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Western Treatment Plant Outputs
to Port Phillip Bay

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EXECUTIVE SUMMARY

Estimates of nutrient and toxicant discharge loads from the Western Treatment Plant at Werribee (WTP) - formerly referred to as the Werribee Treatment Complex - are a fundamental requirement for the development of integrated models with the Port Phillip Bay Environmental Study. The WTP discharges treated wastewater to Port Phillip Bay via five outlets. Records of average weekly flow rates from each of the outlets together with weekly measurements of nitrogen (NH_3, NO_3, NO_2 and organic N), phosphorus (orthophosphate and total P) and organic carbon and fortnightly measurements of various metals (Cd, Cr, Cu, Fe, Hg, Ni, Pb and Zn) in the treated wastewater for the period 1/1/80 to 31/12/89 were provided by Melbourne Water and are analysed here.

A mean flow rate of about 420 ML/d is discharged to Port Phillip Bay from the WTP. Outflow from the drains exhibits a strong seasonal cycle with highest flows during the late winter and spring. The annual volume of wastewater discharged increased from about 0.12 km^3 in 1980 to almost 0.16 km^3 in 1989.

Four forms of nitrogen are measured in the effluent discharged from the WTP - ammonium, nitrate, nitrite and organic nitrogen. The concentration of ammonium in wastewater is highest during winter and spring (20-30 mg/l), whereas concentrations of nitrate, nitrite and organic nitrogen are highest (about 6, 2 and 15 mg/l respectively) during summer. The annual discharge of ammonium from the WTP increased during the early 1980s, but values in the later part of the decade were down from peak levels in 1984. Discharge of organic N remained steady at about 800 tonnes/year, nitrate at about 150 tonnes/year and nitrite about 40 tonnes/year.

Orthophosphate and total phosphorus are the two measures of phosphorus discharge from WTP. The concentration of both forms of phosphorus in wastewater exhibit a slight annual minimum during autumn, and discharge of both is greatest (about 3 tonnes/day combined) during spring. Annual quantities of phosphorus discharged from WTP doubled over the 1980s to more than 1000 tonnes/year in 1989.

Discharge of organic carbon from WTP declined by about half over the 1980s to 4000-5000 tonnes/year in the late 1980s, with highest rates of discharge (15-20 tonnes/day) occurring during late autumn through early spring.

Concentrations of metals in discharges from WTP are generally slightly in excess of ANZECC guidelines for ambient levels, with highest discharge rates for most of the species examined during late autumn. Quantities of most of the metals discharged from WTP remained fairly constant throughout the 1980s with the most notable exceptions being a decline in the quantity of chromium discharged after 1985 (from about 4 tonnes/year to less than 3 tonnes/year) and a steady increase in discharge of iron from about 150 to 250 tonnes/year.

1.0 Introduction

Port Phillip Bay (PPB) is an almost enclosed marine embayment with the City of Melbourne and its metropolitan area (population 2.6×10^6) around its northern and north-eastern shores. The waters of this bay exchange only slowly with oceanic water and the exchange time is currently estimated at about one year (Hunter 1992). This restricted flushing has important implications for the management of water quality and the ecology of those waters receiving run-off and treated sewage effluent discharge from a city the size of Melbourne.

Pollutants entering the Bay will build up to equilibrium concentrations dependent on both flushing rates and deposition mechanisms. The results from other research tasks in the Port Phillip Bay Environmental Study show that most metal and organic toxicant inputs are precipitated close to the entry of freshwater discharges into the saline Bay. The combination of this phenomenon and tidal flushing reduces toxicant levels in the water of the Bay to very low concentrations - in some cases undetectable levels.

One of the largest sources of pollution is the Western Treatment Plant at Werribee (WTP) - formerly referred to as the Werribee Treatment Complex. Established in 1897, the WTP is located adjacent to the foreshore of Port Phillip Bay about 35 km south-west of the City of Melbourne (Figure 1). The facility occupies 10,851 ha (6,700 ha of which is used for treatment purposes) and currently treats an average of 520 ML/d or more than half of Melbourne's wastewater. Included in this quantity is about 90% of Melbourne’s industrially generated liquid waste. Treatment consists of lagooning (all year) supplemented by land irrigation during warmer months and by grass filtration during cooler months. Following a treatment period of between 60-90 days the final treated wastewater is discharged directly to Port Phillip Bay *via* five outlets (one of which is operational only during winter months) at a rate of about 420 ML/d (Figure 1).

In spite of the period of operation of the WTP facility there have been no satisfactory estimates of WTP discharge characteristics derived from systematically collected data (see Chiffings *et al*. 1992). Such data are a fundamental requirement for the development of integrated management models which are a required output of the Port Phillip Bay Environmental Study.

1.1. Objectives

The two principle objectives of this study were to:-

1) Quantify the annual loads of various nutrients and toxicants to Port Phillip Bay from treated wastewater discharged from the WTP.
2) Determine and quantify any seasonal variations in load for each of the nutrient and toxicant species.

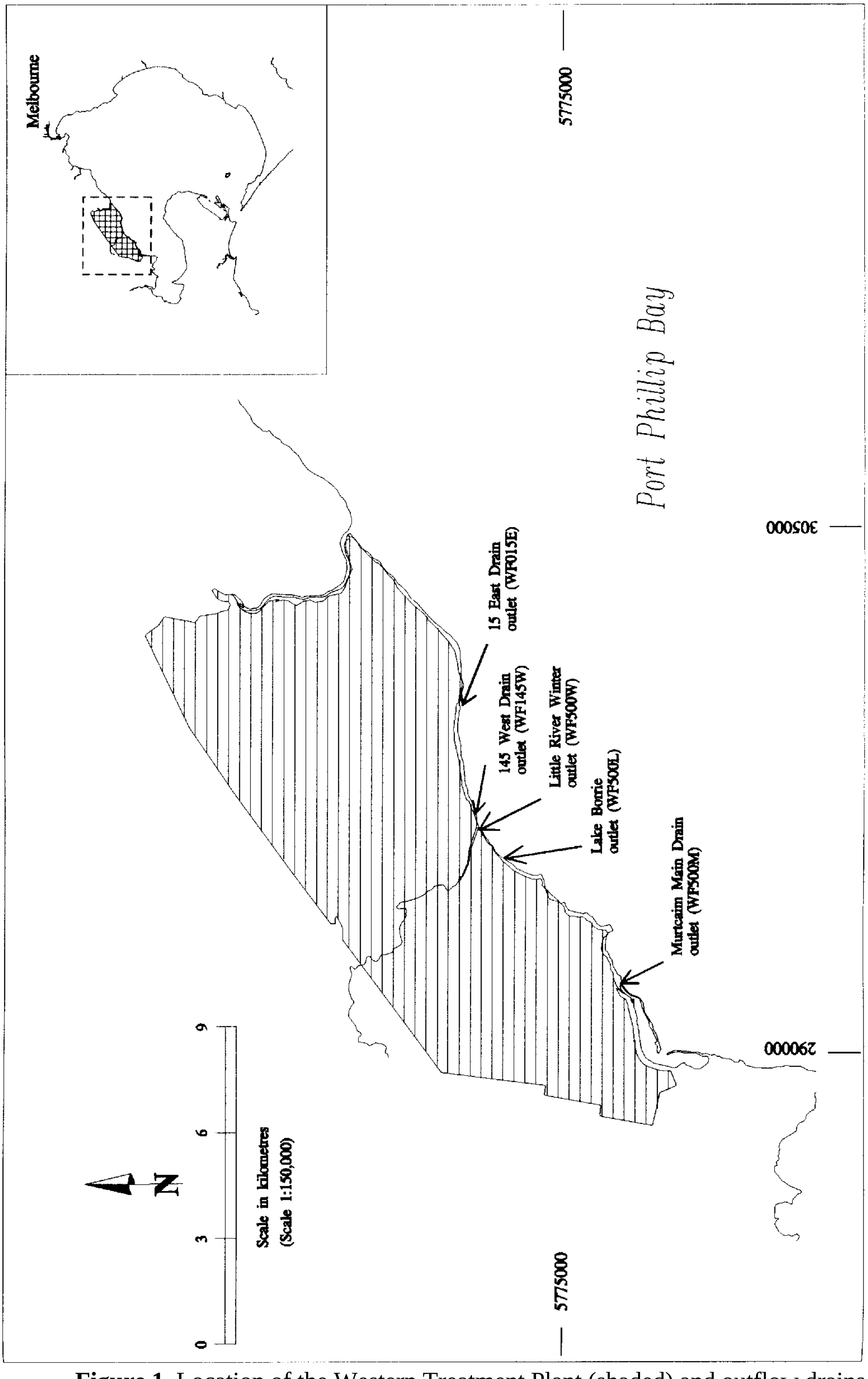


Figure 1. Location of the Western Treatment Plant (shaded) and outflow drains to Port Phillip Bay

Figure 1. Location of the Western Treatment Plant (shaded) and outflow drains to Port Phillip Bay

1.2. Methodology

Melbourne Water has collected an extensive data set on the outputs from the WTP. These include weekly measurements of nitrogen forms (NH_3, NO_3, NO_2 and organic N), phosphorus (orthophosphate and total P) and organic carbon and fortnightly measurements of various metals (Cd, Cr, Cu, Fe, Hg, Ni, Pb and Zn). Other parameters such as suspended and dissolved solids, dissolved oxygen, oxygen demand and colour have not been examined here but the data exist. There has been no systematic collection of data on discharge of individual organic compounds.

Data were available covering the period 1/1/1980 to 30/6/93. Only the period 1/1/1980 to 31/12/89 have is presented here since ten years was a convenient period for analysis. Output occurred through four or five drains (one operational only in winter). From the flow and concentration measurements in these drains I have established loads and considered some of their temporal variation.

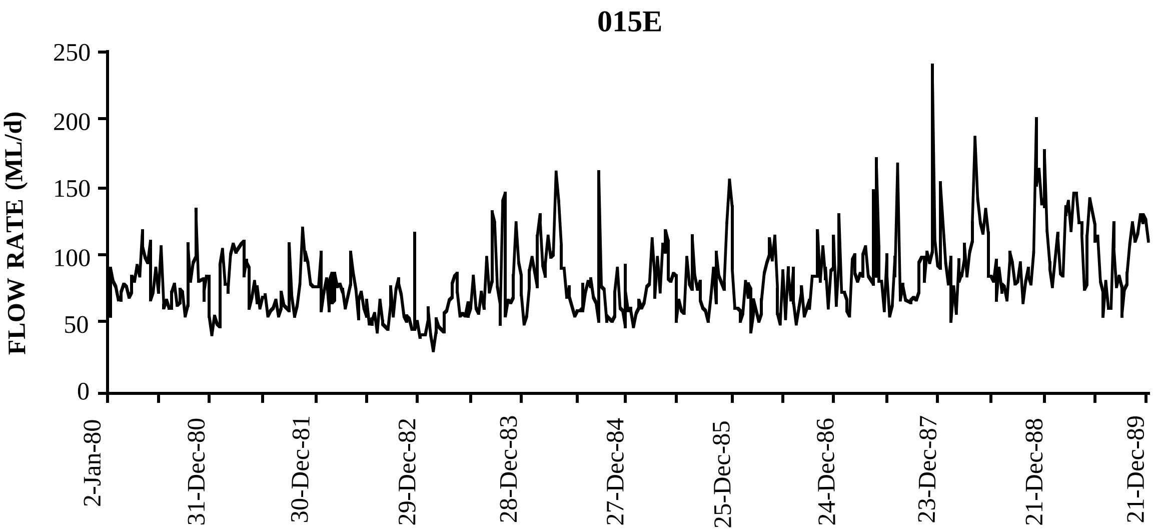
Plots showing the seasonal variation in concentration of nutrients and metals were derived by plotting the mean concentration of each nutrient and metal from all of the WTP drains on each day of sampling. Loads were estimated by multiplying the daily concentration by the flow rate at each drain and then summing all values to gain a load estimate from all drains, and then averaging the daily load estimates from all drains in a given month.

2.0 Flow

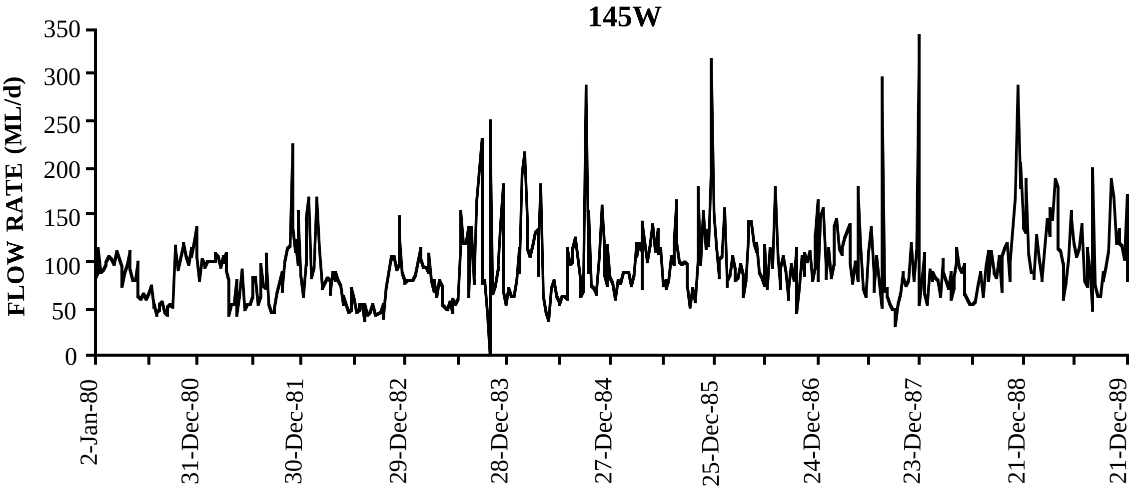
Water is released from the WTP *via* five drains. Flow data is presented for each of these drains for the period 1980-89 (Figures 2a-e). Three of these drains (15E, 145W and Lake Borrie) are fairly constant in flow whilst the other two (Murtcaim and Little River) are winter overflow drains with much lower, or non-existent, flows during summer months.

Figure 2. Weekly flow from each of the five WTP outlets over the period 1/1/80 to 31/12/89. [(a) = 015E, (b) = 145W, (c) = Lake Borrie, (d) = Murtcaim and (e) = Little River]

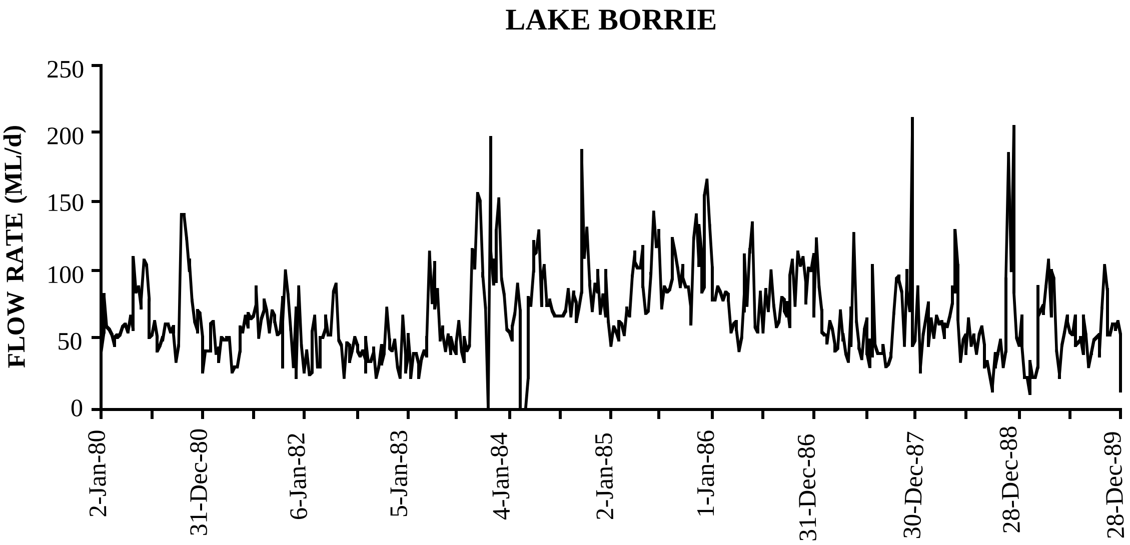
a)



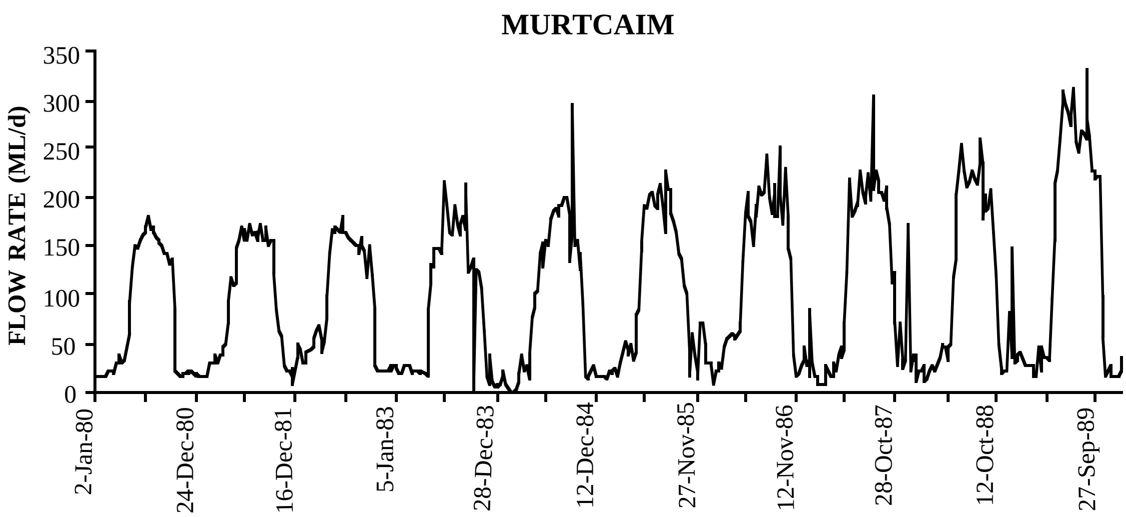
b)


145W
FLOW RATE (ML/d)
350
300
250
200
150
100
50
0
2-Jan-80
31-Dec-80
30-Dec-81
29-Dec-82
28-Dec-83
27-Dec-84
25-Dec-85
24-Dec-86
23-Dec-87
21-Dec-88
21-Dec-89

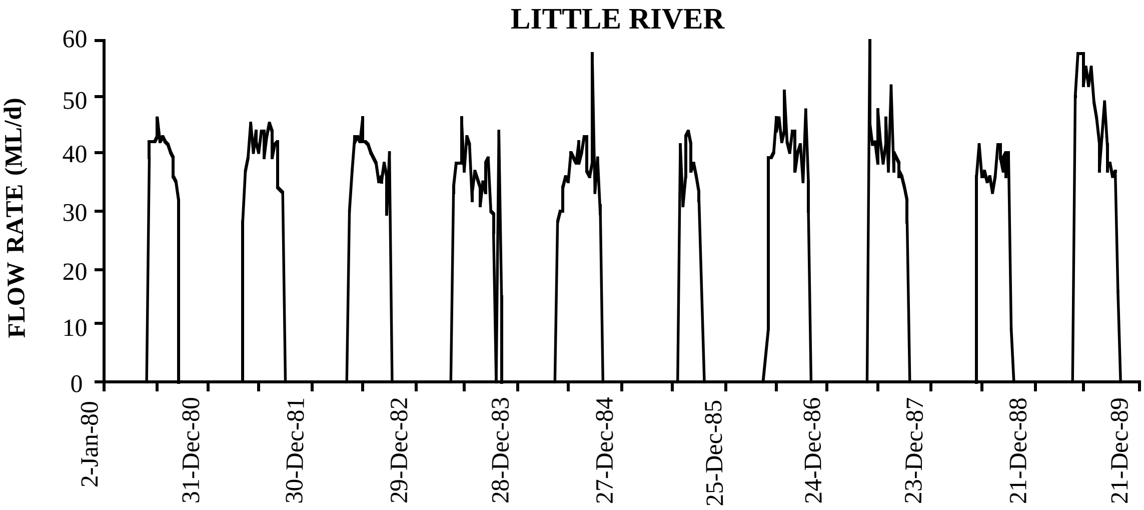
c)


LAKE BORRIE
FLOW RATE (ML/d)
250
200
150
100
50
0
2-Jan-80
31-Dec-80
6-Jan-82
5-Jan-83
4-Jan-84
2-Jan-85
1-Jan-86
31-Dec-86
30-Dec-87
28-Dec-88
28-Dec-89

d)

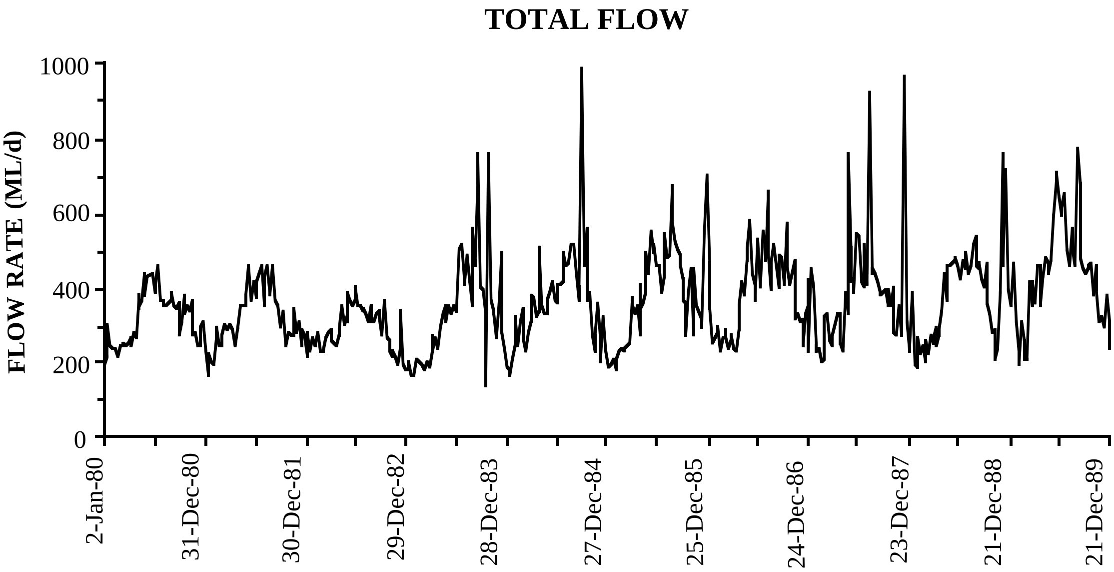

MURTCAIM
FLOW RATE (ML/d)
350
300
250
200
150
100
50
0
2-Jan-80
24-Dec-80
16-Dec-81
5-Jan-83
28-Dec-83
12-Dec-84
27-Nov-85
12-Nov-86
28-Oct-87
12-Oct-88
27-Sep-89

e)



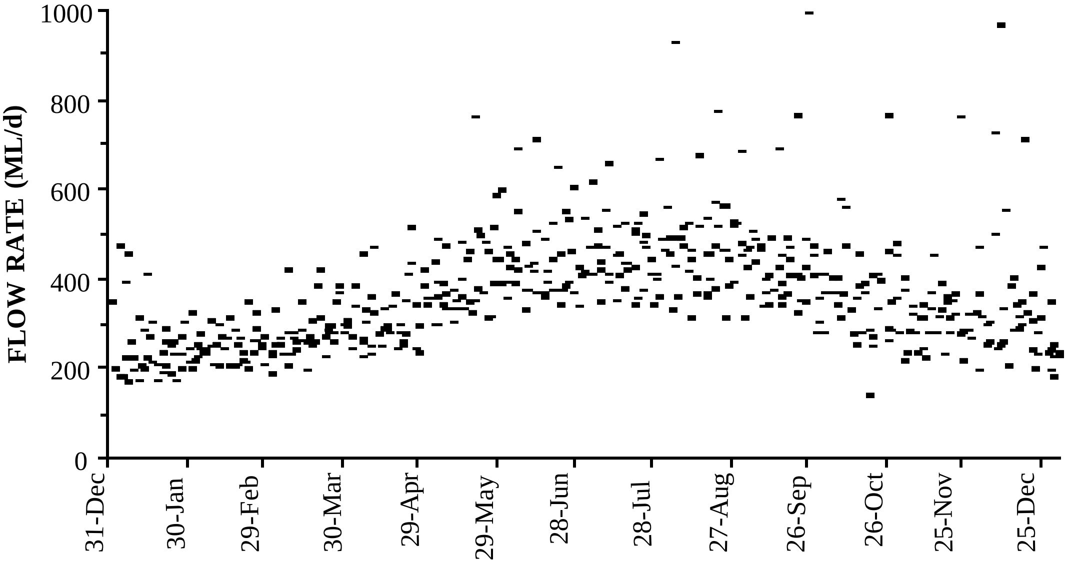
The combined outflow from the drains exhibits a strong seasonal cycle with peak discharges during winter/spring and lower discharges during summer/autumn (Figure 3).

Figure 3. Instantaneous flow rate (recorded weekly) of treated wastewater from all WTP outlets over the period 1/1/80 to 31/12/89.



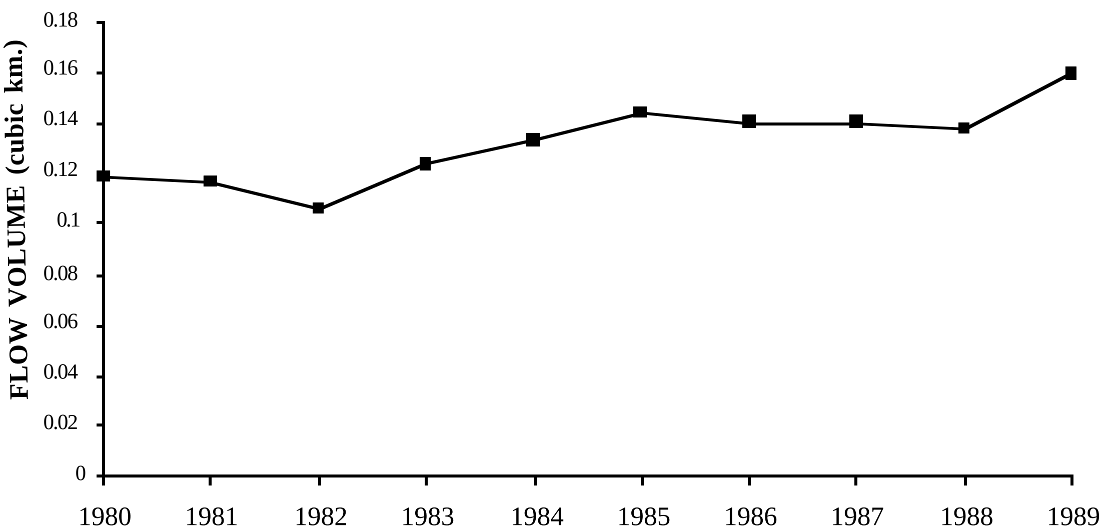
The distribution of flows throughout the year can best be examined by comparing all the flows versus day of the year throughout the 1980s (Figure 4). The seasonal signal shows a general increase in discharge during May through to September. It is also apparent that strongly increased flow, due to storm events, occurs mostly during late winter and spring.

Figure 4. Seasonal variation in discharge of treated effluent from WTP [scatterplot of weekly measurements made over the period 1/1/80 to 31/12/89 (n = 521)].



There is also major interannual variation in flow. The annual volume of water discharged from WTP during the 1980s varied by around 30% from a minimum in 1982 to a maximum in 1989 (Figure 5). The higher rates of flow continue into the 1990s.

Figure 5. Annual volume of treated effluent discharged from WTP for the years 1980 to 1992.



The flow records show short term (event), medium-term (seasonal) and long-term (interannual) scales of variation. Short term events of less than a week cannot be resolved in the 1980s data set, however there is daily data from the 1990s. Unfortunately there is no daily data on concentrations so although this data could be used to resolve water discharge patterns it does not aid resolving nutrient or toxicant discharges.

3.0 Nutrients

3.1 Nitrogen

Four forms of nitrogen are measured in the treated effluent discharged from WTP; ammonium, nitrate, nitrite and organic N. The concentrations of these all exhibit seasonal cycles, particularly ammonium whose concentrations are highest (20-30mg/l) in winter (Figure 6). This is thought to be the result of nitrification and denitrification processes in the WTP being faster in summer than in winter. The highest nitrate and nitrite concentrations occur in summer (Figures 7 and 8), presumably reflecting the nitrification necessary as a precursor to denitrification.

Figure 6. Seasonal variation in ammonium concentration in treated effluent discharged from WTP [scatterplot of weekly measurements made over the period 1/1/80 to 31/12/89 (n = 521)]

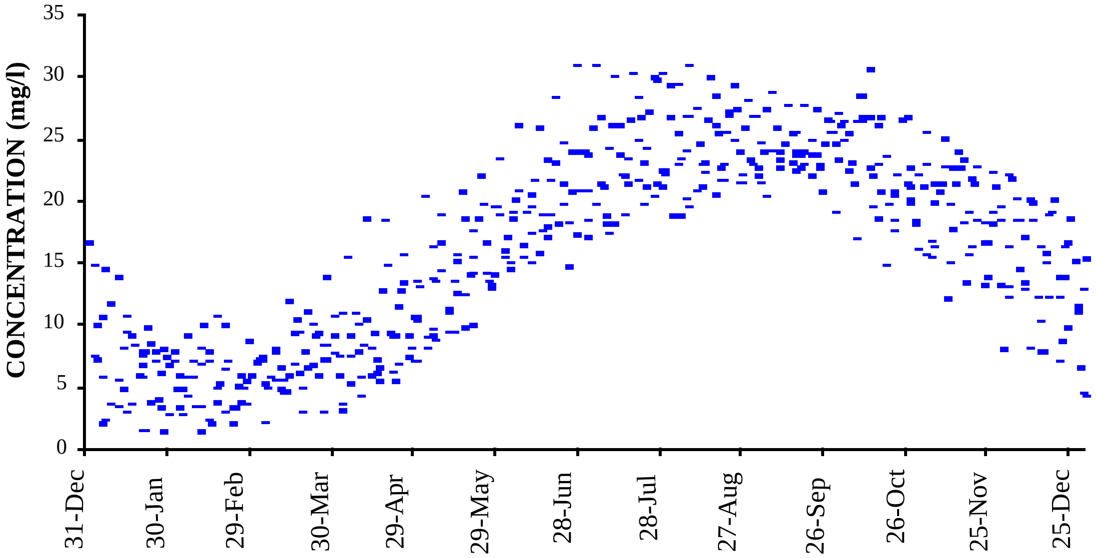


Figure 7. Seasonal variation in nitrate concentration in treated effluent discharged from WTP [scatterplot of weekly measurements made over the period 1/1/80 to 31/12/89 (n = 521)]

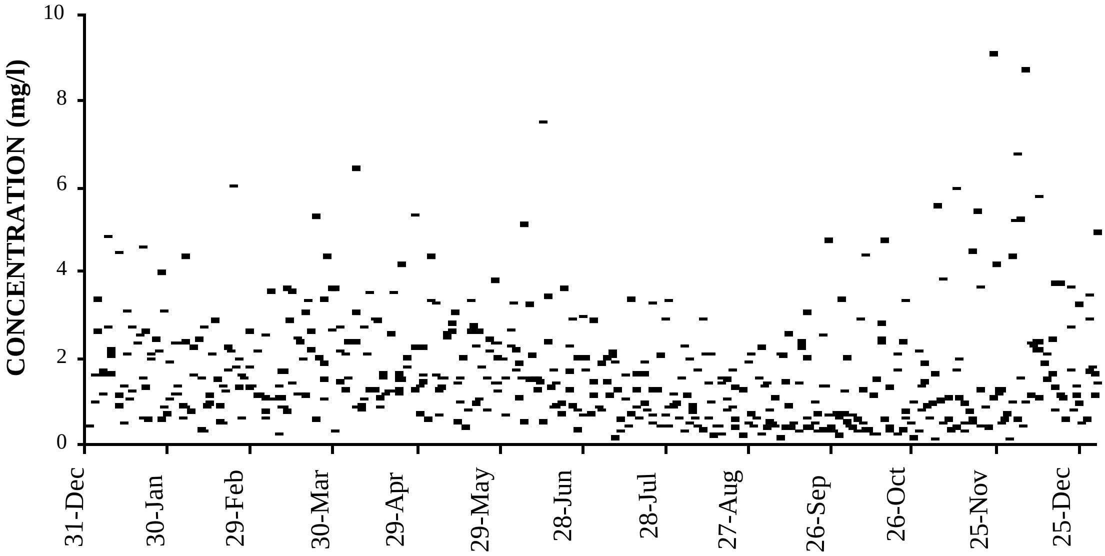
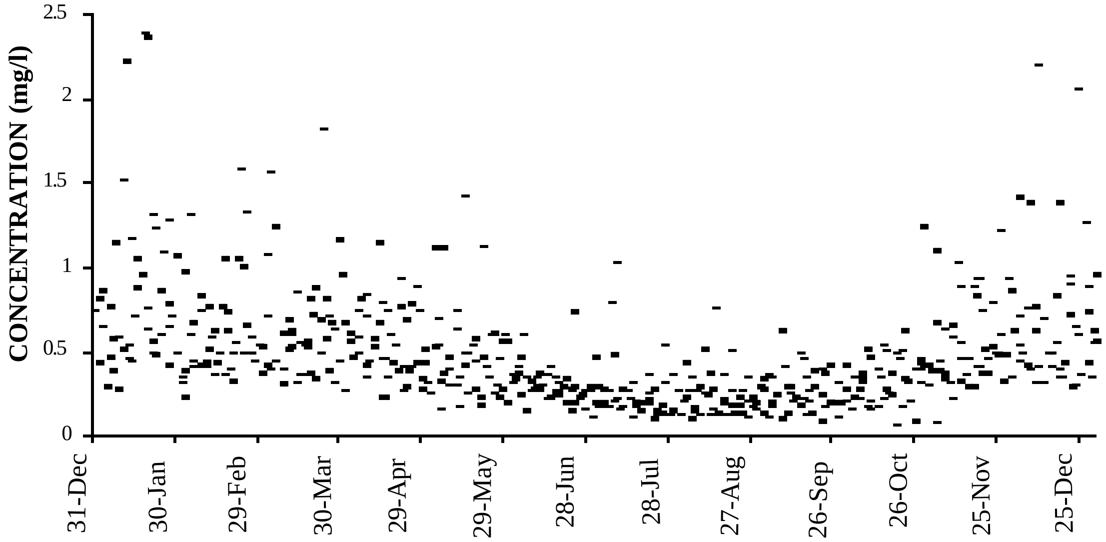
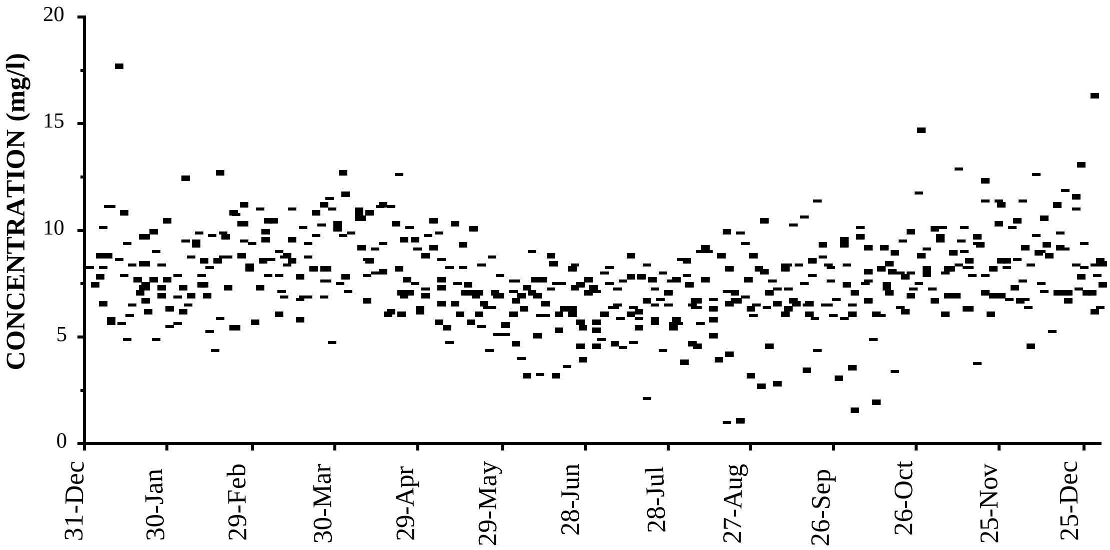


Figure 8. Seasonal variation in nitrite concentration in effluent discharged from WTP [scatterplot of weekly measurements made over the period 1/1/80 to 31/12/89 (n = 521)]



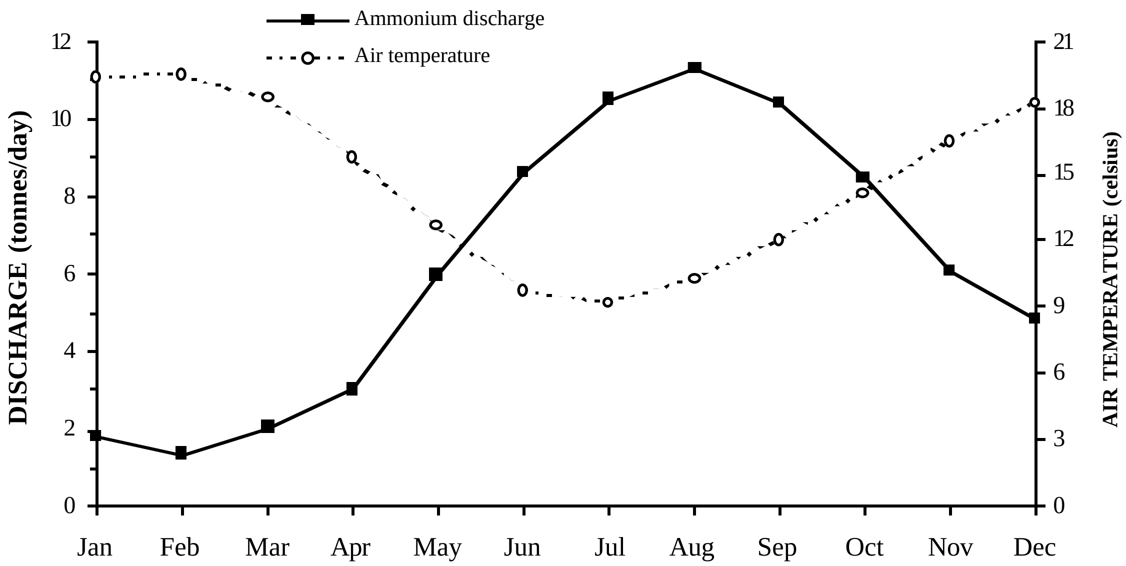
Organic nitrogen concentrations are slightly lower in winter (Figure 9), but this partly reflects dilution by higher discharge rates - a slightly higher load being carried in a much larger flow.

Figure 9. Seasonal variation in organic nitrogen concentration in treated effluent discharged from WTP [scatterplot of weekly measurements made over the period 1/1/80 to 31/12/89 (n = 521)]



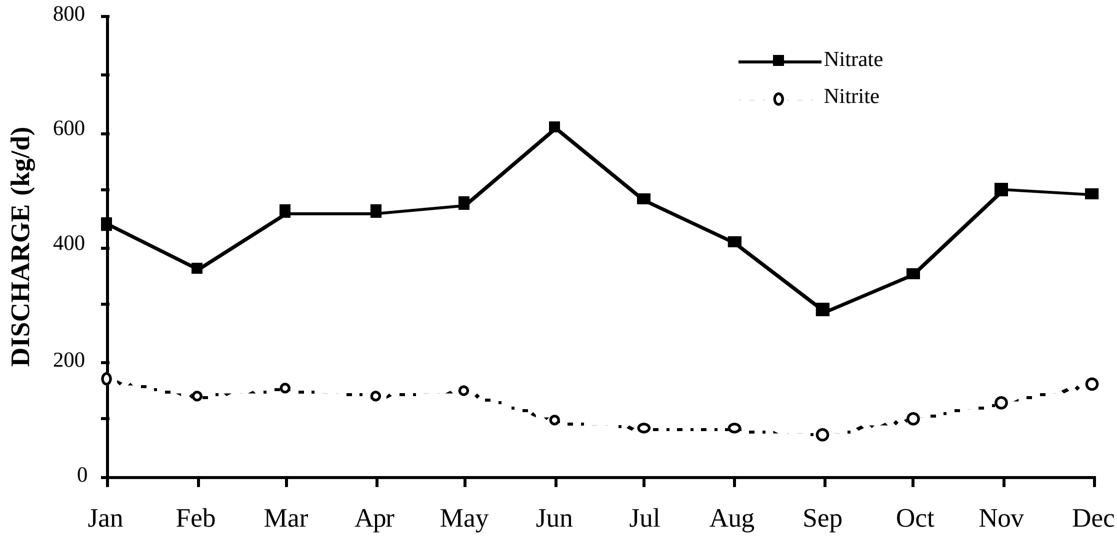
The discharge (concentration flow) of ammonium exhibits a very clear sine curve when overall monthly averages through the 1980s are plotted (Figure 10). Monthly average discharge rates for ammonium vary from about 2 tonnes/day during summer to more than 10 tonnes/day during winter/spring (see Appendix 1).

Figure 10. Average monthly discharge of ammonium from WTP during the 1980s and mean monthly air temperatures at Pt Cook over the period August 1985 to December 1990.



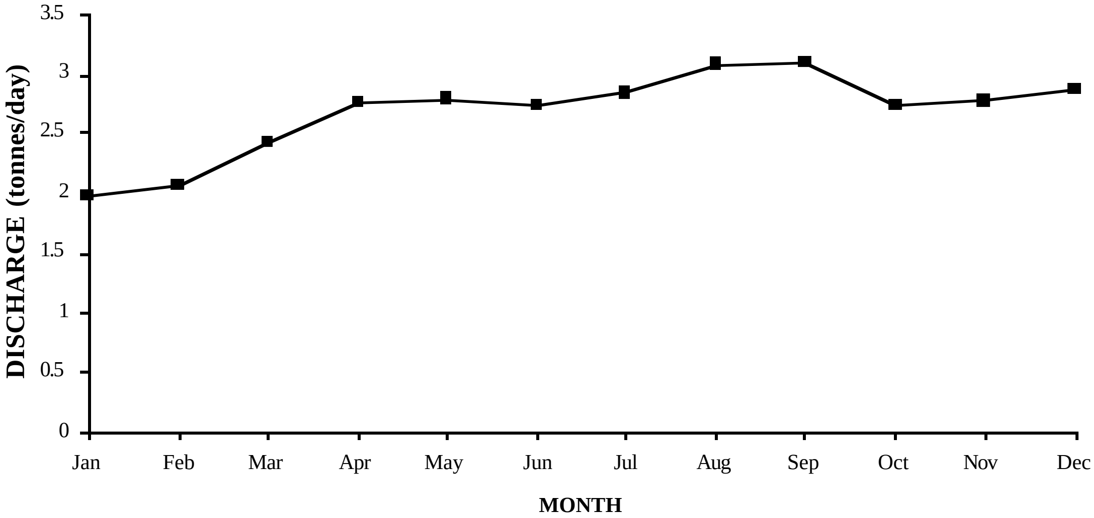
Discharge of nitrate from WTP is lowest during spring (< 300 kg/d) and highest in mid-winter with moderate rates prevalent during summer (Figure 11). Discharge of nitrite from WTP is lowest during winter and spring (120 kg/d). Note that these discharges are much lower than ammonium flux (although still significant as a proportion of total nitrogen in summer).

Figure 11. Average monthly discharge of nitrate and nitrite from WTP during the 1980s



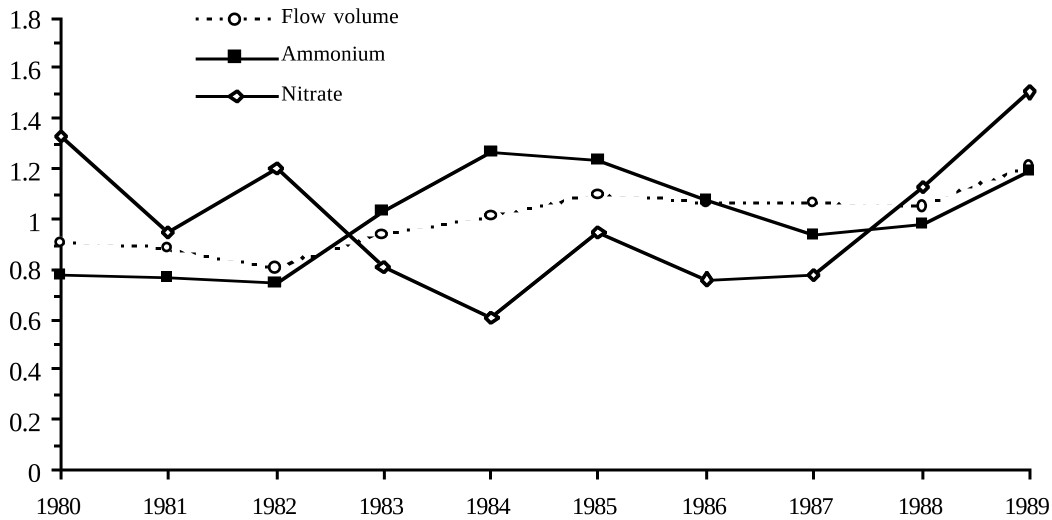
The reduced concentrations of organic N observed in winter (Figure 9) are compensated for by increased flow. Discharge of organic N is thus higher in winter and spring than during the summer minimum by up to 50% (Figure 12).

Figure 12. Average monthly discharge of organic nitrogen from WTP during the 1980s.



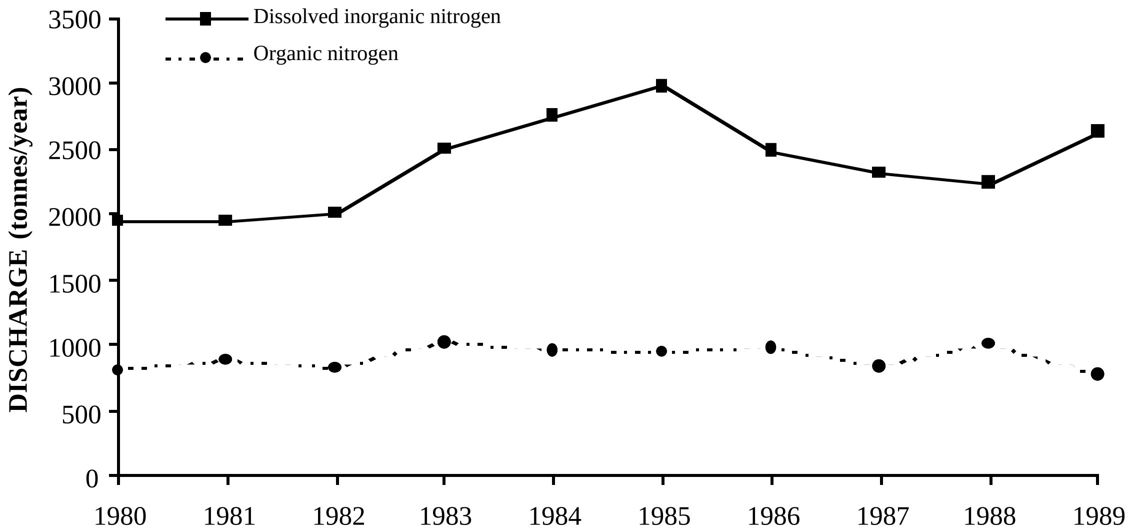
Ammonium discharge at the end of the 1980s was about 40% higher than that at the beginning (Figure 13). However the highest ammonium discharge occurred in the mid 1980s. This was almost 50% higher than in 1980. The peak discharge 1984 corresponded to a period of rapidly increasing flow, not the peak of flow which levelled out in 1985. The normalisation factor (i.e. average 1980's value) is 0.138 km^3 y^{-1} for flow, and 6.8 and 0.52 tonnes d^{-1} for NH_3 and NO_3 respectively.

Figure 13. Normalised annual flow rate and discharge of ammonium and nitrate from WTP during the 1980s.



The overall trend of DIN ($NH_3 + NO_3 + NO_2$) and organic N discharge as used for model forcing functions shows little change in organic N throughout the 1980s. Although there was a net increase in DIN discharge, this was small relative to interannual variation (Figure 14).

Figure 14. Annual discharge of organic and dissolved inorganic nitrogen from WTP during the 1980s.



3.2 Phosphorus

There are two measures of phosphorus discharge from WTP; orthophosphate and total P. Total P concentrations are only slightly higher (a difference of 1-2 mg/l) than orthophosphate, and both show similarly slight seasonal variation with lowest values in autumn when flow rises and highest values during spring (Figures 15 and 16).

Figure 15. Seasonal variation in orthophosphate concentration in treated effluent discharged from WTP [scatterplot of weekly measurements made over the period 1/1/80 to 31/12/89 (n=521)]

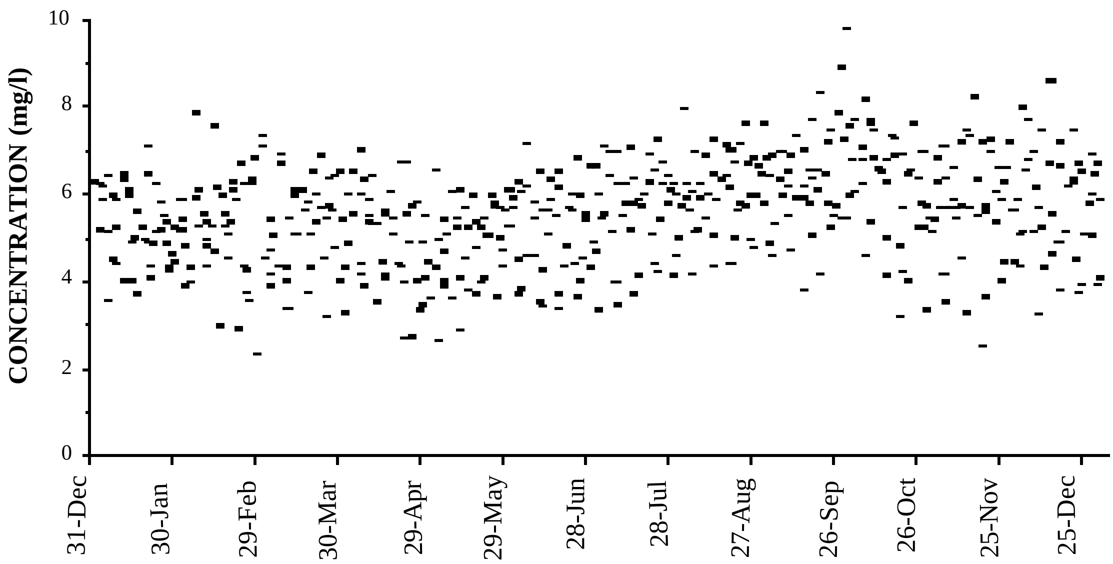
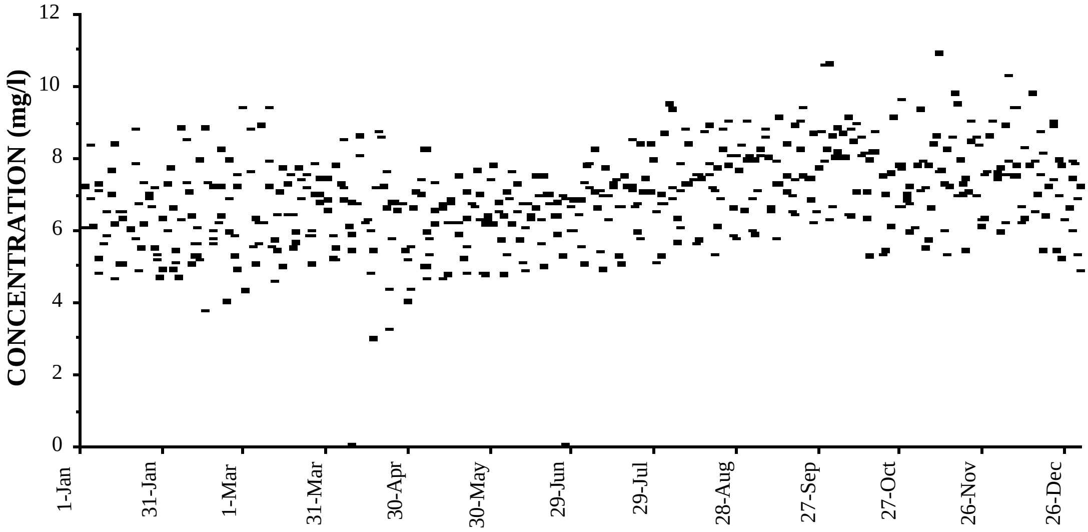
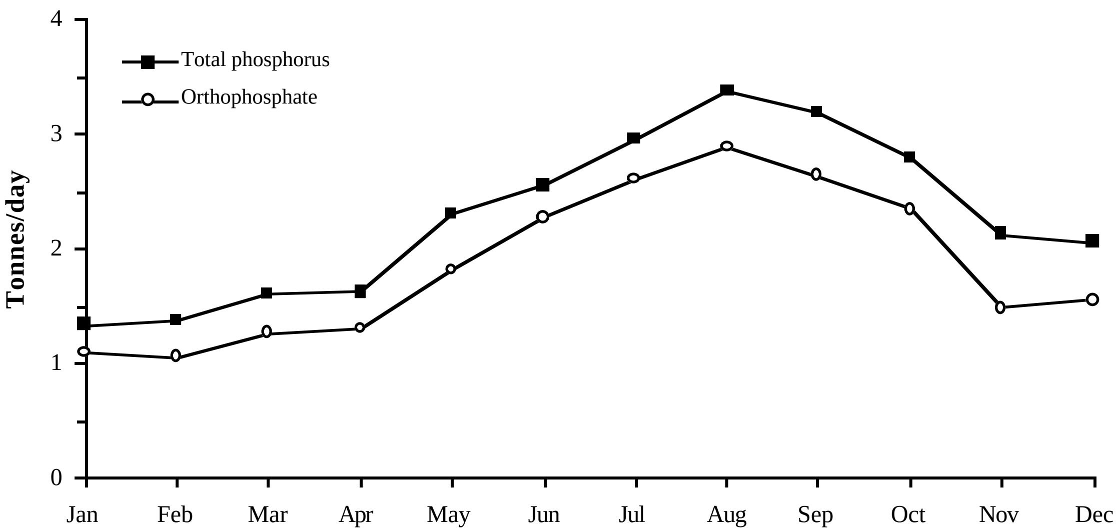


Figure 16. Seasonal variation in total phosphorus concentration in treated effluent discharged from WTP [scatterplot of weekly measurements made over the period 1/1/80 to 31/12/89 (n=521)]



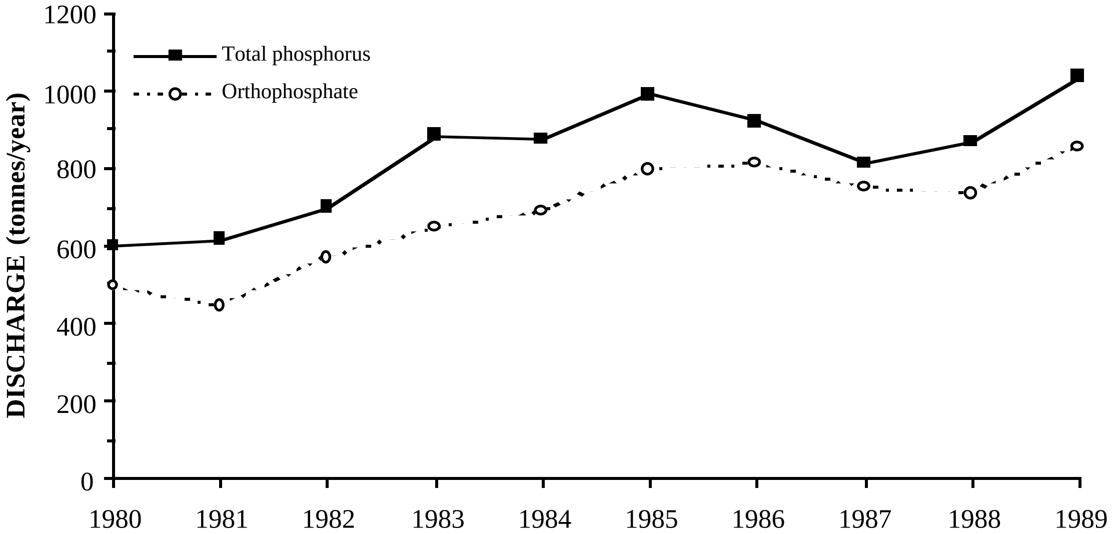
The absence of strong seasonal variation in orthophosphate and total P concentration indicate that the discharges of these correspond closely to water flow, with a maximum in late winter (Figure 17).

Figure 17. Average monthly discharge rates of orthophosphate and total phosphorus from WTP.



Total phosphorus discharges increased by almost 70% over the 1980s to about 1000 tonnes/year in 1989 (Figure 18). Increase was fairly linear, although total P appeared to be larger during the period of higher flows in the mid 1980s (see Figure 3). During the 1990s (not shown) discharge of total P stabilised at about 1000 tonnes/year.

Figure 18. Annual discharge of orthophosphate and total phosphorus from WTP during the 1980s.



3.3 Organic carbon

Annual discharges of dissolved organic carbon from the WTP declined during the 1980s (Figure 19). Annual outputs of 4000-5000 tonnes/y during the late 1980s correspond to a Bay loading of about 0.5 m.mol.C/m^{-2}/d. This may be contrasted with the probable turnover of carbon through phytoplankton production of 6 m.mol.C/m^{-2}/d. As organic carbon is released at higher rates in winter (Figure 20), when phytoplankton production is probably low, the relative importance of heterotrophy in the Bay may increase in winter.

Figure 19. Annual discharge of dissolved organic carbon from WTP during the 1980s.

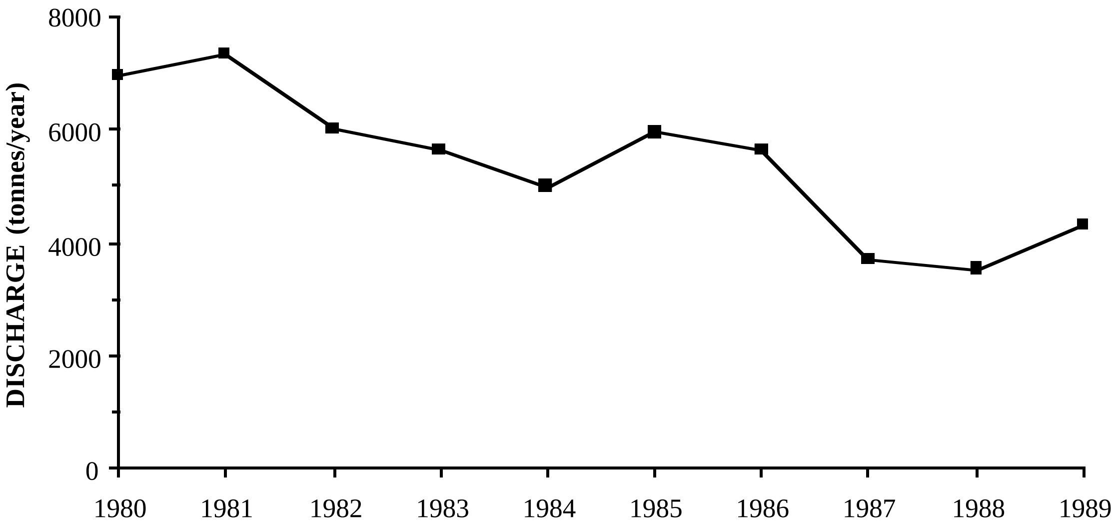
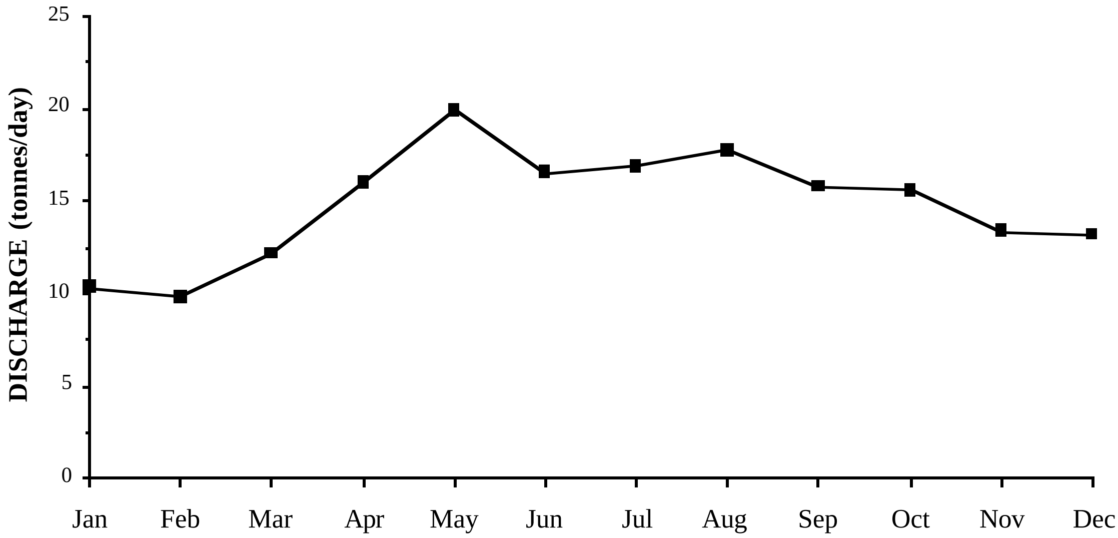


Figure 20. Average monthly discharge rates of organic carbon from WTP during the 1980s.

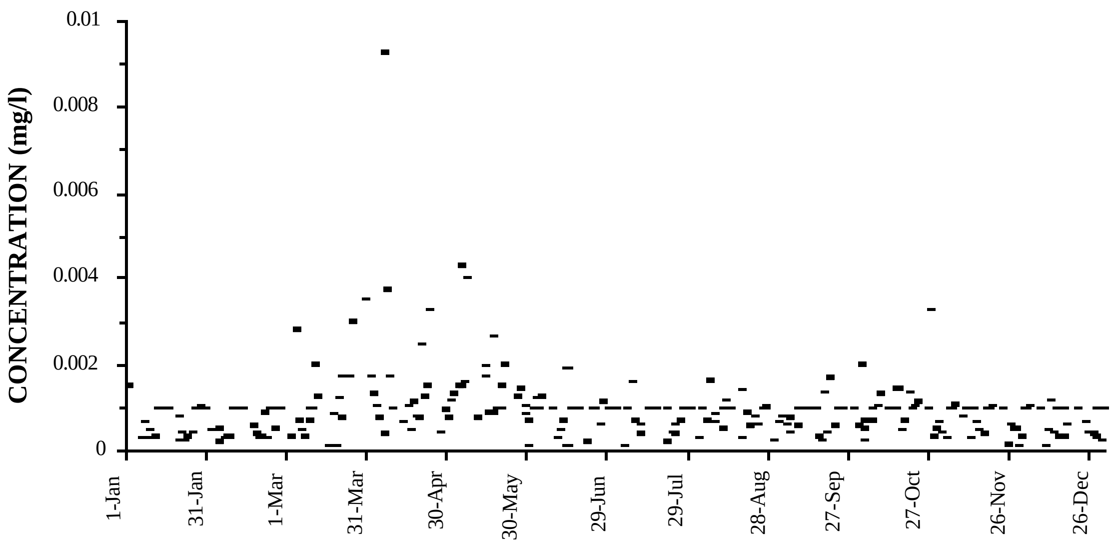


4.0 Metals

4.1 Metal concentrations

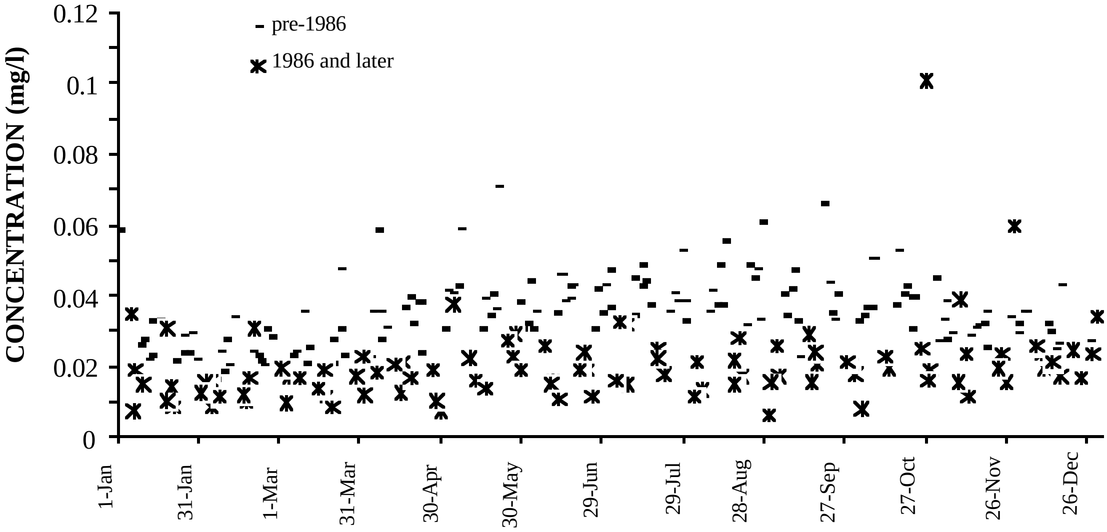
Information is available on the discharge of several metals from WTP into Port Phillip Bay. These metals are Cd, Cr, Cu, Fe, Hg, Ni, Pb and Zn. Two of these (Cd and Hg) proved too close to their limits of detection for the data to be of much use (Figures 21 and 25).

Figure 21. Seasonal variation in cadmium (Cd) concentration in effluent discharged from WTP [scatterplot of fortnightly measurements made over the period 1/1/80 to 31/12/89 (n=261)]



The chromium signal is rather noisy (Figure 22). Chromium outputs were greatly reduced in 1986 (see Figures 22 and 32) so there are two different (pre- and post- 86) annual cycles superimposed in Figure 22.

Figure 22. Seasonal variation in chromium (Cr) concentration in effluent discharged from WTP [scatterplot of fortnightly measurements made over the period 1/1/80 to 31/12/89 (n=261)]



Elevated concentrations of both copper (Figure 23) and iron (Figure 24) in treated effluent discharged from WTP are evident during autumn with a smaller elevation during spring.

Figure 23. Seasonal variation in copper (Cu) concentration in effluent discharged from WTP [scatterplot of fortnightly measurements made over the period 1/1/80 to 31/12/89 (n=261)]

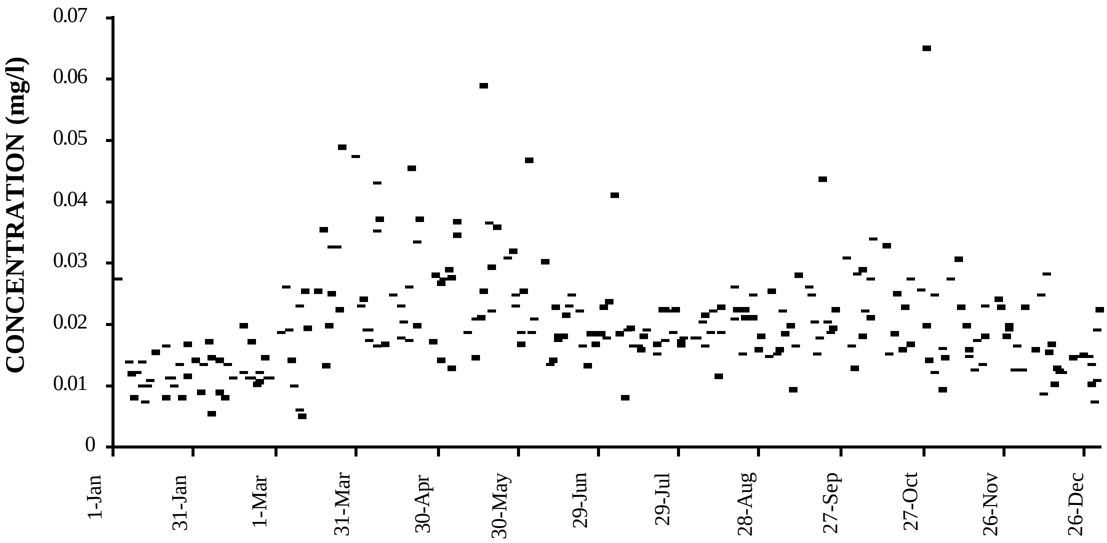
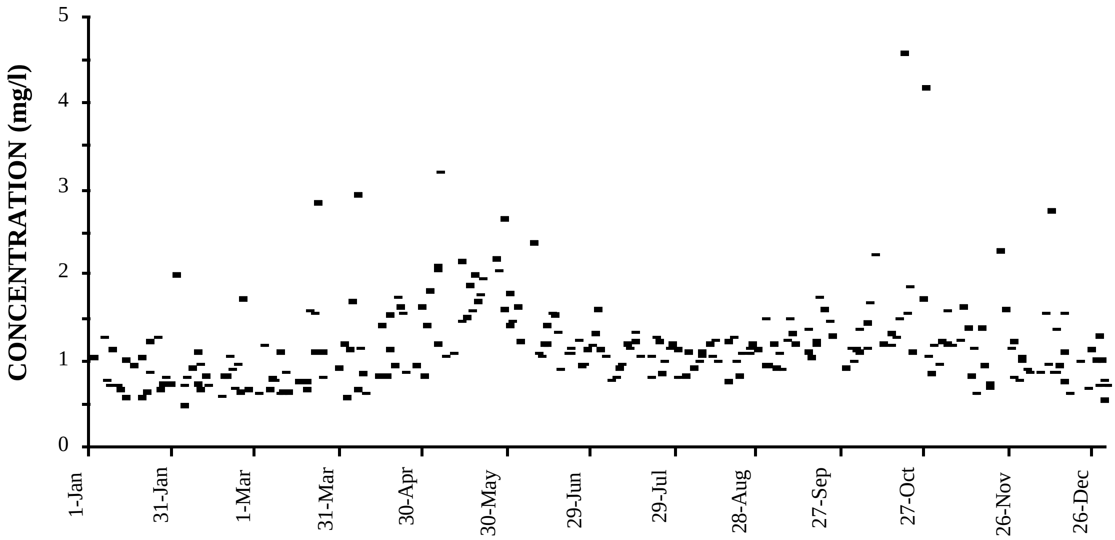
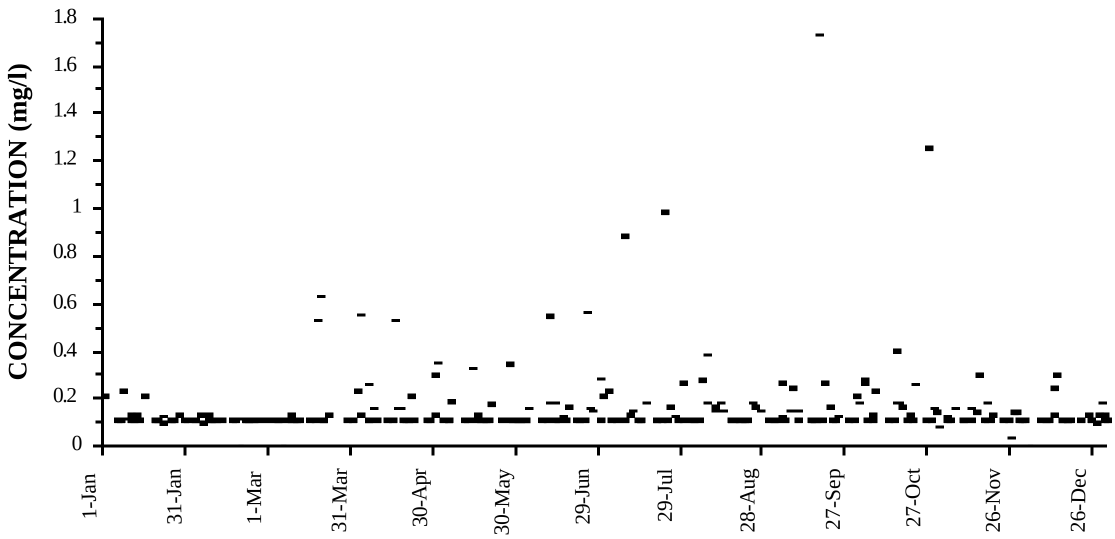


Figure 24. Seasonal variation in iron (Fe) concentration in treated effluent discharged from WTP [scatterplot derived from fortnightly measurements made over the period 1/1/80 to 31/12/89 (n=261)]



Mercury is rarely above the limit of detection (Figure 25). On those occasions that it is, it would appear that many such measurements are questionable. For example one value is 1000.2 μg/l (omitted during derivation of Figure 25) when its neighbours are just 0.2 μg/l. These anomalies totally confuse attempts at analysis.

Figure 25. Seasonal variation in mercury (Hg) concentration in treated effluent discharged from WTP [scatterplot derived from fortnightly measurements made over the period 1/1/80 to 31/12/89 (n=261)]



Elevated concentrations of nickel (Figure 26), lead (Figure 27) and zinc (Figure 28) in treated effluent discharged from WTP are evident during autumn and spring.

Figure 26. Seasonal variation in nickel (Ni) concentration in effluent discharged from WTP [scatterplot of fortnightly measurements made over the period 1/1/80 to 31/12/89 (n=261)]

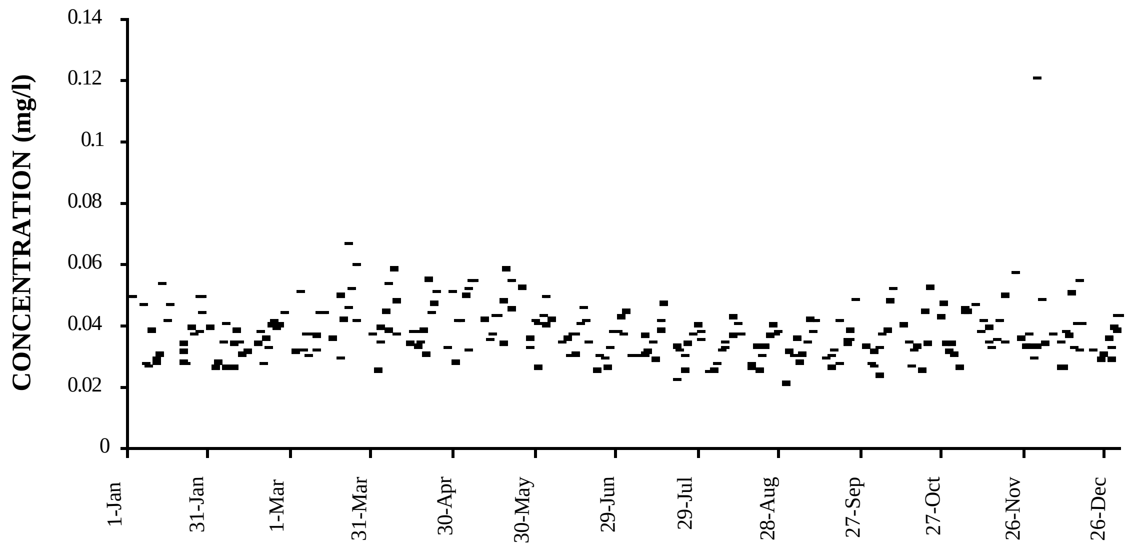


Figure 27. Seasonal variation in lead (Pb) concentration in effluent discharged from WTP [scatterplot of fortnightly measurements made over the period 1/1/80 to 31/12/89 (n=261)]

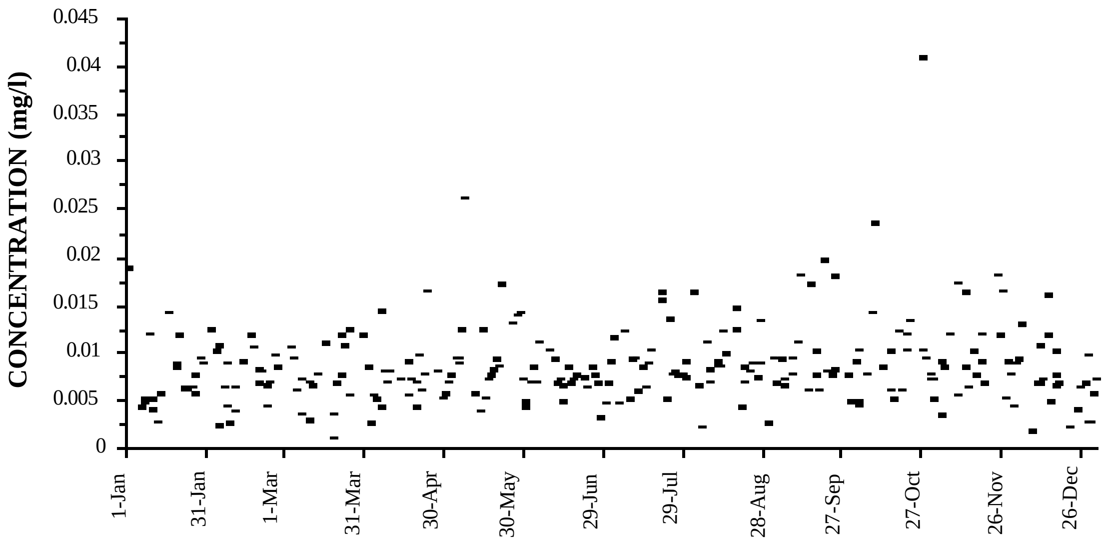
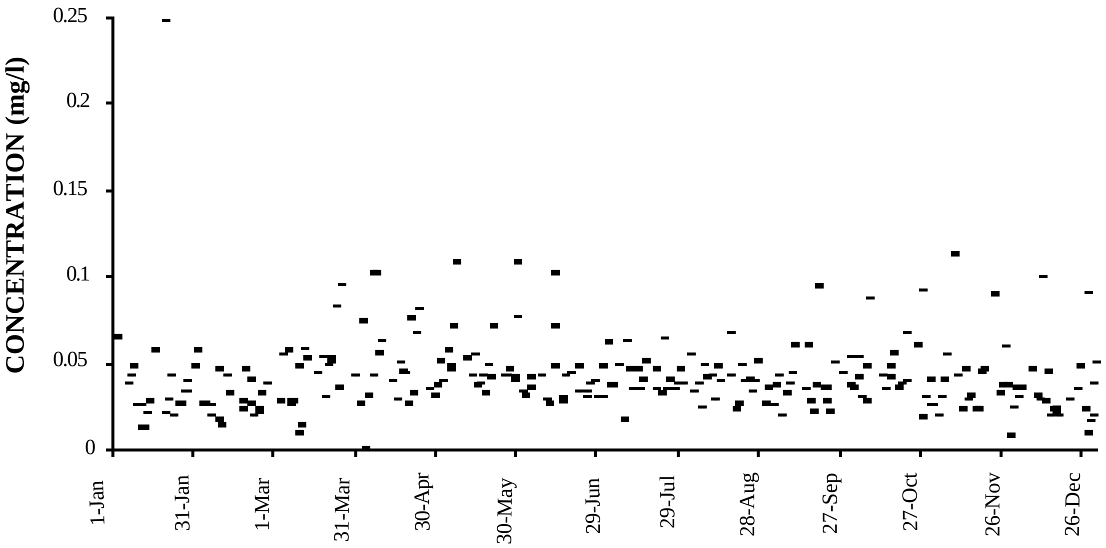


Figure 28. Seasonal variation in zinc (Zn) concentration in effluent discharged from WTP [scatterplot of fortnightly measurements made over the period 1/1/80 to 31/12/89 (n=261)]



Concentrations of metals in WTP discharges are generally slightly in excess of ANZECC guidelines for ambient levels in receiving waters (see Batley 1992). Some chromium discharges in the early 1980s were 80 times guideline levels. Generally discharges slightly in excess of guideline concentration of lead, iron and zinc will very rapidly dilute to safe levels. Nickel and copper could be a problem locally. Discharge of copper from WTP has been up to 16 times the safety limit and is regularly five times the limit. Chromium is a special problem because whilst discharges have been reduced, the average concentration in effluent during the late 1980s was still ten times the recommended level. As highest concentrations generally occur during autumn (Figure 22) when flow rates start to rise, but are still very low, discharges may not be as serious as Table 1 might imply. Some metals also precipitate out as salinity rises on mixing of effluent with bay water again reducing damage to the aquatic biota of the Bay. Free copper ions, for example, are very sensitive to salinity (Bryan and Langston 1992).

Table 1: Ratio of Metal Concentration to ANZECC Guideline Level

	Pb	Ni	Cr	Cu	Zn
1980	2.6	3.0	20.5	4.9	1.2
1981	1.9	3.0	17.3	4.8	1.0
1982	1.5	3.1	19.4	4.1	0.8
1983	1.4	2.5	17.5	4.0	0.7
1984	1.6	2.6	19.0	3.9	0.8
1985	1.4	2.4	15.5	4.1	0.9
1986	1.7	2.0	8.0	3.3	0.8
1987	1.5	2.3	10.2	3.9	0.6
1988	1.7	2.4	11.6	4.8	1.0
1989	2.0	2.2	11.0	4.4	1.3

4.2 Metal discharges

Metal discharges correlate to some extent (Table 2). Mercury and cadmium are excluded since these metals are frequently at the limits of detection and correlation is not very meaningful. Copper correlates best with all other metals and so could be used as a representative metal if monitoring were reduced.

Table 2: Metal Discharge Correlation Coefficients

	Cr	**Cu**	**Fe**	**Ni**	**Pb**	**Zn**
Cr	1	.376	.344	.408	.417	.192
Cu	.376	1	.459	.565	.499	.512
Fe	.344	.459	1	.242	.264	.297
Ni	.408	.565	.242	1	.384	.339
Pb	.417	.499	.264	.384	1	.382
Zn	.192	.512	.297	.339	.382	1

Mercury and cadmium are discharged at or near their limits of detection, although cadmium is elevated in early autumn. Therefore analysis of seasonal fluxes of these metals is not possible. Copper and lead are discharged at detectable levels and therefore analysis of monthly discharges is possible. This shows rates of discharge in autumn, winter and summer to be roughly in the ratio 3:2:1 (Figure 29). The pattern is repeated at higher values for Cr, Ni and Zn (Figure 30) and at much higher levels for iron (Figure 31)

Figure 29. Seasonal variation in lead and copper discharged in treated effluent from WTP [derived from mean fortnightly measurements made over the period 1/1/80 to 31/12/89 (n=261)]

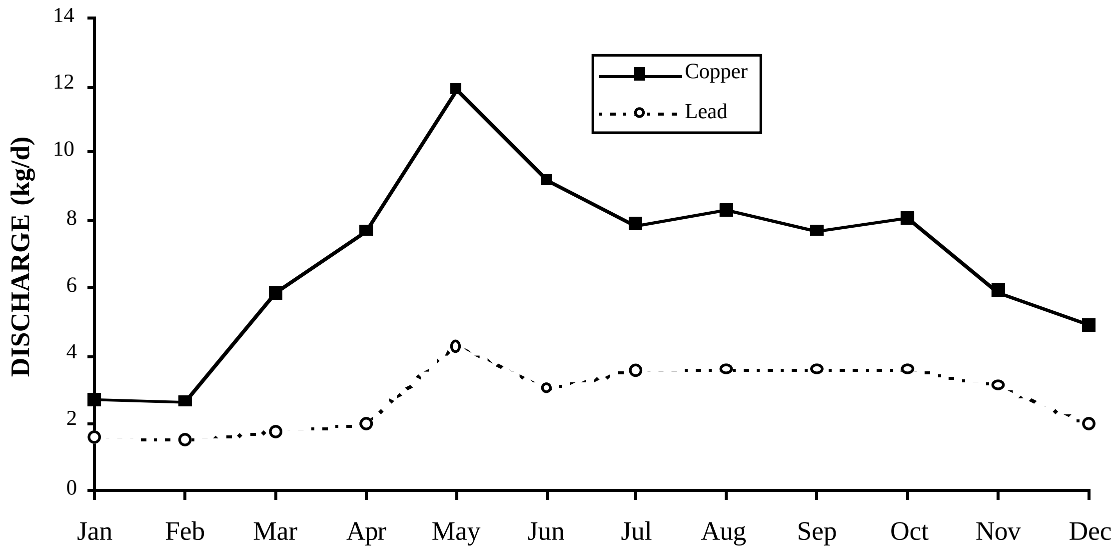


Figure 30. Seasonal variation in zinc, nickel and chromium discharged in treated effluent from WTP [derived from mean fortnightly measurements made over the period 1/1/80 to 31/12/89 (n=261)]

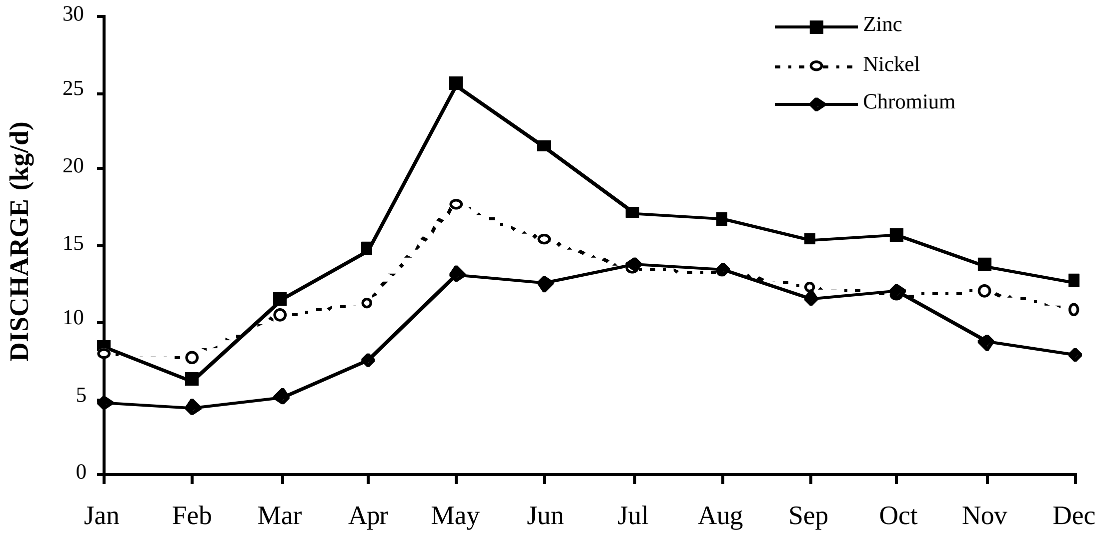
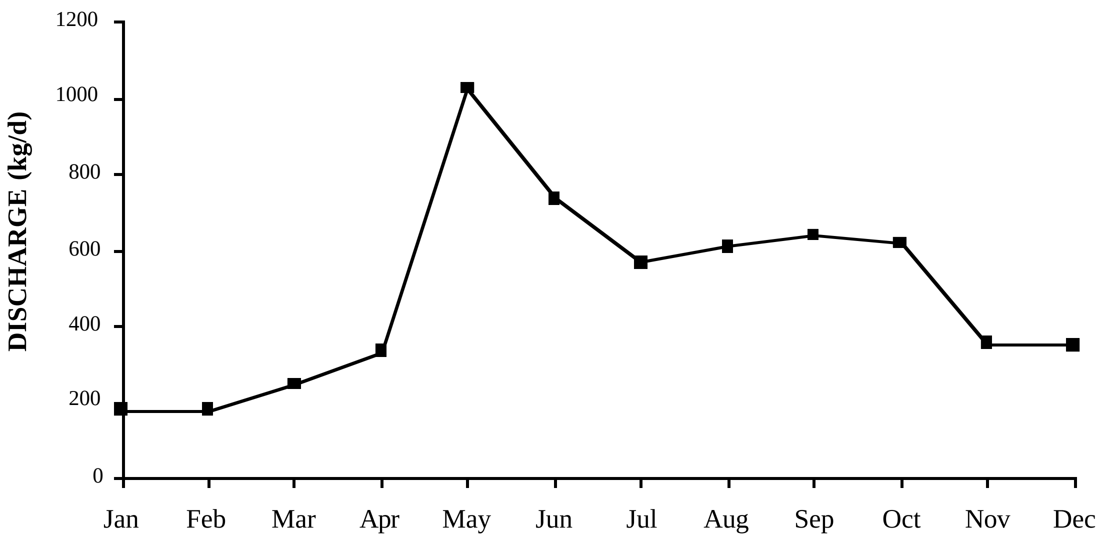


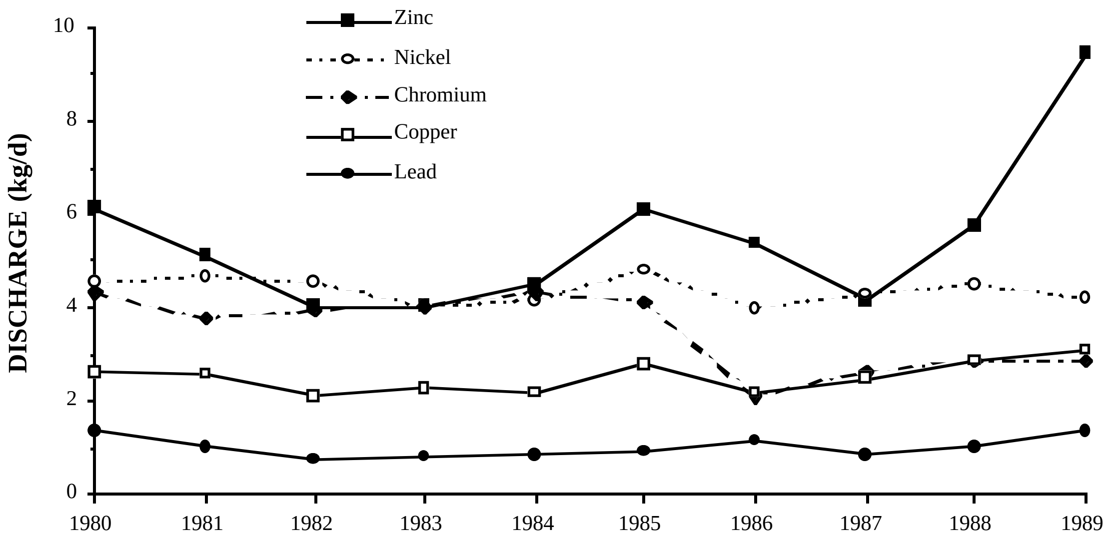
Figure 31. Seasonal variation in iron discharged in treated effluent from WTP [derived from mean fortnightly measurements made over the period 1/1/80 to 31/12/89 (n=261)]



Annual discharges of lead, copper and nickel were fairly constant throughout the period at approximately 1.1, 2.7 and 4.9 tonnes/year respectively (Figure 32). Chromium discharges declined in 1986 from previous levels of about 4.5 tonnes/year to levels of 2-3 tonnes/year. Discharges of zinc increased from 4 to 10 tonnes/year over 1987-9. Even when the zinc discharges were so elevated the concentration of zinc in effluent was nearer to ANZECC guidelines than any other metal. These discharge estimates for zinc are considerably lower than previously estimated (see Batley 1992) because concentrations were highest when flow started to increase, which is, by definition, the time of near minimum flow. There is no evidence of a systematic increase as recently suggested (Batley 1992). This analysis was extended to 1992 (not shown) because zinc discharges rose rapidly in 1987-9.

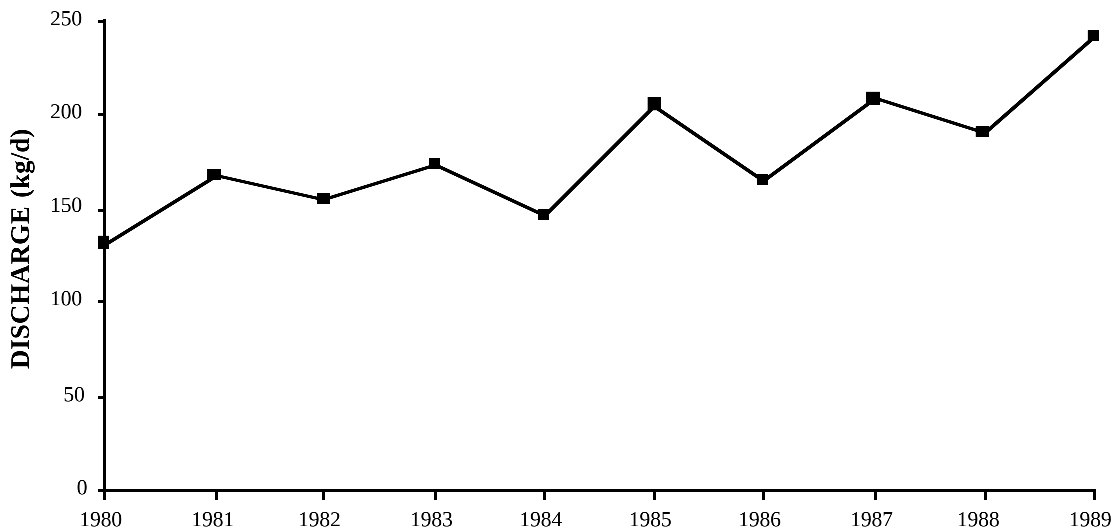
However, this proved to be a short lived peak with zinc discharges returning to lower levels (about six tonnes/year) by 1993. Several metals exhibited sharp declines in discharge in the 1990s presumably reflecting changes in WTP management practices or in industrial discharge.

Figure 32. Annual discharge of various heavy metals from WTP.



The annual discharge of iron from WTP increased steadily during the 1980s from about 150 to 200 tonnes/year (Figure 33). However iron is not toxic in seawater, so this does not present a problem.

Figure 33. Annual discharge of iron from WTP during the 1980s.



5.0 Annual Discharges Summarised

The average annual discharges for the 1980s are tabulated in Table 3 and compared with estimates for other surface inputs (NSR Environmental Consultants 1993). WTP is clearly the major source of nutrients, although inputs from the Yarra may be underestimated (Skyring *et al*. 1992). WTP is also a significant source of chromium, copper and nickel. However it should be noted that many nutrients or metals show considerable interannual variation, and a long-term trend in the case of lead and iron (increase) and organic carbon (decrease). All components show some seasonal variation in discharge.

Table 3: Mean Annual Discharges

	WTP	Yarra	Others
Flow (ML/y)	150000	486000	273000
Nutrients (T/y)			
NH_3	2386		
NO_3	198		
NO_2	55		
DIN	2639	458*	530*
Organic N	1019	590	1106
Orthophosphate	759		
Total P	941	114	374
Organic C	5957		
Metals (T/y)			
Cr	3.9	7.8	4.8
Cu	2.7	6.6	8
Fe	180	2373	1235
Ni	4.9	6.3	2.9
Pb	1.1	19	11
Zn	5.8	63	58
*** = Oxidised N**			

High metal levels in the tissues of mussels tend to occur either near the Yarra river discharge in Hobsons Bay or in Corio Bay, but there does not appear to be a problem off-shore from WTP (Phillips *et al*. 1992). However a more detailed analysis of Cr , Cu or Ni concentrations in fauna near the Werribee shoreline might prove instructive.

6.0 Conclusions

The available data shows that discharges of nutrients from WTP increased substantially over the 1980's. Discharge of phosphorus increased linearly whereas DIN discharge was lower in 1989 than in 1984-85. Whilst the volume of effluent discharged from WTP also increased through the 1980s, the amount of dissolved organic carbon discharged declined substantially. Metal discharges declined or remained constant except for a temporary increase in zinc discharge in the late 1980s. The annual discharge of chromium was halved in the mid 1980s and remained at a reasonably constant level for the remainder of the decade.

Previous analyses based on the product of average flow and average concentration fail to account for the fact that concentrations and flows vary with different patterns. This is particularly relevant to metals whose maximum concentrations occur just when flows start to increase, i.e. when flows are near minimum. This approach caused Coller *et al*. (1991) to substantially overestimate outputs in 1989-90, which led Batley (1992) to conclude that metal outputs were increasing when in fact they were decreasing.

Another thing that becomes apparent from this analysis is that concentrations of Hg and Cd are frequently below the detection limits of the methods used, and therefore statistical analysis of results for these metals is not very meaningful. In the case of Hg, errors in recording make the data even more difficult to use. Data, if used carefully, may be valid for the autumn period of high concentration discharge. WTC should decide either to abandon analyses of these metals or to revise its measurement techniques. Since even low levels of mercury can cause problems (Bryan and Langston 1992) the latter approach seems more sensible.

7.0 References

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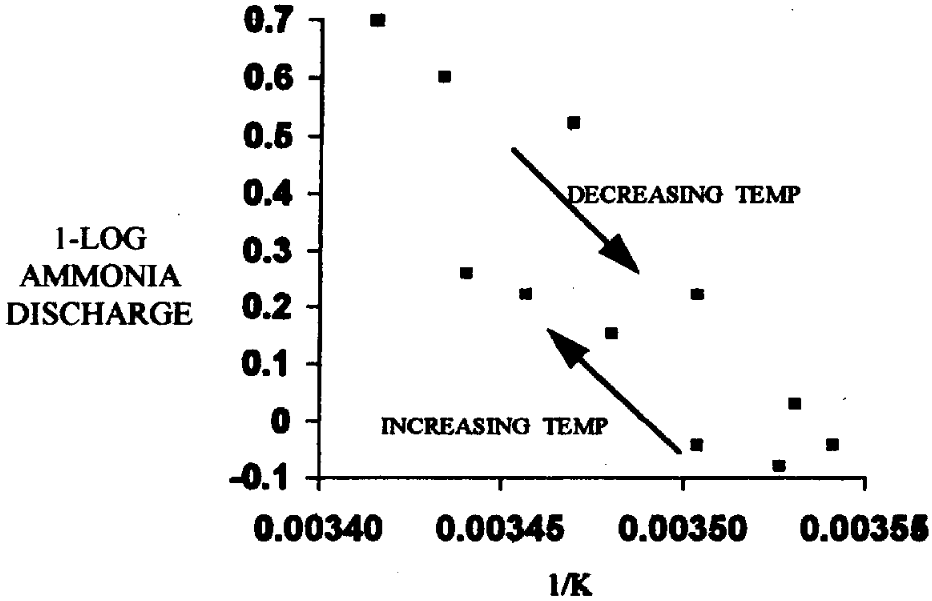
APPENDIX 1. Arrhenius plot of 1/K vs 1-log ammonia discharge rate in tonnes per day.



The seasonal factors which may affect ammonia oxidation rates are: low pH, anoxia, high concentrations of amino nitrogen (at least in culture), cytochrome toxicants or temperature. The Arrhenius plot of 1/K vs 1-log ammonia discharge rate in tonnes per day is a negative linear regression. This indicates that nitrification is rate limited by seasonal temperature changes in a predictable manner with a Q_{10} of 5. This value seems high but sulfate reduction Q_{10} values in coastal sediments are 2 to 4.