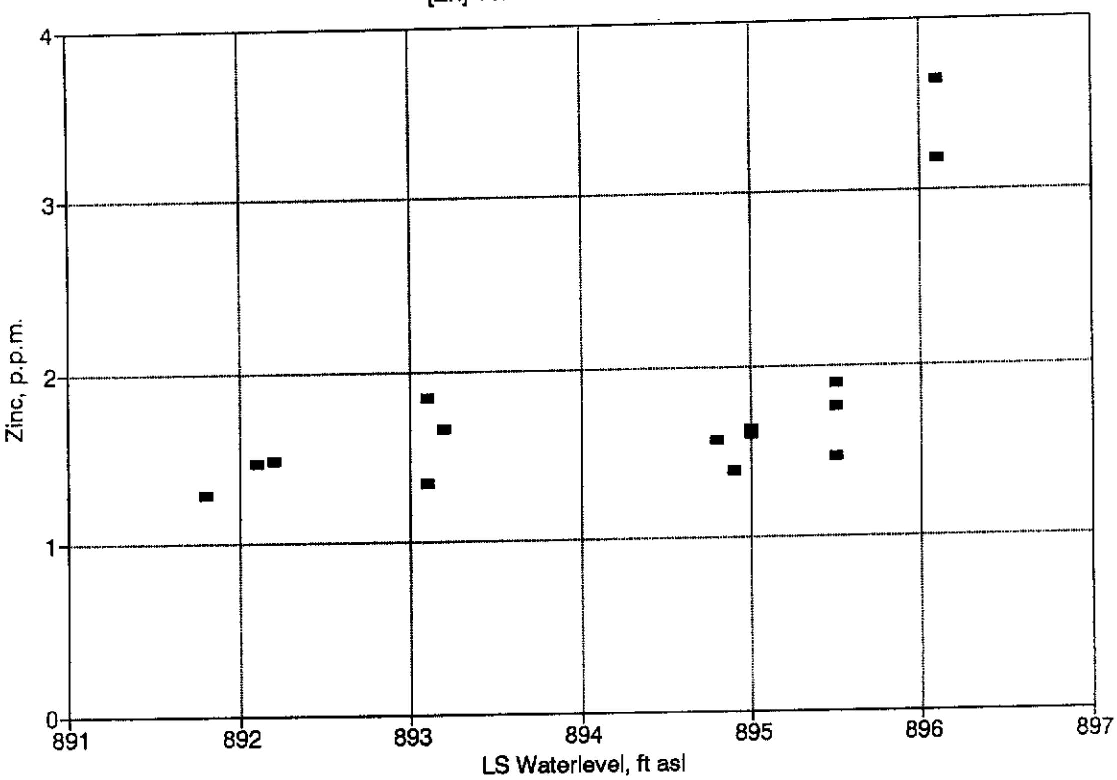


Fig. 8c: VALLEY SOUTH, VS-2
Flow versus LS Waterlevel

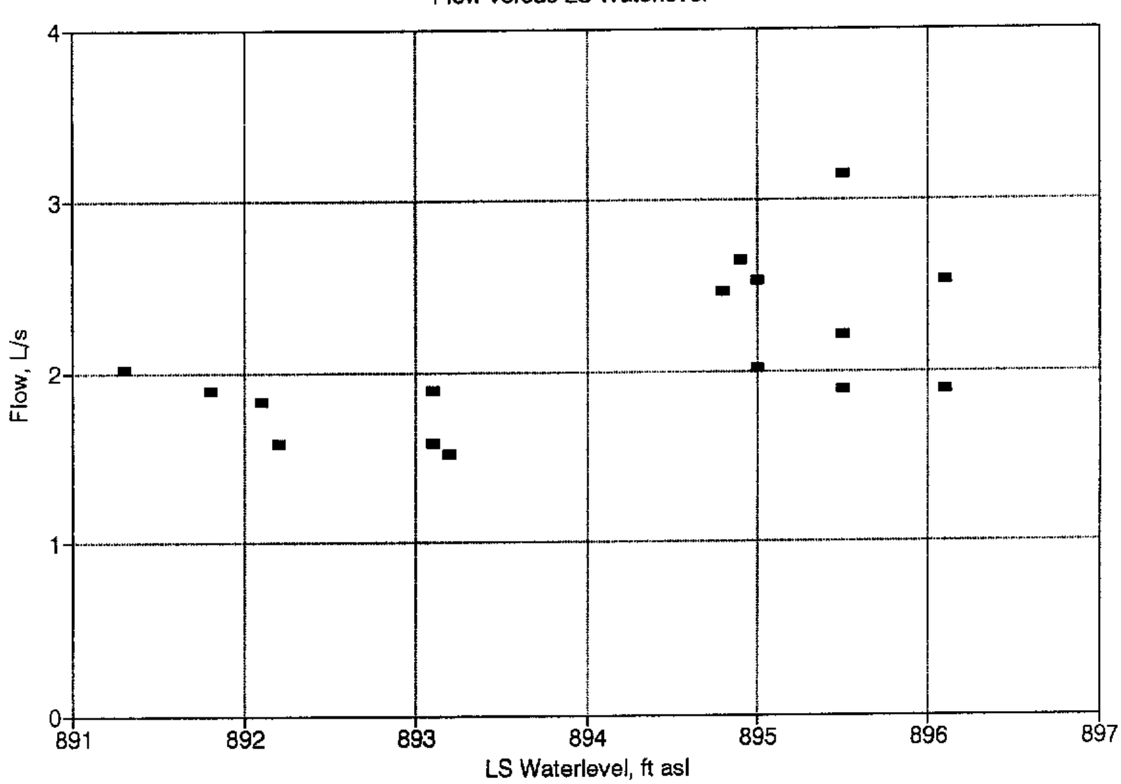


Fig. 9: VALLEY SOUTH, VS-3
[Zn] and Flow versus Time

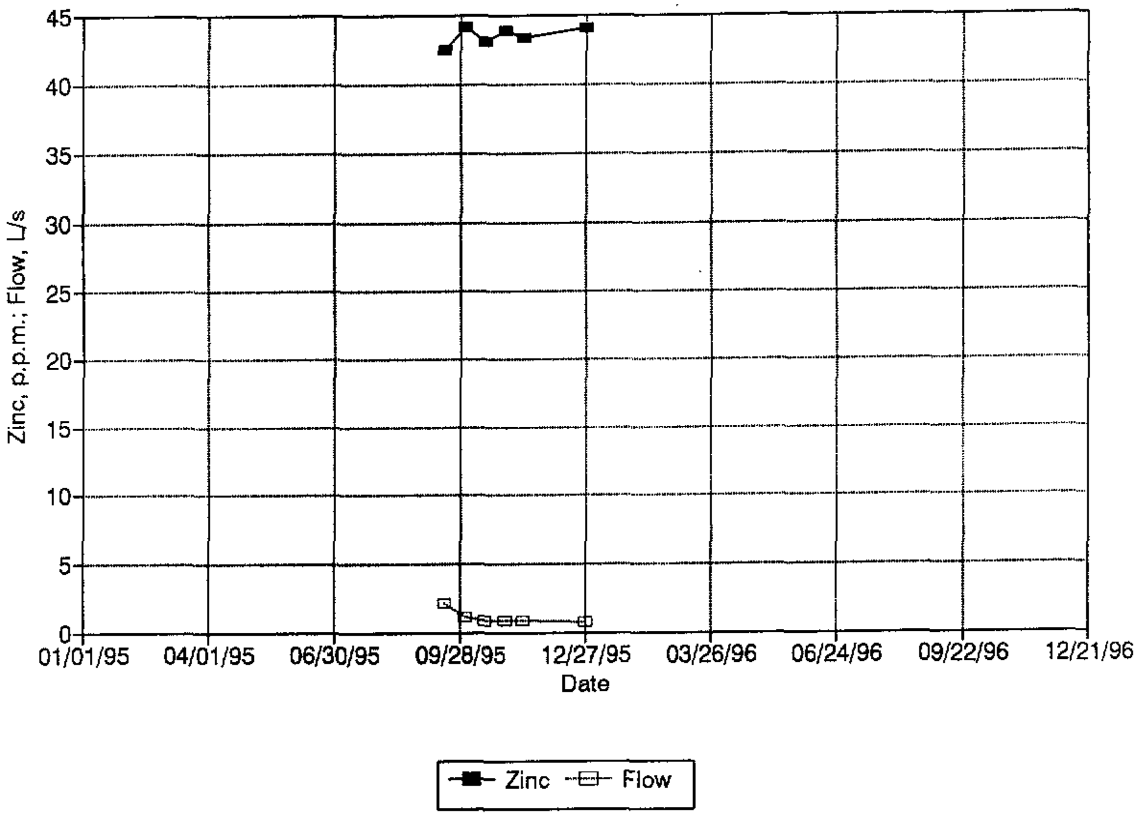
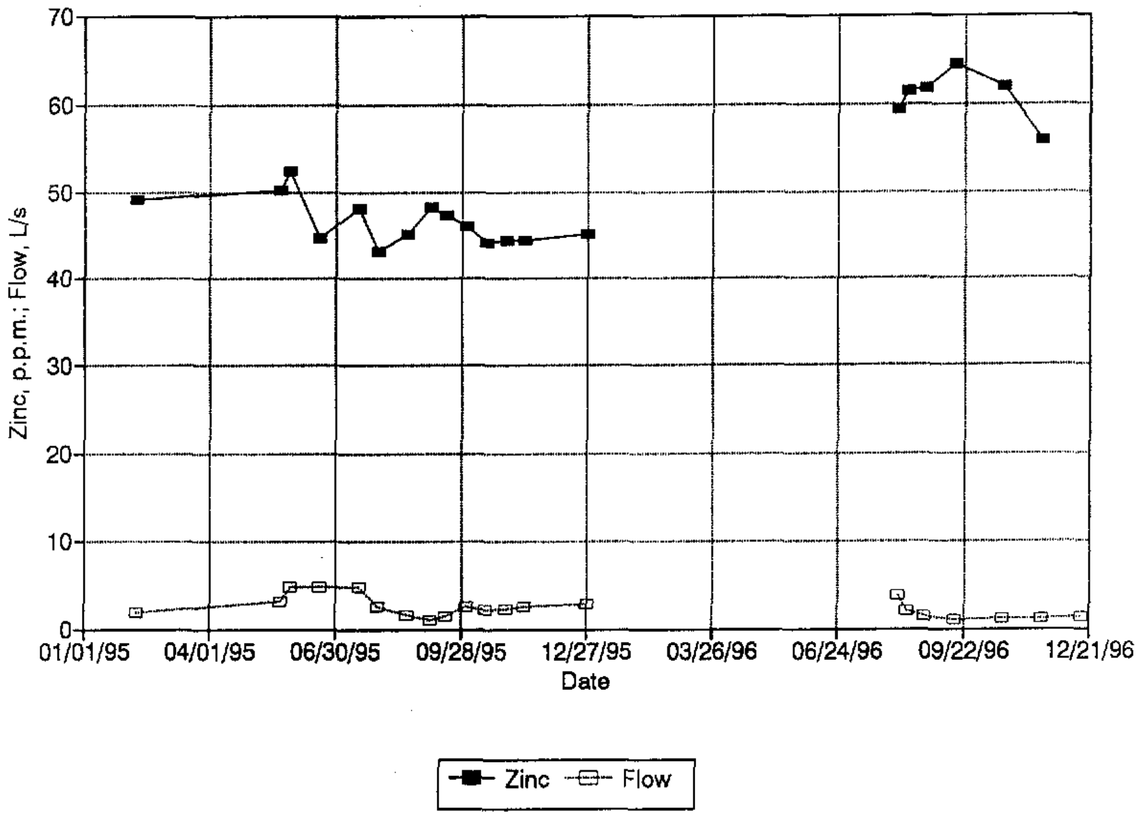


Fig. 10: VALLEY SOUTH, VS-4
[Zn] and Flow versus Time



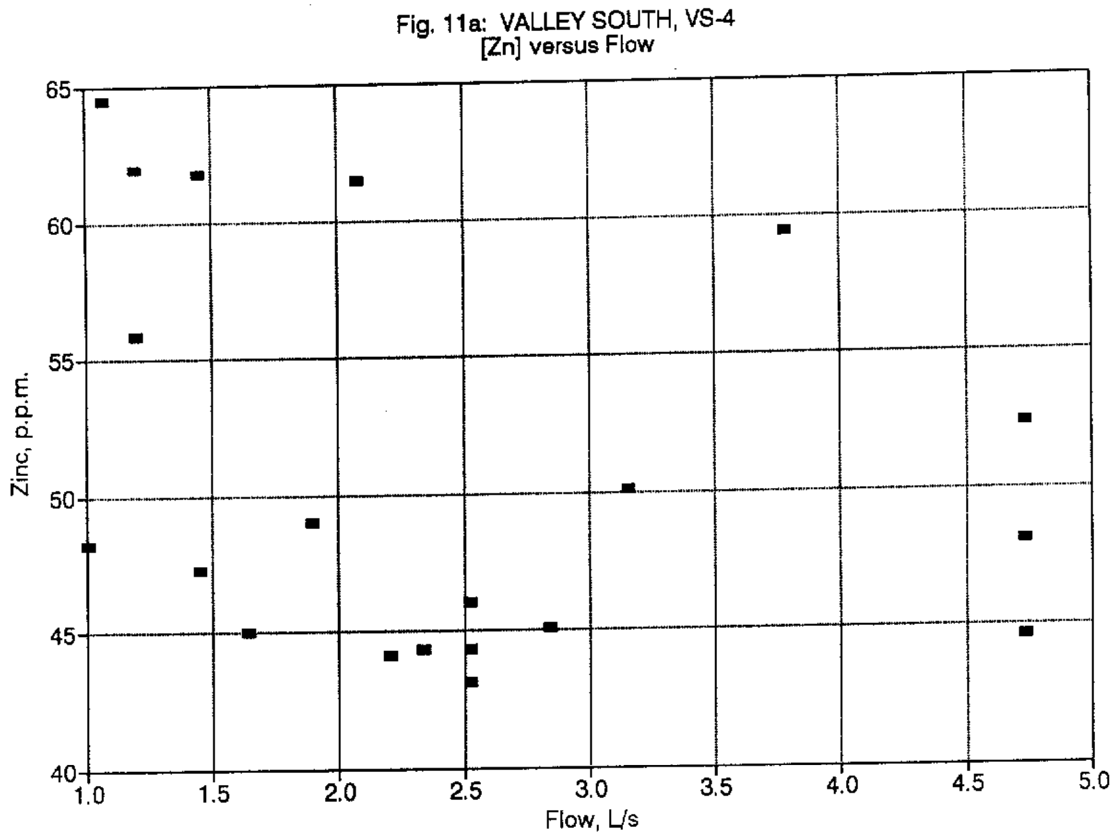


Fig. 11a: VALLEY SOUTH, VS-4
[Zn] versus Flow
Zinc, p.p.m.
65
60
55
50
45
40
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Flow, L/s

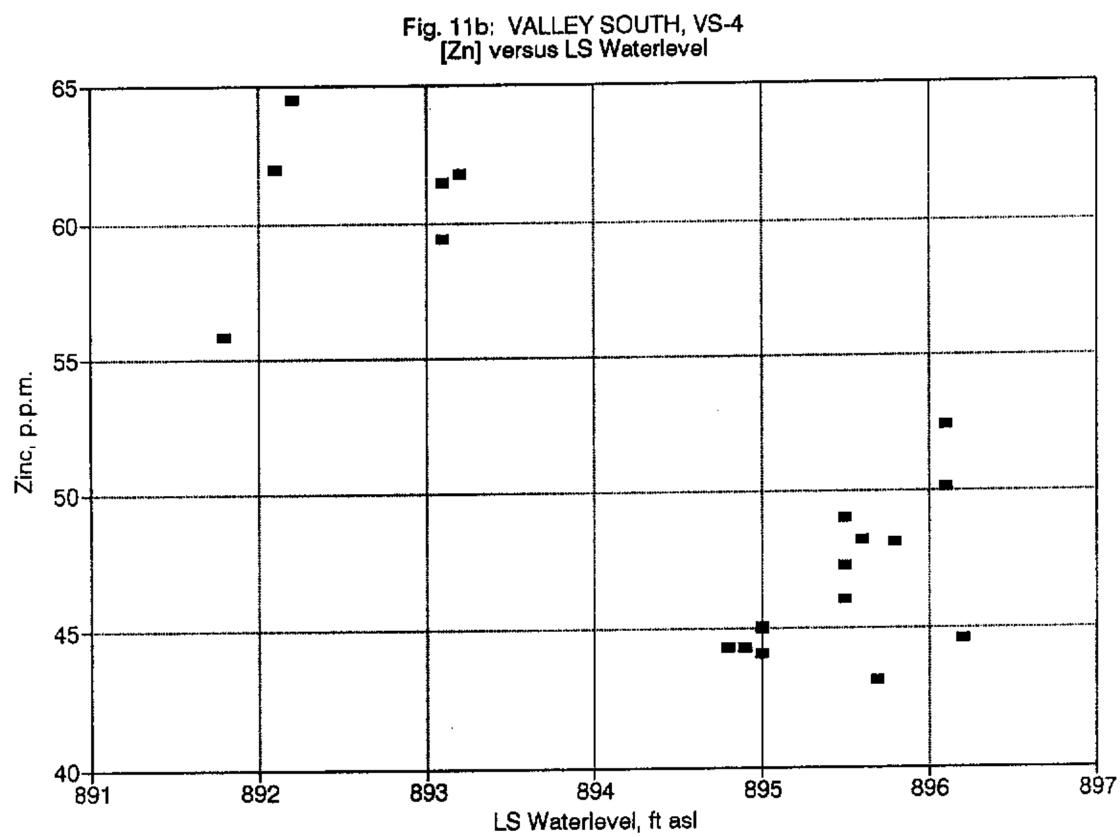


Fig. 11b: VALLEY SOUTH, VS-4
[Zn] versus LS Waterlevel
Zinc, p.p.m.
65
60
55
50
45
40
891
892
893
894
895
896
897
LS Waterlevel, ft asl

Fig. 11c: VALLEY SOUTH, VS-4
Flow versus LS Waterlevel

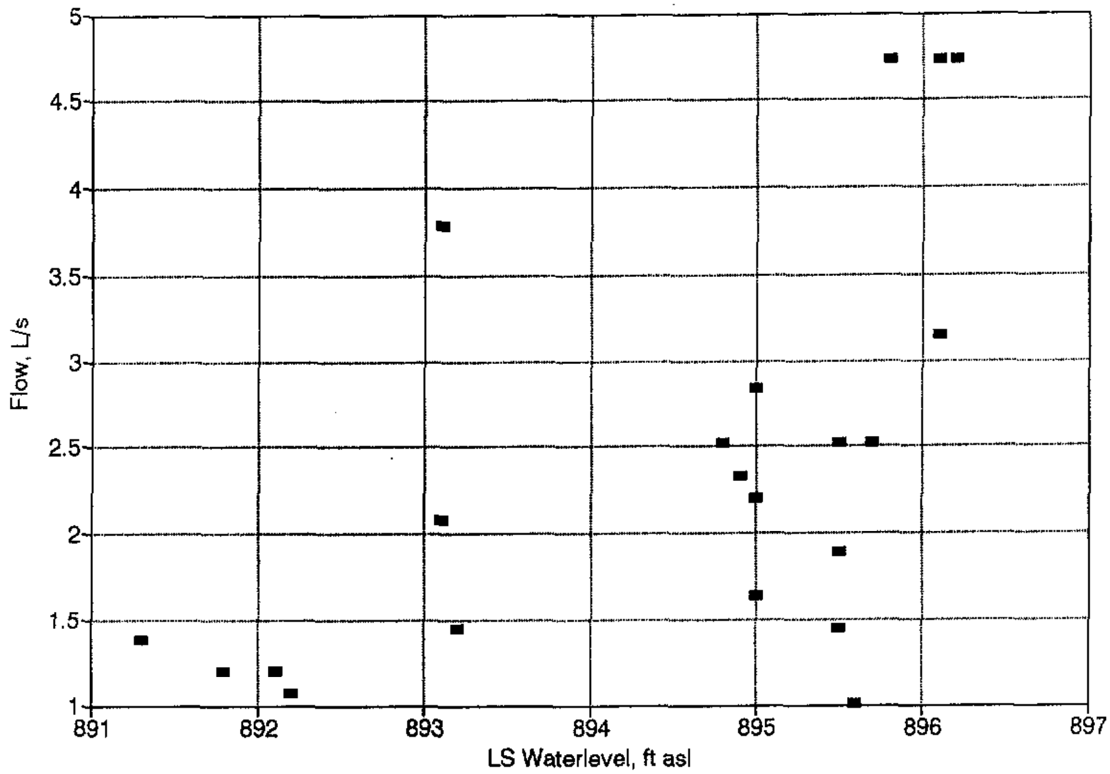


Fig. 12: VALLEY SOUTH, VS-5
[Zn] and Flow versus Time

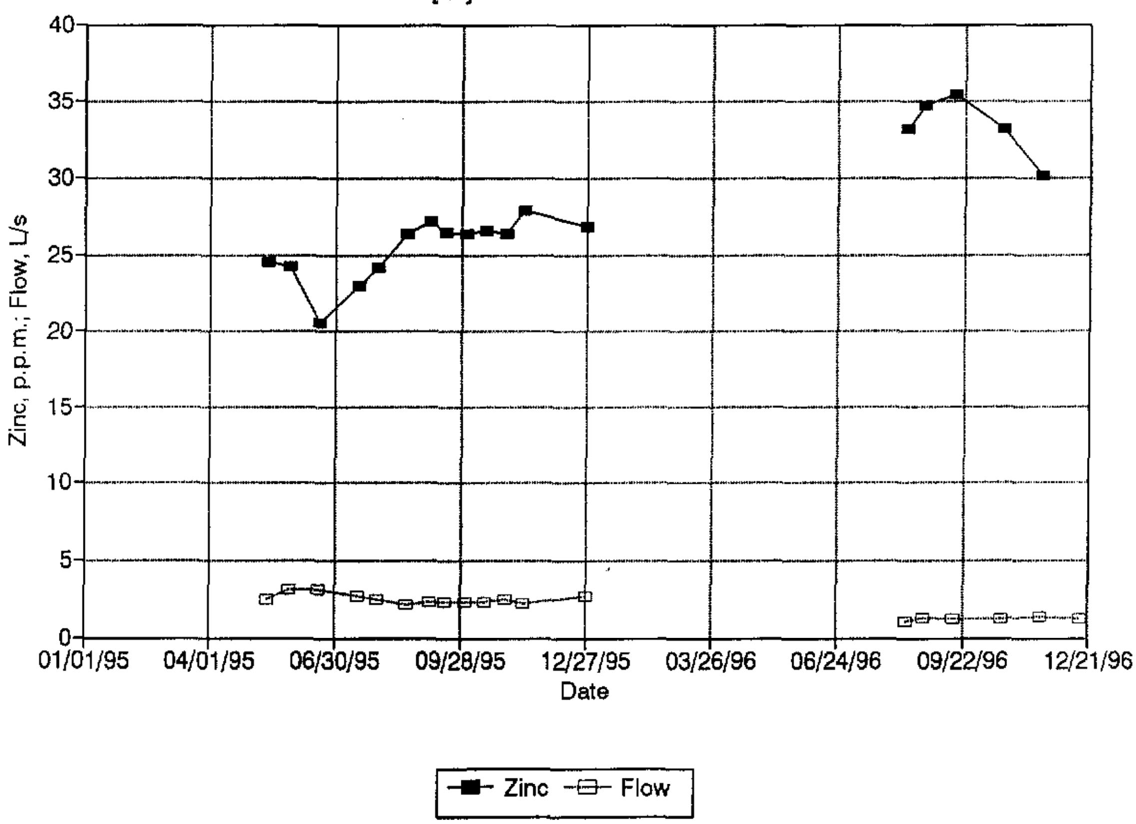


Fig. 13a: VALLEY SOUTH, VS-5
[Zn] versus Flow

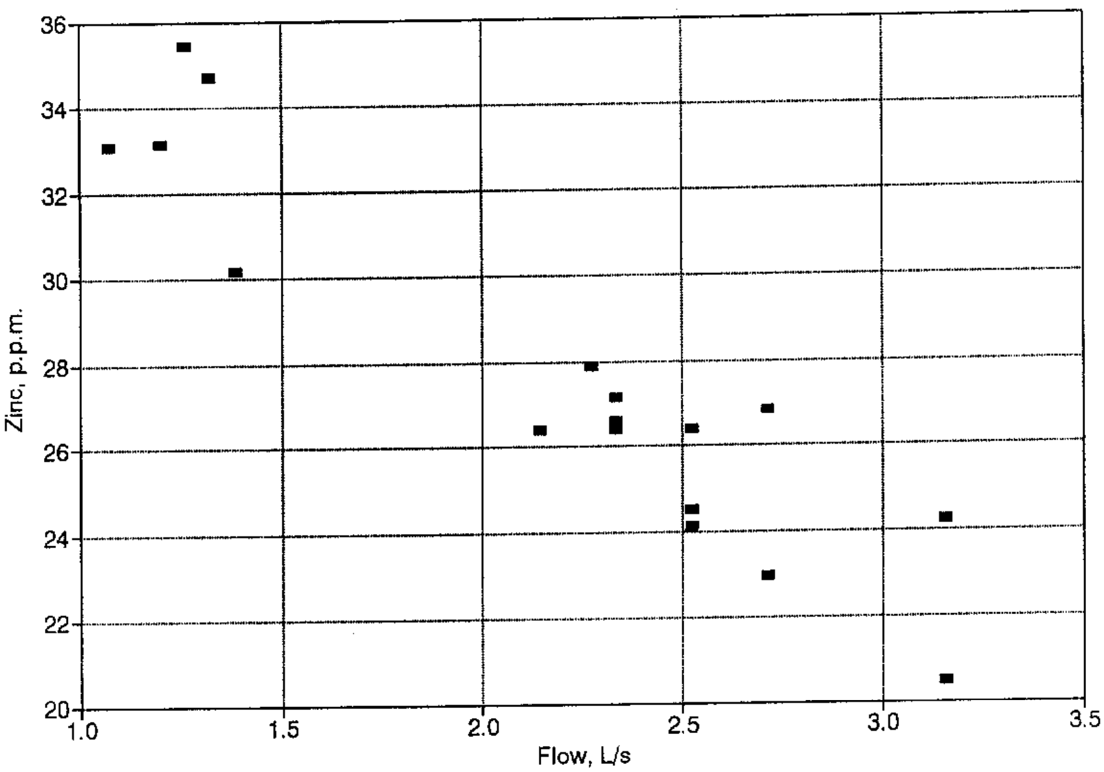


Fig. 13b: VALLEY SOUTH, VS-5
[Zn] versus LS Waterlevel

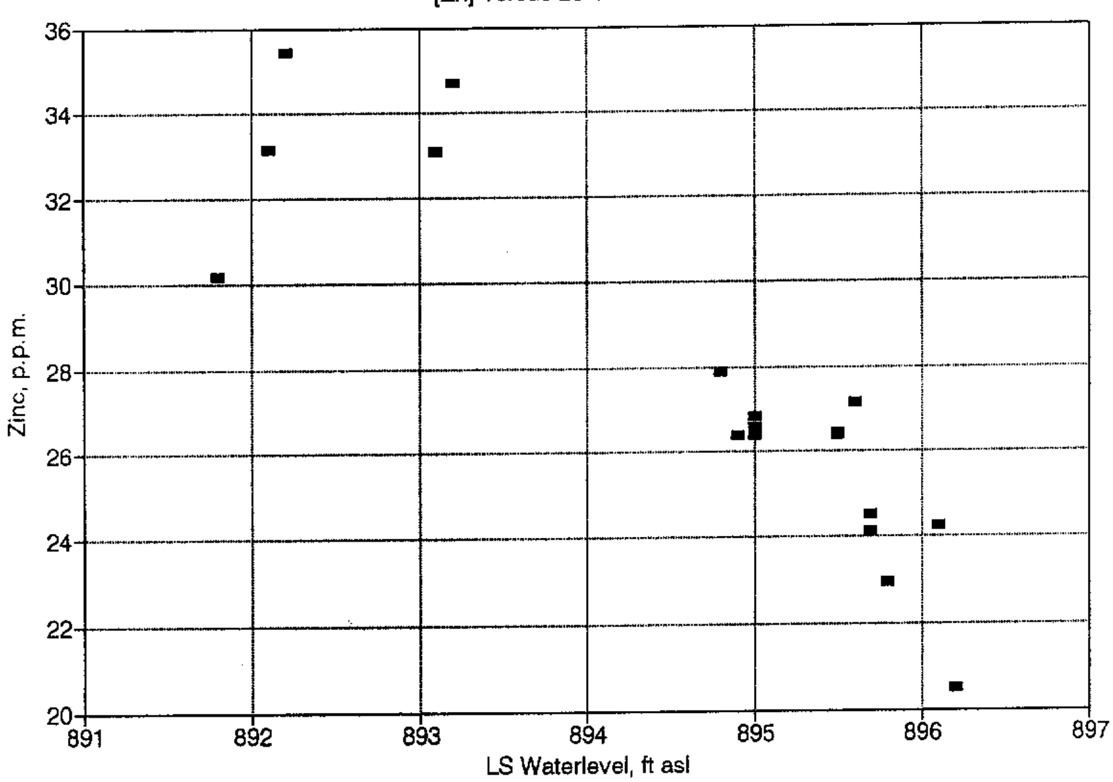


Fig. 13c: VALLEY SOUTH, VS-5
Flow versus LS Waterlevel

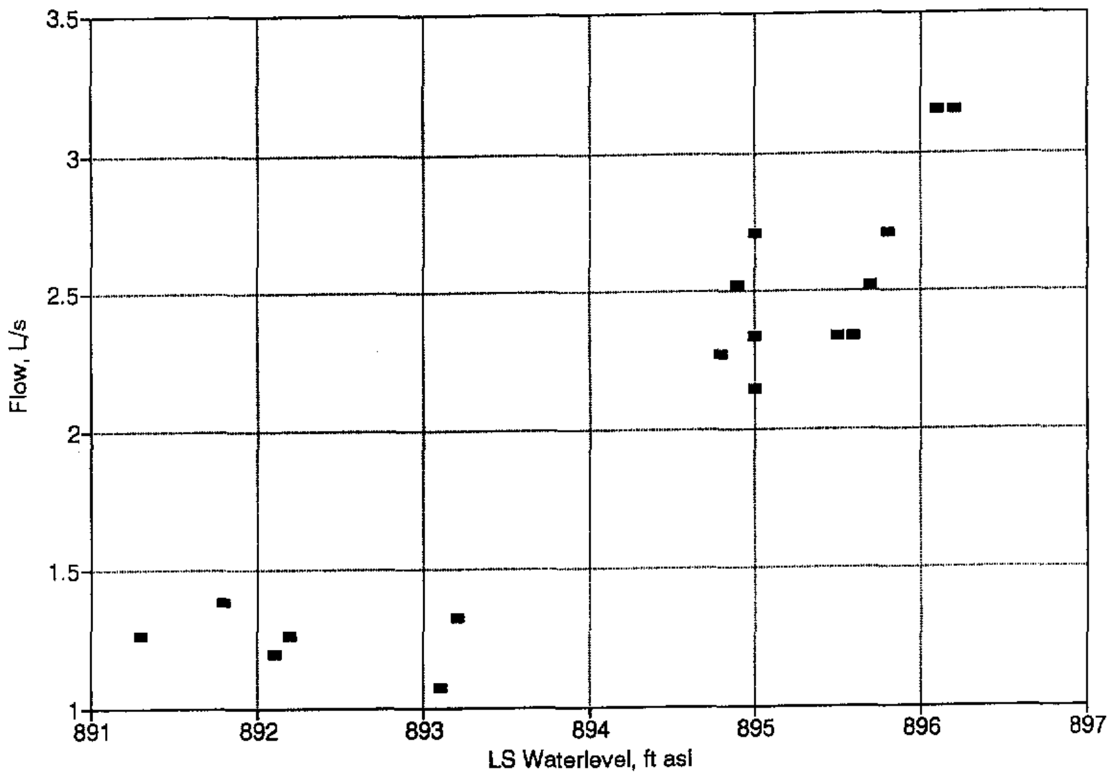


Fig. 14: VALLEY SOUTH, VS-6
[Zn] and Flow versus Time

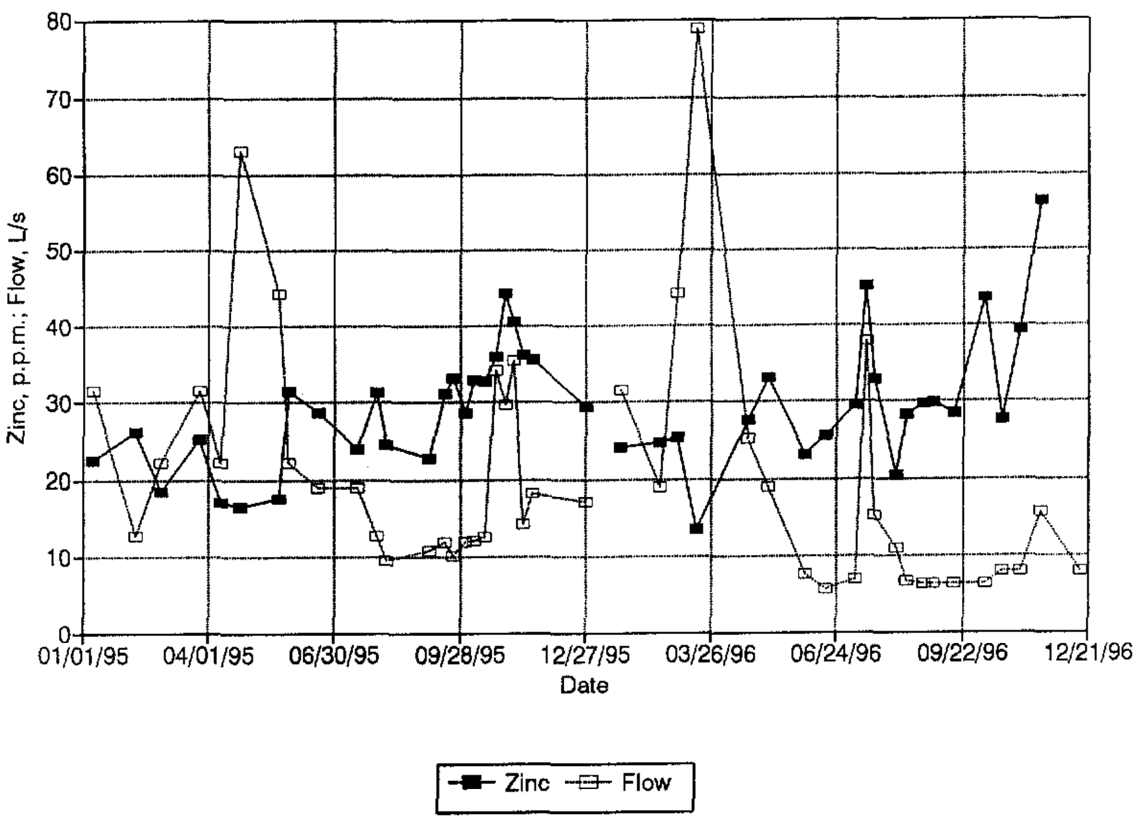


Fig. 15a: VALLEY SOUTH, VS-6
[Zn] versus Flow

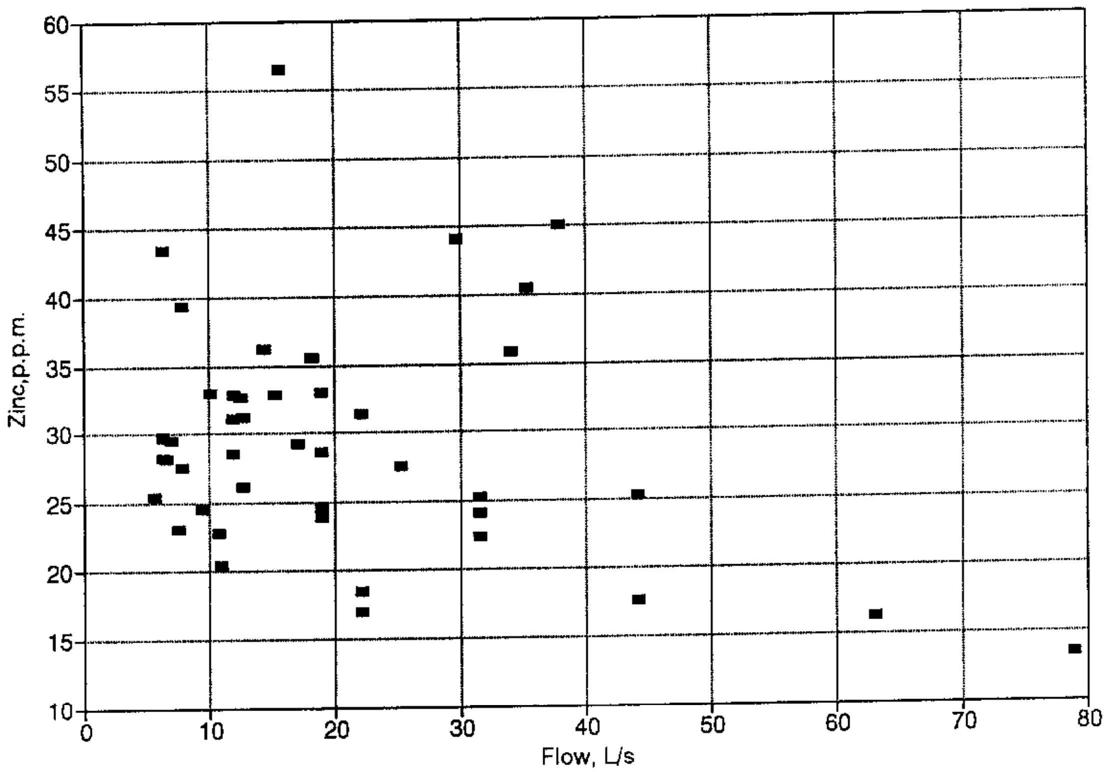


Fig. 15b: VALLEY SOUTH, VS-6
[Zn] versus LS Waterlevel

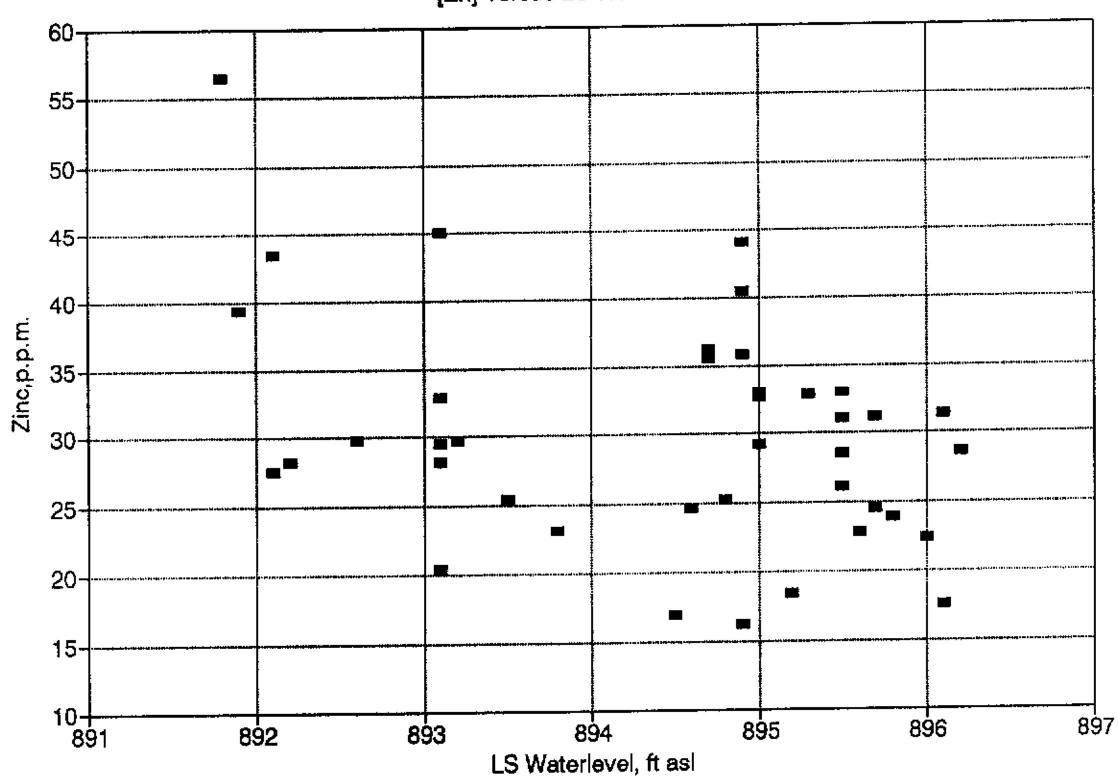


Fig. 15c: VALLEY SOUTH, VS-6
Flow versus LS Waterlevel

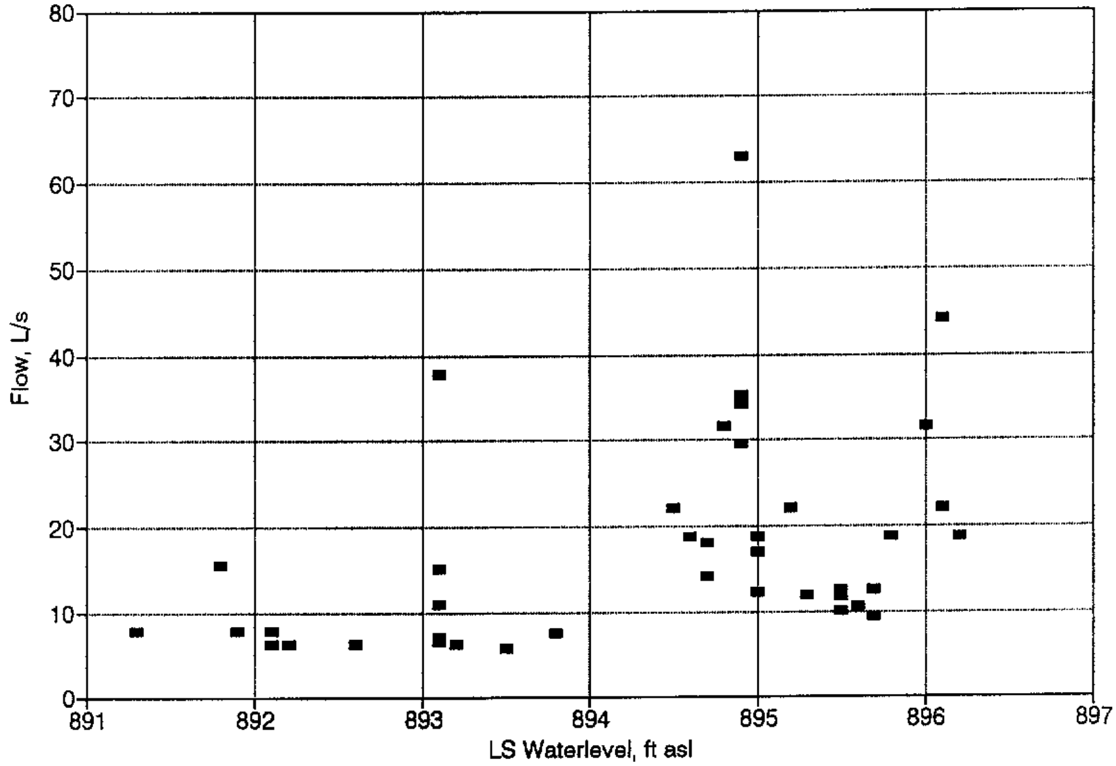


Fig. 16: VALLEY SOUTH
Zinc Concentration versus Time

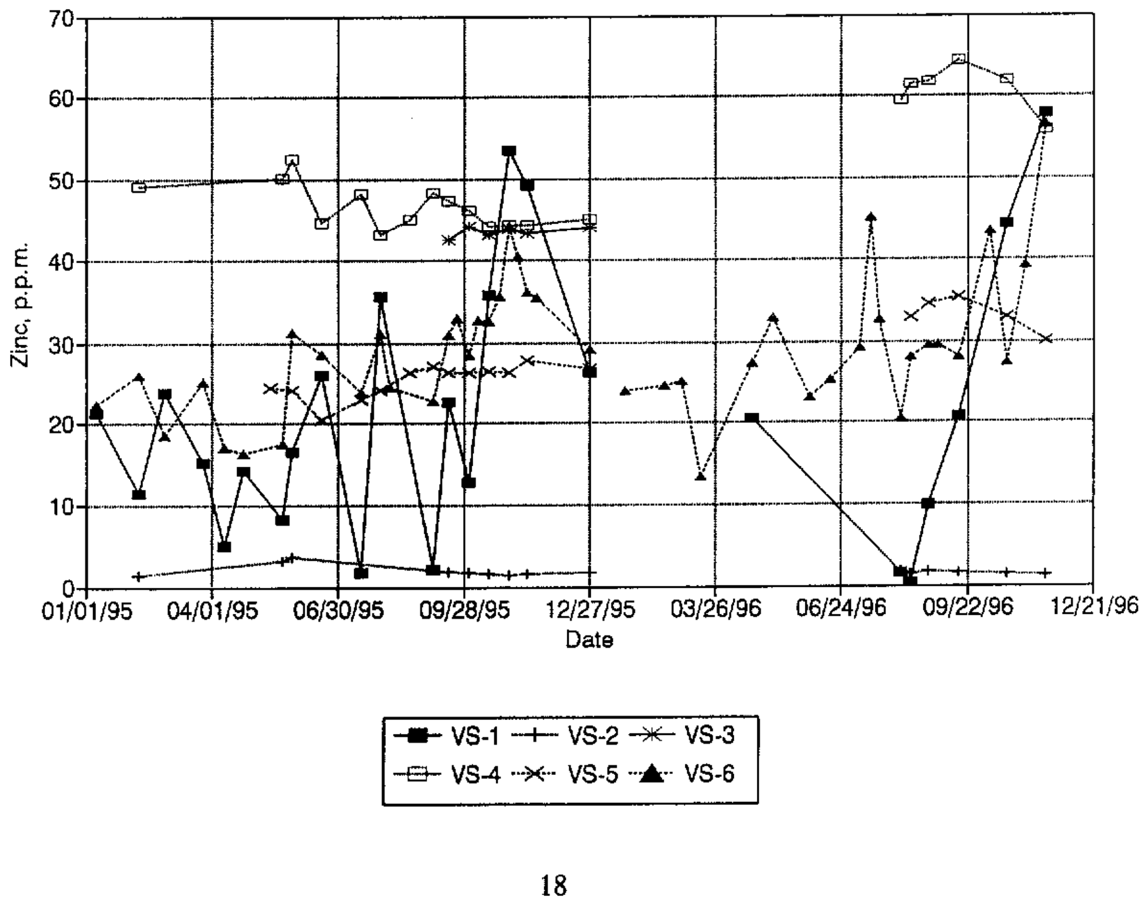


Fig. 17: LSP, DT and VALLEY S. SEEPS
Concent. of Selected Elem., May 28,95

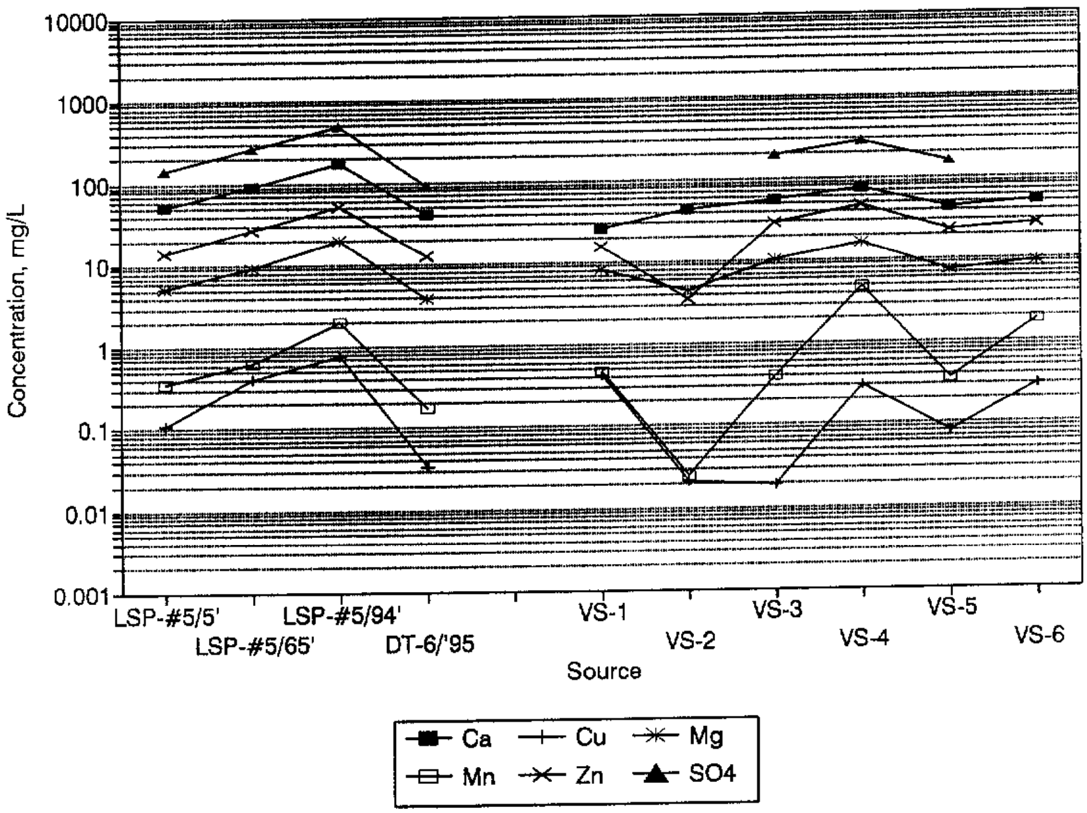


Fig. 18: LSP, DT and VALLEY S. SEEPS
Concent. of Selected Elem., Aug 13,96

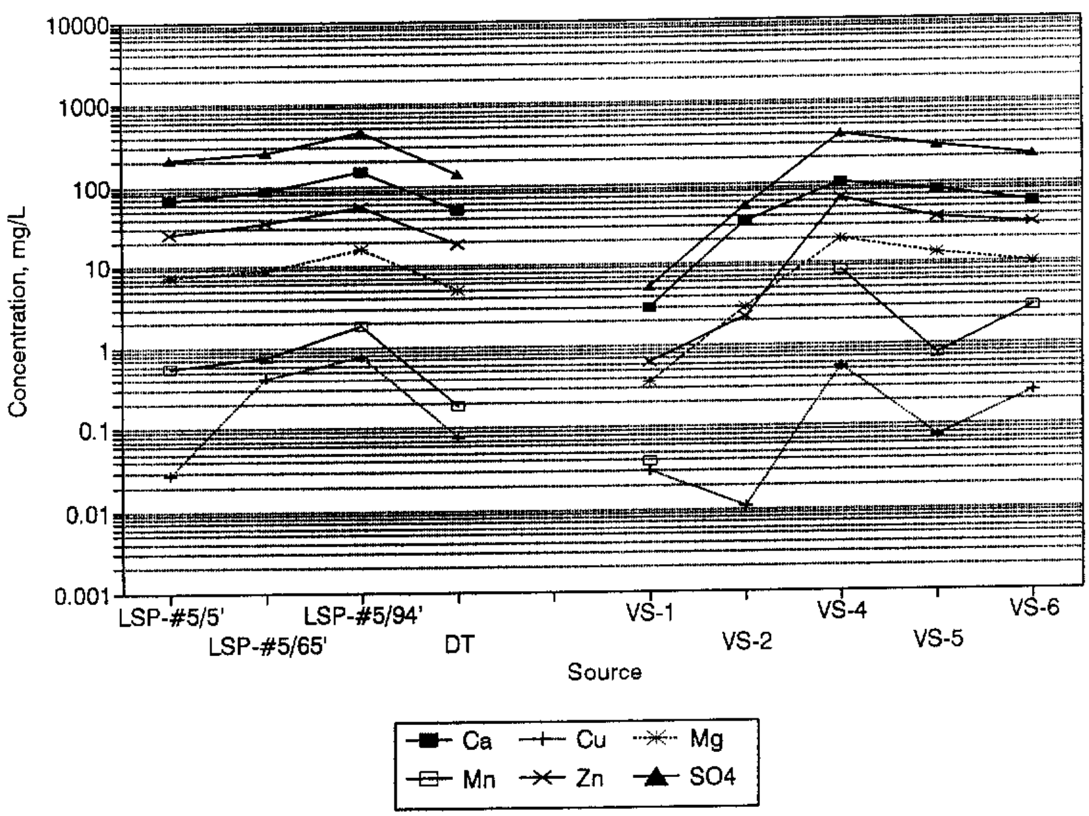


Fig. 19: VALLEY WEST, VW-1
[Zn] and Flow versus Time

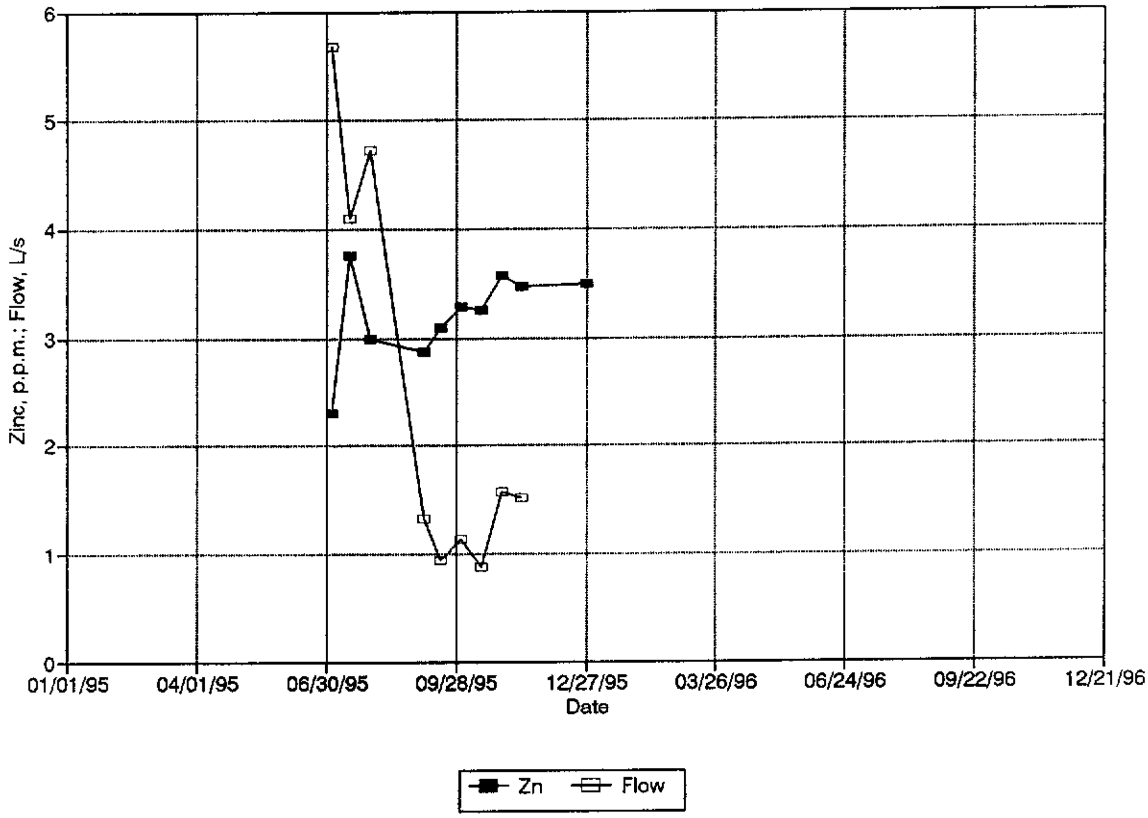


Fig. 20: VALLEY WEST, VW-2
[Zn] and Flow versus Time

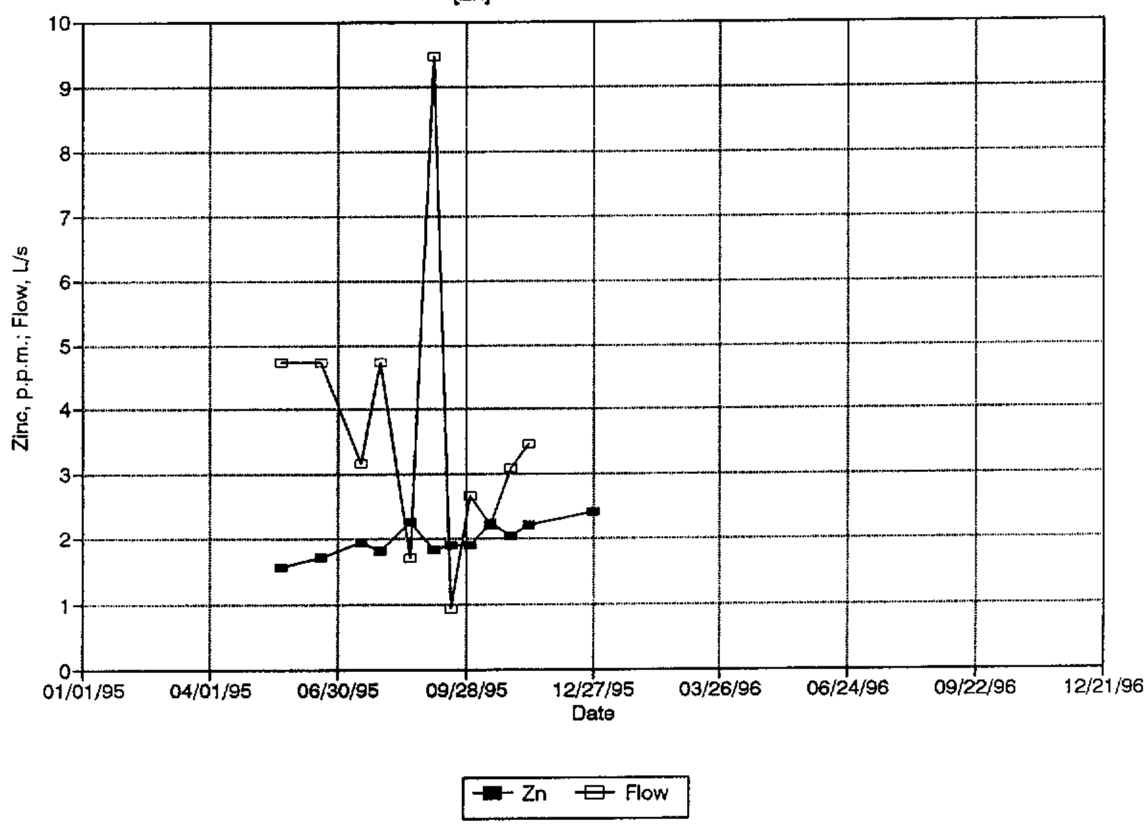


Fig. 21: VALLEY WEST, VW-3
[Zn] and Flow versus Time

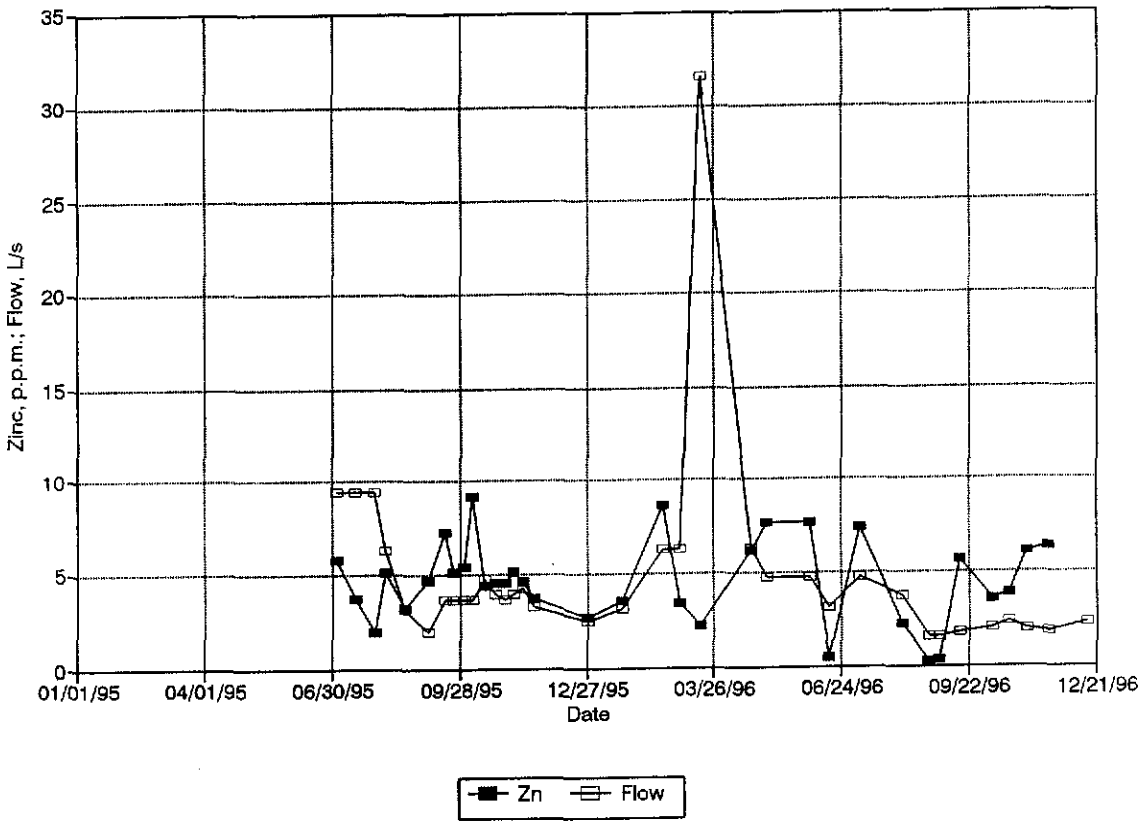


Fig. 22a: VALLEY WEST, VW-3
[Zn] versus Flow

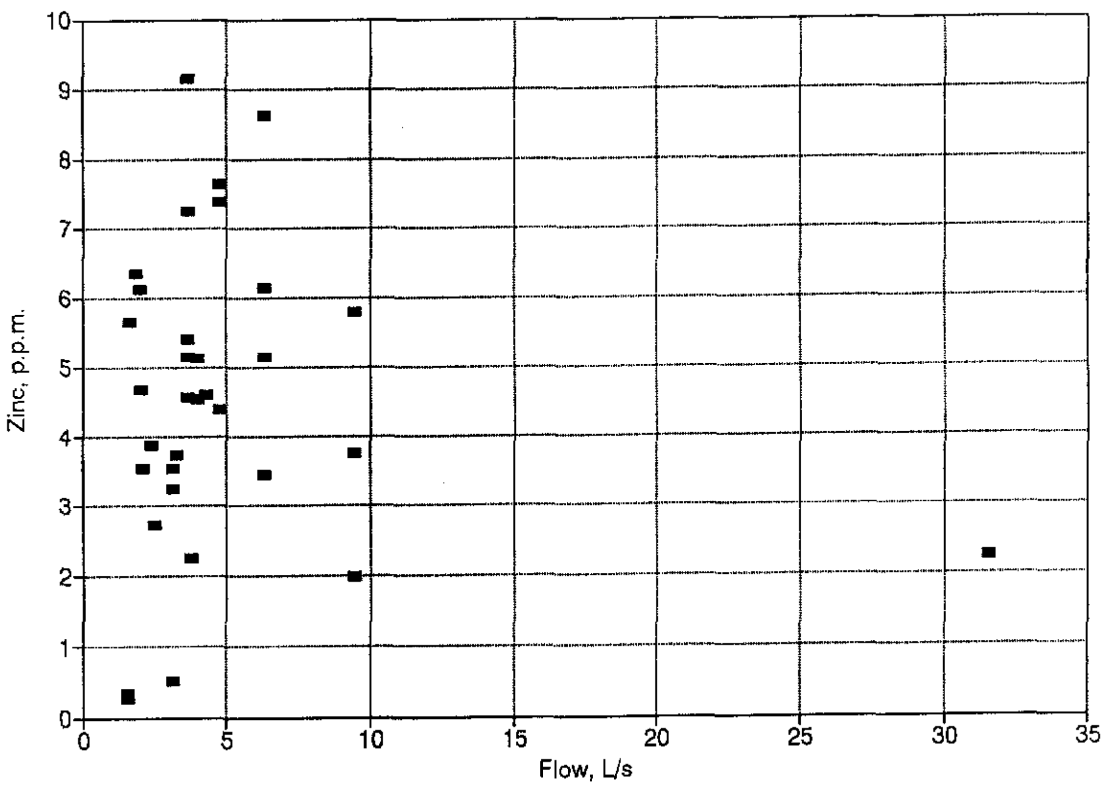


Fig. 22b: VALLEY WEST, VW-3
[Zn] versus LS Waterlevel

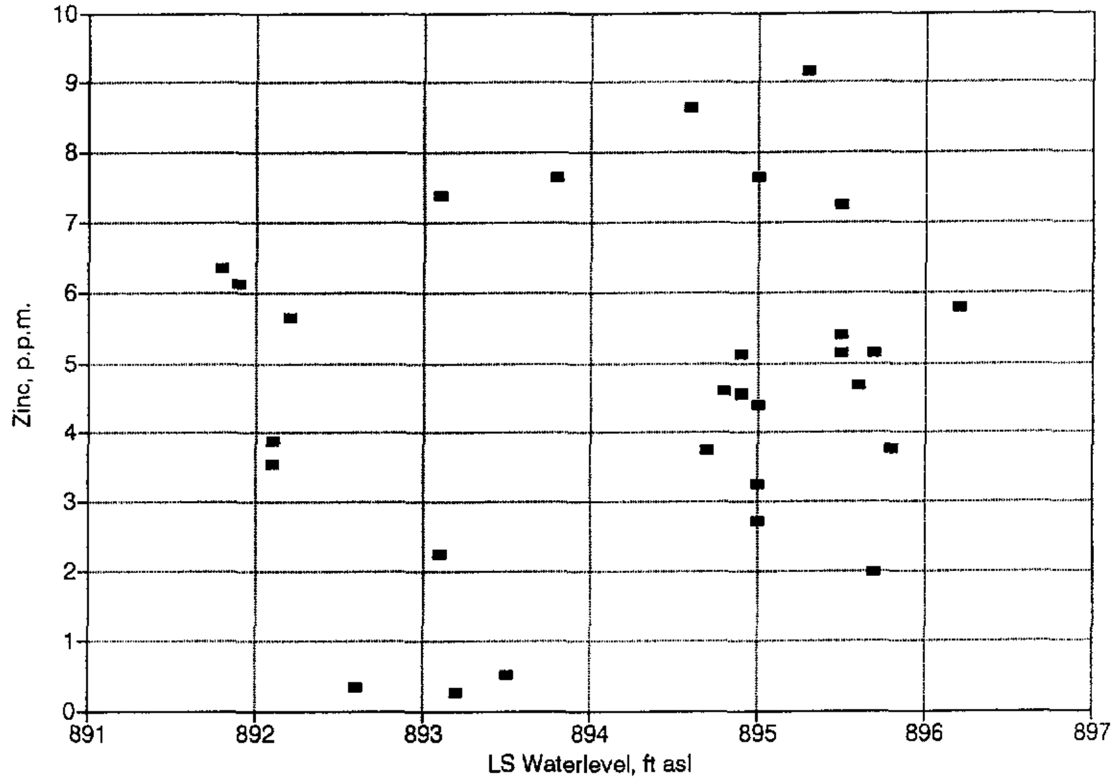


Fig. 22c: VALLEY WEST, VW-3
Flow versus LS Waterlevel

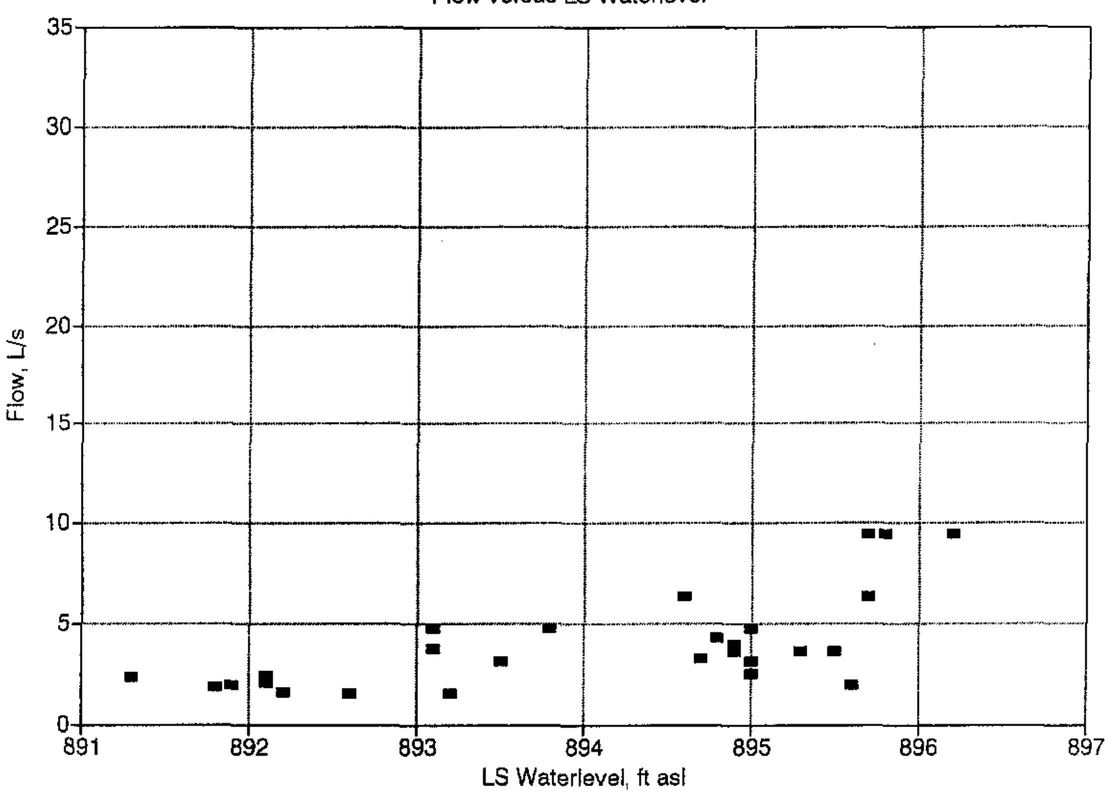
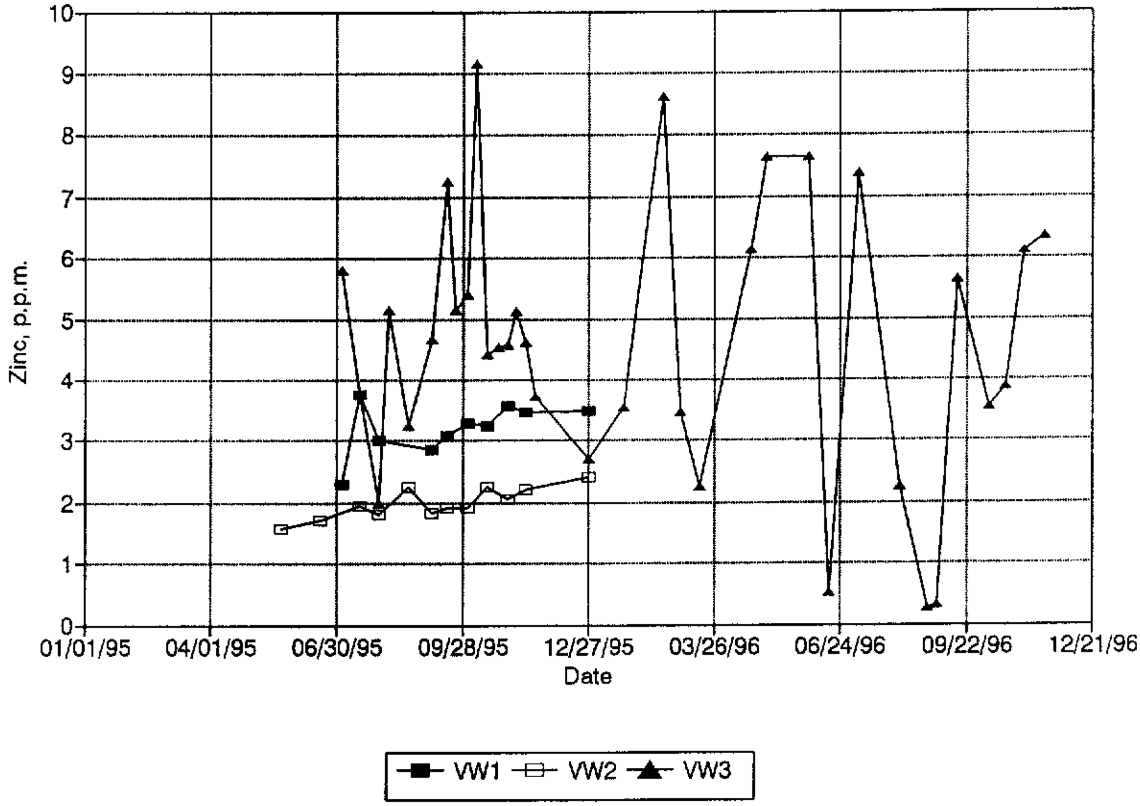


Fig. 23: VALLEY WEST
Zinc Concentration versus Time



Valley Seepages at Buchans

Dr. Jan Gerits
University of Toronto
(January 1997)

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1.0 INTRODUCTION

After termination of the mining activities at Buchans in 1984, the mine workings were flooded. This resulted in a rise of the water levels in the Lucky Strike (LS), the Oriental West (OWP) and the Oriental East (OEP) pits. Initially the discharge from the Drainage Tunnel (DT) showed an increase with the rise of the water level in the Lucky Strike pit. After installation of a concrete plug in the Drainage Tunnel (1988) the discharge dropped to about 80% of the discharge before the installation of the plug. Pumping of the discharge from the Drainage Tunnel (DT) to the Oriental West pit (OWP) started on September 27, 1994. During the period between August 2, 1992 and November 18, 1994 water from Tailings Pond #1 (TP1) was siphoned into the Lucky Strike pit. This caused a rapid rise of the water level in the Lucky Strike pit which finally approached a more 'natural' elevation (approx. 272.5 m) in July 1995. Associated with the flooding of the mine workings are a number seepages occurring East of the Lucky Strike pit. These seepages are the focus of this study.

At present it is not clear if the seepages and their associated Zn loadings to the Buchans River, are *mainly* caused by flooding the Lucky Strike pit or if they are due to a *combination* of several factors, including changes in groundwater table elevations and groundwater flow patterns associated with the local geologic structure and aquifer characteristics. To investigate the origin or the source of the seepages, a separate hydrological and geochemical approach were chosen. This report represents the geochemical study approach.

Since the beginning of 1995, discharge, pH, conductivity and Zn concentrations of several seepages (map location and elevation) have been monitored periodically (G.N. Neary). Three of the seepages occur in the sandfill deposits, NE of the Lucky Strike pit: **VW1** (N6600'/E7800', 252.7 m), the combined sandpit seeps; **VW2** (N6550'/E8150', 239.6 m), the seepage from the bank near the DT pumphouse; **VW3** (N6650'/E8300', 239.6 m), the total drainage from the West discharging into the Buchans River.

Three other, isolated seepages occur SE of the Drainage Tunnel, at the bank close to the "swimming pool" road, S of the DT pumphouse: **VS4** (N6193'/E8080', 248.1 m), the combined upper seeps; **VS5** (N6400'/E8200', 243.8 m), the combined lower seeps; **VS4-5**, between VS4 and VS5, 220' S of the DT pumphouse. Seepage from the area E of the Mucky Ditch and the "swimming pool" road is sampled at **VS2** (N6166'/E8246', 249.6 m) at a pipe near the swimming pool pump box.

The discharge from the Mucky Ditch is measured at **VS1** (N6070'/E8130', 255.7 m). The total drainage from the South is sampled at **VS6** (N6448'/E8551', 239.0 m), downstream from VS1 in the Mucky Ditch near Buchans River.

In addition to monitoring the valley seepages, water levels have been measured frequently (G.N. Neary) in the Lucky Strike pit and in several drill holes (DH) close to the flooded Lucky Strike pit: **DH #3325** (N4750'/E5500', 239.0 m); **DH #3341** (N5765'/E4500', 284.1 m); **DH #3342** (N6250'/E4500', 286.8 m); **DH #3343** (N7500'/E4500', 289.9 m) and **DH #3344** (N5270'/E3000', 281.3 m).

2.0 MONITORING DATA

2.1 Hydrology

A comparison between the water levels in several drill holes and the water levels in the LS pit is shown in Fig. 1 for the period between April 4, 1995 and September 23, 1996. The groundwater elevations in the drill holes increase linearly with the rise of the water level in the LS pit. This linear correlation appears to be better for DH #3325 compared to the other drill holes for which the data show considerably more variation. Considering this variation in data it is difficult to attribute any significance to differences in the slope of the linear correlation between water levels in the LS pit and the drill holes. Drill holes #3341, #3342 and #3343 are located at an increasing distance, N from the LS pit. Drill hole #3325 (SE) is located at a larger distance from the LS pit than drill hole #3341 (N). Apparently there is no simple relation between groundwater elevation and distance from the LS pit. Groundwater elevations in the drill holes are always higher than the water levels in the LS pit.

Daily precipitation at Buchans (Environment Canada) and water levels in the drill holes and the LS pit are plotted in Figs. 2A (rainfall) and 2B (rainfall + snowfall) for the period between January 1, 1995 and November 1, 1996. As expected, there exists no clear relation between the precipitation record and the fluctuations of the water levels in the drill holes and the LS pit. Even snowmelt runoff does not appear to have a significant effect on the water levels in the drill holes and LS pit.

Similar to Figs. 2A and 2B, daily precipitation and periodically measured discharge rates (Q) from seepages are shown in Figs. 3A and 3B (VW1 and VW2), Figs. 4A and 4B (VS2 and VS4) and Figs. 5A and 5B (VS4 and VS5). Despite the short monitoring period, the discharge from seepages in the sandfill deposits (Figs. 3) shows a rapid response to the daily precipitation. This close relation between precipitation and seepage rate (Q) may be attributed to the porous nature of the overburden. The discharge rates of the other seepages (Figs. 4 and Figs. 5) do not appear to be closely related to the daily precipitation record, even if one assumes a lag time in seepage response. A better relation, notably for VS4 in 1995, appears to exist between seepage rate and snowmelt runoff. However, this relation is less clear for the other seepages (VS2 and VS5) and during 1996. Obviously, the distinction of a pattern in seepage rate, related to precipitation and snowmelt events, also depends on the monitoring intensity of the seepages.

Seepage rates (Q) and water levels in the drill holes and the LS pit is shown in Figs. 6A-E. From these figures it is evident that changes in seepage rates are much larger and more frequent than fluctuations in water levels. There appears to be no relation between water levels and seepage rates.

The absence of *any* relation between seepage rates and water levels in the drill holes and the LS pit (Figs. 6) suggests that the seepages are largely fed by meteoric water (rainfall and snowmelt) rather than phreatic water. A somewhat better relation, although not evident at all seeps, exists between seepage rates and precipitation or snowmelt runoff (Figs. 3-5). The absence of a clear relation may be caused by a low monitoring intensity or differences in catchment size of the seeps. Presently, phreatic water (drill holes) seems to be the major source of the water in the LS pit.

2.2 Chemistry

The Zn concentrations in the seepages which discharge into the Buchans River, are of major concern. The Zn concentrations in several seepages are shown in Fig. 7. Excluding the sites where total drainage is collected (VW3, VS1 and VS6), the highest Zn concentrations occur in seepages at VS4 (40-70 ppm) and VS5 (20-40 ppm). The lowest Zn concentrations (1-5 ppb) occur in the seepages from the sandfill deposits (VW1 and VW2). The temporal variation in Zn loadings at site VS4 (Fig. 8) appears to be more pronounced but similar to the temporal variation in seepage rates (Figs. 5). The contrary applies to the temporal variation in Zn loadings at site VS5. This can be attributed to a dilution effect: the Zn concentrations in seepage at VS5 decline with increasing seepage rates (Fig. 9). The data of site VS4 show a considerable scatter and no correlation between Zn concentration and seepage rate. At all seepage sites, Zn loading increases linearly with seepage rate (Fig. 10). The rate of increase is largest for site VS4 and lowest for sites VS2, VW1 and VW2. This suggests that all seepage sites have a constant Zn source but the contribution of that (same) source varies among the different seepage sites. The contribution of the Zn source to the seepages is largest at site VS4 (approx. 50 mg Zn per lt seepage).

The seepages could originate from the LS pit, phreatic or meteoric water. Based on the hydrological data discussed previously, meteoric water would be the major source of the seepages. Meteoric water would acquire Zn by reaction with waste rock or local ore deposits in the vadose zone. Larger contributions of meteoric water would produce larger seepage rates and aquire more Zn (increased weathering rates ?) and result in larger Zn loadings (e.g. Fig. 10). A similar scenario could also apply to water from the LS pit and the drill holes (phreatic water) or mixtures of different waters. However, with the available hydrological and chemical monitoring data it is very difficult to determine the sources of the seepages. One approach to determine the sources of the seepages is to derive the chemical composition of the seepages by geochemical modelling using different potential sources of water in contact with the bedrock or overburden. This approach is demonstrated below.

3.0 GEOCHEMISTRY

3.1 Water Analyses and Mineralogy

Chemical analyses of selected water samples from drill holes, seepage sites, LS pit, DT, rain and the Sandfill Spring (SS) are listed in Tables 1 and 2. Except for the Sandfill Spring and rainwater, the analyses in Table 1 apply to samples collected in 1995 and 1996. The chemical analysis of rainwater (NW Atlantic) was taken from Table 3.1 in Berner and Berner (1996). The analyses of water samples from the drill holes (Table 2) date from 1991 and were published in a previous report (December 1991). Water samples from the LS pit were taken at three different depths (5, 65 and 94 feet). The following discussion of the chemical data from Tables 1 and 2 will be concentrated on water samples from DH #2243a (closest balance of cations and anions), VS4, VS4-5 and VS5 (most representative seepages), LS, DT and rain.

Except for the water samples from the LS pit (LS5 and LS65) and DH #3342a, the concentration of chloride in rainwater (salt spray) is smaller than that in the other samples (LS94, DT, VS4, VS5 and VS4-5). Assuming that chloride behaves conservatively, this implies that only groundwater (DH #3342a) and water from the upper part of the LS pit can be derived from the reaction of rainwater (meteoric) with bedrock, ore deposit or overburden. The formation of all other waters from meteoric water requires *additional* evaporative concentration (of rainwater) to attain higher Cl concentrations since Cl containing minerals (e.g. halite) do not occur in the geologic formations and overburden at Buchans (Swanson et al., 1981). The same applies to the formation of seepage waters from water of the LS pit (LS5 or LS65) and groundwater (DH #3342a). Concentration of meteoric water or a mixture of phreatic and meteoric water often occurs as a result of capillary movement and evaporation during repeated wetting and drying of the vadose zone (e.g. Smith and Drever, 1976).

The seepage waters (VS4, VS4-5 and VS5) and the deeper water in the LS pit are often characterized by a low pH, and high sulphate, iron and zinc concentrations caused by the oxidation of sulfides in the ores (e.g. sphalerite and pyrite). Without further evidence from geochemical modelling it is not clear if these high concentrations could also be due to evaporative concentration of the water. The concentrations of the same elements are much lower in the groundwater sampled in the drill holes (e.g. DH #3342a).

The predominant minerals in the ore deposits at Buchans are sphalerite, galena and barite. Other abundant minerals include pyrite and chalcopyrite. Minor metal containing minerals are chalcocite, bornite, pyrrotite and cerussite. The most important rock-forming minerals at Buchans are K-feldspar, plagioclase, illite, montmorillonite, chlorite, quartz and calcite (Swanson et al., 1981).

3.2 Modelling Approach

Waters or mixture of waters considered to be potential sources of the seepages include: water from the LS pit (three different depths), groundwater (DH #3342a) and rainwater. Using PHREEQC (Parkhurst, 1995), the composition of the potential source water (or mixture of source waters) was compared with that of the seepage waters and DT water by an 'inverse modelling' procedure (explained below). Assuming specific phase transformations of minerals and gases (required input), the model calculates the quantity of the suggested phase transformations, the mixing proportions and the evaporation that account for the differences in the composition between the seepage water and the source water(s).

A detailed example of an 'inverse modelling' simulation run (input and output files) is shown in the Appendix. In the example the phase transformation, mixing proportions and amount of evaporation that account for the difference in chemical composition between an unknown mixture of rain and LS5 water (source) and seepage water (VS4), are determined.

Considering that not all samples have anion/cation analysis, only 8 parameters were used to define the chemical composition of the water samples (solutions 1-3). The uncertainty value defines the maximum fraction by which the input concentrations are allowed to vary during the simulation run. Lower uncertainty values impose greater constraints. Next, the specific phase transformations are defined (dissolution or precipitation). Balances are specific uncertainty constraints applied to a particular input concentration. Here chloride is used and allowed to vary only by 10% from its specified input concentration. As chloride behaves conservatively the higher imposed constraint 'steers' the mixing and evaporation process. Finally, additional thermodynamic data are given for phases not defined in the thermodynamic database of the program.

The output file shows first the calculated solution characteristics of each input solution. After this it lists the original (first column), the required adjustments (second column) and the adjusted (third column) analytical data for the three input solutions. The adjustments must be within the defined uncertainty and balances defined in the input file. Next, the calculated mixing proportions of the first two solutions (seepage water sources) are listed. Finally, the required mole transfers of the previously defined phases are listed: negative values indicate precipitation, positive values indicate dissolution.

The program calculates first a model with a minimal number of phase transformations (minimal model) before it explores other models with more phase transformations. The number of models found is obviously constrained by the earlier defined uncertainty value and balances.

3.3 Modelling Results

Successful modelling results (minimal model) are shown in Table 3. Unsuccessful modelling results included runs with only one source water (LS, DH # 3342a and rain) and runs with water from DH #3342a (improper ion balance of input solution).

The data in Table 3 show that the composition of seepage and DT waters (solution 3) can be simulated by different mixtures of rain and LS water subjected to various amounts of evaporation, degassing (CO_2 (g)) and/or calcite precipitation. Only two models involving DT water (1995) were unsuccessful; they are listed for completeness of the data set.

The formation of seepage waters from rain and LS waters (minimal model) does not require any other mineral phase transformation than those listed in Table 3 ! Other models (results not shown in Table 3), involved only minor mineral transformations of mostly rock-forming minerals (e.g. K-feldspar). This implies that the Zn loadings from the seepages are *exclusively* derived from the LS waters. The variation of the Zn concentrations in the seepages is mainly determined by the dilution of LS waters with rainwater (similar to a varying degree of evaporation of their mixture). This dilution effect increases from site VS4, to sites VS4-5 and VS5 and varies at different times (1995 and 1996). The dilution effect appears to be less for the DT water, however, the evaporation is also considerably less than that for the seepages.

Considering the listed (minimum) values for the applied uncertainty (15-25%), the number of input solution parameters used (8) and the complexity of the simulation scenario (mixing *and* evaporation), the 'inverse modelling' results are very good. The mineral transformations are relatively simple and involve predominantly precipitation of calcite.

4.0 CONCLUSIONS

1. The chemical composition of waters from the seepages and the DT can be formed by mixing rainwater and LS waters, followed by evaporation, degassing and only calcite precipitation.

2. The processes of mixing and evaporation of the different source waters for the seepages in the field is most likely due to capillary movement and evaporation during repeated wetting and drying of the vadose zone.

3. The differences in the chemical composition of the water from the various seepage sites appear to be governed by dilution of LS water with meteoric water (rain or snowmelt runoff). This is confirmed by some of the patterns observed in the response of seepage rates to particular hydrological events (e.g. precipitation and snowmelt runoff).

4. Differences in the chemical composition of the water from the various seepage sites (dilution) could also be related to differences in soil or aquifer characteristics (e.g. porosity) and the size of the catchment area (meteoric water) of each seepage.

5. The dissolved Zn concentration in seepage and DT waters appears to be entirely derived from (concentrated) LS waters. No additional dissolution of sphalerite in the aquifer or vadose zone seems to be necessary.

6. The composition of seepage and DT waters could not be simulated with a mixture of rain and groundwater (e.g. DH #3342). This is probably only due to the poor quality of the groundwater composition data. As the LS pit is largely fed by groundwater, it must be possible to 'simulate' the chemical composition of the LS water from that of the groundwater. Hence it is expected that the composition of the seepage and DT waters can also be 'derived' from a mixture of rain and groundwater.

Figure 1: DDH3325, DDH3341, DDH3342, DDH3343 Water Levels versus Lucky Strike Water Levels, April 4, 1995 - September 23, 1996

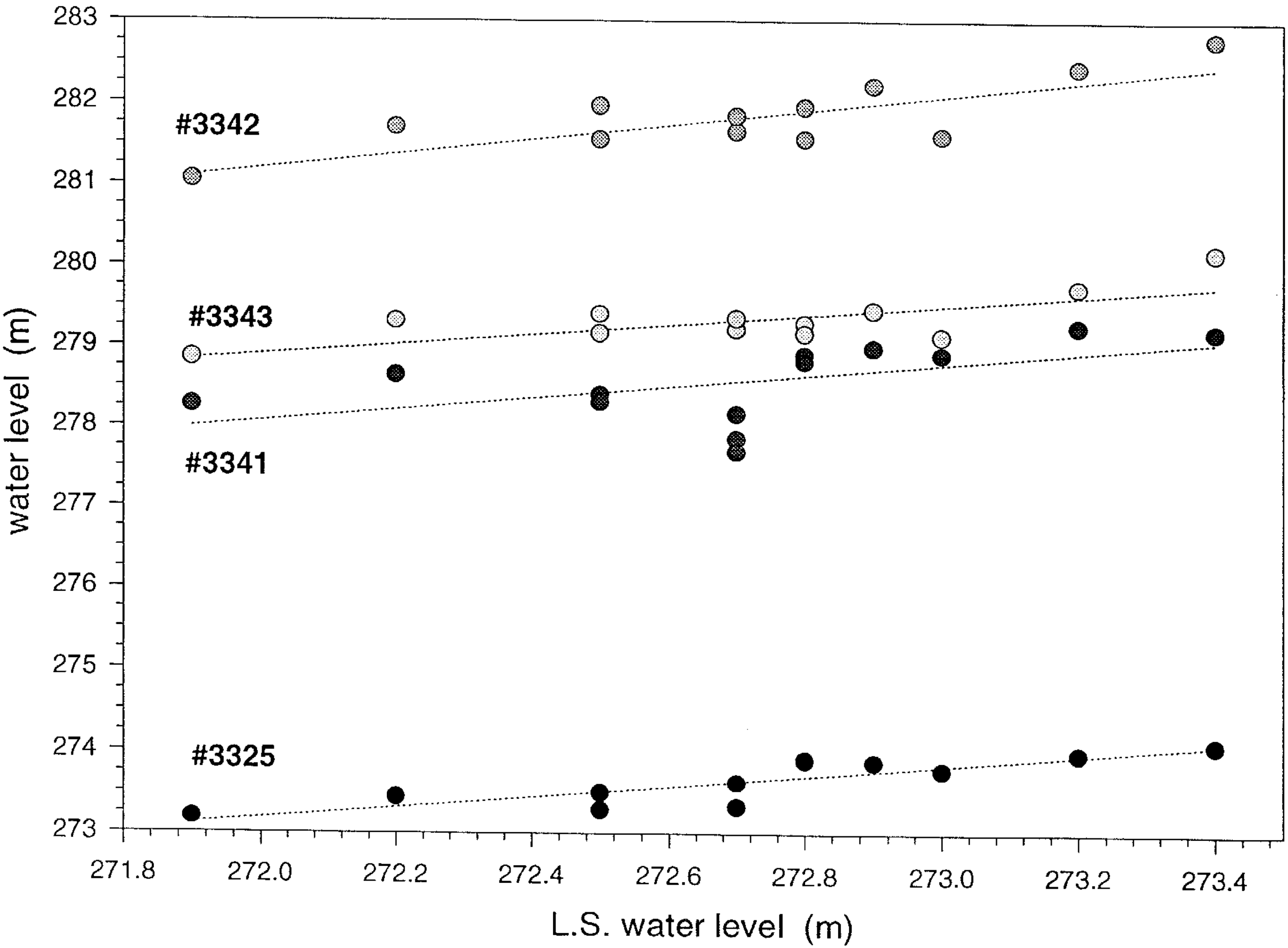


Figure 2a: DDH3325, DDH3341, DDH3342, DDH3343, Lucky Strike Water Levels and Daily Precipitation (RAINFALL) versus Time, January 1, 1995 - November 1, 1996

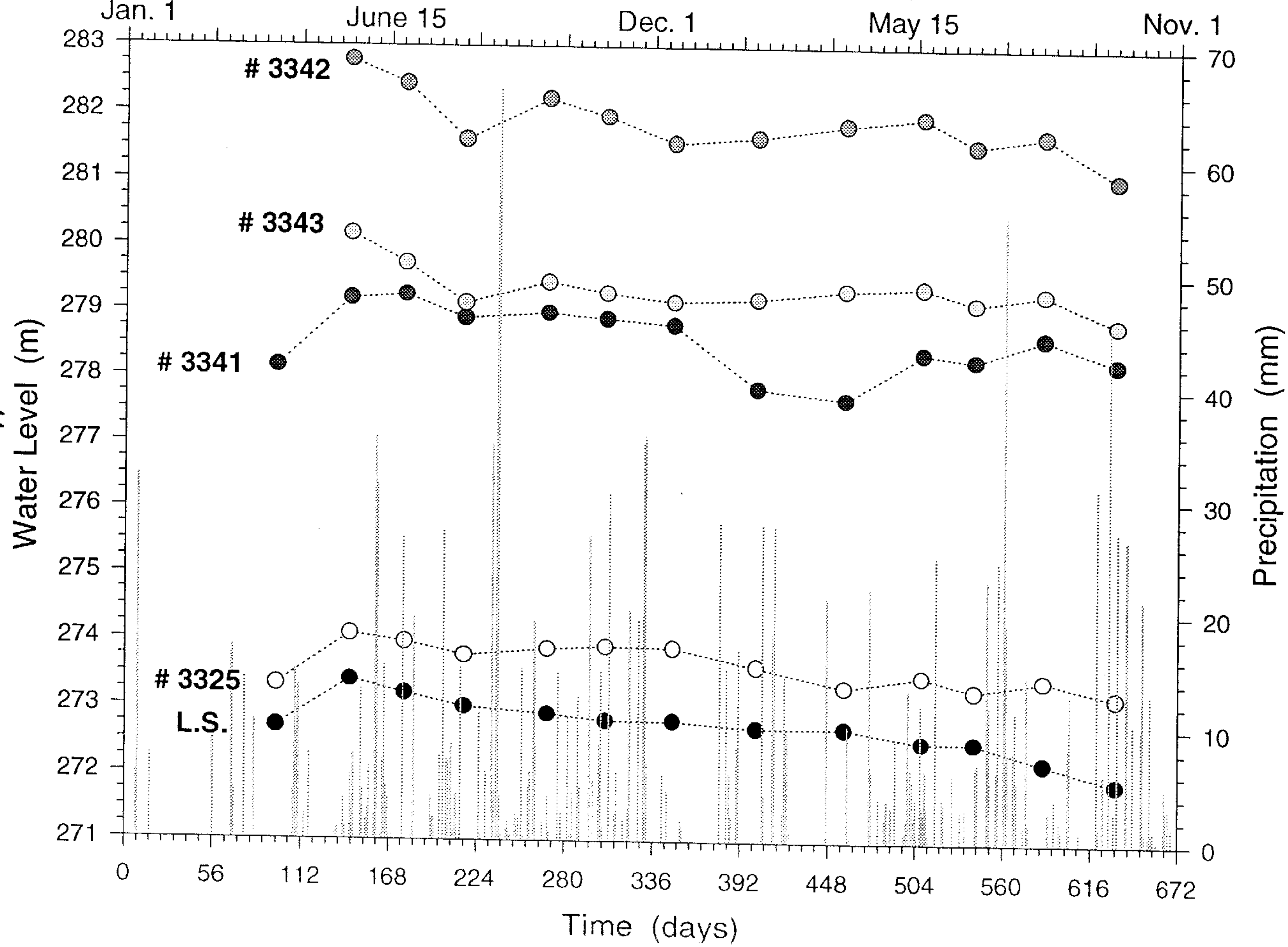


Figure 2b: DDH3325, DDH3341, DDH3342, DDH3343, Lucky Strike Water Levels and Daily Precipitation (RAINFALL+SNOWFALL) versus Time, January 1, 1995 - November 1, 1996

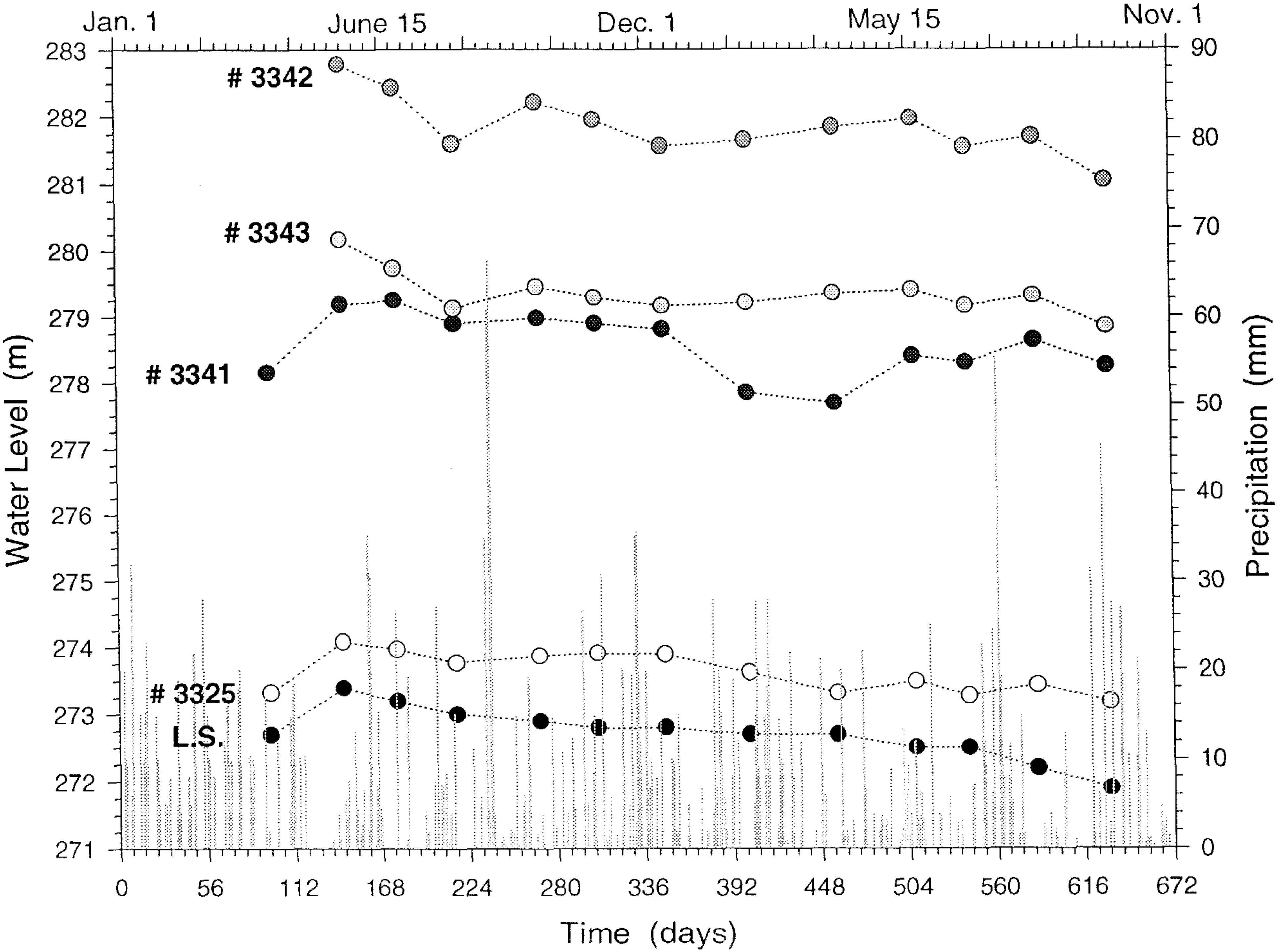


Figure 3a: Discharge Rates from Seepages VW1 and VW2 and Daily Precipitation (RAINFALL) versus Time, January 1, 1995 - November 1, 1996

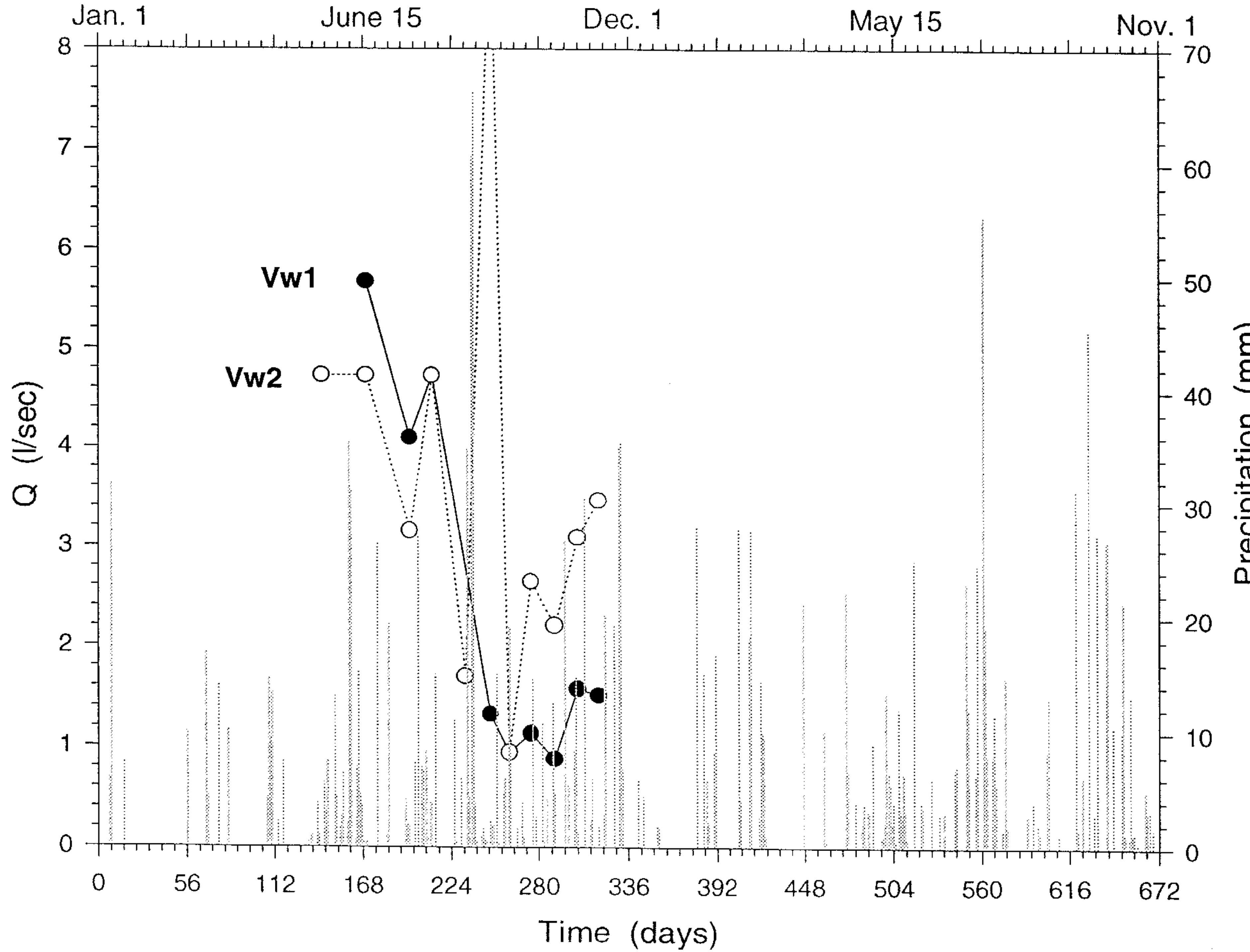


Figure 3b: Discharge Rates from Seepages VW1 and VW2 and Daily Precipitation (RAINFALL+ SNOWFALL) versus Time, January 1, 1995-November 1, 1996

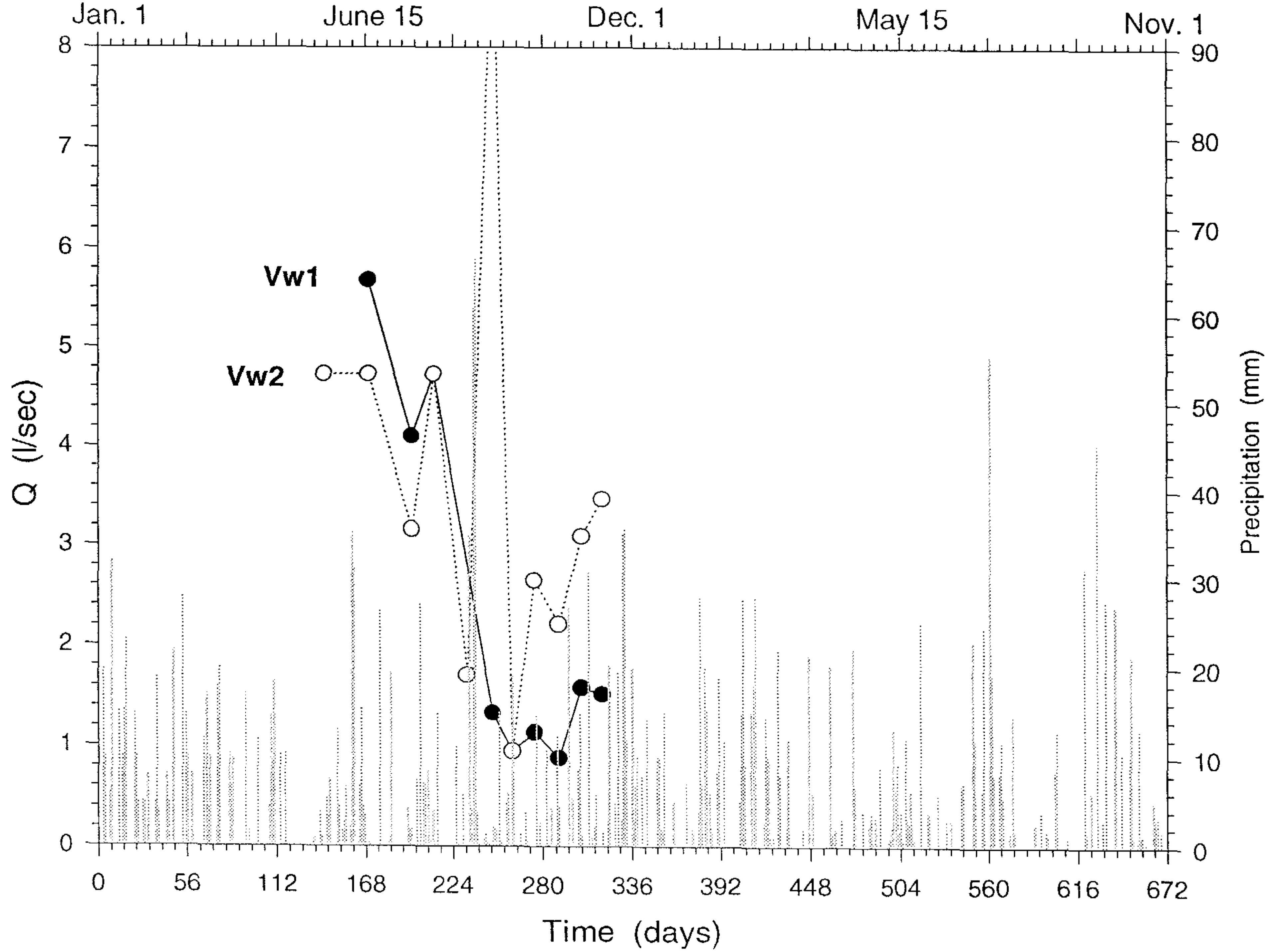


Figure 4a: Discharge Rates from Seepages VS2 and VS4 and Daily Precipitation (RAINFALL) versus Time, January 1, 1995 - November 1, 1996

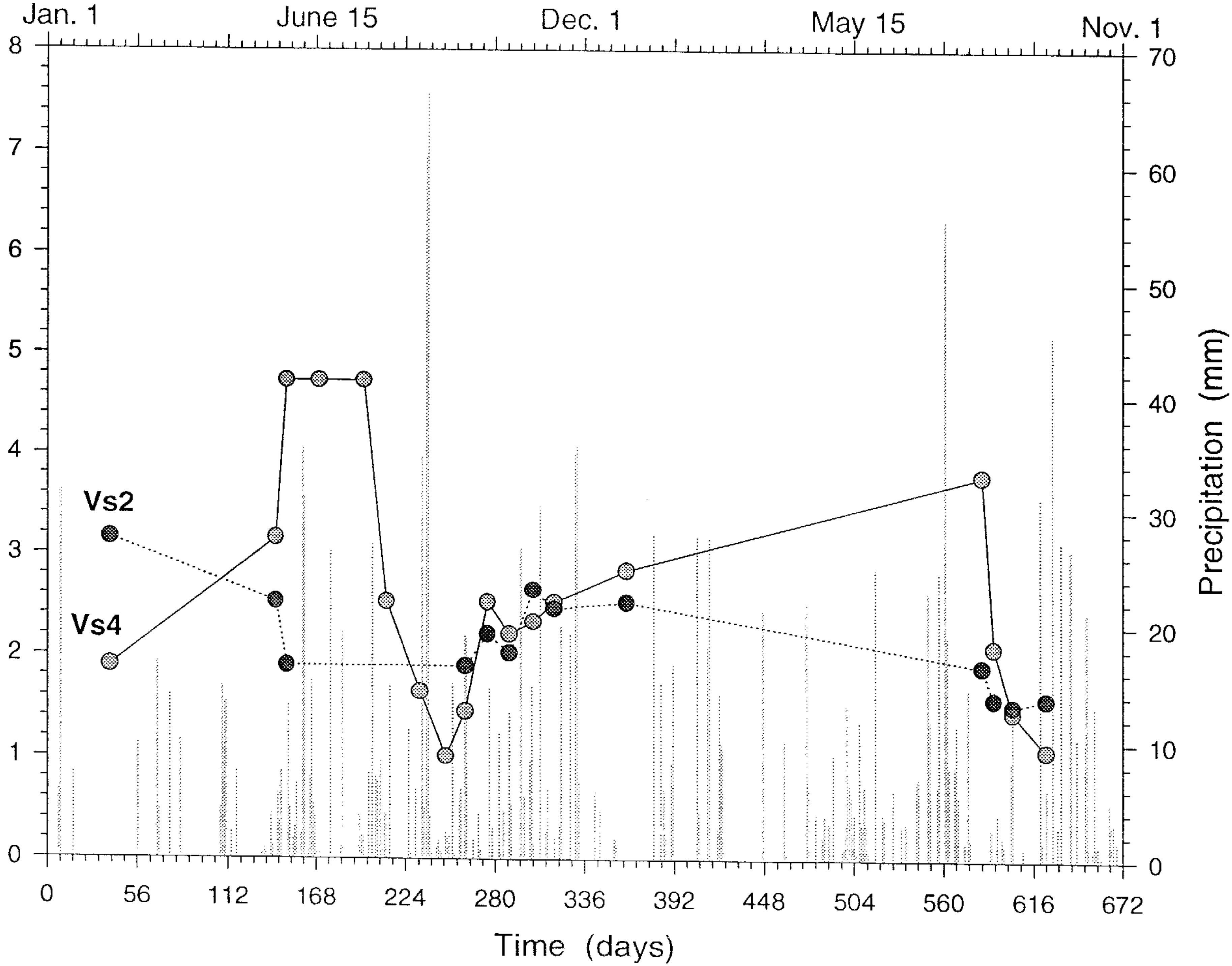


Figure 4b: Discharge Rates from Seepages VS2 and VS4 and Daily Precipitation (RAINFALL+ SNOWFALL) versus Time, January 1, 1995-November 1, 1996

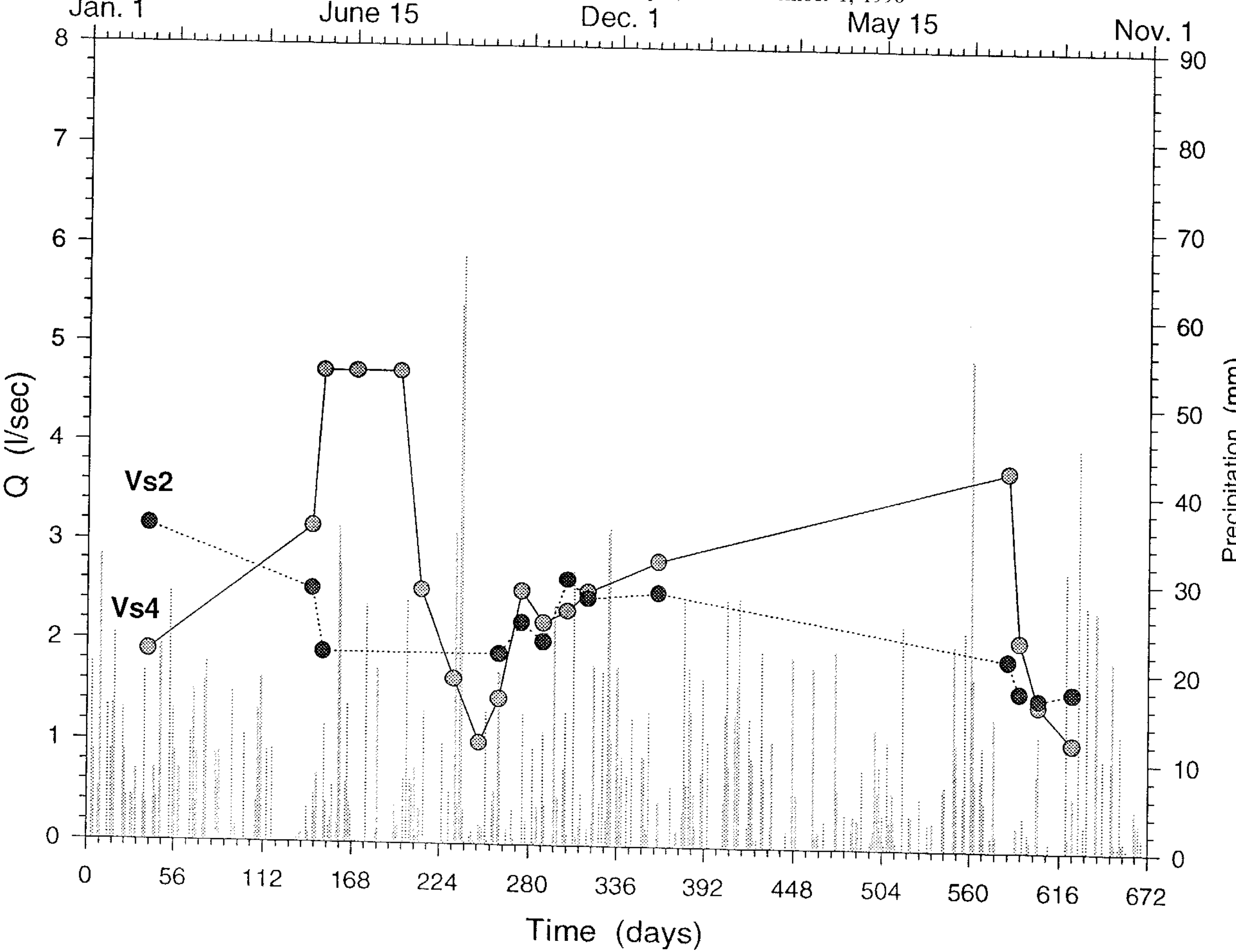


Figure 5a: Discharge Rates from Seepages VS2 and VS4 and Daily Precipitation (RAINFALL) versus Time, January 1, 1995 - November 1, 1996

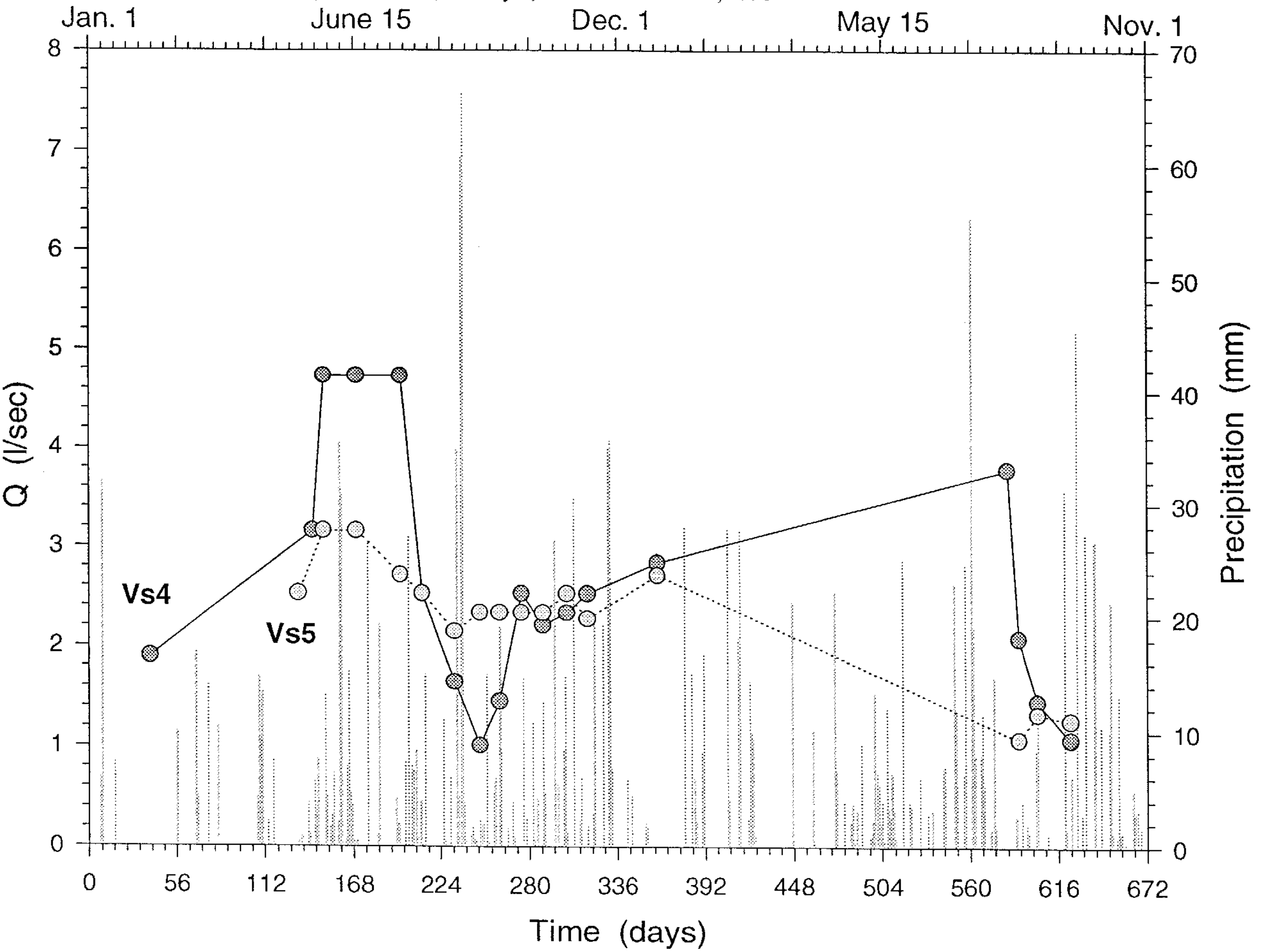
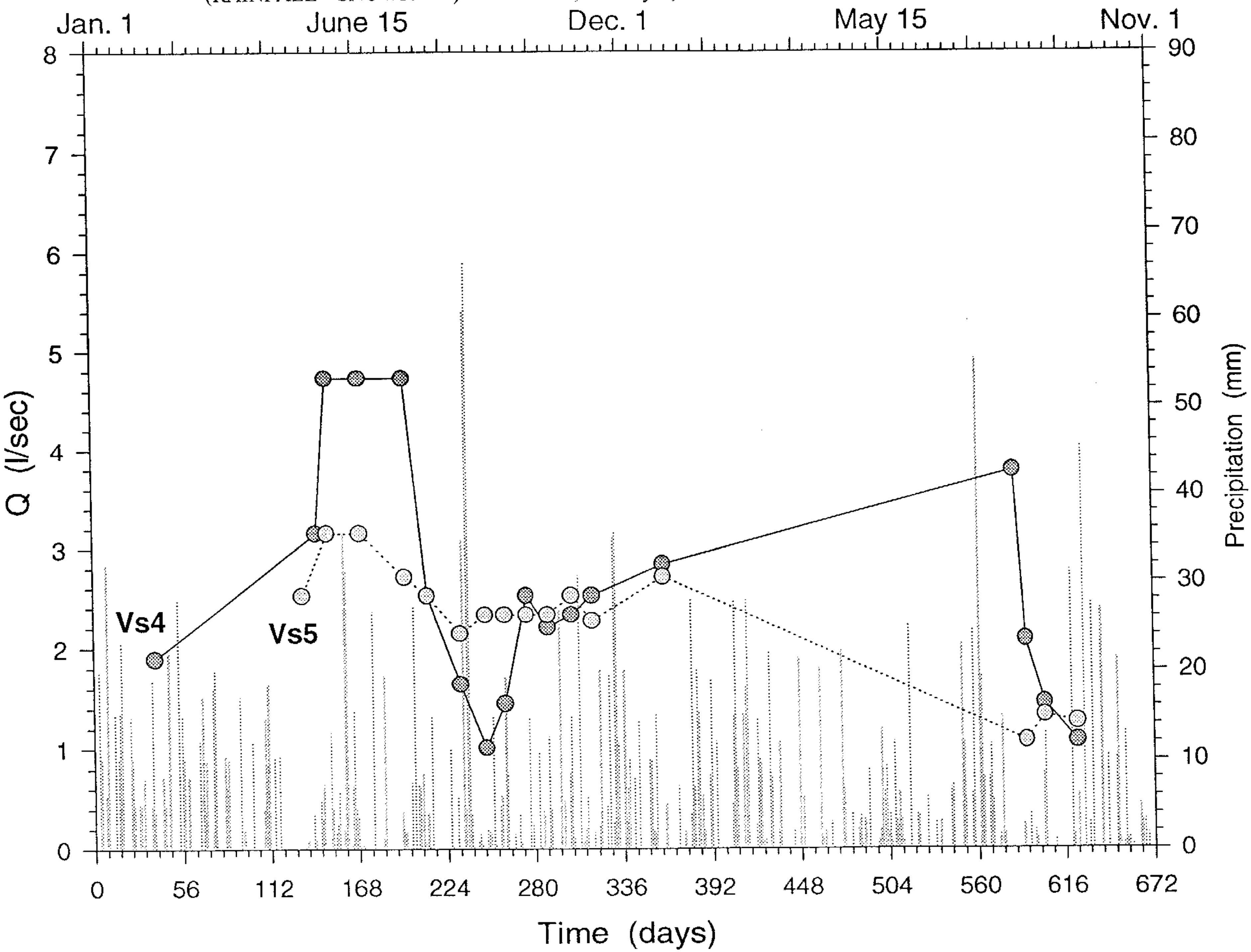


Figure 5b: Discharge Rates from Seepages VS2 and VS4 and Daily Precipitation (RAINFALL+ SNOWFALL) versus Time, January 1, 1995-November 1, 1996



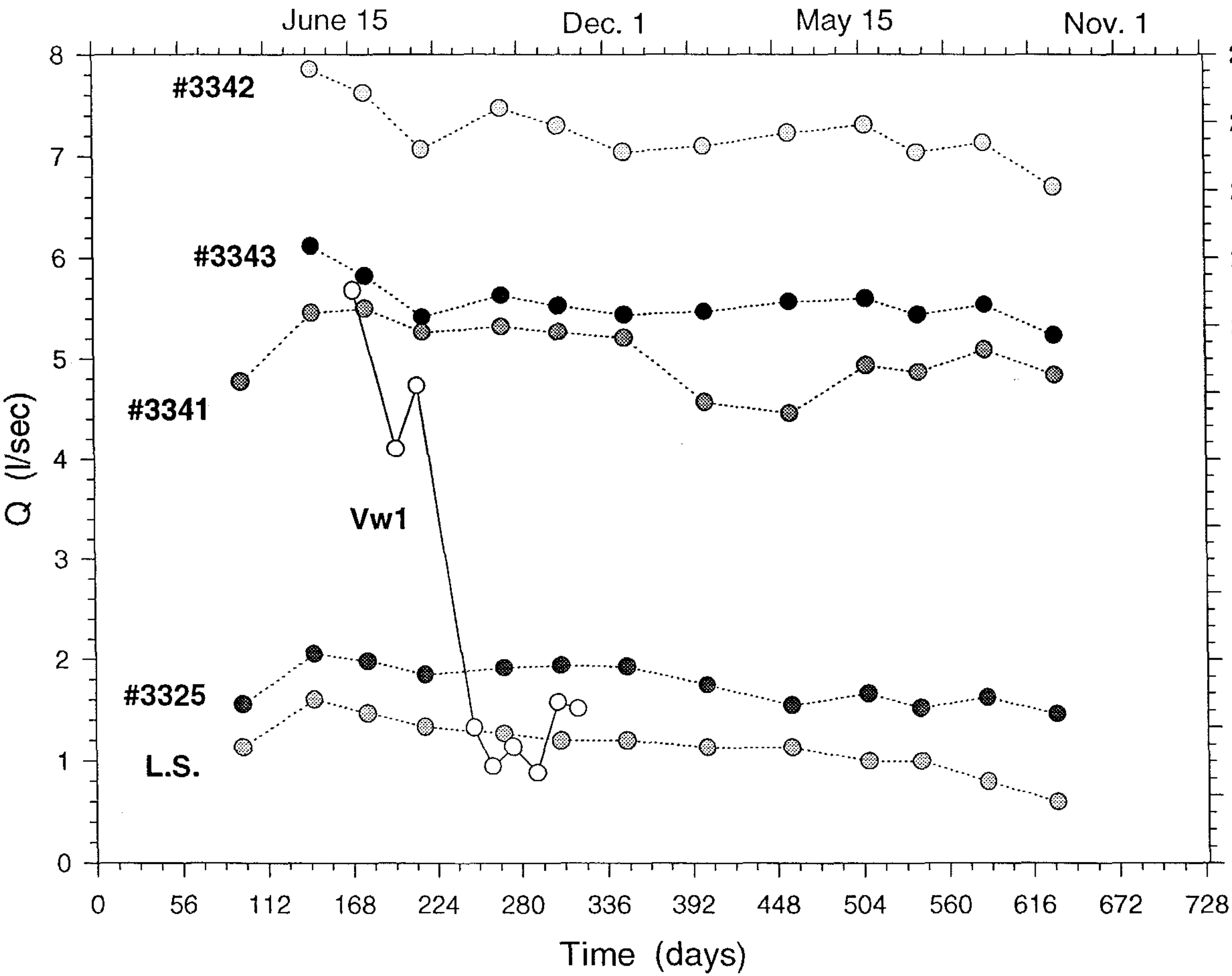


Figure 6a: DDH3325, DDH3341, DDH3342, DDH3343, Lucky Strike Water Levels and Discharge Rates from Seepage VW1 versus Time, January 1, 1995 - November 1, 1996

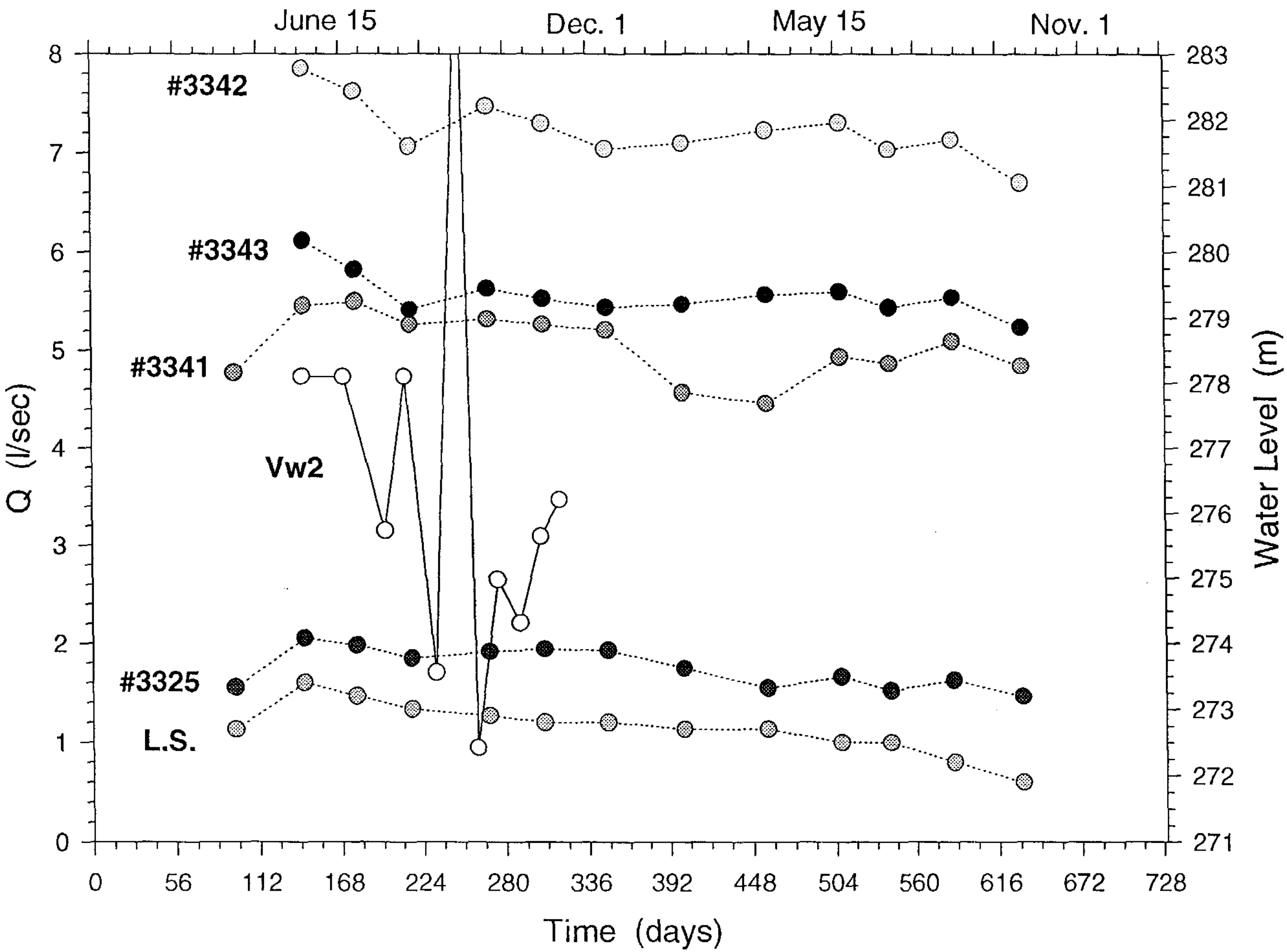


Figure 6b: DDH3325, DDH3341, DDH3342, DDH3343, Lucky Strike Water Levels and Discharge Rates from Seepage VW2 versus Time, January 1, 1995 - November 1, 1996

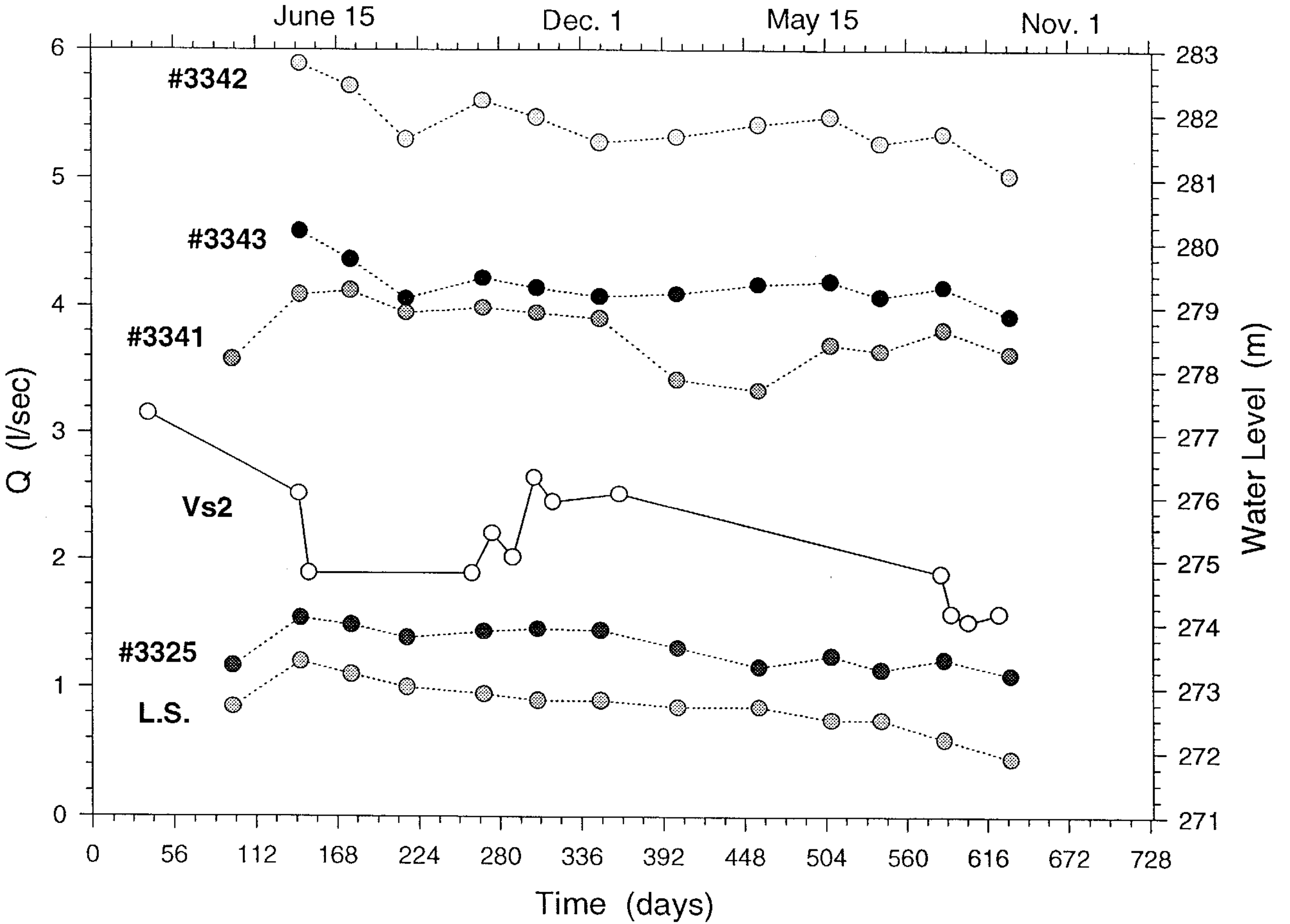


Figure 6c: DDH3325, DDH3341, DDH3342, DDH3343, Lucky Strike Water Levels and Discharge Rates from Seepage VS2 versus Time, January 1, 1995 - November 1, 1996

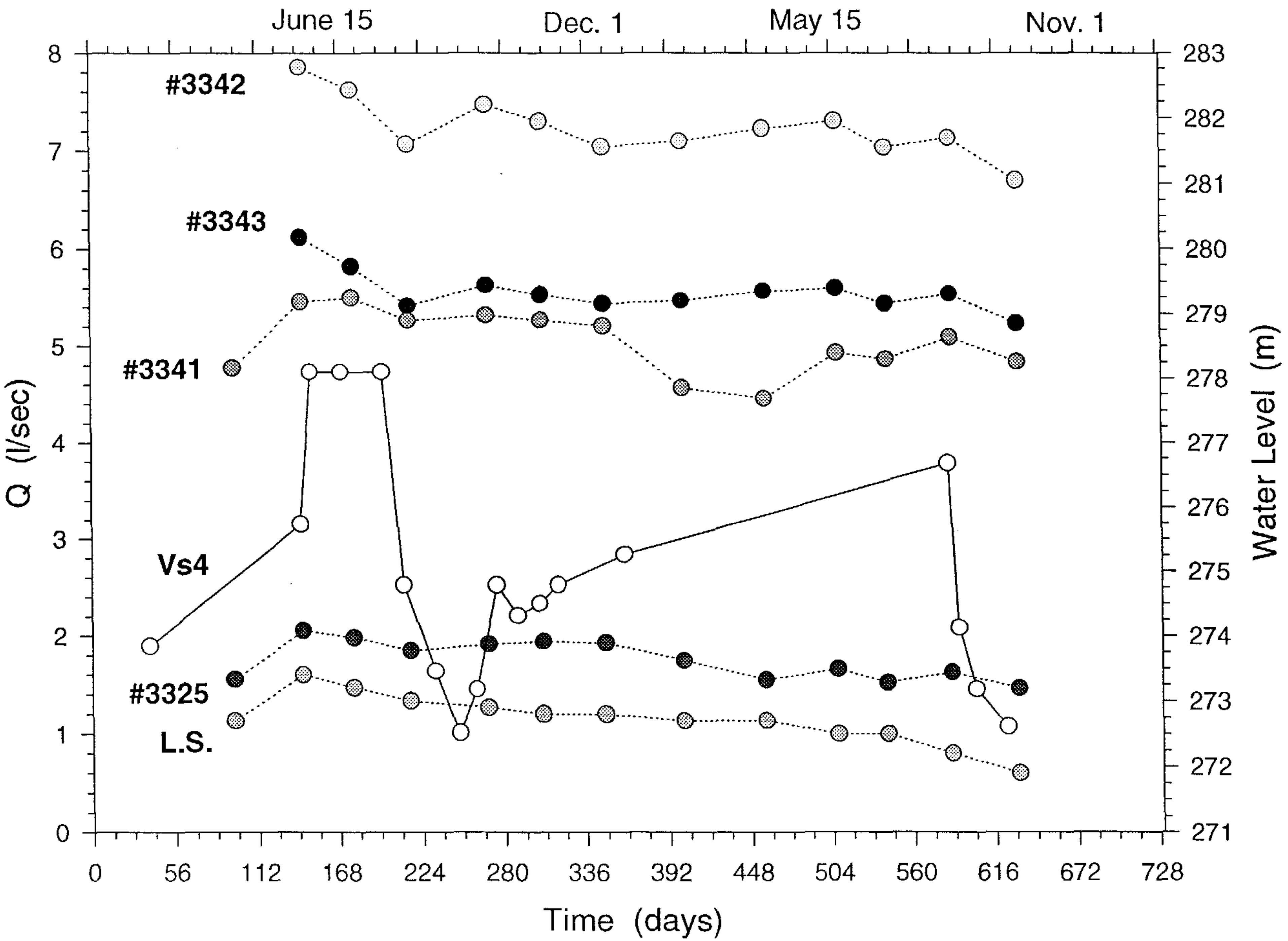


Figure 6d: DDH3325, DDH3341, DDH3342, DDH3343, Lucky Strike Water Levels and Discharge Rates from Seepage VS4 versus Time, January 1, 1995 - November 1, 1996

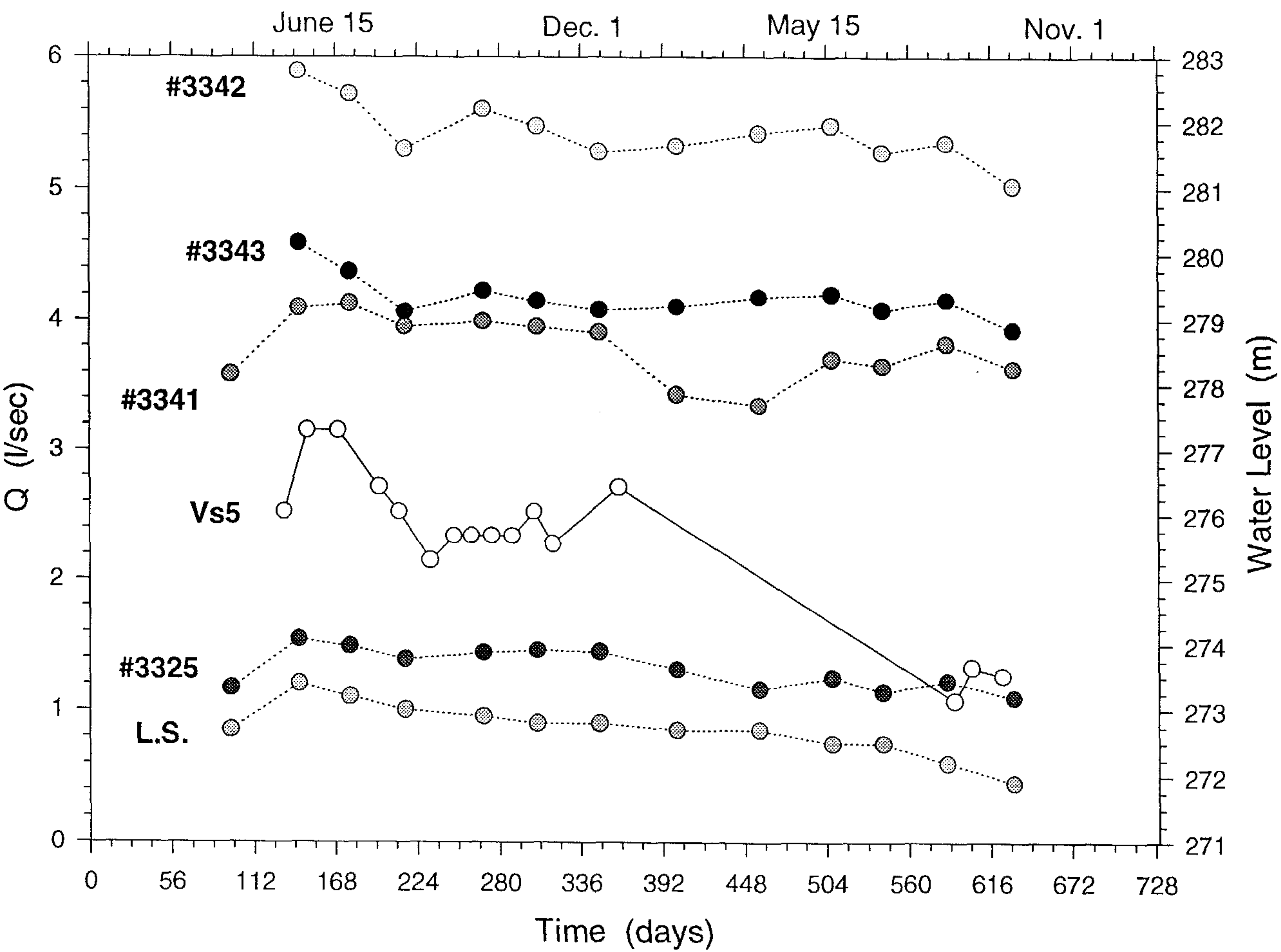


Figure 6e: DDH3325, DDH3341, DDH3342, DDH3343, Lucky Strike Water Levels and Discharge Rates from Seepage VS5 versus Time, January 1, 1995 - November 1, 1996

Figure 7: Zinc Concentration for Seepages: VW1, VW2, VS2, VS4, VS5 versus Time, January 1, 1995 - November 1, 1996

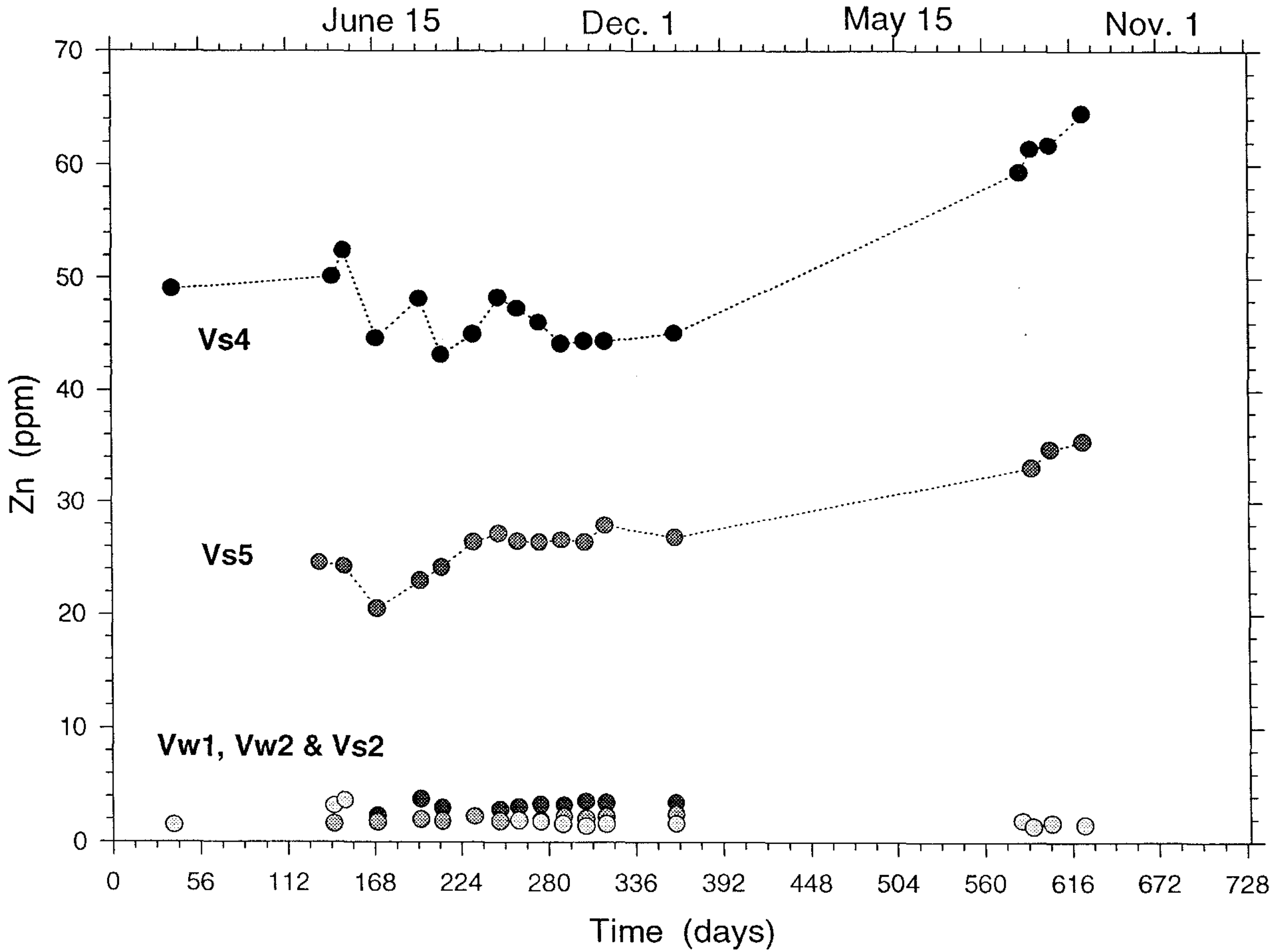


Figure 8: Zinc Loading for Seepages: VW1, VW2, VS2, VS4, VS5 versus Time, January 1, 1995 - November 1, 1996

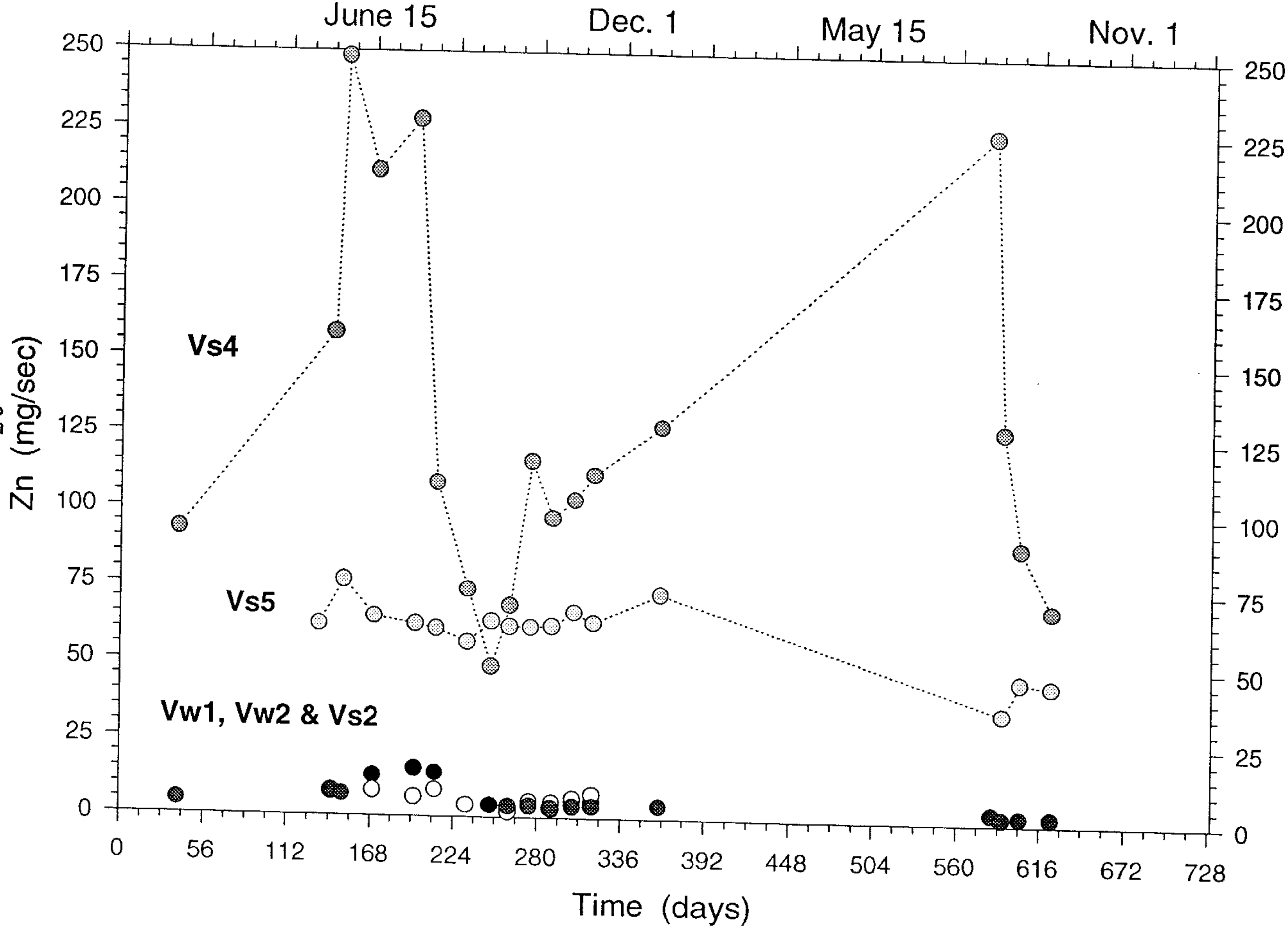


Figure 9: Zinc Concentration for Seepages: VW1, VW2, VS2, VS4, VS5 versus Seepage Discharge Rates

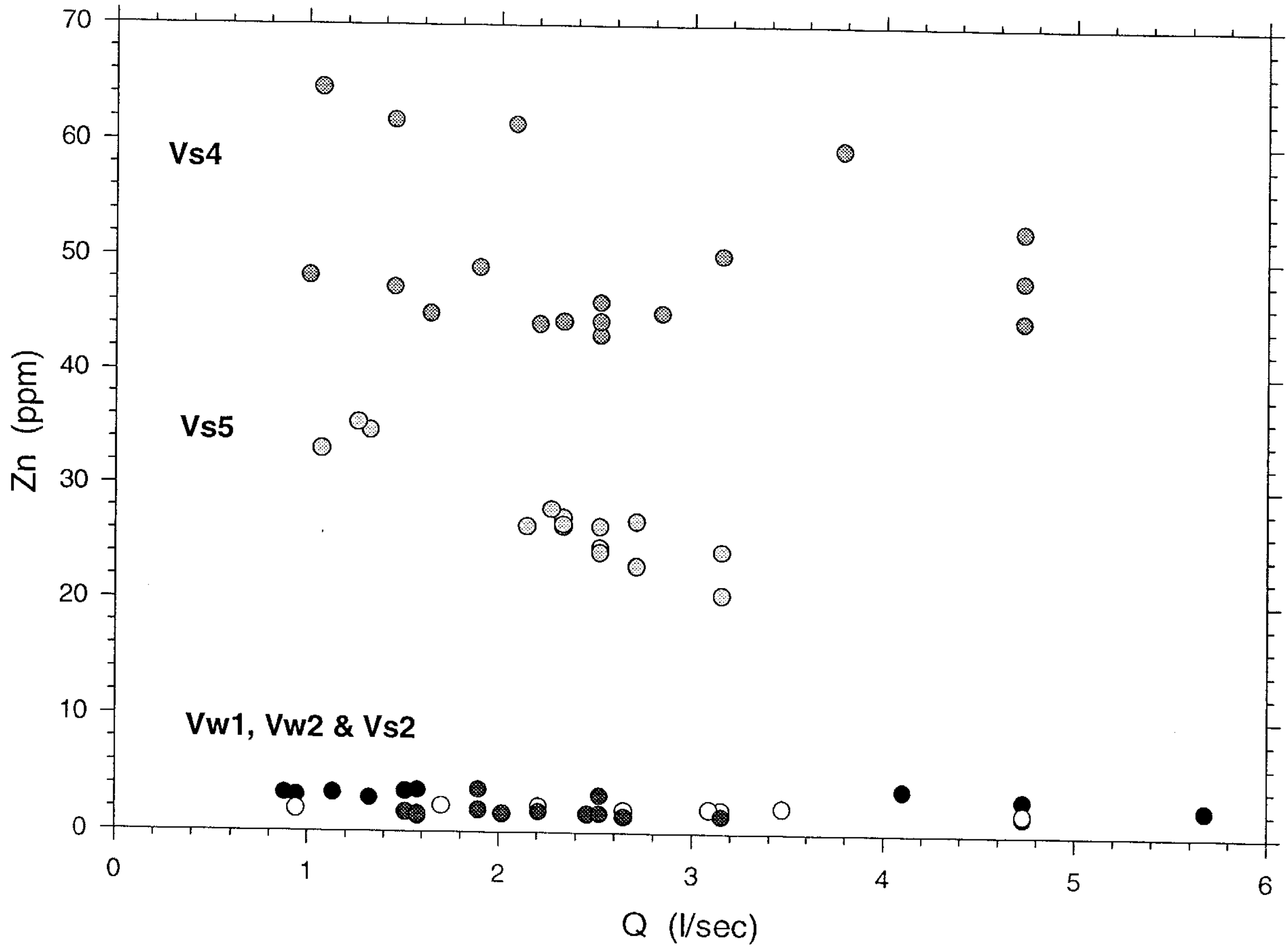


Figure 10: Zinc Loading for Seepages: VW1, VW2, VS2, VS4, VS5 versus Seepage Discharge Rates

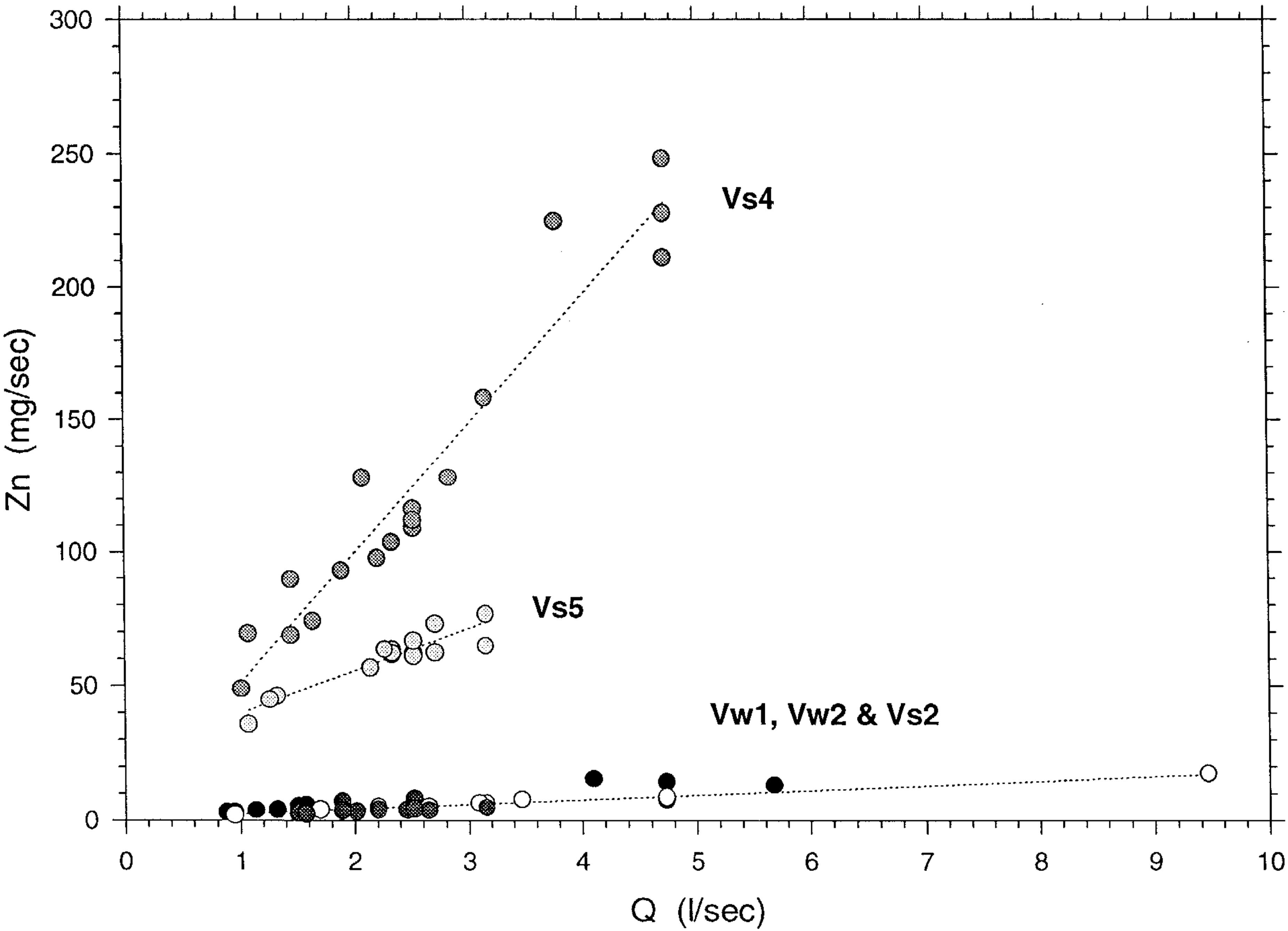


Table 1: Concentration of Selected Elements for Lucky Strike, Drainage Tunnel, Seepages VS1, VS2, VS4, VS5, VS6 and Sandfill Spring

Code		LS5	LS5	LS65	LS65	LS94	LS94	DT	DT	Vs1	Vs1	Vs2	Vs2	Vs4	Vs4	Vs5	Vs5	Vs6	Vs6	Vs4-5		SS	Rain
No.		5566	5972	5567	5973	5568	5974	5575	5971	5572	5966	5574	5967	5571	5968	5569	5969	5573	5970	5570		2912	
Date		19-5-95	13-8-96	19-4-95	13-8-96	19-4-95	13-8-96	14-6-95	13-8-96	28-5-95	13-8-96	28-5-95	13-8-96	28-5-95	13-8-96	28-5-95	13-8-96	28-5-95	13-8-96	28-5-95		5-7-91	
pH		6.7	6.2	6.7	6.1	6.6	6.1	6.4	5.9	[illegible]	5.1	[illegible]	5.9	4.7	4.3	6.2	5.3	[illegible]	4.6	5.9		5.9	4.9
Cond	uS/cm	355	470	580	559	1000	880	314	386	[illegible]	37	[illegible]	357	728	822	456	679	[illegible]	638	564		123	
Cl	mg/l	3.2	2.8	4.3	3.3	15.1	9.2	10.9	14.8	[illegible]	3.0	[illegible]	55.3	41.4	28.6	29.2	49.8	[illegible]	30.5	39.8		2.0	5.5
SO4	mg/l	142.0	214.0	268.0	258.0	484.0	458.0	93.6	137.0	[illegible]	5.3	[illegible]	54.3	288.0	402.0	160.0	281.0	[illegible]	217.0	198.0		3.6	1.2
NO3	mg/l	0.4	0.3	0.4	0.4	0.3	0.3	4.2	3.5	[illegible]		[illegible]	4.1	4.5	3.5	3.9	1.9	[illegible]	2.1	2.2		3.5	0.3
HCO3	mg/l	16.0	15.0	32.4	23.9	50.0	45.9	28.0	27.1	[illegible]		[illegible]	18.7	[illegible]		0.9	1.6	[illegible]		1.4		6.1	
Na	mg/l	4.0	4.1	5.7	4.9	15.6	11.8	9.4	11.6	6.0		51.9	35.3	26.4	20.3	25.7	35.5	21.6	19.9	29.3		5.0	3.0
Ca	mg/l	51.6	68.7	93.4	88.7	174.0	153.0	41.1	49.3	26.6	3.0	43.7	34.0	76.1	101.0	43.0	81.7	51.8	57.8	55.4		17.0	0.2
Mg	mg/l	5.4	7.4	9.5	8.9	19.6	16.3	3.9	5.0	8.1	0.4	4.4	2.9	18.1	19.8	7.5	13.2	9.3	10.0	10.6		3.0	0.3
K	mg/l	1.4	1.0	2.5	0.8	1.4	1.2	0.7	1.0	1.0		2.5	2.2	2.6	2.8	2.1	2.5	2.0	1.8	3.2		15.0	0.2
Al	mg/l	0.06		[illegible]		0.05		[illegible]		1.03	0.07	0.06		1.37	2.32	0.17	0.13	0.58	0.49	0.14		2.00	
Fe	mg/l	0.02		[illegible]		[illegible]		0.01		1.54	0.27	[illegible]		[illegible]		[illegible]		0.10		0.03			
Mn	mg/l	0.36	0.56	0.63	0.75	2.01	1.82	0.17	0.19	0.47	0.04	0.03		4.78	8.31	0.36	0.75	1.84	2.85	0.40			
Ba	mg/l	0.04	0.04	0.04	0.04	0.02	0.02	0.03	0.02	0.05	0.10	0.10	0.07	0.03	0.02	0.02	0.04	0.03	0.06	0.03			
Cd	mg/l	0.07	0.13	0.12	0.17	0.21	0.22	0.04	0.06	0.06		0.01	0.01	0.07	0.10	0.06	0.08	0.06	0.05	0.06			
Cu	mg/l	0.11	0.03	0.42	0.43	0.79	0.77	0.03	0.08	0.42	0.03	0.02	0.01	0.30	0.54	0.08	0.07	0.31	0.26	0.02			
Pb	mg/l	0.06	0.04	[illegible]	0.04	0.25	0.12	[illegible]		1.14	0.30	[illegible]		[illegible]		[illegible]		0.66	0.50	0.08			
Sr	mg/l	0.19		[illegible]	0.28	0.69	0.56	0.09		0.07		[illegible]		0.18		[illegible]	0.28	0.13		0.16			
Zn	mg/l	14.1	24.9	[illegible]	35.0	[illegible]	54.8	[illegible]	18.9	15.7	0.6	[illegible]	2.3	[illegible]	66.2	[illegible]	36.2	27.1	31.0	28.9			
Na:Cl		1.27	1.44	[illegible]	1.47	1.03	1.28	0.86	0.78	[illegible]		[illegible]	0.64	0.64	0.71	[illegible]	0.71	[illegible]	0.65	0.74		2.50	0.55
Cat	me/l	3.7	5.0	[illegible]	6.5	12.6	11.2	3.2	4.0	2.8		5.0	3.6	7.8	9.6	[illegible]	7.9	5.2	5.6	5.9		1.9	0.2
An	me/l	3.4	4.8	[illegible]	5.9	11.6	10.7	2.9	4.0	[illegible]		[illegible]	3.9	7.2	9.2	[illegible]	8.1	[illegible]	5.4	5.9		0.3	0.2

Table 2: Concentration of Selected Elements for DDH3325, DDH3341, DDH3342, DDH3344 and Sandfill Spring

		#3325a	#3341a	#3342a	#3342c	#3344b	SS	Rain
pH		7.9	7.6	6.8	6.9	6.8	5.9	4.9
Eh	Volt	-0.050	-0.003	-0.009	-0.089	-0.228		[illegible]
Cl	ppm		3.0	2.0	2.0	4.7	2.0	5.5
SO4	ppm	201.9	16.8	5.1	5.0	2.0	3.6	1.2
HCO3	ppm	24.4	89.1	18.3	100.1	717.3	6.1	[illegible]
Na	ppm	29.8	4.3	2.7	4.0	12.0	5.0	3.0
Ca	ppm	63.6	44.5	9.5	15.0	100.0	17.0	0.2
Mg	ppm	7.3	2.8	0.7		3.0	3.0	0.3
K	ppm	2.0	1.0	[illegible]		1.0	15.0	0.2
Al	ppm		0.03	0.04			2.00	
Fe	ppm		0.20	0.20		11.00		
Mn	ppm	0.52	0.07	0.03				
SiO2	ppm	1.50	20.60	7.49	10.70	30.00		
Ba	ppm	0.15	0.37	0.42		2.00		
Cu	ppm	0.06						
Sr	ppm	0.37	0.07	0.03				
Zn	ppm	0.11	0.05	[illegible]		0.64		
Na:Cl			1.43	1.35	2.00	2.55	2.50	0.55
Cat	me/l	5.16	2.69	0.69	0.92	6.21	1.90	0.17
An	me/l	4.60	1.92	0.47	1.80	11.94	0.30	0.19

		#3325a	#3341a	#3342a	#3342c	#3344b	SS	Rain
pH		7.9	7.6	6.8	6.9	6.8	5.9	4.9
Eh	Volt	-0.050	-0.003	-0.009	-0.089	-0.228		[illegible]
Cl	mmol/l		0.08	0.06	0.06	0.13	0.06	0.16
SO4	mmol/l	2.10	0.17	0.05	0.05	0.02	0.04	0.01
HCO3	mmol/l	0.40	1.46	0.30	1.64	11.76	0.10	[illegible]
Na	mmol/l	1.30	0.19	0.12	0.17	0.52	0.22	0.13
Ca	mmol/l	1.59	1.11	0.24	0.37	2.50	0.42	0.00
Mg	mmol/l	0.30	0.12	0.03		0.12	0.12	0.01
K	mmol/l	0.05	0.03	[illegible]		0.03	0.38	0.01
Al	mmol/l		0.001	0.001			0.074	
Fe	mmol/l		0.004	0.004		0.197		
Mn	mmol/l	0.009	0.001	0.001				
SiO2	mmol/l	0.025	0.343	0.125	0.178	0.500		
Ba	mmol/l	0.001	0.003	0.003		0.015		
Cu	mmol/l	0.001						
Sr	mmol/l	0.004	0.001	0.000				
Zn	mmol/l	0.002	0.001			0.010		
Na:Cl	mmol/l		2.21	2.08	3.08	3.94	3.85	0.84
Cat	mmol/l	5.16	2.69	0.69	0.92	6.21	1.90	0.17
An	mmol/l	4.60	1.92	0.47	1.80	11.94	0.30	0.19

Table 3: Modelling Results

Year	Solution 1	Solution 2	Sol.1:Sol.2 (mixing)	Solution 3	Uncertainty	Models	H2O Mol	CaCO3 Mol	CO2(g) Mol
95	rain	LS5	3.0:1	Vs4	0.25	3	-3.82E+02	-1.61E-04	-3.56E-04
96	rain	LS5	2.1:1	Vs4	0.15	2	-2.89E+02	-1.18E-04	-3.80E-04
95	rain	LS65	4.8:1	Vs4	0.20	3	-3.08E+02	-1.97E-04	-4.01E-04
96	rain	LS65	2.9:1	Vs4	0.15	1	-2.86E+02	-1.28E-04	-4.98E-04
95	rain	LS94	9.9:1	Vs4	0.20	1	-3.05E+02	-1.45E-04	-3.44E-04
96	rain	LS94	5.1:1	Vs4	0.15	1	-2.61E+02	-1.46E-04	-5.55E-04
95	rain	LS5	4.2:1	Vs5	0.15	3	-2.88E+02	-9.30E-05	-2.44E-04
96	rain	LS5	6.4:1	Vs5	0.15	8	-4.87E+02	-2.00E-05	-2.77E-04
95	rain	LS65	7.4:1	Vs5	0.20	3	-2.81E+02	-1.03E-04	-2.65E-04
96	rain	LS65	8.3:1	Vs5	0.15	6	-4.78E+02	-2.70E-04	-3.52E-04
95	rain	LS94	12.7:1	Vs5	0.20	1	-2.37E+02	-7.50E-05	-2.25E-04
96	rain	LS94	12.8:1	Vs5	0.15	5	-4.24E+02	-4.70E-05	-4.01E-04
95	rain	LS5	4.2:1	Vs4-5	0.15	4	-3.81E+02	-1.00E-04	-2.75E-04
95	rain	LS65	9.0:1	Vs4-5	0.15	4	-3.75E+02	-1.04E-04	-2.87E-04
95	rain	LS94	12.7:1	Vs4-5	0.20	1	-2.37E+02	-7.50E-05	-2.25E-04
95	rain	LS5	na	DT	0.25	0	na	na	na
96	rain	LS5	2.5:1	DT	0.25	4	-1.18E+02	0.00E+00	-6.00E-05
95	rain	LS65	na	DT	0.25	0	na	na	na
96	rain	LS65	3.3:1	DT	0.20	5	-1.07E+02	0.00E+00	-3.60E-05
95	rain	LS94	4.0:1	DT	0.25	5	-2.50E+01	0.00E+00	4.90E-05
96	rain	LS94	5.2:1	DT	0.15	6	-6.80E+01	0.00E+00	6.60E-05

5.0 EXAMPLE OF "INVERSE MODELLING" SIMULATION RUN

```
------------------------------------
Reading input data for simulation 1.
------------------------------------

      TITLE
      --Inverse modeling of Rain + LS5 + evaporation --> Vs4 (1995)
      SOLUTION 1  Rain
              units   mg/L
              pH      4.9
              Ca      0.2
              Mg      0.3
              Na      3.0
              K       0.2
              S(6)    1.2
              Cl      5.5
              C(4)    0.0    as HCO3
              Zn      0.0
      SOLUTION 2  LS5
              units   mg/L
              pH      6.7
              Ca      51.6
              Mg      5.4
              Na      4.0
              K       1.4
              S(6)    142.0
              Cl      3.2
              C(4)    16.0    as HCO3
              Zn      14.1
      SOLUTION 3  Vs4
              units   mg/L
              pH      4.7
              Ca      76.1
              Mg      16.1
              Na      26.4
              K       2.6
              S(6)    288.0
              Cl      41.4
              C(4)    0.0    as HCO3
              Zn      46.3
      INVERSE_MODELING
              solutions 1 2 3
              uncertainties .25
              phases
                      Sphalerite      dis
                      Pyrite
                      Chalcopyrite
                      H2O             pre
                      Calcite         pre
                      CO2(g)
                      Plagioclase     dis
                      K-feldspar      dis
                      Illite          pre
                      Chlorite(14A)   pre
                      Ca-Montmorillonite      pre
```

```
        balances
                Cl      0.10
PHASES
H2O
        H2O = H2O
        log_k   0.0
chalcopyrite
        CuFeS2 + 2H+ = Cu+2 + Fe+2 + 2HS-
        log_k   -35.27
        delta_h 35.48 kcal
plagioclase
        Na0.62Ca0.37Al1.38Si2.625O8 + 5.5 H+ + 2.5H2O =  0.62Na+ +
        0.37Ca+2 + 1.38Al+3 + 2.625H4SiO4
        log_k   0.0
END
```

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Beginning of initial solution calculations.
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Initial solution 1.     Rain

      Elements           Molality       Moles

      Ca               4.990e-06   4.990e-06
      Cl               1.551e-04   1.551e-04
      K                5.115e-06   5.115e-06
      Mg               1.234e-05   1.234e-05
      Na               1.305e-04   1.305e-04
      S(6)             1.249e-05   1.249e-05

                              pH  =   4.900
                              pe  =   4.000
               Activity of water  =   1.000
                  Ionic strength  =   2.112e-04
              Mass of water (kg)  =   1.000e+00
        Total alkalinity (eq/kg)  =  -1.281e-05
           Total carbon (mol/kg)  =   0.000e+00
              Total CO2 (mol/kg)  =   0.000e+00
             Temperature (deg C)  =  25.000
         Electrical balance (eq)  =   2.959e-06
                      Iterations  =   3
                         Total H  = 1.110124e+02
                         Total O  = 5.550627e+01

                                                      Log        Log         Log
      Species            Molality    Activity   Molality   Activity       Gamma

      H+               1.280e-05   1.259e-05     -4.893     -4.900      -0.007
      OH-              8.087e-10   7.952e-10     -9.092     -9.100      -0.007
      H2O              5.551e+01   1.000e+00      0.000      0.000       0.000
Ca              4.990e-06
      Ca+2             4.979e-06   4.658e-06     -5.303     -5.332      -0.029
      CaSO4            1.080e-08   1.080e-08     -7.966     -7.966       0.000
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	CaOH+	6.244e-14	6.140e-14	-13.205	-13.212	-0.007
Cl		1.551e-04				
	Cl-	1.551e-04	1.526e-04	-3.809	-3.817	-0.007
H(0)		2.244e-21				
	H2	1.122e-21	1.122e-21	-20.950	-20.950	0.000
K		5.115e-06				
	K+	5.114e-06	5.029e-06	-5.291	-5.298	-0.007
	KSO4-	4.209e-10	4.139e-10	-9.376	-9.383	-0.007
	KOH	1.385e-15	1.385e-15	-14.859	-14.859	0.000
Mg		1.234e-05				
	Mg+2	1.231e-05	1.152e-05	-4.910	-4.939	-0.029
	MgSO4	3.138e-08	3.138e-08	-7.503	-7.503	0.000
	MgOH+	3.377e-12	3.321e-12	-11.471	-11.479	-0.007
Na		1.305e-04				
	Na+	1.305e-04	1.283e-04	-3.884	-3.892	-0.007
	NaSO4-	7.602e-09	7.476e-09	-8.119	-8.126	-0.007
	NaOH	6.734e-14	6.734e-14	-13.172	-13.172	0.000
O(0)		0.000e+00				
	O2	0.000e+00	0.000e+00	-50.480	-50.480	0.000
S(6)		1.249e-05				
	SO4-2	1.243e-05	1.162e-05	-4.906	-4.935	-0.029
	MgSO4	3.138e-08	3.138e-08	-7.503	-7.503	0.000
	HSO4-	1.447e-08	1.423e-08	-7.840	-7.847	-0.007
	CaSO4	1.080e-08	1.080e-08	-7.966	-7.966	0.000
	NaSO4-	7.602e-09	7.476e-09	-8.119	-8.126	-0.007
	KSO4-	4.209e-10	4.139e-10	-9.376	-9.383	-0.007

Phase	SI	log IAP	log KT	
Anhydrite	-5.91	-10.27	-4.36	CaSO4
Gypsum	-5.69	-10.27	-4.58	CaSO4:2H2O
H2(g)	-17.80	-17.80	0.00	H2
H2O	0.00	0.00	0.00	H2O
O2(g)	-47.52	35.60	83.12	O2

Initial solution 2. LS5

Elements	Molality	Moles
C(4)	2.623e-04	2.623e-04
Ca	1.288e-03	1.288e-03
Cl	9.028e-05	9.028e-05
K	3.581e-05	3.581e-05
Mg	2.222e-04	2.222e-04
Na	1.740e-04	1.740e-04
S(6)	1.479e-03	1.479e-03
Zn	2.157e-04	2.157e-04

pH = 6.700
pe = 4.000
Activity of water = 1.000
Ionic strength = 5.793e-03
Mass of water (kg) = 1.000e+00
Total alkalinity (eq/kg) = 1.892e-04

Total CO2 (mol/kg)	=	2.623e-04
Temperature (deg C)	=	25.000
Electrical balance (eq)	=	4.246e-04
Iterations	=	8
Total H	=	1.110126e+02
Total O	=	5.551284e+01

	Species		Molality	Activity	Log Molality	Log Activity	Log Gamma
	H+		2.147e-07	1.995e-07	-6.668	-6.700	-0.032
	OH-		5.447e-08	5.017e-08	-7.264	-7.300	-0.036
	H2O		5.551e+01	9.999e-01	0.000	0.000	0.000
C(4)		2.623e-04					
	HCO3-		1.810e-04	1.672e-04	-3.742	-3.777	-0.034
	CO2		7.492e-05	7.502e-05	-4.125	-4.125	0.001
	ZnHCO3+		3.023e-06	2.787e-06	-5.520	-5.555	-0.035
	CaHCO3+		1.909e-06	1.764e-06	-5.719	-5.754	-0.034
	ZnCO3		1.037e-06	1.038e-06	-5.984	-5.984	0.001
	MgHCO3+		2.976e-07	2.744e-07	-6.526	-6.562	-0.035
	CaCO3		5.452e-08	5.459e-08	-7.263	-7.263	0.001
	CO3-2		5.389e-08	3.931e-08	-7.269	-7.406	-0.137
	NaHCO3		1.501e-08	1.503e-08	-7.824	-7.823	0.001
	MgCO3		5.253e-09	5.260e-09	-8.280	-8.279	0.001
	Zn(CO3)2-2		1.207e-09	8.724e-10	-8.918	-9.059	-0.141
	NaCO3-		1.269e-10	1.170e-10	-9.897	-9.932	-0.035
Ca		1.288e-03					
	Ca+2		1.134e-03	8.267e-04	-2.945	-3.083	-0.137
	CaSO4		1.517e-04	1.519e-04	-3.819	-3.819	0.001
	CaHCO3+		1.909e-06	1.764e-06	-5.719	-5.754	-0.034
	CaCO3		5.452e-08	5.459e-08	-7.263	-7.263	0.001
	CaOH+		7.457e-10	6.876e-10	-9.127	-9.163	-0.035
Cl		9.028e-05					
	Cl-		9.025e-05	8.313e-05	-4.045	-4.080	-0.036
	ZnCl+		3.212e-08	2.962e-08	-7.493	-7.528	-0.035
	ZnCl2		2.575e-12	2.579e-12	-11.589	-11.589	0.001
	ZnCl3-		2.609e-16	2.405e-16	-15.584	-15.619	-0.035
	ZnCl4-2		1.386e-20	1.002e-20	-19.858	-19.999	-0.141
H(0)		5.629e-25					
	H2		2.815e-25	2.818e-25	-24.551	-24.550	0.001
K		3.581e-05					
	K+		3.558e-05	3.278e-05	-4.449	-4.484	-0.036
	KSO4-		2.317e-07	2.136e-07	-6.635	-6.670	-0.035
	KOH		5.688e-13	5.695e-13	-12.245	-12.244	0.001
Mg		2.222e-04					
	Mg+2		1.916e-04	1.402e-04	-3.718	-3.853	-0.136
	MgSO4		3.023e-05	3.027e-05	-4.520	-4.519	0.001
	MgHCO3+		2.976e-07	2.744e-07	-6.526	-6.562	-0.035
	MgCO3		5.253e-09	5.260e-09	-8.280	-8.279	0.001
	MgOH+		2.768e-09	2.552e-09	-8.558	-8.593	-0.035
Na		1.740e-04					
	Na+		1.732e-04	1.598e-04	-3.761	-3.796	-0.035
	NaSO4-		7.999e-07	7.376e-07	-6.097	-6.132	-0.035
	NaHCO3		1.501e-08	1.503e-08	-7.824	-7.823	0.001

	NaCO3-	1.269e-10	1.170e-10	-9.897	-9.932	-0.035
	NaOH	5.285e-12	5.292e-12	-11.277	-11.276	0.001
O(0)	0.000e+00					
	O2	0.000e+00	0.000e+00	-43.281	-43.280	0.001
S(6)	1.479e-03					
	SO4-2	1.266e-03	9.207e-04	-2.897	-3.036	-0.138
	CaSO4	1.517e-04	1.519e-04	-3.819	-3.819	0.001
	MgSO4	3.023e-05	3.027e-05	-4.520	-4.519	0.001
	ZnSO4	2.853e-05	2.857e-05	-4.545	-4.544	0.001
	NaSO4-	7.999e-07	7.376e-07	-6.097	-6.132	-0.035
	Zn(SO4)2-2	2.958e-07	2.138e-07	-6.529	-6.670	-0.141
	KSO4-	2.317e-07	2.136e-07	-6.635	-6.670	-0.035
	HSO4-	1.937e-08	1.786e-08	-7.713	-7.748	-0.035
Zn	2.157e-04					
	Zn+2	1.820e-04	1.324e-04	-3.740	-3.878	-0.138
	ZnSO4	2.853e-05	2.857e-05	-4.545	-4.544	0.001
	ZnHCO3+	3.023e-06	2.787e-06	-5.520	-5.555	-0.035
	ZnCO3	1.037e-06	1.038e-06	-5.984	-5.984	0.001
	ZnOH+	7.889e-07	7.274e-07	-6.103	-6.138	-0.035
	Zn(SO4)2-2	2.958e-07	2.138e-07	-6.529	-6.670	-0.141
	Zn(OH)2	4.180e-08	4.186e-08	-7.379	-7.378	0.001
	ZnCl+	3.212e-08	2.962e-08	-7.493	-7.528	-0.035
	Zn(CO3)2-2	1.207e-09	8.724e-10	-8.918	-9.059	-0.141
	ZnCl2	2.575e-12	2.579e-12	-11.589	-11.589	0.001
	Zn(OH)3-	7.194e-13	6.633e-13	-12.143	-12.178	-0.035
	ZnCl3-	2.609e-16	2.405e-16	-15.584	-15.619	-0.035
	Zn(OH)4-2	7.289e-19	5.269e-19	-18.137	-18.278	-0.141
	ZnCl4-2	1.386e-20	1.002e-20	-19.858	-19.999	-0.141

Phase	SI	log IAP	log KT	
Anhydrite	-1.76	-6.12	-4.36	CaSO4
Aragonite	-2.15	-10.49	-8.34	CaCO3
Calcite	-2.01	-10.49	-8.48	CaCO3
CO2(g)	-2.66	-20.81	-18.15	CO2
Dolomite	-4.66	-21.75	-17.09	CaMg(CO3)2
Gypsum	-1.54	-6.12	-4.58	CaSO4:2H2O
H2(g)	-21.40	-21.40	0.00	H2
H2O	0.00	0.00	0.00	H2O
O2(g)	-40.32	42.80	83.12	O2
Smithsonite	-1.28	-11.28	-10.00	ZnCO3
Zn(OH)2(e)	-1.98	9.52	11.50	Zn(OH)2

Initial solution 3. Vs4

Elements	Molality	Moles
Ca	1.900e-03	1.900e-03
Cl	1.168e-03	1.168e-03
K	6.653e-05	6.653e-05
Mg	6.626e-04	6.626e-04
Na	1.149e-03	1.149e-03
S(6)	2.999e-03	2.999e-03
Zn	7.086e-04	7.086e-04

pH	=	4.700
pe	=	4.000
Activity of water	=	1.000
Ionic strength	=	1.136e-02
Mass of water (kg)	=	1.000e+00
Total alkalinity (eq/kg)	=	-2.530e-05
Total carbon (mol/kg)	=	0.000e+00
Total CO2 (mol/kg)	=	0.000e+00
Temperature (deg C)	=	25.000
Electrical balance (eq)	=	6.151e-04
Iterations	=	4
Total H	=	1.110125e+02
Total O	=	5.551821e+01

	Species	Molality	Activity	Log Molality	Log Activity	Log Gamma
	H+	2.195e-05	1.995e-05	-4.659	-4.700	-0.041
	OH-	5.609e-10	5.017e-10	-9.251	-9.300	-0.049
	H2O	5.551e+01	9.999e-01	0.000	0.000	0.000
Ca		1.900e-03				
	Ca+2	1.578e-03	1.034e-03	-2.802	-2.985	-0.183
	CaSO4	3.214e-04	3.223e-04	-3.493	-3.492	0.001
	CaOH+	9.596e-12	8.602e-12	-11.018	-11.065	-0.047
Cl		1.168e-03				
	Cl-	1.167e-03	1.044e-03	-2.933	-2.981	-0.048
	ZnCl+	1.164e-06	1.044e-06	-5.934	-5.981	-0.047
	ZnCl2	1.138e-09	1.141e-09	-8.944	-8.943	0.001
	ZnCl3-	1.492e-12	1.337e-12	-11.826	-11.874	-0.047
	ZnCl4-2	1.084e-15	6.999e-16	-14.965	-15.155	-0.190
H(0)		5.622e-21				
	H2	2.811e-21	2.818e-21	-20.551	-20.550	0.001
K		6.653e-05				
	K+	6.580e-05	5.887e-05	-4.182	-4.230	-0.048
	KSO4-	7.260e-07	6.508e-07	-6.139	-6.187	-0.047
	KOH	1.020e-14	1.023e-14	-13.991	-13.990	0.001
Mg		6.626e-04				
	Mg+2	5.339e-04	3.524e-04	-3.273	-3.453	-0.180
	MgSO4	1.287e-04	1.290e-04	-3.891	-3.889	0.001
	MgOH+	7.153e-11	6.412e-11	-10.146	-10.193	-0.047
Na		1.149e-03				
	Na+	1.140e-03	1.023e-03	-2.943	-2.990	-0.047
	NaSO4-	8.933e-06	8.008e-06	-5.049	-5.096	-0.047
	NaOH	3.379e-13	3.388e-13	-12.471	-12.470	0.001
O(0)		0.000e+00				
	O2	0.000e+00	0.000e+00	-51.281	-51.280	0.001
S(6)		2.999e-03				
	SO4-2	2.395e-03	1.562e-03	-2.621	-2.806	-0.186
	CaSO4	3.214e-04	3.223e-04	-3.493	-3.492	0.001
	ZnSO4	1.356e-04	1.360e-04	-3.868	-3.867	0.001
	MgSO4	1.287e-04	1.290e-04	-3.891	-3.889	0.001
	NaSO4-	8.933e-06	8.008e-06	-5.049	-5.096	-0.047
	HSO4-	3.379e-06	3.029e-06	-5.471	-5.519	-0.047
	Zn(SO4)2-2	2.672e-06	1.726e-06	-5.573	-5.763	-0.190

KSO4-	7.260e-07	6.508e-07	-6.139	-6.187	-0.047
Zn 7.086e-04					
Zn+2	5.692e-04	3.714e-04	-3.245	-3.430	-0.185
ZnSO4	1.356e-04	1.360e-04	-3.868	-3.867	0.001
Zn(SO4)2-2	2.672e-06	1.726e-06	-5.573	-5.763	-0.190
ZnCl+	1.164e-06	1.044e-06	-5.934	-5.981	-0.047
ZnOH+	2.277e-08	2.041e-08	-7.643	-7.690	-0.047
ZnCl2	1.138e-09	1.141e-09	-8.944	-8.943	0.001
Zn(OH)2	1.171e-11	1.174e-11	-10.931	-10.930	0.001
ZnCl3-	1.492e-12	1.337e-12	-11.826	-11.874	-0.047
ZnCl4-2	1.084e-15	6.999e-16	-14.965	-15.155	-0.190
Zn(OH)3-	2.076e-18	1.861e-18	-17.683	-17.730	-0.047
Zn(OH)4-2	2.288e-26	1.478e-26	-25.640	-25.830	-0.190

Phase	SI	log IAP	log KT	
Anhydrite	-1.43	-5.79	-4.36	CaSO4
Gypsum	-1.21	-5.79	-4.58	CaSO4:2H2O
H2(g)	-17.40	-17.40	0.00	H2
H2O	0.00	0.00	0.00	H2O
O2(g)	-48.32	34.80	83.12	O2
Zn(OH)2(e)	-5.53	5.97	11.50	Zn(OH)2

Beginning of inverse modeling calculations.

Solution 1: Rain

pH	4.900e+00	+	0.000e+00	=	4.900e+00
Al	0.000e+00	+	0.000e+00	=	0.000e+00
Alkalinity	-1.281e-05	+	0.000e+00	=	-1.281e-05
C(-4)	0.000e+00	+	0.000e+00	=	0.000e+00
C(4)	0.000e+00	+	0.000e+00	=	0.000e+00
Ca	4.990e-06	+	0.000e+00	=	4.990e-06
Cl	1.551e-04	+	0.000e+00	=	1.551e-04
Cu(1)	0.000e+00	+	0.000e+00	=	0.000e+00
Cu(2)	0.000e+00	+	0.000e+00	=	0.000e+00
Fe(2)	0.000e+00	+	0.000e+00	=	0.000e+00
Fe(3)	0.000e+00	+	0.000e+00	=	0.000e+00
H(0)	0.000e+00	+	0.000e+00	=	0.000e+00
K	5.115e-06	+	0.000e+00	=	5.115e-06
Mg	1.234e-05	+	0.000e+00	=	1.234e-05
Na	1.305e-04	+	-2.959e-06	=	1.275e-04
O(0)	0.000e+00	+	0.000e+00	=	0.000e+00
S(-2)	0.000e+00	+	0.000e+00	=	0.000e+00
S(6)	1.249e-05	+	0.000e+00	=	1.249e-05
Si	0.000e+00	+	0.000e+00	=	0.000e+00
Zn	0.000e+00	+	0.000e+00	=	0.000e+00

Solution 2: LS5

pH	6.700e+00	+	0.000e+00	=	6.700e+00
Al	0.000e+00	+	0.000e+00	=	0.000e+00
Alkalinity	1.892e-04	+	0.000e+00	=	1.892e-04
C(-4)	0.000e+00	+	0.000e+00	=	0.000e+00

```
              C(4)      2.623e-04  +   0.000e+00  =   2.623e-04
                Ca      1.288e-03  +  -2.569e-04  =   1.031e-03
                Cl      9.028e-05  +   0.000e+00  =   9.028e-05
             Cu(1)      0.000e+00  +   0.000e+00  =   0.000e+00
             Cu(2)      0.000e+00  +   0.000e+00  =   0.000e+00
             Fe(2)      0.000e+00  +   0.000e+00  =   0.000e+00
             Fe(3)      0.000e+00  +   0.000e+00  =   0.000e+00
              H(0)      0.000e+00  +   0.000e+00  =   0.000e+00
                 K      3.581e-05  +  -8.953e-06  =   2.686e-05
                Mg      2.222e-04  +   0.000e+00  =   2.222e-04
                Na      1.740e-04  +   0.000e+00  =   1.740e-04
              O(0)      0.000e+00  +   0.000e+00  =   0.000e+00
             S(-2)      0.000e+00  +   0.000e+00  =   0.000e+00
              S(6)      1.479e-03  +   4.804e-06  =   1.483e-03
                Si      0.000e+00  +   0.000e+00  =   0.000e+00
                Zn      2.157e-04  +   5.394e-05  =   2.697e-04

Solution 3: Vs4
                pH      4.700e+00  +   0.000e+00  =   4.700e+00
                Al      0.000e+00  +   0.000e+00  =   0.000e+00
        Alkalinity     -2.530e-05  +   0.000e+00  =  -2.530e-05
             C(-4)      0.000e+00  +   0.000e+00  =   0.000e+00
              C(4)      0.000e+00  +   0.000e+00  =   0.000e+00
                Ca      1.900e-03  +   0.000e+00  =   1.900e-03
                Cl      1.168e-03  +  -7.366e-05  =   1.095e-03
             Cu(1)      0.000e+00  +   0.000e+00  =   0.000e+00
             Cu(2)      0.000e+00  +   0.000e+00  =   0.000e+00
             Fe(2)      0.000e+00  +   0.000e+00  =   0.000e+00
             Fe(3)      0.000e+00  +   0.000e+00  =   0.000e+00
              H(0)      0.000e+00  +   0.000e+00  =   0.000e+00
                 K      6.653e-05  +   1.663e-05  =   8.316e-05
                Mg      6.626e-04  +  -1.518e-04  =   5.107e-04
                Na      1.149e-03  +  -5.230e-05  =   1.097e-03
              O(0)      0.000e+00  +   0.000e+00  =   0.000e+00
             S(-2)      0.000e+00  +   0.000e+00  =   0.000e+00
              S(6)      2.999e-03  +  -2.428e-06  =   2.997e-03
                Si      0.000e+00  +   0.000e+00  =   0.000e+00
                Zn      7.086e-04  +  -1.772e-04  =   5.315e-04

Solution fractions:                   Minimum        Maximum
   Solution   1         5.909e+00   0.000e+00      0.000e+00
   Solution   2         1.971e+00   0.000e+00      0.000e+00
   Solution   3         1.000e+00   0.000e+00      0.000e+00

Phase mole transfers:                 Minimum        Maximum
              H2O      -3.819e+02   0.000e+00      0.000e+00   H2O
          Calcite      -1.612e-04   0.000e+00      0.000e+00   CaCO3
           CO2(g)      -3.556e-04   0.000e+00      0.000e+00   CO2

Sum of residuals:                                    9.808e+00
Maximum fractional error in element concentration:   2.500e-01

Model contains minimum number of phases.
==============================================================================
```

Solution 1: Rain

pH	4.900e+00	+	0.000e+00	=	4.900e+00
Al	0.000e+00	+	0.000e+00	=	0.000e+00
Alkalinity	-1.281e-05	+	0.000e+00	=	-1.281e-05
C(-4)	0.000e+00	+	0.000e+00	=	0.000e+00
C(4)	0.000e+00	+	0.000e+00	=	0.000e+00
Ca	4.990e-06	+	0.000e+00	=	4.990e-06
Cl	1.551e-04	+	0.000e+00	=	1.551e-04
Cu(1)	0.000e+00	+	0.000e+00	=	0.000e+00
Cu(2)	0.000e+00	+	0.000e+00	=	0.000e+00
Fe(2)	0.000e+00	+	0.000e+00	=	0.000e+00
Fe(3)	0.000e+00	+	0.000e+00	=	0.000e+00
H(0)	0.000e+00	+	0.000e+00	=	0.000e+00
K	5.115e-06	+	0.000e+00	=	5.115e-06
Mg	1.234e-05	+	0.000e+00	=	1.234e-05
Na	1.305e-04	+	-2.959e-06	=	1.275e-04
O(0)	0.000e+00	+	0.000e+00	=	0.000e+00
S(-2)	0.000e+00	+	0.000e+00	=	0.000e+00
S(6)	1.249e-05	+	0.000e+00	=	1.249e-05
Si	0.000e+00	+	0.000e+00	=	0.000e+00
Zn	0.000e+00	+	0.000e+00	=	0.000e+00

Solution 2: LS5

pH	6.700e+00	+	0.000e+00	=	6.700e+00
Al	0.000e+00	+	0.000e+00	=	0.000e+00
Alkalinity	1.892e-04	+	0.000e+00	=	1.892e-04
C(-4)	0.000e+00	+	0.000e+00	=	0.000e+00
C(4)	2.623e-04	+	0.000e+00	=	2.623e-04
Ca	1.288e-03	+	-2.205e-04	=	1.067e-03
Cl	9.028e-05	+	0.000e+00	=	9.028e-05
Cu(1)	0.000e+00	+	0.000e+00	=	0.000e+00
Cu(2)	0.000e+00	+	0.000e+00	=	0.000e+00
Fe(2)	0.000e+00	+	0.000e+00	=	0.000e+00
Fe(3)	0.000e+00	+	0.000e+00	=	0.000e+00
H(0)	0.000e+00	+	0.000e+00	=	0.000e+00
K	3.581e-05	+	0.000e+00	=	3.581e-05
Mg	2.222e-04	+	0.000e+00	=	2.222e-04
Na	1.740e-04	+	0.000e+00	=	1.740e-04
O(0)	0.000e+00	+	0.000e+00	=	0.000e+00
S(-2)	0.000e+00	+	0.000e+00	=	0.000e+00
S(6)	1.479e-03	+	0.000e+00	=	1.479e-03
Si	0.000e+00	+	0.000e+00	=	0.000e+00
Zn	2.157e-04	+	8.214e-06	=	2.240e-04

Solution 3: Vs4

pH	4.700e+00	+	0.000e+00	=	4.700e+00
Al	0.000e+00	+	0.000e+00	=	0.000e+00
Alkalinity	-2.530e-05	+	0.000e+00	=	-2.530e-05
C(-4)	0.000e+00	+	0.000e+00	=	0.000e+00
C(4)	0.000e+00	+	0.000e+00	=	0.000e+00
Ca	1.900e-03	+	4.749e-04	=	2.375e-03
Cl	1.168e-03	+	0.000e+00	=	1.168e-03
Cu(1)	0.000e+00	+	0.000e+00	=	0.000e+00
Cu(2)	0.000e+00	+	0.000e+00	=	0.000e+00

Fe(2)	0.000e+00	+	0.000e+00	=	0.000e+00
Fe(3)	0.000e+00	+	0.000e+00	=	0.000e+00
H(0)	0.000e+00	+	0.000e+00	=	0.000e+00
K	6.653e-05	+	0.000e+00	=	6.653e-05
Mg	6.626e-04	+	-6.839e-05	=	5.942e-04
Na	1.149e-03	+	9.813e-05	=	1.247e-03
O(0)	0.000e+00	+	0.000e+00	=	0.000e+00
S(-2)	0.000e+00	+	0.000e+00	=	0.000e+00
S(6)	2.999e-03	+	5.860e-04	=	3.585e-03
Si	0.000e+00	+	0.000e+00	=	0.000e+00
Zn	7.086e-04	+	-1.772e-04	=	5.315e-04

Solution fractions:		Minimum	Maximum
Solution 1	6.150e+00	0.000e+00	0.000e+00
Solution 2	2.373e+00	0.000e+00	0.000e+00
Solution 3	1.000e+00	0.000e+00	0.000e+00

Phase mole transfers:		Minimum	Maximum	
H2O	-4.176e+02	0.000e+00	0.000e+00	H2O
Calcite	-2.184e-04	0.000e+00	0.000e+00	CaCO3
CO2(g)	-4.040e-04	0.000e+00	0.000e+00	CO2
plagioclase	8.018e-05	0.000e+00	0.000e+00	
K-feldspar	-2.848e-05	0.000e+00	0.000e+00	KAlSi3O8
Illite	-3.573e-05	0.000e+00	0.000e+00	

Sum of residuals: 6.081e+00

Maximum fractional error in element concentration: 2.500e-01

==

Solution 1: Rain

pH	4.900e+00	+	0.000e+00	=	4.900e+00
Al	0.000e+00	+	0.000e+00	=	0.000e+00
Alkalinity	-1.281e-05	+	0.000e+00	=	-1.281e-05
C(-4)	0.000e+00	+	0.000e+00	=	0.000e+00
C(4)	0.000e+00	+	0.000e+00	=	0.000e+00
Ca	4.990e-06	+	0.000e+00	=	4.990e-06
Cl	1.551e-04	+	0.000e+00	=	1.551e-04
Cu(1)	0.000e+00	+	0.000e+00	=	0.000e+00
Cu(2)	0.000e+00	+	0.000e+00	=	0.000e+00
Fe(2)	0.000e+00	+	0.000e+00	=	0.000e+00
Fe(3)	0.000e+00	+	0.000e+00	=	0.000e+00
H(0)	0.000e+00	+	0.000e+00	=	0.000e+00
K	5.115e-06	+	0.000e+00	=	5.115e-06
Mg	1.234e-05	+	0.000e+00	=	1.234e-05
Na	1.305e-04	+	-2.959e-06	=	1.275e-04
O(0)	0.000e+00	+	0.000e+00	=	0.000e+00
S(-2)	0.000e+00	+	0.000e+00	=	0.000e+00
S(6)	1.249e-05	+	0.000e+00	=	1.249e-05
Si	0.000e+00	+	0.000e+00	=	0.000e+00
Zn	0.000e+00	+	0.000e+00	=	0.000e+00

Solution 2: LS5

pH	6.700e+00	+	0.000e+00	=	6.700e+00
Al	0.000e+00	+	0.000e+00	=	0.000e+00
Alkalinity	1.892e-04	+	0.000e+00	=	1.892e-04
C(-4)	0.000e+00	+	0.000e+00	=	0.000e+00

C(4)	2.623e-04	+	0.000e+00	=	2.623e-04
Ca	1.288e-03	+	-1.762e-04	=	1.112e-03
Cl	9.028e-05	+	0.000e+00	=	9.028e-05
Cu(1)	0.000e+00	+	0.000e+00	=	0.000e+00
Cu(2)	0.000e+00	+	0.000e+00	=	0.000e+00
Fe(2)	0.000e+00	+	0.000e+00	=	0.000e+00
Fe(3)	0.000e+00	+	0.000e+00	=	0.000e+00
H(0)	0.000e+00	+	0.000e+00	=	0.000e+00
K	3.581e-05	+	0.000e+00	=	3.581e-05
Mg	2.222e-04	+	0.000e+00	=	2.222e-04
Na	1.740e-04	+	0.000e+00	=	1.740e-04
O(0)	0.000e+00	+	0.000e+00	=	0.000e+00
S(-2)	0.000e+00	+	0.000e+00	=	0.000e+00
S(6)	1.479e-03	+	9.001e-05	=	1.569e-03
Si	0.000e+00	+	0.000e+00	=	0.000e+00
Zn	2.157e-04	+	5.394e-05	=	2.697e-04

Solution 3: Vs4

pH	4.700e+00	+	0.000e+00	=	4.700e+00
Al	0.000e+00	+	0.000e+00	=	0.000e+00
Alkalinity	-2.530e-05	+	0.000e+00	=	-2.530e-05
C(-4)	0.000e+00	+	0.000e+00	=	0.000e+00
C(4)	0.000e+00	+	0.000e+00	=	0.000e+00
Ca	1.900e-03	+	0.000e+00	=	1.900e-03
Cl	1.168e-03	+	0.000e+00	=	1.168e-03
Cu(1)	0.000e+00	+	0.000e+00	=	0.000e+00
Cu(2)	0.000e+00	+	0.000e+00	=	0.000e+00
Fe(2)	0.000e+00	+	0.000e+00	=	0.000e+00
Fe(3)	0.000e+00	+	0.000e+00	=	0.000e+00
H(0)	0.000e+00	+	0.000e+00	=	0.000e+00
K	6.653e-05	+	1.663e-05	=	8.316e-05
Mg	6.626e-04	+	2.765e-05	=	6.902e-04
Na	1.149e-03	+	1.012e-05	=	1.159e-03
O(0)	0.000e+00	+	0.000e+00	=	0.000e+00
S(-2)	0.000e+00	+	0.000e+00	=	0.000e+00
S(6)	2.999e-03	+	1.714e-04	=	3.171e-03
Si	0.000e+00	+	0.000e+00	=	0.000e+00
Zn	7.086e-04	+	-1.772e-04	=	5.315e-04

Solution fractions:		Minimum	Maximum
Solution 1	6.384e+00	0.000e+00	0.000e+00
Solution 2	1.971e+00	0.000e+00	0.000e+00
Solution 3	1.000e+00	0.000e+00	0.000e+00

Phase mole transfers:		Minimum	Maximum	
H2O	-4.082e+02	0.000e+00	0.000e+00	H2O
Calcite	-3.238e-04	0.000e+00	0.000e+00	CaCO3
CO2(g)	-1.931e-04	0.000e+00	0.000e+00	CO2
plagioclase	3.014e-06	0.000e+00	0.000e+00	
Illite	-3.345e-05	0.000e+00	0.000e+00	
Chlorite(14A)	3.639e-05	0.000e+00	0.000e+00	

Sum of residuals: 6.539e+00
Maximum fractional error in element concentration: 2.500e-01

```
================================================================================
Summary of inverse modeling:

      Number of models found: 3
      Number of minimal models found: 1
      Number of infeasible sets of phases saved: 10
      Number of calls to cl1: 269
------------------
End of simulation.
------------------

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Reading input data for simulation 2.
-------------------------------------

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End of run.
-----------
```

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The marginal performance of the polishing ponds during the winter months and the repeated good zinc removal (Figures 37 to 43; Section 7) during summer months prompted a re-evaluation of the zinc removal process. The assumption was made that, if the removal process is understood, it can then be controlled or promoted. In Schematic 3, all disciplines utilized, or potential areas which may be affecting performance, are given.

The nutrient limiting plant growth in the system, phosphate, has been identified. In April, 1996, geochemical simulations suggested that additions of phosphate would result in zinc phosphate formation, but the reactions are rather slow and biological activity could potentially remove the phosphate prior to any chemical reactions. This appeared to be confirmed by laboratory growth experiments where phosphate, added to periphyton cultures, was rapidly removed from solution.

A small field trial in Polishing Pond 11 produced important results regarding the fate of phosphate following addition to the system. Concentrations of phosphate could be predicted based on the flow in the pond. In mini-limnocorrals, where a relatively large mass of periphyton was incubated in a closed volume of pond water over 3 days, most of the added phosphate was not detectable in this solution. This confirmed the results of the geochemical simulations which suggested that zinc-phosphate should slowly form and precipitate. The results of analysis of the filter paper used to filter the mini-limnocorral solution (Table 27, Section 6) confirms that a considerable quantity of zinc and phosphate had precipitated in this solution.

If some phosphate remobilizes from zinc phosphate settled to the bottom of polishing ponds, primary productivity in these ponds should increase, as indicated by from the results of phytoplankton counts for OWP and Polishing Pond 17 (Table 19 and 20; Section 5). These data on small-celled phytoplankton also revealed that virtually no phytoplankton growth is present the OEP, even though the TOC values were relatively high in OEP bottom water samples (Table 36; Section 8.1). This could be explained if picoplankton growth was present in this pit, information which are still outstanding at this time. It was concluded that, based on available phytoplankton data, physical factors in OEP inhibit growth, as these organisms are subjected to poor/ lethal growing conditions, including low light availability, variable water chemistry in surface water, and turbulent flow in the epilimnion as it mixes with hypolimnion water along the thermocline stratum in summer. Turbulent flow in summer months was suggested from observations of round/globular particles during the growing season but more elongated, crystalline particles towards the end of the growing season.

If we assume that particle formation can be assisted by the production of phytoplankton particles and that zinc, adsorbed onto iron hydroxide particles, will be captured by periphyton biomass surfaces in the polishing ponds, then performance data for the polishing ponds during the summer can be reasonably well explained. However, the iron precipitation experiments, discussed in Section 3.0, clearly indicate that zinc precipitation and iron precipitation are independent processes. A review of the chemistry of the removal process, outlined in previous reports, suggested that zinc carbonate is formed. This has been confirmed by the assay data indicating zinc accumulation in polishing pond algae and moss biomass, and by the SEM/EDX observations on the material from the sedimentation traps (Section 4.0).

The monitoring data were reanalyzed on the premise that, if there is an independent zinc removal process involving zinc carbonate precipitation, then variation in zinc removal with the seasons should be observed. This has been confirmed for effluents close to the waste source (Section 1.0). With this new removal process in mind, the main objective was then to determine the specific mechanism of zinc carbonate formation and precipitation, particularly in relation to seasonal variations in temperature, flow patterns and gas exchange between the water bodies and the atmosphere.

The SEM/EDX clearly suggested that small crystals accumulate around the iron particles. Surface science parameters for particle formation and settling were reviewed. In Figure 44, the buoyancy and sedimentation coefficients are given for selected bio-organic and inorganic particles, including those species known to be present in the OEP or OWP water.

A field experiment testing iron oxide-rich local sand, as well as bentonite, confirmed that zinc was not adsorbed, as the negatively-charged surface of the bentonite did not reduce zinc concentrations. Thus, additions of oxides and/or bentonite would not assist the settling of the particles.

In Figure 44, the distribution of various major compounds, typically found in surface waters is presented according to particle size. This figure reveals that the arbitrary cut off size, 0.45 μm, typically used to distinguish dissolved compounds from particulate, is inappropriate for present purposes, since both iron hydroxide and inorganic precipitates of zinc carbonate can be less than 0.45 μm in size. SEM examinations at 20,000 x magnification suggested that the coat of zinc carbonate is about 100 nm on particles 0.25 to 1 μm in size. These size ranges also explained the last experiment (conducted in January by G. Neary), where fertilizer-treated OEP water samples, filtered through 0.45 μm filters contained similar zinc concentrations as whole samples (Table 18, Section 3). In this experiment, where fertilizer was added such that phosphate molar concentration was the same as the molar concentration of Ca+Mg+Zn, Mg+Zn or just Zn, 73 % to 87 % of the zinc was removed in the Zn or Mg+Zn treatments, respectively. These results suggested that indeed zinc phosphate may be formed. The precipitate is presently being subjected to SEM/EDX for determination of the composition of the particles/ precipitates.

Assuming that all the above observations solidly back zinc carbonate precipitation as the removal process, then a completely different picture emerges for the biological polishing approach. The biological components and the physical components of the system are integral to the zinc removal process, in that zinc carbonate can only form when CO_2 can degas from surfacing ground water, and particles can only settle when the hydrodynamic conditions permit, such as in the vicinity of periphyton biomass in quiet parts of the polishing ponds, and on iron hydroxide particles large enough to settle despite flow conditions.

In Schematic 4, an overview of the ongoing processes are summarized, including the basics of the 'iron wheel' and the carbon dioxide-bicarbonate-carbonate reaction series. The findings of the geochemical simulations suggest that the Valley seeps are composed of Lucky Strike water which has evaporated and then degassed, again demonstrating the dominance of inorganic carbon species as a controlling factor in the precipitation zinc carbonate. The solubilities of carbon dioxide are given in Table 39, for connection of the behaviour of the biological polishing system to temperature and, in turn, to the formation of a zinc carbonate. In Figures 46, 47 and 48, other aspects of the carbon dioxide-bicarbonate-carbonate series, controlling the zinc removal process, are presented. Inorganic carbon chemistry has to be fully integrated before a complete understanding of the removal mechanism is reached.

Since the Buchans water chemistry is dominated by the inorganic carbon reaction series, other elements competing with zinc for carbonate, as well as phosphate, will also come into play. The concentrations of Ca, Fe, Mg and Mn in OEP and OWP, all potential forming carbonates and phosphates, are plotted for the surface and bottom waters of both glory holes. All available ICP data for these elements, collected since decommissioning activities started, are presented. In OEP, a decrease in the Ca concentration over the years is noted in the surface water, but not for bottom water. Fe, Mn and Mg remained at relatively constant concentrations in both surface and bottom waters. However if the scale is changed, a subtle decrease in Mg concentrations in the surface water since 1989 is noted for OEP (Fig 50c), from 40 mg/L to 20 mg/L. In bottom water, the Mg concentration is constant at around 45 mg/L. Iron concentration have been somewhat erratic over time. In the OWP, a similar decrease in Ca concentrations is noted (Figure 51a and 51b) for the bottom water, but not surface water, while Fe, Mg and Mn have remained at constant concentrations.

Although this type of analysis remains to be completed for other elements, these observations suggest that different sources of water are entering the gloryholes at different locations, and that some elements could be precipitating, as observed for zinc. In Figure 52, the comparison of the slope of the Zn curve to that of Mg suggests that, indeed, these two elements may be removed by the very similar processes. In Table 40, Ca, Fe, Mg and Mn concentration data in water and captured by filter papers are summarized for both OEP and OWP. Although this is a crude 'shotgun' approach (the information drawn from Paradox database without quantification and verification of the conversion from concentrations on filter paper to amount filtered), given that the elements are reported in the filter paper analyses, these elements must be forming aggregates of particles larger than 0.45 μm.

In Figure 49a and 49b, the same elements which are suspected to be part of the zinc precipitation process are plotted for the periphyton and sedimentation trap material. Data presented in this manner suggest that Mg and Zn are strongly associated in OWP, but this association is essentially absent in solids collected from the Polishing Ponds. Note that the data were only available for the Polishing Ponds 1 to 6, since analytical costs have been minimized since scale-up of the polishing pond system. From these preliminary analyses, it is suggested that, in different parts of the system, different elements play a role in controlling the zinc precipitation process.

One further new aspect shedding additional light on long-term conditions in OEP is drawn from the conclusion of freshwater input to OEP, based on the mass balance calculations for chloride (Section 2). The flow model developed for the polishing ponds (Section 7) was extended to be used for the Drainage Tunnel and the OEP. Preliminary model calculations are given in Figures 53 a to 53 d, each utilizing different zinc input concentrations/changes with time, with and without zinc removal by sedimentation, for comparison to the measured zinc concentration trend in OEP outflow water.

In Figure 53c, the zinc concentration decreases calculated by the model and the measured decreases are in close agreement. In this scenario, zinc-containing solids, as captured in the sedimentation traps, is recycling or, as suggested in Figure 53d (Case 5), the initial concentrations was lower in the pit and the groundwater concentration is at 45 mg/L zinc. Although not all reasonable scenarios have been tested, it is likely that a considerable amounts of iron and zinc precipitating and settling in OEP are recycling. If recycling can be prevented, there may be an end to long-term treatment.

Given these radical new findings, and the overwhelming amount of data available for confirmation of these key conclusions, further analysis of the compiled data in the present report will be required. However, there is no doubt that the zinc removal process was incorrectly identified as coprecipitation with iron hydroxide and that fresh water is entering the OEP. Freshwater input may even be responsible for the observed long-term decrease in zinc concentrations, in view of the fact that iron and zinc may be recycled. Although the magnitude of this recycled fraction is not known, and the data have to be analyzed in more detail, it provides a new treatment alternative which was not recognized before.

The results of the phosphate addition experiments completed late January, 1997 using OEP water, as well as the particle size and hydrodynamic considerations, provide for the possibility of a one or two-time treatment with phosphate, and possible addition of organics as a sealant promoter of organic phosphate cycling.

If it can be confirmed that portions of zinc and iron are recycling in the OEP, that the contribution from the underground is diminishing, and that zinc-free fresh water is entering the OEP, then with a one time removal of the iron and zinc, in form of the iron phosphate/zinc phosphate, a final decommissioning solution would be provided. The particles have to be settled and chemoclines have to be destroyed. A healthy pond would replace the problem of the OEP, providing continuous polishing for the ground water zinc contribution. The elegant component of the 1996 results is the fact that, if this can be confirmed, the observations on the Valley seeps, the Lucky Strike and the Drainage Tunnel are all part of the same solution and would essentially solve the problems presented by all contaminant sources in the Buchans area.

9.2 Recommendations

1) Data Interpretation

The 1996 work has resulted in a completely new view of the Buchans situation. These new scenarios have to be evaluated in detail. The present report is considered a data report, assembling all the information gathered this year, but also represents a review of previous years' work. Normally, after all data are assembled, a systematic analysis and interpretation of the data is carried out. The 1996 objectives involved such an extensive scope of work that many aspects have not been analyzed yet and oversights of the seemingly contradictory behaviour of the chemistry cannot yet be eliminated. Therefore, Task 1 will confirm, using all available data, the new scenario.

Furthermore, organization of the available data is urgently needed, as there are 1,195 chemical analysis, of which there are 717 water chemistry analyses, 106 biomass sample analyses, 137 filter paper analyses and 235 solids analyses.
Digitized maps of the Buchans area have been completed, which can be used to generate detailed site maps providing coordinates for any sampling point.

After the data are fully interpreted, the following activities can be identified:

Final experiments and measurement to be done in winter, 1997.

- Field Studies
  - under ice experiments - phosphate reactions in ambient conditions
  - Monitoring under ice - LS, OWP, OEP, Polishing Ponds: iron, zinc, phosphate.
  - sourcing non-acidifying, non-Ca, Mg, Na fast release phosphate source, e.g. potassium phosphate.
- geochemical modelling of any changes or additions based on the existing model with O_2, CO_2 degassing; new PHEQUE version
  - are carbonates truly formed?
- Phosphate addition to OEP in winter - major considerations?
- Phosphate addition to Drainage Tunnel pump house - a consideration?
- Lucky Strike Gloryhole - Action plan?

Organize the data and validate entry and units for all data points, analyze the data set for complete set of elements which are part of the precipitation process. Test the decreases (surface and bottom) for all water bodies and all elements, i.e. Drainage Tunnel, Lucky Strike, Valley Seeps, Tailings Ponds as well as OEP and OWP.

Task 2: Phosphate Cycling in System

To arrive at these new perspectives, Dr. Hellebust (Dept. of Botany, U of Toronto) was consulted. He had periodically contributed to the biological aspects of the site for the past 10 years ago. He has agreed to evaluate the possibility to use radioactive phosphate in tracing the fate of phosphate. This clearly is a key component in zinc removal and for the biological integrity of the polishing system. The picoplankton data which are coming, together with the identifications of the precipitates from the

January experiments, will be evaluated and biological productivities projected for each polishing area, taking the present physical /chemical limitations into account.

The fate and stability of phosphate for zinc removal in the context of primary productivity in the Buchans waters. Development of a field test protocol to differentiate between biological and chemical phosphate fate. Sediment release of precipitated phosphate to provide long term phosphate fertilisation.

To determine the long term fate of the particles, their biological components are being identified. This is proposed to be carried out as an M.Sc. thesis using epifluorescence microscopy, which can identify living forms on solids particles. It can be expected that phosphate particles will be microbially transformed in the long term, since it contains one of the key limiting nutrients. In the first year, the colonisation (coating observed in SEM investigation) will be delineated.

Task 3: Factors Controlling Particle Formation

It is proposed that a surface scientist (Dr. Mikahailovski) should engaged. He has already provided perspectives on particle formation and particle sizes and their relevance in forming colloids, aggregates and hence their ability to settle out of the water column. During 1996, he has assisted in reviewing the Buchans data and has pointed out one of the key facts; only particles large enough to respond to gravitational forces would end up in the sedimentation traps. His insight into the physics and colloid chemistry added new dimensions to the sequential extractions of sedimentation trap materials (not discussed in this report; M.Sc. thesis, U of T) and oxygen availability in the OEP. A microelectrophoresis apparatus for the determination of particle sizes and charges has been located at the University of Toronto and zeta-potentials of various particles and their aggregates/colloids will be determined. With this information, the hydrodynamical changes required in the pits can be estimated. Upon this assessment, it will be possible to determine whether improvements in the particle settling characteristics can be achieved.

Task 4: Inorganic Carbon Solution Chemistry; Partial Pressure and Degassing

The new geochemist, using a version of PHREQUE which integrates gases, has provided insight into the processes which may be responsible for observed solution chemistry. Evaporation as a concentrating process for zinc in the overburden was identified. Based on chloride concentrations, using sea spray numbers and the drill hole water quality as background data, combined with degassing, produced Valley seep concentrations from Lucky strike water. The concentration process through evaporation has to be evaluated and possibly tested. Many of these aspects, given the new scenario, have to evaluated in detail, time not permitting to date. One key aspect which needs to be addressed is whether there is the potential for Lucky Strike pit's limnology to resemble that of OWP prior to Drainage Tunnel discharge, i.e. turn acid. While there was some past effort extended (some years ago) to identify the source of bicarbonate, information regarding this source in of increasing importance for the Lucky Strike, since this water is reaching the Drainage Tunnel and the Valley seeps.

Gas References	$K \times 10^{-7}$ $K = P/X$ P = partial pressure mm. of Hg X = mole fraction									
	$t = 0°$	10°	20°	30°	38°	40°	50°	60°	70°	80°
Argon.......... 1, 8, 14, 15, 17	1.65	2.18	2.58	3.02	3.41	3.49	3.76	3.92	4.12	4.25
Carbon dioxide.. 6, 7, 9, 12	.0555	.0788	.108	.139	.168	.173	.217	.258		
Helium......... 1, 3, 8, 12, 14, 15, 18, 21	10.0	10.5	10.9	11.1	11.0	10.9	10.5	10.3	9.88	
Hydrogen...... 6, 12	4.42	4.82	5.20	5.51	5.72	5.78	5.82	5.80	5.77	5.73
Krypton........ 2, 14, 15	0.853	1.20	1.52	1.85	2.13	2.18	2.43	2.66	2.83	2.94
Neon.......... (2), 8	7.68	8.49	9.14	9.45	9.76	9.80	10.0			
Nitrogen........ 12, 16, 20, 22, 23, 24	4.09	4.87	5.75	6.68	7.51	7.60	8.20	8.70	9.20	
Oxygen......... 6, 10, 12, 13	1.91	2.48	2.95	3.52	4.04	4.14	4.50	4.84	5.13	5.28

Table 39: Solubilities of Various Gases in Water. Henry's Law Constant K.

Table 40: OWP and OEP statistics for selected elements.

ORIENTAL EAST PIT				
WATER SAMPLES				
	Ca	Fe	Mg	Mn
Min	224	0.01	19.6	4.67
Max	547	88.9	57.0	17.0
Avg	387	18.0	38.5	10.6
N	76	80	76	80
FILTER PAPERS				
	Ca	Fe	Mg	Mn
Min	0.11	0.24	0.02	0.00
Max	15.0	3.53	0.58	5.75
Avg	1.33	2.09	0.12	0.38
N	16	16	16	16
ORIENTAL WEST PIT				
WATER SAMPLES				
	Ca	Fe	Mg	Mn
Min	31.0	0.02	4.00	0.18
Max	170	21.1	17	5.11
Avg	90.5	1.91	10.5	2.34
N	65	72	65	72
FILTER PAPERS				
	Ca	Fe	Mg	Mn
Min	0.14	0.22	0.04	0.002
Max	0.50	0.50	0.50	0.50
Avg	0.37	0.39	0.27	0.25
N	4	4	4	4

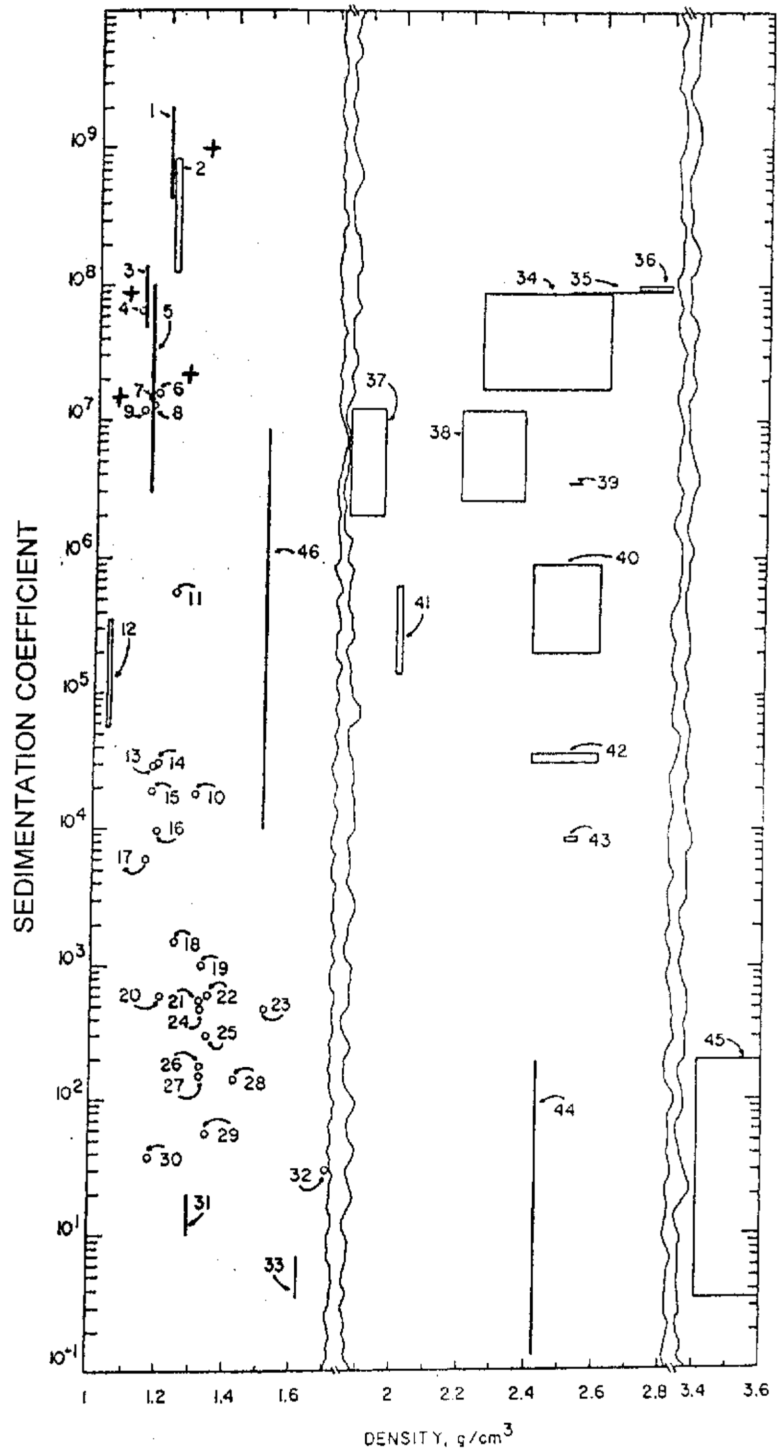


Figure 44: Semilogarithmic plot of buoyancy density and sedimentation coefficient of selected bio-organic and inorganic particles found in natural water. Species found in Buchans OWP and OEP are marked with '+'. From Ciaccio, 1971.

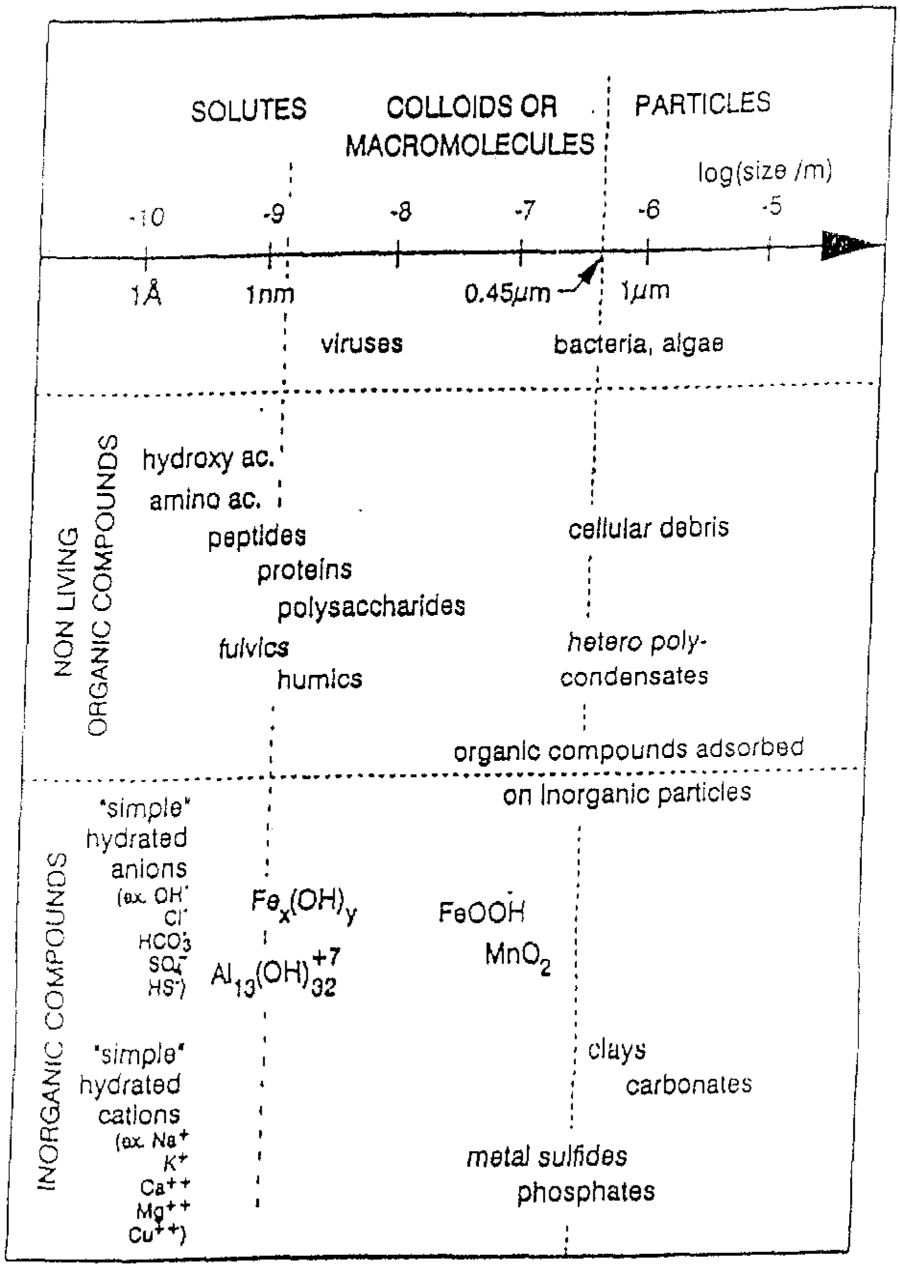
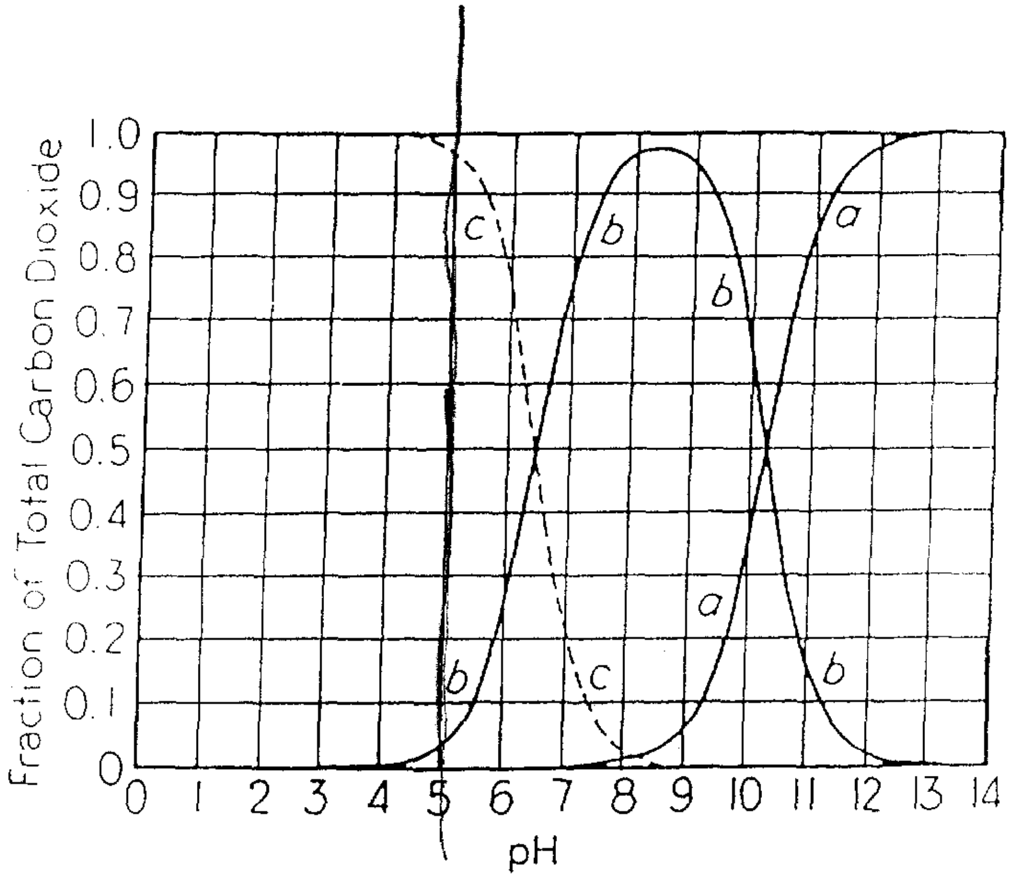


Figure 45: Nature and size domain of the important particles of aquatic systems.



a - CO_3^{-}, b - HCO_3^{-}, c - H_2CO_3

Figure 46: Curves Showing Fractions of Total Carbon Dioxide Present as the Respective Ions at Various Hydrogen Ion Concentrations.

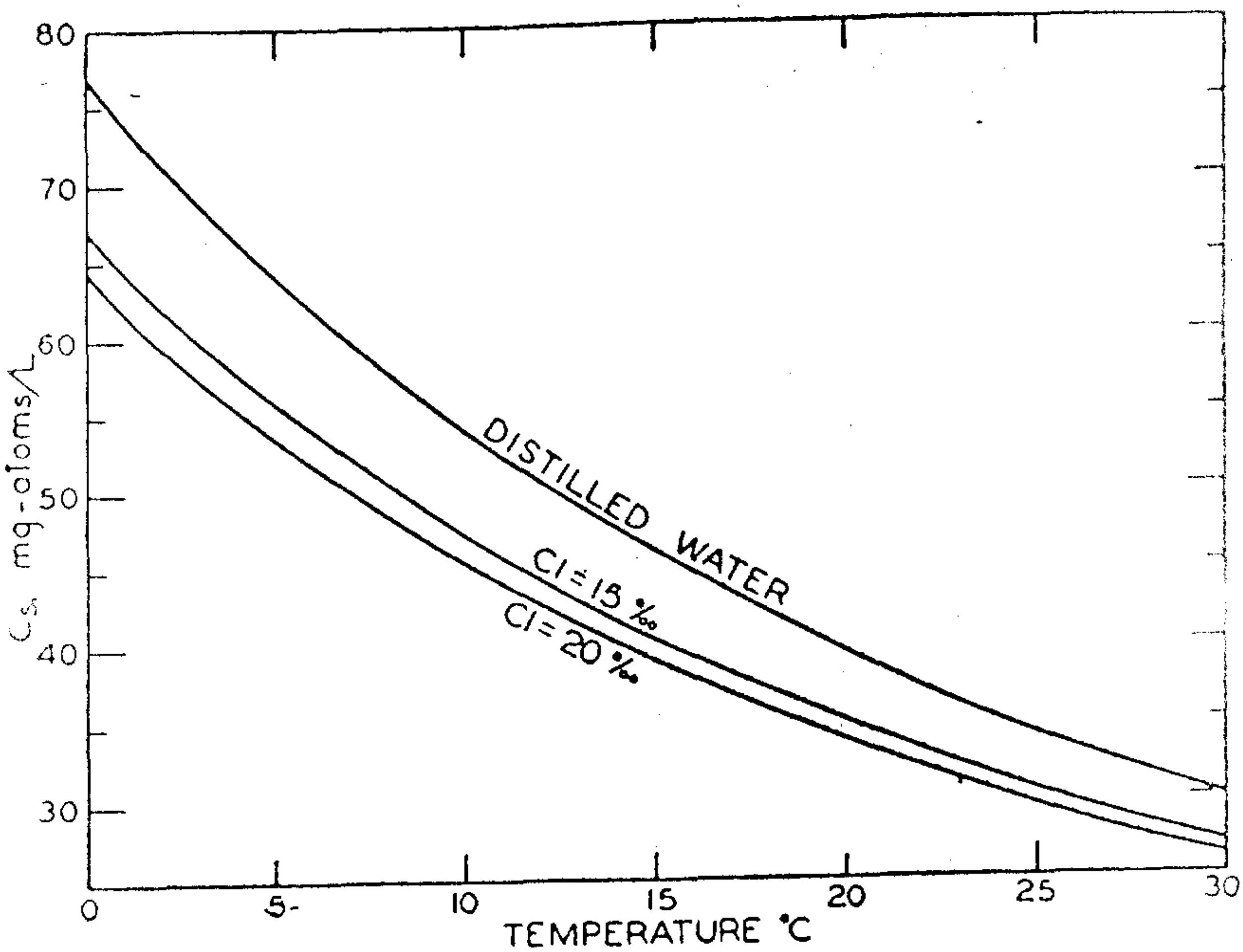


Figure 47: Adsorption coefficient C_s of carbon dioxide in sea water as a function of temperature and chlorinity.

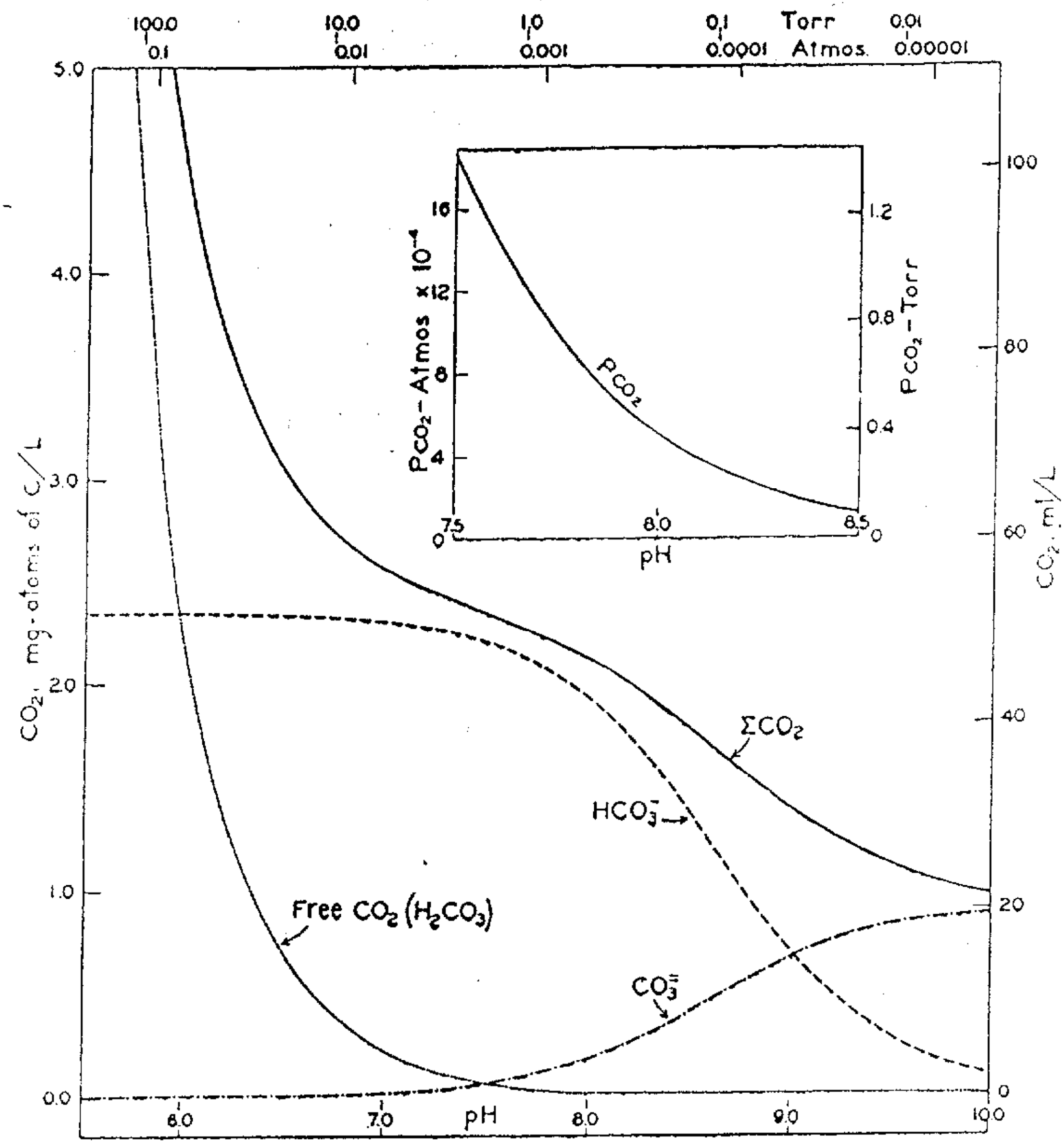


Figure 48: Carbon components in sea water of Cl =19.00 ‰ at 20° C as a function of pH and the partial pressure of carbon dioxide.

Fig. 49a: Periphyton and Sed Trap Data
Magnesium:Zinc Ratio

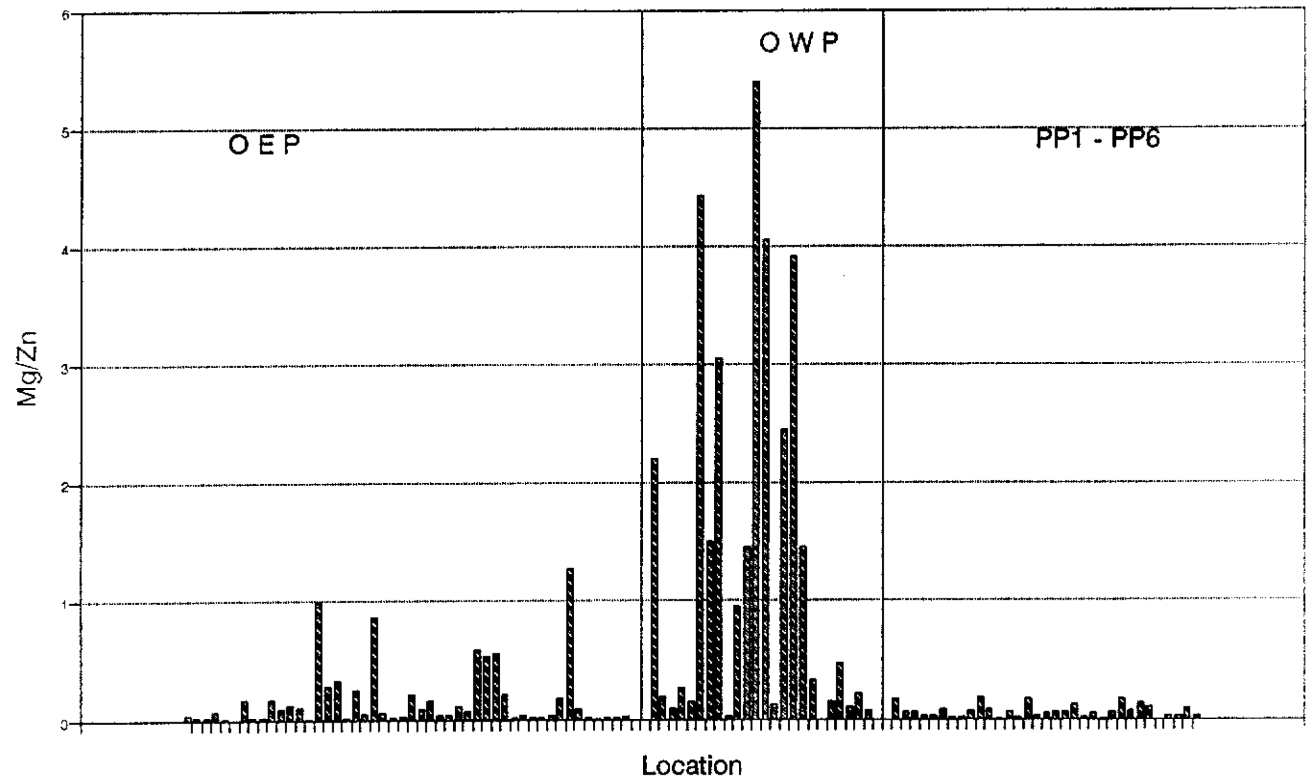


Fig. 49b: Periphyton and Sed Trap Data
Manganese:Zinc Ratio

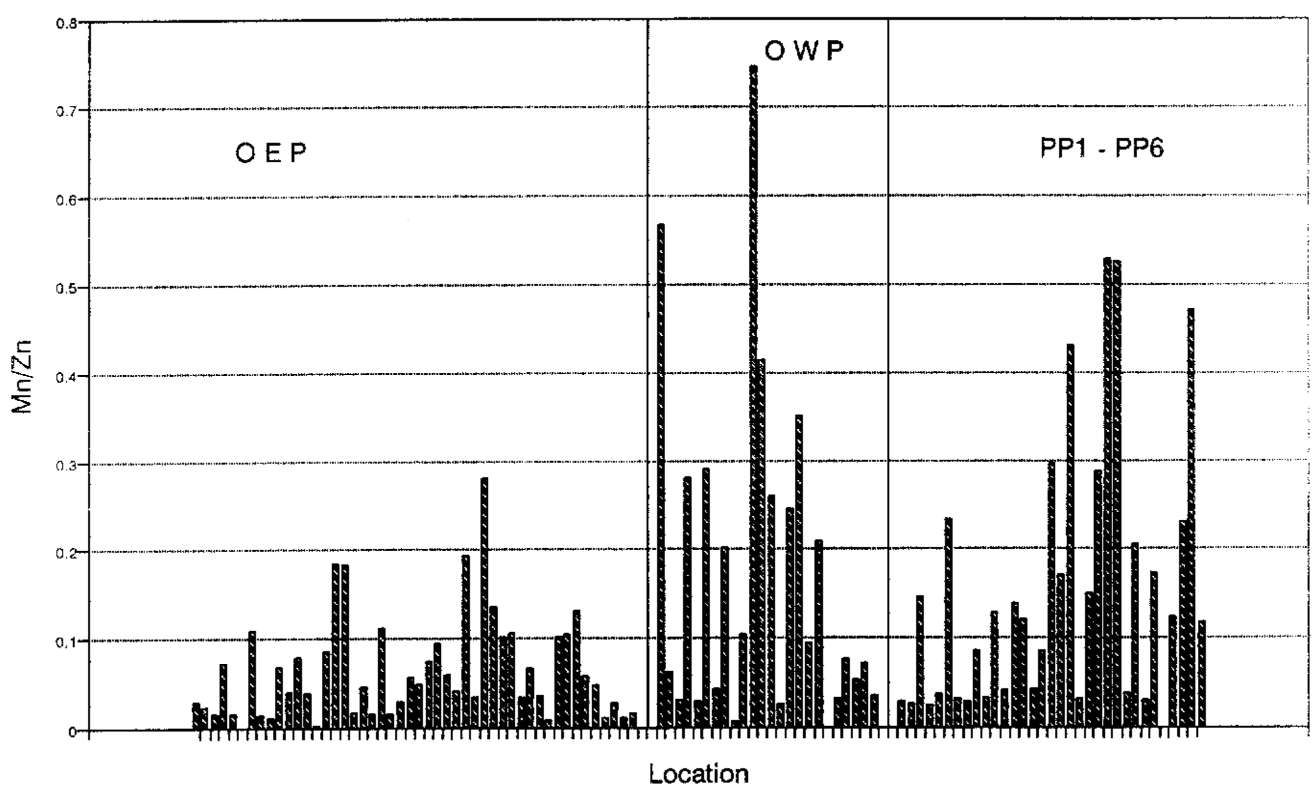


Fig.50a: OEP Surface Water
1988 - 1996

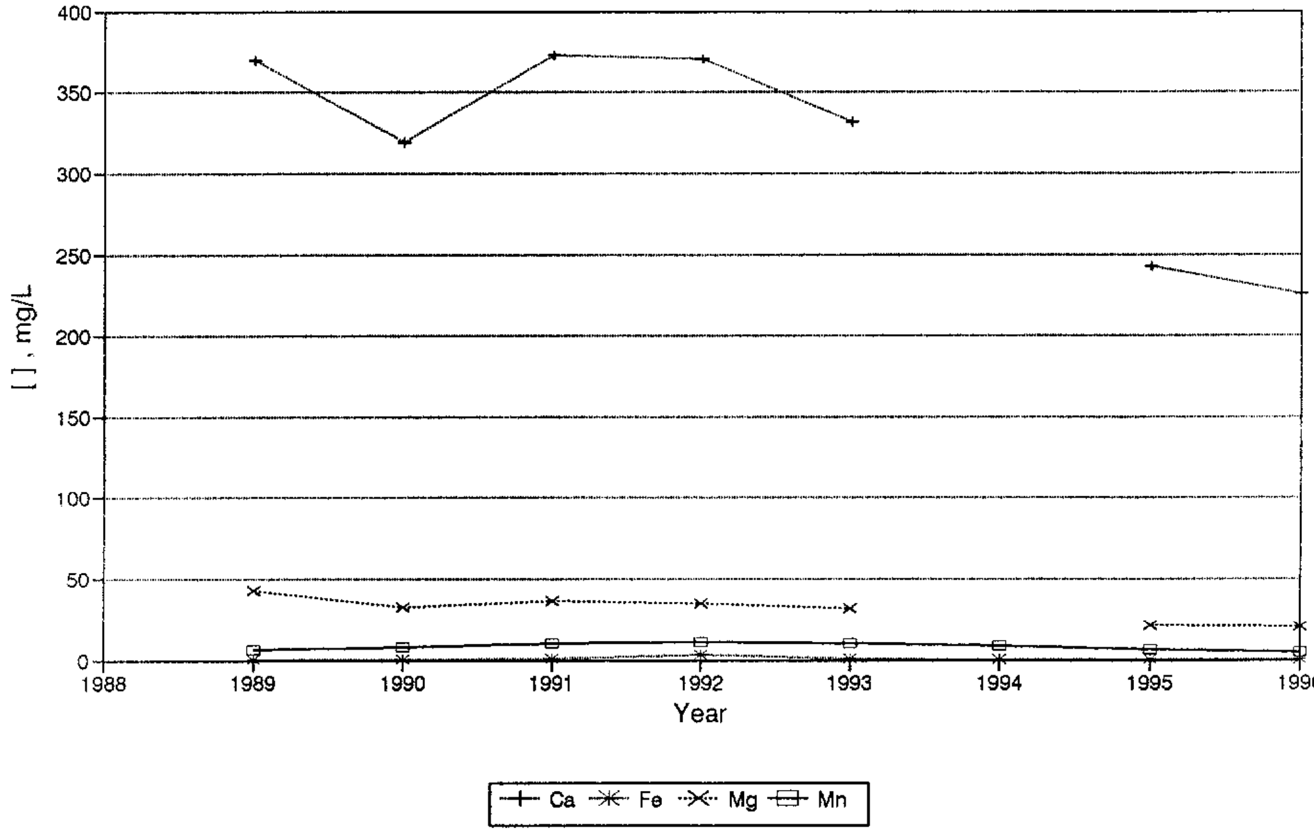


Fig.50b: OEP Bottom Water
1988 - 1996

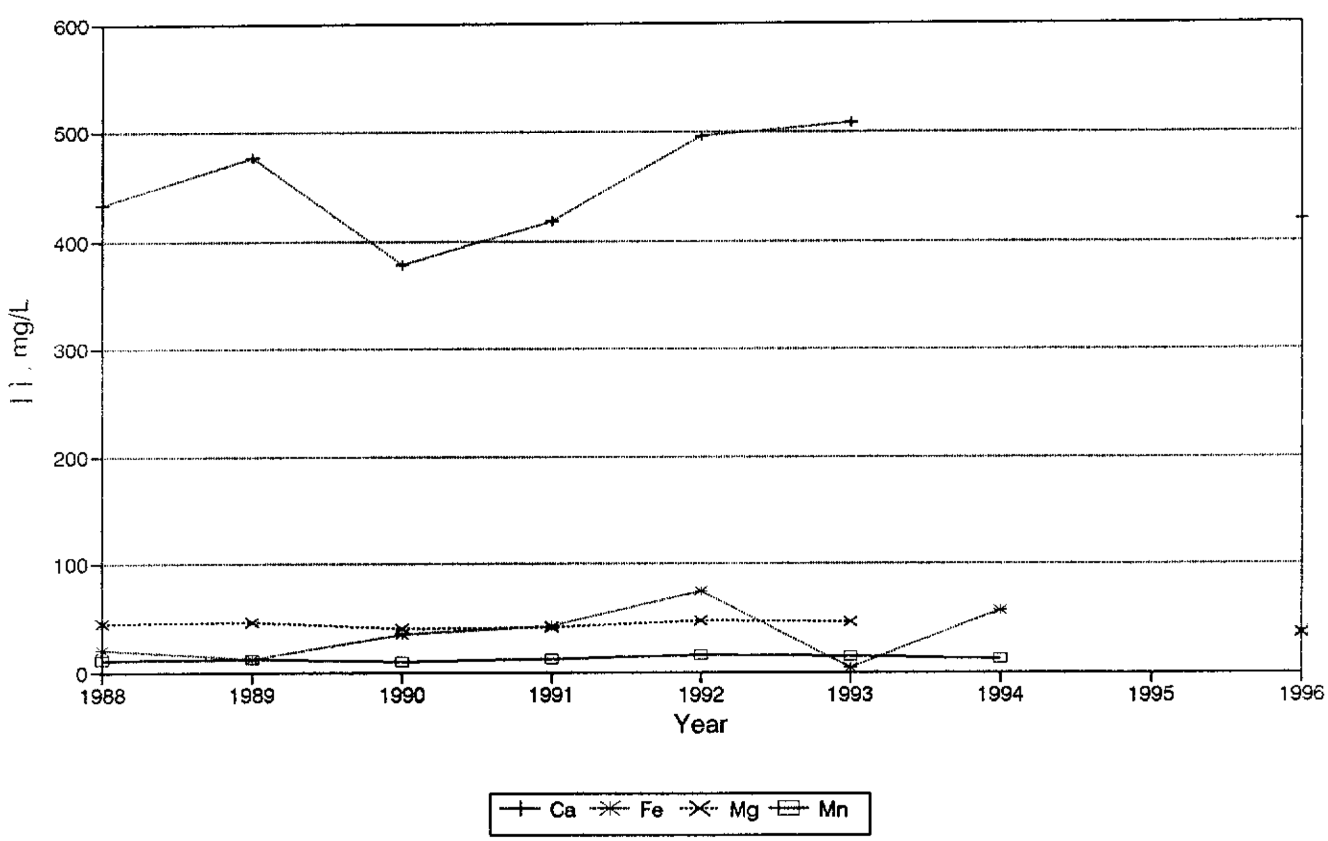


Fig. 50c: OEP Surface Water
1988 - 1996

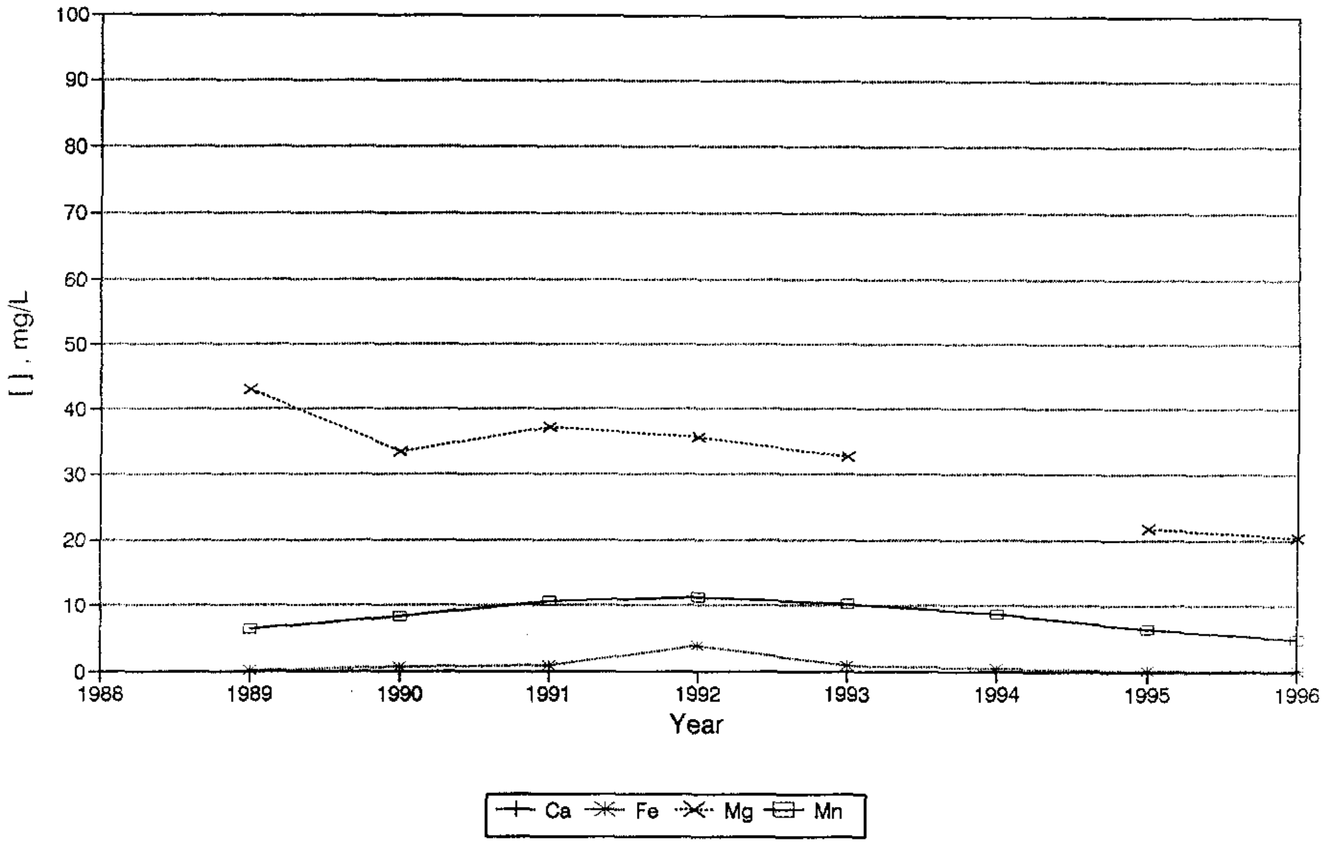


Fig. 50d: OEP Bottom Water
1988 - 1996

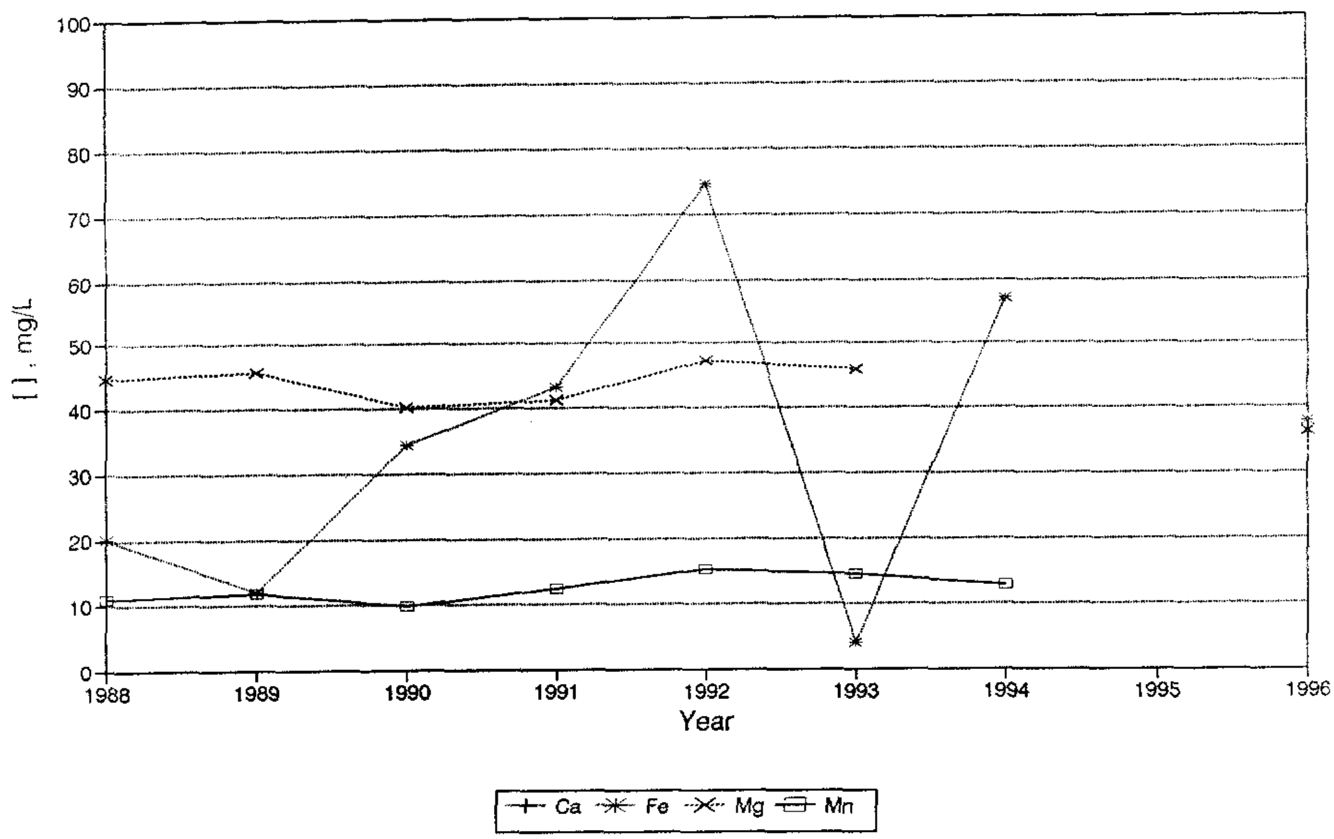


Fig. 51a: OWP Surface Water
1988 - 1996

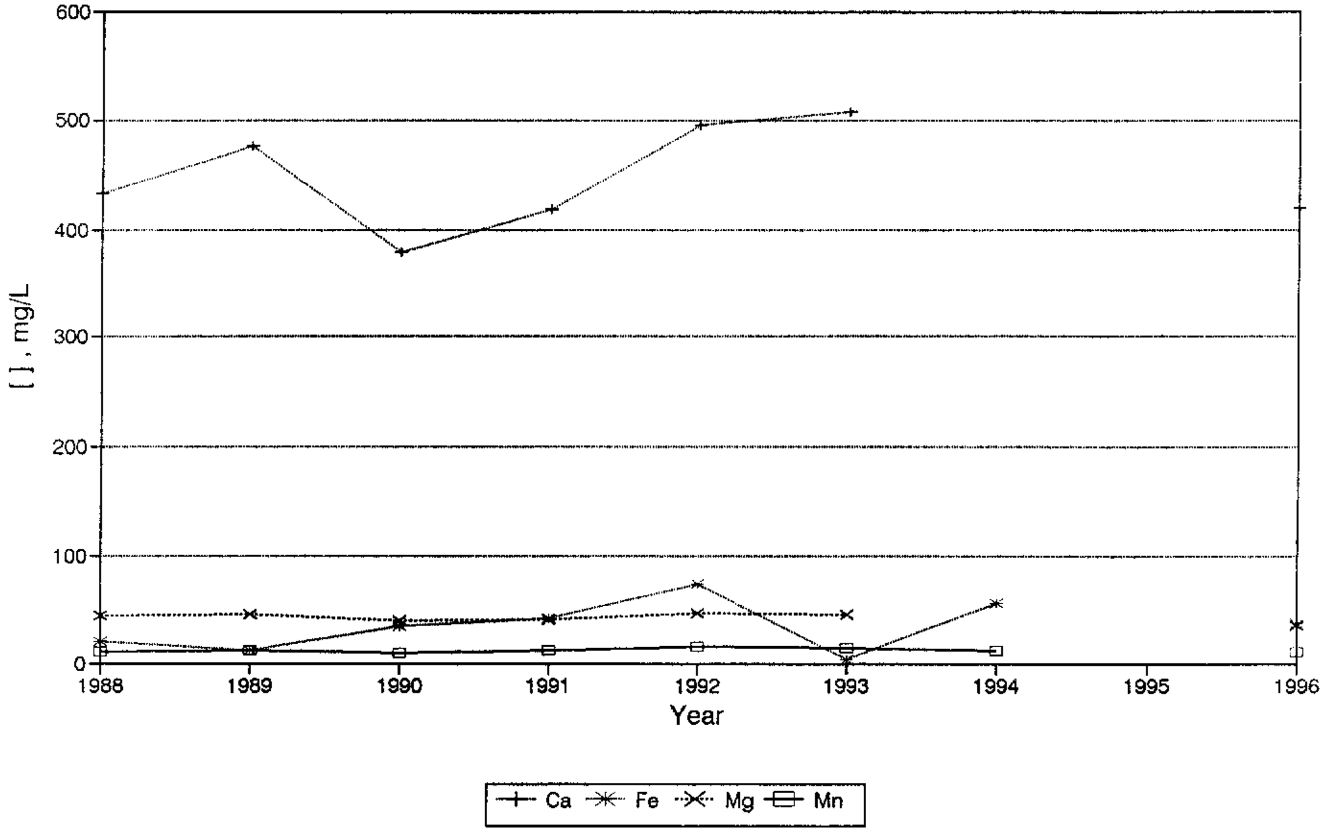


Fig. 51b: OWP Bottom Water
1988 - 1996

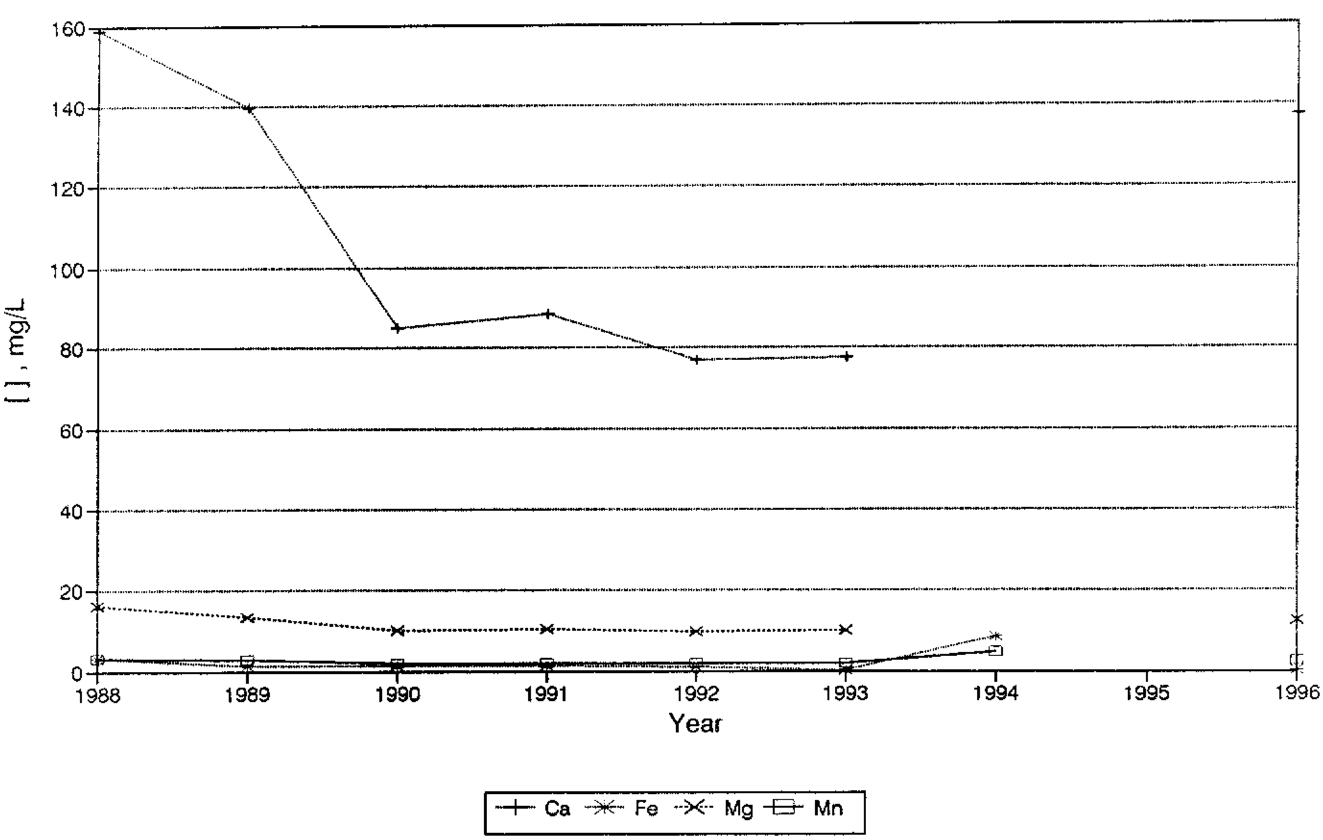


Fig. 52: OEP Surface, 1989-1996
Average [Zn] and [Mg]

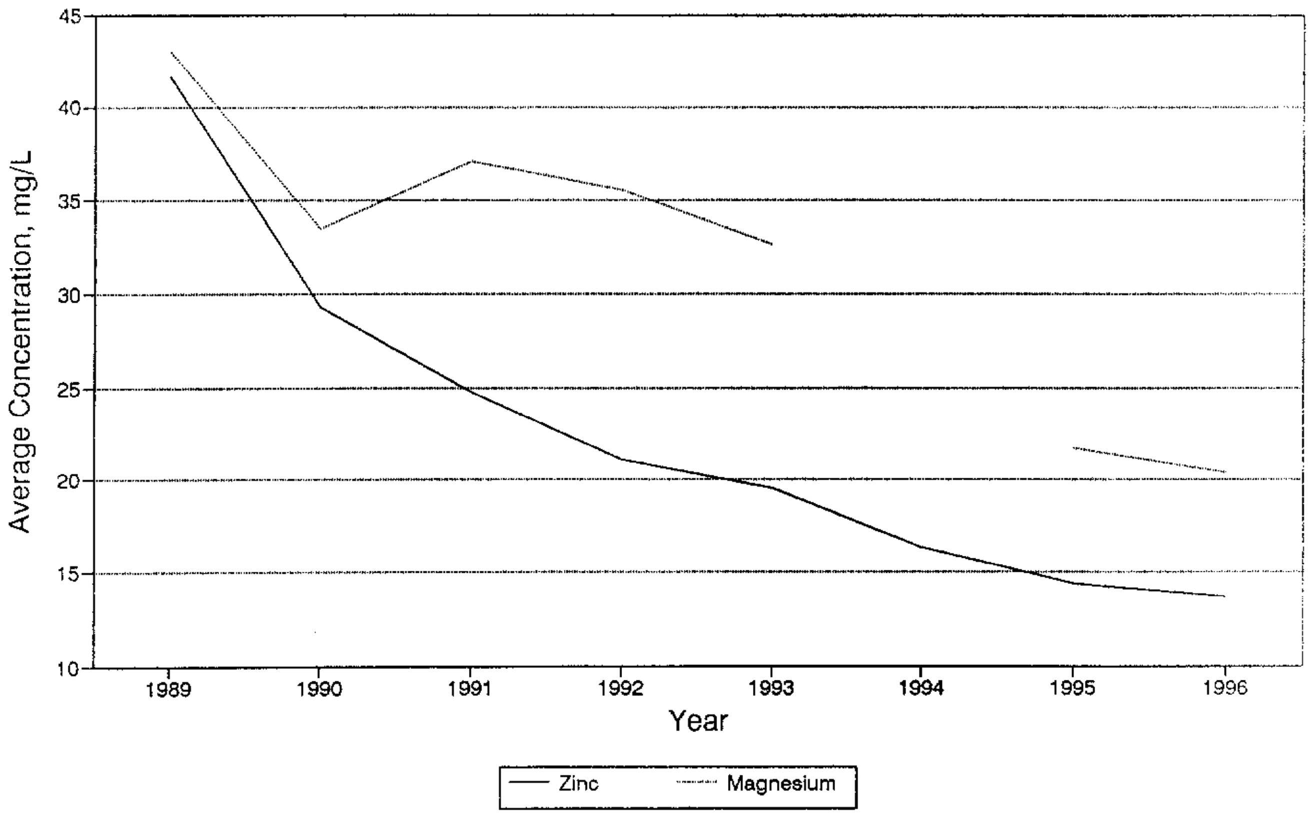


Fig. 53a: OEP Zinc Model
Case 1:

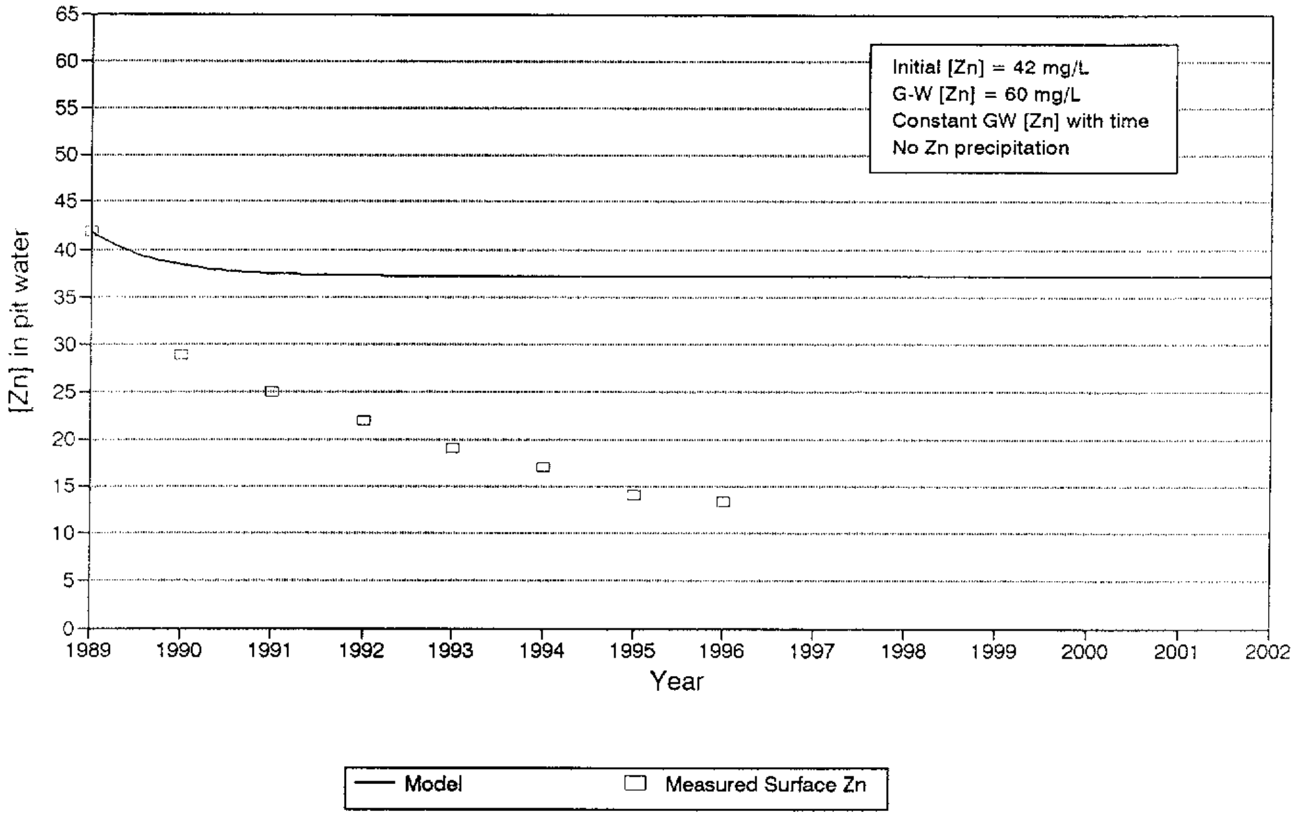


Fig. 53b: OEP Zinc Model
Case 2:

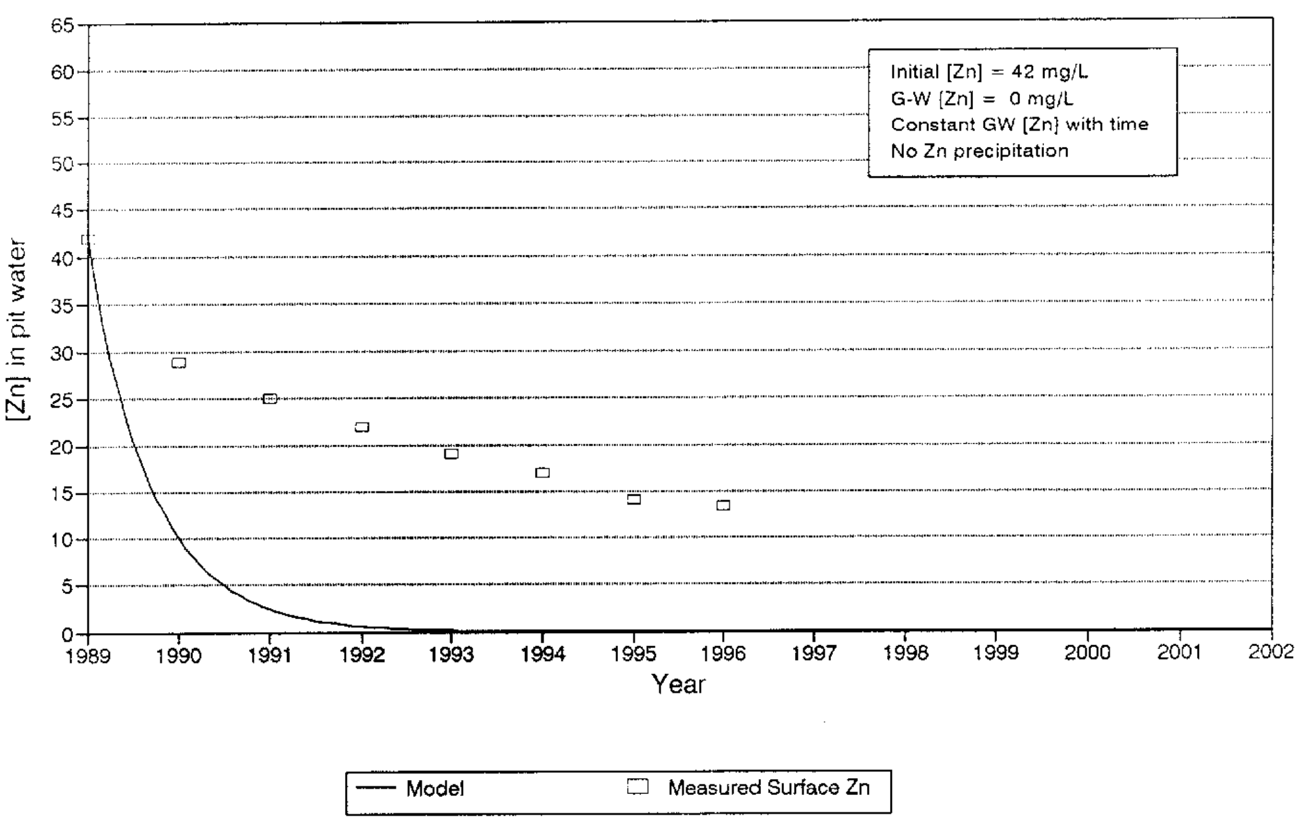


Fig. 53c: OEP Zinc Model
Case 3:

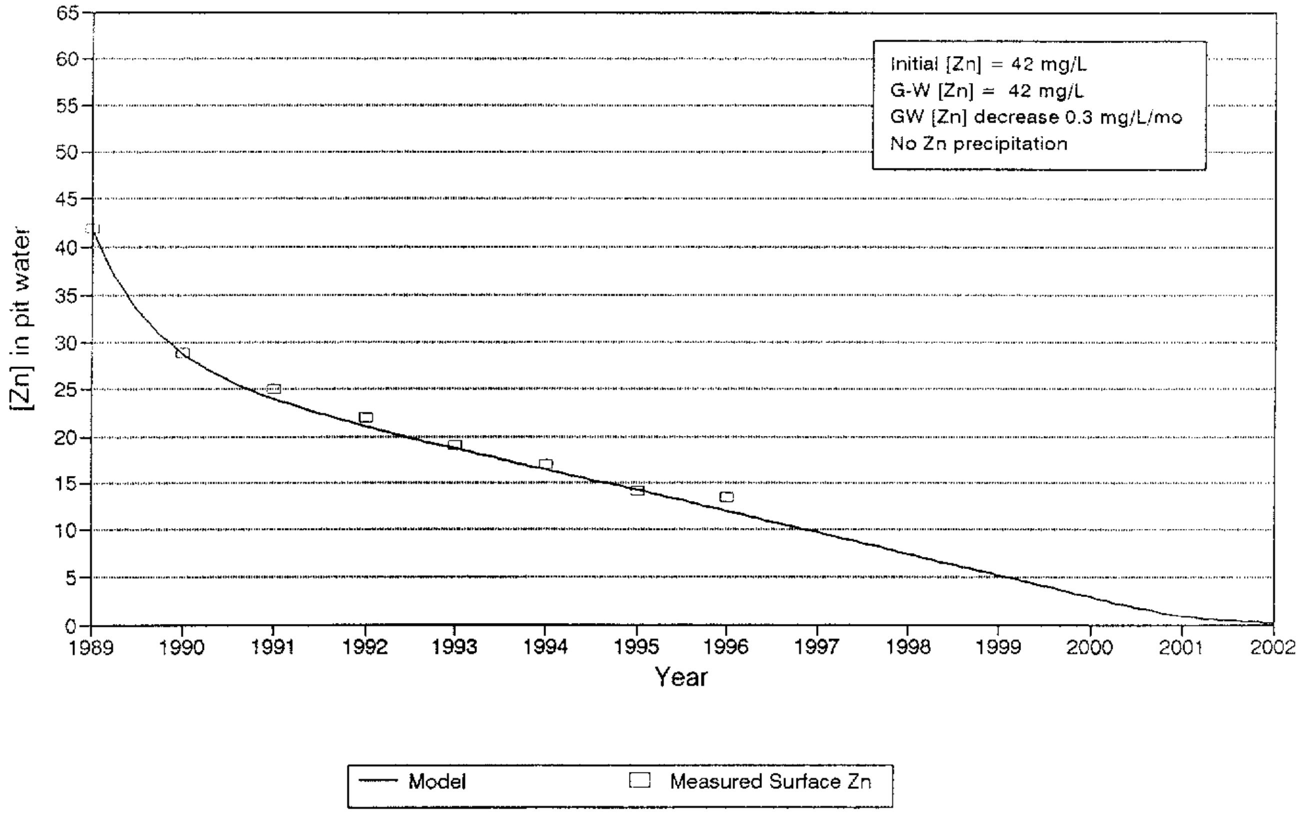


Fig. 53d: OEP Zinc Model
Case 4:

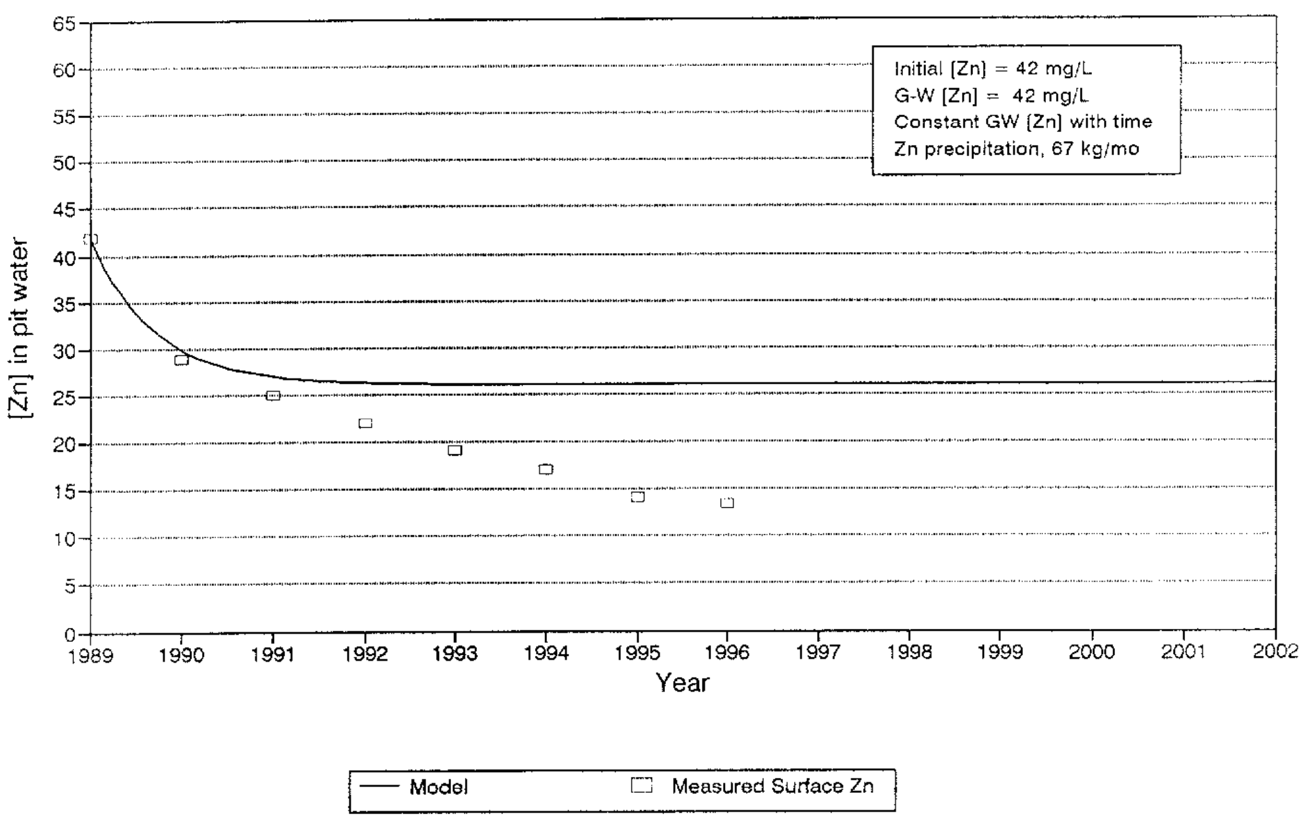
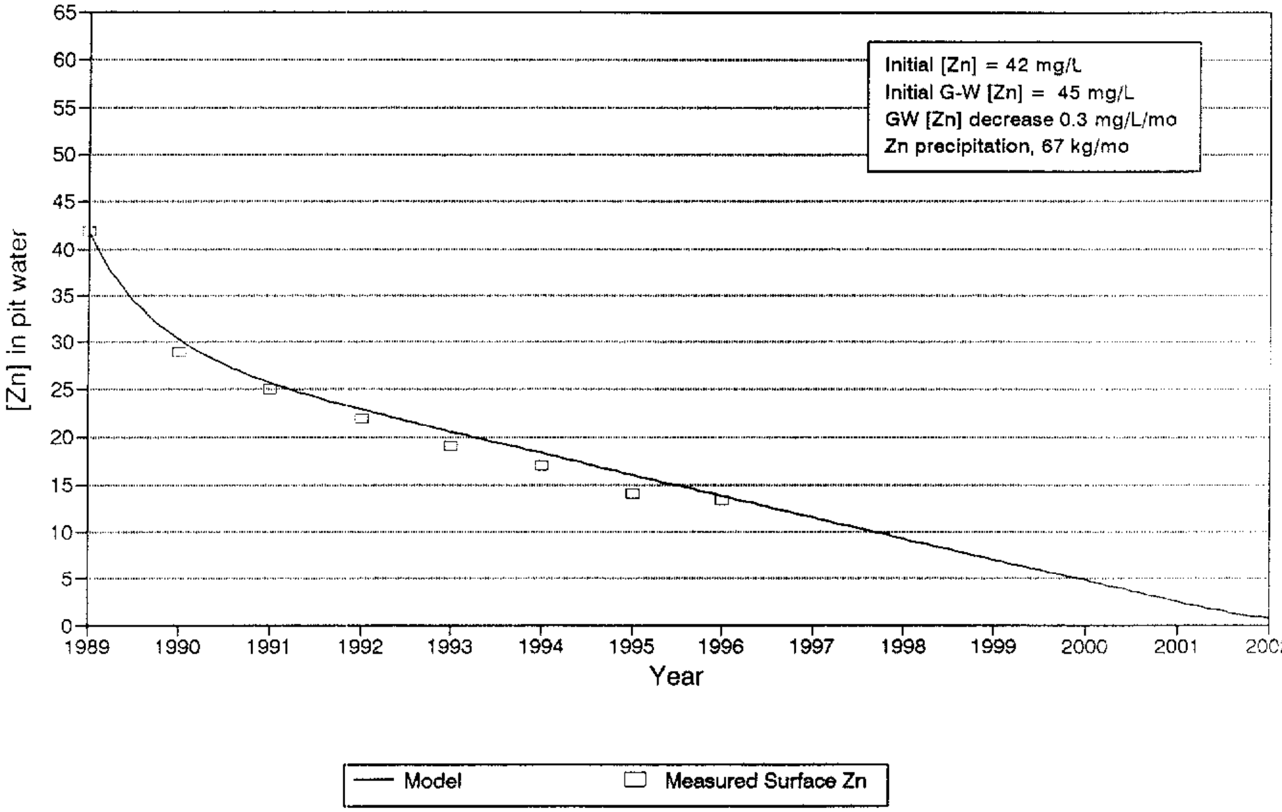
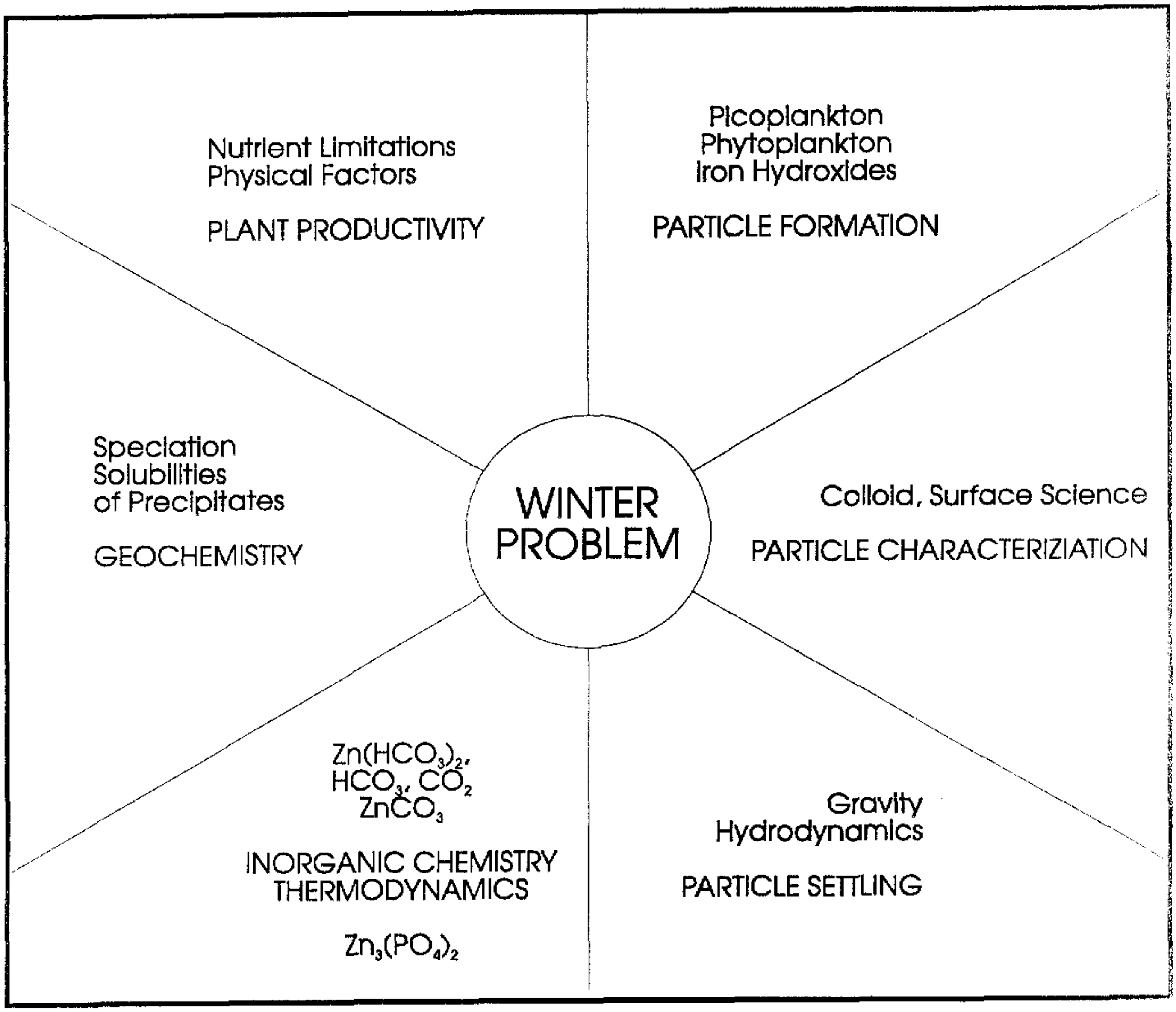
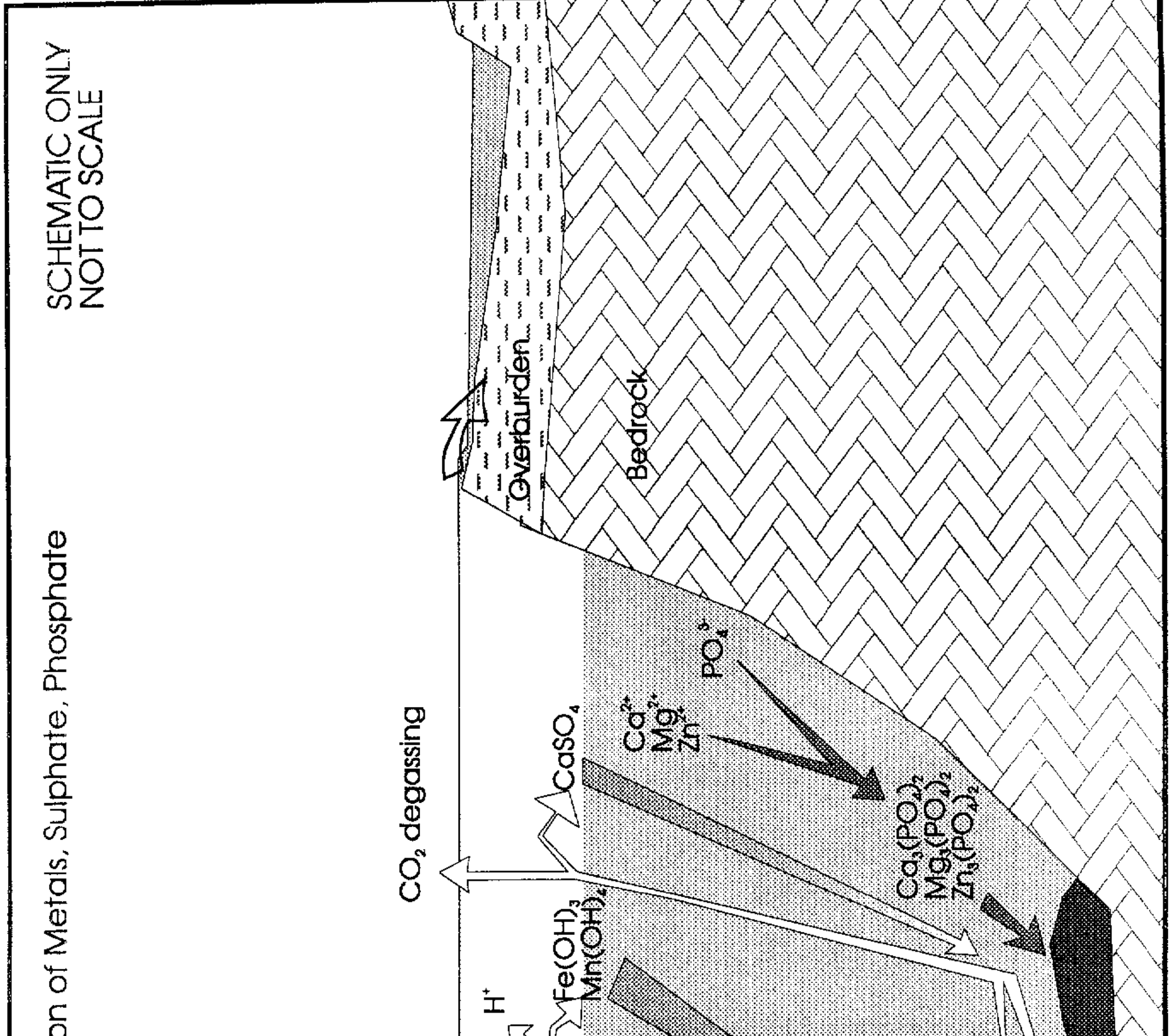


Fig. 53e: OEP Zinc Model
Case 5:





Schematic 3: **Physical, Chemical and Biological Factors Affecting Winter Zinc Removal Performance in the OWP-OEP-Polishing Ponds System.**



Schematic 4: Schematic Representation of Metals, Sulphate, Phosphate and CO_2 - HCO_3^- - CO_3^{2-} Cycling in OEP