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1998 FINAL REPORT

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Joint Venture Group at Buchans NFLD
ASARCO INC. - Abitibi-Price Inc.

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SUMMARY

The final report for the year I998 consists of summary statements supported by data collected in the system. The Biological Polishing process selected for the Buchans waste water is based on the water chemistry of the mine waste effluents, and not on the biology. In fact, as the project developed over the past decade, the biological component of the waste water treatment process became relatively small. The algae/moss growth in the polishing ponds only serves two functions. The first function is to provide surface area for particulate collection, and the second function is to shift the distribution of the forms of inorganic carbon towards carbonate for zinc carbonate precipitation. Therefore, the waste water treatment has focused, over all these years, on the water chemistry.

The first objective of the work in I998 was to determine the effects of the addition of Valley Seeps on Drainage Tunnel water characteristics and, in turn on the OWP and OEP system's chemistry. A model for OWP, based on flows, was constructed. The projected zinc concentrations in OWP agreed very well with the zinc concentrations measured following Valley Seeps addition.

A second objective was to determine where and how much of phosphate fertilizer to add to the Drainage Tunnel. In the data summary, several facts about the new chemical conditions of the system are given in capitalized bold letters, to highlight the key changes of the system. It is evident that the system has changed.

As the phosphate addition is expected to aggregate particles, it was of outmost importance to determine what, if any changes, are expected to take place with respect to particle formation. Sedimentation traps were suspended in OWP at different depths. Following commencement of Valley Seeps input, a significant increase in sedimentation rates, as well as increase in zinc and iron concentrations in trapped solids were noted in OWP. In contrast, OEP sedimentation rates in 1998 were constant with depth, while zinc and iron concentrations in trapped solids decreased with depth. This reflects the dynamics expected from the iron chemistry.

As the system is undergoing so many changes, including a slight reduction in pH, a change which might affect zinc stability in particles, time should be given for the system to stabilize.

In conclusion, we have a very good understanding of the chemistry of the waste water and the system as a whole. Once the system has stabilized in 1999, it is recommended that an experimental addition of phosphate be carried out, as outlined in the report dated July, 1997, *Scale-Up of Phosphate Applications*. This experiment should only be carried out if the conditions remained favorable for particle formation. It is therefore suggested that sedimentation traps remain in the OWP pit over the winter, and frequent sampling continues through 1999.

Based on the 1998 Polishing Pond system monitoring data, it appears that the process appears to be more robust than anticipated. The data summary presented in this report should be interpreted in more detail prior to the proposed experiment. In this way, the addition of fertilizer would be carried out according to a framework which includes projections of the expected results. This is of particular importance, as we do not have any data on the stability of the formed agglomerated particulates which will settle out of the OWP.

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1.0 INTRODUCTION

With respect to decommissioning the Buchan Unit, the most important technical development in 1998 was the diversion of Valley Seeps flow to the Oriental West Pit via the Drainage Tunnel pump and pipe system on August 3, 1998.

Prior to diversion, it was already known that this contaminated water source (relatively low pH, substantial flow, high zinc load) would both increase the zinc load to, and reduce the residence time of water in, the OWP-OEP-Polishing Pond system.

The potential effects of the addition of the Valley Seeps flow which were not known included those upon:

- existing zinc removal processes;
- the zinc-containing sediments which have accumulated to date in the OWP, OEP and Polishing Ponds;
- the effectiveness of (tentatively planned) phosphate addition.

These potential effects warranted some consideration and represented potential concerns, as outlined in Boojum Progress Report #1, *Valley Seepage Additions to OWP*, April 3, 1998.

During the spring and summer of 1998, extensive quantification of sedimentation rates and sediment composition was performed prior to, and to some degree following, August 3, 1998, the date on which Valley Seeps addition to OWP commenced. This report examines the zinc removal processes in the system, and compares removal estimates based on long term monitoring data with sedimentation trap monitoring results.

2.0 VALLEY SEEPS ADDITION TO OWP

Table 1: Revised Areas, Volumes and Residence Times of Water in OWP, OEP and Polishing Ponds.

- All retention times estimated in this report are theoretical only, in that perfect mixing of the water in each water body is assumed. In reality, actual residence times are shorter periods of time. In the case of the polishing ponds, relatively short periods, compared to the theoretical residence times, were demonstrated in the field and reported in the 1995 Final Report.

- In the 1996 Final Report, it was estimated that the retention time of water in OWP was 77 days, based on water input primarily from the Drainage Tunnel (8.3 $L.s^{-1}$) and another 1.7 $L.s^{-1}$ from contaminated groundwater entering at depth in OWP (Table 8 in 1996 Report).

- In 1996, the residence time for water in OEP was estimated at 126 days. The OEP was, at that time, receiving surface overflow water from OWP (10 $L.s^{-1}$), as well as clean (3.4 $L.s^{-1}$) and contaminated (5.8 $L.s^{-1}$) groundwater. The total flow leaving OEP was 19.2 $L.s^{-1}$.

- In 1996, Polishing Ponds 10 through 13 were receiving 40 % of the OEP discharge, while Polishing Ponds 14 through 17 were receiving 60 %. The residence times for the two systems were 9 and 6 days, respectively.

- These conditions generally prevailed, plus or minus seasonal variations in flows, until August 3, 1998, when a flow gathered from the Valley Seeps was diverted to, and joined with, the Drainage Tunnel Discharge to OWP.

- Subsequently, the flow volumes have increased, and residence times have decreased throughout the Drainage Tunnel - OWP - OEP -Polishing Ponds System. New estimates of flows and residence times are presented in Table 1.

- The flow volume of water now (post August 3, 1998) being pumped to OWP has increased from 8.3 $L.s^{-1}$ (D.T. alone) to approximately 13.6 $L.s^{-1}$. Assuming that some groundwater is still entering OWP (about 1.7 $L.s^{-1}$), the flow entering OWP is estimated at 15.3 $L.s^{-1}$, giving a residence time of 50 days, a 35 % reduction from previous flow conditions (Table 1).

- The residence time of water entering OEP has also decreased, in this case to 98 days, a reduction of 22 % from previous conditions (Table 1).

- Assuming that the two Polishing Pond systems still receive a 60:40 split of flows, the residence times have decreased to 7 days (40 % of flow to PP10-13) and 4.7 days (60 % of flow to PP14-17), both reductions equivalent to 22 % (Table 1).

2.1 Addition of Valley Seeps: Expected and Measured Water Quality

Table 2: Summary of D.T.- OWP - OEP pH and Zinc Concentrations, 1997-1998.

- The Valley Seeps have a low pH (1998 pH range, 4.5 to 4.9) relative to Drainage Tunnel, OWP and OEP water (1997 to August 2,1998 pH range, 6.0 to 7.1: Table 2).

- The Valley Seeps also contain high zinc concentrations (39 to 48 $mg.L^{-1}$), relative to the Drainage Tunnel, OWP and OEP (range, 2 to 38 $mg.L^{-1}$: Table 2).

- Because of their chemical characteristics, the addition of the Valley Seeps flow to OWP via the Drainage Tunnel pumping system warrants some concern.

- Careful analyses regarding the existing zinc removal processes in the entire system, and projected zinc removal processes if phosphate addition is commenced, must be performed.

- Data is available for a 70 day monitoring period between August 3 and October 11, 1998 at this time for examination of changes in OWP's water quality following commencement of Valley Seeps addition.

- In Table 2, the average, minimum and maximum values of pH and zinc in te system for all of 1997, 1998 to August 2, and from August 3 to October 11, 1998, are presented.

2.1.1 Valley Seeps Water Quality

Figure 1: Valley Seeps (total) at Pumphouse: pH, 1998.

- In Figure 1, it can be seen that the pH of the combined Valley Seeps is relative stable, ranging from pH 4.5 to 4.9, and averaging pH 4.6 (before) and pH 4.7 (after August 3, 1998: Table 2).

Figure 2: Valley Seeps (total) at Pumphouse: Zinc Concentrations, 1998.

- In 1998, zinc concentrations in the combined Valley Seeps have ranged from 39 to 49 $mg.L^{-1}$, averaging 44 $mg.L^{-1}$ (before) and 45 $mg.L^{-1}$ (after August 3, 1998: Table 2).

Figure 3: Valley Seeps (total) at Pumphouse: Flows and Loads, 1998.

- The flow of the combined Valley Seeps was relatively constant between June 16 and September 16, 1998 (Figure 2). Thereafter, flows appreciably increased. Whether this is due to increased run-off in the autumn, or is due to diversion of additional Valley Seeps to the pumphouse, is not known at this time.

- The average flow of the Valley Seeps prior to August 3 was 4.6 $L.s^{-1}$. Following August 3, 1998, the average flow was 5.7 $L.s^{-1}$, reflecting the higher flows in September and October 1998, noted above (Figure 3).

- The Valley Seeps zinc load was considerably higher after September 16, 1998, due to the relatively high flows in this latter part of the monitoring period. Prior to August 3, the zinc load averaged 17 $kg.d^{-1}$. After August 3, the zinc load averaged 22 $kg.d^{-1}$.

2.1.2 Drainage Tunnel Water Quality

Figure 4: Drainage Tunnel Discharge pH, 1995 - 1998.

- The pH of Drainage Tunnel water appears to have very gradually decreased between 1995 and 1997 (Figure 4).

- The average pH in 1997 was 6.1, while in 1998 prior to August 3, the pH also averaged 6.1 (Table 2).

Figure 5: Drainage Tunnel Discharge [Zn] and Flow, 1995^{-1}998.

- The flow measured at the Drainage Tunnel discharge has been very consistent since 1995, with little to no seasonal variation (Figure 5). There appears to a very gradual decrease in the flow between 1995 and 1998.

- Zinc concentrations in Drainage Tunnel discharge water are highly variable (Figure 5), likely reflecting seasonal dilution due in periods of high infiltration (spring, fall).

- In 1997, Drainage Tunnel zinc concentrations ranged from 2.1 to 28 $mg.L^{-1}$, and averaged 15 $mg.L^{-1}$. In 1998, the average zinc concentration was 13 $mg.L^{-1}$ (before and after August 3, 1998; (Table 2).

Figure 6: Drainage Tunnel Discharge; Daily Zinc Load, 1995 - 1998.

- Although the Drainage Tunnel flow is relatively constant, the highly variable zinc concentrations result in similarly variable daily zinc loads (Figure 6).

- In 1998, the average zinc load was 9.1 $kg.d^{-1}$ (before) and 9.2 $kg.d^{-1}$ (after August 3).

2.1.3 Combined Drainage Tunnel-Valley Seeps Water Quality at OWP

Figure 7: DT +Vs at OWP: pH, 1998.

- The pH of the combined Drainage Tunnel-Valley Seeps water (pumped to OWP) diminished between August 3 and October 12, 1998, from an initial pH of 6 to a final pH of 5.8 (last record). This is likely due to a consistent flow of Drainage Tunnel water, but an increasing flow of low pH Valley Seep water after September 16.

Figure 8: DT + Vs at OWP; Zinc Concentration, 1998.

- On August 3, 1998 the zinc concentration in the combined flow was about 25 $mg.L^{-1}$. The zinc concentration increased to above 26 $mg.L^{-1}$ at the start of September, and thereafter declined to about 22.6 $mg.L^{-1}$ by October 11. This was due to lower zinc concentrations in Valley Seeps water in September and October.

Figure 9: DT + Vs at OWP; Flow and Load, 1998

- Because the Valley Seeps flow sharply increased after September 16, 1998, the combined flow also increased. Lower zinc concentrations in Valley Seeps water were insufficient to offset the effects of higher flow on the combined flow zinc load. The zinc load discharged to OWP was considerably higher in September and October than in August, 1998.

- Overall, the zinc load to OWP averaged 27.8 $kg.d^{-1}$, and ranged from 25.5 to 30 $kg.d^{-1}$, between August 3 and October 11, 1998.

2.1.4 OWP Water Quality

Figure 10: OWP pH, 1992 - 1998

- Since joining OWP with OEP by a culvert, OWP's pH increased from values typically less than pH 4 (prior to 1994) to pHs greater than pH 6.0 (1994 to 1998; see Figure 10).

- There is some indication that OWP's pH is now slightly declining with time. The highest pHs were recorded in 1995 and 1996 (Figure 10). The measured pHs were overall lower in 1997, and lower still in 1998. However, in 1998, the pH of OWP has remained above pH 6.0, even following 70 days of Vs + D.T. input (pH 6.4 on October 4, 1998).

Figure 11: OWP Zinc Concentration, 1995 - 1998.

- In 1995 and 1996, OWP's zinc concentrations were relatively constant, ranging from about 14 to 18 $mg.L^{-1}$ (Figure 11). In 1997, zinc concentrations, although highly very variable, were overall much lower than in the previous two years, averaging about 12 $mg.L^{-1}$.

- In 1998, zinc concentrations were higher than in 1997, averaging 17 $mg.L^{-1}$ even before addition of Valley Seep water (Table 2). The zinc load from the Drainage Tunnel was quite consistent for all three years (Figure 6), and does not explain the higher OWP zinc concentrations in 1998 prior to August 3.

- Following the onset on Valley Seep addition to OWP, the OWP zinc concentrations increased, as expected (Figure 11). In the period between May 3 and August 4, the zinc concentrations ranged from 13.0 to 13.8 $mg.L^{-1}$. On August 30 and October 4, the zinc concentration was about 21 $mg.L^{-1}$, reflecting the Valley Seeps effect.

2.1.5 OEP Water Quality

Figure 12: OEP pH, 1995-1998

- The pH of water at OEP's outflow has typically been low during winter (pH 6.0 to 6.4) compared to the ice-free seasons (pH 6.6 to 7.3; Figure 12).

- In 1998, the recorded pHs for the first 180 days were similar to the previous 3 years (Figure 12). However, the pH un-characteristically decreased to about pH 6.5 after August 3, 1998 (day 215), a period when the pH was typically 6.9 to 7.0 in previous years. This change in pH can be directly attributed to the onset of addition of the Valley Seeps to OWP.

- The observed 1998 OEP pH decrease was greater than that observed in OWP (Figures 10 and 12). It appears that, following addition of Valley Seeps water to OWP, the pH is decreased to around pH 6.4. OWP water, with its new chemical composition (and greater buffering capacity?), enters and mixes with OEP water, decreasing OEP's pH to about 6.4. In previous years, OWP water entering and mixing with OEP water did not depress the pH of OEP discharge water.

Figure 13: OEP Zinc Concentrations, 1995^{-1}998

- A downward trend in zinc concentrations in OEP has been observed over the past few years. The year 1997 was no exception, and some of the lowest zinc concentrations were measured in that year (Figure 13).

- It appears that, for the first 215 days of 1998, up to August 3, the zinc concentrations were overall very similar the those measured in 1997 (Figure 13). This indicates that the long-term trend of decreasing zinc concentrations in OEP discharge water may no longer hold in 1998, and may be due to the continuous input of zinc from OWP.

- With OWP input, zinc concentrations may have ranged from 10 $mg.L^{-1}$ (summer) to 15 $mg.L^{-1}$ (winter) in the coming years, had the Valley Seeps not been added to the system.

- Following addition of Valley Seeps water to OWP, the zinc concentrations increased in OEP discharge water (Figure 13). However, the pattern of this increase does not depart from what can be observed for 1997, and cannot be attributed to the Valley seeps based on this evidence alone.

Figure 14: OEP Flow, 1995 - 1998.

- The pattern of flow volumes discharge from OEP for the first 215 days of 1998 are within the range observed during the previous three years (Figure 14).

- After day 215 (August 3, 1998), flow volumes increased to record levels for that period of the year, clearly indicating the effect of Valley Seeps discharge to OWP (Figure 14).

Figure 15: OEP Zn Load, 1995 - 1998

- The higher flows through the OEP after day 215 are resulting in larger zinc loads discharging from the OEP (Figure 15).

- A larger load of zinc has been leaving OEP in October, 1998 than in the same period during the previous three years.

2.2 Bucket Experiments

Table 3: 1998 Bucket Experiments; Mixing Valley Seeps with Drainage Tunnel

- In order to gain some idea of what the pH and zinc concentrations may be in a combined Valley Seeps-Drainage Tunnel solution, batch mixing tests were performed using volumes of each solution which are proportional to their projected contribution to flow in the field. Laboratory "bucket" experiments were performed in the Buchans lab during late March and early April, 1998.

- In Test 1, only the pH of the three source waters (Vs4, Vs5, D.T.) and the mixture was measured. Although the Valley Seeps' pHs were relatively low (4.5 and 5.2), these solutions did not reduce the pH of Drainage Tunnel water immediately following mixing, in contrast to what could be calculated (calculated pH is 5.2).

- In Test 2, both pH and zinc concentrations were measured in the source and mixed solutions. In this test, some depression of the drainage tunnel pH (6.1) immediately following mixing was observed (pH 5.9), but the pH upon mixing was still higher than the calculated pH of the mixture of 5.4. In Test 2, the mixture was allowed to sit for a week before re-measuring pH. On April 6, 1998, the pH had increased to 6.1.

- In Test 2, the zinc concentration in the mixture (20.5 $mg.L^{-1}$) was virtually the same as calculated (20.7 $mg.L^{-1}$), based on the three source waters' zinc concentration and volume contribution.

- In Test 3, Valley Seeps solutions were mixed with OEP water alone (OEP + Vs4 + Vs5) or with some additional precipitate collected from OEP outflow (OEP + Vs4 + Vs5 + Precip). Again, the measured pH of solution just after mixing (pH 6.3) was higher than the calculated pH (5.6). The pH of both mixtures (without and with precipitate) increased after 24 hours to pH 6.7 and 6.6, respectively.

- In Test 3, the zinc concentration in the solution without precipitate addition immediately after mixing was 15 $mg.L^{-1}$, very similar to the calculated concentration of 15.2 $mg.L^{-1}$. The zinc concentration decreased only slightly over 24 hours, to 14.9 $mg.L^{-1}$.

- *In Test 3 where the mixture included precipitates, the zinc concentration* immediately after mixing was actually lower (13.1 $mg.L^{-1}$) than the mixture with no precipitates added (15.0 $mg.L^{-1}$). After 24 hours, the zinc concentration further decreased to 12.2 $mg.L^{-1}$. This supports the hypothesis that further settleable particle formation is enhanced with increasing suspended particle density in solution.

- Overall, the Drainage Tunnel and the OEP solution contain some alkalinity which offsets some of the pH depression induced by Valley Seeps addition. However, this neutralizing capacity may come at the expense of reduced particle formation and settling downstream to the polishing ponds.

2.3 The Results of Zinc Concentration Predictions From Modelling

- In Boojum's April 3, 1998 Progress Report #1, the assumptions are presented for the mathematical program used to calibrate and predict zinc concentrations in OWP and OEP following addition of the Valley Seeps flow (see Progress Report #1 in Appendix). The predicted zinc concentrations over time are given in Figure 16.

- The predicted zinc concentration for OWP was 21.9 $mg.L^{-1}$, 25 days after commencing diversion of the Valley Seeps to OWP (Figure 16). As can be *seen in Figure 11, OWP surface water zinc concentrations reached* 21.6 $mg.L^{-1}$, 27 days after August 3, 1998 and remained at that level until October 4, the last datum received. **THEREFORE, THE PREDICTED OWP ZINC CONCENTRATION WAS QUITE ACCURATE.**

- For OEP, a much larger water body downstream, the predicted zinc concentration was expected to reach 16.9 $mg.L^{-1}$ only after approximately 250 days, assuming good mixing of the OEP's entire volume. As of October 11 (70 days after August 3), the OEP discharge's zinc concentration was around 15.6 $mg.L^{-1}$, **A VALUE IN THE RANGE PREDICTED FOR OEP AT THIS TIME (FIGURE 16).**

- It has been well established that the OEP does not vertically mix, and that a thermo-and chemocline exists at about 2 to 3 m. OWP water discharged to OEP likely mixes primarily with the top 2 m of water prior to discharge, while the modelling does not take this into account. Therefore, higher actual zinc concentrations at OEP outflow can be expected than predicted from modelling.

3.0 PARTICLE SEDIMENTATION IN OWP AND OEP

Table 4: Sedimentation Rates (DW $g.m^{-2}.d^{-1}$) in OWP, OEP and Lucky Strike, 1990 - 1998.

Map 1: OWP Grid Locations and locations of sedimentation traps at 2m and 7m depths.

- Sedimentation traps have been used at Buchans since September, 1990 (OEP) in order to assess the rate at which particles are settling in the flooded pits, and to estimate zinc removal by this process (Table 4). For OWP, sedimentation traps have been operated since July, 1994, following joining of the OWP and OEP and OWP change in chemistry (neutral pH, visible particle formation).

- All sedimentation rates used in analyses in this report are presented in Table 4, in units of g $(DW).m^{-2}.d^{-1}$. For OEP, the data for three dates, marked NI in Table 4, were not included in further estimates, as these sedimentation rates were abnormally high, and likely represent trap samples contaminated by periodic slumping of sediment from steeper areas of the submerged pit walls.

3.1 Sedimentation Rates

Figure 17: OEP: Estimated Annual Sedimentation Rates

- In Figure 17, the sedimentation rates are presented on a yearly basis, grouping data according to the sampling periods, and pro-rating this total mass per m^2 for a 1 year period.

- In this graph, separate bars are presented for the 4 m, 11 m and 20 m sedimentation trap data. The 20 m sedimentation trap data suggests that sedimentation rates are quite variable year to year. However, the 4 m and 11 m trap data suggest relatively consistent sedimentation of particles year to year. The 20 m traps are most vulnerable to contamination by material (e.g. slumping) other than that forming and settling through the water column, and sedimentation rates estimated for this depth may be generally exaggerated.

Figure 18: OWP Estimated Annual Sedimentation Rates (7m)

- In Figure 18, the sedimentation rate data for the OWP 7 m sedimentation trap are presented, in units of $kg.m^{-2}.y^{-1}$.

- Although it appears that the 1995-96 period had exceptionally high sedimentation rates, this is based on one exceptionally high datum (43 $g.m^{-2}.d^{-1}$ for 7 m trap collected July 10, 1998). This datum is included, however, since the data, 21 $g.m^{-2}.d^{-1}$ (July 23, 1997) and an average of 23 $g.m^{-2}.d^{-1}$ (September 18, 1998) also exist in the data set.

- Overall, based on data presented in Figures 17 and 18, there does not appear to be more or less particles sedimenting in OEP or OWP with time since sampling commenced.

- The examples of potentially erroneous data make a good case for more frequent sampling, as performed in 1998.

Figure 19: OWP Sedimentation Rates, June - September, 1998.

- The data presented in Figure 17 suggest that the OEP 2 m and 11 m sedimentation traps collect similar masses of settling particles, while the 20 m trap typically collects more particles. This would suggest that, in the OEP, a second group of settleable particles, or existing particle coatings, are forming at depth, below 11 m in the water column. The 20 m sedimentation trap collects these new or modified particles, as well as particles settling from the mixed 0 to 3 m surface layer up above.

- Contamination of the OEP 20 m trap by slumping may consistently occur, and explain some of the elevated 20 m trap data. However, the 1998 OWP sedimentation trap data also suggest that particles are forming at depth, since the OWP 7 m traps consistently collected more settling particles than the 2 m traps (Figure 19).

- Additional particle mass formation and settling at depth is likely occurring in OWP, due to the following factors:

  - first, there is some dissolved iron at depth available for oxidizing and precipitation. This is also true for OEP;

  - second, the OWP is relatively small and more easily influenced that the OEP;

  - third, the D.T. pumping system generates some vertical mixing;

  - fourth, OWP receives a continuous input of dissolved oxygen generated by water spilling from the D.T. pumping system. OEP receives oxygen near the surface only.

- In Figure 19, another important observation must be pointed out. Sedimentation rates, in $g.m^{-2}.d^{-1}$, greatly increased at the 7 m depth, but only *increased somewhat at the 2 m depth, following commencement of* Valley Seeps addition to the system. Increased water velocities and turbulence in the upper 2 m stratum of the OWP with increased inflow may offset the potential trapping of a greater density of particles by the 2 m traps.

- Alternately, it is possible that, following the start of Valley Seep input, settleable particles are now mainly forming at depth below the 2 m traps, to be captured by the 7 m traps.

- A second alternative is that, upon addition of the Valley Seeps flow to OWP, particles settling through the OWP water column are picking up additional compounds, such as iron hydroxide, now being formed in larger amounts due to greater oxygen supply at depth.

3.2 Chemical Composition

- Sedimentation trap dried solids have been analysed for major compounds including zinc, iron, aluminum, manganese, as well as more minor elements, such as copper, lead, barium and molybdenum.

3.2.1 OEP Sedimentation Trap Solids Composition

Figure 20a: OEP [Iron] in S.T.
Figure 20b: OEP [Zinc] in S.T.
Figure 20c: OEP [Aluminum] in S.T.
Figure 20d: OEP [Manganese] in S.T.
Figure 20e: OEP [Barium] in S.T.
Figure 20f: OEP [Copper] in S.T.
Figure 20g: OEP [Lead] in S.T.
Figure 20h: OEP [Molybdenum] in S.T.

- Ideally, in order to examine particles' composition as they settle out through the OEP water column, complete sets of 2 m, 11 m, and 20 m analyses on several occasions would be available. However, as explained for Table 4 above, three OEP 20 m sedimentation trap samples could not be included, as their masses were anomalously high, their physical appearance departed from normal, and the chemical analyses were very inconsistent with the remainder of samples. This leaves only two occasions where chemical analyses are available for all three depths, and another four occasions where pairs of sedimentation trap samples (2 m with 11 m, or 11 m with 21 m) were analysed (see Figures 20a - 20h).

- The solids collected from the 2 m, 11 m and 21 m sedimentation traps sampled on October 11, 1995 and August 3, 1998 were all analysed for elemental composition.

- Iron is primary element comprising these solids, present as iron hydroxide compounds. In these two sets of samples, the iron concentrations in collected solids slightly decrease with the depth of the sedimentation trap. This slight trend is also suggested among the remainder of pairs of samples (Figure 20a). This corroborates with iron solution chemistry.

- There is some indication that zinc concentrations in sedimentation trap solids diminish with increasing depth of the traps, although this trend is even weaker than iron (Figure 20b).

- There is some suggestion in the data that aluminum concentrations in sedimentation trap solids can slightly increase with depth (Figure 20c). Apart from the results of analysis of one of the first samples collected (October 22, 1990), aluminum concentrations are generally low. These clays could be diluting the iron and zinc content of sampling collecting at depth, explaining the slight trend of these elements' decreasing concentrations with depth.

- While there are some indications of increasing (Al) or decreasing (Fe, Zn) trends for these elements, there does not appear to be a simple pattern for manganese (Figure 20d).

- Barium (Figure 20e), copper (Figure 20 f) and especially lead (Figure 20g) concentrations increased with depth of the sedimentation trap for several dates. No simple pattern is evident for molybdenum (Figure 20h).

3.2.2 OWP Sedimentation Trap Solids Composition

Figure 21a: OWP [Fe] and [Zn] in 7 m S.T.
Figure 21b: OWP [Cu] and [Pb] in 7 m S.T.
Figure 21c: OWP [Mn] and [Ba] in 7 m S.T.
Figure 21d: OWP [Al] in 7 m S.T.
Figure 21e: OWP [Mo] in 7 m S.T.

- Most solids samples collected in sedimentation traps in OWP were from the 7 m depth. Shallow sedimentation traps (2 m) were not placed in OWP until 1998 (Map 1). Therefore, most available analytical data can be used only for examining long term variation in settling particles in the OWP.

- However, both analyses performed on samples collected in 1998 show sharp increases in these elements' concentrations. These changes cannot be attributed to the Valley Seeps addition, since both samples were collected before August 3, 1998.

- The concentrations of copper in sedimentation trap solids was also higher in 1998 samples (Figure 21b). Lead concentrations in settled solids from the 7 m OWP trap have been overall quite constant, with the exception of the first sample analysed, collected in September, 1994 (Figure 21b).

- *There is only minor variation in manganese concentrations in* OWP 7 m sedimentation trap solids (Figure 21c). There does not appear to be an increasing or decreasing trend in these Mn data.

- Aluminum concentrations increased in the two samples collected in 1996 and 1997, but were diminished in 1998 (Figure 21d). The concentrations of molybdenum in the OWP 7 m samples show a reverse trend to that of Al, in that the lowest Mo concentrations were detected in the 1996 and 1997 samples (Figure 21e).

3.2.3 Iron and Zinc Removal by Sedimentation in OWP

Figure 22a: OWP: Rate of Zinc Sedimentation

Figure 22b: OWP: Rate of Iron Sedimentation

- In Figure 19 (above), higher sedimentation rates were measured in the 7 m traps compared to the 2 m traps. In Figures 22a and 22b, these higher sedimentation rates at depth translate to higher rates of particulate zinc and *iron settlement, or downward flux, at most grid points, compared to shallow* strata.

- At one grid point, GP-4, the 2 m sedimentation trap sampled on August 3, 1998, collected zinc and iron more quickly than the 7 m trap below, in contrast with the other five pairs of sedimentation traps (Figures 22a and 22b). This trap also collected zinc and iron at a higher rate than any other trap, 2 m or 7 m, sampled on this date. The 7 m trap of the two lone traps stationed in the middle of the pit between October 9, 1997 and June 19, 1998 collected iron at the fastest rate, compared to any other trap in 1998. It also collected zinc at one of the fastest rates.

- The dynamics of water and particle movement at the grid point GP-4 appear to be the best of the six locations, in terms of downward flux, or settlement of zinc and iron carrying particles, according the results from the sedimentation traps (Figures 22a and 22b). In contrast, GP-8 appears to be the location where rate of particle settlement was slowest in the pit in this period.

- **OVERALL, A GREATER DOWNWARD FLUX OF PARTICULATE ZINC AND IRON IS OCCURRING AT A DEPTH OF 7 M, COMPARED TO 2 M, WITH THE EXCEPTION OF GP-4, WHERE THE DOWNWARD FLUX OF PARTICULATE ZN AND FE AT 2 M DEPTH WERE THE HIGHEST COMPARED TO ALL OTHER LOCATIONS AND DEPTHS SAMPLED ON THIS DATE.**

- Elements such as iron and zinc are being transferred from dissolved/suspended forms to settleable forms throughout the water column, and not just in surface strata exposed to the atmosphere and greater mixing. The flow and circulation patterns in OWP created by Drainage Tunnel water inflow (now augmented by Valley Seeps addition) likely create areas which favour particle formation, other areas which favour particle settling (e.g. GP-4 to the surface, and the remainder of the pit at depth) and other peripheral zones which are essentially stagnant and do not greatly assist in zinc or iron removal in the OWP (e.g. GP-8).

3.3 Estimation of Mass Sedimenting Annually in OWP and OEP

Table 5: Sedimentation Rate Data and Calculations for OEP and OWP, 1990 to 1998.

Table 6: Estimated Sedimentation of Elements in OWP and OEP, 1990 to 1998.

- The mass of elements, such as iron and zinc, sedimenting as particles in the OWP or OEP can be calculated by first, calculating the total mass of particles sedimenting in a period, followed by proportionally partitioning these periods into the calendar years (Table 5). The results of assays of sedimentation trap solids are used to calculate the total mass of each element which was removed as settling particulates for each year (Table 6).

- Based on the calculations presented in Table 5, the annual mass of particles settling in OEP has ranged from 15 tonnes per year (latter part of 1990 pro-rated to entire year;) to 125 tonnes per year ($t.y^{-1}$; 1992). Apart from these extreme years and 1998 (incomplete), annual masses range from 41 (1995) to 67 $t.y^{-1}$ (1997).

- During the first 9 months of 1998, a particle mass of only 15 tonnes are estimated to have accumulated in OEP; this is equivalent to 19 $t.y^{-1}$ when pro-rated for the whole year (Table 5).

- Pro-rating the 1998 OWP data collected to August 3, 1998 gives an estimate of 13.5 $t.y^{-1}$. When pro-rating the OWP data collected after August 3, the estimate is 23 $t.y^{-1}$.

- These estimates of the annual mass of settling precipitates are used in conjunction with sedimentation trap sample assay data to estimate the mass of zinc, iron, aluminum and phosphorus removed in these years from OWP and OEP as particulates (Table 6).

- For the OEP, the removal of Zn, Fe, Al and P as sedimenting particles is, to date, overall poor in 1998 (pro-rated), compared to previous years (back to 1990). **LESS ZN, AL, AND P WAS REMOVED IN 1998 THAN IN ANY OTHER YEAR, AND FE SEDIMENTATION WAS THE SECOND LOWEST YEAR TO DATE.**

- In contrast, more Zn and Fe were removed by sedimentation in OWP in 1998 (pro-rated) than in the previous four years. Much of this estimated zinc and iron removal in OWP is due to increased sedimentation rates measured after August 3, 1998, when the Valley Seeps joined the Drainage Tunnel flow to OWP.

4.0 ZINC REMOVAL

Figure 23: Zn Loads, $kg.d^{-1}$: D.T., Vs, OWP In, OWP, OEP

Table 7: Estimated Zinc Loads and Removal in the D.T.-OWP-OEP System.

4.1 Zinc Loads and Removal Rates

- In Figure 23, the daily mass, or load, of zinc, in $kg.d^{-1}$, moving through Drainage Tunnel-OWP-OEP system is shown for the period, January 1997 until October 11, 1998, the most recent data available. These daily loads were calculated by multiplying the zinc concentration for a particular date by the flow on that date. For calculating OWP's load, flow rates from the Drainage Tunnel were used prior to August 3, and the Drainage Tunnel plus Valley Seeps combined flows after August 3, 1998. Prior to August 3, 1998, the `DT' load is exactly that of `OWP In' but, after this date, the valley Seeps flow increases this loading at OWP In (Figure 23).

- Zinc loads in the system clearly increased soon after addition of the Valley Seeps. **THE ZINC LOADS LEAVING OWP AND OEP IN THE SUMMER OF 1998 (BETWEEN 9 AND 14 $KG.D^{-1}$) INCREASED TO ABOUT 25 TO 30 $KG.D^{-1}$, REFLECTING THE VALLEY SEEPS CONTRIBUTION OF BETWEEN 15 AND 25 $KG.D^{-1}$ (FIGURE 23).**

- In Table 7, the zinc loads used in mass balance calculations in Table 5 of the 1996 Final Report (pg. 32) are presented for comparison to the sum of daily zinc loads calculated for 1997 and 1998 using the existing monitoring data.

- In 1996, it was estimated that the Drainage Tunnel contributed about 4.3 $t.y^{-1}$ of zinc to the system. Based on mass balance calculations using chloride as a tracer, contaminated groundwater must be entering OWP, contributing about 0.8 $t.y^{-1}$ of zinc to OWP load. These two sources of zinc amounted to about 5.1 $t.y^{-1}$, while it was estimated that 5.2 $t.y^{-1}$ of zinc was leaving OWP and joining OEP. Therefore, given the excess of zinc in the system, no zinc removal was attributed to the OWP.

- Based on the 1996 sedimentation trap results, an estimated 0.2 $t.y^{-1}$ of zinc was present in settling solids in OWP, equivalent to only 2 % removal of zinc. *Since this rate of removal was small, it is not surprising that this minor loss of* zinc, occurring in OWP, was not detected based on the flow and water quality data (Table 7).

- The 1996 mass balance calculations using chloride as a tracer suggested that 2.8 $t.y^{-1}$ of zinc was added to OEP from contaminated groundwater. This load, combined with the 5.2 $t.y^{-1}$ load from OWP, amounts to 6.0 $t.y^{-1}$ of zinc. In 1996, monitoring data suggested that only 5.8 $t.y^{-1}$ left OEP at the outflow, a 10 % reduction in the zinc load. For this same year, the estimated annual zinc removal based on sedimentation data was about 0.8 $t.y^{-1}$, also 10 % of the load entering OEP.

- For 1997, the daily zinc loads were summed to estimate annual zinc loads moving through each component of the system. In this year, the Drainage Tunnel contributed 3.6 $t.y^{-1}$, while it was assumed that groundwater added another 0.8 $t.y^{-1}$. Therefore, a total of 4.4 t of zinc entered OWP in 1997. Based on water quality and estimated outflow (D.T. flow +1.7 $L.s^{-1}$ from groundwater), about 3.9 $t.y^{-1}$ left OWP to join OEP surface water, about 12 % less zinc than entered OWP. **ACCORDING TO THE ESTIMATE OF ZINC REMOVAL BASED ON SEDIMENTATION TRAP DATA, ABOUT 1.9 % OF THE ZINC LOAD TO OWP SETTLED TO THE BOTTOM IN PARTICULATE FORM, A MUCH LOWER ESTIMATE THAN THE CALCULATED REDUCTION BASED ON FLOW AND WATER QUALITY DATA.**

- In 1997, the OEP is estimated to have received 6.6 $t.y^{-1}$ of zinc from the OWP and contaminated groundwater (Table 7). The zinc load leaving OEP was estimated at 5.8 $t.y^{-1}$, about 12 % less than the load it received. The sedimentation trap data suggested an annual zinc removal of 9.9 % for 1997, a value very similar to to 12 % removal according to water quality and flow data.

- The 1998 *calendar year is incomplete.* Load calculations *are based on the first* 214 days (prior to August 3) and the next 46 days (sedimentation trap data) up to September 11, 1998, or 70 days (water quality monitoring data) up to October 11, 1998 (Table 7).

- Over the first 214 days of 1998, about 2.1 t of zinc were added to OWP. In this period, an estimated 2.2 t exited as outflow to OEP, indicated no zinc removal in the OWP in this period. However, the sedimentation traps captured the equivalent of 0.07 t of zinc, or about 2.9 % of the zinc load to OWP (Table 7). Again, because so little zinc is actually removed in OWP, combined with inherent errors in estimating loads, the two methods for estimated zinc removal in OWP do not agree.

- As reported for 1996 and 1997, the 1998 OEP zinc removal estimate of 4.1 % for the first 214 days, based on water quality monitoring , agrees well with the estimate based on OEP sedimentation trap data of 4.9 % (Table 7).

- The otherwise good agreement between zinc removal estimates based on water quality and sedimentation trap data for OEP does not hold for the most recent monitoring period, following addition of Valley Seeps water to the system. The estimated zinc removal according to water quality data (38 %), versus % zinc removal based on sedimentation trap data (7 %), demonstrates that elevated zinc loads moving through the system had not yet reached OEP outflow for a considerable time, maintaining low zinc concentrations at the outflow and therefore overestimating zinc removal in OEP.

- Overall, estimates of zinc removal in OWP according to water quality data do not agree with zinc removal estimates based on sedimentation trap data. However, for OEP, very good agreement was typically found between these two completely independent calculations in 1996, 1997 and the first 214 days of 1998 (Table 7).

- In Table 7, pro-rated estimates of zinc loads in 1998 are presented for the periods before and after Valley Seeps addition. The annual zinc load from the Drainage Tunnel has remained quite consistent since 1996, ranging from 3.2 to 4.3 $t.y^{-1}$.

- However, following commencement of Valley Seeps addition, the load to OWP has increased from 4.6 - 5.1 $t.y^{-1}$ to 11.5 $t.y^{-1}$, more than double that of recent years.

- The annual zinc load to OEP has increased to 14.3 $t.y^{-1}$, compared to 6.6 - 8.0 $t.y^{-1}$ over the past 2.5 years.

- Residence time in OWP has simultaneously been reduced from 77 days to 50 days (Table 1), while for OEP, residence time has decreased from 126 days to 98 days; more zinc must now be removed in fewer days throughout the system.

4.2 Required Zinc Removal Rates in OWP and OEP

- Following commencement of Valley Seeps input to OWP on August 3, 1998, the zinc loads to OWP and OEP in the last third of 1998 onwards are as follows:

- Valley Seeps: 25 kg of Zn in 458 m^3 (5.3 $L.s^{-1}$) each day

- Drainage Tunnel: 10 kg of Zn in 717 m^3 (8.3 $L.s^{-1}$) each day

- OWP (incl. V.s. + D.T): 35 kg of Zn in 1,322 m^3 (15.3 $L.s^{-1}$) each day

- OEP (incl. OWP): 39 kg of Zn in 2,160 m^3 (25 $L.s^{-1}$) each day

4.3 Projected Utility, Requirements and Performance of Phosphate Addition

- Phosphate addition experiments conducted in 1997 were performed using Drainage Tunnel, OWP and OEP solutions with chemical characteristics for that period.

- To date, no phosphate experiments using Valley Seeps, or mixtures of Valley Seeps with other solutions, have been conducted.

- While zinc removal was achieved upon addition of phosphate as 10-52-10 fertilizer or as K_2HPO_4, **A SIMPLE, DIRECT RELATIONSHIP WAS NOT EVIDENT BETWEEN THE AMOUNT OF PHOSPHATE AND THE RATE/ DEGREE OF ZINC REMOVAL.**

- Removal of zinc from solution by phosphate is currently attributed to phosphate's ability to flocculate small suspended zinc carbonate particles into larger, settleable particles.

- The theoretical retention time of water in OWP is currently 50 days, and for OEP, 98 days. Lab experiments using phosphate were conducted over periods no longer than 25 days.

- Batch tests were performed in the lab. It is possible that zinc carbonate compounds flocculated with phosphate compounds could be recycled to flocculate more zinc. Such lab experiments, which could be designed to determine ways to optimize zinc removal and minimize phosphate consumption, have not been performed.

- Zinc removal rates of 0.005 $mM.h^{-1}$ or higher were observed at phosphate concentrations at around 1 mM. This is equivalent to 95 g of phosphate per m^3 of water removing 0.12 moles (=7.8 g) of zinc per m^3 per day. If the process is complete in 48 hours, about 95 g of phosphate have served to flocculate about 16 g of zinc in 2 m^3 of water.

- Using a zinc load of 35 kg per day at OWP outflow, about 200 kg of phosphate are required per day.

- Using a cheap but soluble form of phosphate such asNa_3PO_4 would require 720 kg of this material each day. At $1,250 per t, the cost per day would be $900, or, per year, $329,000. Clearly, attempts to optimize the process in dynamic conditions are needed via pilot/field tests to bring the costs down.

5.0 PERFORMANCE OF POLISHING POND SYSTEM: MONITORING DATA

Figure 24: pH, 1997-1998, OEP Weir, Final Effluent, PP13, PP17.

Figure 25: Zinc Concentration, 1997-1998, OEP Weir, Final Effluent, PP13 and PP17.

Figure 26: Zinc Load, 1997-1998, OEP Weir and Final Effluent

Figure 27: Pond Performance, 1996-1998.

Figure 28: Zinc Load, 1997-1998, PP10 and PP13.

Figure 29: Zinc Load, 1997-1998, PP14 and PP17

- The pH at the OEP weir in 1998 followed very closely to pHs measured in 1997 up to about day 170 (Figure 24). Thereafter, the 1998 pHs appreciably dropped to less than pH 6.8. Although the Valley Seeps were reportedly added to the system after day 215 (August 3, 1998), it looks like low pH water was entering the system in July.

- The final effluent had typically lower zinc concentrations in 1998 than in 1997 prior to day 215 (Figure 25). However, after August 3, 1998, higher zinc concentrations were present in the final effluent.

- Zinc loads in the OEP outflow and the final effluent in 1998 were generally lower than loads at these locations in1997 (Figure 26), up to day 215. Thereafter, 1998 loads were exceptionally high.

- The overall 1998 polishing pond performance was comparable to 1996 and 1997 performance up to day 215 (Figure 27). Thereafter, performance appreciably diminished.

Table 1: Revised 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 $L.s^{-1}$	Theoretical Residence Time days	Top 1 m Residence Time days
Drainage Tunnel	NA	NA	NA	8.3	NA	NA
Valley Seeps	NA	NA	NA	5.3	NA	NA
OWP	4,645	66,245	4,645	15	50	3.5
OEP	19,510	208,197	19,510	25	98	9.2
PP10-13 (40 % of flow)	13,016	5,951	NA	9.8	7.0	NA
PP14-17 (60% of flow)	13,142	6,009	NA	15	4.7	NA

Table 2: D.T.-OWP-OEP pH and Zinc Concentrations, 1997-1998.

		pH D.T.	V.s.	D.T.+V.S. Discharge to OWP	OWP	OEP	[Zinc] D.T.	V.s.	D.T.+V.S. Discharge to OWP	OWP	OEP
1997	**Average**	**6.1**			**6.5**	**6.4**	**15**			**12**	**12**
	Minimum	5.9			6.3	6	2.1			3	4.7
	Maximum	6.7			6.8	7.1	28			20	17
1998	**To Aug 2**										
	Average	**6.1**	**4.7**		**6.3**	**6.4**	**13**	**44**		**13**	**11**
	Minimum	6	4.6		6.1	6	2.0	42		13	2.7
	Maximum	6.3	4.9		6.7	6.9	22	47		14	25
1998	**Aug 3-Oct 11**										
	Average	**6.0**	**4.6**	**5.9**	**6.5**	**6.6**	**13**	**45**	**25**	**19**	**14**
	Minimum	5.9	4.5	5.7	6.4	6.4	4.3	39	23	13	11
	Maximum	6.2	4.7	6	6.7	6.9	24	49	26	22	16

Table 3: 1998 Bucket Experiments: Mixing Valley Seeps with Drainage Tunnel or OEP

	Measured pH			Calc. pH	Avg Flow, 1997 USGPM	L.s^{-1}	Test Vol. (mL)	Temperature (C)		Cond. (uS.cm^{-1})	Measured [Zn] mg.L^{-1}			Calc.[Zn] mg.L^{-1}
Test 1	26-Mar													
Vs4	4.5				28	1.8	350							
Vs5	5.2				22	1.4	275							
D.T.	6.0				129	8.1	1612.5							
Mix	6.0			5.2	179	11.3	2237.5							
Test 2	30-Mar	6-Apr						30-Mar	6-Apr					
Vs4	4.7	4.6			28	1.8	559	6	15	470	45.2			
Vs5	5.4	5.3			21	1.3	413	5	15	312	20.6			
D.T.	6.1	6.2			123	7.8	2466	5.4	15	250	15.2			
Mix	5.9	6.1		5.4	172	10.8	3438	9	15	311	20.5			20.7
Test 3														
07-Apr-98	Start	60 min	24 hrs								Start	60 min	24 hrs	
Vs4	4.6										47.8			
Vs5	5.7										19.0			
OEP	6.3	6.3	6.8								11.9	12.0	11.7	
OEP+Vs4+Vs5	6.3	6.3	6.7	5.6							15.0	15.2	14.9	15.2
OEP+Vs4+Vs5+Precip	6.3	6.4	6.6								13.1	13.2	12.2	

Table 4: Sedimentation Rates (DW $g.m^{-2}.d^{-1}$) in OWP, OEP and Lucky Strike, 1990 - 1998.

Starting	Retrieving	Days	OEP outflow	OEP 4m	OEP 11m	OEP 20m		OWP 2m	N=	OWP 7m	N=	LS* 5m	LS 7m
20-Sep-90	22-Oct-90	32	0.6			2.1							
22-Oct-90	28-May-91	218	4.6			4.6							
28-May-91	18-Oct-91	143	1.9			5.3							
18-Oct-91	29-Sep-92	347	3.8			19							
14-Jun-93	30-Aug-93	77		5.9	9.9	354	NI						
30-Aug-93	07-Nov-94	315		5.1	4.5	103	NI						
11-Jul-94	07-Sep-94	58				21				6.2			
07-Sep-94	07-Jul-95	303		3.9	3.2	12				4.9			
07-Jul-95	12-Oct-95	97		5.3	4.9	6.2				6.2			
12-Oct-95	10-Jul-96	272		4.5	4.5	59.6	NI			43			
10-Jul-96	29-Sep-96	81		4.8	5.5	9.3				7.0			
29-Sep-96	23-Jul-97	297			4.6	13				21			
23-Jul-97	09-Oct-97	78			3								
23-Jul-97	22-Oct-97	91				2.3				4.1			
28-Aug-97	09-Oct-97	42											
28-Aug-97	22-Oct-97	55						1.9				<dl**	<dl**
22-Oct-97	18-Jun-98	239											0.77
09-Oct-97	18-Jun-98	252			1.9	0.89		1.3		6.8			
19-Jun-98	03-Aug-98	45		5.0	4.8	5.7		*2.2*	*6*	*4.7*	*6*		
03-Aug-98	18-Sep-98	46		6.5	7.0	6.3		*4.4*	*6*	*23*	*6*		
Average			**2.7**	**5.1**	**4.9**	**8.3**		**2.4**		**12.7**			

* Flooded Lucky Strike gloryhole

** not detected, traps seemed empty of particles.

Italic values are average from six samples.

NI Not Included in Averages

Table 5: Sedimentation Rate Data and Calculations for OEP and OWP, 1990 to 1998.

Sedimentation Traps Placed	Retrieved	No. of Days in Period	Sed. Rate, $g.m^{-2}.d^{-1}$ 20 m	11 m	4 m	OEP Area = 19,510 m^2 Average Sedimentation $kg.pit^{-1}.d^{-1}$	N	Sediment in period kg	Cumulativ to date kg	Proportions for years *** (current,	prev/next)	OWP Area = 4,645 m^2 Sed. Rate, $g.m^{-2}.d^{-1}$ 7 m	N	2 m	N	Average Sediment. $kg.pit^{-1}.d^{-1}$	Sediment in period kg	Cumulative to date kg	Year	OEP Estimate for year $kg.y^{-1}$	OWP Estimated for year $kg.y^{-1}$
20-Sep-90	22-Oct-90	32	2.1			41	1	1,311	1,311	1.00									*1990 PR**	14,954	
22-Oct-90	28-May-91	218	4.6			90	1	19,565	20,876	0.32	0.68								1991	55,500	
28-May-91	18-Oct-91	143	5.3			103	1	14,787	35,662	1.00											
18-Oct-91	29-Sep-92	347	19			371	1	128,629	164,292	0.21	0.79								1992	125,602	
29-Sep-92	14-Jun-93	258				262	0[2]	67,702	231,993	0.36	0.64								1993	66,684	
14-Jun-93	30-Aug-93	77	*354*[1]	9.9	5.9	154	2	11,668	243,661	1.00											
30-Aug-93	11-Jul-94	315	*103*	4.5	5.1	94	2	29,499	273,360	0.39	0.61								1994	56,028	4,288
11-Jul-94	07-Sep-94	58	21			410	1	23,763	297,124	1.00		6.2				29	1,670	1,670	1994 PR*		8,151
07-Sep-94	07-Jul-95	303	12	3.2	3.9	124	3	37,637	334,760	0.38	0.62	4.9				23	6,896	8,567	1995	40,721	23,051
07-Jul-95	12-Oct-95	97	6.2	4.9	5.3	107	3	10,346	345,106	1.00		6.2				29	2,794	11,360			
12-Oct-95	10-Jul-96	272	*69.6*	4.5	4.5	88	2	23,880	368,986	0.29	0.71	43.0				200	54,328	65,688	*1996*	*43,148*	*50,055*
10-Jul-96	29-Sep-96	81	9.3	5.5	4.8	127	3	10,325	379,311	1.00		7.0				33	2,634	68,322			
29-Sep-96	23-Jul-97	297	13	*4.6*		172	2	50,991	430,302	0.31	0.69	21.0				98	28,971	97,293	1997	41,849	23,194
23-Jul-97	09-Oct-97	78		3		59	1	4,565	434,867	1.00											
23-Jul-97	22-Oct-97	91	2.3							1.00		4.1				19	1,733	99,026			
28-Aug-97	09-Oct-97	42								1.00											
28-Aug-97	22-Oct-97	55								1.00				1.9		9	485				
22-Oct-97	18-Jun-98	239								0.29	0.71										
09-Oct-97	19-Jun-98	253	0.89	1.9		27	2	6,886	441,753	0.33	0.67	6.8		1.3		19	4,759	103,785	1998 to date	15,066	6,846
19-Jun-98	03-Aug-98	45	5.7	4.8	5	101	3	4,536	446,289	1.00		4.7	6	2.2	6	16	721	104,506	1998 PR*	19,385	13,465
03-Aug-98	18-Sep-98	46	6.3	7	6.5	129	3	5,923	452,213	1.00		23.0	6	4.4	6	64	2,927	107,434	Before Aug 3:PR		6,654
																			After Aug 3:PR		23,227

1 Values in italics considered invalid data and are not used in calculations. Pit wall slumping suspected.
2 Average of previous and next periods' sedimentation rate used for this period.
PR* *Pro-Rated Estimate of Sedimented Mass for all of 1990 or 1998*

Table 6: Estimated Sedimentation of Elements in OWP and OEP, 1990 to 1998.
(pro-rated yearly sedimentation rates used)

	OEP (all trap samples)					OWP (7 m trap samples)					OEP				OWP			
	t.y-1	[Zn] kg.t-1	[Fe] kg.t-1	[Al] kg.t-1	[P] kg.t-1	t.y-1	[Zn] kg.t-1	[Fe] kg.t-1	[Al] kg.t-1	[P] kg.t-1	Zn kg.y-1	Fe kg.y-1	Al kg.y-1	P kg.y-1	Zn kg.y-1	Fe kg.y-1	Al kg.y-1	P kg.y-1
1990	15	*27*	*316*	*18*	*0.85*						*408*	*4,722*	*262*	*13*				
1991	55.50	*23*	*338*	*10*	*0.46*						*1,300*	*18,753*	*575*	*25*				
1992	126	*23*	*338*	*10*	*0.46*						*2,942*	*42,439*	*1,302*	*57*				
1993	67	20	360	3.2	0.06						1,304	24,006	212	4.0				
1994	56	10.7	165	4.5	*0.06*	8.2	12	220	9.7	*0.39*	600	9,245	252	3.5	96	1,793	79	*3.1*
1995	41	22	399	1.3	*0.06*	23	6.2	156	3.8	*0.39*	912	16,261	54	2.5	142	3,596	88	*8.9*
1996	43	19	446	2.2	0.06	50	2.4	77	14	0.39	805	19,233	94	2.8	120	3,847	706	19
1997	42	16	396	4.0	0.23	23	3.6	55	20	0.46	660	16,558	169	9.8	83	1,285	462	11
1998 to date	15.1	20	383	2.1	0.12	6.8	17	371	7.9	0.19	304	5,775	32	1.8	116	2,538	54	1.3
1998 to Aug 3	9.2					3.9					185	3,508	19	1.1	66	1,453	31	0.8
1998 After Aug 3	5.9					2.9					119	2,267	13	0.7	50	1,085	23	0.6
1998: PR	19	20	383	2.1	0.12	13	17	371	7.9	0.19	391	7,420	41	2.3	228	4,992	106	2.6
1998 Before Aug.3; PR						*6.7*	*17*	*371*	*7.9*	*0.19*					*113*	*2,467*	*52*	*1.3*
1998 After Aug.3: PR*						23	17	371	7.9	0.19					394	8,611	183	4.5
Total to Date, t	460					111					9.2	157	3.0	0.12	558	13,059	1,388	43

Values in italics based on averages of estimates in previous and following years.

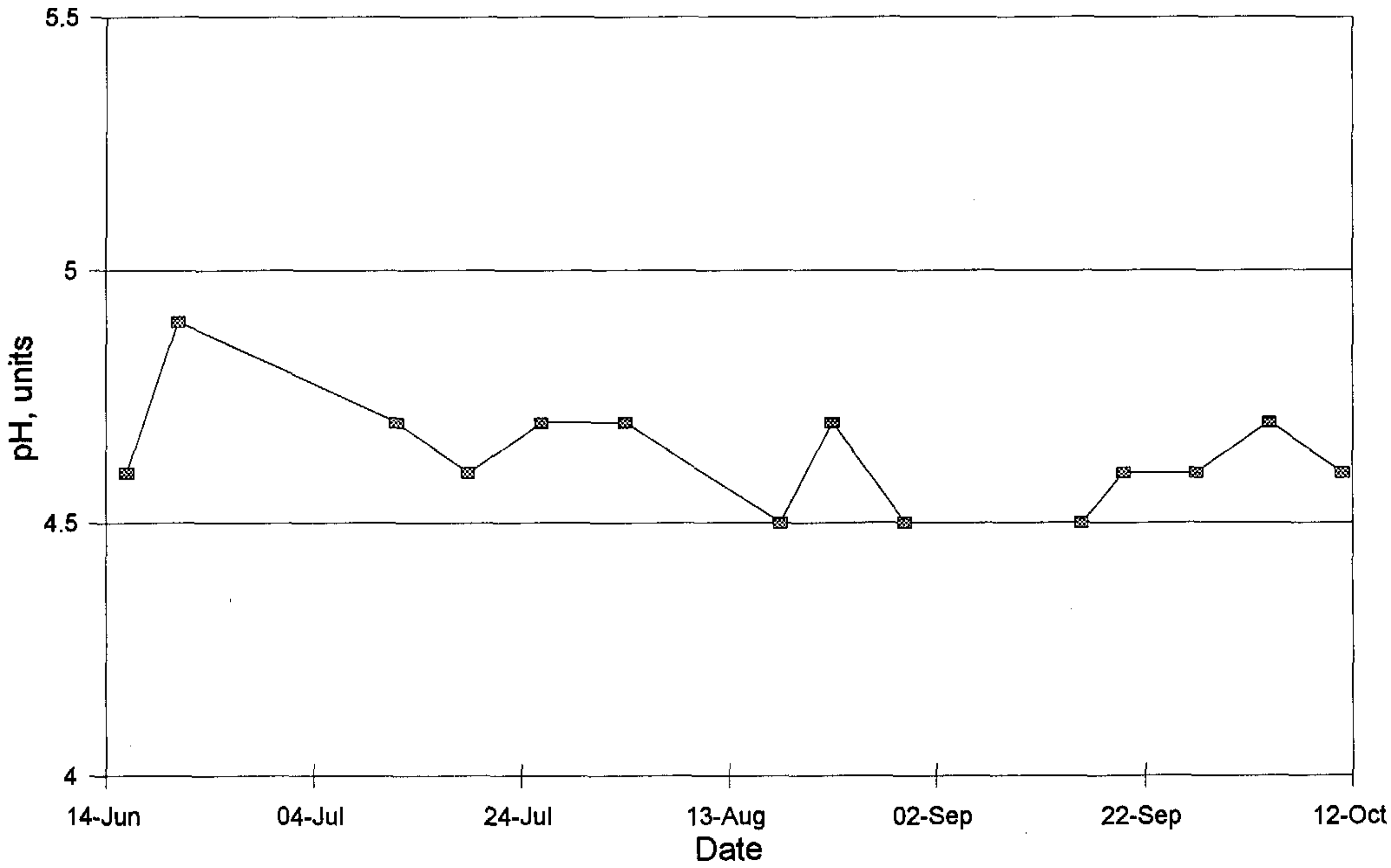
* Assay Data for sedimentation trap samples only available for pre-August 3, 1998 period.

PR Pro-rated for year

Table 7: Estimated Zinc Loads and Zinc Removal in The D.T.-OWP-OEP System.

		days	Drainage Tunnel Zn Load kg in period	Valley Seep Zn Load kg in period	Groundwater To OWP Zn Load kg in period	Discharge To OWP Zn Load kg in period	OWP Discharge = =OEP Inflow Zn Load kg in period	Contam G-W To OEP Zn Load kg in period	Clean G-W To OEP Zn Load kg in period	Discharge To OEP Zn Load kg in period	OEP Outflow Zn Load kg in period
1996			a	b	(est.)	a+b+c=d	e	f (est)	g (est.)	e+f+g=h	i
(from 1996 Report)	Zinc Load	365	4,267	0	831	5,098	5,235	2,780	1	8,016	7,205
	Apparent Removal						-2.7%				10%
	S.T.'s: Zinc Sedimented						120				805
	Removal						2.4%				10%
			sum of daily loads (water quality flow)								
1997					(est.)			(est.)	(est.)		
	Zinc Load	365	3,563	0	831	4,394	3,866	2,780	1	6,647	5,829
	Apparent Removal						12%				12%
	S.T.'s: Zinc Sedimented	365					83				660
	Removal						1.9%				9.9%
1998					(est.)			(est.)	(est.)		
January 1 to August 2	Zinc Load	214	2,184		487	2,671	2,302	1,630	0.6	3,933	3,772
	Pro-Rated for year	*365*	*3,725*		*831*	*4,556*	*3,927*	*2,780*	*1*	*6,708*	*6,433*
	Apparent Removal						14%				4.1%
	S.T.'s: Zinc Sedimented	214					66				185
	Removal						2.9%				4.9%
					(est.)			(est.)	(est.)		
August 3 - October 11	Zinc Load	70	611	1,745	159	2,114	2,211	533	0.2	2,744	1,710
	Pro-Rated for year	*365*	*3,186*	*9,101*	*831*	*11,024*	*11,527*	*2,780*	*1*	*14,308*	*8,915*
	Apparent Removal						-4.6%				37.7%
August 3 - September 18	S.T.'s: Zinc Sedimented	46					50				119
	Removal						2.2%				7.0%

Fig.1: Valley Seeps at Pumphouse
pH, 1998



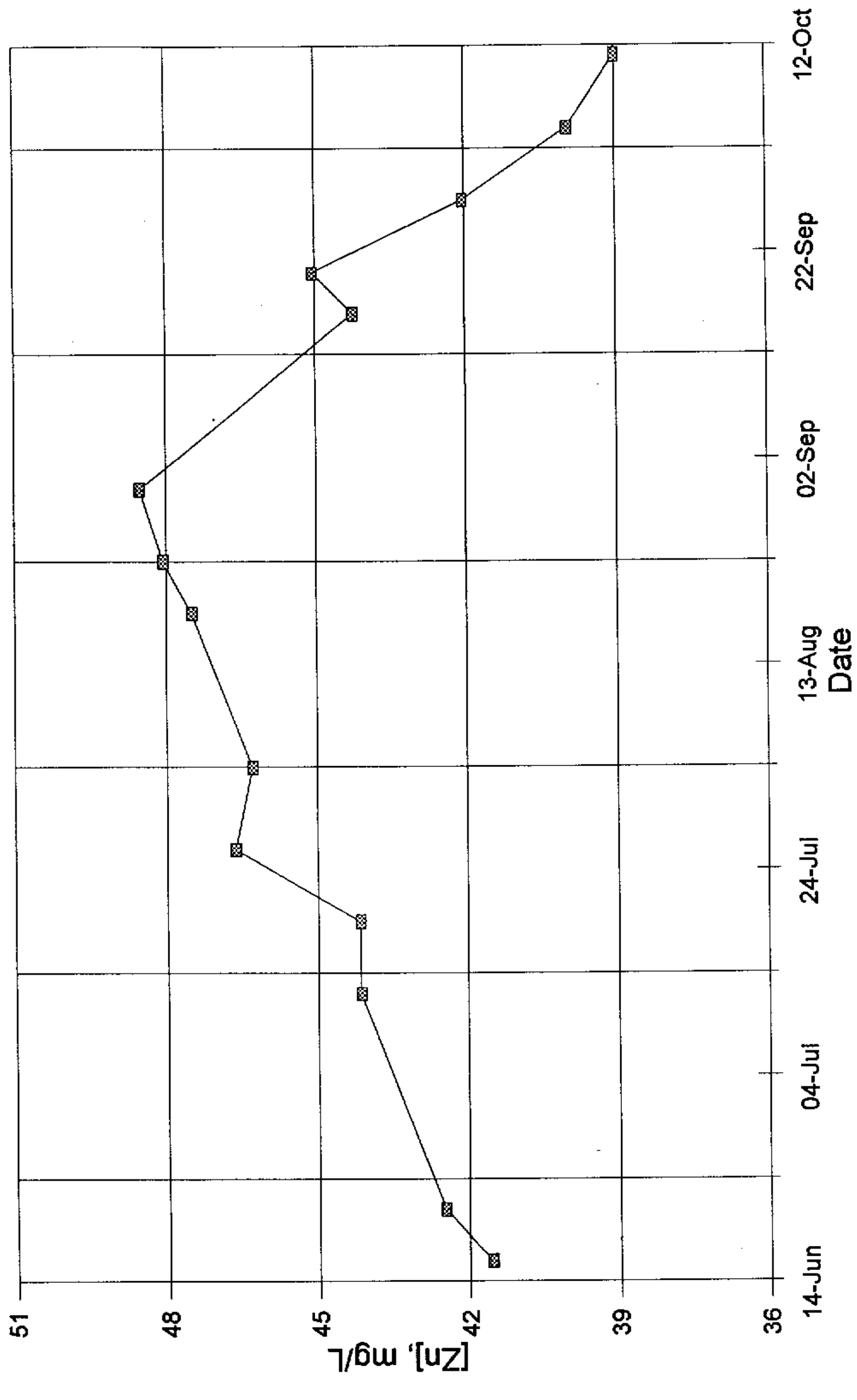


Fig. 2: Valley Seeps at Pumphouse
Zinc Concentration, 1998

Fig. 3: Valley Seeps at Pumphouse
Flow and Load, 1998

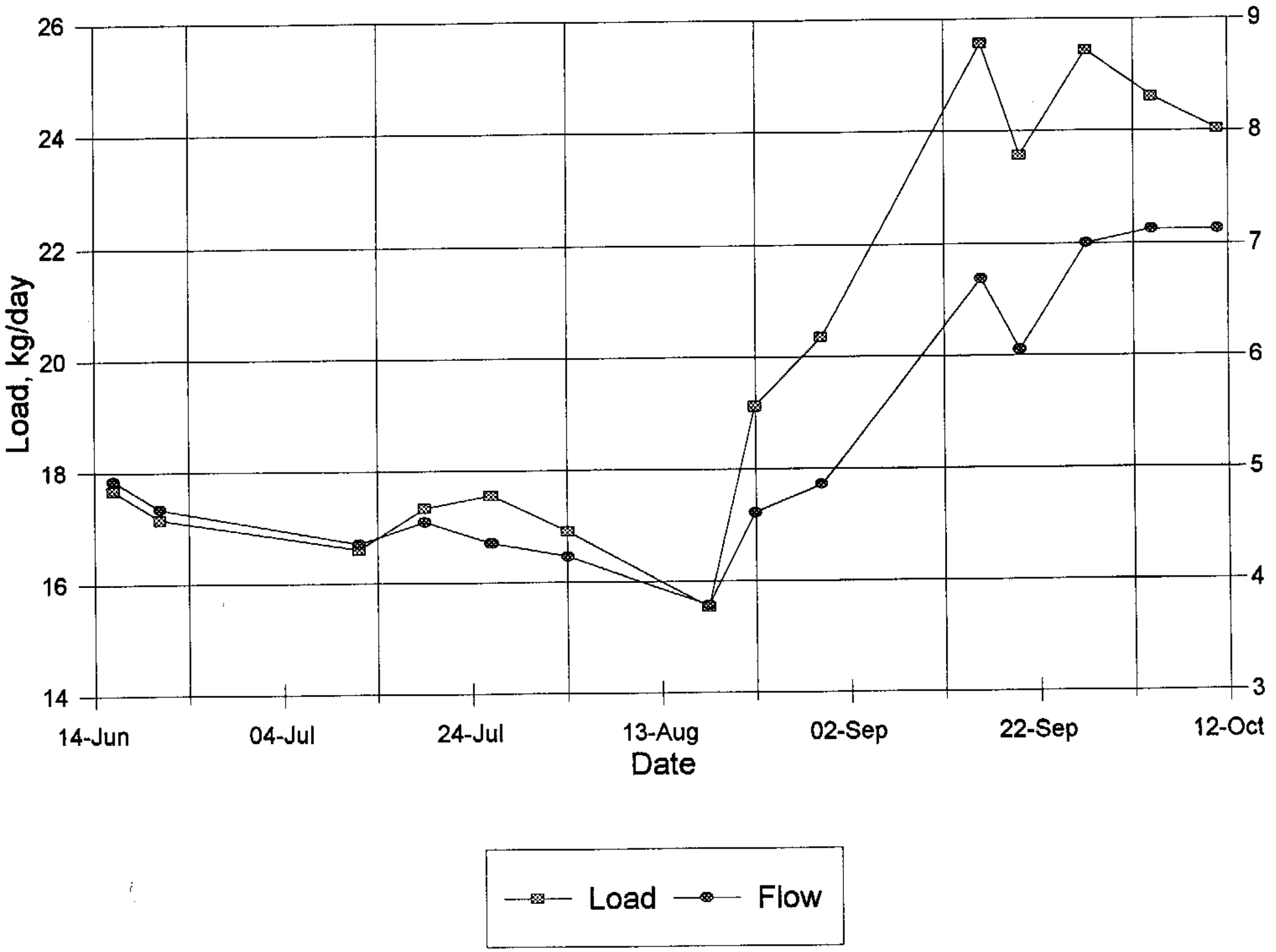


Fig. 4: Drainage Tunnel Discharge
pH, 1995 - 1998

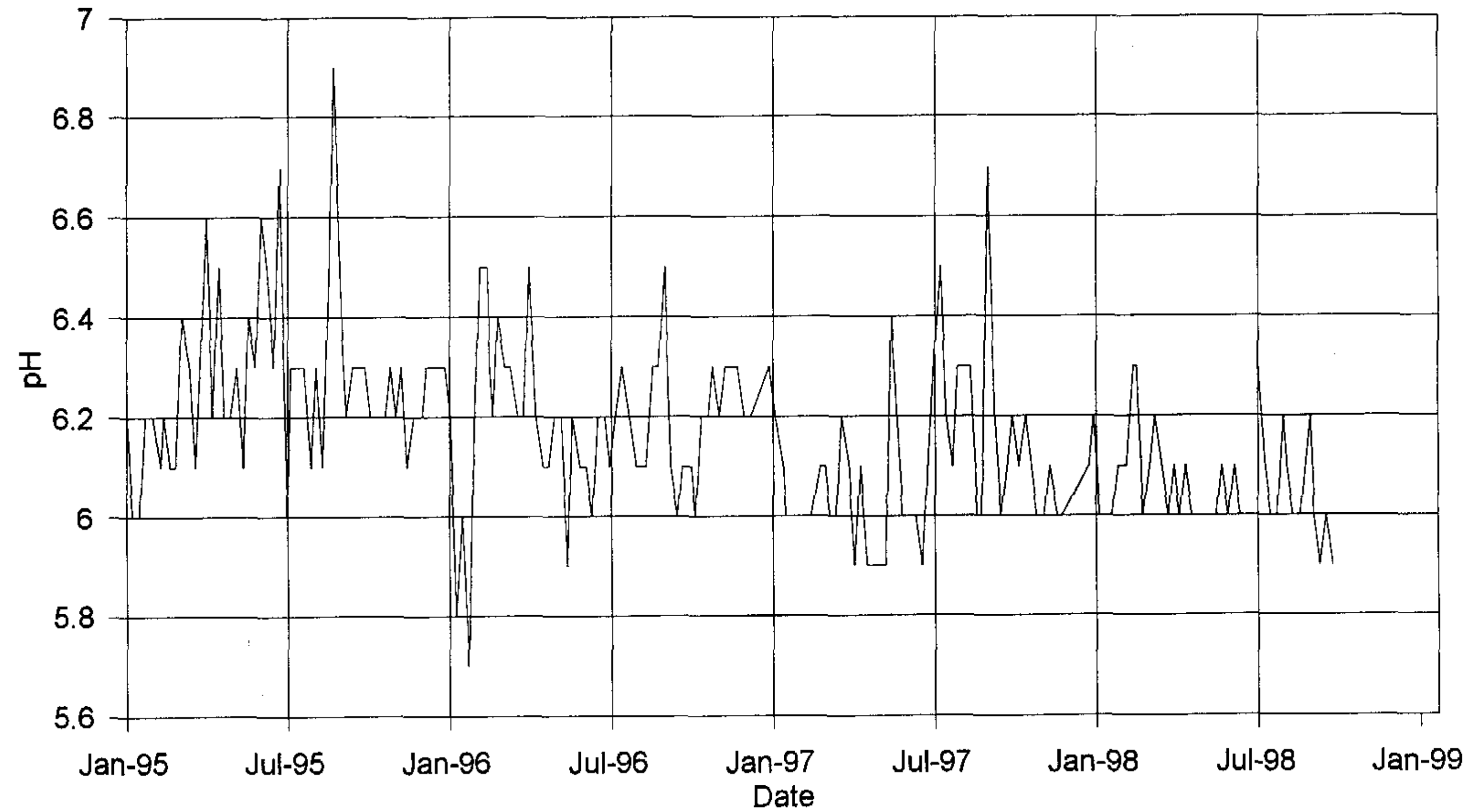
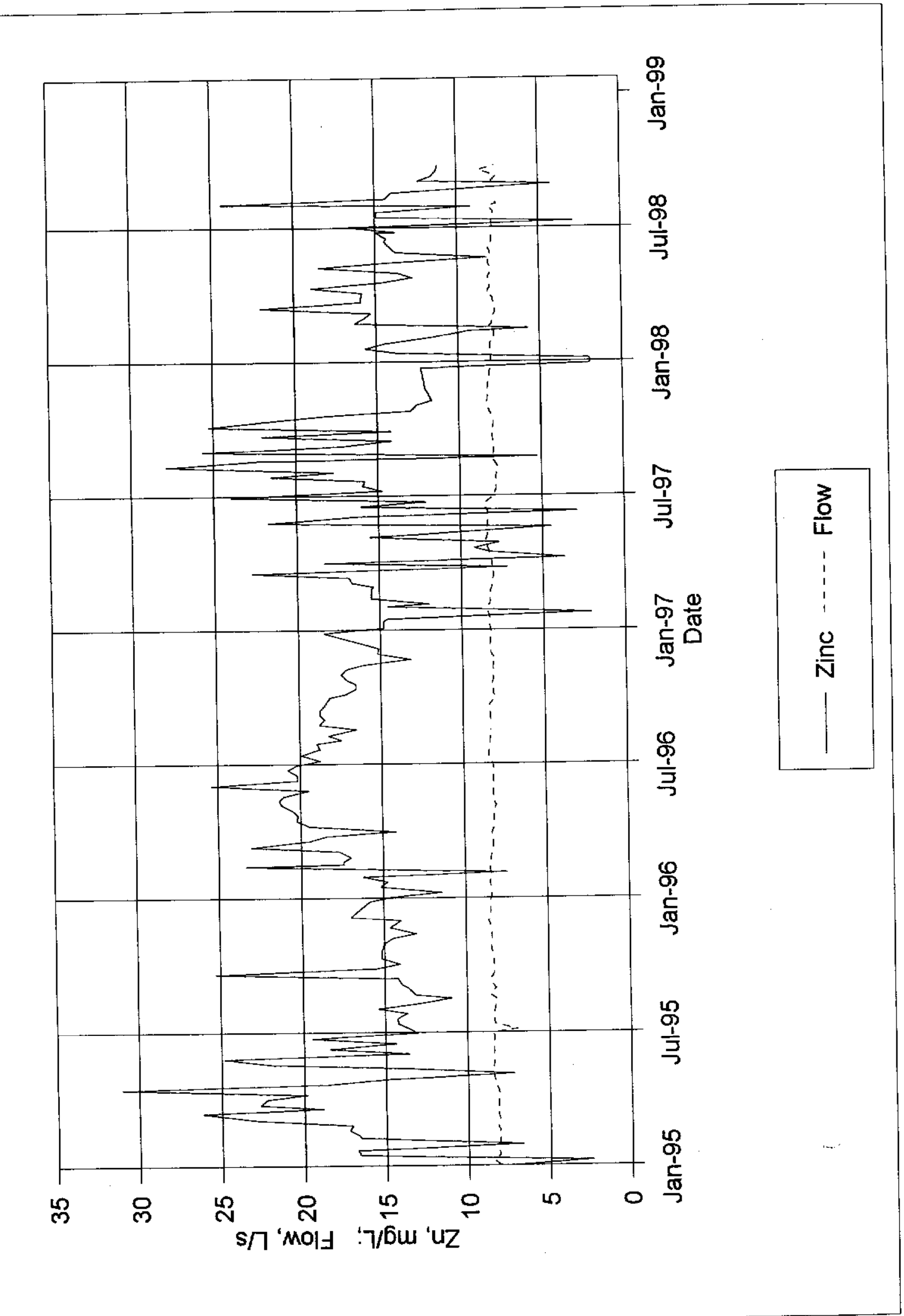


Fig. 5: Drainage Tunnel Discharge
[Zn] and Flow, 1995 - 1998



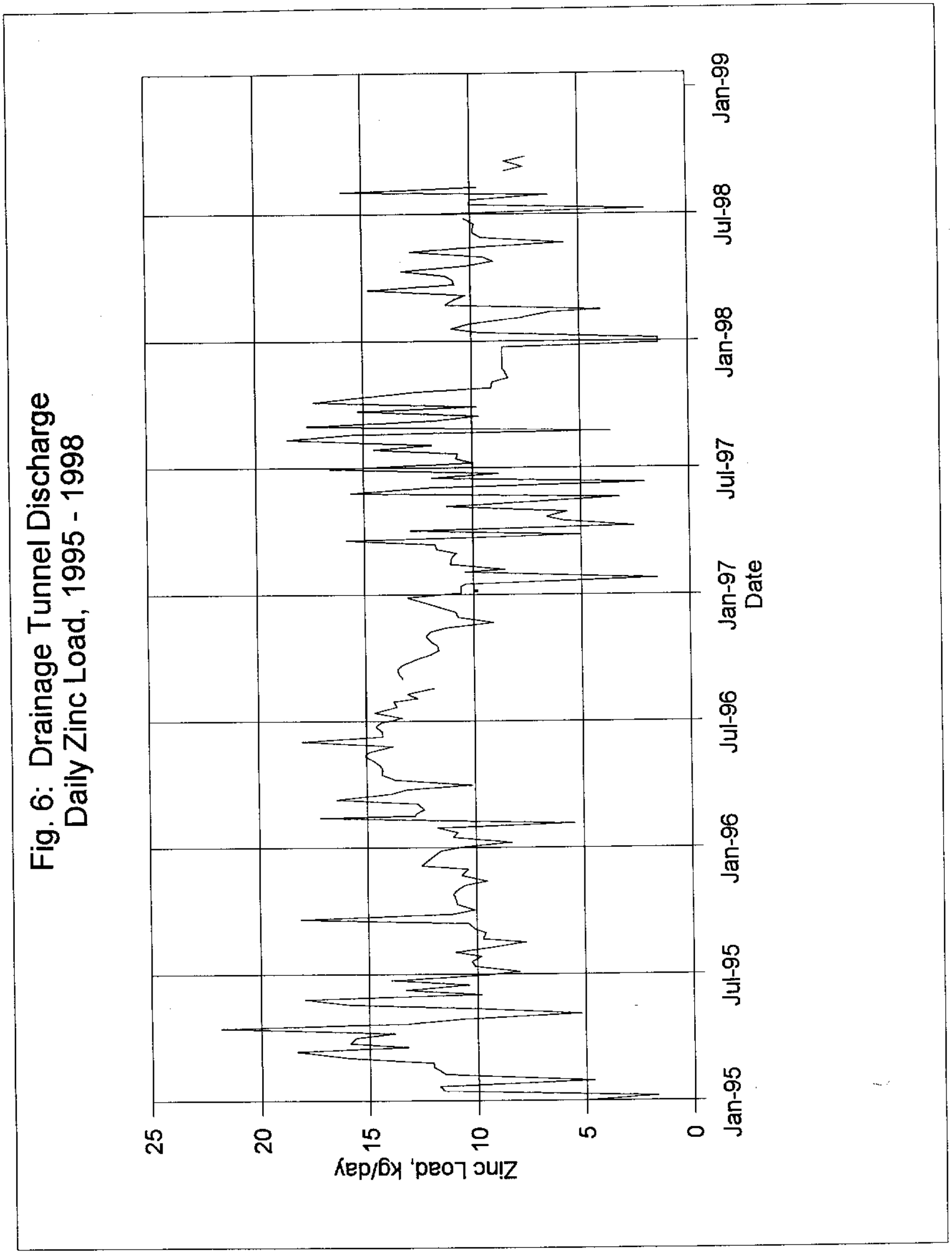


Fig. 6: Drainage Tunnel Discharge
Daily Zinc Load, 1995 - 1998

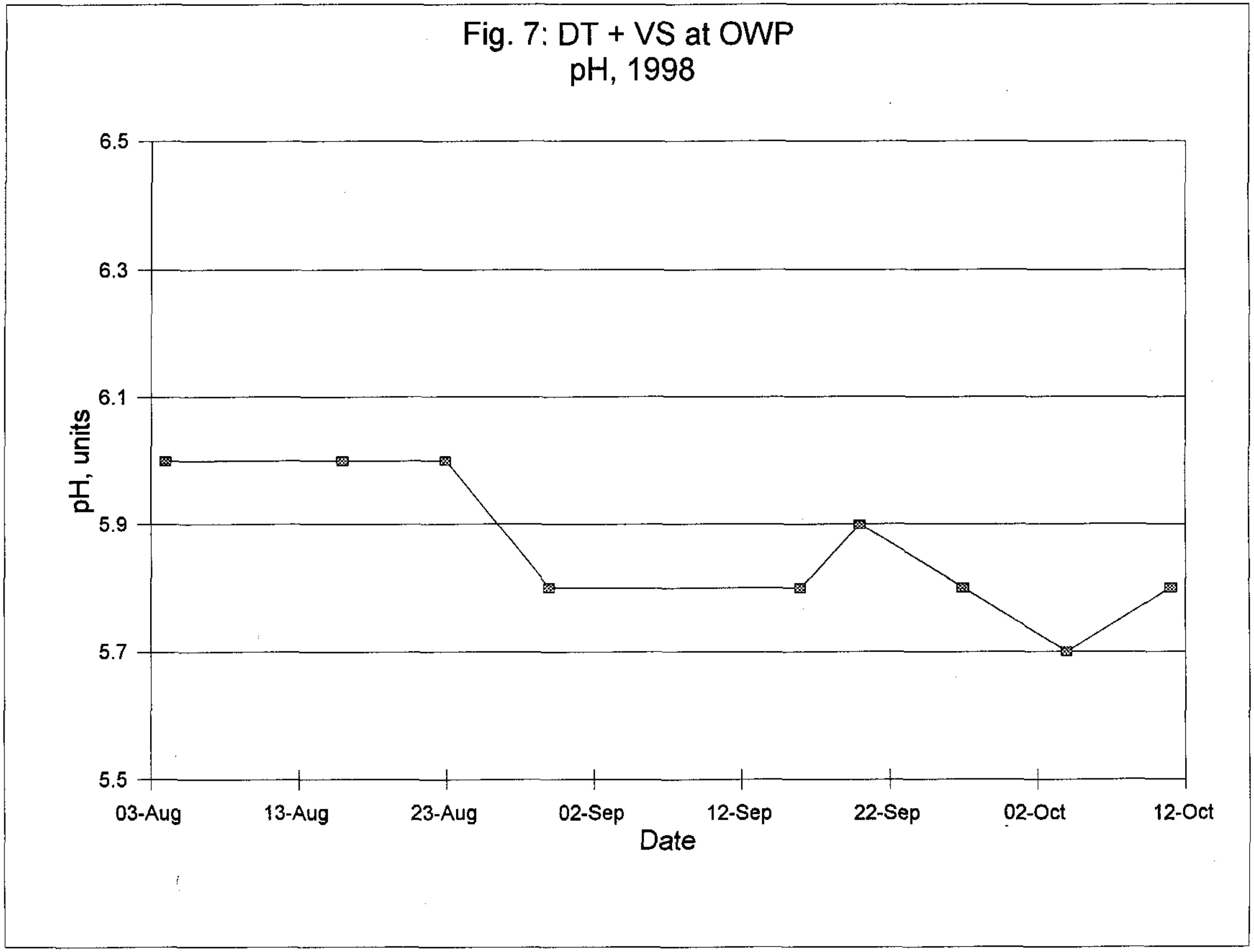
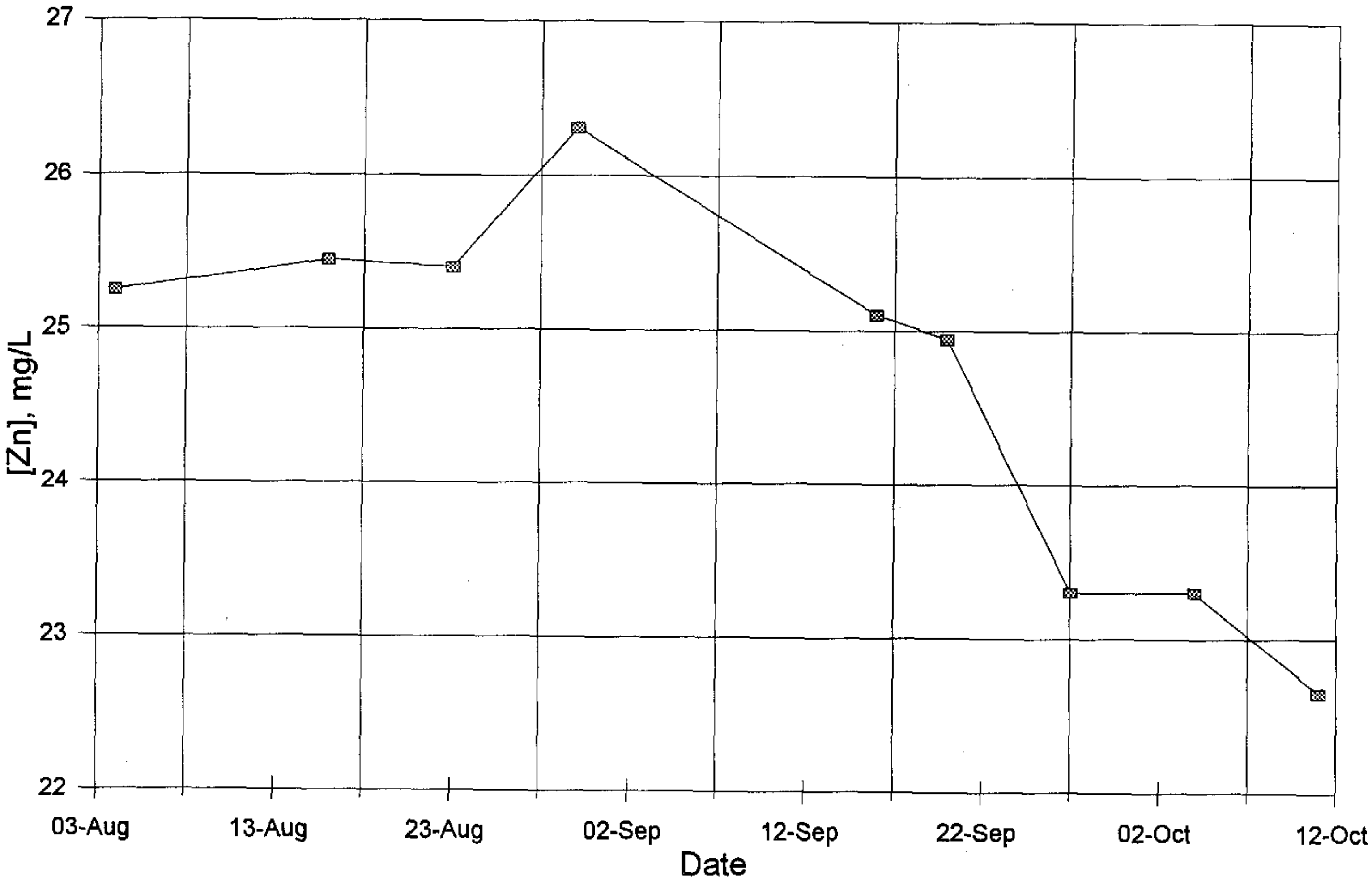


Fig. 7: DT + VS at OWP
pH, 1998
6.5
6.3
6.1
5.9
5.7
5.5
pH, units
03-Aug
13-Aug
23-Aug
02-Sep
12-Sep
22-Sep
02-Oct
12-Oct
Date

Fig. 8: DT + VS at OWP
Zinc Concentration, 1998



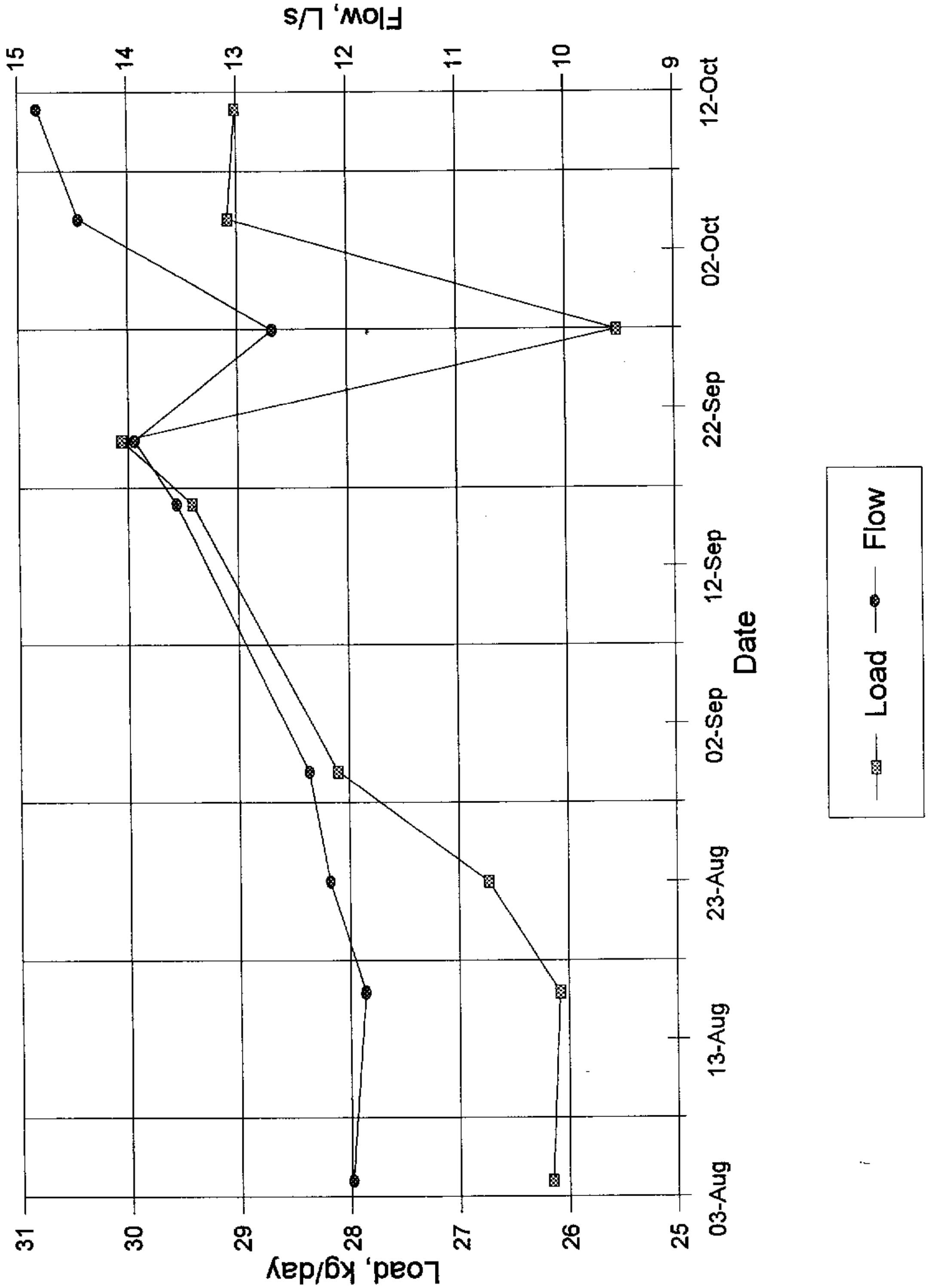


Fig. 9: DT + VS at OWP
Flow and Load, 1988

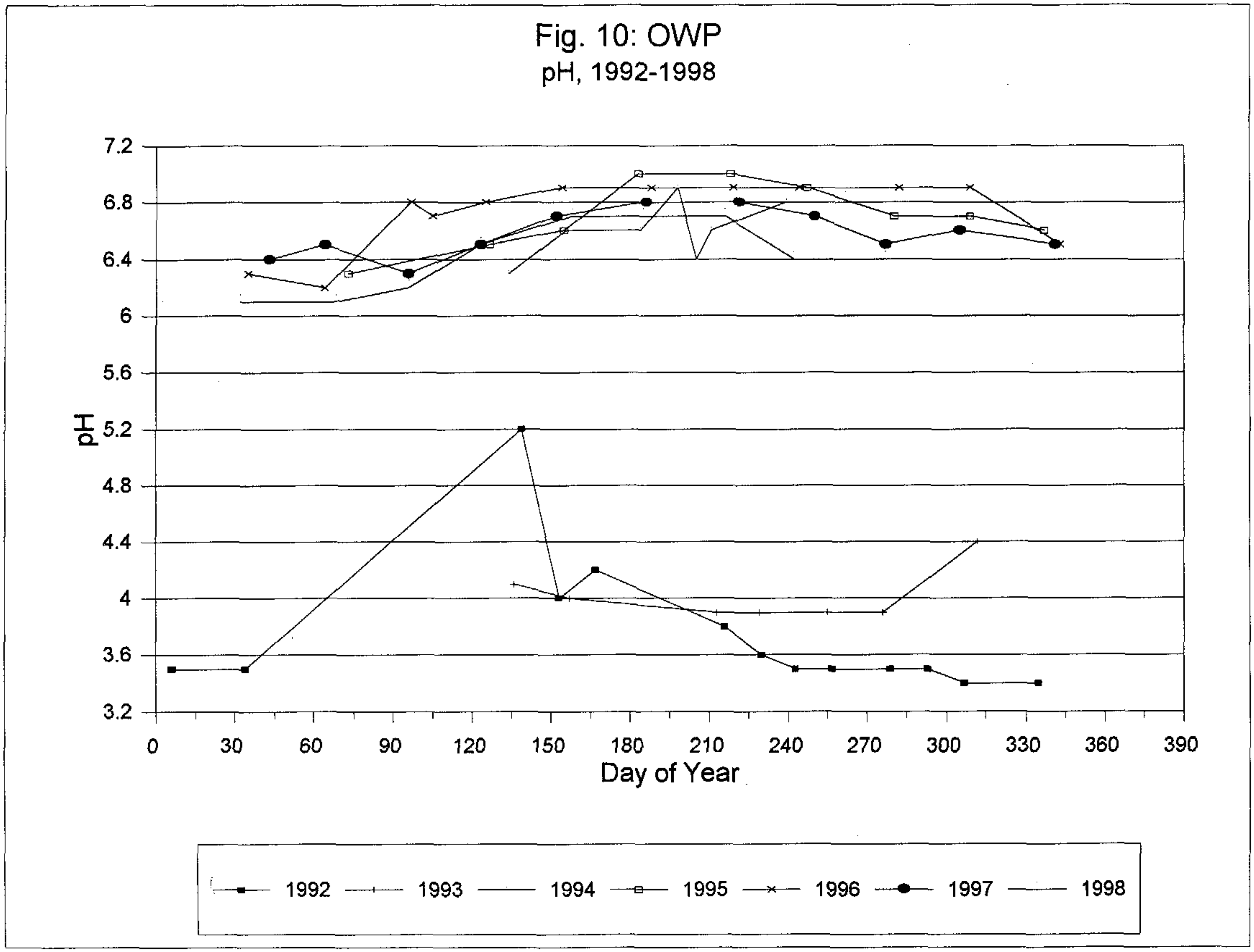
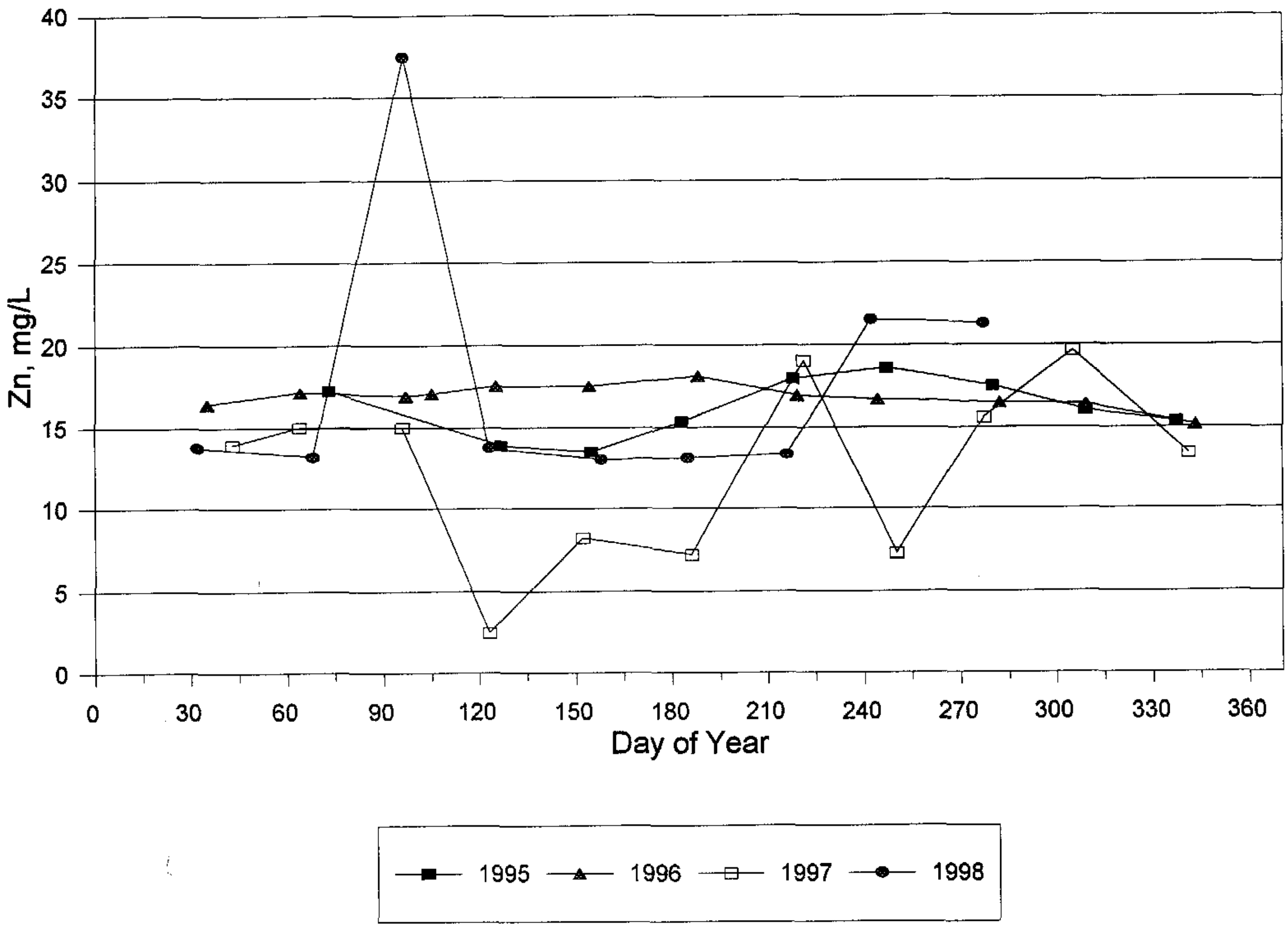


Fig. 10: OWP
pH, 1992-1998

Fig. 11: OWP
Zinc Concentration, 1995-1998



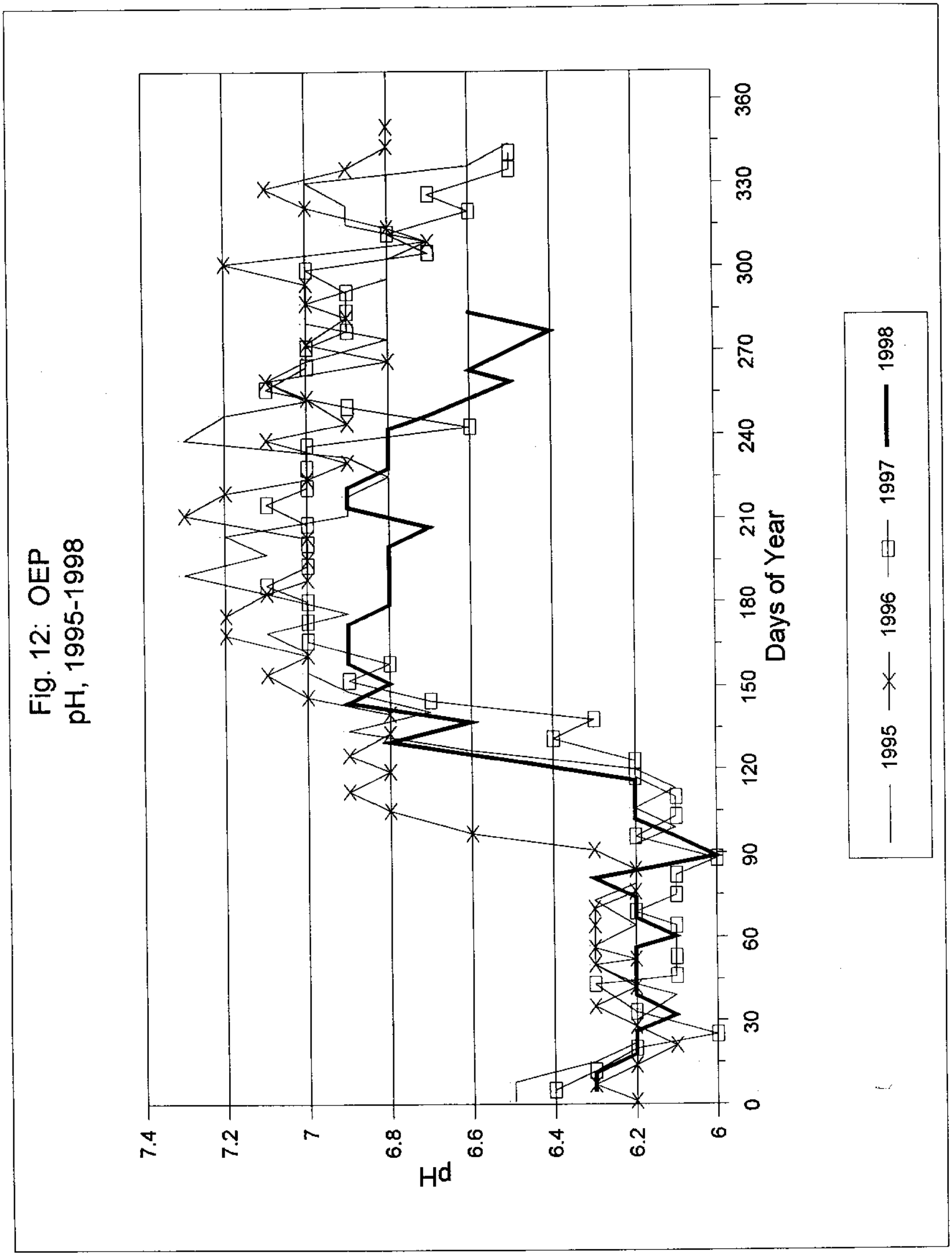


Fig. 12: OEP
pH, 1995-1998
pH
7.4
7.2
7
6.8
6.6
6.4
6.2
6
Days of Year
0
30
60
90
120
150
180
210
240
270
300
330
360
1995
1996
1997
1998

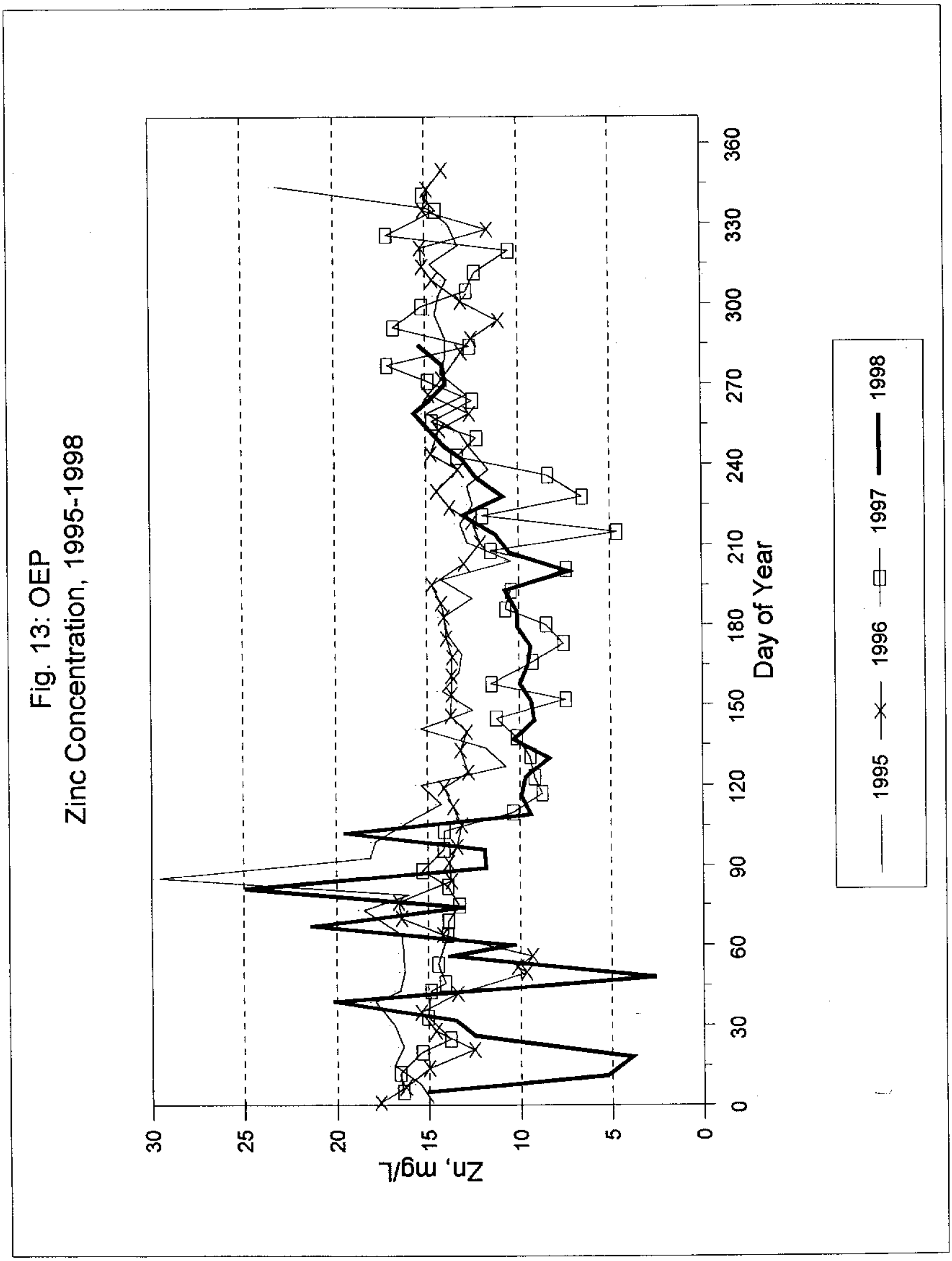


Fig. 13: OEP
Zinc Concentration, 1995-1998
Zn, mg/L
30
25
20
15
10
5
0
Day of Year
0
30
60
90
120
150
180
210
240
270
300
330
360
1995
1996
1997
1998

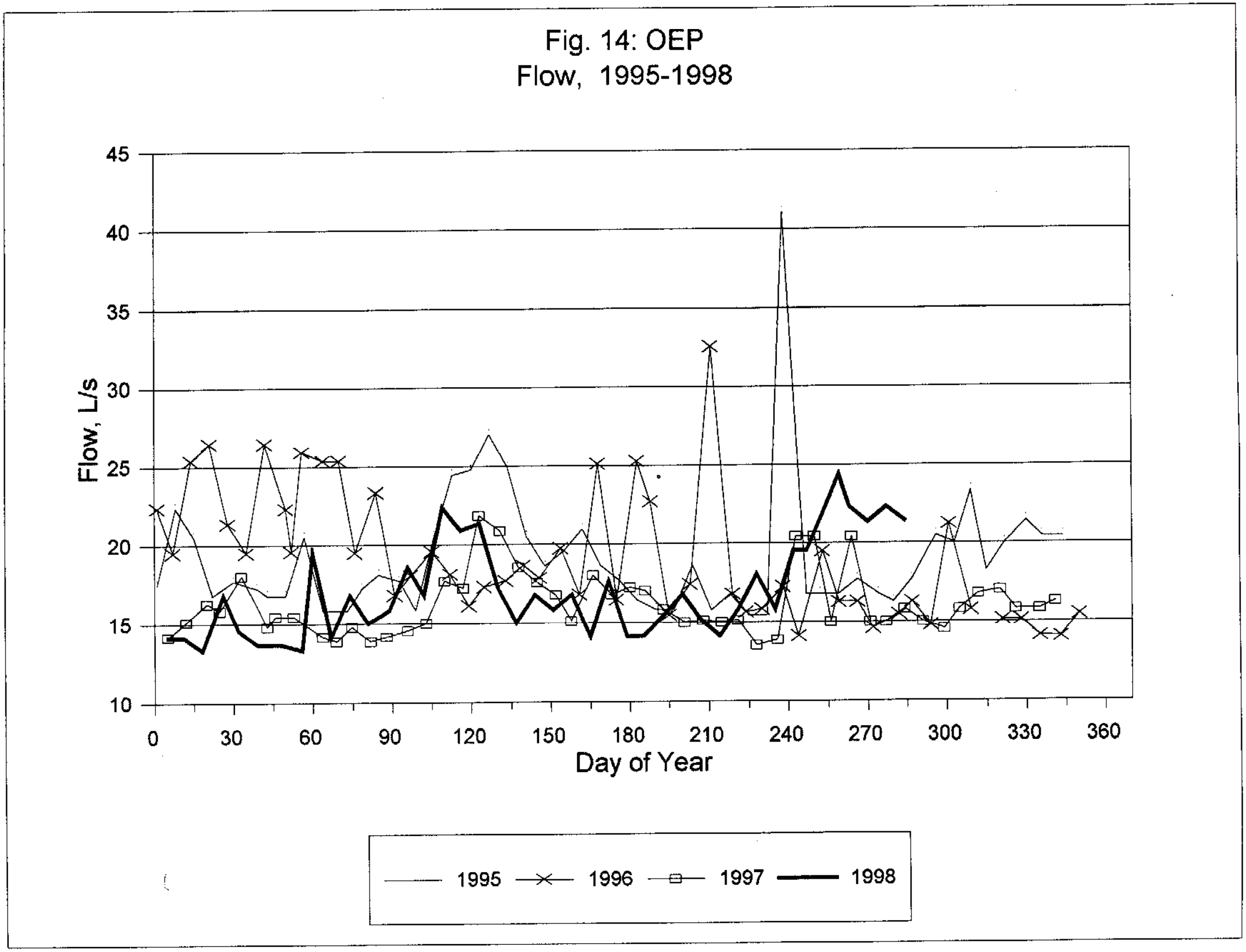


Fig. 14: OEP
Flow, 1995-1998

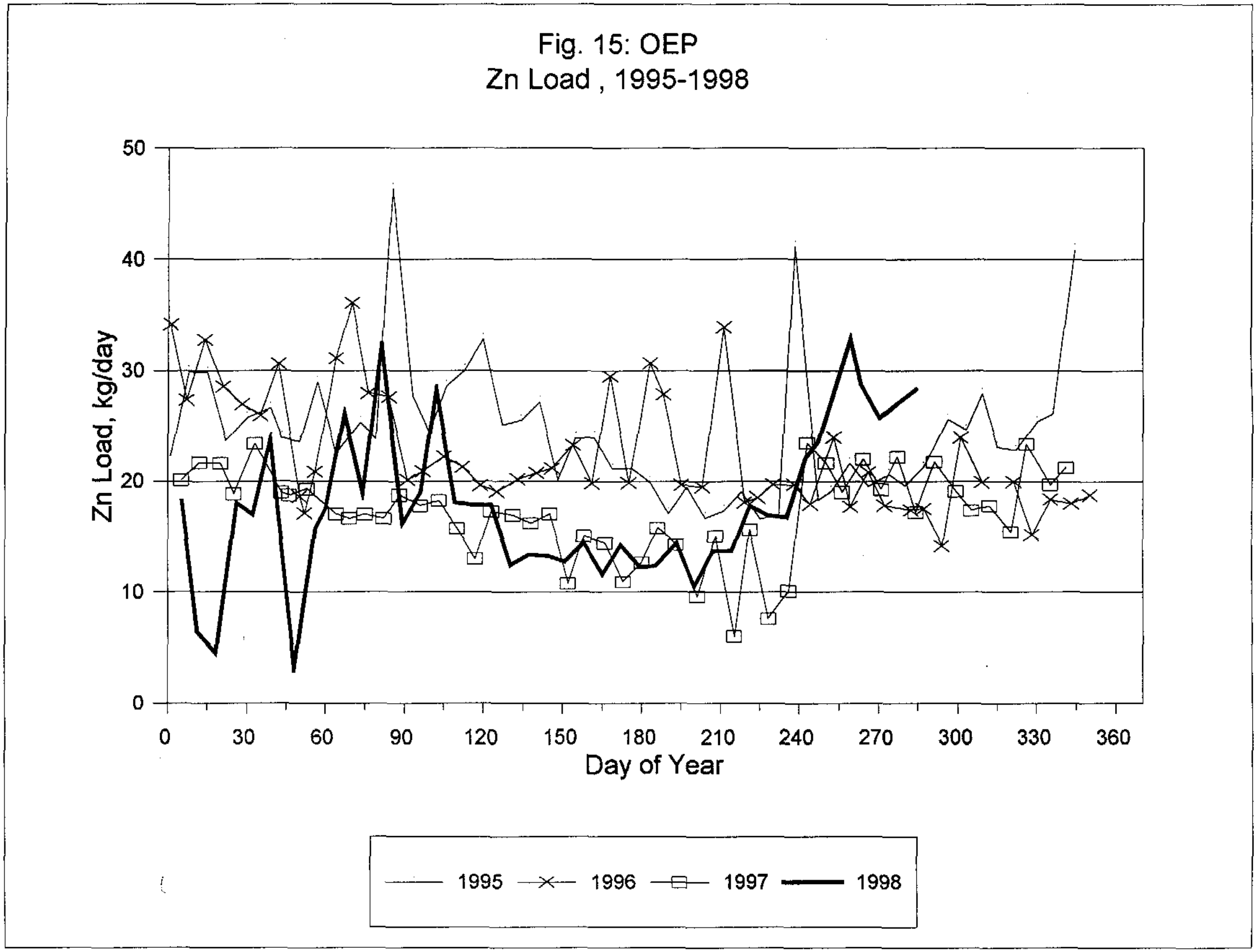


Fig. 15: OEP
Zn Load , 1995-1998
Zn Load, kg/day
0
10
20
30
40
50
0
30
60
90
120
150
180
210
240
270
300
330
360
Day of Year
1995
1996
1997
1998

Fig. 16: OEP and OWP
[Zn] before and after VS4 and VS5

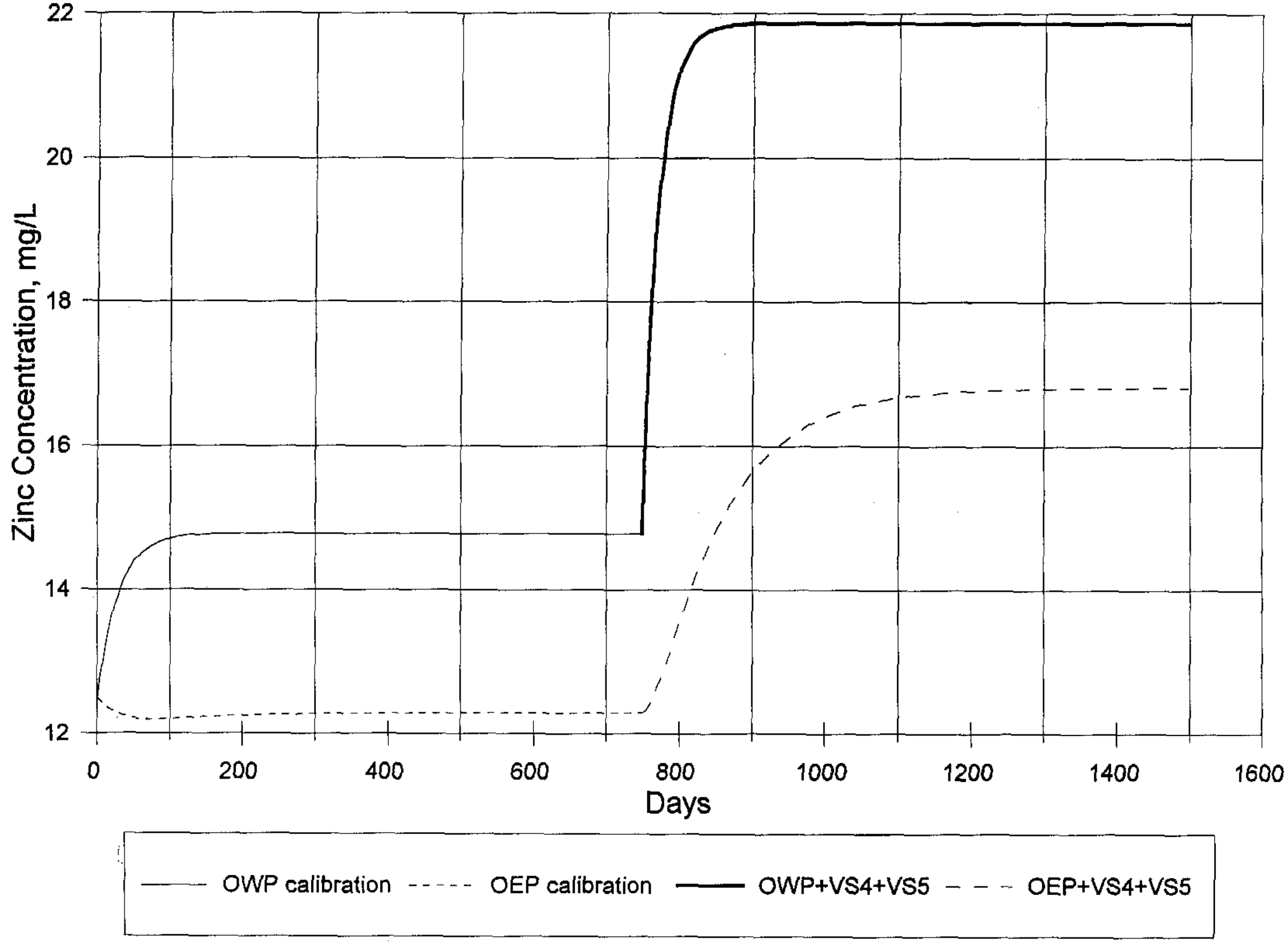


Fig. 17: Estimated Annual Sedimentation Rates in OEP

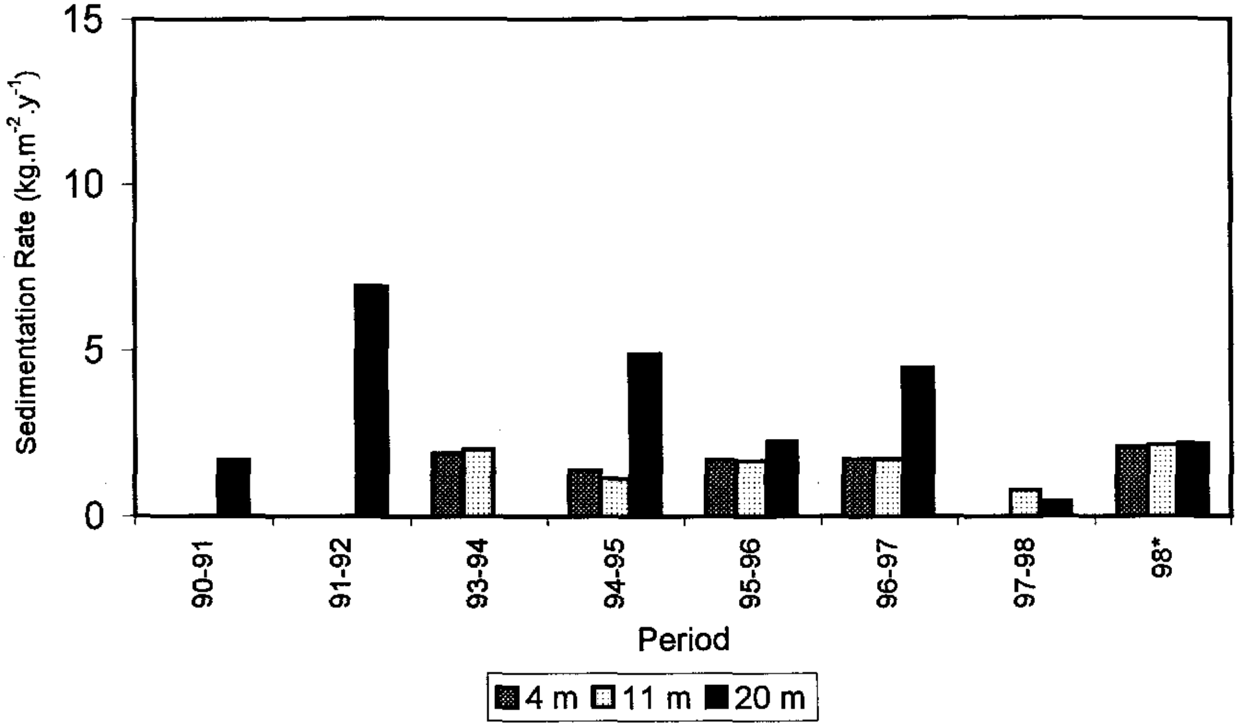


Fig.18:Yearly Changes in Sedimentation Rates at OWP,7 m

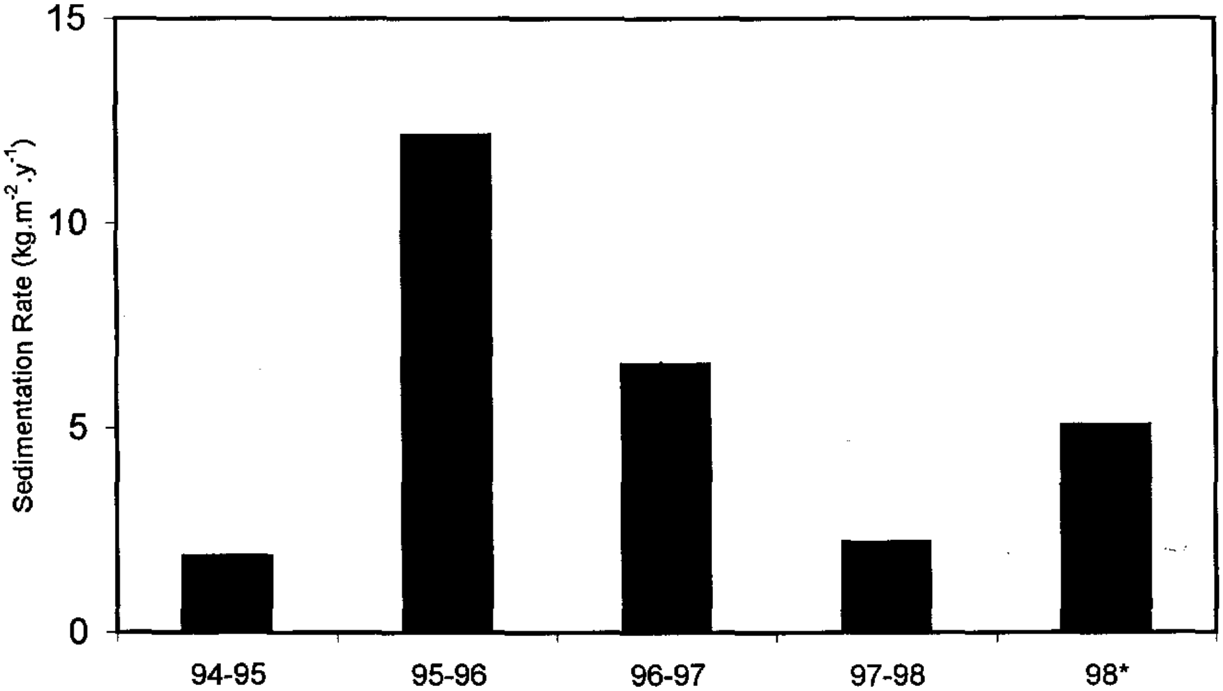


Fig. 19: Sedimentation Rates at OWP

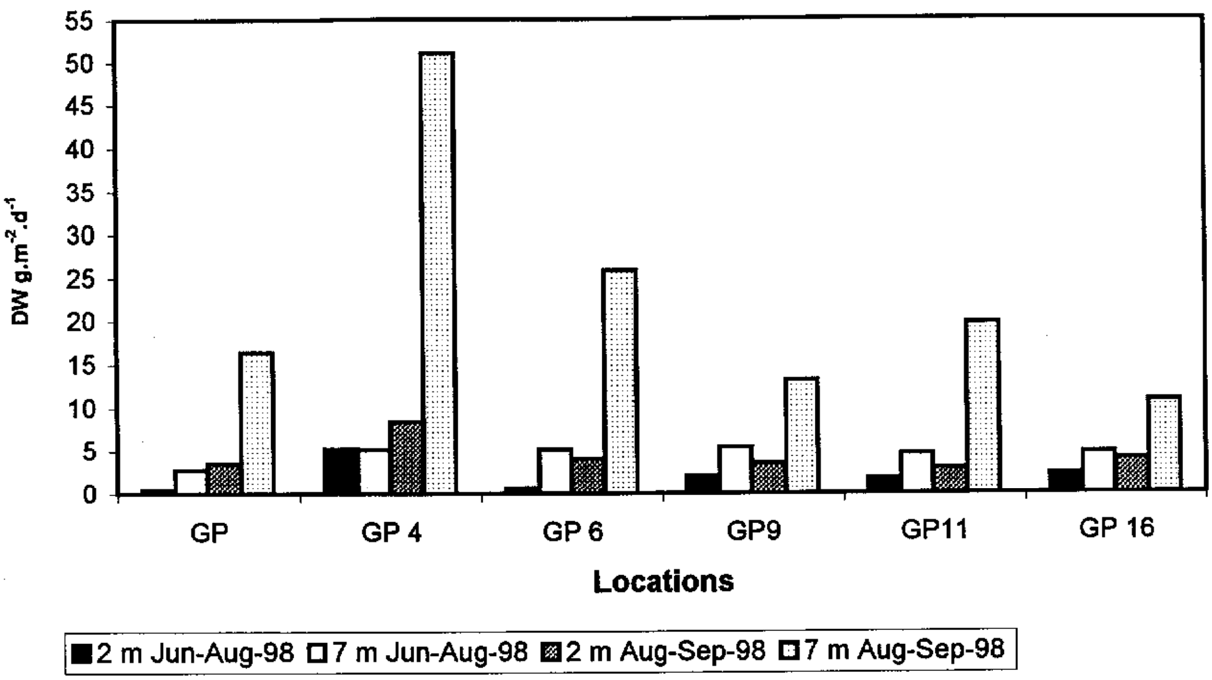


Fig. 20a: OEP [Iron] in S.T.

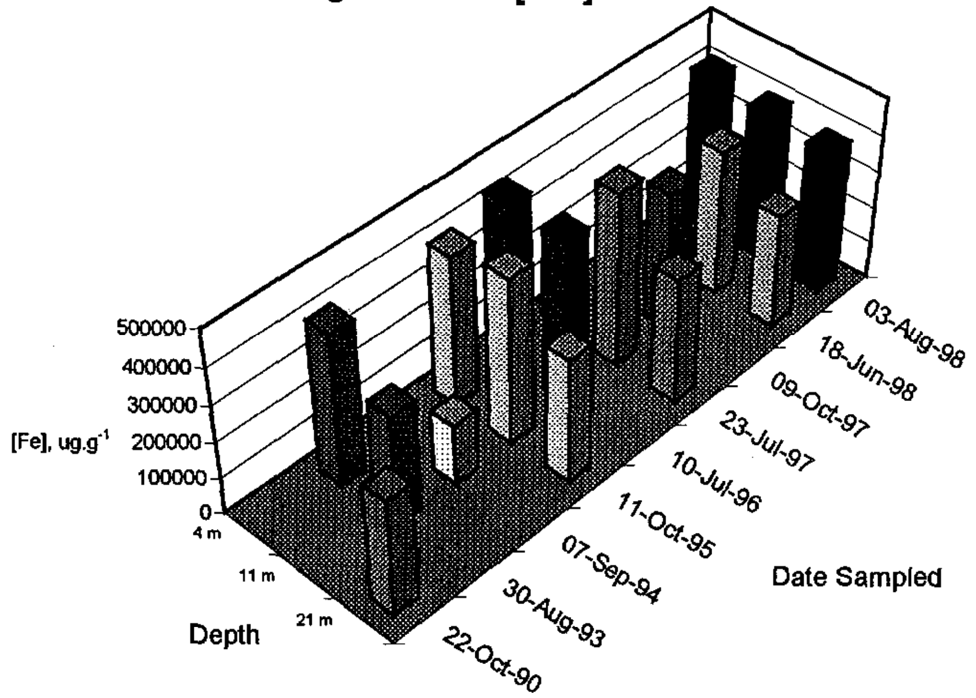
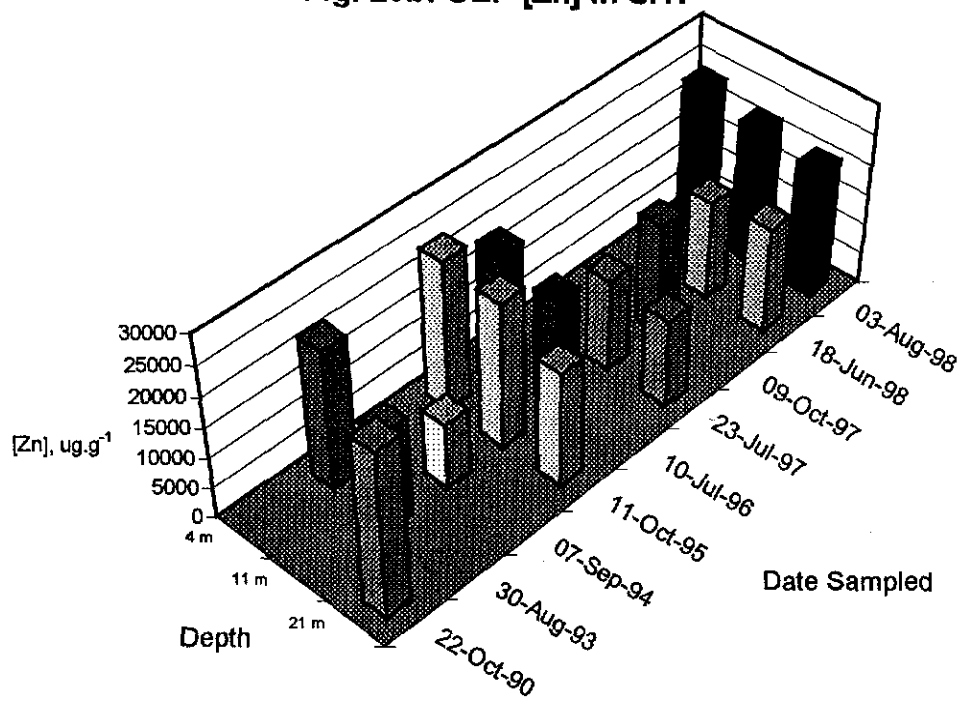


Fig. 20b: OEP [Zn] in S.T.



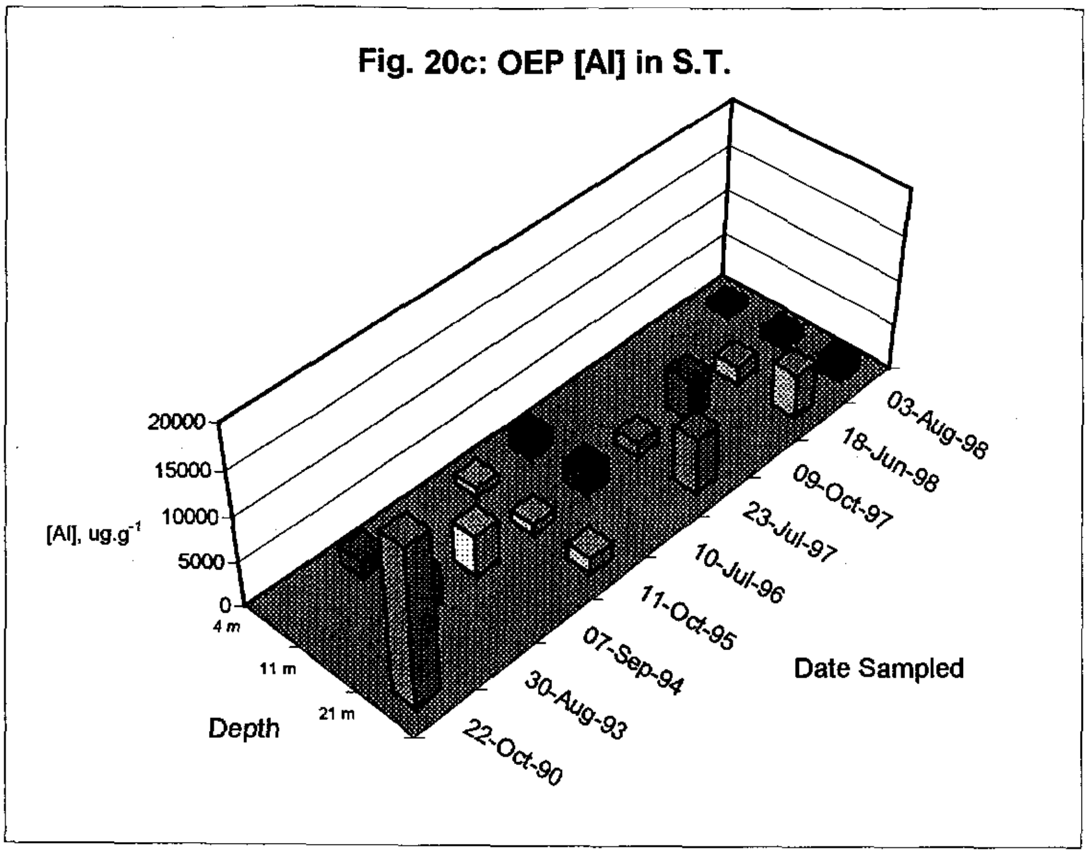


Fig. 20c: OEP [Al] in S.T.
20000
15000
10000
5000
0
[Al], ug.g-1
4 m
11 m
21 m
Depth
03-Aug-98
18-Jun-98
09-Oct-97
23-Jul-97
10-Jul-96
11-Oct-95
07-Sep-94
30-Aug-93
22-Oct-90
Date Sampled

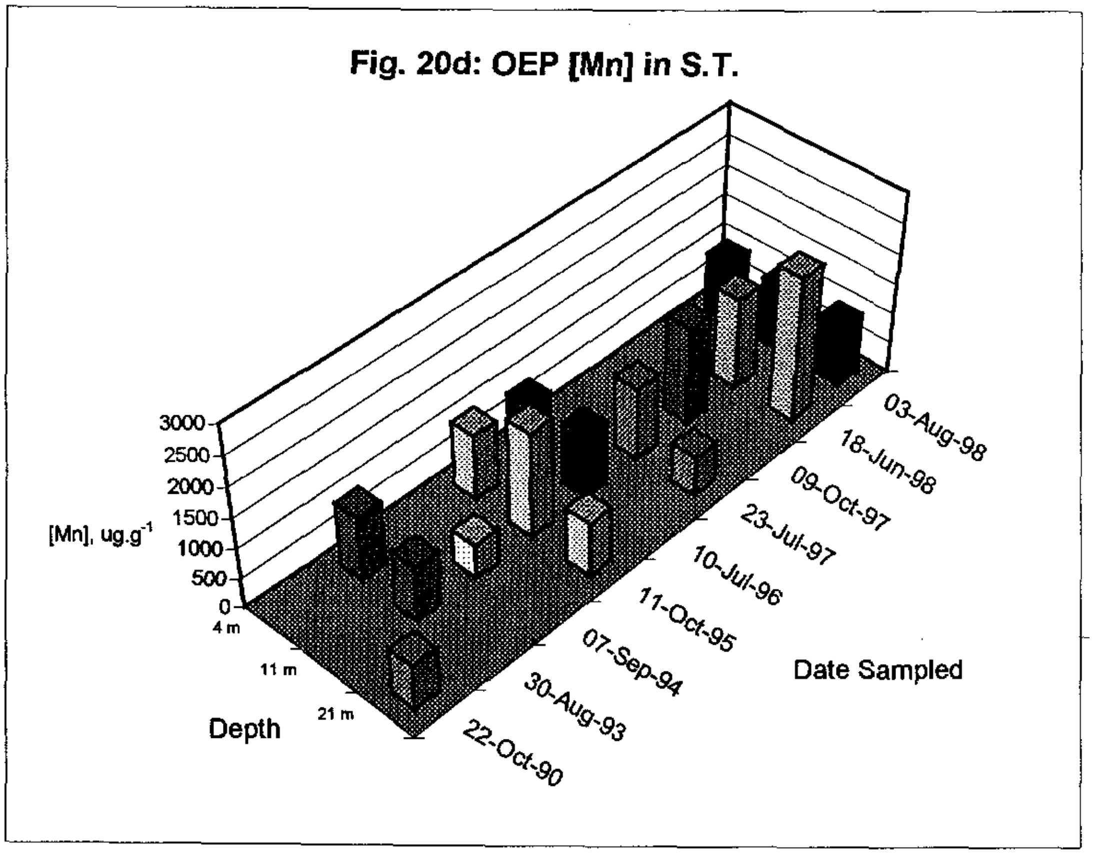


Fig. 20d: OEP [Mn] in S.T.
3000
2500
2000
1500
1000
500
0
[Mn], ug.g-1
4 m
11 m
21 m
Depth
03-Aug-98
18-Jun-98
09-Oct-97
23-Jul-97
10-Jul-96
11-Oct-95
07-Sep-94
30-Aug-93
22-Oct-90
Date Sampled

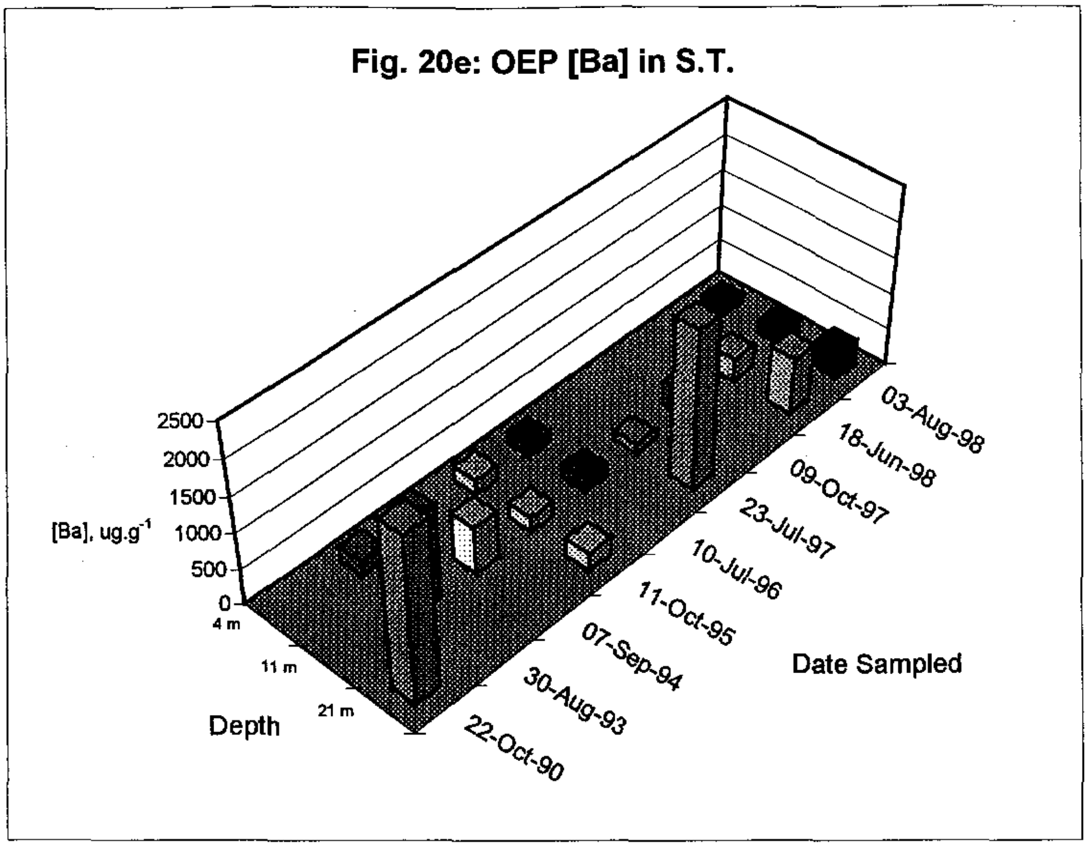


Fig. 20e: OEP [Ba] in S.T.
2500
2000
1500
[Ba], ug.g-1
1000
500
0
4 m
11 m
21 m
Depth
03-Aug-98
18-Jun-98
09-Oct-97
23-Jul-97
10-Jul-96
11-Oct-95
07-Sep-94
30-Aug-93
22-Oct-90
Date Sampled

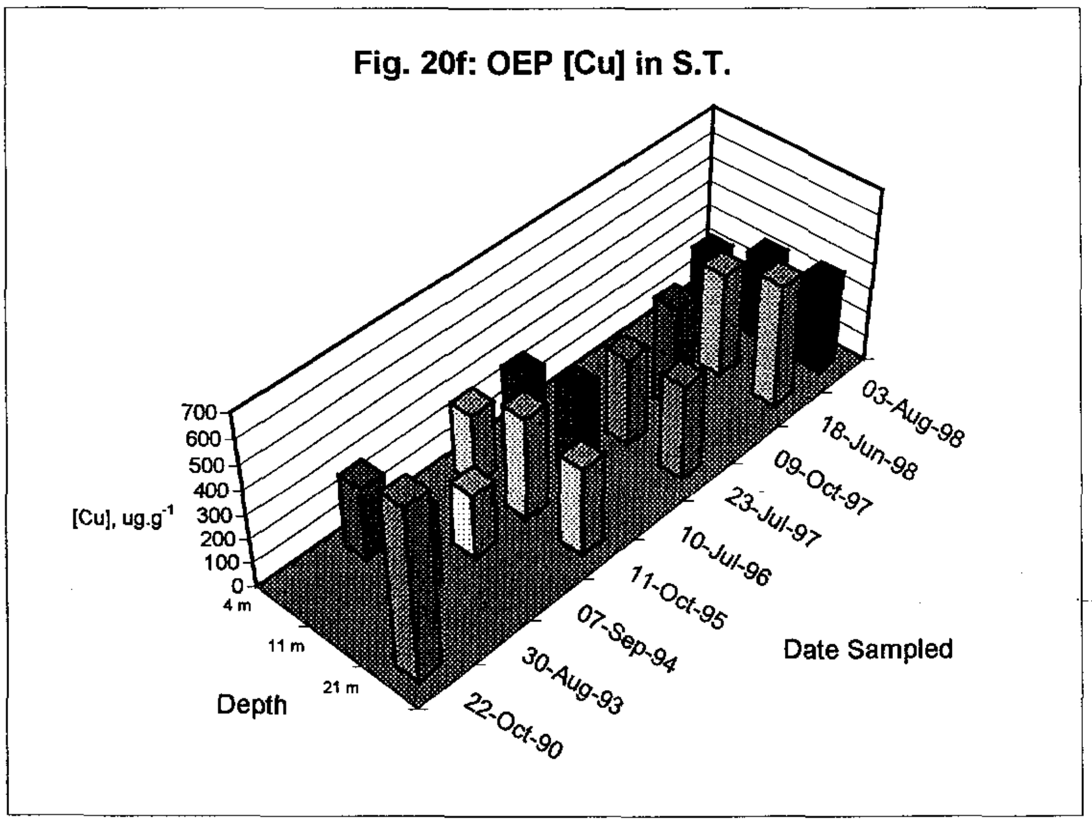


Fig. 20f: OEP [Cu] in S.T.
700
600
500
400
[Cu], ug.g-1
300
200
100
0
4 m
11 m
21 m
Depth
03-Aug-98
18-Jun-98
09-Oct-97
23-Jul-97
10-Jul-96
11-Oct-95
07-Sep-94
30-Aug-93
22-Oct-90
Date Sampled

Fig. 20g: OEP [Pb] in S.T.

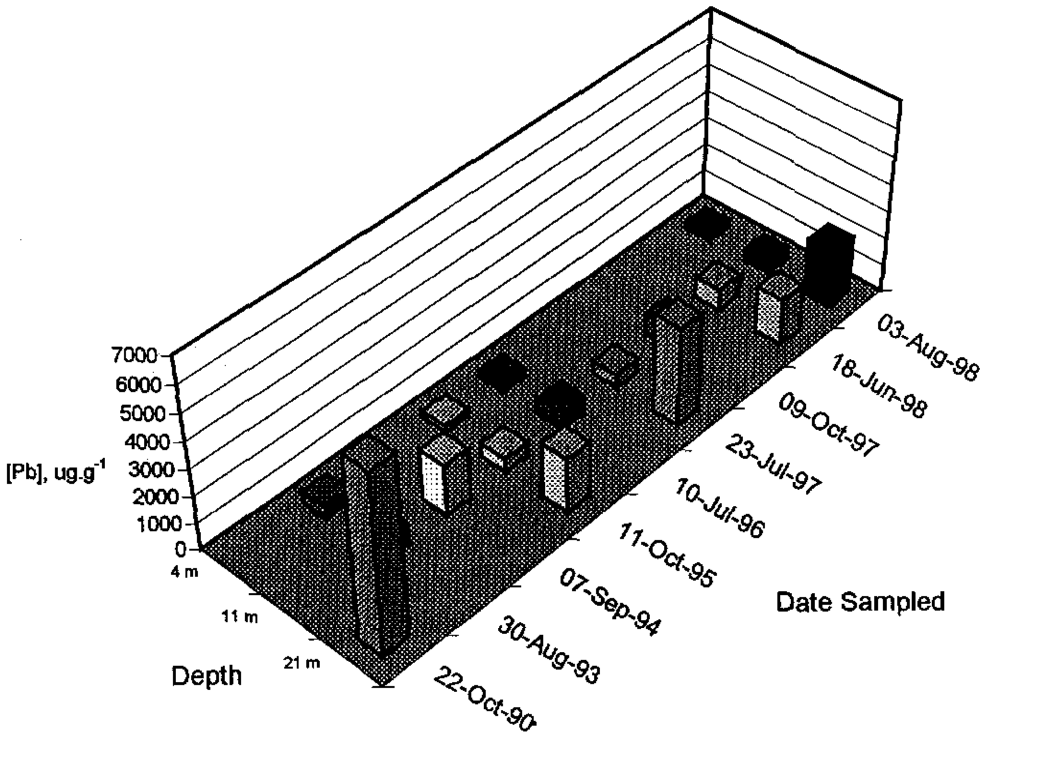
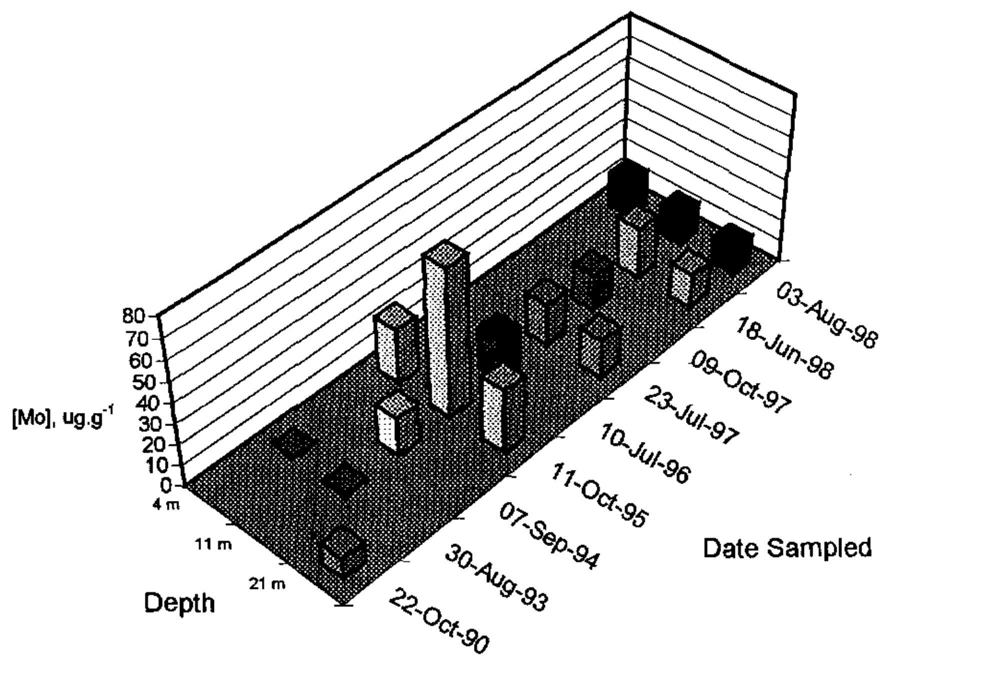


Fig. 20h: OEP [Mo] in S.T.



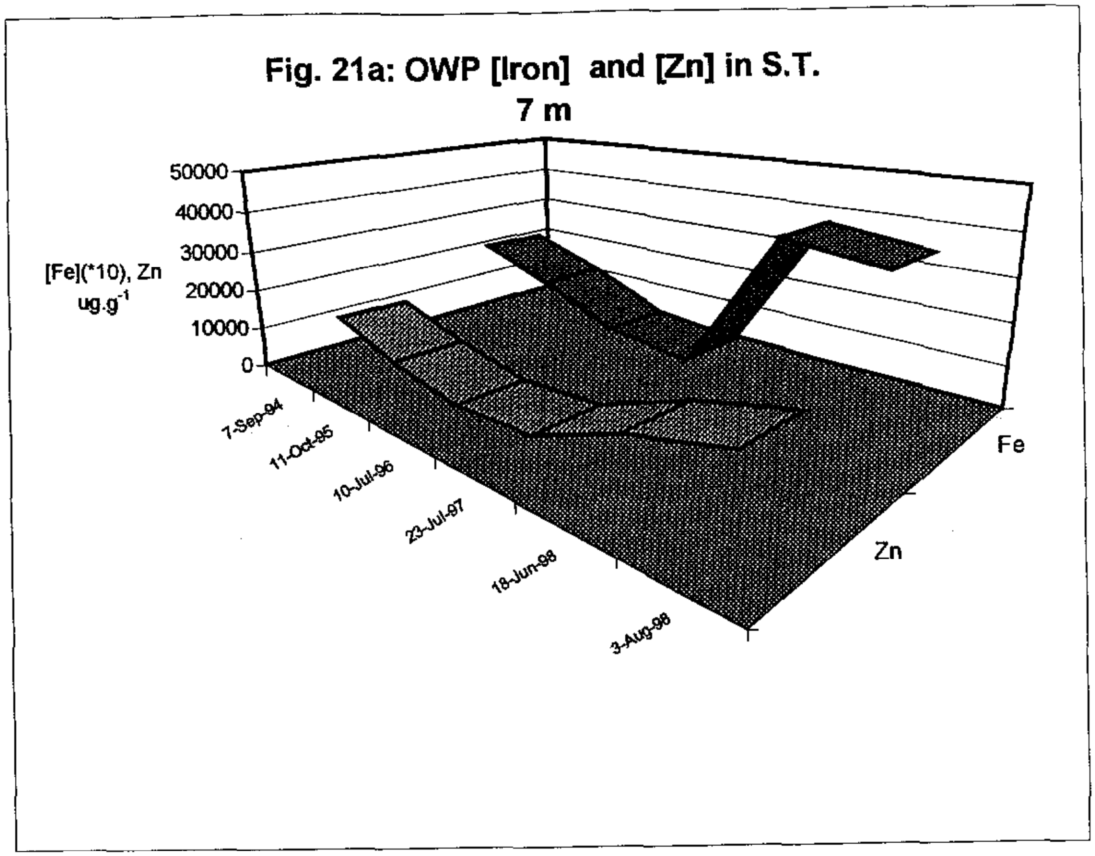


Fig. 21a: OWP [Iron] and [Zn] in S.T.
7 m
50000
40000
30000
20000
10000
0
[Fe](*10), Zn
ug.g-1
7-Sep-94
11-Oct-95
10-Jul-96
23-Jul-97
18-Jun-98
3-Aug-98
Fe
Zn

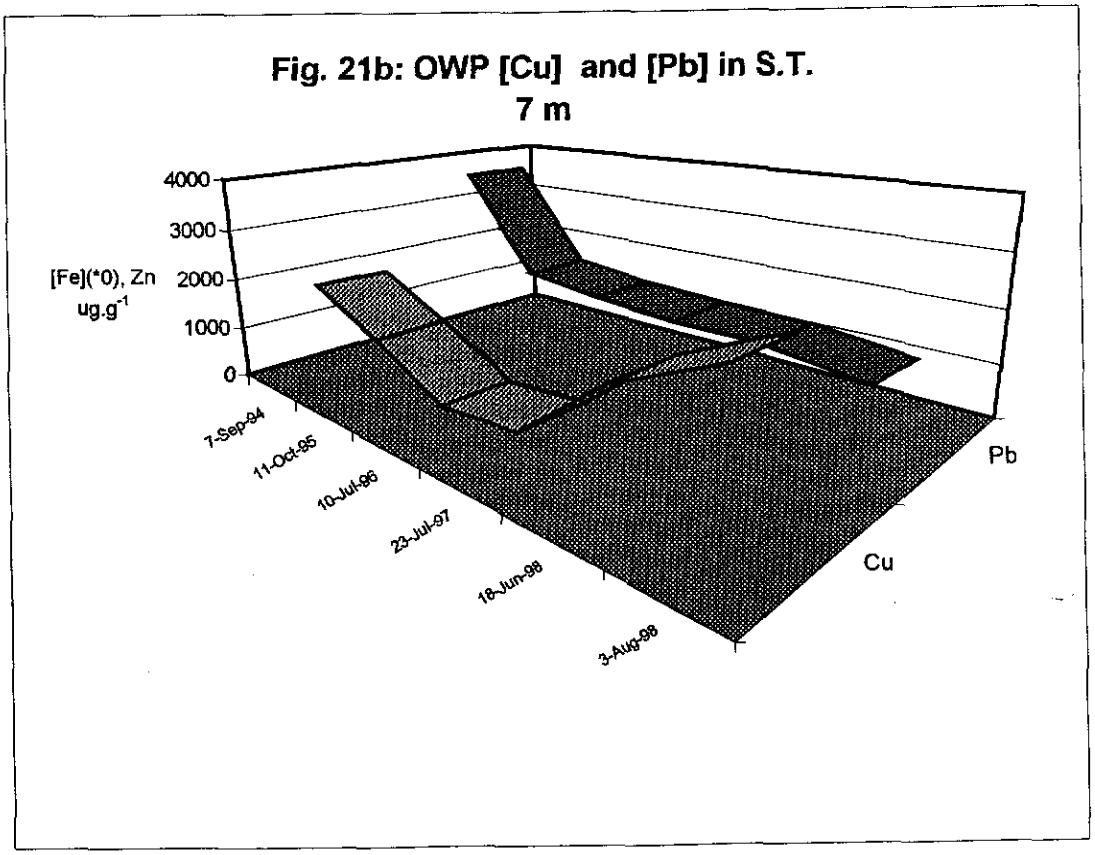


Fig. 21b: OWP [Cu] and [Pb] in S.T.
7 m
4000
3000
2000
1000
0
[Fe](*0), Zn
ug.g-1
7-Sep-94
11-Oct-95
10-Jul-96
23-Jul-97
18-Jun-98
3-Aug-98
Pb
Cu

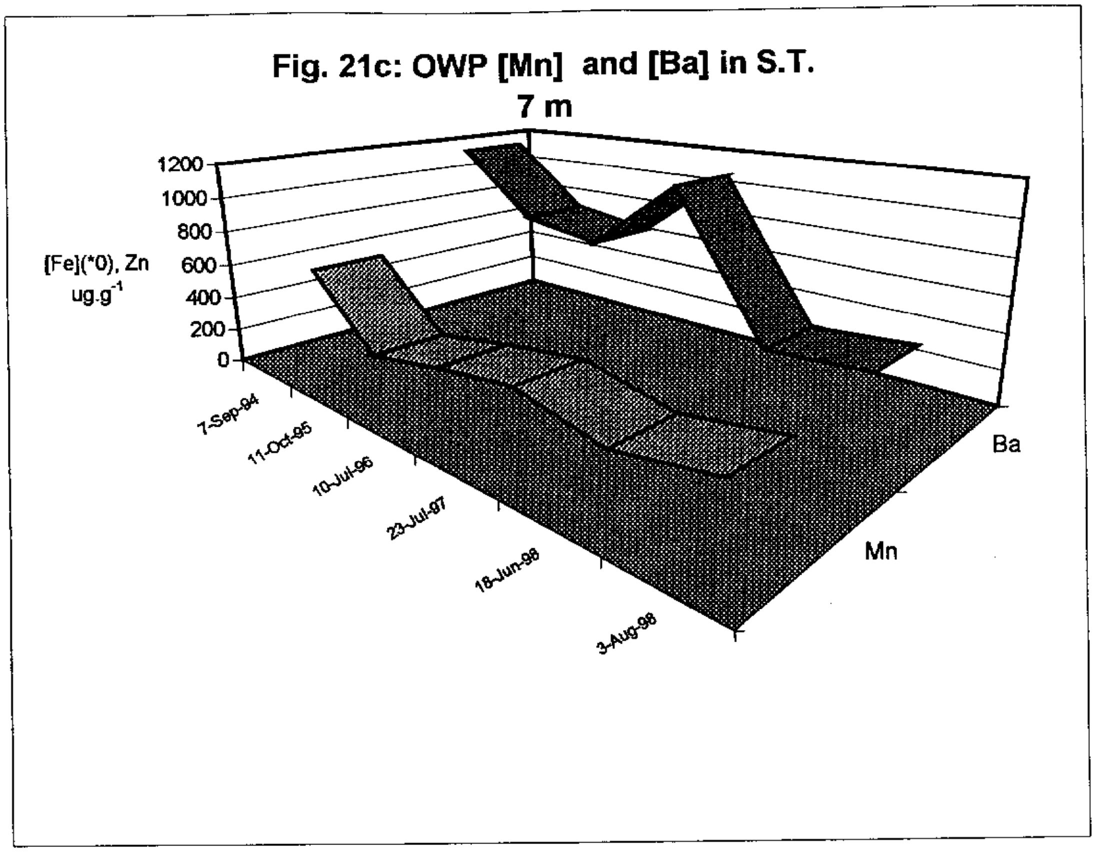


Fig. 21c: OWP [Mn] and [Ba] in S.T.
7 m
1200
1000
800
600
400
200
0
[Fe](*0), Zn
ug.g-1
7-Sep-94
11-Oct-95
10-Jul-96
23-Jul-97
18-Jun-98
3-Aug-98
Ba
Mn

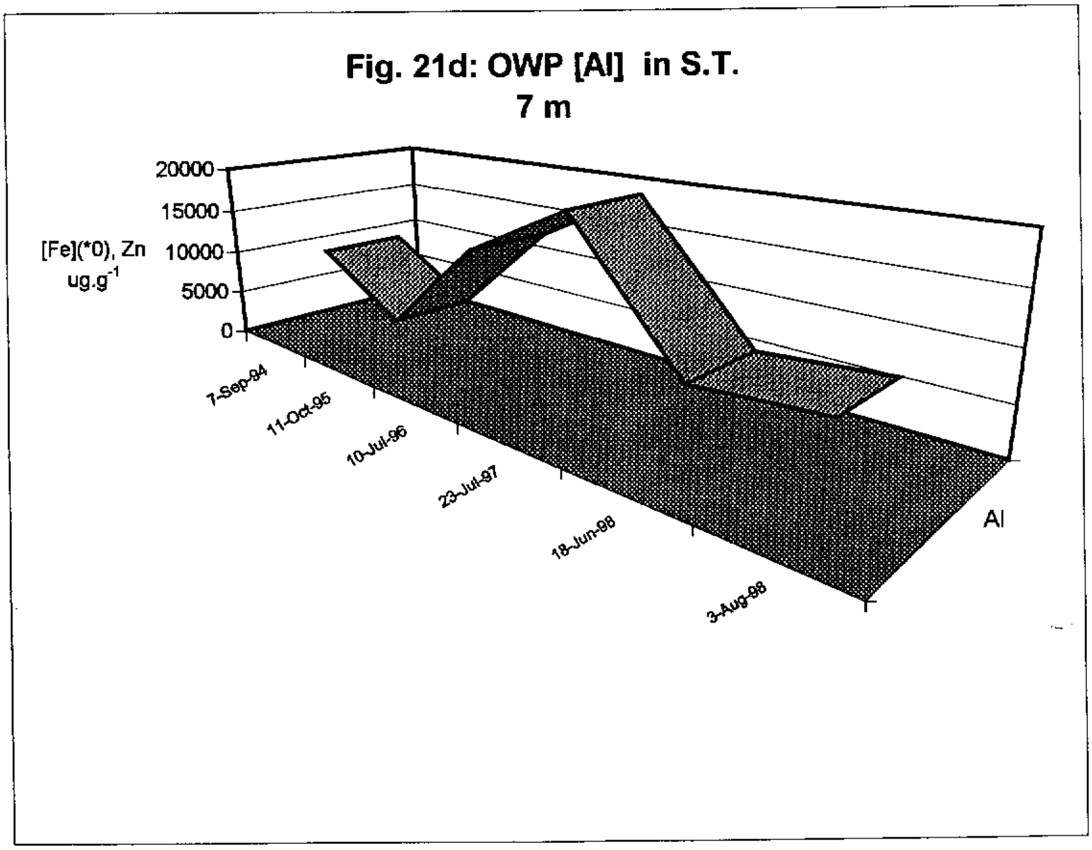


Fig. 21d: OWP [Al] in S.T.
7 m
20000
15000
10000
5000
0
[Fe](*0), Zn
ug.g-1
7-Sep-94
11-Oct-95
10-Jul-96
23-Jul-97
18-Jun-98
3-Aug-98
Al

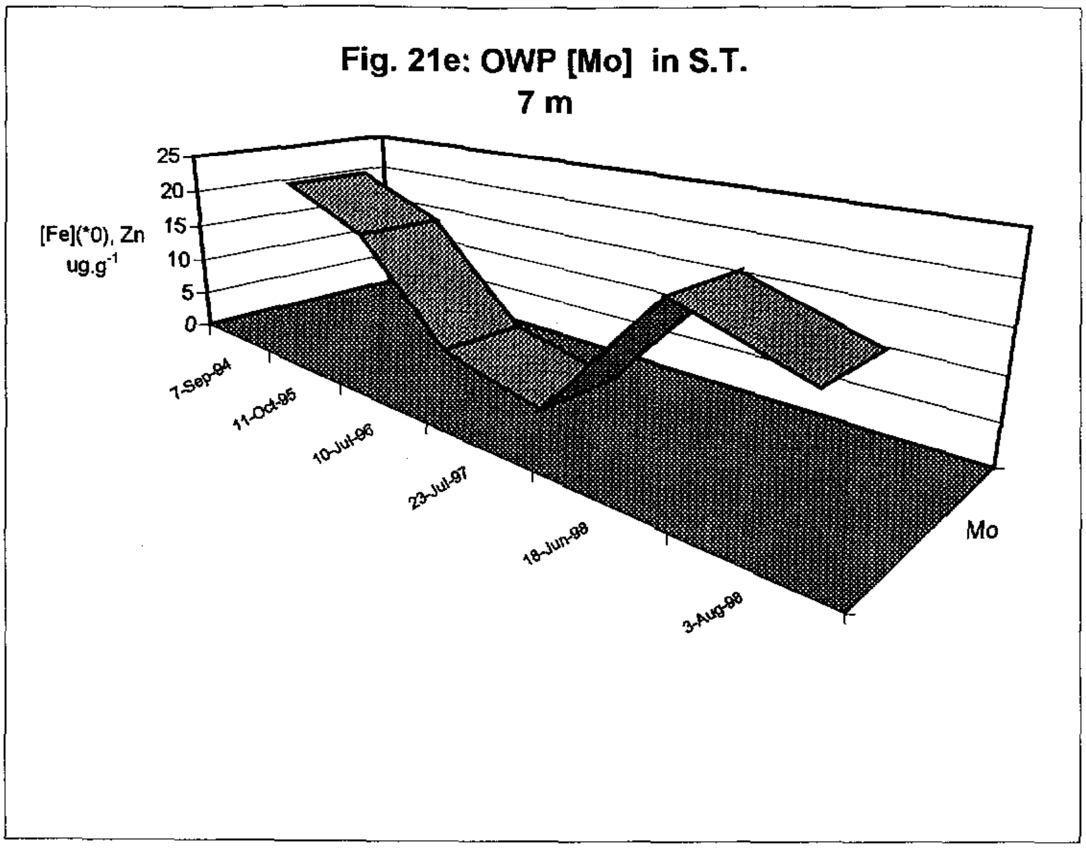


Fig. 21e: OWP [Mo] in S.T.
7 m
[Fe](*0), Zn
ug.g-1
25
20
15
10
5
0
7-Sep-94
11-Oct-95
10-Jul-96
23-Jul-97
18-Jun-98
3-Aug-98
Mo

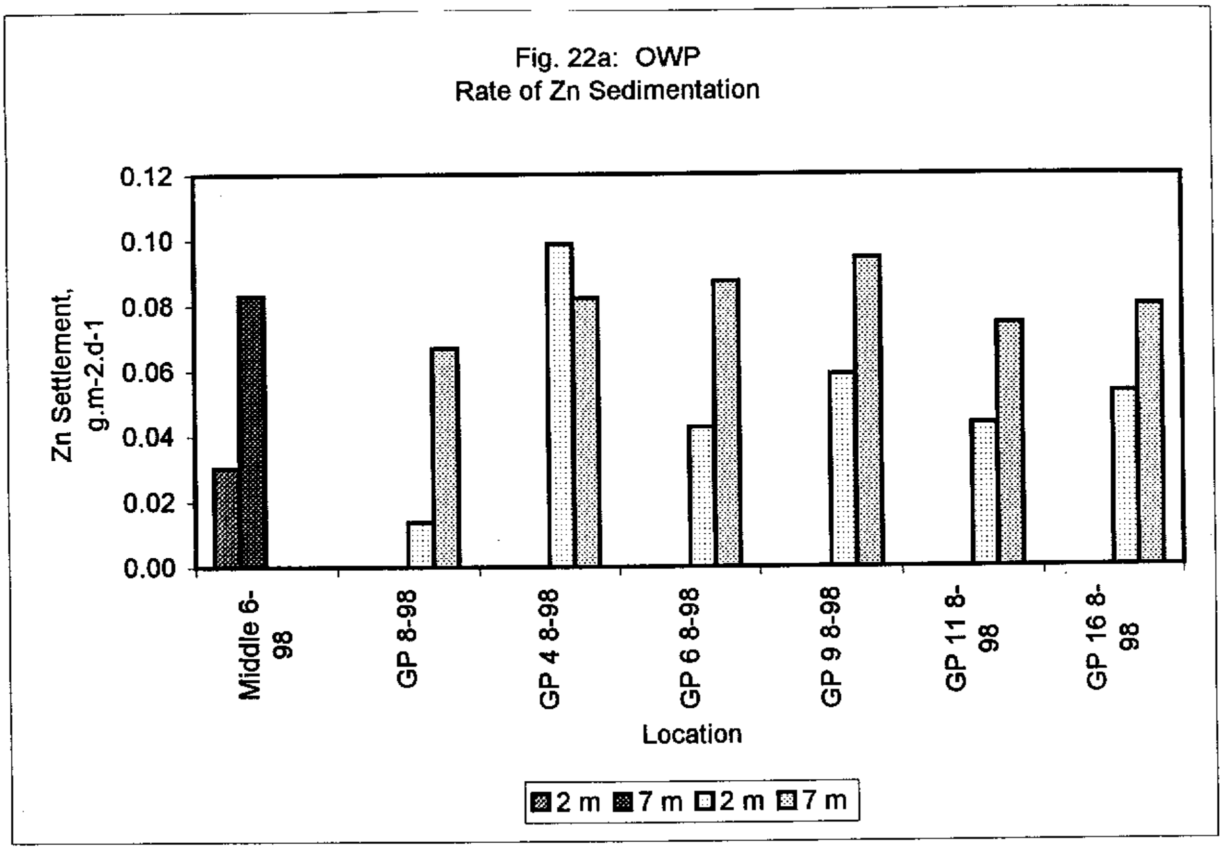


Fig. 22a: OWP
Rate of Zn Sedimentation
Zn Settlement, g.m-2.d-1
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Middle 6-98
GP 8-98
GP 4 8-98
GP 6 8-98
GP 9 8-98
GP 11 8-98
GP 16 8-98
Location
2 m
7 m
2 m
7 m

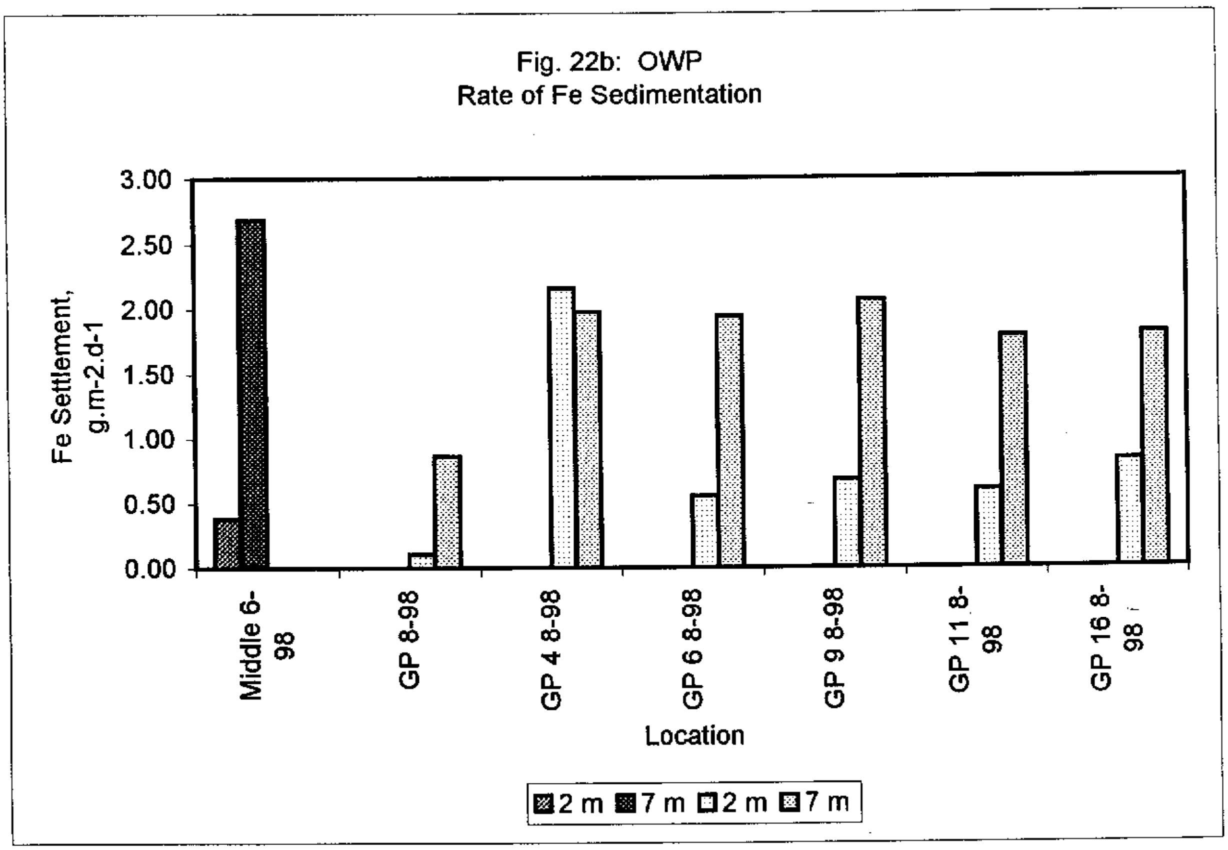
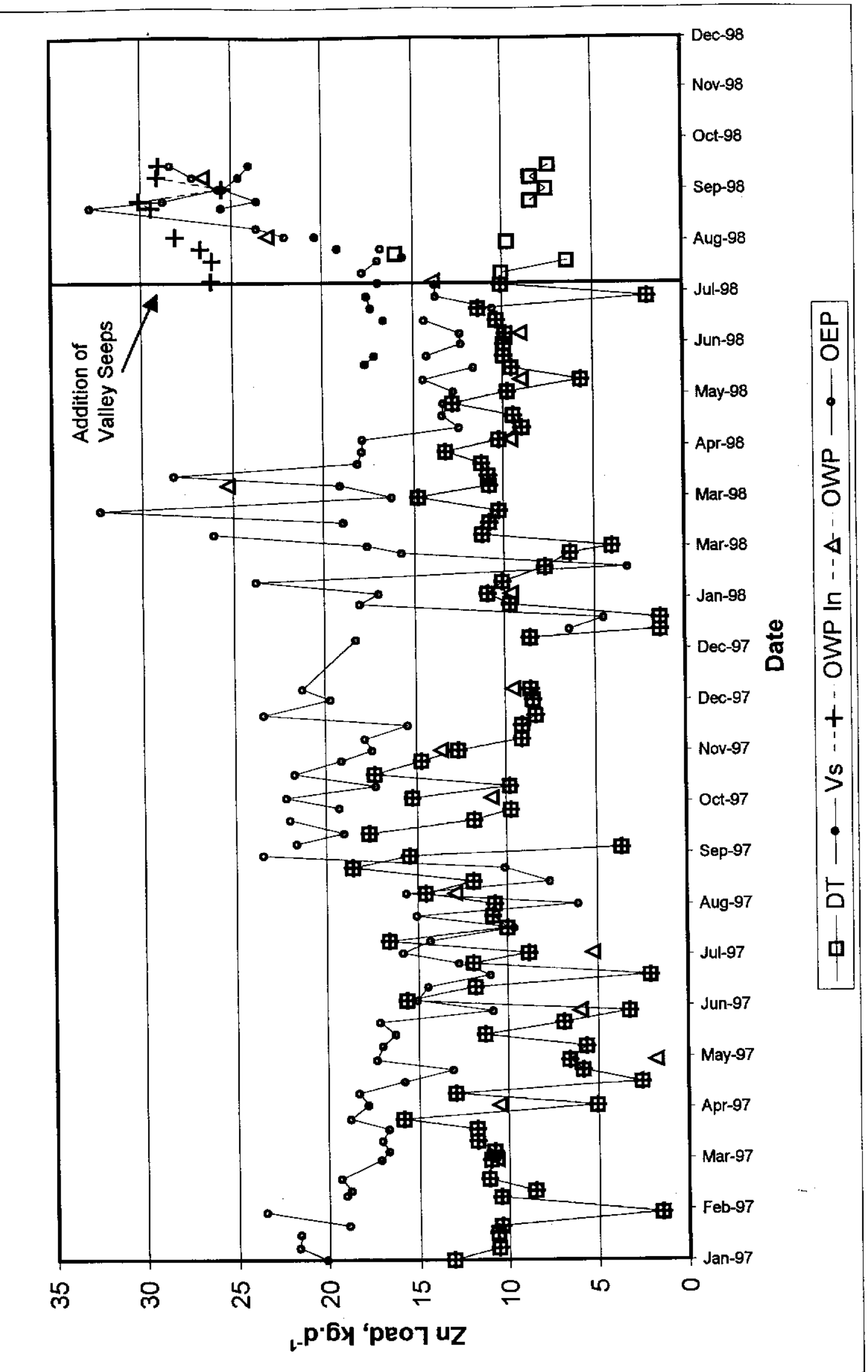


Fig. 22b: OWP
Rate of Fe Sedimentation
Fe Settlement, g.m-2.d-1
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Middle 6-98
GP 8-98
GP 4 8-98
GP 6 8-98
GP 9 8-98
GP 11 8-98
GP 16 8-98
Location
2 m
7 m
2 m
7 m

Fig. 23: Zn Loads
D.T., Vs, OWP In, OWP, OEP



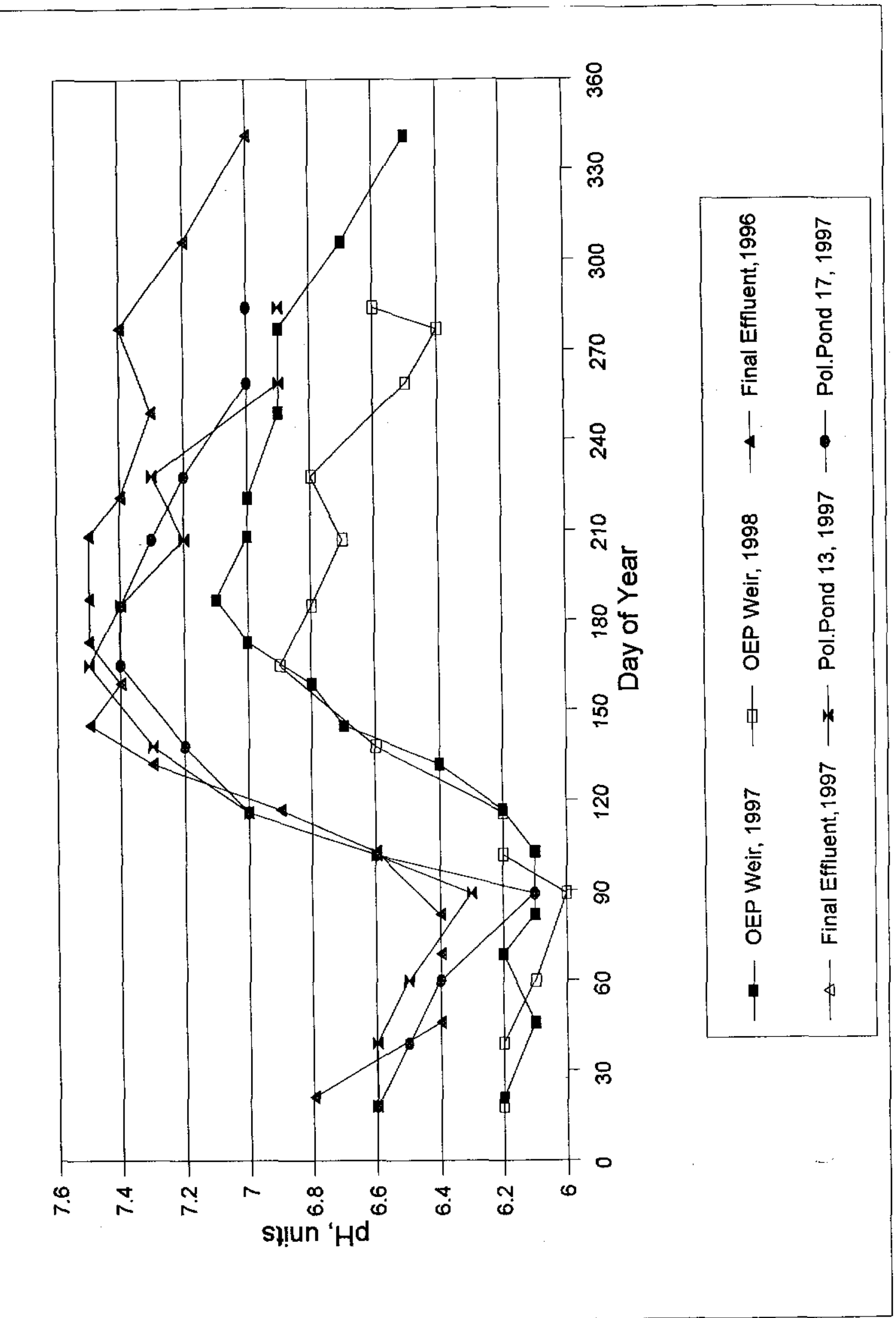


Fig. 24: pH, 1997-1998
OEP Weir, Final Effluent, PP13, PP17

Fig. 25: Zinc Concentration, 1997-1998
OEP Weir, Final Effluent, PP13,PP17

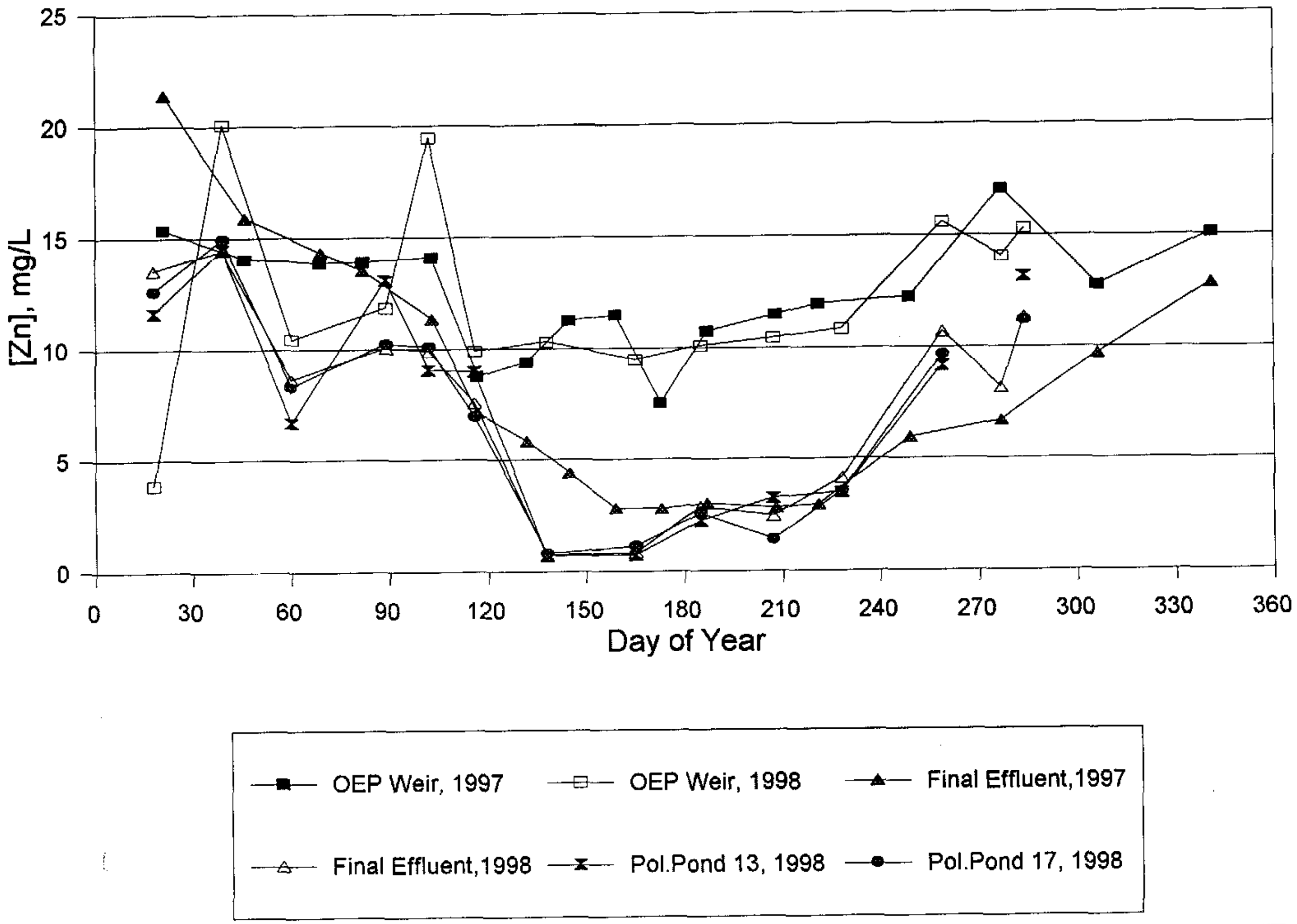
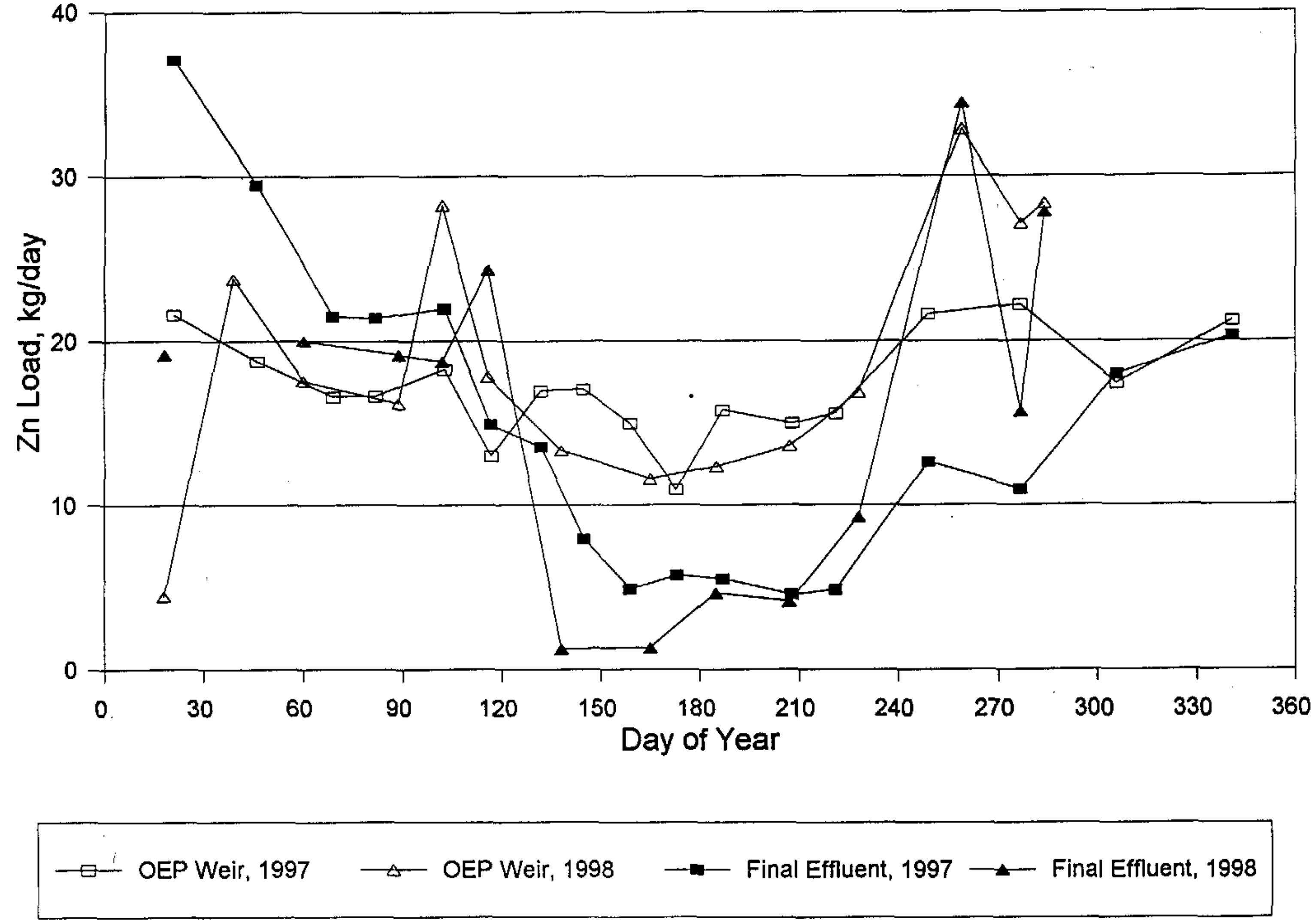


Fig. 26: Zinc Load, 1997-1998
OEP Weir and Final Effluent



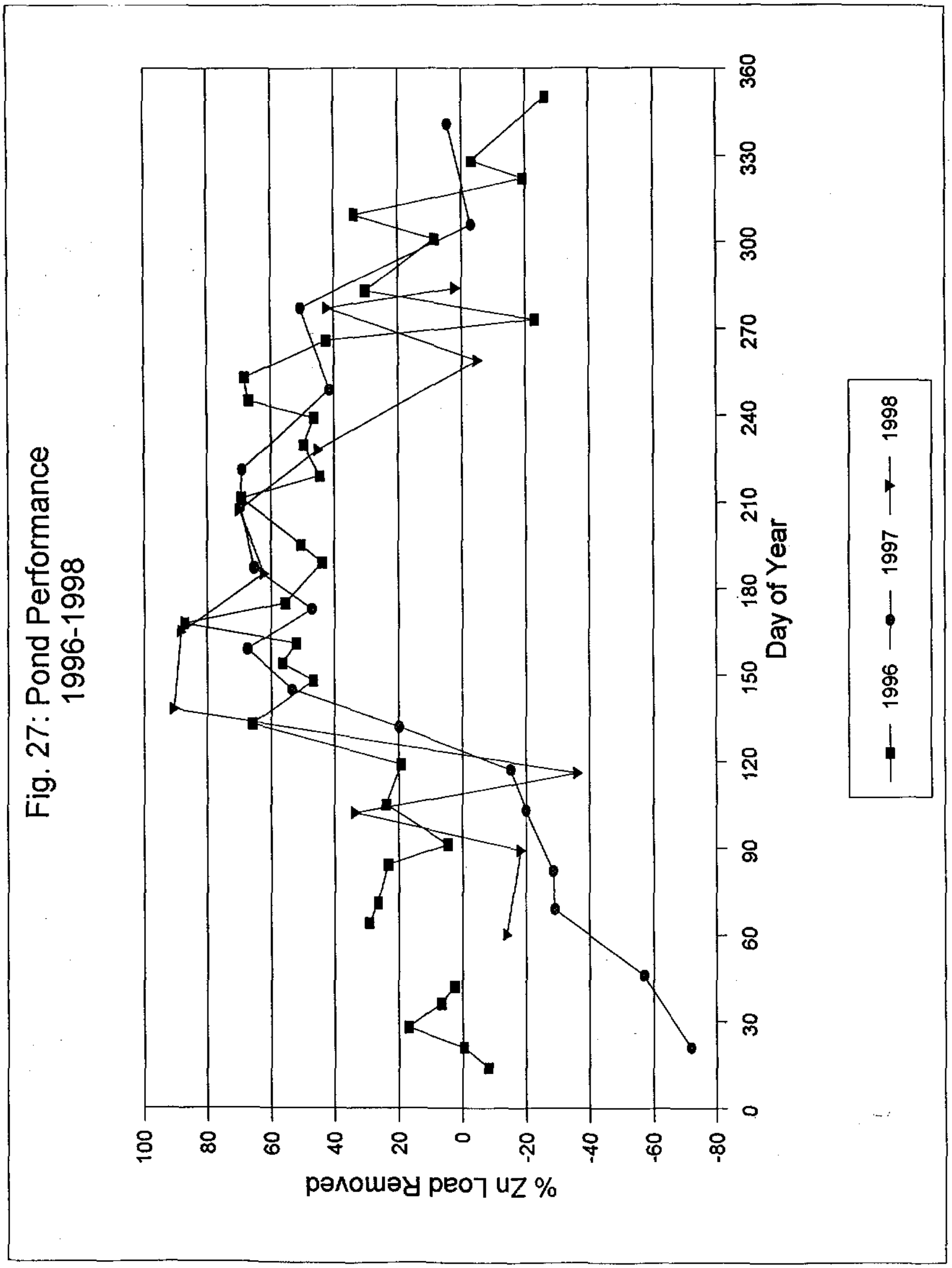
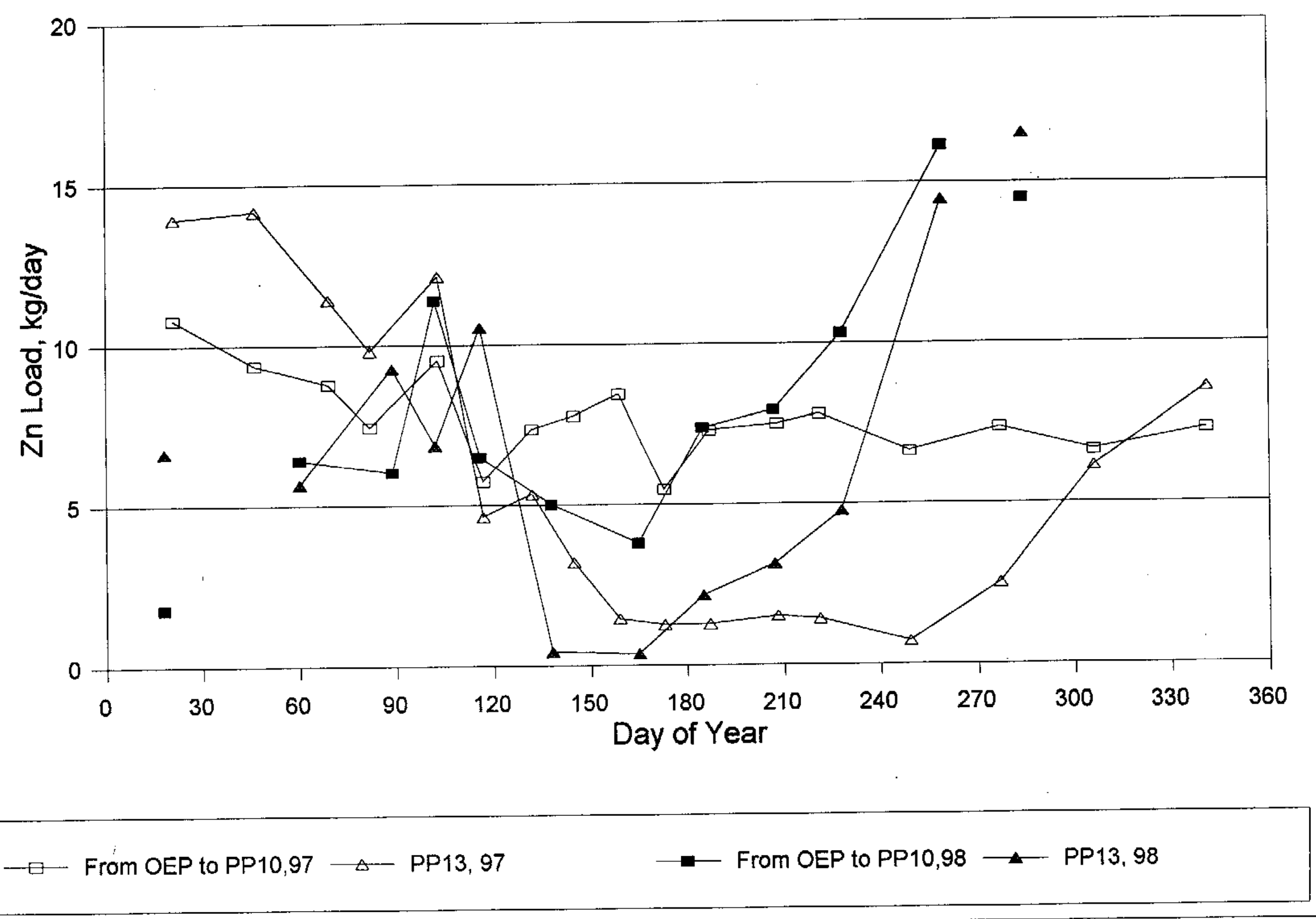


Fig. 27: Pond Performance
1996-1998
% Zn Load Removed
Day of Year
100
80
60
40
20
0
-20
-40
-60
-80
0
30
60
90
120
150
180
210
240
270
300
330
360
1996
1997
1998

Fig. 28: Zinc Load, 1997-1998
PP10 and PP13



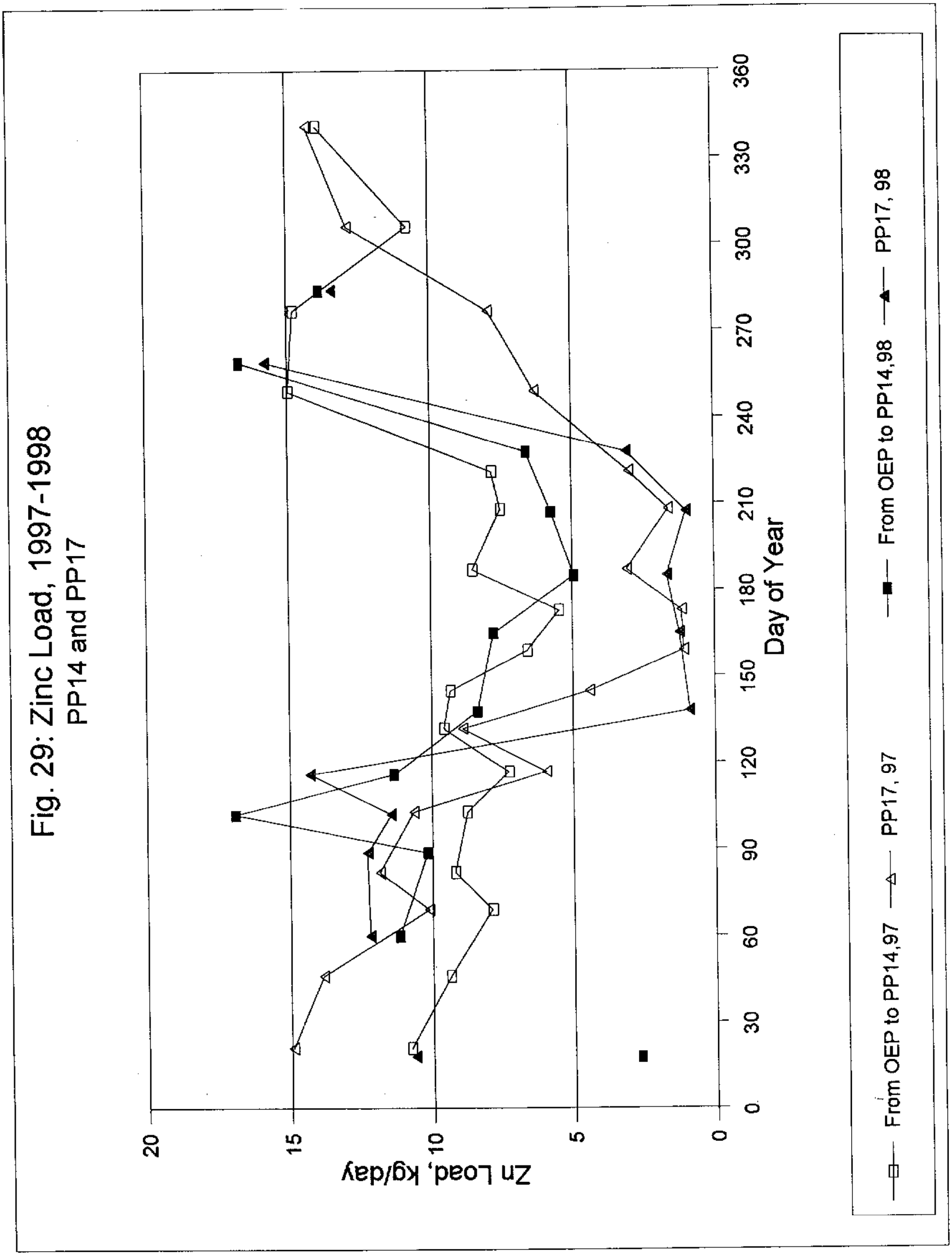
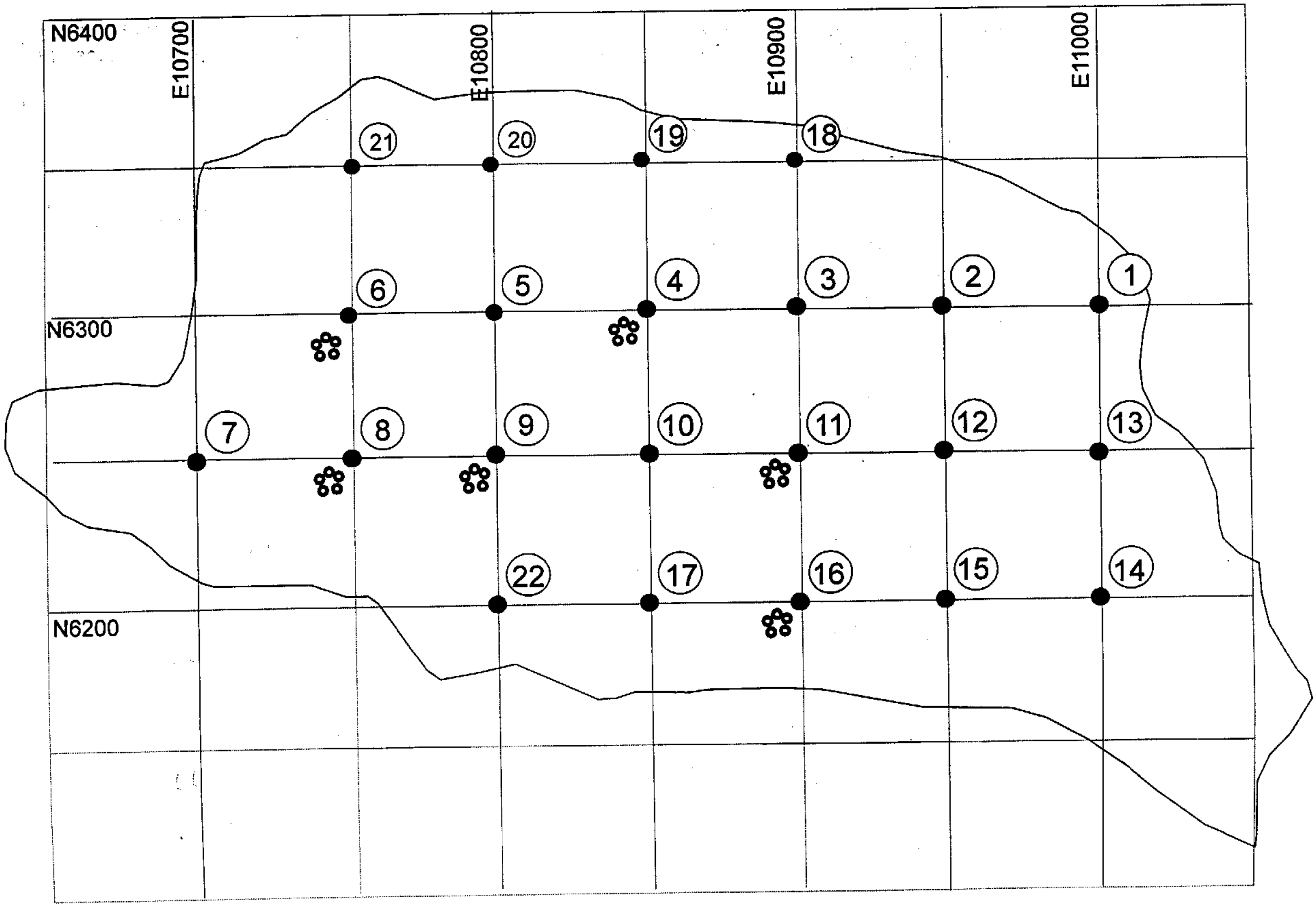


Fig. 29: Zinc Load, 1997-1998
PP14 and PP17

Map 1: OWP Grid Point Locations. [trap symbol] denotes location of sedimentation traps at 2 m and 7 m depths.



VALLEY SEEPAGE ADDITIONS TO OWP

PROGRESS REPORT #1

APRIL 3RD 1998

Valley seepage additions to OWP

Progress Report # 1

April 3rd 1998

The addition of the 2 Valley seeps to the OWP which receives the flow from the Drainage Tünnel is considered in 1998. Boojum had expressed concern that this action may affect negatively the present contaminant removal processes by letter and fax dated February 15th 1998. The rational for the concern was outlined in broad conceptual terms.

Although the recommendation was evaluated by the Owners meeting , it was decided that the diversion is to be implemented. Boojum Research was requested to evaluate some basic considerations of such a flow addition to the present polishing system (OWP -OEP and Polishing ponds) . As a model based on flow and average concentrations had been developed previously, this model was used to predict contaminant concentrations in the first two components of the system. It is expected that the concentration of zinc will increase to 22 mg/l in the first 25 days of the flow additions. Geochemical modelling was not carried out.

One of the key changes due jto the addition of the seepgs might be those of pH. If the pH is going to be depressed, by the addition, a release of the zinc accumulatated in the bottom of the pits with the ironhyrdoxide precipitates is possible. The simplest way to determine this was by a bucket experiment, which was recommended to be carried out. It is presently under way and results for a temperature close to the summer surface water are anticipated.

This progress report summarized data in part already submitted by fax. They are included for completeness with the submission of the invoice. Should the pH drop in the experiment and zinc concentrations increase in the static bucket tests, it is extremely difficult to justify any phosphate additions. The proposed phosphate aggregation of the particles is based on surface reactions for particles formed in a higher pH range. We will await the results of the bucket tests before construction of the sedimentation traps.

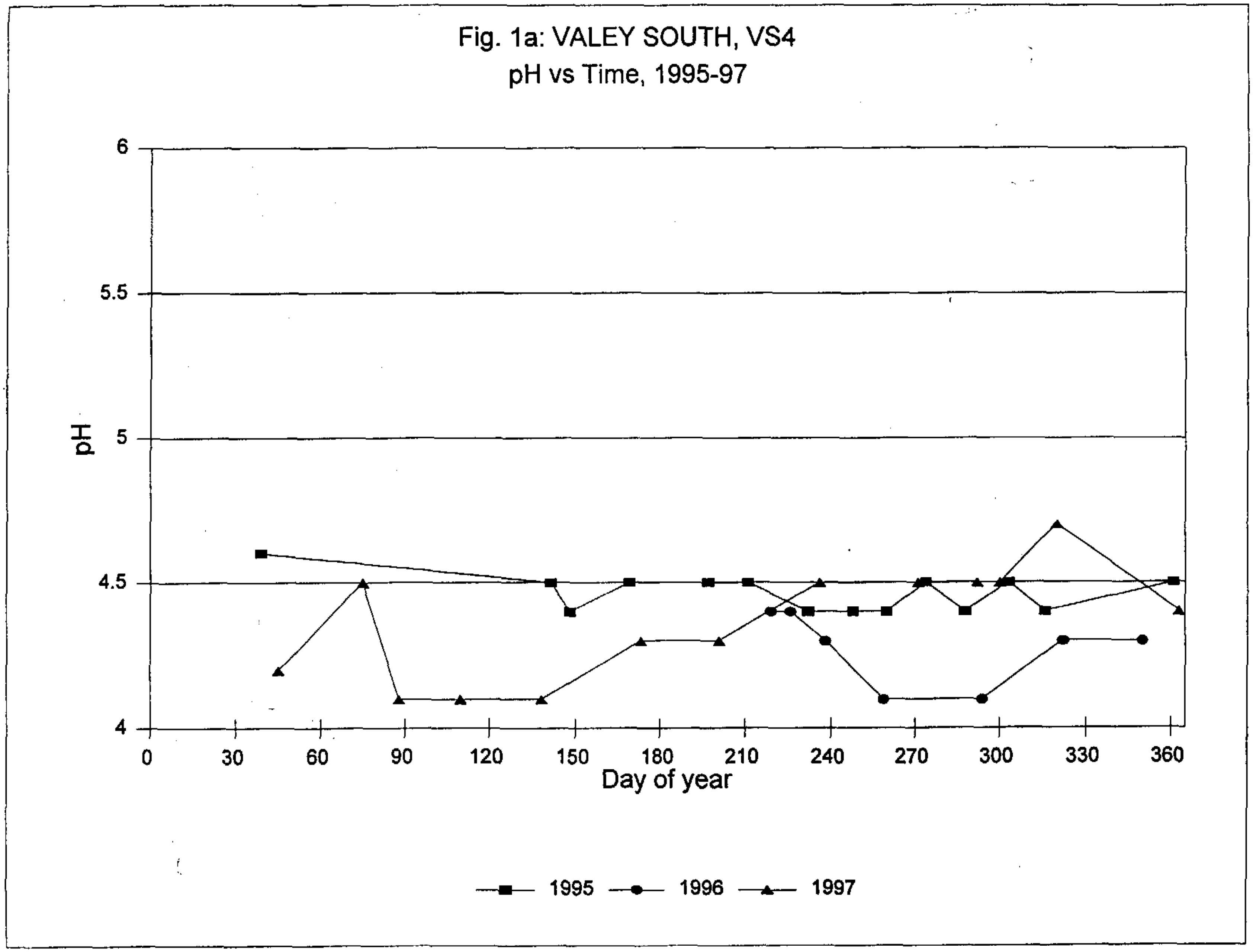


Fig. 1a: VALEY SOUTH, VS4
pH vs Time, 1995-97
6
5.5
5
4.5
4
pH
0
30
60
90
120
150
180
210
240
270
300
330
360
Day of year
1995
1996
1997

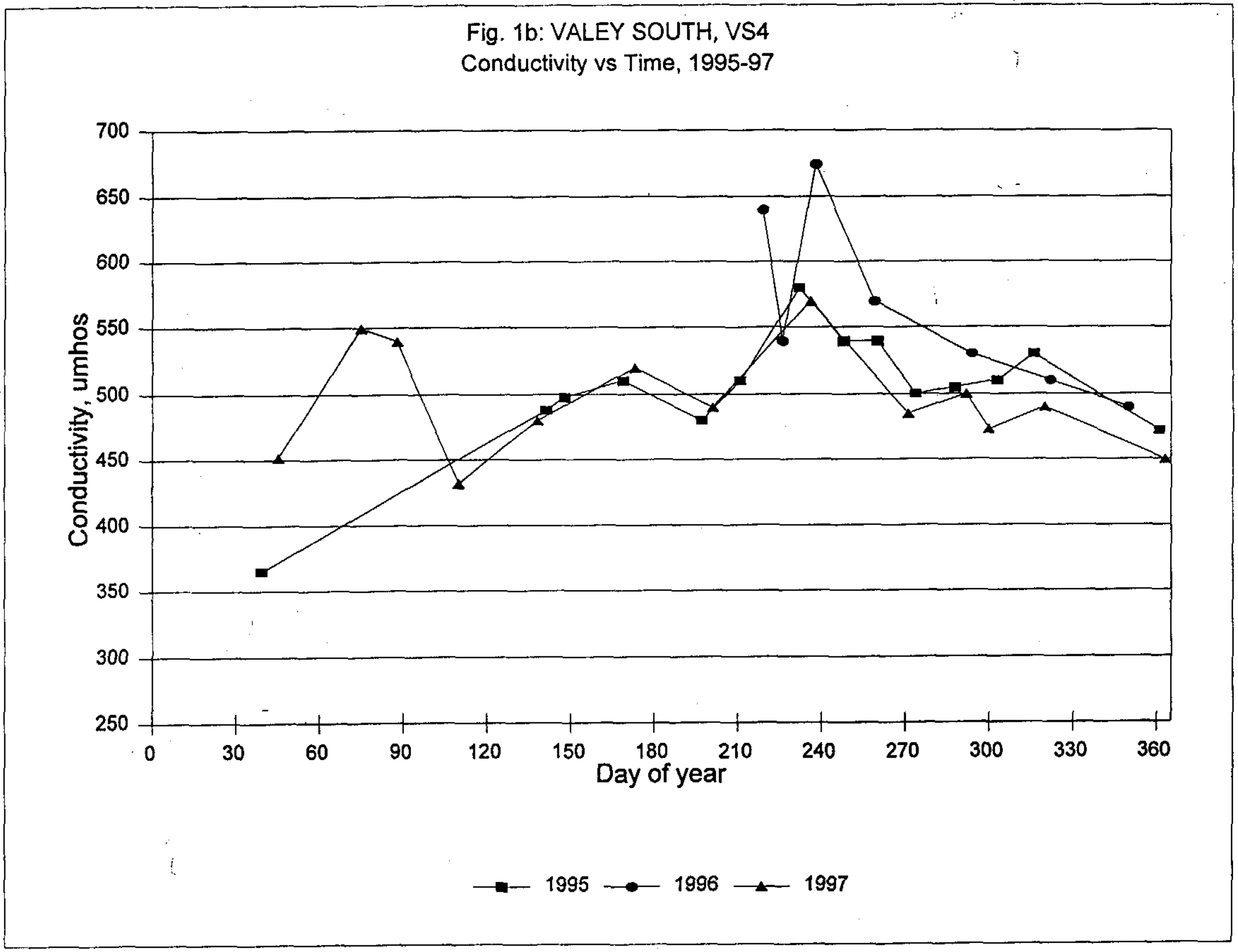


Fig. 1b: VALEY SOUTH, VS4
Conductivity vs Time, 1995-97
700
650
600
550
500
450
400
350
300
250
Conductivity, umhos
0
30
60
90
120
150
180
210
240
270
300
330
360
Day of year
1995
1996
1997

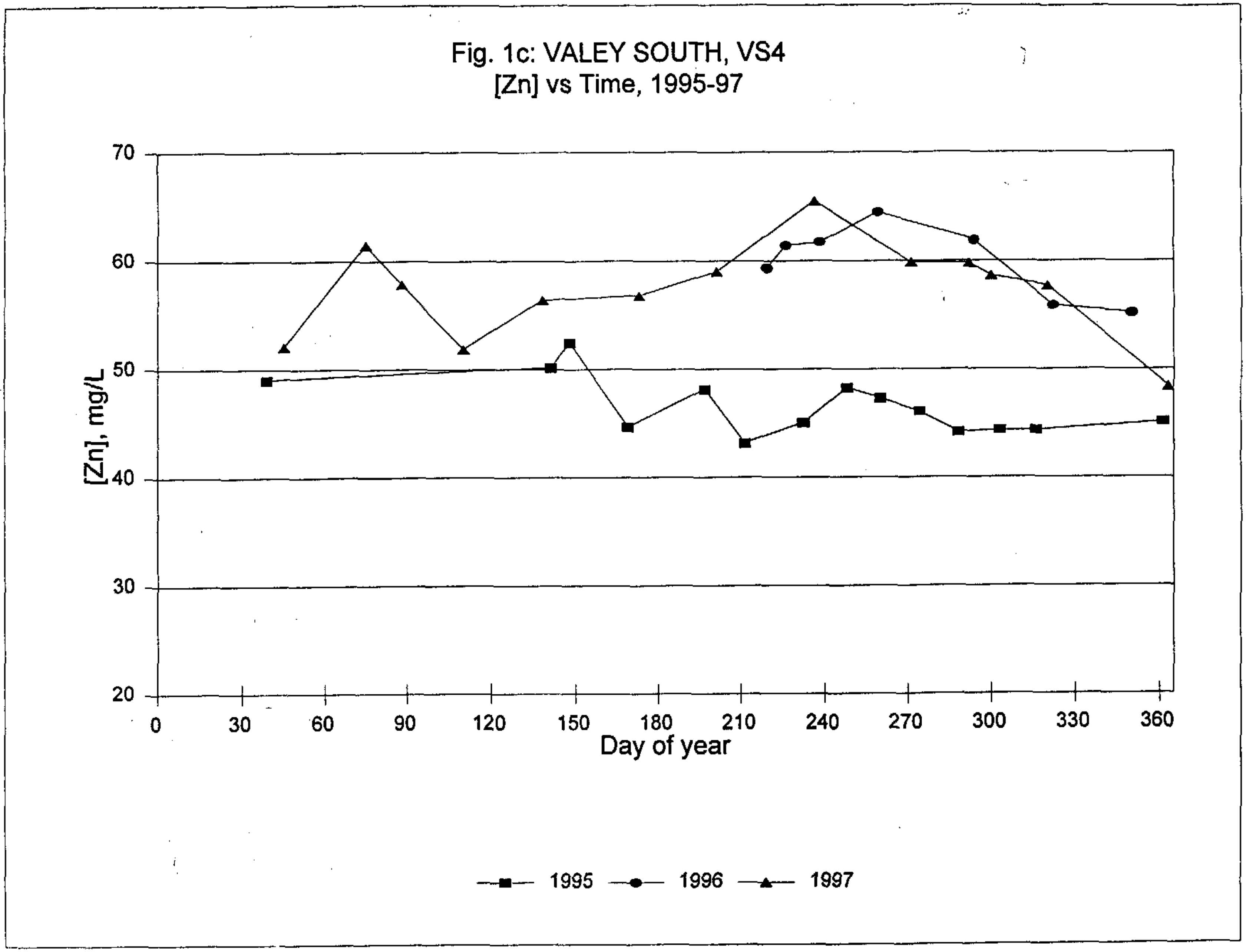


Fig. 1c: VALEY SOUTH, VS4
[Zn] vs Time, 1995-97
[Zn], mg/L
70
60
50
40
30
20
0
30
60
90
120
150
180
210
240
270
300
330
360
Day of year
1995
1996
1997

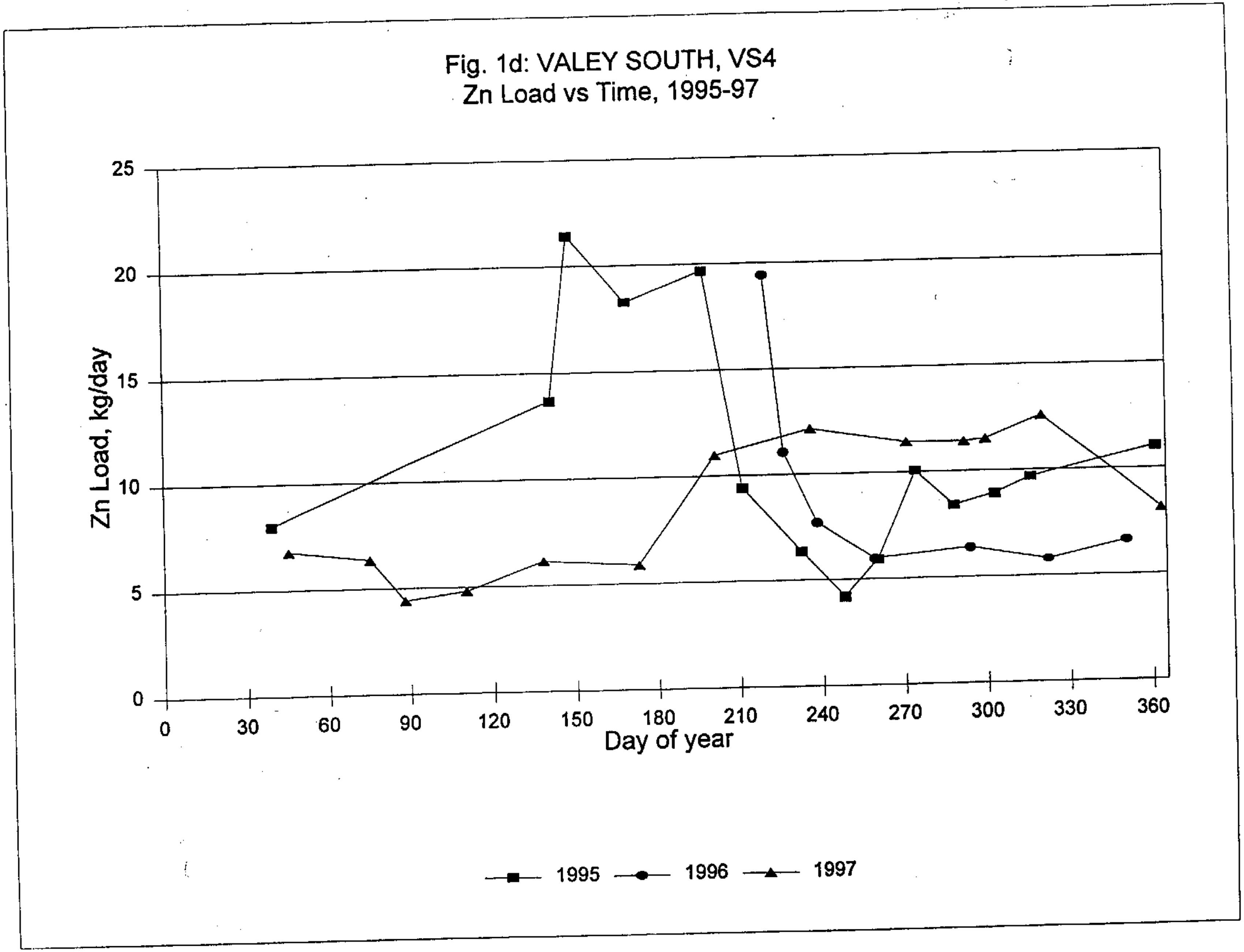


Fig. 1d: VALEY SOUTH, VS4
Zn Load vs Time, 1995-97
Zn Load, kg/day
25
20
15
10
5
0
0
30
60
90
120
150
180
210
240
270
300
330
360
Day of year
1995
1996
1997

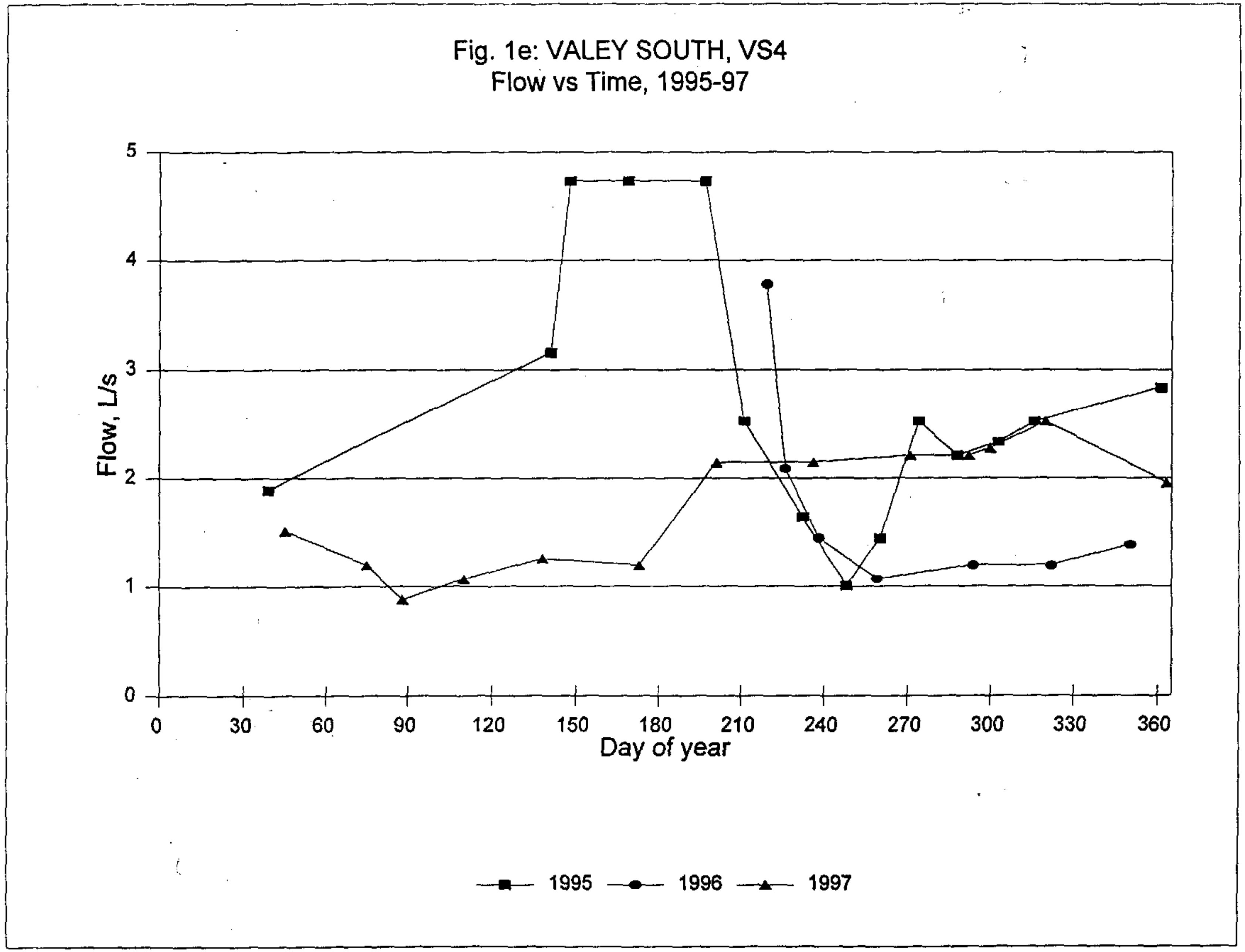


Fig. 1e: VALEY SOUTH, VS4
Flow vs Time, 1995-97
Flow, L/s
Day of year
0
1
2
3
4
5
0
30
60
90
120
150
180
210
240
270
300
330
360
1995
1996
1997

Fig. 1f: VALEY SOUTH, VS4
[Zn], Zn Load, Flow vs Time, 1995-97

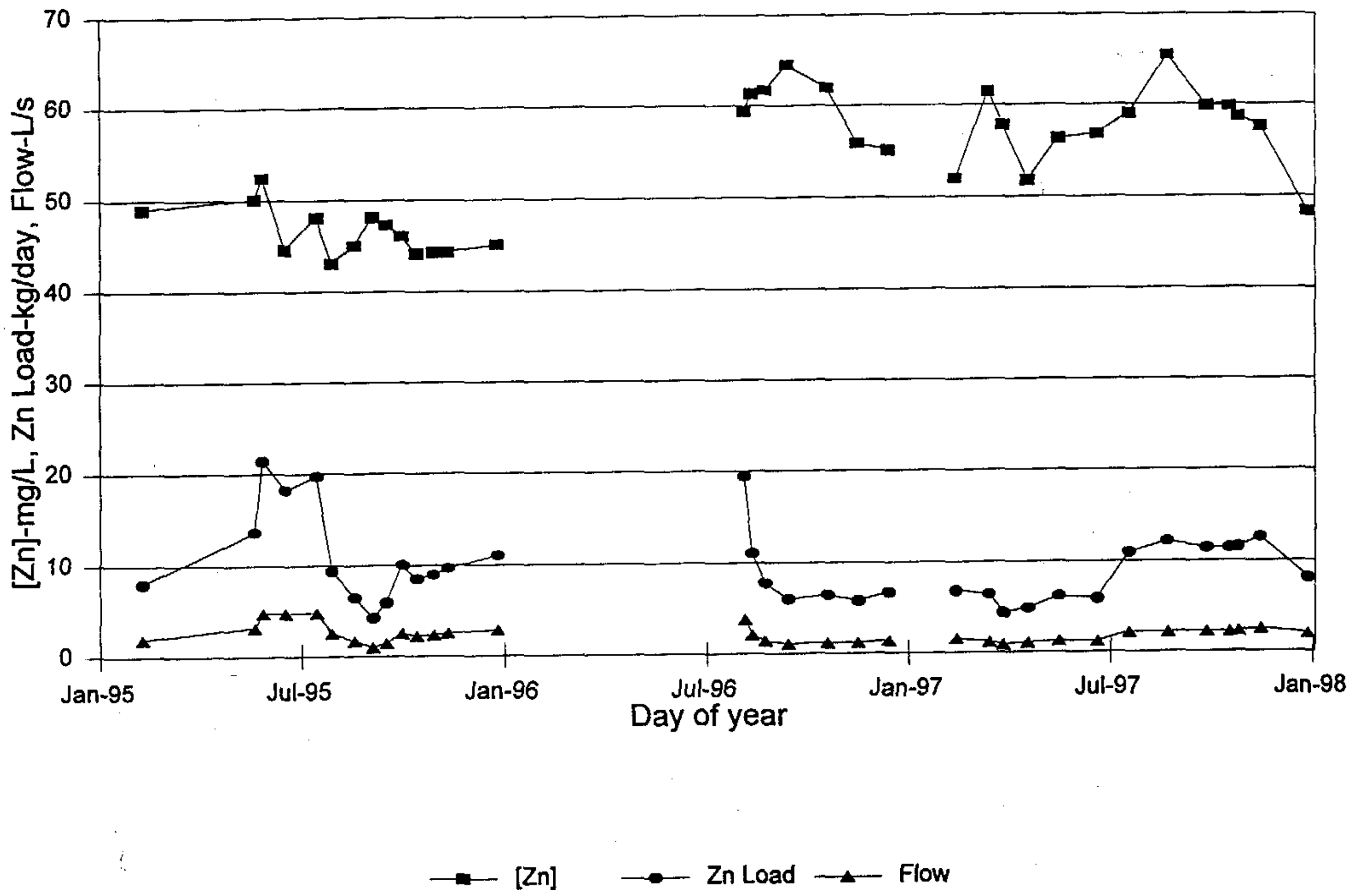
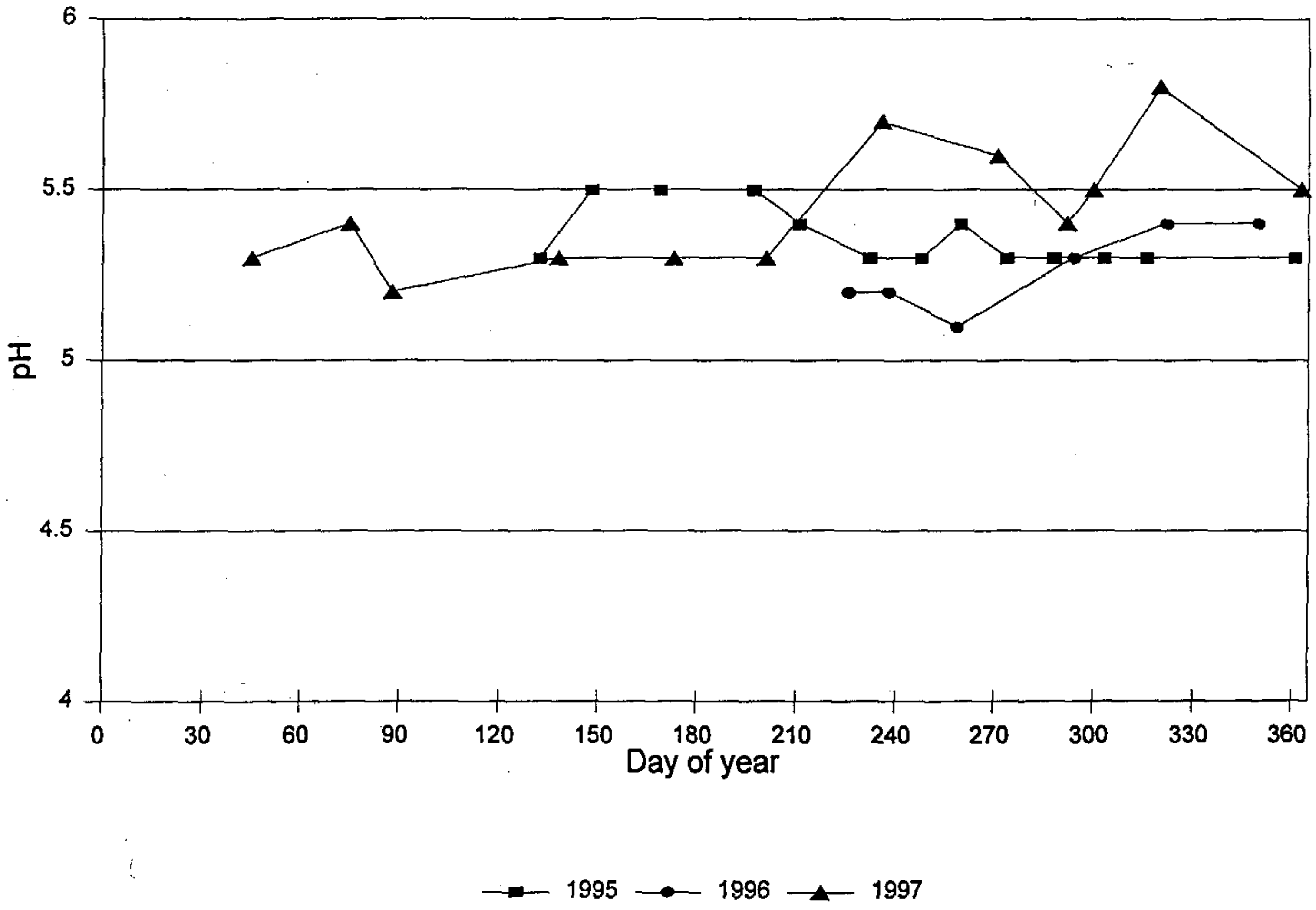


Fig. 2a: VALLEY SOUTH, VS5
pH vs Time, 1995-1997



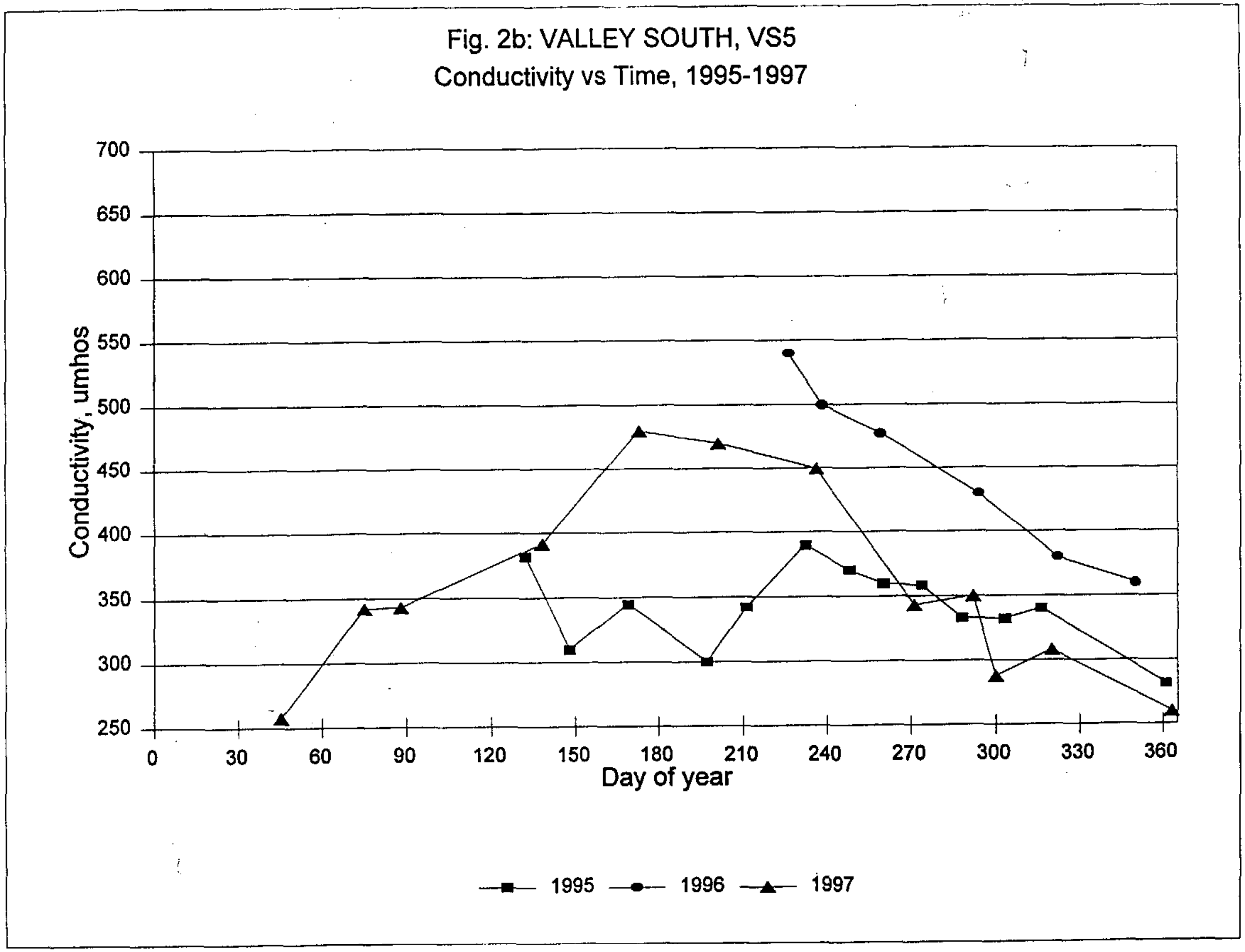


Fig. 2b: VALLEY SOUTH, VS5
Conductivity vs Time, 1995-1997
700
650
600
550
500
450
400
350
300
250
Conductivity, umhos
0
30
60
90
120
150
180
210
240
270
300
330
360
Day of year
1995
1996
1997

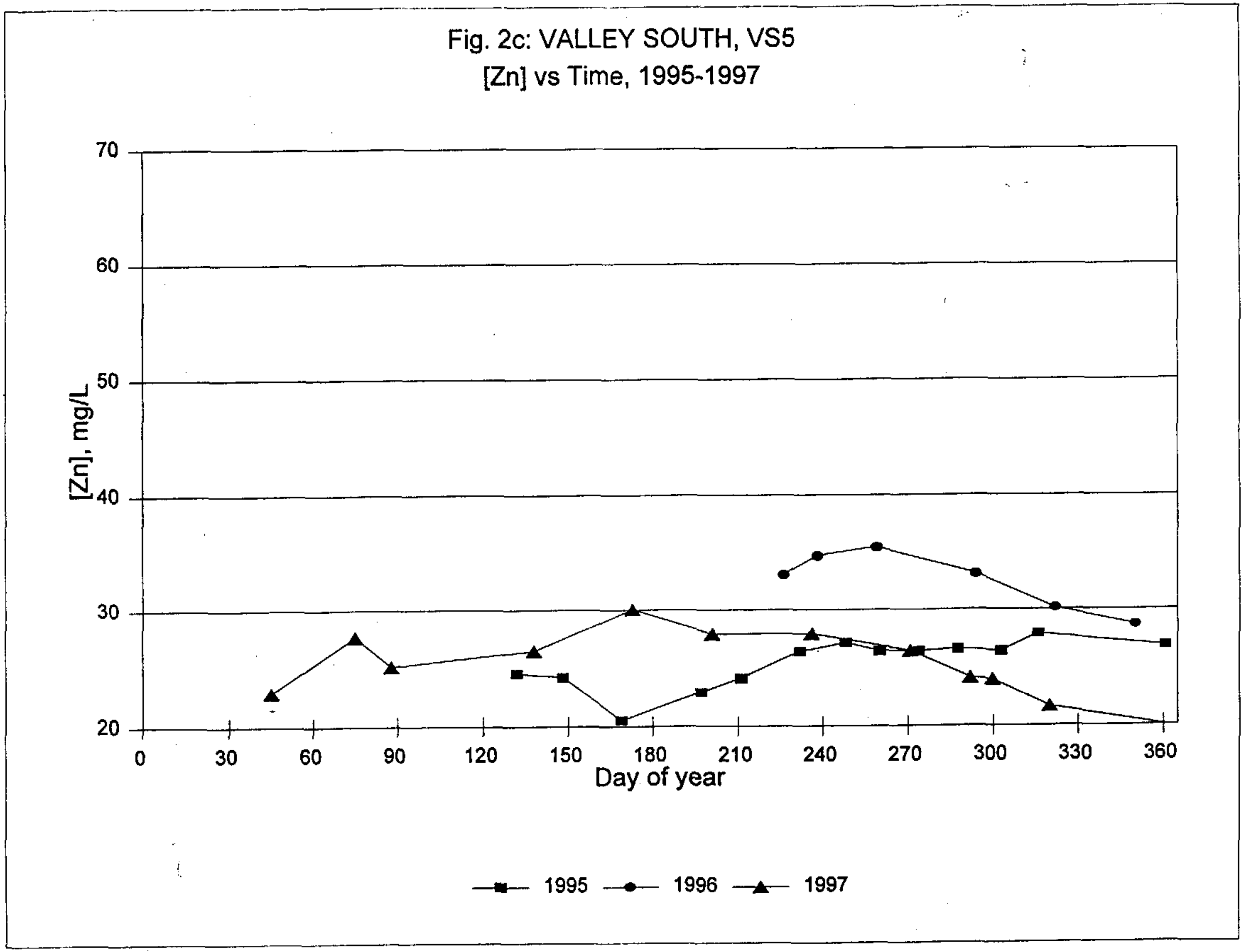


Fig. 2c: VALLEY SOUTH, VS5
[Zn] vs Time, 1995-1997
70
60
50
40
30
20
[Zn], mg/L
0
30
60
90
120
150
180
210
240
270
300
330
360
Day of year
1995
1996
1997

Fig. 2d: VALLEY SOUTH, VS5
Zn Load vs Time, 1995-1997

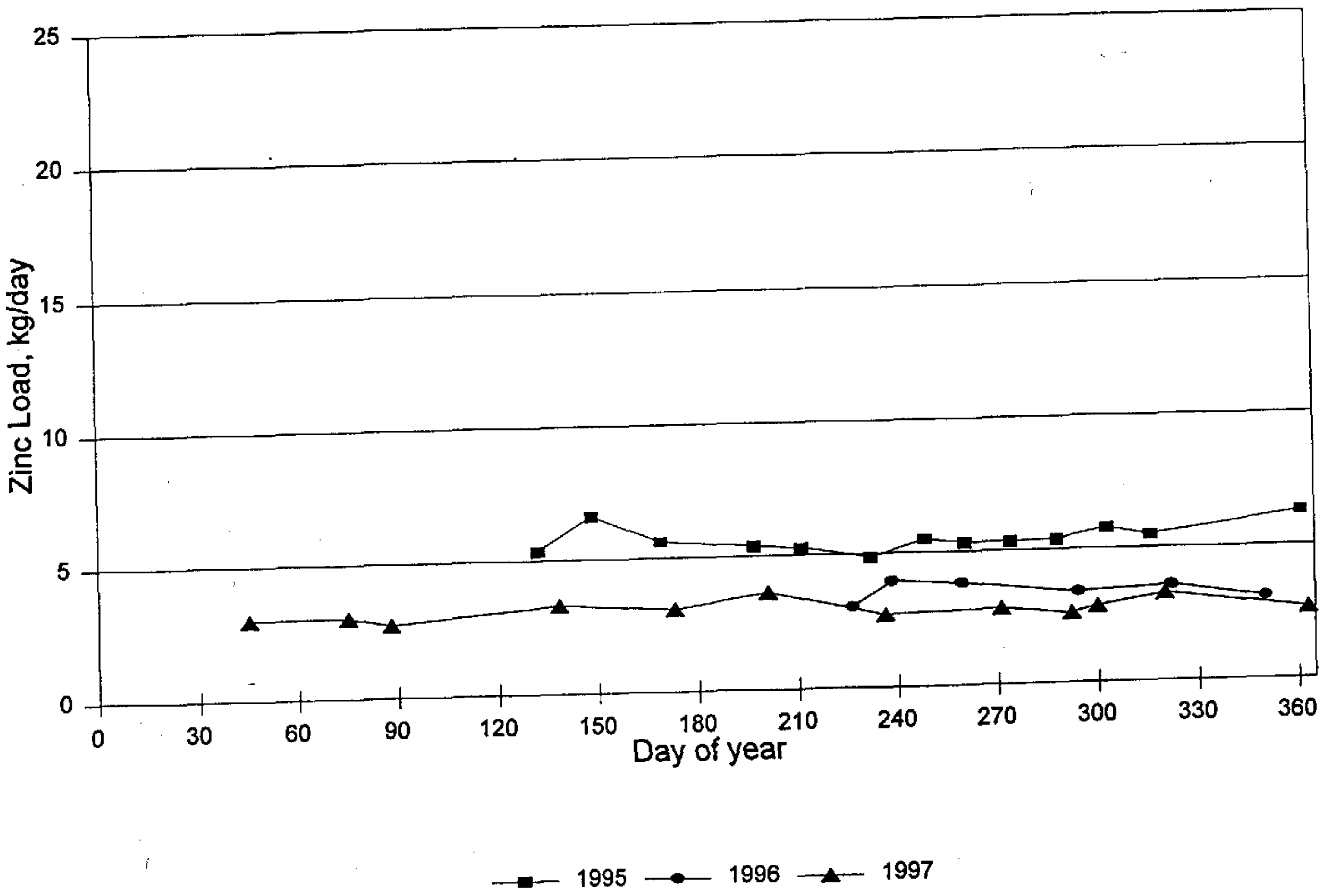
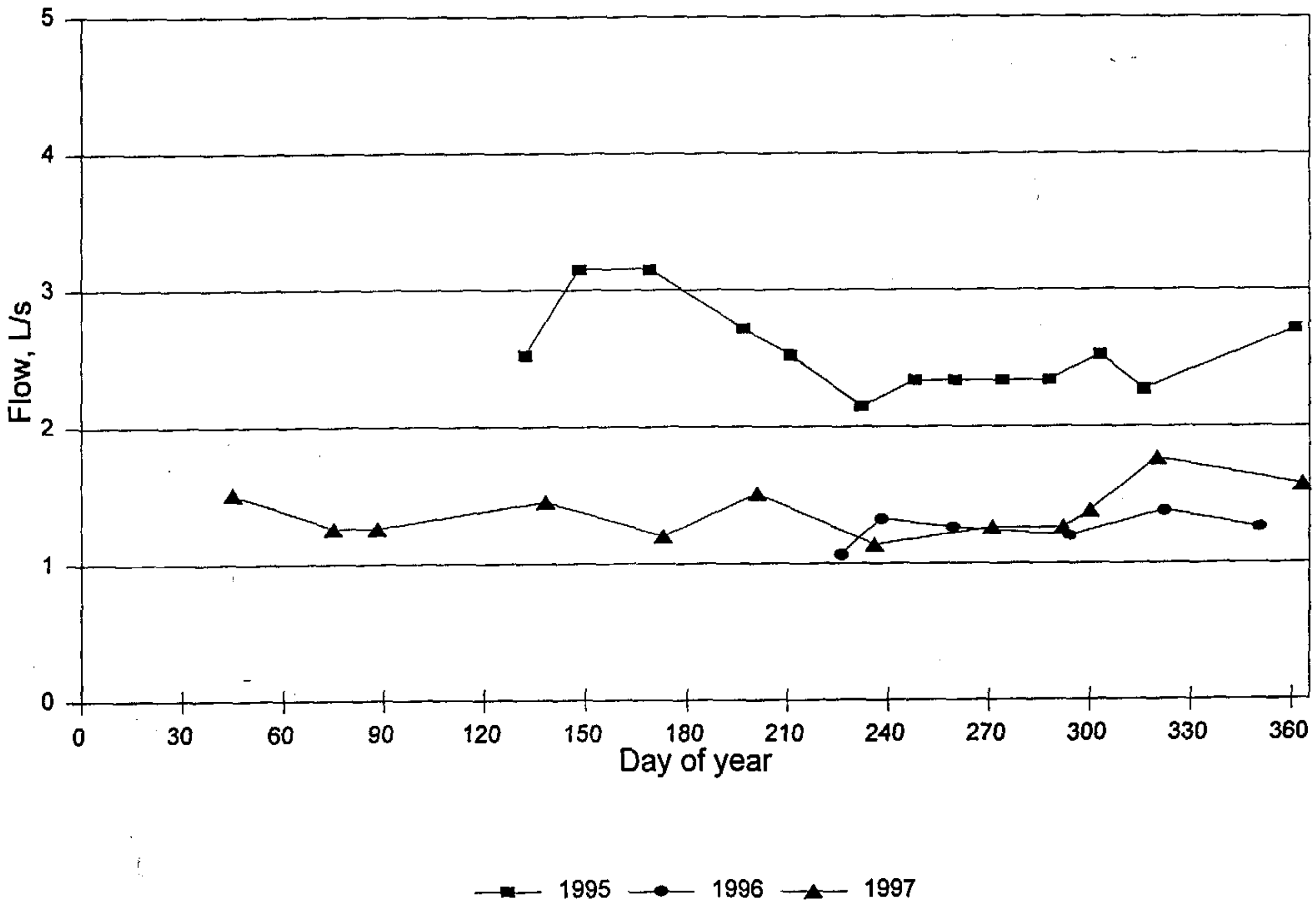


Fig. 2e: VALLEY SOUTH, VS5
Flow vs Time, 1995-1997



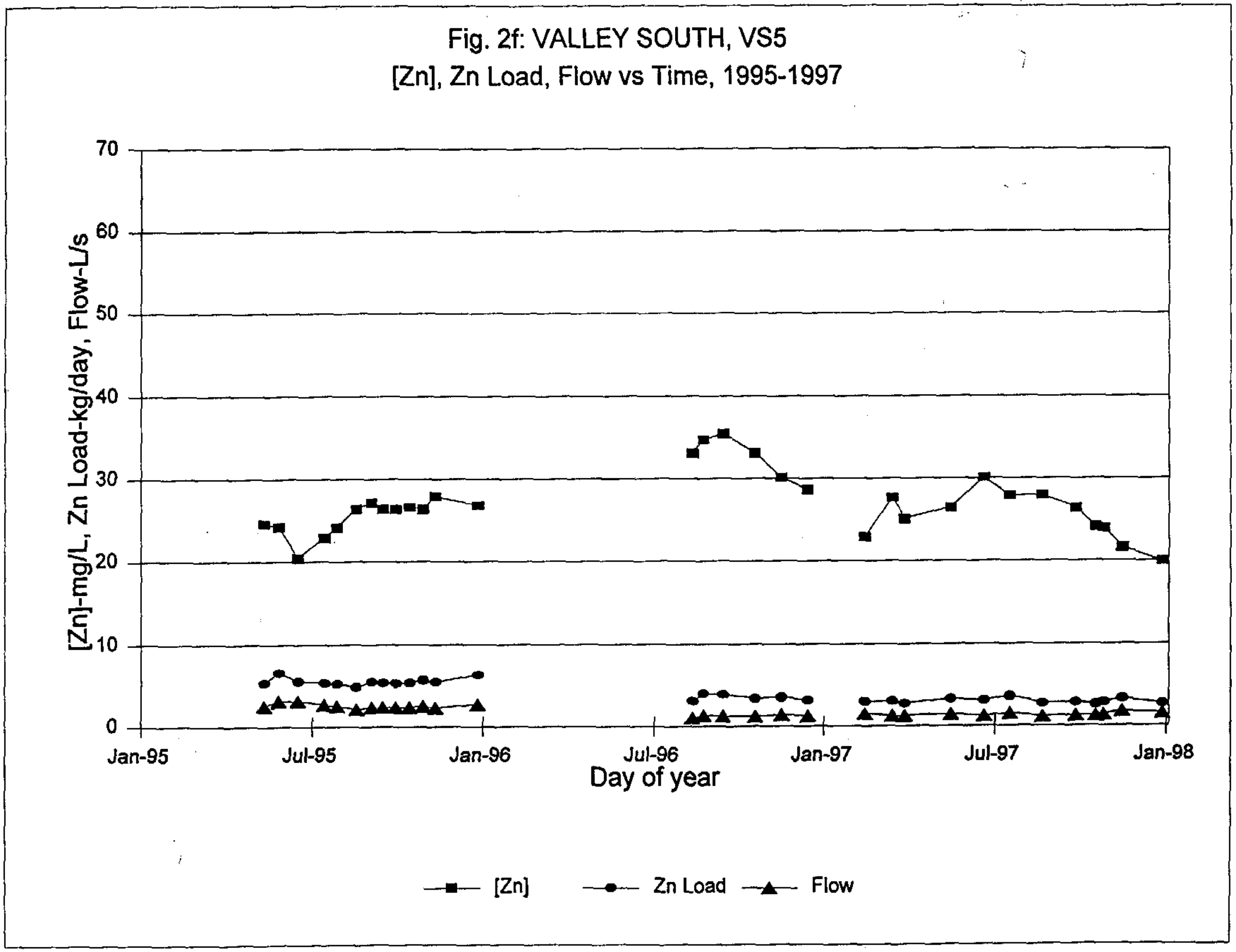


Fig. 2f: VALLEY SOUTH, VS5
[Zn], Zn Load, Flow vs Time, 1995-1997
[Zn]-mg/L, Zn Load-kg/day, Flow-L/s
70
60
50
40
30
20
10
0
Jan-95
Jul-95
Jan-96
Jul-96
Jan-97
Jul-97
Jan-98
Day of year
[Zn]
Zn Load
Flow

Table 1: Comparison of selected elements, VS4, VS5, Drainage Tunnel, OWP, OEP, 1993-1996

	VS4	VS5	DRAINAGE TUNNEL		OWP - SURFACE		OWP - BOTTOM		OEP - SURFACE		OEP - BOTTOM	
DATE	13-Aug 1996	13-Aug 1996	06-Apr 1993	13-Aug 1996	06-Apr 1993	13-Aug 1996	06-Apr 1993	13-Aug 1996	06-Apr 1993	13-Aug 1996	06-Apr 1993	13-Aug 1996
F*Temp. (C)	13	12.5	5.5	6	1.1	15	4.5	6.3	4.8	18.5	6.5	10.8
F*pH	5.2	5.0	6.1	6.2	3.8	6.7	3.6	5.8	6.2	6.9	6.3	6.3
F*Cond. (uS/cm)	540	320	242	248	332	590	378	700	1280	2000	1715	1925
L*Temp. (C)	22.5	23	17.5	22.7	17.6	22.9	17.4	23.1	17.7	22.7	17.8	23.3
L* pH	5.11	4.91	5.62	6.15	3.91	6.49	3.84	5.73	6.02	6.89	6.09	6.2
L*Cond. (uS/cm)	681	530	450	385	465	748	495	962	1510	1235	2040	2410
L*Eh (mV)	643	672	353	641	559	417	623	452	241	632	230	247
L*Acidity (mg/L)	68.4	57.8	54.5	53.4	81.4	32.9	94.3	171.3	248.5	44.6	397.8	71.5
L*Alkalinity (mg/L)	3	2.1	29.5	25.9		63.5		42.8	229.7	112.9	340.6	301.3
Al	0.13	0.49	<0.025	<0.025	2.72	<0.025	3.07	<0.025	0.025	<0.025	<0.025	<0.025
Ca	81.7	57.8	43.2	49.3	71.1	112	79	168	332	224	508	505
Cu	0.074	0.257	0.065	0.078	0.581	0.021	0.603	0.021	0.003	0.006	<0.003	<0.003
Fe	<0.02	<0.02	0.006	<0.02	0.15	<0.02	0.202	<0.02	0.788	<0.02	3.97	10.1
K	2.5	1.8	1.9	1	1.8	1.3	1.8	2.5	3.7	2.2	4.6	4.9
Mg	13.2	10	5.76	5	9.61	10.3	10.2	15.2	32.6	19.6	45.9	41.2
Mn	0.749	2.85	0.267	0.187	2	2.03	2.22	3.88	10.3	5.15	14.6	13.2
Na	35.5	19.9	12.6	11.6	2.86	24.2	2.86	23.1	88.5	51.7	127	116
Sr	<0.25	<0.25	0.128	<0.25	0.231	0.49	0.249	0.73	2	1.11	2.83	2.64
Zn	36.2	31	23.9	18.9	29	16.3	33.8	29.9	17.2	13.4	24.2	13
Bromide	<0.05	<0.05	<0.05	<0.05	<0.05	0.19	<0.05	0.21	3.13	<0.05	4.51	1.44
Chloride	49.8	30.5	20.9	14.8	1.54	31.1	1.54	25.8	129	51.7	196	141
Fluoride	0.18	0.35	0.19	0.14	0.14	0.12	0.14	0.03	0.34	0.21	0.61	0.29
Nitrate	0.43	0.47	4.69	0.8	0.13	0.36	0.13	<0.05	0.13	0.2	0.13	<0.05
Sulphate	281	217	122	137	267	286	310	452	861	488	1260	1170
Bicarbonate	1.6	<0.1	23	27.1	<0.1	61.9	<0.1	41.4	170	125	220	285
T.D.S	505	374	259	269	390	548	447	763	1650	982	2410	2300

OLD BUCHANS DRAINAGE/ VALLEY SOUTH
South of pumphouse-lower seeps+5(a) **VS5**
N6400' E8200' Elev 800'

	Date	Temp C	pH	Zn mg/L	Cond.	Flow USGPM	Elev ft	Flow L/s	Zn LOAD kg/d
1995	12-May-95	15	5.3	24.550	382	40	895.7	2.52	5.35
	28-May-95	9	5.5	24.255	310	50	896.1	3.15	6.61
	18-Jun-95	18	5.5	20.500	345	50	896.2	3.15	5.59
	16-Jul-95	11	5.5	22.950	300	43	895.8	2.71	5.38
	30-Jul-95	15	5.4	24.150	342	40	895.7	2.52	5.27
	20-Aug-95	14	5.3	26.405	390	34	895.0	2.15	4.89
	05-Sep-95	12	5.3	27.155	370	37	895.6	2.33	5.48
	17-Sep-95	12	5.4	26.450	360	37	895.5	2.33	5.33
	01-Oct-95	11	5.3	26.400	358	37	895.5	2.33	5.32
	15-Oct-95	8	5.3	26.600	333	37	895.0	2.33	5.36
	30-Oct-95	8	5.3	26.400	332	40	894.9	2.52	5.76
	12-Nov-95	7	5.3	27.900	340	36	894.8	2.27	5.47
	27-Dec-95	3	5.3	26.850	282	43	895.0	2.71	6.29
1996	13-Aug-96	13	5.2	33.105	540	17	893.1	1.07	3.07
	25-Aug-96	16	5.2	34.700	500	21	893.2	1.32	3.97
	15-Sep-96	10	5.1	35.450	478	20	892.2	1.26	3.86
	20-Oct-96	6	5.3	33.150	430	19	892.1	1.20	3.43
	17-Nov-96	3	5.4	30.15	380	22	891.8	1.39	3.62
	15-Dec-96	2	5.4	28.7	360	20	891.3	1.26	3.13
1997	14-Feb-97	0	5.3	22.95	258	24	890.7	1.51	3.00
	16-Mar-97	1	5.4	27.705	342	20	889.8	1.26	3.02
	29-Mar-97	1	5.2	25.15	343	20	889.6	1.26	2.74
	18-May-97	9	5.3	26.505	392	23	890.1	1.45	3.32
	22-Jun-97	14	5.3	30.05	480	19	890.1	1.20	3.11
	20-Jul-97	14	5.3	27.9	470	24	890.2	1.51	3.65
	24-Aug-97	11	5.7	27.95	450	18	890	1.14	2.74
	28-Sep-97	6	5.6	26.45	343	20	889.8	1.26	2.88
	19-Oct-97	8	5.4	24.15	350	20	889.5	1.26	2.63
	27-Oct-97	5	5.5	24.005	288	22	889.4	1.39	2.88
	16-Nov-97	4	5.8	21.65	308	28	889.5	1.77	3.30
	29-Dec-97	1	5.5	19.905	260	25	889	1.58	2.71
				19.905	258			1.0725	2.63275
				35.45	540			3.15442	6.6105

OLD BUCHANS DRAINAGE/ VALLEY SOUTH

South of pumphouse-combined upper s VS4

N6120' E8080' Elev 832'

	Date	Temp C	pH	Zn mg/L	Cond.	Flow USGPM	Elev ft	Flow L/s	Zn LOAD kg/d
1995	08-Feb-95	4	4.6	49.050	365	30	895.5	1.89	8.02
	21-May-95	7	4.5	50.155	488	50	896.1	3.15	13.67
	28-May-95	8	4.4	52.450	498	75	896.1	4.73	21.44
	18-Jun-95	13	4.5	44.655	510	75	896.2	4.73	18.26
	16-Jul-95	8	4.5	48.150	480	75	895.8	4.73	19.68
	30-Jul-95	13	4.5	43.150	510	40	895.7	2.52	9.41
	20-Aug-95	13	4.4	45.005	580	26	895	1.64	6.38
	05-Sep-95	10	4.4	48.250	540	16	895.6	1.01	4.21
	17-Sep-95	12	4.4	47.305	540	23	895.5	1.45	5.93
	01-Oct-95	10	4.5	46.055	500	40	895.5	2.52	10.04
	15-Oct-95	7	4.4	44.150	5.5	35	895	2.21	8.42
	30-Oct-95	8	4.5	44.350	510	37	894.9	2.33	8.94
	12-Nov-95	8	4.4	44.350	530	40	894.8	2.52	9.67
	27-Dec-95	6	4.5	45.105	472	45	895	2.84	11.06
1996	06-Aug-96	13	4.4	59.400	640	60	893.1	3.79	19.43
	13-Aug-96	7	4.4	61.450	540	33	893.1	2.08	11.05
	25-Aug-96	13	4.3	61.750	675	23	893.2	1.45	7.74
	15-Sep-96	10	4.1	64.500	570	17	892.2	1.07	5.98
	20-Oct-96	9	4.1	61.950	530	19	892.1	1.20	6.42
	17-Nov-96	6	4.3	55.85	510	19	891.8	1.20	5.78
	15-Dec-96	4	4.3	55.205	490	22	891.3	1.39	6.62
1997	14-Feb-97	2	4.2	52.07	452	24	890.7	1.51	6.81
	16-Mar-97	5	4.5	61.55	550	19	889.8	1.20	6.37
	29-Mar-97	9	4.1	57.85	540	14	889.6	0.88	4.41
	20-Apr-97	4	4.1	51.85	432	17	889.5	1.07	4.80
	18-May-97	7	4.1	56.4	480	20	890.1	1.26	6.15
	22-Jun-97	10	4.3	56.805	520	19	890.1	1.20	5.88
	20-Jul-97	8	4.3	59.05	490	34	890.2	2.15	10.94
	24-Aug-97	10	4.5	65.505	570	34	890	2.15	12.14
	28-Sep-97	7	4.5	59.9	485	35	889.8	2.21	11.43
	19-Oct-97	8	4.5	59.805	500	35	889.5	2.21	11.41
	27-Oct-97	5	4.5	58.65	473	36	889.4	2.27	11.51
	16-Nov-97	5	4.7	57.705	490	40	889.5	2.52	12.58
	29-Dec-97	5	4.4	48.35	450	31	889	1.96	8.17

MODEL ASSUMPTIONS FOR CALIBRATION

Drainage Tunnel

Flow	8.3 L/s
[Zn]	14.63 mg/L

Oriental West Pit

GW Flow to OWP	1.7 L/s
[Zn] of GW	15.5 mg/L
Flow	8.3 + 1.7 = 10 L/s
Volume	26,750 m^3
Initial [Zn]	12.46 mg/L

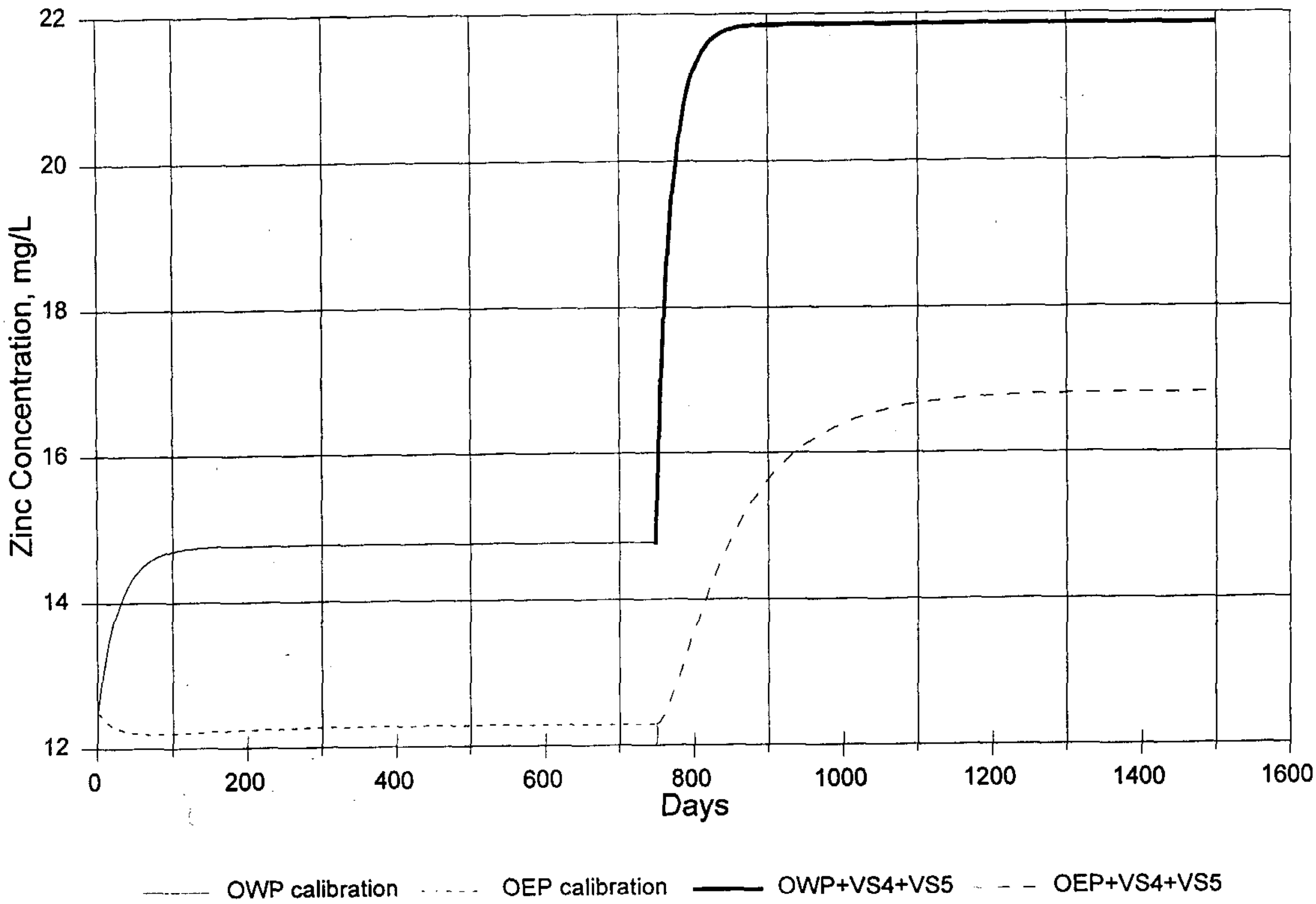
Oriental East Pit

GW Flow to OEP	
Clean	3.4 L/s
Contaminated	5.8 L/s
[Zn] of GW	
Clean	0.01 mg/L
Contaminated	15.2 mg/L
Flow	10 + 3.8 + 5.8 = 19.2 L/s
Volume	188,500 m^3
Initial [Zn]	12.5 g/L

pH of Drainage Tunnel + VS4 + VS5

Drainage Tunnel			
	Average pH 1997	6.1	Flow 8.3 L/s
VS4			
	Average pH 1997	4.32	Flow 1.8 L/s
VS5			
	Average pH 1997	5.41	Flow 1.4 L/s
	pH of the mixture	**5.07**	**Flow 11.5 L/s**

Fig. 3: [Zn] OEP and OWP
before and after VS4 and VS5



MODEL ASSUMPTIONS FOR PREDICTION

VS4	Flow	1.8 L/s
	[Zn]	58 mg/L
VS5	Flow	1.4 L/s
	[Zn]	26 mg/L
Drainage Tunnel		
	Flow	8.3 L/s
	[Zn]	14.63 mg/L
Drainage Tunnel+VS4+VS5		
	Flow	8.3+1.4+1.8 = 11.5 L/s
	[Zn]	22.80 mg/L
Oriental West Pit		
	GW Flow to OWP	1.7 L/s
	[Zn] of GW	15.5 mg/L
	Flow	11.5 + 1.7 = 13.2 L/s
	Volume	26,750 m^3
	Calibrated [Zn]	14.78 mg/L
Oriental East Pit		
	GW Flow to OEP	
	Clean	3.4 L/s
	Contaminated	5.8 L/s
	[Zn] of GW	
	Clean	0.01 mg/L
	Contaminated	15.2 mg/L
	Flow	13.2 + 3.4 + 5.8 = 22.8 L/s
	Volume	188,500 m^3
	Calibrated [Zn]	12.29 mg/L