ISSN 1039-
3218

Surface Inputs into Port Phillip Bay (excluding the Yarra River and WTC)

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Technical Report No. 12

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October 1993

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EXECUTIVE SUMMARY

The loads of nutrients, toxicants and suspended solids entering Port Phillip Bay must be known to model physical and chemical processes in the Bay. Potentially relevant data which have been collected by a number of Victorian Government agencies have been analysed to estimate these loads.

The main database is that established by the Victorian Environment Protection Authority's 1979-81 sampling program, in which 196 sites representing a large number of rivers and drains discharging into the Bay were sampled and analysed for total P, Kjeldahl N, oxidised N (Nox), non-filterable residue (NFR), surfactants, Pb, Hg, Zn, Cd, Cu, As, Cr(t), Ni and Fe. In this report, data from 108 sites have been evaluated; the remaining sites were excluded because they were either upstream or within the Yarra River catchment. Discharges from the Werribee Treatment Complex and other EPA-licensed discharges have also not been included in the database.

The resulting water quality data are typical of, or lower than, results obtained in other studies of urban drainage in Melbourne. For example, median total P values range from 0.04 to 2.5 mg/L, while corresponding ranges for NFR and Cu are 3 to 63 mg/L and 0.9 to 350 μg/L respectively. Complex relationships exist between water quality variables and discharge. Using the data for Patterson River as an example, nutrients such as total P, Kjeldahl N and Nox show increasing concentrations with initial increases in flow. This then changes to constant or slightly decreasing concentrations with further increases in flow. Other variables such as NFR show a clear increase in concentration with increasing flow, while a third group of variables, such as Cd and Ni, exhibit no apparent relationship between concentration and flow.

Some relationships confirm expectations. For example, Fe is related to NFR, which in turn increases in concentration with increasing flow. However, NFR is not well-correlated with either nutrients or most of the other metals, indicating that in this system NFR is not a good predictor of other water quality variables.

Loads were calculated on the basis of flow-weighted mean concentrations and the average daily flow at each site, which was obtained from the discharge estimates made at the time of sampling. Calculated annual inputs (t/year) into the Bay during the sampling period were:

- total P - 367
- Kjeldahl N - 1083
- oxidised N - 522
- NFR - 13822
- Surfactants - 53
- Pb - 11
- Hg - 0.04
- Zn - 57
- Cd - 0.14
- Cu - 8
- As - 0.9
- Cr(t) - 4.8
- Ni - 2.8
- Fe - 1214

The ten top-ranked sites contributed between 75 and 94% of the loads entering the Bay from the 108 sites which were evaluated. Of these, the Patterson River/Mordialloc Main Drain system was the major contributor. For example, Patterson River at Wells Road contributed 30% of the total load of total P, 30% of the Kjeldahl N, 48% of the NFR and 15 to 29% of the metal loads. When combined with the Mordialloc Main Drain and Mordialloc Settlement drain (which are hydrologically linked), these contributions increase to 64% of the total P, 62% of the Kjeldahl N, 61% of the NFR and 35 to 75% of the metal loads (excluding Fe).

When the same database has been used to estimate loads entering the Bay from the Yarra River, non-Yarra River inputs into the Bay account for 36% of the flow and 27% (NFR) to 77% (total P) of pollutant loads.

The estimated total flow for the Patterson River/Mordialloc Main Drain system during the 3-year sampling period was 318,000 ML, based on more than 300 flow measurements made at the time of sampling. This agreed well with the calculated inflows of 308,000 ML to the system from Mile, Dandenong and Eumemmerring creeks, plus the discharge from Melbourne Water's Wastewater Treatment Plant at Dandenong. The sampling was therefore likely to be representative for this system. A quantitative assessment of the errors likely to be associated with the sampling regime in terms of non-representativeness shows that the upper 95% confidence limit is generally less than 1.5 times the load estimate.

Comparison of the water quality data obtained in 1979-81 with more recent data (1989) for a number of sites shows that the older data still appears to be relevant to the present situation. For the Patterson River/Mordialloc Main Drain system, the current quality and quantity of the discharge from the Wastewater Treatment Plant at Dandenong, which is a major contributor to this system, has not changed substantially since 1979-81. However, loads from this system are expected to decrease when discharge stops in the near future.

Relationships between rainfall and pollutant loads for the major load-contributing sites have been investigated using multiple linear regression techniques on untransformed data. Although flow control is exercised in the Patterson River/Mordialloc Main Drain system, the sites have been treated separately. Regression equations for the Patterson River data exhibit R^2 values greater than 0.5 for NFR, Zn, Cu, As and Cr(t). Nutrient loads at both sites are poorly correlated with rainfall; this may be due to the inputs from the Wastewater Treatment Plant. Regression analyses between rainfall and pollutant loads for the other main sites show variable relationships.

The predictive capabilities of models relating loads to rainfall are substantially improved by using linear regressions of the natural log-transformed daily flows and load estimates for each site, with R^2 values greater than 0.8 often being obtained. This reflects the dominance of the flow component in determining loads, and allows daily loads to be predicted for the major surface inputs on the basis of flows.

As a result of these findings, the following recommendations can be made:

- Non-Yarra River sources should be accounted for in any consideration of surface inputs into Port Phillip Bay.

- The focus of these non-Yarra River sources should be on the Patterson River, Mordialloc Main Drain and Mordialloc Settlement drain.

- If resources allow, validation of the predictive capabilities of flow measurements in the Patterson River/Mordialloc Main Drain system should be considered given that the main sampling program was undertaken more than twelve years ago. This would need to take into account:

  - Flow control in the system below the existing stream gauging stations.
  - Inflows from the Mordialloc Settlement drain below the sampling sites used in the 1979-81 study.
  - Possible changes in flow quality and quantity since the 1979-81 study and the anticipated cessation of discharges from the Wastewater Treatment Plant at Dandenong.

  Two possible approaches to such a program are either long-term sampling or a number of intensive flow-related sampling exercises at each of the three sites. Considering the latter, temporary gauging stations could be established at each site to provide flow estimates and the subsequent confirmation of load/discharge relationships.

- Other surface inputs which should be considered in any assessment of surface inputs into Port Phillip Bay are Kororoit Creek, Kananook Creek, Heatherton Road drain, Laverton Creek, Cowderoy Creek drain, Earimil Creek and Cowies Creek. These represent the four highest-ranking inputs for all the variables examined (in addition to the Patterson River/Mordialloc Main Drain system and Mordialloc Settlement drain).

- Access to stream flow data should be pursued to provide a predictive capability for surface inputs entering Port Phillip Bay.

- Consideration should be given to assessment of EPA-licensed discharges, possible sources of organic contaminants, and other potentially-significant sources not included in the main database. This could be by review of other existing data or by undertaking a sampling and analytical program.

1 INTRODUCTION

1.1 Background

The Port Phillip Bay Environmental Study (PPBES) requires estimates of the nutrient, toxicant and suspended matter loads entering the Bay from surface waters in order to enable physical and chemical processes in the Bay to be modelled. Potentially relevant data on rainfall, streamflow and water quality collected by Victorian Government agencies have been analysed in this report, so that the representativeness of derived estimates of loads to the Bay, and the utility of these estimates to the Bay model, can be assessed. Data for the Yarra River and licensed discharges (including the Werribee Treatment Complex [WTC]) are to be dealt with in separate studies and are outside the scope of this review.

The main database was established by the Victorian Environment Protection Authority's (EPA) 1979-81 sampling of rivers and drains discharging to the Bay. Additional data from a much smaller EPA investigation of discharges to Corio Bay, and from the monitoring programs of Melbourne Water, have also been evaluated.

1.2 Objectives

The main objectives of this report are to:

- Determine the magnitude of toxicant, nutrient and suspended particulate matter (referred to in this report as non-filterable residue [NFR]) inputs to Port Phillip Bay from selected creeks and drains (other than the Yarra River and licensed discharges).
- Provide, if possible, a basis for predicting the loads of these materials entering the Bay.

A secondary objective is to compare loads from these sources with those contributed by the Yarra River.

1.3 Approach

The approach adopted in this report is as follows:

- The representativeness of the data has been assessed primarily in terms of ability of the data to establish reasonable load estimates.
- These loads have then been calculated, compared with previous estimates, and used in simple predictive models relating rainfall, streamflow and contaminant load.
- Factors affecting the relevance to present day circumstances of the data and derived load estimates are discussed, including sampling and analytical errors and catchment changes.

The study has not examined the role of contaminant load estimates in the main model of the physical and chemical processes of the Bay proper. Clearly, the use to which the estimates are put, and the reliability and representativeness of other Bay model components, are relevant to the final assessment of the utility of the contaminant load estimates.

A constraint on the study is that the main database was established by the EPA on the basis of its 1979-81 sampling and analytical program. Streams and drains which were not included in that program have therefore not been included in this assessment.

Considerable information was obtained from discussions with officers from various government organisations, as acknowledged in Section 6.

2 WATER QUALITY & HYDROLOGY

2.1 EPA Port Phillip Bay Input Streams Program, 1979-81

The EPA's "Port Phillip Bay Input Streams Monitoring Program" was designed to estimate the magnitude and geographic distribution of pollutant loads entering the Bay, and to detect any long-term trends or changes in these loads.

Inputs into the Bay (excluding licensed effluents) were divided into several strata, with each stratum consisting of a defined population of rivers, creeks and/or storm water drains. Descriptions of some of the catchments can be found in EPA (1979). Random sampling (with respect to time) was undertaken within each stratum between 1979 and 1981, although limits were placed on the degree of randomness in that sample collection was restricted to daylight (working) hours and a larger number of samples were required to be taken from those sites considered to be of more importance than other sites. Samples were analysed for key water quality variables and flow estimates obtained at the time of sampling.

The variables measured relevant to the PPBES are total P, Kjeldahl N, oxidised N (Nox), NFR, surfactants, Pb, Hg, Zn, Cd, Cu, As, Cr(t), Ni and Fe.

Analytical methods were based largely on EPA (1977). Metals were determined by flame atomic absorption spectrometry after solvent extraction of the digested (1% HNO_3) samples. All Cr in the samples was oxidised to Cr(VI) prior to extraction. Flow was estimated by timing the passage of a float over a specified length and multiplying this by the cross-sectional area at the site.

The number of results for water quality variables at each site approximated the number of flow estimates. This varied from one at a drain on the Nepean Highway near the Dromana Hospital to 325 for the Patterson River at Wells Road.

Of the 196 sites established by the EPA, data from 108 have been evaluated for this current report. The sites deleted were located either upstream of sites closer to the Bay or were within the Yarra River system.

2.2 Other Data

Although the main data set used for this study was that from the 1979-81 EPA program, additional data evaluated and discussed in following sections includes:

- Corio Bay Inputs Survey (unpublished data collected by EPA in 1986-87).
- Inland Water Quality Monitoring Network (data collected in 1989 [EPA, 1992]).
- Water Quality in Melbourne's Waterways (data collected in 1989-91 [Melbourne Water, 1992]).
- Water Quality of Three Urban Drains in Metropolitan Melbourne (data collected in 1986 [MMBW, 1987]).
- Characterisation of Pollution in Urban Stormwater Runoff (data collected in 1978 [Gutteridge, Haskins and Davey Pty Ltd/EPA, 1981]).

2.3 Water Quality

Given the large number of sites sampled in the main program (1979-81), initial data analysis focussed on selected sites including Patterson River at Wells Road (which was the largest data set available), Werribee River, Mordialloc Main Drain, Kororoit Creek and Cowies Creek (Figures 1 and 2). Selection of these sites was based on a *prima facie* assessment of the likely importance of these inputs, based primarily on a review of existing data and discussions with government officers.

A statistical summary of water quality data for some of these sites is shown in Table 1, while that for the remainder of the selected sites is given in Attachment 1.

Examination of the data shows a wide range in both median discharge values and concentrations of water quality variables. For example, the highest median flow value for the 24 sites for which full descriptive statistics were obtained (Attachment 1) was found for Patterson River (94 ML/day), while the lowest was at the Crisp Street drain (0.23 ML/day). Corresponding sites for selected water quality variables were:

- *Total P* - highest at Mordialloc Main Drain (at Springvale Road) (2.5 mg/L), lowest at Werribee River (at Werribee Park ford) and Earimil Creek (at the mouth) (0.04 mg/L).
- *NFR* - highest at Cowderoy Street drain (at Canterbury Road) (63 mg/L), lowest at Chinaman's Creek (at Nepean Highway) (3 mg/L).
- *Cu* - highest at Mordialloc Settlement drain (at Canterbury Road) (350 μg/L), lowest at Werribee River (at Werribee Park ford) (0.9 μg/L).
- *As* - highest at Crisp Street drain (16.2 μg/L), lowest at Werribee River (at Werribee Park ford) and Earimil Creek (at the mouth) 0.9 μg/L).

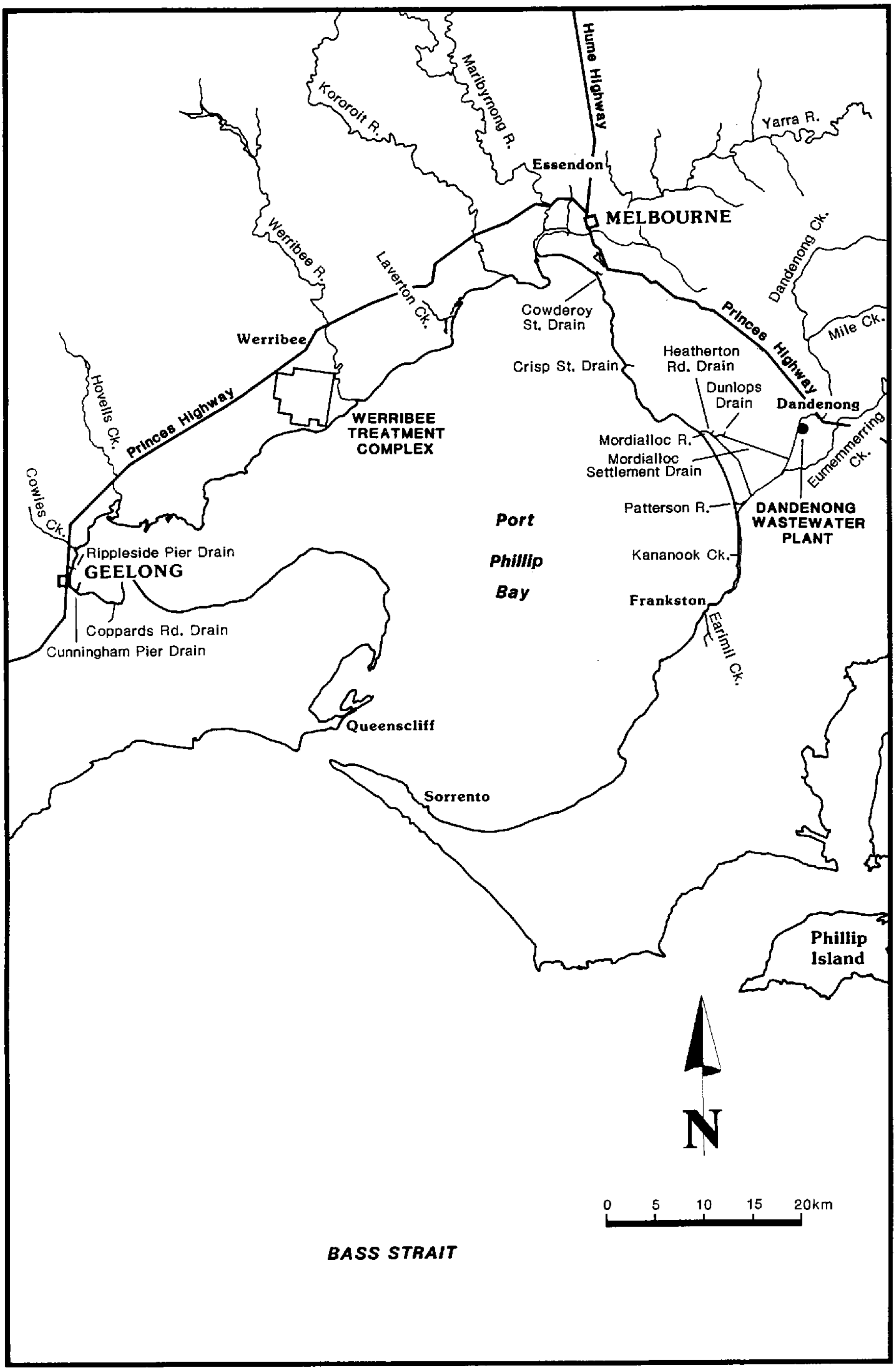


Figure 1. Location of major surface inputs to Port Phillip Bay

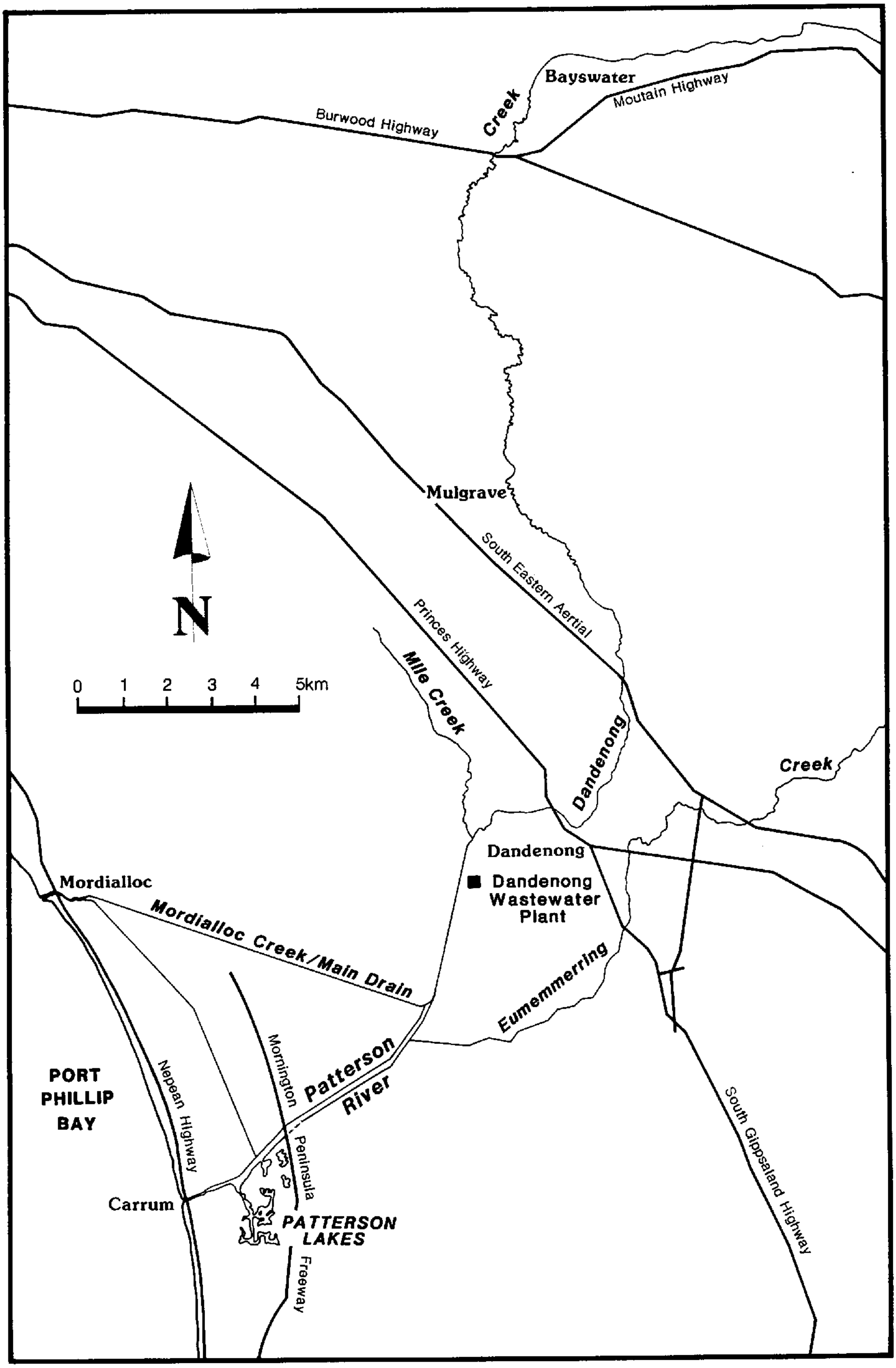


Figure 2. Location of Patterson River / Mordialloc Main Drain area

Table 1. Statistical summary of water quality data for selected stations

	Flow (ML/d)	Total P (mg/L)	Kjeldahl N (mg/L)	Oxidised N (mg/L)	NFR (mg/L)	Surfactant (mg/L)	Pb (µg/L)	Hg (µg/L)	Zn (µg/L)	Cd (µg/L)	Cu (µg/L)	As (µg/L)	Cr (t) (µg/L)	Ni (µg/L)	Fe (µg/L)
Werribee River Lower at Werribee Park ford, Werribee															
Sample Number	6	8	8	8	2	8	8	8	8	8	8	8	8	8	8
Max	20.00	0.084	0.85	2.90	8	0.10	5	0.1	10	0.2	3.2	2.2	5	3	2450
Min	0.20	0.020	0.45	0.33	1	0.02	1	0.0	1	0.2	0.2	0.5	1	1	50
Mean	10.05	0.045	0.62	2.03	4	0.04	2	0.0	3	0.2	1.1	1.1	2	2	668
Std Dev	7.13	0.024	0.13	1.02	5	0.03	2	0.0	3	0.0	0.9	0.6	1	1	1023
Median	8.20	0.036	0.63	2.30	4	0.03	1	0.0	2	0.2	0.9	0.9	1	2	135
10%ile	3.65	0.026	0.49	0.50	1	0.03	1	0.0	1	0.2	0.4	0.6	1	2	71
90%ile	18.30	0.078	0.75	2.90	7	0.05	4	0.1	7	0.2	2.0	1.8	3	2	2268
Mordialloc Main Drain at Springvale Rd															
Sample Number	113	109	111	112	63	113	112	111	112	112	112	112	112	112	112
Max	768.00	6.800	14.00	10.50	340	0.47	330	0.2	540	1.6	53.0	15.8	26	70	13500
Min	0.00	0.500	1.40	0.02	2	0.02	2	0.0	30	0.2	5.0	1.0	1	2	320
Mean	97.25	2.757	5.81	3.65	40	0.22	25	0.1	119	0.2	15.5	4.2	10	8	2772
Std Dev	123.12	1.541	3.17	1.91	60	0.11	37	0.0	80	0.2	8.2	3.2	5	6	2699
Median	61.20	2.500	5.20	3.25	22	0.20	18	0.1	110	0.2	13.0	2.8	9	8	1945
10%ile	3.95	0.934	2.20	1.80	9	0.08	6	0.0	50	0.2	8.4	1.8	3	4	542
90%ile	220.00	5.100	11.00	5.89	82	0.37	37	0.1	180	0.4	25.4	8.5	17	11	5471
Kororoit Ck at Racecourse Rd, Altona U/S Ford															
Sample Number	230	237	238	239	171	239	241	239	242	242	242	242	241	242	242
Max	405.00	43.000	19.00	7.10	72	1.30	33	1.2	140	2.9	70.0	10.0	650	73	28700
Min	13.80	0.094	0.50	0.02	4	0.02	1	0.0	1	0.2	1.0	0.1	1	1	130
Mean	45.61	1.998	4.14	1.79	22	0.28	9	0.3	39	0.4	10.9	1.8	54	12	1229
Std Dev	41.39	3.631	2.01	1.18	11	0.16	5	0.2	25	0.3	6.7	0.8	59	9	2378
Median	36.20	1.400	3.60	1.70	21	0.26	8	0.2	35	0.3	10.0	1.8	38	9	850
10%ile	23.10	0.796	2.27	0.38	10	0.11	4	0.1	15	0.2	5.0	1.0	13	5	531
90%ile	70.34	2.400	6.46	3.20	35	0.46	17	0.5	70	0.5	18.7	2.4	110	20	1490

Table 1. Statistical summary of water quality data for selected stations

Table 1 continued

	Flow (ML/d)	Total P (mg/L)	Kjeldahl N (mg/L)	Oxidised N (mg/L)	NFR (mg/L)	Surfactant (mg/L)	Pb (µg/L)	Hg (µg/L)	Zn (µg/L)	Cd (µg/L)	Cu (µg/L)	As (µg/L)	Cr (t) (µg/L)	Ni (µg/L)	Fe (µg/L)
Patterson River at Wells Rd															
Sample Number	325	320	324	324	232	324	327	324	327	326	326	327	326	326	327
Max	3645.00	6.200	18.00	6.50	720	0.76	270	2.5	1230	10.0	90.0	7.9	49	70	18900
Min	0.00	0.240	0.10	0.01	8	0.01	1	0.0	6	0.2	1.3	0.5	1	1	260
Mean	188.80	2.417	5.87	2.62	61	0.22	21	0.1	109	0.5	15.6	2.0	10	9	2446
Std Dev	306.75	1.293	2.80	1.05	68	0.13	23	0.2	102	1.4	9.4	0.7	5	6	2371
Median	94.00	2.300	5.45	2.70	41	0.20	15	0.1	90	0.2	14.0	2.0	10	8	1640
10%ile	11.00	0.790	2.63	1.40	22	0.07	6	0.0	40	0.2	6.4	1.0	4	4	710
90%ile	476.20	4.100	9.67	3.80	120	0.40	39	0.1	180	0.5	23.8	2.9	16	13	4888
Cowies Ck at Corio Quay Rd															
Sample Number	119	112	115	115	68	111	115	115	115	115	115	115	115	115	115
Max	146.88	2.700	16.00	11.00	150	2.00	150	3.0	1710	2.0	90.0	19.4	220	97	83600
Min	0.00	0.043	0.45	0.35	2	0.01	1	0.0	19	0.2	2.0	0.5	1	1	120
Mean	9.63	0.237	1.98	2.44	22	0.18	14	0.1	452	0.5	14.7	2.3	11	13	6364
Std Dev	20.10	0.389	2.20	2.14	26	0.28	26	0.3	310	0.3	12.4	1.8	33	13	16842
Median	2.90	0.113	1.30	1.80	13	0.08	5	0.1	430	0.5	11.0	2.0	2	8	1100
10%ile	0.80	0.064	0.80	0.73	6	0.02	2	0.0	50	0.2	4.5	1.3	1	4	574
90%ile	20.06	0.499	3.86	6.08	49	0.36	33	0.1	826	0.8	28.0	3.2	20	24	10024
All data															
Sample Number	1558	1558	1572	1576	976	1569	1590	1575	1591	1590	1591	1592	1579	1591	1591
Max	3645.00	43.000	100.00	36.00	1700	36.00	6550	25.0	5950	150.0	4360.0	132.0	650	460	149000
Min	0.00	0.005	0.05	0.00	1	0.01	1	0.0	1	0.2	0.2	0.1	1	1	15
Mean	55.00	1.330	4.00	2.55	37	0.34	30	0.1	180	0.6	20.0	3.5	17	9	2620
Std Dev	163.00	2.050	6.70	3.32	77	1.38	190	0.7	280	3.9	110.0	5.9	38	17	7270
Median	4.90	0.740	2.50	1.90	21	0.15	11	0.1	90	0.2	12.0	2.0	7	6	1150
10%ile	0.10	0.094	0.80	0.14	4	0.03	2	0.0	14	0.2	2.8	1.0	1	2	420
90%ile	136.00	3.400	8.00	4.50	76	0.43	44	0.2	450	0.8	31.0	6.2	40	16	4530

Table 1. Statistical summary of water quality data for selected stations (continued)

A comparison of mean values for selected water quality variables from the total data set with reported mean values from other studies (Table 2) shows that the grand mean values obtained for this study appear to be typical of (e.g. total P, Kjeldahl N and Cu), or lower than (e.g. NFR and Pb), mean values found in other studies of Melbourne's urban runoff.

Table 2. Comparison of EPA 1979-81 water quality data with other studies of urban drainage in Melbourne

Variable	Parameter/Site	Conc. (mg/L)	Reference
Total P	Mean (5 Melb Metro. drains) (1978-79)	0.3-1.2	GHD/EPA (1981)
	Mean (Elster Ck/Elwood Canal) (1969-70)	2.4-19	MMBW (1987)
	Mean (Mor'lloc Settlement drain) (1972-83)	1.1-1.2	MMBW (1987)
	Mean (all data) (1979-81)	1.3	This study
Kjeldahl N	Mean (5 Melb Metro. drains) (1978-79)	1.9-5.6	GHD/EPA (1981)
	Mean (Elster Ck/Elwood Canal) (1969-70)	1.3-3.2	MMBW (1987)
	Mean (Mor'lloc Settlement drain) (1972-83)	1.9-3.8	MMBW (1987)
	Mean (all data) (1979-81)	4.0	This study
NFR	Mean (5 Melb Metro. drains) (1978-79)	146-597	GHD/EPA (1981)
	Mean (Elster Ck/Elwood Canal) (1969-70)	na	MMBW (1987)
	Mean (Mor'lloc Settlement drain) (1972-83)	65-68	MMBW (1987)
	Mean (all data) (1979-81)	37	This study
Pb	Mean (5 Melb Metro. drains) (1978-79)	0.16-0.53	GHD/EPA (1981)
	Mean (General urban runoff)	0.08-0.30	GHD/EPA (1981)
	Mean (Mor'lloc Settlement drain) (1972-83)	na	MMBW (1987)
	Mean (all data) (1979-81)	0.03	This study
Zn	Mean (5 Melb Metro. drains) (1978-79)	0.21-5.8	GHD/EPA (1981)
	Mean (General urban runoff)	1.2-1.9	GHD/EPA (1981)
	Mean (Mor'lloc Settlement drain) (1972-83)	na	MMBW (1987)
	Mean (all data) (1979-81)	0.18	This study
Cu	Mean (5 Melb Metro. drains) (1978-79)	0.026-0.48	GHD/EPA (1981)
	Mean (General urban runoff)	0.007-0.03	GHD/EPA (1981)
	Mean (Mor'lloc Settlement drain) (1972-83)	na	MMBW (1987)
	Mean (all data) (1979-81)	0.020	This study
Cr	Mean (5 Melb Metro. drains) (1978-79)	0.020-0.58	GHD/EPA (1981)
	Mean (General urban runoff)	0.018-0.085	GHD/EPA (1981)
	Mean (Mor'lloc Settlement drain) (1972-83)	na	MMBW (1987)
	Mean (all data) (1979-81)	0.017	This study

Plots of variable concentration against discharge for the Patterson River at Wells Road, which had the largest data set (n = 325), are shown in Figure 3. To allow more detailed examination of the data, these have been grouped according to flow, where low to medium flows range from 0 to 200 ML/day and medium to high flows range from 200 to 1600 ML/day. Examination of these plots (Figures 4 and 5) show that any relationships between concentration and discharge are poorly defined. Some variables, such as total P, Kjeldahl N and Nox, exhibit a tendency for low values to occur at low flow, although no clear trend is evident since considerably higher values (up to 10 times) occur at the same flows. There is then some decrease as flow increases until variable concentrations at extreme flows approach those observed at very low flows. Other variables, such as NFR, exhibit a clear increase with discharge, while for a third category (exemplified by Cd and Ni) there is no apparent relationship at all between concentration and discharge.

These trends reflect the mechanisms controlling variable concentrations and discharge. While a power relationship is commonly observed between conductivity (or TDS) and discharge (Walling and Webb, 1983), increases in NFR concentrations with flow are also typical, although relationships between the two depend on the source(s) of the material (Strunk, 1992). Given the large number of physical and chemical processes contributing to contaminant transport, it is not surprising that a simple relationship is not universally applicable.

Nonetheless, some relationships confirm expectations. For example, Fe is generally associated with particulates, and hence increases in NFR values with flow would be expected to be reflected in similar increases in Fe concentrations, as indeed they are. Plots of variable concentration as a function of NFR levels are shown in Figure 6, again for the Patterson River. However, the applicability of such a simple model to the results for the other metals is made more difficult by the unknown contributions of the dissolved fraction, and the fact that a considerable number of the values were near the detection limits and therefore unreliable.

The decreasing total P concentrations with increasing NFR levels shown in Figure 6 are suggestive of a point source for total P, since increases in both variables commonly occur in streams carrying non-point source contaminants where phosphorus is associated with particulate matter. Modelling this variable, plus the other three variables (Kjeldahl N, Nox and surfactants) which decrease in concentrations as flow increases, was attempted by fitting either an exponential decay model or a linear regression model, with goodness-of-fit being assessed on the basis of highest correlation and lowest standard error. The best R^2 value for these variables was 0.275, where total P, Kjeldahl N and Nox were modelled using linear regression and surfactant concentrations were best modelled using an exponential decay function. These data indicate that NFR is not a particularly good predictor of nutrient or surfactant concentrations in this system. Those variables which increase in concentration as NFR increases were modelled using a linear model; R^2 values range between 0.074 (As) and 0.289 (Pb). No clear relationship was evident between NFR and Cd, Ni and Hg so these variables were not modelled.

The possibility of using flow measurements from sites gauged by Melbourne Water or the Rural Water Corporation was investigated. However, the data from most of these gauging stations was of little use due to inappropriate locations or a lack of records for the sampling period. Data was available for the Patterson River/Mordialloc Main Drain system and this is discussed in following sections.

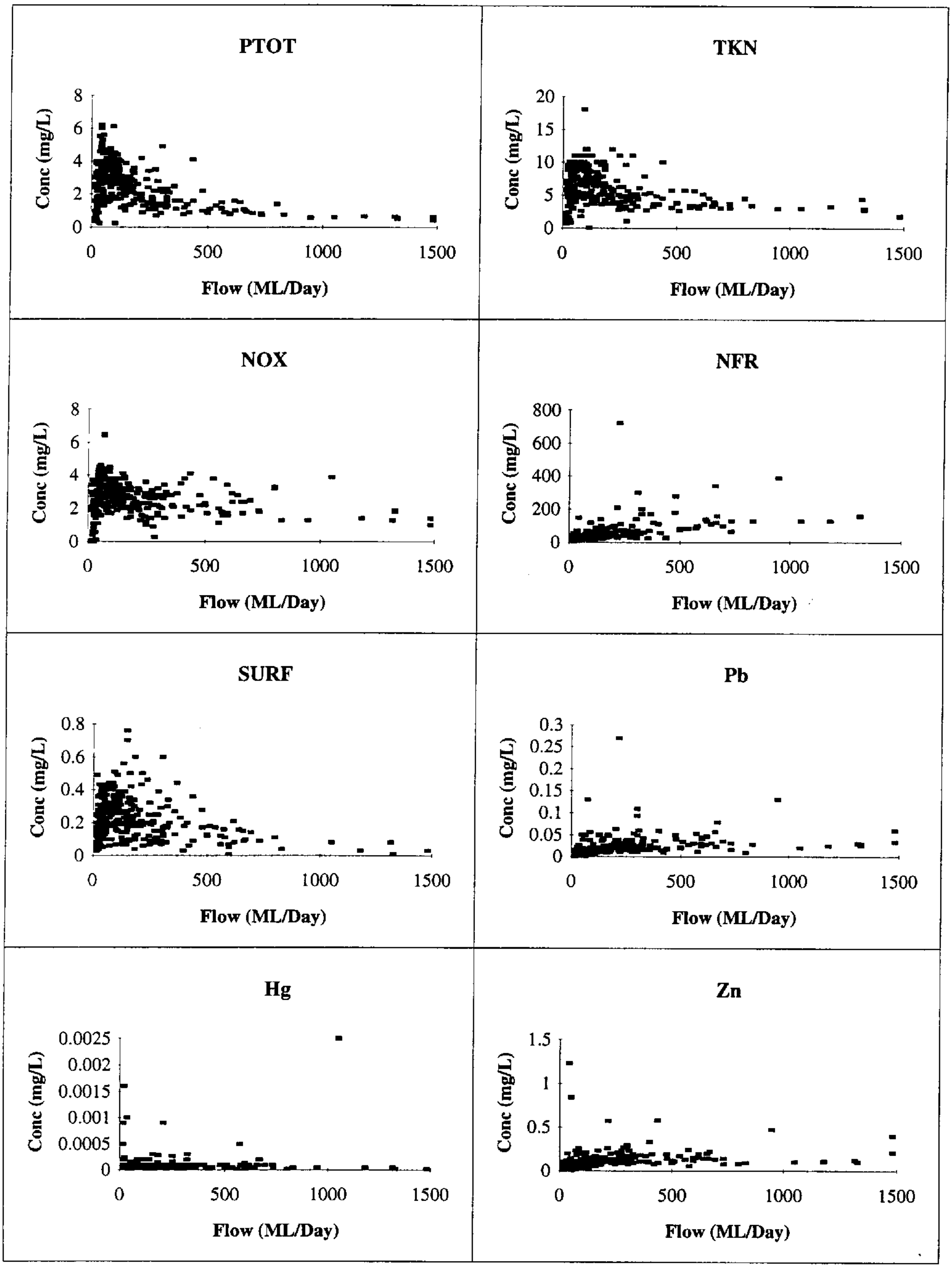


Figure 3. Concentration vs discharge for the Patterson River (Page 1)

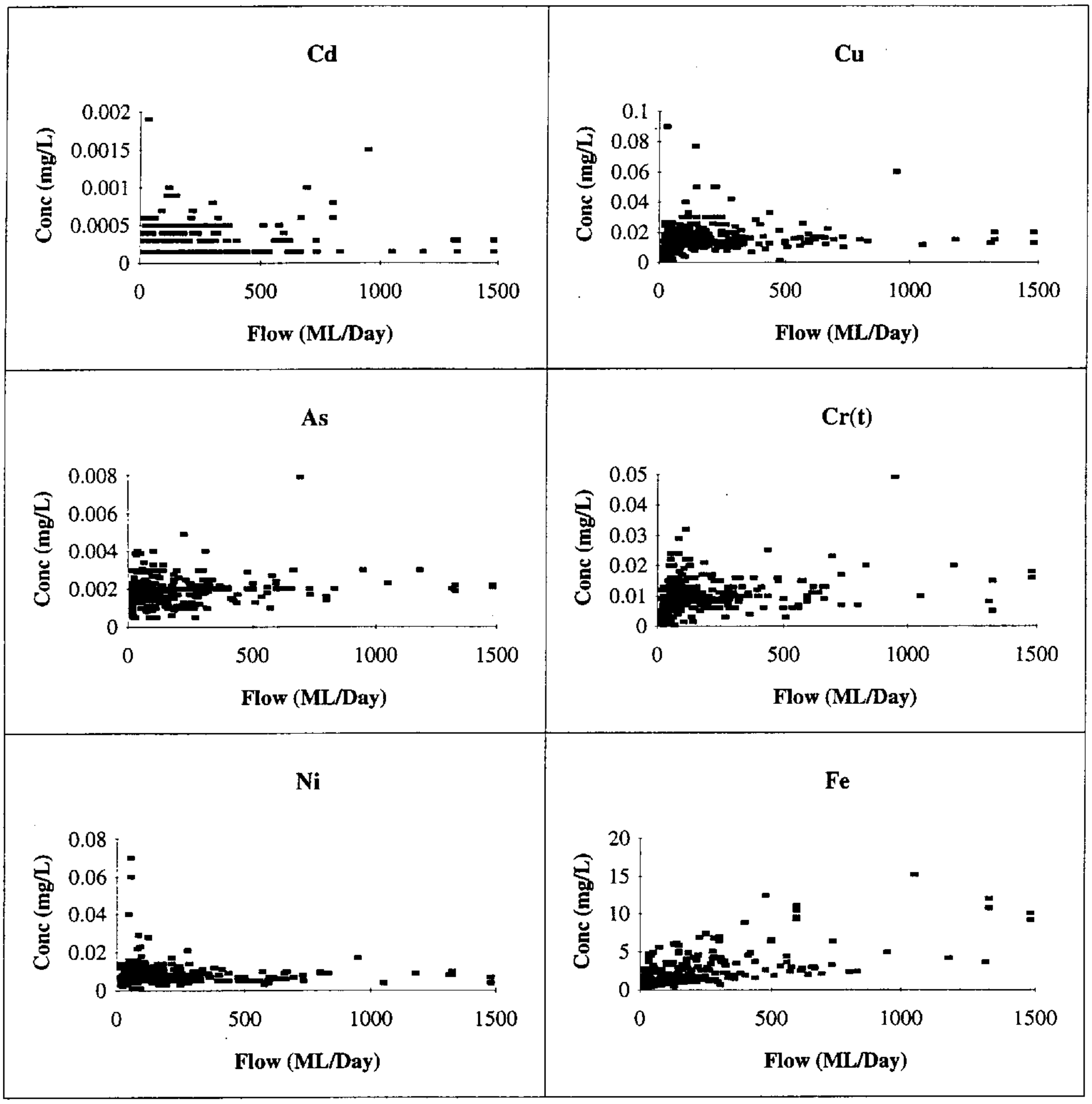


Figure 3. Concentration vs discharge for the Patterson River (Page 2)

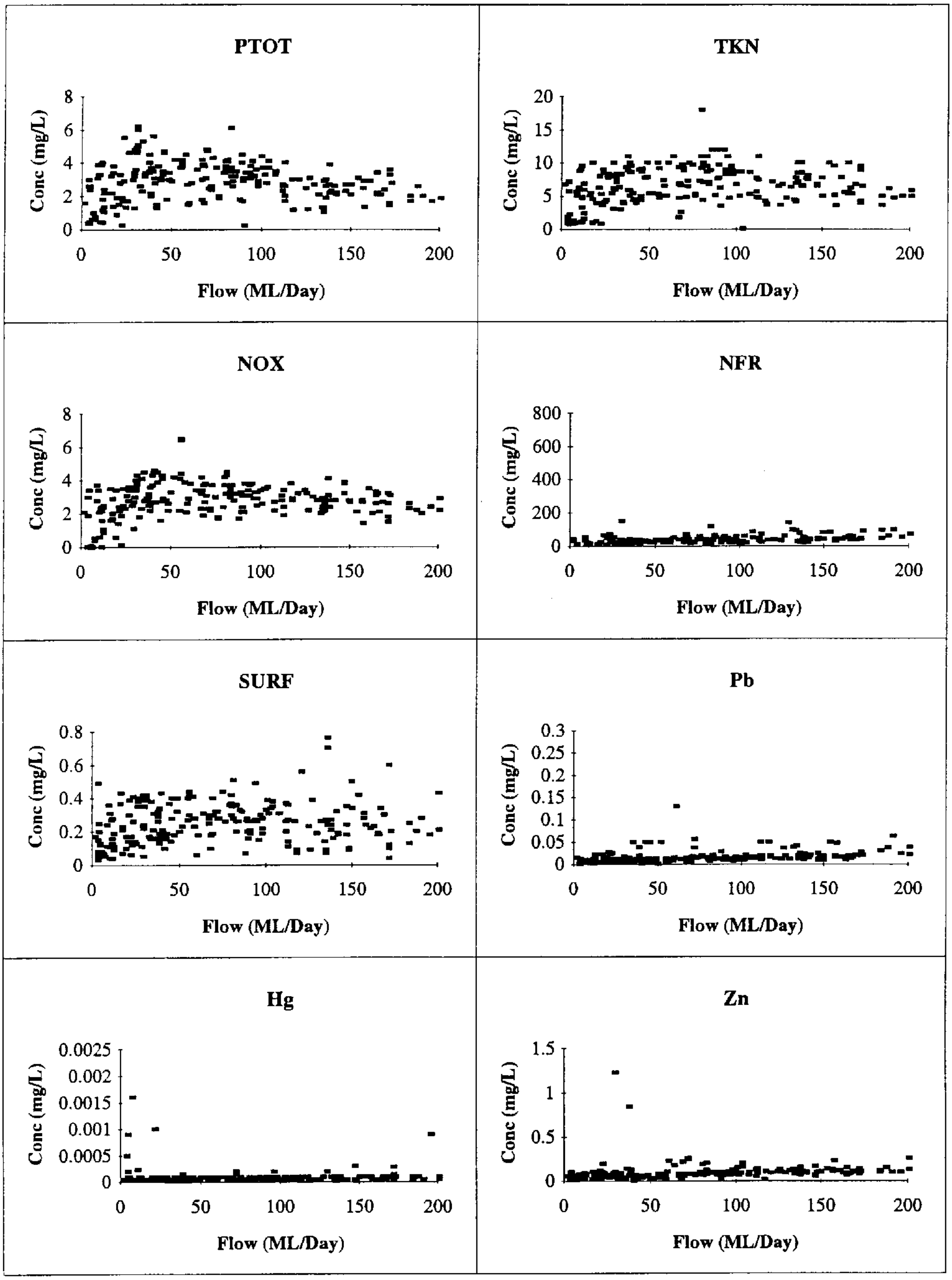


Figure 4. Concentration vs discharge for the Patterson River at 0 to 200 ML/day range (Page 1)

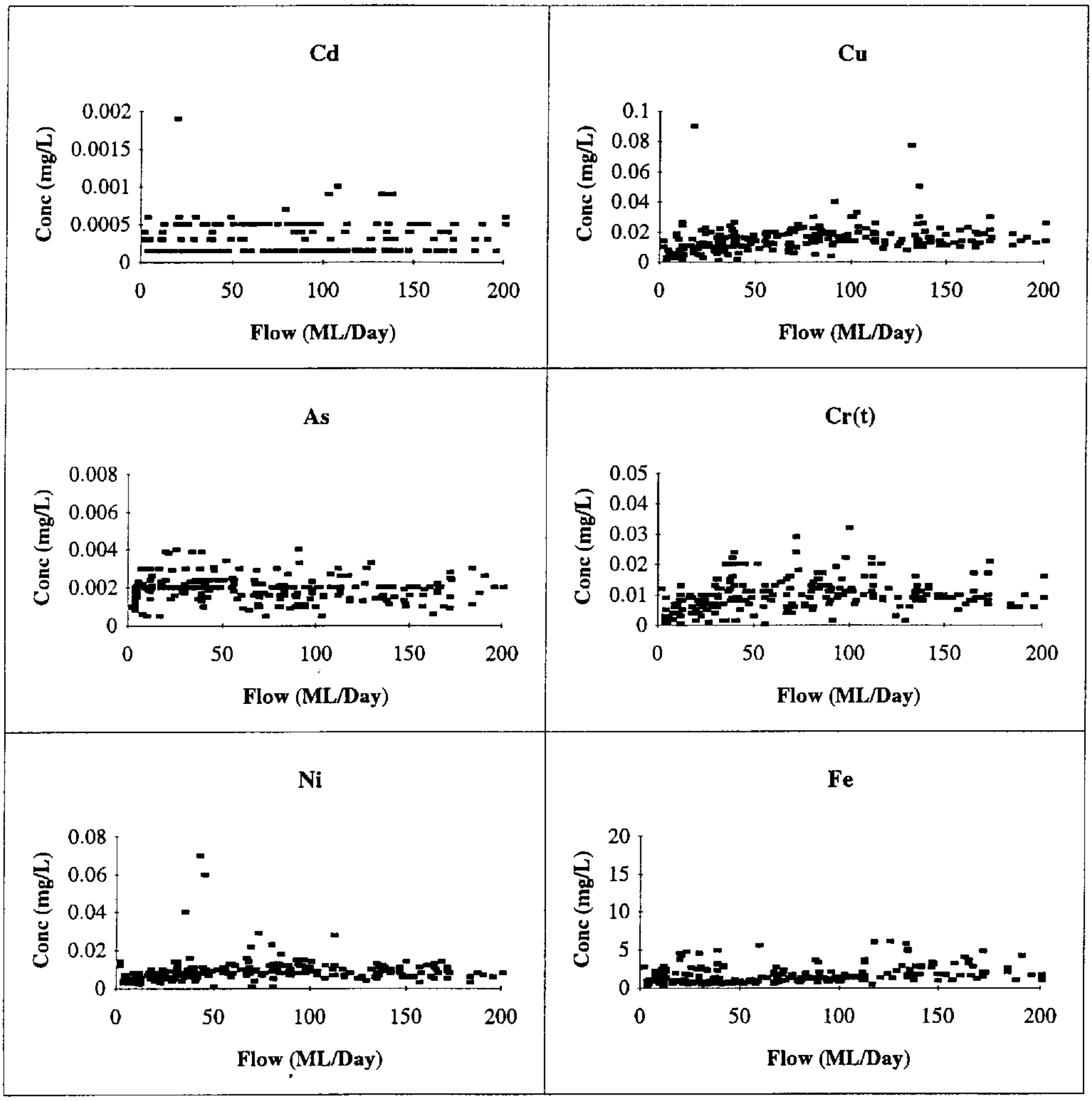


Figure 4. Concentration vs discharge for the Patterson River at 0 to 200 ML/day range (Page 2)

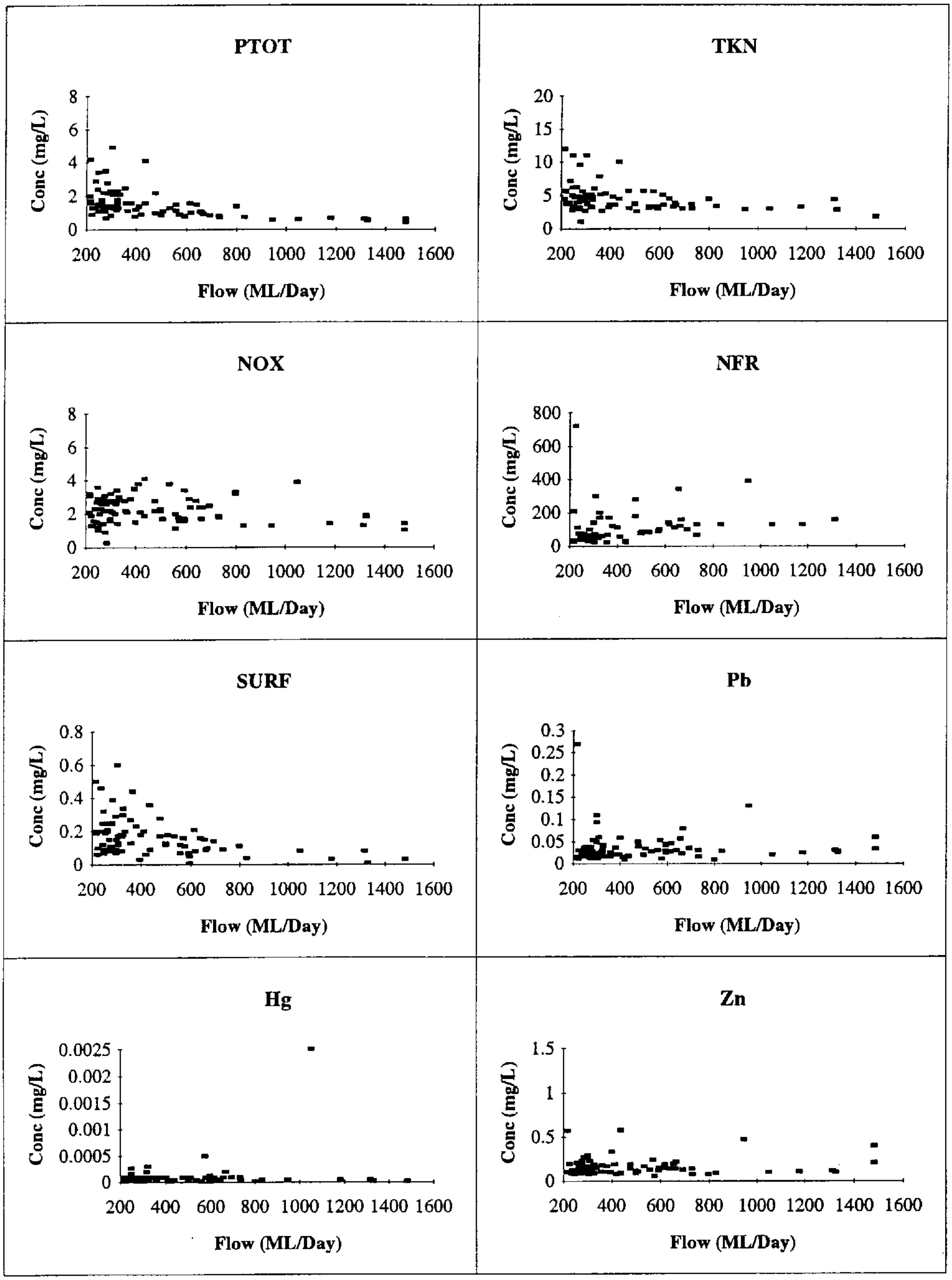


Figure 5. Concentration vs discharge for the Patterson River at 200 to 1600 ML/day range (Page 1)

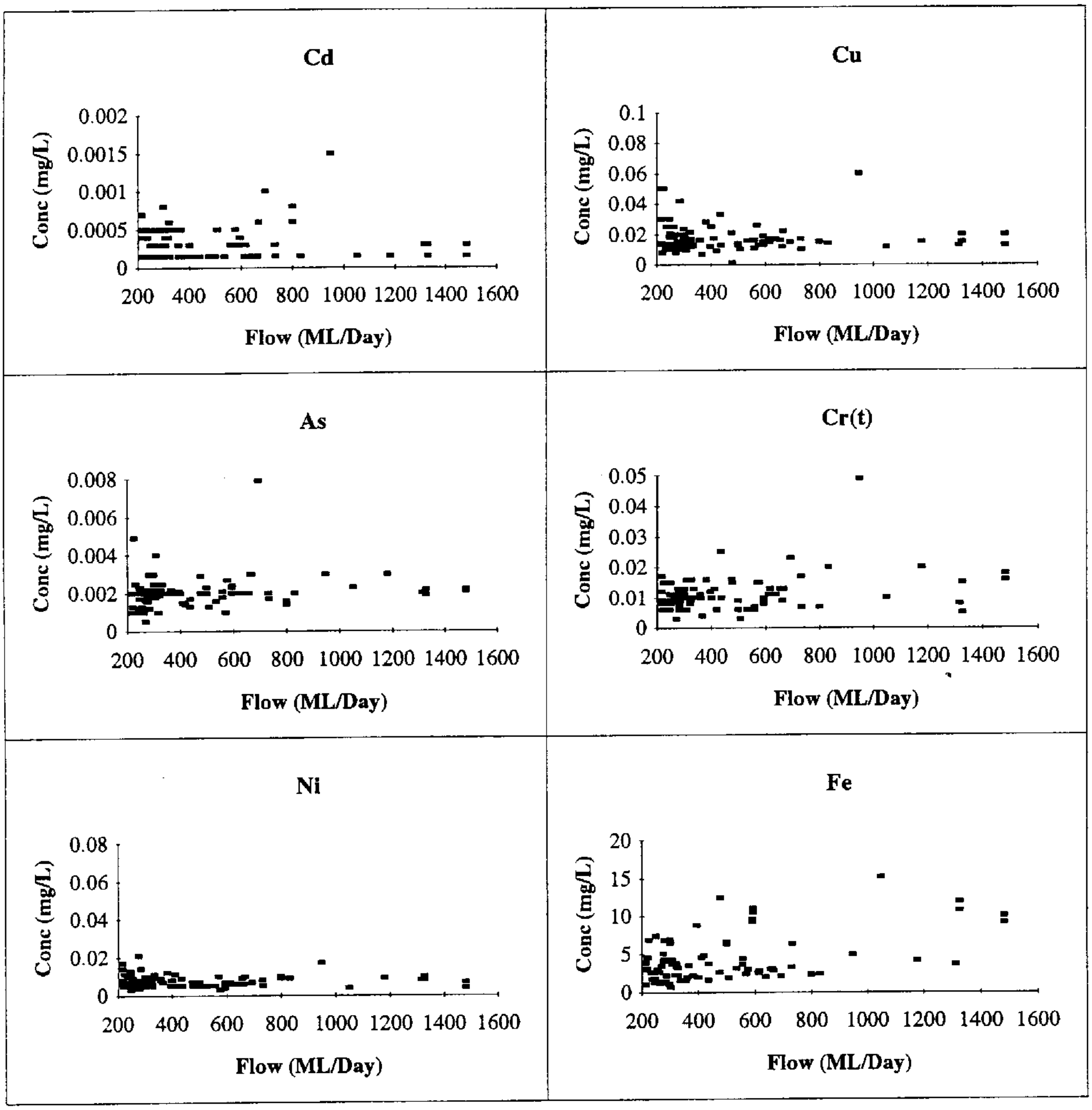


Figure 5. Concentration vs discharge for the Patterson River at 200 to 1600 ML/day range (Page

2

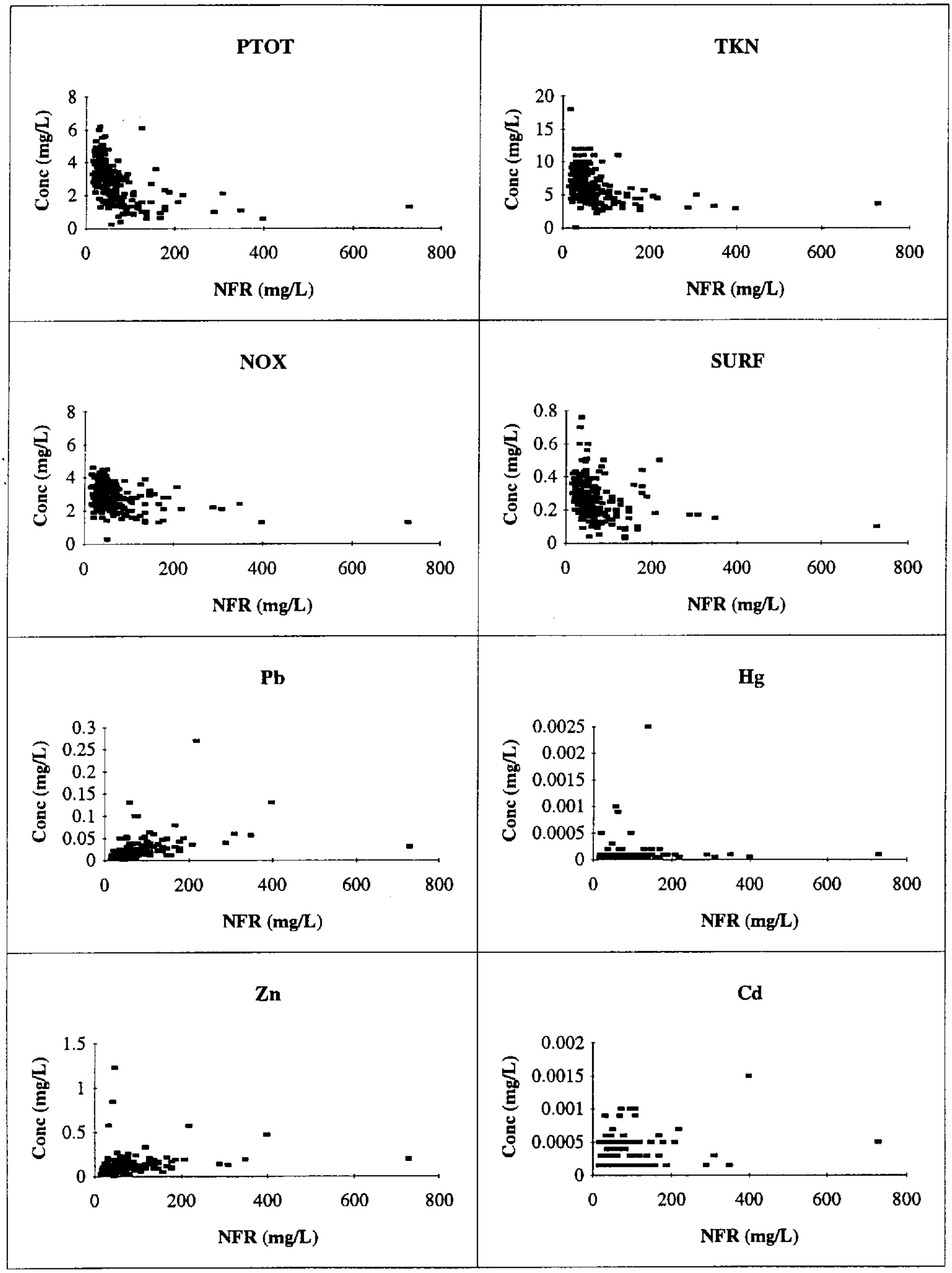


Figure 6. Variable concentration vs NFR concentration for the Patterson River (Page 1)

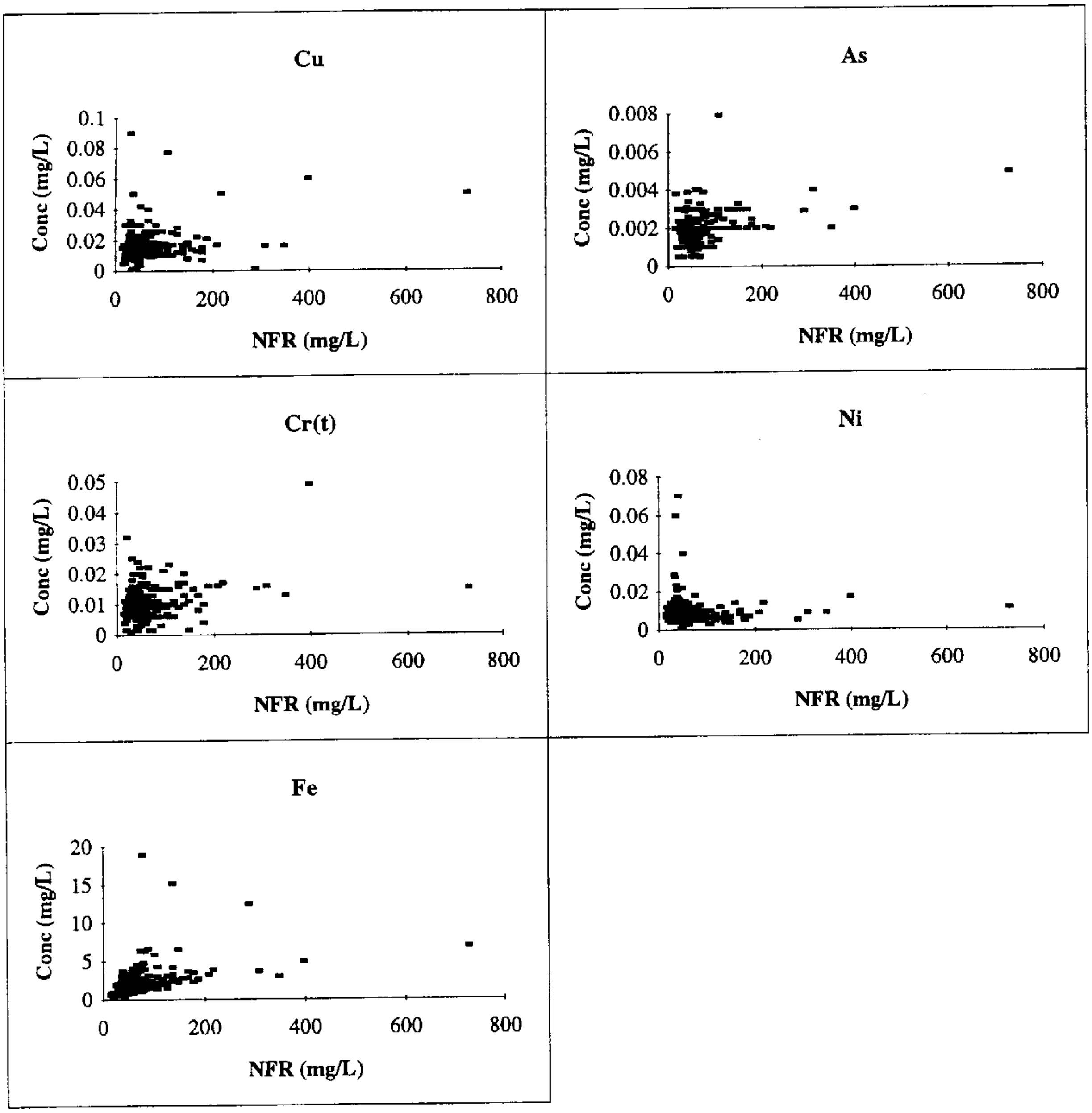


Figure 6. Variable concentration vs NFR concentration for the Patterson River (Page 2)

3. LOAD ESTIMATES

3.1 Load Calculations

The approach adopted for this study has been to make values reported as "less than" equal to one half the detection limit. The EPA's approach was to make such values equal to a concentration one significant figure lower than that level of detection.

Loads were calculated using two methods:

Mean flow/mean concentration

In the first method, the mean concentration $(\bar{x}, \text{ mg / L})$ of each variable was calculated from all the water samples analysed. The total discharge was estimated by multiplying the average daily discharge $(\overline{Flow}, \text{ ML/d})$ from all discharge estimates by the total number of days in the sampling period (1112). Combining these two values gives a total load estimate, i.e.

$$\text{Load}_1 = \frac{\overline{Flow}\ (\text{ML/d}) \times [\bar{x}](\text{mg / L}) \times \text{No. days in sampling period}}{1000}\ (\text{tonne})$$

Mean flow/flow weighted mean concentration

In the second method, the mean concentration was replaced with the flow-weighted mean, where the latter is calculated by:

$$\text{FWM} = \frac{\sum_{i=1}^{n} Flow_i \times [\text{x}_i]}{\sum_{i=1}^{n} Flow_i}\ \ (\text{mg / L})$$

where i = day number and n = number of days on which the site was sampled.

Therefore,

$$\text{Load}_2 = \frac{\overline{Flow}\ (\text{ML/d}) \times \text{FWM}(\text{mg / L}) \times \text{No. days in sampling period}}{1000}\ \ (\text{tonne})$$

The use of median flow, rather than mean flow, was considered but not used on the basis that, for positively skewed distributions, the median value is likely to be less than the mean (Zar, 1984) and hence use of the median may tend to underestimate loads.

3.2 Load Estimates

The following discussion excludes results for the Yarra-Maribyrnong catchment, the WTC, and other EPA-licensed discharges, except where specifically mentioned.

3.2.1 Comparison of load estimates methods

Load estimates for each variable for the Patterson River obtained by the two methods described are given in Table 3. The arithmetic mean technique yielded higher loads for nutrients, surfactants and 7 of the 9 toxicants (including Fe), while the flow-weighted mean approach gave higher values for the remaining 7 toxicants. Similar differences were reported in GHD/EPA (1981) between arithmetic mean and flow-weighted mean concentrations, with no consistent pattern observed between different urban catchments.

Table 3. Comparison of total load estimates obtained using different methods for the Patterson River over the survey period (1979-81)

Variable	Mean flow/Mean Conc. (t) ($Load_1$)	Mean flow/FWM Conc. (t) ($Load_2$)	($Load_1$)/($Load_2$)
P(tot)	508	333	1.5
TKN	1230	979	1.3
NOx	549	516	1.1
NFR	12700	20300	0.6
Surfactants	47.2	34.2	1.4
Pb	4.4	7.1	0.6
Hg	0.020	0.024	0.8
Zn	22.8	30.1	0.8
Cd	0.11	0.08	1.4
Cu	3.27	3.52	0.9
As	0.41	0.44	0.9
Cr(t)	2.10	2.51	0.8
Ni	1.82	1.67	1.1
Fe	514	1070	0.5

There is a general preference for the flow-weighted mean to represent concentration because it gives weighting in the load calculation to the concentrations at higher flows, these being the relatively short periods of time when a disproportionate fraction of a stream's total load is transported. Discharge is clearly best represented by a continuous gauging record, but since these do not exist for most sampling stations, the arithmetic mean of the sampling flow estimates has been used.

3.2.2 Inputs

Total surface drainage inputs into the Bay (excluding the Yarra River, WTC and other EPA-licensed discharges) during the 3-year sampling period and annual values for each variable are shown in Table 4. Calculations were undertaken according to the flow-weighted mean technique.

Table 4. Total surface drainage inputs into Port Phillip Bay* (tonne)

Variable	Total input 1979-81	Annual load
P(tot)	1120	367
TKN	3300	1083
Nox	1590	522
NFR	42060	13822
Surfactants	161	53
Pb	34	11
Hg	0.11	0.04
Zn	174	57
Cd	0.43	0.14
Cu	24	8
As	2.6	0.9
Cr(t)	14.5	4.8
Ni	8.6	2.8
Fe	3700	1214

*Excluding WTC and Yarra River

The major feature of the data is that a relatively small number of sources account for most of the load of each variable entering the Bay. When ranked according to their loads, the top 10 sources for each variable account for between 75 and 94% of the total load (Table 5). The contributions by the top 10 sources for each variable are given in Table 6 and the data is presented graphically in Figure 7.

The sites (refer to Figure 1 for their location) can be grouped on the basis of their ranking with regard to flow, nutrients, NFR and toxicants, as follows:

Flow

1 Patterson River at Wells Road
2 Mordialloc Main Drain at Springvale Road
3 Mordialloc Settlement drain at Canterbury Road
4 Kananook Creek at Beach Street, Frankston
5 Kororoit Creek at Racecourse Road, Altona

P(tot)/TKN/NOX

1 Patterson River at Wells Road
2 Mordialloc Main Drain at Springvale Road
3 Mordialloc Settlement drain at Canterbury Road
4 Kororoit Creek at Racecourse Road, Altona
5 Kananook Creek at Beach Street, Frankston
6 Dunlops drain at Canterbury Road, Mordialloc
7 Heatherton Road drain at Crown Ave, Mordialloc

NFR

1 Patterson River at Wells Road
2 Mordialloc Main Drain at Springvale Road
3 Heatherton Road drain at Crown Ave, Mordialloc
4 Laverton Creek from swamp at Queen St, Altona
5 Cowderoy St drain, Canterbury Road, St Kilda
6 Kororoit Creek at Racecourse Road, Altona
7 Kananook Creek at Beach Street, Frankston

Pb/Hg/Zn/Cd/Cu/As/Cr(t)/Ni/Fe

1 Mordialloc Settlement drain at Canterbury Road
2 Patterson River at Wells Road
3 Mordialloc Main Drain at Springvale Road
4 Kananook Creek at Beach Street, Frankston

Table 5. Percentage of total surface drainage loads into Port Phillip Bay* contributed by the top 10 sources for each variable*

Variable	% of total load
P(tot)	94
TKN	89
NOX	85
NFR	88
Surfactants	77
Pb	87
Hg	85
Zn	82
Cd	82
Cu	90
As	75
Cr(t)	91
Ni	86
Fe	86

*Excluding WTC and Yarra River

A number of inputs are noteworthy for particular reasons. For example, Patterson River at Wells Road is ranked 1 for P(tot) (with 30% of the total load), 1 for TKN (30%), 1 for NOX (33%), 1 for NFR (48%), 1 for surfactants (21%), 2 for Pb (21%), 2 for Hg (22%), 2 for Zn (17%), 2 for Cd (19%), 2 for Cu (15%), 2 for As (17%), 2 for Cr(t) (17%), 2 for Ni (20%) and 1 for Fe (29%).

Table 6. The ten highest-ranking sources for each input variable (page 1)

Rank	Site	Total Phosphorous Load (Tonnes)	% of Total Load	Site	Kjeldahl Nitrogen Load (Tonnes)	% of Total Load
1	Patterson River at Wells Rd	3.33E+02	29.7	Patterson River at Wells Rd	9.79E+02	29.6
2	Mordialloc Main Drain at Springvale Rd	2.69E+02	24.0	Mordialloc Main Drain at Springvale Rd	6.57E+02	19.9
3	Kororoit Creek at Racecourse Rd	1.67E+02	14.9	Kananook Creek at Beach St	5.15E+02	15.6
4	Mordialloc Settlement drain at Canterbury Rd	1.13E+02	10.0	Mordialloc Settlement drain at Canterbury Road	4.01E+02	12.1
5	Kananook Creek at Beach Street	9.68E+01	8.6	Kororoit Creek at Racecourse Rd	1.95E+02	5.9
6	Dunlops drain at Canterbury Road	2.74E+01	2.4	Dunlops drain at Canterbury Rd	5.28E+01	1.6
7	Saltworks drain Newcomb	1.39E+01	1.2	Heatherton Road drain at Crown Ave	4.86E+01	1.5
8	Heatherton Road drain at Crown Ave	1.16E+01	1.0	Laverton Creek At Queens St	4.52E+01	1.4
9	Laverton Creek at Queen St	9.19E+00	0.8	Saltworks drain Newcomb	3.12E+01	0.9
10	Chinamans Creek at Nepean Hwy	9.09E+00	0.8	Cowderoy Street Main drain at Railway Culvert Canterbury Rd	2.87E+01	0.9
	Others (n=98)	7.19E+01	6.4	Others (n=98)	3.54E+02	10.7
Total		**1.12E+03**			**3.31E+03**	

Rank	Site	Oxidised Nitrogen Load (Tonnes)	% of Total Load	Site	Non-Filtered Residue Load (Tonnes)	% of Total Load
1	Patterson River at Wells Rd	5.16E+02	32.5	Patterson River at Wells Rd	2.03E+04	48.2
2	Mordialloc Main Drain at Springvale Rd	3.32E+02	20.9	Mordialloc Main Drain at Springvale Rd	4.52E+03	10.8
3	Mordialloc Settlement drain at Canterbury Rd	2.23E+02	14.0	Heatherton Road drain at Crown Ave	3.58E+03	8.5
4	Kororoit Creek at Racecourse Rd	1.03E+02	6.5	Laverton Creek At Queens St	3.40E+03	8.1
5	Dunlops drain at Canterbury Road	4.21E+01	2.7	Cowderoy Street Main drain at Railway Culvert Canterbury Rd	1.43E+03	3.4
6	Heatherton Road drain at Crown Ave	3.79E+01	2.4	Kororoit Creek at Racecourse Rd	1.23E+03	2.9
7	Kananook Creek at Beach Street	3.47E+01	2.2	Kananook Creek at Beach St	1.12E+03	2.7
8	Werribee River at Werribee Park Ford	2.73E+01	1.7	Mordialloc Settlement drain at Canterbury Road	8.50E+02	2.0
9	Cunningham Pier drain outside council offices Geelong	2.13E+01	1.3	Ballar Creek at mouth	4.87E+02	1.2
10	drain D4 at mouth on Port Phillip Bay	1.79E+01	1.1	Beach Street drain at outlet	4.42E+02	1.0
	Others (n=98)	2.33E+02	14.7	Others (n=98)	4.70E+03	11.2
Total		**1.59E+03**			**4.21E+04**	

Table 6. The ten highest-ranking sources for each imput variable (Page 1)

Table 6. The ten highest-ranking sources for each input variable (page 2)

Rank	Surfactant Site	Load (Tonnes)	% of Total Load	Lead Site	Load (Tonnes)	% of Total Load
1	Patterson River at Wells Rd	3.42E+01	21.3	Mordialloc Settlement drain at Canterbury Road	7.65E+00	22.3
2	Mordialloc Main Drain at Springvale Rd	2.06E+01	12.8	Patterson River at Wells Rd	7.13E+00	20.8
3	Mordialloc Settlement drain at Canterbury Rd	1.92E+01	11.9	Cowderoy Street Main drain at Railway Culvert Canterbury Rd	5.02E+00	14.6
4	Kororoit Creek at Racecourse Rd	1.38E+01	8.6	Heatherton Road drain at Crown Ave	3.43E+00	10.0
5	Kananook Creek at Beach Street	1.23E+01	7.6	Mordialloc Main Drain at Springvale Rd	3.29E+00	9.6
6	Centre Swamp drain North at DVA pumphouse Mordialloc	6.27E+00	3.9	Cunningham Pier drain outside council offices Geelong	8.97E-01	2.6
7	Coppards Road drain at Salt Works Geelong	5.85E+00	3.6	Shakespeare Grove Main drain at Albert Street	6.42E-01	1.9
8	Heatherton Road drain at Crown Ave	5.19E+00	3.2	Kananook Creek at Beach St	5.84E-01	1.7
9	Shakespeare Grove Main drain at Albert St	4.17E+00	2.6	Crisp Street Main drain at coastal outlet	5.05E-01	1.5
10	Beach Street drain at outlet	4.06E+00	2.5	Kororoit Creek at Racecourse Rd	4.95E-01	1.4
	Others (n=98)	3.49E+01	21.7	Others (n=98)	4.60E+00	13.4
Total		**1.61E+02**			**3.42E+01**	

Rank	Mercury Site	Load (Tonnes)	% of Total Load	Zinc Site	Load (Tonnes)	% of Total Load
1	Earimil Creek at mouth	2.78E-02	25.5	Mordialloc Settlement drain at Canterbury Road	5.80E+01	33.3
2	Patterson River at Wells Rd	2.43E-02	22.3	Patterson River at Wells Rd	3.01E+01	17.3
3	Kororoit Creek at Racecourse Rd	1.25E-02	11.5	Mordialloc Main Drain at Springvale Rd	1.72E+01	9.9
4	Mordialloc Settlement drain at Canterbury Rd	7.87E-03	7.2	Heatherton Road drain at Crown Ave	1.04E+01	6.0
5	Mordialloc Main Drain at Springvale Rd	6.16E-03	5.6	Cowderoy Street Main drain at Railway Culvert Canterbury Rd	8.44E+00	4.9
6	Kananook Creek at Beach Street	4.32E-03	4.0	Cowies Creek at Corio Quay Rd	4.67E+00	2.7
7	Laverton Creek at Queen St	4.27E-03	3.9	Kananook Creek at Beach St	4.34E+00	2.5
8	Kackeraboite Creek at Old Mornington Rd	1.92E-03	1.8	Shakespeare Grove Main drain at Albert Street	3.55E+00	2.0
9	Cowderoy Street Main drain at Railway Culvert Canterbury Rd	1.87E-03	1.7	Byron Street drain at confluence with Elwood Canal	2.95E+00	1.7
10	Chinamans Creek at Nepean Hwy	1.75E-03	1.6	Crisp Street Main drain at coastal outlet	2.62E+00	1.5
	Others (n=98)	1.63E-02	14.9	Others (n=98)	3.15E+01	18.1
Total		**1.09E-01**			**1.74E+02**	

Table 6. The ten highest-ranking sources for each imput variable (Page 2)

Table 6. The ten highest-ranking sources for each input variable (page 3)

Rank	Cadmium: Site	Load (Tonnes)	% of Total Load	Copper: Site	Load (Tonnes)	% of Total Load
1	Heatherton Road drain at Crown Ave	9.84E-02	22.9	Mordialloc Settlement drain at Canterbury Road	1.28E+01	52.7
2	Patterson River at Wells Rd	8.04E-02	18.7	Patterson River at Wells Rd	3.52E+00	14.5
3	Mordialloc Settlement drain at Canterbury Rd	7.22E-02	16.8	Mordialloc Main Drain at Springvale Rd	1.99E+00	8.2
4	Mordialloc Main Drain at Springvale Rd	3.22E-02	7.5	Cowderoy Street Main drain at Railway Culvert Canterbury Rd	9.82E-01	4.0
5	Kororoit Creek at Racecourse Rd	2.52E-02	5.9	Kananook Creek at Beach St	5.47E-01	2.2
6	Kananook Creek at Beach Street	1.80E-02	4.2	Kororoit Creek at Racecourse Rd	5.40E-01	2.2
7	Cowderoy Street Main drain at Railway Culvert Canterbury Rd	8.13E-03	1.9	Cunningham Pier drain outside council offices Geelong	4.53E-01	1.9
8	Laverton Creek at Queen St	7.54E-03	1.8	Heatherton Road drain at Crown Ave	4.39E-01	1.8
9	Cowies Creek at Corio Quay Rd Geelong	5.94E-03	1.4	Dromana Hotel drain at mouth	3.24E-01	1.3
10	Balcombe Creek at Footbridge off Uralla Rd	5.70E-03	1.3	Cowies Creek at Corio Quay Rd	1.92E-01	0.8
	Others (n=98)	7.57E-02	17.6	Others (n=98)	2.52E+00	10.4
Total		**4.29E-01**			**2.43E+01**	

Rank	Arsenic: Site	Load (Tonnes)	% of Total Load	Total Chromium: Site	Load (Tonnes)	% of Total Load
1	Mordialloc Settlement drain at Canterbury Rd	4.79E-01	18.2	Mordialloc Settlement drain at Canterbury Road	4.82E+00	33.3
2	Patterson River at Wells Rd	4.43E-01	16.8	Patterson River at Wells Rd	2.51E+00	17.3
3	Mordialloc Main Drain at Springvale Rd	3.11E-01	11.8	Kororoit Creek at Racecourse Rd	2.32E+00	16.0
4	Kananook Creek at Beach Street	2.04E-01	7.7	Mordialloc Main Drain at Springvale Rd	1.29E+00	8.9
5	Saltworks drain Newcomb	1.34E-01	5.1	Heatherton Road drain at Crown Ave	9.12E-01	6.3
6	Laverton Creek at Queen St	9.55E-02	3.6	Cowderoy Street Main drain at Railway Culvert Canterbury Rd	4.37E-01	3.0
7	Kororoit Creek at Racecourse Rd	9.38E-02	3.6	Cowies Creek at Corio Quay Rd	3.62E-01	2.5
8	Dunlops drain at Canterbury Road	8.14E-02	3.1	Kananook Creek at Beach St	2.35E-01	1.6
9	Chinamans Creek at Nepean Hwy	7.00E-02	2.7	Chinamans Creek at Nepean Hwy	2.26E-01	1.6
10	Cowderoy Street Main drain at Railway Culvert Canterbury Rd	5.93E-02	2.2	Laverton Creek At Queens St	1.47E-01	1.0
	Others (n=98)	6.68E-01	25.3	Others (n=98)	1.25E+00	8.6
Total		**2.64E+00**			**1.45E+01**	

Table 6. The ten highest-ranking sources for each imput variable (Page 3)

Table 6. The ten highest-ranking sources for each input variable (page 4)

	Nickel			Iron		
Rank	Site	Load (Tonnes)	% of Total Load	Site	Load (Tonnes)	% of Total Load
1	Mordialloc Settlement drain at Canterbury Rd	1.94E+00	22.6	Patterson River at Wells Rd	1.07E+03	29.0
2	Patterson River at Wells Rd	1.67E+00	19.5	Mordialloc Settlement drain at Canterbury Road	8.70E+02	23.5
3	Mordialloc Main Drain at Springvale Rd	8.81E-01	10.3	Mordialloc Main Drain at Springvale Rd	4.45E+02	12.0
4	Heatherton Road drain at Crown Ave	7.72E-01	9.0	Cowies Creek at Corio Quay Rd	1.70E+02	4.6
5	Kororoit Creek at Racecourse Rd	6.06E-01	7.1	Dromana Hotel drain at mouth	1.63E+02	4.4
6	Kananook Creek at Beach Street	5.18E-01	6.1	Sweetwater Creek at Nepean Hwy	1.40E+02	3.8
7	Laverton Creek at Queen St	3.14E-01	3.7	Heatherton Road drain at Crown Ave	9.61E+01	2.6
8	Dunlops drain at Canterbury Road	2.68E-01	3.1	Kananook Creek at Beach St	8.68E+01	2.3
9	Cowies Creek at Corio Quay Rd Geelong	2.36E-01	2.8	Cowderoy Street Main drain at Railway Culvert Canterbury Rd	8.58E+01	2.3
10	Cowderoy Street Main drain at Railway Culvert Canterbury Rd	1.78E-01	2.1	Kororoit Creek at Racecourse Rd	6.29E+01	1.7
	Others (n=98)	1.19E+00	13.9	Others (n=98)	5.11E+02	13.8
Total		**8.56E+00**			**3.70E+03**	

Table 6. The ten highest-ranking sources for each imput variable (Page 4)

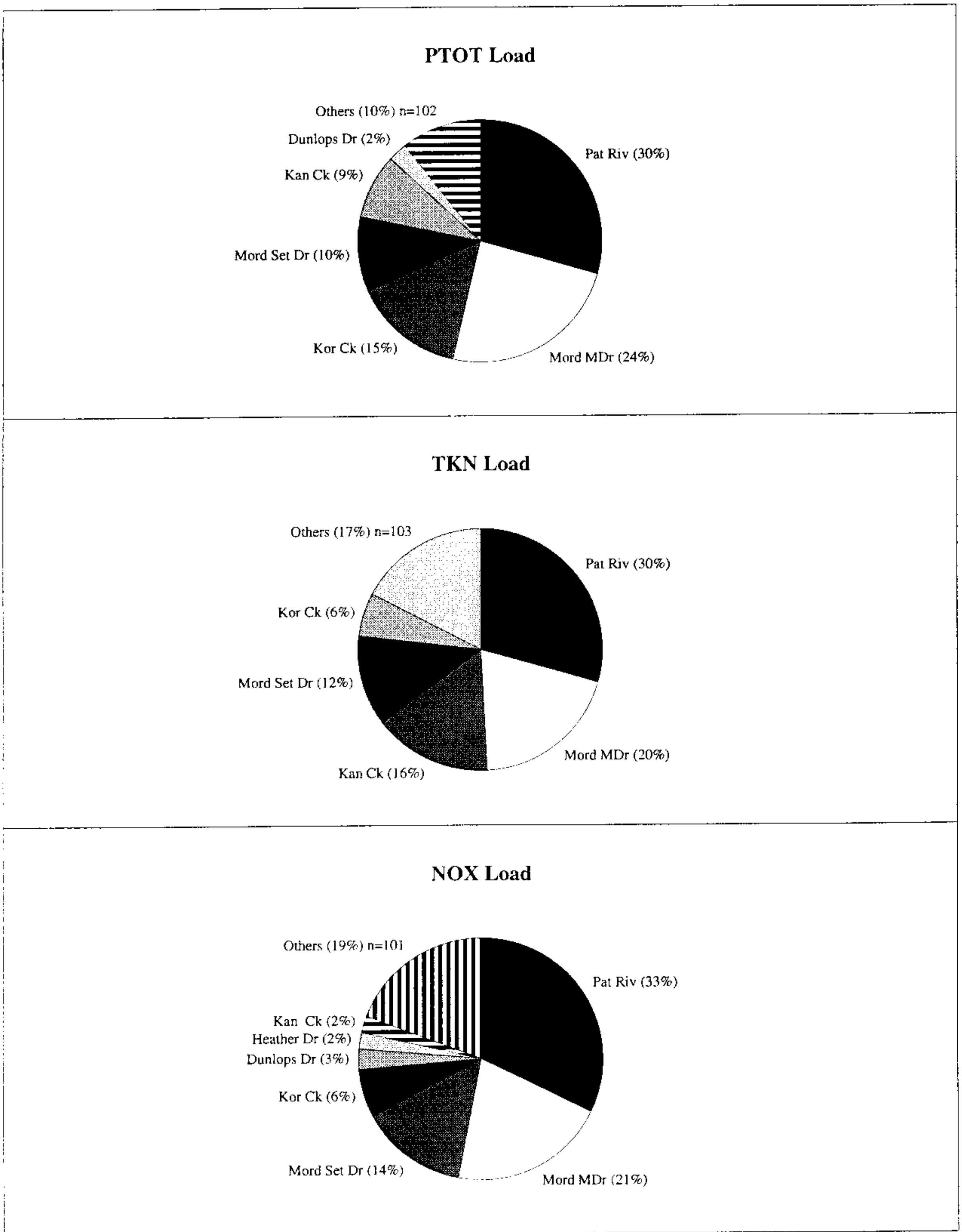


Figure 7. Percentage contribution of surface drainage imputs into Port Phillip Bay
(Page 1)

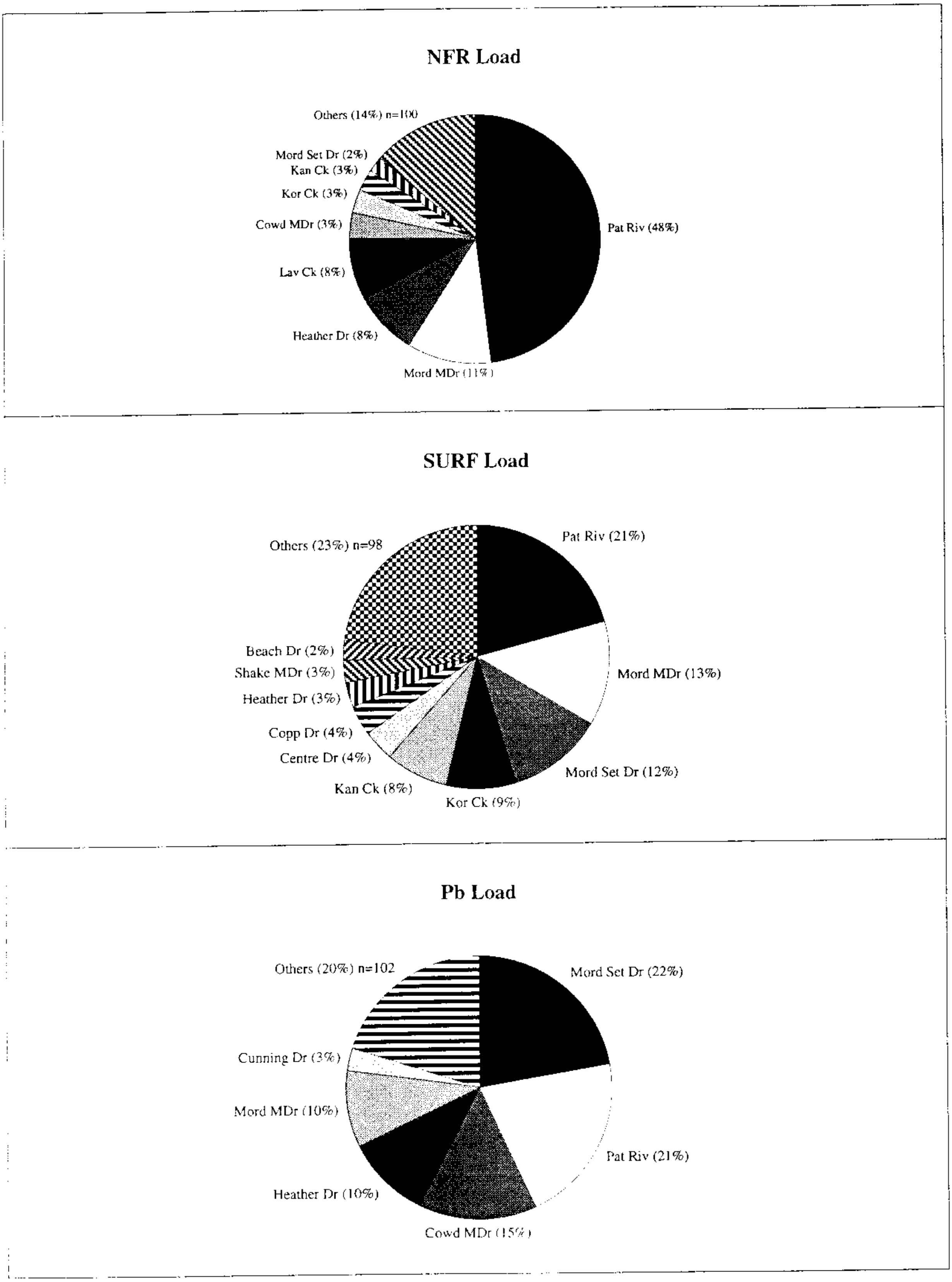


Figure 7. Percentage contribution of surface drainage imputs into Port Phillip Bay (Page 2)

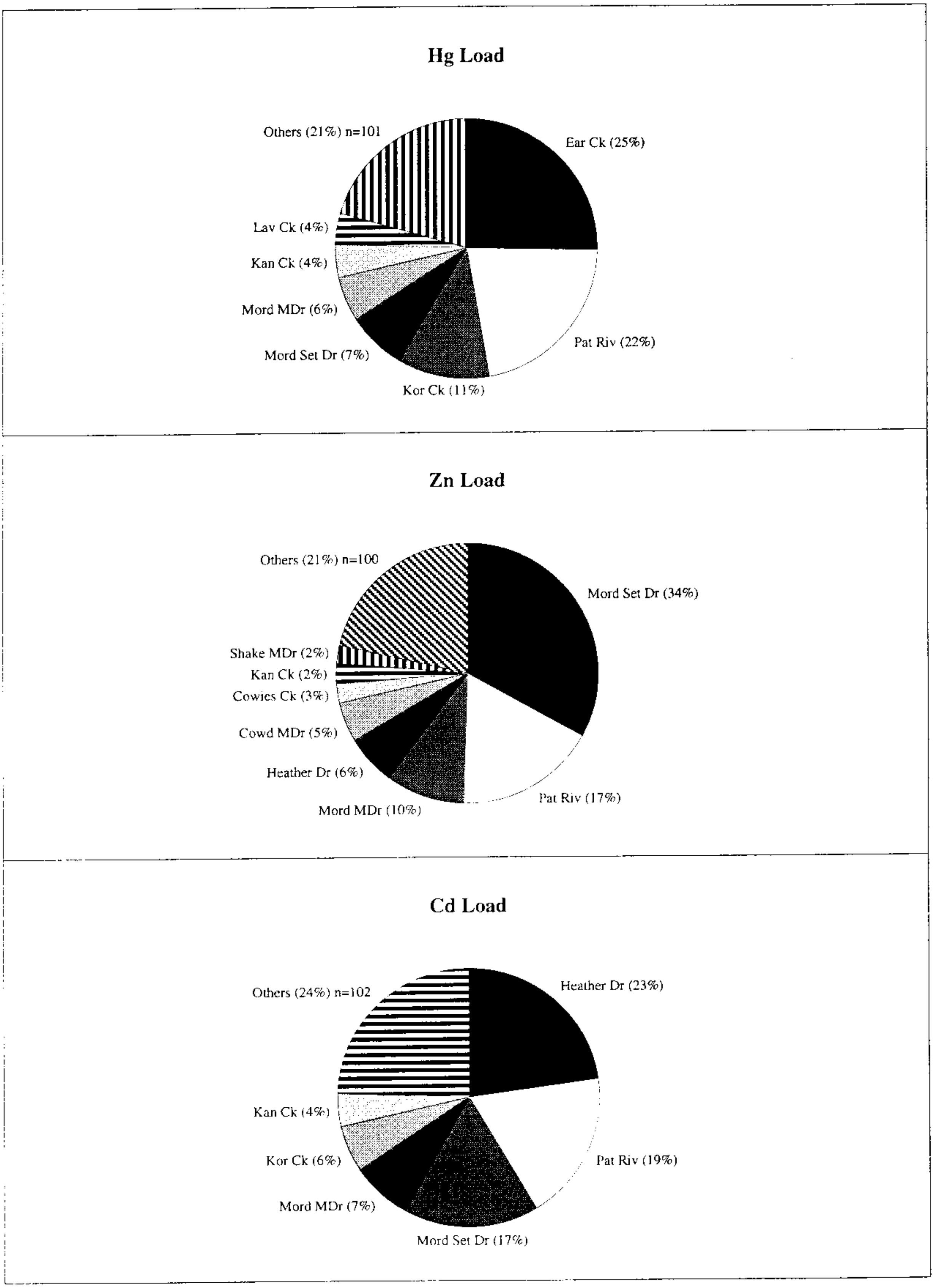


Figure 7. Percentage contribution of surface drainage imputs into Port Phillip Bay
(Page 3)

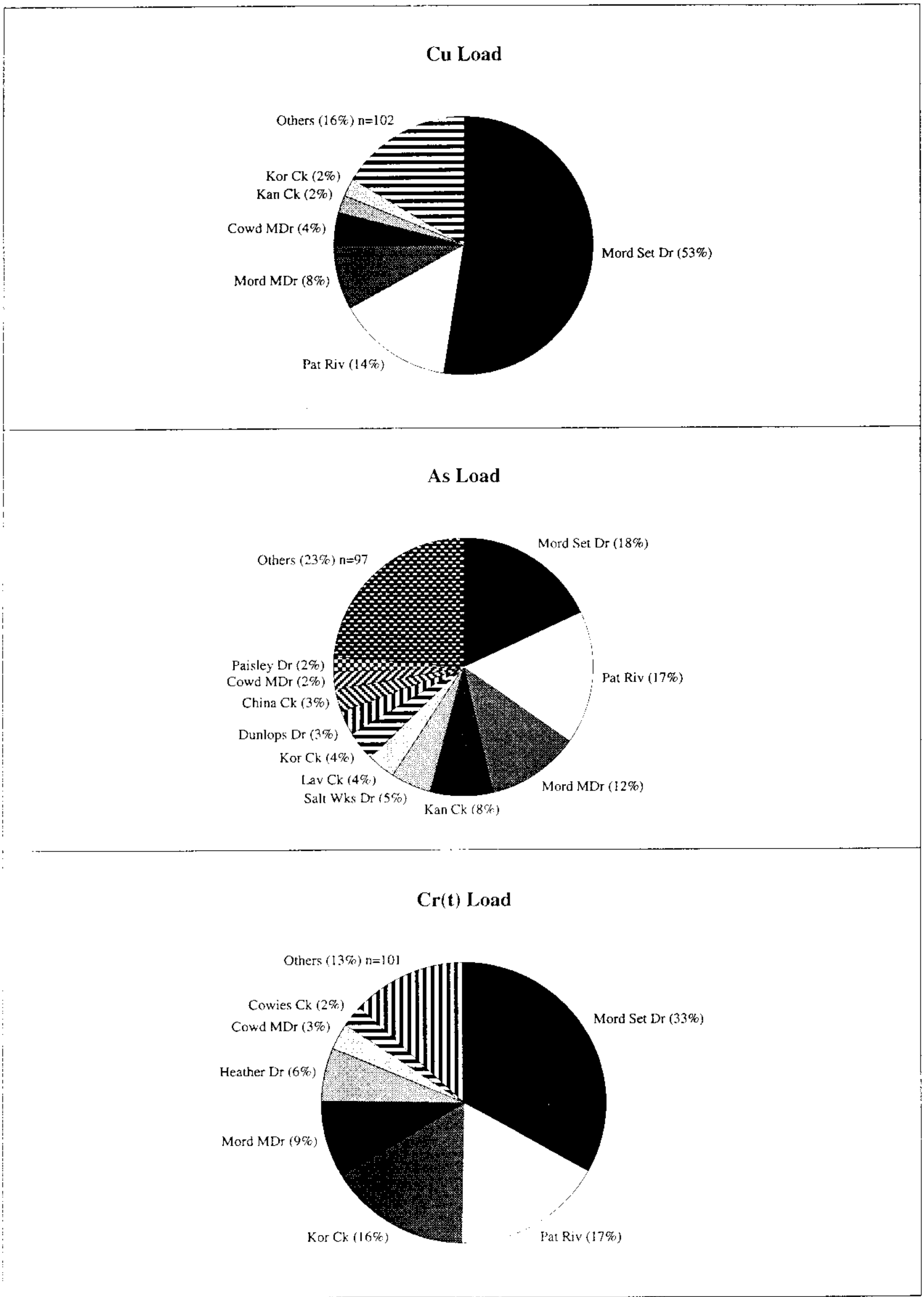
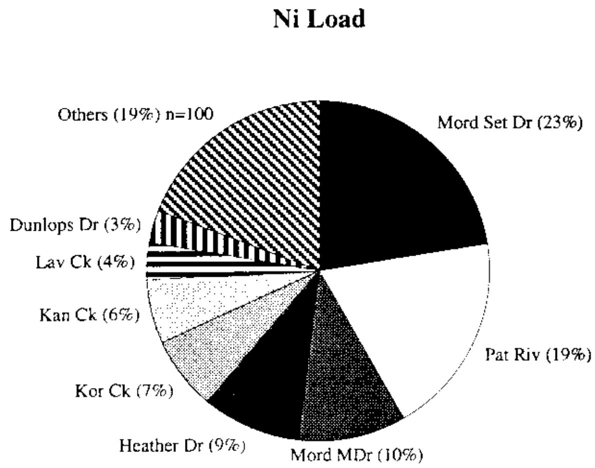


Figure 7. Percentage contribution of surface drainage imputs into Port Phillip Bay (Page 4)



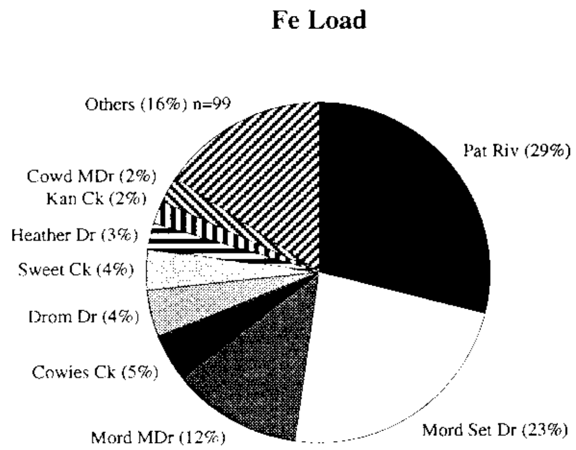


Figure 7. Percentage contribution of surface drainage imputs into Port Phillip Bay (Page 5)

Cowies Creek at Corio Quay Road, which has been previously identified as a major source of metals into Corio Bay, is ranked 6 for Zn, 9 for Cd, 10 for Cu, 7 for Cr(t), 9 for Ni and 4 for Fe. Similarly, Kororoit Creek at Racecourse Rd, Altona, is ranked 3 for P(tot) (15% of total load), 5 for TKN (6%), 4 for NOX (7%), 6 for NFR (3%), 4 for surfactants (9%), 10 for Pb (1%), 3 for Hg (12%), >10 for Zn (<2%), 5 for Cd (6%), 6 for Cu (2%), 7 for As (4%), 3 for Cr(t) (16%), 5 for Ni (7%) and 10 for Fe (2%). A somewhat anomalous feature is that Earimil Creek at Mt Eliza is ranked 1 for Hg, with a contribution of 26% of total input. This is largely the result of a single very high concentration out of 9 samples analysed.

The most significant input to Port Phillip Bay, excluding the Yarra River and WTC discharges, is from the Patterson River/Mordialloc Main Drain catchment. This is primarily a feature of the relatively large flow contribution of these two sources, which collectively account for about 54% of the total flow from minor sources entering the Bay. Three other drains in the area, namely Dunlops drain, Mordialloc Settlement drain and Heatherton Road drain, also flow into the Mordialloc Main Drain downstream of the sampling site on the drain. The loads from these drains feature prominently in terms of percentage contribution to load totals, particularly those associated with the Mordialloc Settlement drain which discharges high loads of Pb, Zn, Cu, As, Cr, Ni and Fe.

Comparison with other estimates of nutrient loads for the Patterson River is possible. The daily load estimates from the 1979-81 data are 300 kg/d (total P) and 1344 kg/d (Kjeldahl N and oxidised N), which compare favourably with 320 kg/d (total P) and 1100 kg/d (total N) reported by CCE (1978). Other estimates for the Patterson River (EPA 1979) are 371 kg/d (total P), 1650 kg/d (total N) and 60 kg/d (total Pb, Zn, Cd, Cu, As, Cr and Ni). The latter value can be compared with a value of 45 kg/d found in this study.

3.2.3 Comparison with Yarra River inputs

Although load calculations for the Yarra River catchment were excluded from the initial brief for this study, it was decided in consultation with the Project Manager to undertake a comparison of the findings of this study with inputs from the Yarra River, calculated using the same EPA data set. Therefore, load calculations using the flow-weighted mean method were performed for sites within this catchment and summed to get an approximate representation of total pollutant load. The results (Table 7) show that the Yarra River catchment contributes 64% of all surface flow and 23 to 73% of all surface pollutant loads into Port Phillip Bay (excluding the WTC and other EPA-licensed discharges). These data are summarised in Figure 8.

3.2.4 Sources of error

Sources of error in these load estimates are likely to include:

- Analytical error in the measurement of water quality variable concentrations.
- Error in flow estimation when sampling.
- Non-representative sampling.

Table 7. Comparison of Yarra and non-Yarra River inputs into Port Phillip Bay*

Variable	Input (1979-81) excluding the Yarra R. (tonne/yr)	Input (1979-81) for Yarra R. (tonne/yr)	Yarra R. contribution to total loads (%)
Flow (ML)	273000	486000	64
P(tot)	374	114	23
TKN	1106	590	35
NOX	530	458	46
NFR	14000	38800	73
Surfactants	54	52	49
Pb	11	19	63
Hg	0.04	0.04	50
Zn	58	63	52
Cd	0.14	0.17	55
Cu	8	6.6	45
As	0.9	1.4	61
Cr(t)	4.8	7.8	62
Ni	2.9	6.3	69
Fe	1235	2373	66

*Excluding WTC

The expected precision associated with the determinations of metals and nutrients is ± 25% for low-level concentrations (those less than 20 times the detection limits) and ± 10% for high level concentrations (those greater than 20 times the detection limits) (APHA, 1992). Errors associated with flow estimates are difficult to determine. However, although neither Melbourne Water nor the Rural Water Corporation (RWC) have stream gauging stations close to the two sites on the Patterson River and Mordialloc Main Drain sampled by EPA, discharge measurements are available for Mile Creek and Dandenong Creek at Dandenong, and Eumemmerring Creek at Lyndhurst. These three sites combined represent nearly all of the flow into the Patterson River and Mordialloc Main Drain. The total discharge during the sampling period for these creeks was 263,000 ML, with additional input from Melbourne Water's Wastewater Treatment Plant at Dandenong being about 45,000 ML. This total flow of 308,000 ML agrees well with a total flow estimate of 318,000 ML from EPA's data for Patterson River and Mordialloc Main Drain, and indicates that flow estimates were reasonably accurate.

The largest area of concern is the representativeness of the samples in terms of the total loads carried by the streams and drains. Although a number of sites which produce substantial pollutant loads were sampled in excess of 20 times, e.g. the Patterson River, Mordialloc Main Drain, Kororoit Creek in Altona and Cowies Creek and Cunningham Pier drain in Geelong, loads for other sites were often calculated from less than 20 samples and are thus susceptible to bias by extreme values. An example is the Mordialloc Settlement drain, where for one sample (out of a total of 9) a flow of 600 ML/d was estimated, nearly 95 times greater than the sample median. The corresponding Cu concentration was 0.17 mg/L, about 5 times greater than the sample median. Values such as these were retained in the data set because there was insufficient information to warrant their deletion.

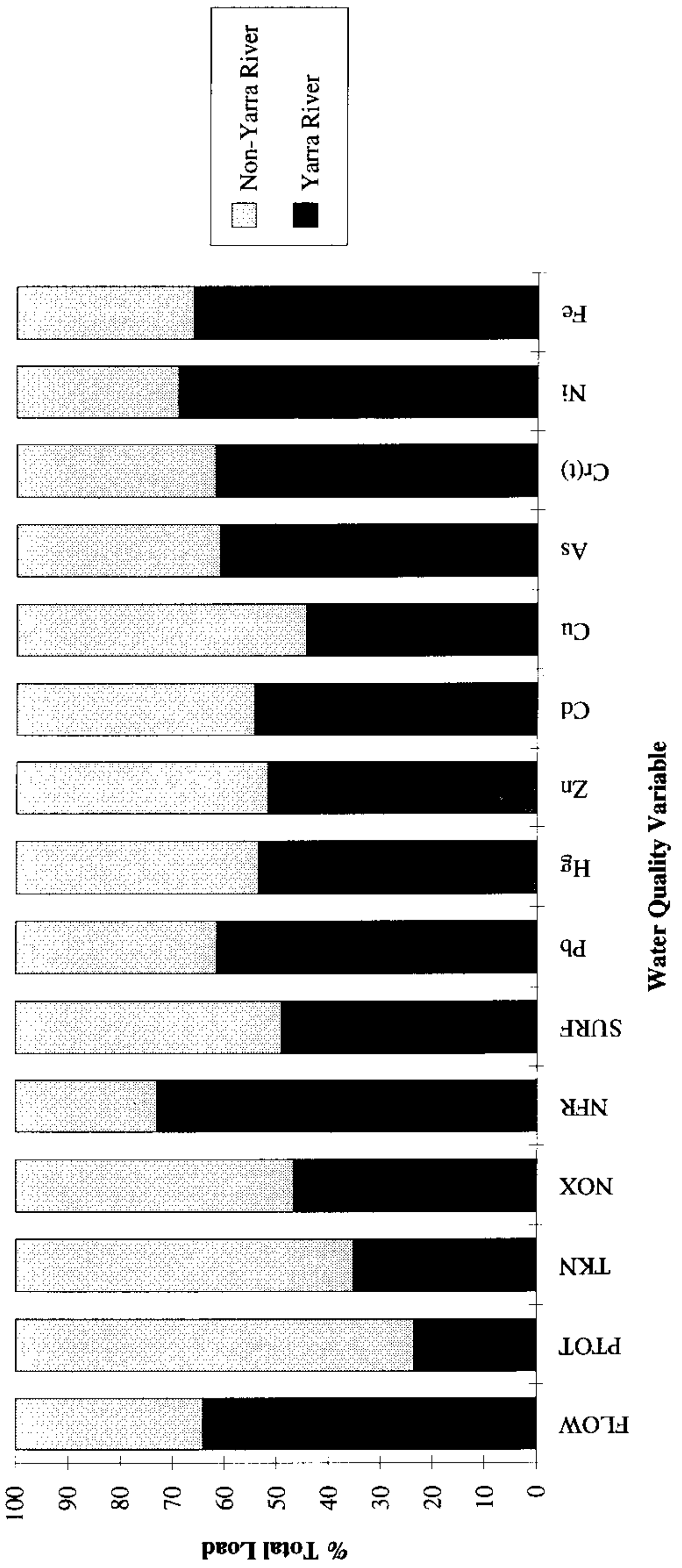


Figure 8. Percentage of Yarra and non-Yarra River surface drainage imputs

An initial assessment of the error associated with possible non-representative sampling is offered by examination of the flow data for the Patterson River. As described above, comparison of estimated flow and measured flow during the sampling period is in good agreement. Assuming that samples were taken concurrently with flow estimates, it appears that the Patterson River, at least, was sampled on a representative basis.

A quantitative estimate of the error associated with these load estimates was undertaken by examining the probability distributions of the calculated loads. Again examining the Patterson River (n = 325) first, frequency histograms and probability plots (i.e. plots of the values of a variable versus its theoretical distribution) indicated that all loads and flow were substantially right skewed and followed a gamma-type probability distribution. Assuming that similar distributions apply to the other sampling sites, the implications for load estimates based on small sample numbers is that although the probability of getting a very large estimate might be quite small in a large sample, just one large result in a small sample would grossly overestimate a load calculation based on mean flow.

Given this non-normal distribution, two approaches were taken to quantifying error and placing confidence limits on load estimates, i.e. defining a range within which there is a 95% probability that the true mean can be found. The first involves the conventional approach of placing a confidence interval on a mean from a normal distribution, i.e. a 100(1-α)% confidence interval for the sample mean is given by:

$$\hat{\theta} \pm Z_{\alpha/2} \frac{s}{\sqrt{n}}$$

where $\hat{\theta}$ is the load estimate of interest and s is the standard deviation from $\hat{\theta}$.

In this case, $\hat{\theta}$ is the estimate gained by multiplying the mean flow by the flow-weighted mean concentration. This is the same as averaging the loads for each sample, provided that the number of flow values is the same as the number of load values. With these data sets, this was not always the case, but in each case $\hat{\theta}$ and the sample mean are approximately equal and hence this approach is not invalidated.

This method is only appropriate if there is a large sample size, which allows the use of the Central Limit Theorem (which implies that $\hat{\theta}$ is approximately normally distributed if the sample size is large). A sample size greater than thirty is usually considered large enough to be approximately normal (Zar, 1984). This method allowed 95% confidence intervals to be determined for the Patterson River and Mordialloc Creek data, where sample sizes were 325 and 113, respectively. The results are shown in Table 8.

To provide a comparative estimate of the size of the confidence intervals, the upper confidence limit has been divided by the load estimate to give a percentage ratio of upper confidence limit to estimate. A large ratio for a particular variable implies a large amount of variation. The results in Table 8 for the Patterson River and Mordialloc Main drain

Table 8. Estimates and confidence intervals for inputs into Port Phillip Bay from Patterson River and Mordialloc Main Drain (Load estimates in tonnes/year)

Patterson River

	Flow (ML)	P(tot)	TKN	NOX	NFR	Surfactant	Pb	Hg	Zn	Cd	Cu	As	Cr(t)	Ni	Fe
Estimated Input	68900	109	321	169	6660	11	2.3	0.008	10	0.03	1.2	0.15	0.8	0.5	352
Lower Confidence Interval	56700	99	283	136	4660	10	1.4	0.002	8	0.02	0.9	0.11	0.6	0.5	180
Upper Confidence Interval	81100	120	360	203	8660	12	3.3	0.014	12	0.03	1.4	0.18	1.0	0.6	524
Ratio of Upper Confidence Limit to Estimate	1.18	1.09	1.12	1.20	1.30	1.11	1.39	1.74	1.23	1.23	1.19	1.22	1.25	1.17	1.49

Mordialloc Main Drain

	Flow (ML)	P(tot)	TKN	NOX	NFR	Surfactant	Pb	Hg	Zn	Cd	Cu	As	Cr(t)	Ni	Fe
Estimated Input	35500	88	216	109	1480	7	1.1	0.002	6	0.01	0.7	0.10	0.4	0.3	146
Lower Confidence Interval	27100	69	156	84	1050	5	0.6	0.001	3	0.01	0.5	0.07	0.3	0.2	80
Upper Confidence Interval	43900	107	276	133	1910	8	1.6	0.003	9	0.01	0.8	0.13	0.6	0.4	212
Ratio of Upper Confidence Limit to Estimate	1.24	1.22	1.28	1.22	1.29	1.22	1.45	1.26	1.51	1.38	1.30	1.27	1.32	1.26	1.45

Table 8. Estimates and confidence intervals for imputs into Port Phillip Bay from Patterson River and Mordialloc Main Drain (Load estimates in tonnes/year)

suggest that the variables having the largest errors associated with the load estimates are NFR, Pb, Hg, Zn, Cd, Cr(t) and Fe. None of the variables, with the exception of Zn in the Mordialloc Main Drain, have an upper confidence level more than 1.5 times greater than the actual estimated input.

An alternative approach is required for small sample sets where the Central Limit Theorem can't be applied. Data transformations, such log(x), $x^{1/2}$ and $x^{1/4}$, were used to transform the approximate gamma distributions to normality, but the resulting estimates were considered too variable to be useful.

A more appropriate method for determining confidence intervals for these small sample sets is a simple bootstrap approach. This requires drawing random subsets from the sample set, calculating the mean flow and loads for each subsample and then use these means to calculate a mean and confidence interval for the entire sample set (Efron, 1987). This method reduces the effect of non-representative data and gives an indication of the range of load estimates when non-representative values are included or excluded. The bootstrap method was therefore used for three sites (Heatherton Road drain, Earimil Creek and Mordialloc Settlement drain) which represented a large proportion of the total load for each variable, but where load estimates were based on less than ten samples. For a sample set of size *n*, *n* samples were drawn randomly with replacement; since all samples sets were small, it was considered sufficient to draw fifteen such subsets for each sample site.

The results are summarised in Table 9. As with the previous estimates, a ratio of upper confidence limit to load estimate has been calculated. Table 9 also includes the original input estimate and the maximum and minimum means of each of the bootstrap samples.

At the Heatherton Road drain, the overall bootstrap mean of all load estimates, except surfactants, decreased slightly in comparison with the original flow-weighted mean concentration/mean flow estimates. The ratios of confidence limit to estimate are similar to those for the Patterson River and Mordialloc Creek, with those for NFR and Cd increasing, and Hg decreasing. Once again, all confidence limits, except NFR, lie within 1.5 times the mean. Similar results were gained at Earimil Creek, with final bootstrap estimates close to the original estimates.

The Mordialloc Settlement drain was sampled only nine times, with one flow sample nearly 100 times greater than the sample median. The ratio of upper confidence limit to bootstrap estimate shows the effect of this extreme value, with the confidence limit for NFR load being the only one which lies within 1.5 times the estimate. Not surprisingly, this indicates the substantial difference in estimated loads when the unusually high flow value is retained. Observing the minimum and maximum bootstrap samples for the Mordialloc Settlement drain, considerable differences can occur in the estimated loads depending when the samples were taken. That is, if many samples were taken at high flow the load estimates would be close to the maximum bootstrap sample, and if they were taken at low flow they would be close to the minimum bootstrap sample. The differences between these estimates is significant; for example, the maximum bootstrap sample mean for flow is 125 times greater than the minimum, while the maximum bootstrap sample mean for Fe loads is 650 times greater than the minimum.

Table 9. Estimates and associated confidence intervals for inputs into Port Phillip Bay at three sites (Load estimates in tonnes/year)

Heatherton Road Drain at Crown Ave

	Flow (ML)	P(tot)	TKN	NOX	NFR	Surfactants	Pb	Hg	Zn	Cd	Cu	As	Cr(t)	Ni	Fe
Original Input Estimate	4800	3.8	16	12.4	1170	1.7	1.13	0.0003	3.4	0.03	0.14	0.01	0.30	0.25	32
Minimum Subsample Mean	1700	1.8	7	7.1	34	0.8	0.03	0.0001	0.8	0.003	0.05	0.01	0.14	0.14	4
Maximum Subsample Mean	6530	4.6	21	16.5	2950	2.9	2.20	0.0004	5.3	0.08	0.23	0.02	0.38	0.37	56
Overall Mean	4030	3.3	14	11.6	940	1.7	0.76	0.0002	2.6	0.03	0.12	0.01	0.26	0.23	23
Lower Confidence Interval	3230	2.8	12	10.1	420	1.3	0.39	0.0002	1.9	0.02	0.09	0.01	0.22	0.19	14
Upper Confidence Interval	4840	3.8	16	13.2	1460	2.1	1.13	0.0003	3.3	0.04	0.15	0.02	0.30	0.27	31
Ratio of Upper Confidence Limit to Estimate	1.20	1.14	1.17	1.13	1.55	1.22	1.49	1.24	1.27	1.43	1.24	1.19	1.15	1.17	1.39

Earimil Creek at mouth

	Flow (ML)	P(tot)	TKN	NOX	NFR	Surfactants	Pb	Hg	Zn	Cd	Cu	As	Cr(t)	Ni	Fe
Original Input Estimate	600	0.03	0.6	0.4	27	0.04	0.008	0.009	0.06	0.0001	0.003	0.001	0.001	0.001	1.6
Minimum Subsample Mean	94	0.004	0.1	0.04	0.21	0.004	0.001	0.00001	0.01	0.00002	0.0003	0.0000	0.0001	0.0003	0.1
Maximum Subsample Mean	1370	0.07	1.6	1.0	47	0.09	0.019	0.027	0.15	0.0002	0.007	0.001	0.002	0.003	4.1
Overall Mean	623	0.03	0.7	0.4	16	0.04	0.009	0.010	0.07	0.0001	0.003	0.001	0.001	0.001	1.7
Lower Confidence Interval	449	0.02	0.5	0.3	7	0.03	0.006	0.006	0.05	0.0001	0.002	0.000	0.001	0.001	1.1
Upper Confidence Interval	798	0.04	0.9	0.6	25	0.05	0.011	0.014	0.09	0.0001	0.004	0.001	0.001	0.002	2.2
Ratio of Upper Confidence Limit to Estimate	1.28	1.27	1.30	1.32	1.54	1.29	1.29	1.41	1.30	1.27	1.28	1.31	1.28	1.25	1.34

Mordialloc Settlement Drain at Canterbury Road

	Flow (ML)	P(tot)	TKN	NOX	NFR	Surfactants	Pb	Hg	Zn	Cd	Cu	As	Cr(t)	Ni	Fe
Original Input Estimate	26400	37	132	73	279	6	2.5	0.003	19	0.02	4	0.2	1.6	0.6	286
Minimum Subsample Mean	599	0.03	1	0.4	7	0.04	0.01	0.0001	0.1	0.0001	0.003	0.001	0.001	0.001	1
Maximum Subsample Mean	74700	102	360	199	40	20	7.4	0.009	56	0.07	12	0.4	4.5	1.8	850
Overall Mean	21400	30	109	59	21	6	2.0	0.003	15	0.02	3	0.1	1.3	0.5	229
Lower Confidence Interval	6850	10	39	21	17	2	0.6	0.001	4	0.01	1	0.0	0.4	0.2	60
Upper Confidence Interval	36000	50	179	97	26	9	3.5	0.004	26	0.03	6	0.2	2.2	0.9	398
Ratio of Upper Confidence Limit to Estimate	1.68	1.66	1.64	1.64	1.23	1.67	1.72	1.64	1.73	1.68	1.73	1.65	1.68	1.68	1.74

Table 9. Estimates and associated confidence intervals for imputs into Port Phillip Bay at three sites (Load estimates in tonnes/year)

3.2.5 Relevance of the data

It should be noted that the relevance of the data to the present will be affected by a number of changes in land-use since the sampling program was completed in 1981 and the ongoing program to connect premises to sewer.

Recent water quality data is shown in Table 10 together with that used in this study for four streams - Werribee River, Mordialloc Main Drain, Kororoit Creek and Patterson River. The data are presented graphically in Figure 9.

Evaluation in terms of median values shows the following:

- Both nutrient and toxicant concentrations for the Patterson River are lower in the 1989 data compared with the 1979-81 results, ranging from 20 to 73% of the latter, while NFR is slightly higher in the more recent data.
- Total P concentrations in the Mordialloc Main Drain/Mordialloc Creek have remained the same, while Kjeldahl N has doubled and oxidised N has halved. Toxicant concentrations are similar for both data sets, and NFR is considerably higher (more than double) in the more recent data.
- All variable levels have decreased in the more recent data for Kororoit Creek, with 1989 median values ranging from 54 to 99% of the earlier results.
- While toxicant, total P and NFR concentrations have increased in the Werribee River, oxidised N values have decreased by an order of magnitude, and Kjeldahl N has remained about the same.

These data do not take into account discharge variations between the two sampling periods. Nevertheless, the 1979-81 results appear to be generally similar to those determined in 1989.

A major factor concerning variable concentrations in the Patterson River/Mordialloc Main Drain system is the fate of effluent from Melbourne Water's Wastewater Treatment Plant at Dandenong. During the 1979-81 sampling period, the average dry weather effluent discharge from the plant was about 41 to 42 ML/day, or 45,000 ML over the entire period. This corresponds to a 17% increment to the combined flow measured in this same period in Mile, Dandenong and Eumemmerring creeks (263,000 ML) (which are the major feeder streams into the system), and indicates the significant volumetric input from the treatment plant. This effluent discharge rate decreased to 38 ML/day in 1990, while combined discharge rates in April and May 1993 from the lagoons were 37 and 36 ML/day, respectively.

Changes in effluent quality can be evaluated by comparing median variable concentrations in the discharges from lagoons 7 and 11 in 1978-80 and 1992-93 (Table 11). These data show that effluent quality in terms of nutrients has remained largely unchanged between the sampling period and the present, apart from a substantial increase in oxidised N concentrations in Lagoon 11, while NFR concentrations have decreased. When these results are considered in conjunction with the discharge data described above, it is apparent that the 1979-81 data are still generally relevant to the present situation with respect to

	Total P	Kjeldahl N	Oxidised N	NFR	Pb	Zn	Cu	Cr (t)	Ni
Werribee River Lower at Werribee Park ford, Werribee (1979-81)									
Sample Number	8	8	8	2	8	8	8	8	8
Median	0.04	0.63	2.30	4.25	0.0013	0.0020	0.0009	0.0010	0.0020
10%ile	0.03	0.49	0.50	1.25	0.0009	0.0009	0.0004	0.0009	0.0016
90%ile	0.08	0.75	2.90	7.25	0.0043	0.0072	0.0020	0.0029	0.0023
Werribee River at Cobbledick ford (1989)									
Sample Number	22	22	22	22	22	22	no data	no data	no data
Median	0.08	0.65	0.22	23.00	0.0020	0.0045	no data	no data	no data
10%ile	0.05	0.5	0.11	14.00	<0.002	<0.002	no data	no data	no data
90%ile	0.37	1.4	0.94	51.00	0.0060	0.0150	no data	no data	no data
Mordialloc Main Drain at Springvale Rd (1979-81)									
Sample Number	109	111	112	63	112	112	112	112	112
Median	2.50	5.20	3.25	22.00	0.0180	0.1100	0.0130	0.0090	0.0080
10%ile	0.93	2.20	1.80	9.00	0.0061	0.0500	0.0084	0.0030	0.0040
90%ile	5.10	11.00	5.89	81.80	0.0369	0.1800	0.0254	0.0169	0.0110
Mordialloc Creek at Wells Rd (1989)									
Sample Number	24	25	25	25	25	22	25	24	25
Median	2.40	9.70	1.20	58.00	0.0150	0.0985	0.0120	0.0075	0.0070
10%ile	0.66	2.80	0.84	22.00	0.0060	0.0800	0.0070	<0.002	0.0030
90%ile	4.80	17.00	1.90	110.00	0.0310	0.1600	0.0340	0.0150	0.0130
Kororoit Ck at Racecourse Rd, Altona U/S Ford (1979-81)									
Sample Number	237	238	239	171	241	242	242	241	242
Median	1.40	3.60	1.70	21.00	0.0080	0.0345	0.0100	0.0380	0.0090
10%ile	0.80	2.27	0.38	10.00	0.0040	0.0150	0.0050	0.0130	0.0051
90%ile	2.40	6.46	3.20	35.00	0.0170	0.0700	0.0187	0.1100	0.0200
Kororoit Ck at Station Rd, Deer Park (1989)									
Sample Number	24	24	24	24	24	24	24	24	24
Median	0.92	3.25	0.92	15.50	0.0075	0.0340	0.0070	0.0300	0.0045
10%ile	0.46	1.90	0.15	10.00	0.0040	0.0170	0.0030	0.0120	0.0020
90%ile	1.80	8.50	2.20	52.00	0.0290	0.0930	0.0240	0.0640	0.0220
Patterson River at Wells Rd (1979-81)									
Sample Number	320	324	324	232	327	327	326	326	326
Median	2.30	5.45	2.70	41.00	0.0150	0.0900	0.0140	0.0100	0.0080
10%ile	0.79	2.63	1.40	22.00	0.0060	0.0400	0.0064	0.0040	0.0040
90%ile	4.10	9.67	3.80	120.00	0.0394	0.1800	0.0238	0.0160	0.0130
Patterson River U/S of freeway (1989)									
Sample Number	25	25	25	25	25	25	25	25	25
Median	0.50	2.20	1.40	50.00	0.0110	0.0490	0.0060	0.0020	0.0030
10%ile	0.32	1.30	0.70	29.00	0.0070	0.0320	0.0030	<0.002	0.0020
90%ile	0.61	3.40	1.90	87.00	0.0160	0.0850	0.0100	0.0040	0.0050

Source: EPA, (1992)

Table 10. Comparison 1978-81 and 1989 water quality data for selected sites (mg/L)

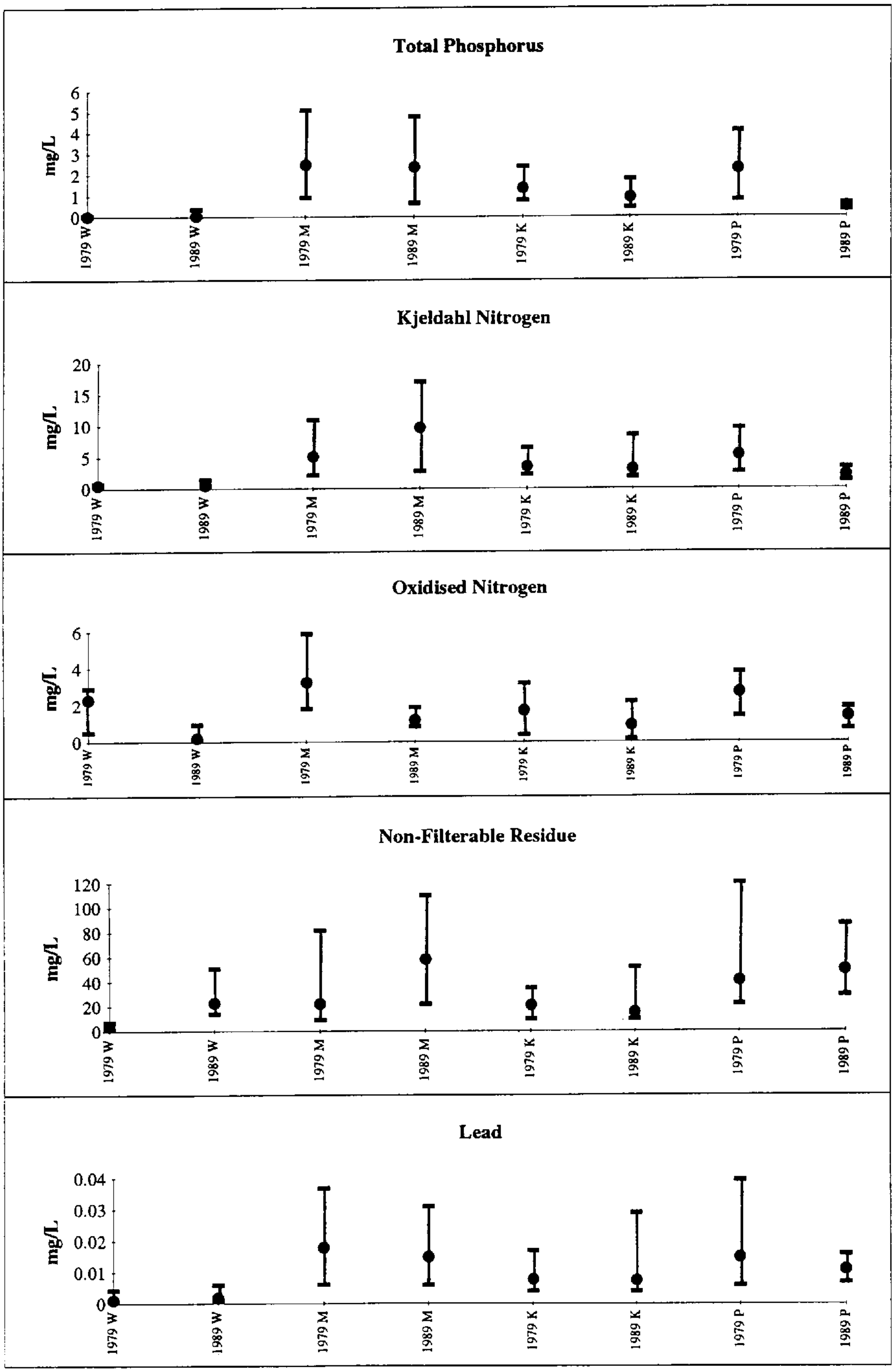


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Figure 9. Comparison 1979-81 and 1989 water quality data for selected sites (page 1)

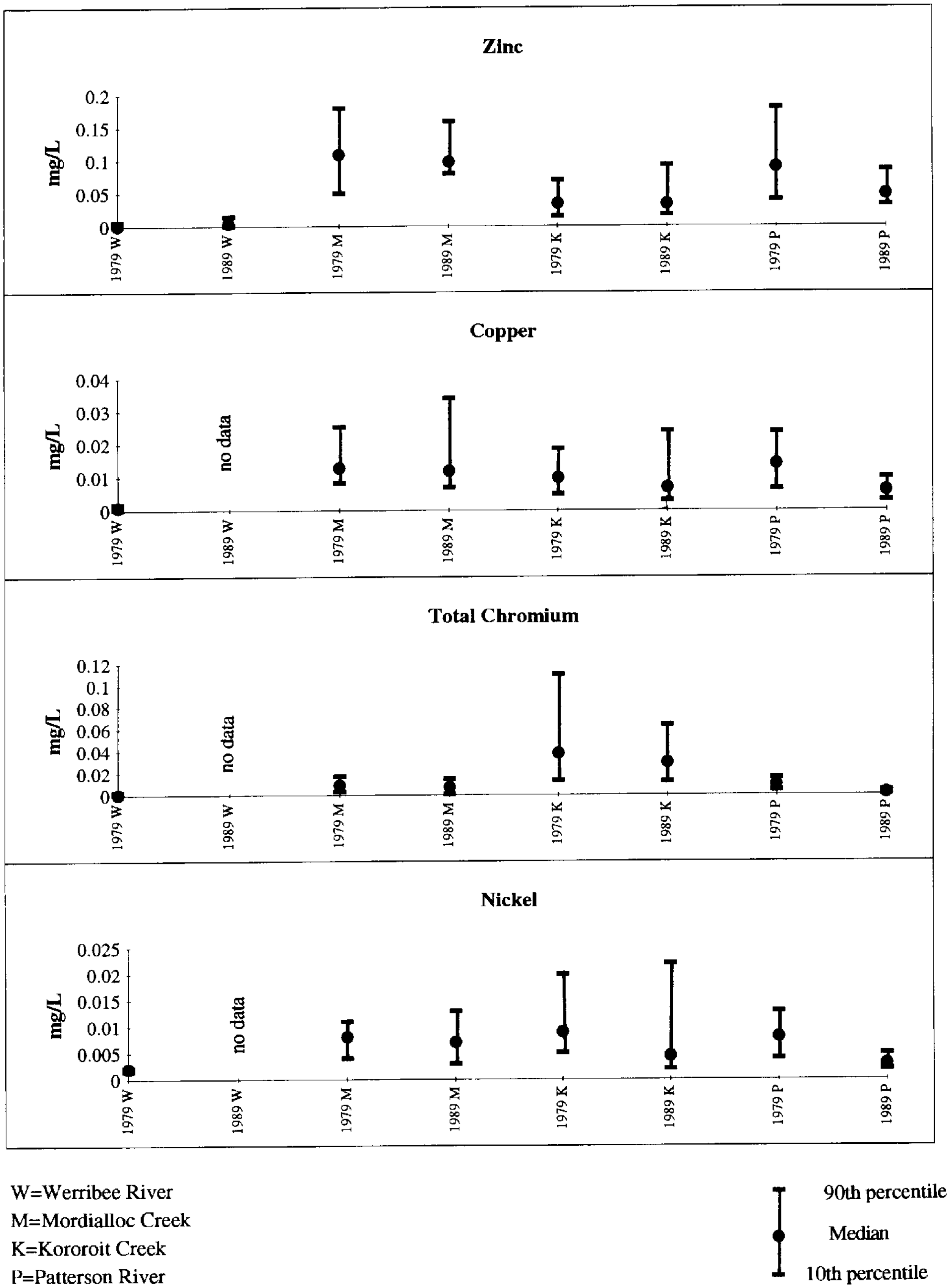

Figure 9. Comparison 1979-81 and 1989 water quality data for selected sites (page 2)

inputs from the Wastewater Treatment Plant, notwithstanding possible decreases in suspended material from the plant. However, this discharge is to cease in 1994, and the EPA is about to embark on a program aimed at improving water quality in the Mordialloc Creek and other streams in the area (EPA, 1993). Depending on the success of this program, loads entering the Bay from this system are expected to decrease in the future.

Table 11. Effluent quality from Melbourne Water's Dandenong Wastewater Treatment Plant (mg/L)

Variable	1978-80		1992-93	
	Lagoon 7	Lagoon 11	Lagoon 7	Lagoon 11
NFR (mean [n])	21 [25]	25 [25]	11 [25]	14[25]
P(tot) (mean [n])	9.6 [25]	9.6 [25]	7.4 [24]	7.8 [24]
NOX (mean [n])	2.3 [25]	0.5 [25]	3.1 [25]	5.1 [25]
Org N (mean [n])	4.7 [25]	5.5 [25]	3.8 [25]	4.8 [25]

Another approach to determining the applicability of the data to the present situation is by examining the discharge data during the sampling period with respect to long-term discharge records. Again focussing on the Patterson River/Mordialloc Main Drain system due to the availability of records and the importance of this system in terms of loads, the combined mean annual flow for Mile, Dandenong and Eumemmerring creeks in 1979-81 was 85,400 ML. This can be compared with a long-term[1] combined mean annual flow of 84,000 ML, and hence indicates that the sampling period occurred during "average" years with respect to stream flow.

Further comparison of loads is possible for Corio Bay inputs, calculated using the 1979-81 data and more recent data. The results of a sampling program undertaken by the EPA in 1986-87 (EPA, unpublished data) are shown in Table 12, which also includes data for the same sites from the 1979-81 program. These data show considerable variation in flow between the two sampling periods, with discharge at one site (Coppards Road drain at the salt works) being two orders of magnitude lower in 1986-87 compared with the earlier data, while flow in the Rippleside Pier drain at Rippleside is almost twice the earlier value. As may be expected, loads also differ greatly. While there is a general pattern of lower loads in the more recent data corresponding to lower flows, exceptions are Hovells Creek and Cowies Creek where toxicant loads have generally increased.

These data therefore indicate that the 1979-81 data still has some relevance to the present situation, notwithstanding catchment-specific variations which affect both pollutant concentrations and flows. It may also be noted that organic toxicants, such as organochlorine and organophosphate pesticides or PAHs, were not included in the main data set and hence have not been addressed in this report.

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[1]Discharge data is available for 1960 to 1982 for Mile Creek, 1965 to 1993 for Dandenong Creek and 1925 to 1993 for Eumemmerring Creek.

Table 12. Comparison of annual loads (tonne/year) for inputs to Corio Bay in 1979-81 and 1986-87

Site No.	Site Name	Sampling Period	Flow*	NFR	Cd	Cr(t)	Cu	Ni	Pb	Zn	NOX	TKN	P(TOT)	Hg	Fe
5900	Coppards Rd Drain	1986-87	87	13.9	0.00001	0.00329	0.00186	0.00175	0.00922	0.017	0.065	0.274	0.096	0.000006	2.211
	at Salt Works	1979-81	6600	290.4	0.00122	0.01198	0.05289	0.02614	0.02783	0.288	1.645	12.547	4.922	0.000417	11.230
5901	Salt works drain at end of	1986-87	111	1.1	0.00002	0.00011	0.00025	0.00029	0.00024	0.001	0.019	0.267	0.019	0.000003	0.047
	road with SEC trans. line	1979-81	1987	7.9	0.00162	0.02537	0.00997	0.01018	0.00566	0.034	0.351	10.235	4.564	0.000185	0.602
5912	Seabeach Pde Drain	1986-87	26	0.5	0.00001	0.00015	0.00063	0.00008	0.00055	0.005	0.021	0.024	0.008	0.000001	0.117
	at outlet	1979-81	47	1.9	0.00002	0.00033	0.00460	0.00050	0.00270	0.016	0.043	0.075	0.025	0.000003	0.217
5915	Corio Tip Drain	1986-87	81	4.6	0.00195	0.00952	0.00271	0.00894	0.01633	0.022	0.044	0.159	0.073	0.000004	4.192
	at outlet	1979-81	1079	8.6	0.00023	0.00233	0.02737	0.00406	0.00871	0.076	1.232	1.449	0.174	0.000100	1.665
5920	Hovells Ck at	1986-87	1741	42.2	0.00030	0.01415	0.01946	0.01775	0.02331	0.028	0.282	2.171	0.392	0.000044	2.428
	Geelong Rd	1979-81	2163	2.6	0.00035	0.01375	0.00736	0.01284	0.00520	0.026	1.149	3.043	1.824	0.000078	10.316
5935	Cowies Ck at	1986-87	2760	97.6	0.02583	0.14637	0.07329	0.10780	0.25126	0.808	3.626	4.286	0.895	0.000069	56.060
	Corio Quay Rd	1979-81	3515	134.9	0.00195	0.11899	0.06287	0.07734	0.07929	1.533	4.788	8.536	1.257	0.000181	55.734
5940	Rippleside Pier Drain	1986-87	854	16.0	0.00117	0.00255	0.00591	0.00234	0.00964	0.092	3.606	0.734	0.124	0.000021	3.300
	at Rippleside	1979-81	462	30.4	0.00171	0.00618	0.00550	0.00228	0.01070	0.080	4.311	1.072	0.186	0.000029	1.203
5945	Cunningham Pier Drain	1986-87	179	40.9	0.00004	0.00273	0.01080	0.00041	0.05664	0.093	1.711	0.576	0.061	0.000004	1.930
	outside Council offices	1979-81	1530	55.2	0.00132	0.01824	0.14880	0.01151	0.29436	0.637	7.006	2.144	0.588	0.000087	7.302
5970	Bellarine St Drain at	1986-87	16	0.3	0.00000	0.00003	0.00197	0.00005	0.00052	0.004	0.013	0.010	0.010	0.000001	0.038
	Brougham St	1979-81	246	8.6	0.00012	0.00291	0.02951	0.00088	0.00677	0.059	0.254	0.294	0.225	0.000033	0.432
5990	Geelong Rifle Range Drain	1986-87	31	0.6	0.00001	0.00006	0.00035	0.00019	0.00202	0.019	0.030	0.024	0.005	0.000001	0.069
	at Limeburners Rd	1979-81	177	20.4	0.00015	0.00221	0.00685	0.00246	0.10183	0.150	0.107	0.444	0.059	0.000010	1.015

*ML

Table 12. Comparison of annual loads (tonne/year) for imputs to Corio Bay in 1979-81 and 1986-87

4. MODELLING

4.1 Approach

Various approaches to relating rainfall, streamflow and pollutant loads were considered. The results presented in this section are obtained from the preferred approach involving multiple linear regression techniques on both transformed and untransformed data.

Daily rainfall data were obtained from the Bureau of Meteorology and Melbourne Water for 33 sites in Melbourne and 8 sites in the Geelong area. The locations of these rainfall stations were plotted on a map to establish their position relative to the input sites and selected stations used to approximate rainfall in the relevant catchments. The locations of the stations used are shown in Figure 10.

Since most of the input loads were contributed by a limited number of inflows, relationships were derived for only the top-ranking sites (excluding Earimil Creek for reasons discussed in Section 3.2.2).

4.2 Multiple Linear Regression Analysis

4.2.1 Patterson River and Mordialloc Main Drain

The largest single contributor of surface water to the Bay (excluding the Yarra River, WTC and other EPA-licensed discharges) is the Mordialloc Main Drain/Patterson River system. Flow from Mile Creek and Dandenong Creek, which are two of the three major tributaries feeding into this system, is regulated by a weir at Bangholme. The three flow regimes for this drainage system are:

- In periods of low flow all the discharge from Dandenong Creek and Mile Creek flows into Mordialloc Main Drain. This occurs for approximately 60% of the time.
- In periods of medium to high flow, some of the discharge from these two creeks flows into the Patterson River.
- During very high flow, all flow from these creeks is diverted into the Patterson River.

In each regime, flow from Eumemmerring Creek continues to enter only the Patterson River.

Despite this flow control, Patterson River and Mordialloc Main Drain were treated as separate sources.

The optimum relationship between pollutant load (kg/day) or flow (ML/day) and daily rainfall (mm) was obtained from a multiple regression analysis, where load was expressed as a function of rainfall on the day of sampling, rainfall on the day before sampling, and rainfall two days before sampling. A regression model was computed for each pollutant (as well as flow) (Table 13), with any variables that were not significant at the 95% confidence level being removed from the model.

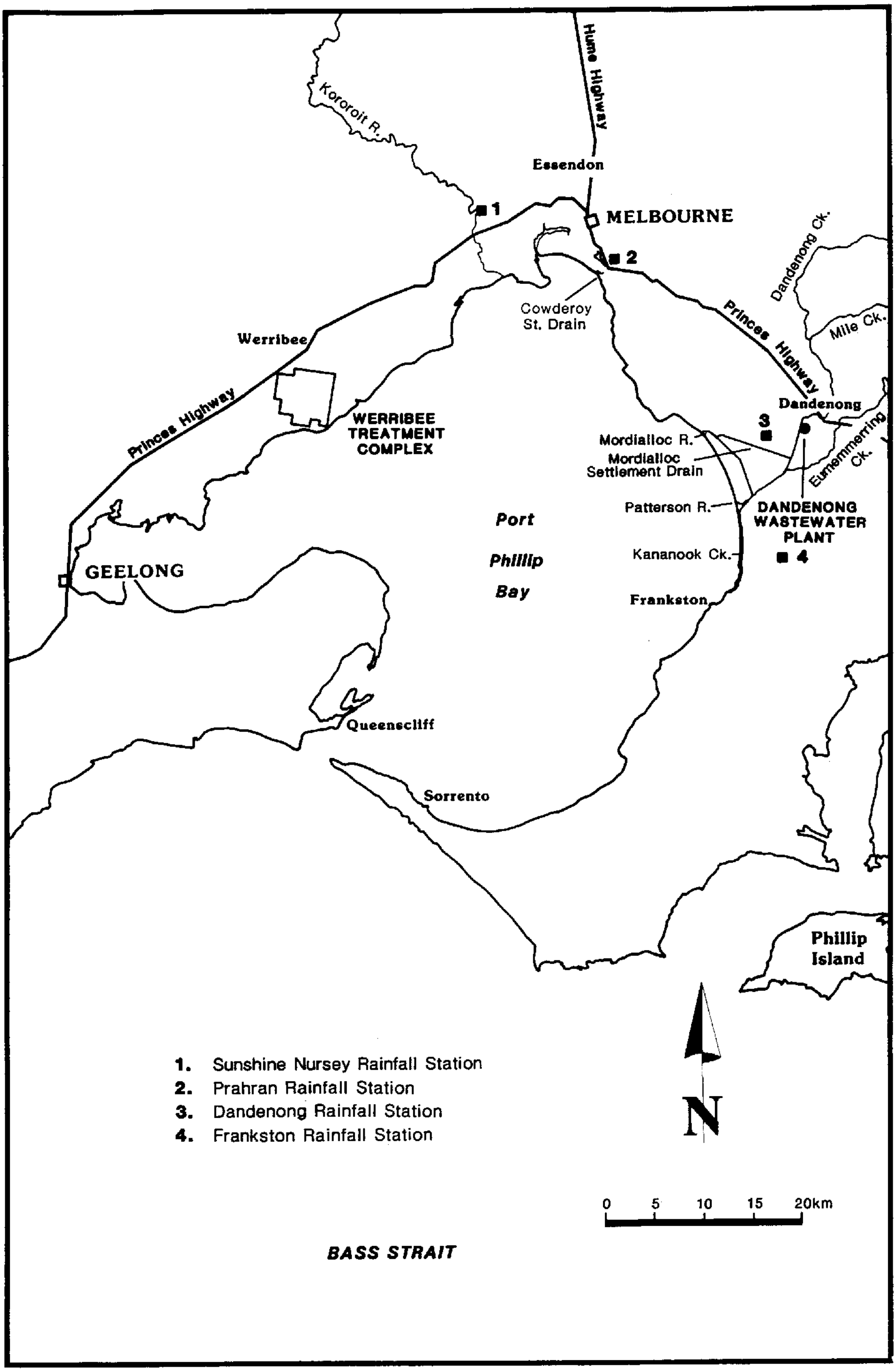

Figure 10. Location of rainfall stations

The fit of the model results to the data is variable, with R^2 values[1] greater than 0.5 obtained for NFR, Zn, Cu, As and Cr(t), but only 0.09 for Hg. Variation may be due to factors such as the flow control between Patterson River and Mordialloc Main Drain, the large number of analytical values reported as not detectable for variables such as Hg, the use of rainfall data from a single site in the catchment, and point sources such as the Wastewater Treatment Plant at Dandenong.

Table 13. Relationships between pollutant loads (kg) and rainfall (mm) for Patterson River

Variable	Regression Equation	R^2
Flow	42.1(Rf) + 19.6(Rf-1) + 11.7(Rf-2) + 52.1	0.41
P(tot)	22.1(Rf) + 8.4(Rf-1) + 246	0.14
Kjeldahl N	98.3(Rf) + 50.5(Rf-1) + 25.5(Rf-2) + 558	0.24
N(ox)	68.8(Rf) + 47.8(Rf-1) + 36.4(Rf-2) + 177.4	0.22
NFR	7653(Rf) + 2165(Rf-1) + 1640(Rf-2)	0.62
Surfactants	2.7(Rf) + 1.5(Rf-1) + 22.7	0.14
Pb	2.7(Rf) + 0.9(Rf-1) + 0.5(Rf-2)	0.34
Hg	0.005(Rf-1) + 0.007(Rf-2)	0.09
Zn	10.0(Rf) + 2.1(Rf-1) + 1.4(Rf-2)	0.57
Cd	0.02(Rf) + 0.006(Rf-1) + 0.03	0.26
Cu	0.95(Rf) + 0.21(Rf-1) + 0.15(Rf-2) + 0.80	0.51
As	0.10(Rf) + 0.07(Rf-1) + 0.03(Rf-2)	0.56
Cr(t)	0.80(Rf) + 0.26(Rf-1) + 0.16(Rf-2)	0.56
Ni	0.34(Rf) + 0.09(Rf-1) + 0.06(Rf-2) + 0.6	0.40
Fe	357(Rf) + 181(Rf-1) + 133(Rf-2)	0.24

Rf = rainfall on the day of sampling, (Rf-1) = rainfall on the day preceding sampling, and (Rf-2) = rainfall on the day two days prior to sampling.

A similar analysis for the Mordialloc Main Drain (Table 14) showed poor agreement between the predicted and actual data, with only Pb, Zn, As and Fe having R^2 values greater than 0.3. Total P, Kjeldahl N, NFR and surfactant loads are unrelated to rainfall, i.e. a constant (the sample mean) is fitted for each case. The regressions for Pb, Zn and Fe do not have a significant constant, indicating that during conditions of no rainfall the loads of these metals approach zero.

4.2.2 Kororoit Creek

Kororoit Creek flows and loads were obtained from the original EPA data, while daily rainfall was obtained from a Bureau of Meteorology station at Sunshine Nursery, Sunshine. Stepwise linear regressions of rainfall versus load were again undertaken (Table 15) and R^2 values greater than 0.3 obtained for flow, total P, oxidised N, NFR, Pb, Hg, Zn, Cd, Cu, As and Ni. Of these, R^2 values greater than 0.5 were obtained for oxidised N, NFR, Pb and Cu.

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[1] R^2 values are a measure of the proportion of variation of a dependant variable, y, due to its relationship with a known variable, x.

Table 14. Relationships between pollutant loads (kg) and rainfall (mm) for Mordialloc Main Drain

Variable	Regression Equation	R^2
Flow	15.2(Rf) + 69.3	0.22
P(tot)	243	0.00
Kjeldahl N	592	0.00
N(ox)	32.4(Rf) + 236	0.12
NFR	1985	0.00
Surfactants	18.5	0.00
Pb	1.1(Rf)	0.35
Hg	0.00074(Rf-1) + 0.00414	0.14
Zn	6.12(Rf)	0.35
Cd	0.00599(Rf) + 0.0176	0.15
Cu	0.30(Rf) + 1.23	0.17
As	0.066(Rf) + 0.156	0.39
Cr(t)	0.213(Rf) + 0.759	0.17
Ni	0.078(Rf) + 0.644	0.08
Fe	145(Rf)	0.35

Table 15. Relationships between pollutant loads (kg/day) and rainfall (mm) for Kororoit Creek

Variable	Regression Equation	R^2
Flow	6.67(Rf) + 2.38(Rf-1) + 3.94(Rf-2) + 29.87	0.50
P(tot)	162.6(Rf-2)	0.45
Kjeldahl N	13.4(Rf) + 10.5(Rf-2) + 148	0.22
N(ox)	23.1(Rf) + 9.2(Rf-1) + 14.8(Rf-2) + 36.2	0.51
NFR	389(Rf) + 509	0.67
Surfactants	1.3(Rf) + 0.4(Rf-2) + 10.5	0.22
Pb	0.16(Rf) + 0.04(Rf-2) + 0.22	0.61
Hg	0.002(Rf) + 0.009	0.33
Zn	0.50(Rf) + 0.37(Rf-2) + 0.93	0.49
Cd	0.004(Rf) + 0.012(Rf-2)	0.40
Cu	0.09(Rf) + 0.04(Rf-2) + 0.33	0.51
As	0.011(Rf) + 0.018(Rf-2) + 0.049	0.45
Cr(t)	2.1	0.00
Ni	0.063(Rf) + 0.129(Rf-2) + 0.318	0.35
Fe	7.0(Rf) + 7.2(Rf-2) + 39.8	0.04

4.2.3 Other creeks

The other creeks and drains which were modelled were Kananook Creek (n = 5), Mordialloc Settlement drain (n = 9) and Cowderoy Street drain (n = 11). Rainfall data were obtained from weather stations at Frankston, Dandenong and Prahran, respectively. The results are shown in Tables 16, 17 and 18.

Since the models were based on few samples, it was decided to model flow and pollutant load from rainfall on the day of sampling only, with no other modelling approaches attempted. Variables which were not statistically significant were excluded, except when neither the rainfall variable nor the constant were significant, in which case the selected model was based on the highest correlation and lowest standard error.

Modelling the Kananook Creek data is confounded by the fact that the flow is regulated by a pumping station at Patterson Lakes which maintains a relatively constant flow (greater than about 1.7 m^3/sec).

Although the Heatherton Road drain in Mordialloc was responsible for a considerable percentage of the load for most pollutants (see Table 6), only 10 samples were taken and no correlation was found between flow and rainfall at either of the two closest weather stations. The data for this site were therefore not modelled.

Table 16. Relationships between pollutant loads (kg/day) and rainfall (mm) for Kananook Creek

Variable	Regression Equation	R^2
Flow	66.6	0.00
P(tot)	75.8(Rf)	0.55
Kjeldahl N	472(Rf)	0.76
N(ox)	25.6(Rf) + 11.8	0.97
NFR	480(Rf) + 240	1.00*
Surfactants	11.0	0.00
Pb	0.525	0.00
Hg	0.004	0.00
Zn	3.821(Rf)	0.77
Cd	0.016	0.00
Cu	0.492	0.00
As	0.183	0.00
Cr(t)	0.20(Rf)	0.75
Ni	0.466	0.00
Fe	72.4(Rf)	0.82

*Regression on two data points.

Table 17. Relationships between pollutant loads (kg/day) and rainfall (mm) for Mordialloc Settlement Drain

Variable	Regression Equation	R^2
Flow	4.382(Rf) + 4.104	1.00
P(tot)	5.96(Rf)	1.00
Kjeldahl N	20.7(Rf)	0.99
N(ox)	11.5(Rf)	0.99
NFR	na	na
Surfactants	1.06(Rf)	1.00
Pb	0.44(Rf)	1.00
Hg	0.0004(Rf)	1.00
Zn	3.35(Rf)	1.00
Cd	0.004(Rf)	1.00
Cu	0.75(Rf)	1.00
As	0.025(Rf)	1.00
Cr(t)	0.265(Rf)	1.00
Ni	0.106(Rf)	1.00
Fe	51.2(Rf)	1.00

Table 18. Relationships between pollutant loads (kg/day) and rainfall (mm) for Cowderoy Street drain

Variable	Regression Equation	R^2
Flow	3.22(Rf)	0.31
P(tot)	0.83(Rf)	0.27
Kjeldahl N	4.79(Rf)	0.28
N(ox)	1.92(Rf)	0.60
NFR	81.4(Rf)	0.93
Surfactants	0.344(Rf)	0.35
Pb	0.84(Rf)	0.20
Hg	0.0003(Rf)	0.25
Zn	1.41(Rf)	0.21
Cd	0.001(Rf)	0.22
Cu	0.163(Rf)	0.23
As	0.011(Rf)	0.50
Cr(t)	0.075(Rf)	0.47
Ni	0.031(Rf)	0.29
Fe	14.5(Rf)	0.22

4.3 Stepwise Approach

An alternative approach to deriving relationships directly between pollutant loads and rainfall is to establish correlations between loads and flow, and then between flow and rainfall. This allows either flow or rainfall to be used as a predictive tool for load estimates, with increasing uncertainty in the predicted load if the latter is used.

Plots of loads versus flow, shown in Figure 11 for selected variables for the Patterson River, indicated that transformation of the data would be appropriate. Linear regressions were therefore performed using the natural log-transformed daily flow and pollutant load estimates for each site. Examples of plots of ln(load) against ln(flow) for each site are shown in Figure 12, and the results are shown in Tables 19, 20, 21, 22, 23 and 24. Also included in each table is the equation for the relationship between flow and rainfall, as described in the previous section.

Generally good fits of the data were obtained, especially for those sites where a considerable number of data points occur. An exception is the data for Kororoit Creek, which exhibits a considerable amount of scatter around the regression line.

Table 19. Relationships between ln [pollutant loads (kg/d)] and ln [flow (ML/d)] for Patterson River

Variable	Coefficient	Constant	R^2
P(tot)	0.949	0.928	0.823
Kjeldahl N	1.036	1.459	0.849
N(ox)	1.271	-0.449	0.797
NFR	1.324	2.313	0.895
Surfactants	0.951	-1.473	0.799
Pb	1.329	-5.648	0.905
Hg	0.974	-9.513	0.823
Zn	1.265	-3.610	0.925
Cd	1.041	-8.398	0.792
Cu	1.178	-5.102	0.912
As	1.024	-6.404	0.942
Cr(t)	1.178	-5.550	0.896
Ni	1.039	-5.049	0.906
Fe	1.281	-0.656	0.899
Flow vs Rainfall (untransformed)	Flow = 42.1(Rf)+19.6(Rf-1)+11.7(Rf-2)+52.1		0.410

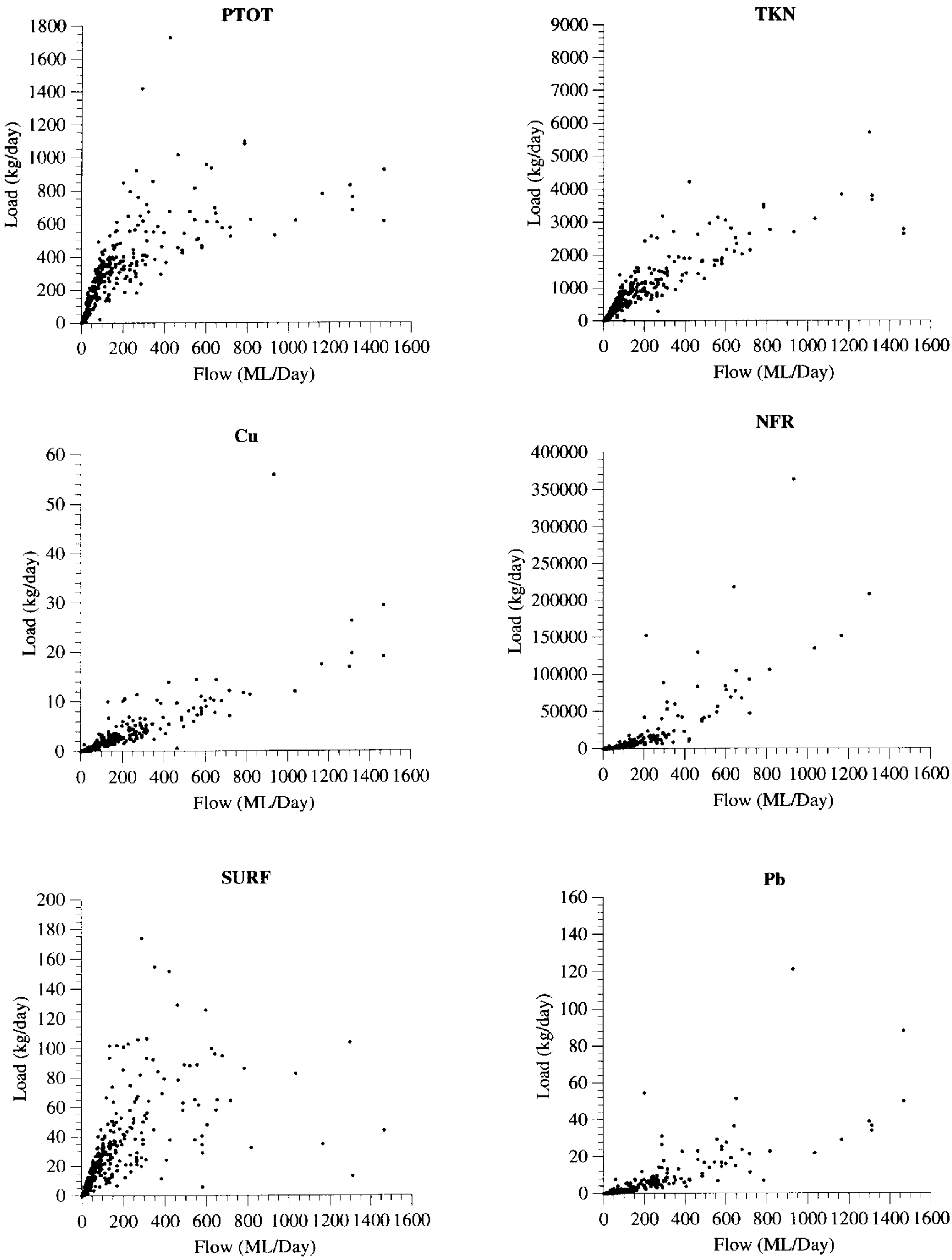

Figure 11. Flow (ML/day) vs variable load (kg/day) at Patterson River

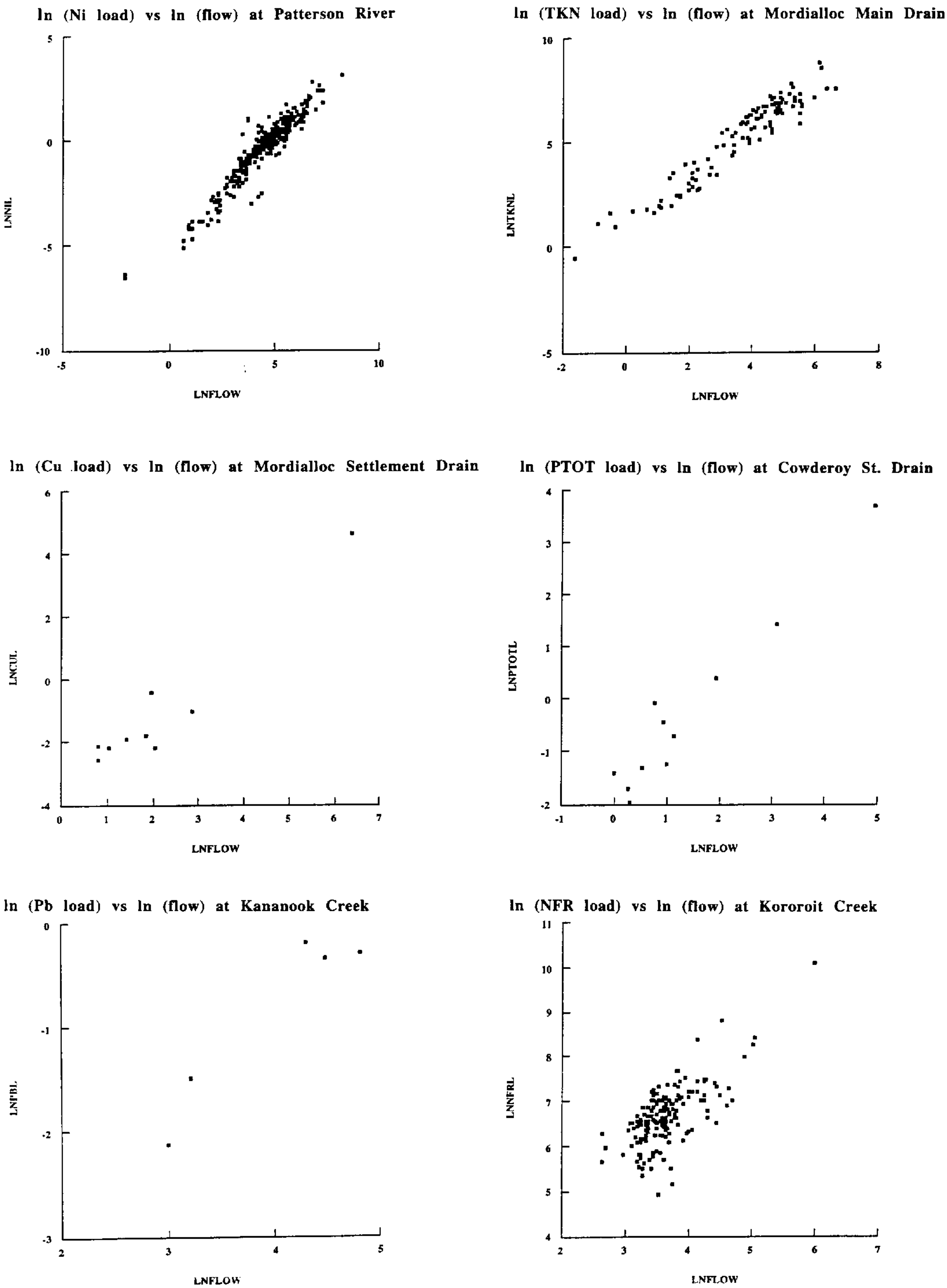

Figure 12. In (variable load) vs In (flow) at selected sites

Table 20. Relationships between ln [pollutant loads (kg/d)] and ln [flow (ML/d)] for Mordialloc Main drain

Variable	Coefficient	Constant	R^2
P(tot)	1.041	0.686	0.886
Kjeldahl N	1.105	1.209	0.915
N(ox)	0.951	1.317	0.798
NFR	0.930	3.381	0.679
Surfactants	0.979	-1.588	0.876
Pb	1.031	-4.157	0.822
Hg	0.933	-9.540	0.982
Zn	1.084	-2.582	0.913
Cd	1.064	-8.709	0.927
Cu	1.087	-4.588	0.944
As	0.738	-4.713	0.861
Cr(t)	1.167	-5.451	0.902
Ni	1.023	-4.998	0.940
Fe	1.057	0.463	0.809
Flow vs Rainfall (untransformed)	Flow = 15.2(Rf)+69.3		0.221

Table 21. Relationships between ln [pollutant loads (kg/d)] and ln [flow (ML/d)] for Mordialloc Settlement drain

Variable	Coefficient	Constant	R^2
P(tot)	1.130	-0.149	0.926
Kjeldahl N	1.094	1.205	0.803
N(ox)	1.029	0.541	0.435
NFR	1.952	0.609	0.924
Surfactants	1.076	-1.813	0.947
Pb	1.201	-3.926	0.844
Hg	1.093	-9.7899	0.977
Zn	1.293	-2.130	0.958
Cd	0.960	-7.449	0.602
Cu	1.242	-3.748	0.919
As	1.013	-5.061	0.944
Cr(t)	0.844	-2.544	0.625
Ni	0.850	-3.296	0.795
Fe	1.482	-0.669	0.951
Flow vs Rainfall (untransformed)	Flow = 4.38(Rf)+4.10		1.000

Table 22. Relationships between ln [pollutant loads (kg/d)] and ln [flow (ML/d)] for Cowderoy Street drain

Variable	Coefficient	Constant	R^2
P(tot)	1.089	-1.793	0.938
Kjeldahl N	0.982	0.394	0.912
N(ox)	0.643	0.960	0.620
NFR	1.131	4.018	0.825
Surfactants	0.991	-2.201	0.716
Pb	1.264	-2.953	0.795
Hg	1.001	-9.551	0.781
Zn	1.117	-1.716	0.859
Cd	1.031	-8.184	0.875
Cu	1.047	-3.410	0.918
As	0.939	-5.351	0.971
Cr(t)	0.817	-3.044	0.818
Ni	1.093	-5.100	0.887
Fe	1.123	0.574	0.896
Flow vs Rainfall (untransformed)	Flow = 3.22(Rf)		0.313

Table 23. Relationships between ln [pollutant loads (kg/d)] and ln [flow (ML/d)] for Kananook Creek

Variable	Coefficient	Constant	R^2
P(tot)	0.861	0.696	0.599
Kjeldahl N	0.433	4.022	0.157
N(ox)	0.248	2.146	0.048
NFR	1.218	1.833	1.000
Surfactants	0.080	1.819	0.007
Pb	1.022	-4.943	0.909
Hg	1.305	-11.341	0.730
Zn	1.483	-5.059	0.832
Cd	1.318	-9.872	0.901
Cu	0.860	-4.307	0.946
As	0.957	-5.770	0.843
Cr(t)	1.472	-7.903	0.844
Ni	0.684	-3.630	0.768
Fe	0.900	0.522	0.655
Flow vs Rainfall (untransformed)	Flow = 66.6		0.000

Table 24. Relationships between ln [pollutant loads (kg/d)] and ln [flow (ML/d)] for Kororoit Creek

Variable	Coefficient	Constant	R^2
P(tot)	1.039	0.224	0.454
Kjeldahl N	0.828	1.958	0.502
N(ox)	1.561	-1.854	0.373
NFR	1.008	2.975	0.468
Surfactants	0.861	-0.871	0.379
Pb	1.089	-5.152	0.498
Hg	0.742	-7.531	0.203
Zn	1.234	-4.296	0.498
Cd	1.376	-9.541	0.548
Cu	0.988	-4.617	0.450
As	1.305	-6.549	0.572
Cr(t)	0.595	-1.803	0.115
Ni	0.946	-4.428	0.400
Fe	1.025	-0.235	0.526
Flow vs Rainfall (untransformed)	Flow = 6.67(Rf)+2.34(RF-1)+(3.94(Rf-2)+29.9		0.499

4.4 The Patterson River/Mordialloc Main Drain system

The availability of a continuous flow record for the three creeks which constitute the majority of the flow in the Mordialloc Main Drain/Patterson River system provides an opportunity for assessing the correlation between estimated loads based on the EPA data and independently-measured flow data. Time series plots for the combined flow with the estimated loads of total P and Cu superimposed are shown in Figures 13 and 14. These plots confirm that most of the flood events occurring during the sampling period were sampled by EPA. They also show that, due to the flow diversion scheme for the Patterson River and Mordialloc Main Drain described in Section 4.2.1, loads are divided between the two watercourses, although apparently not on a consistent basis. For example, both total P and Cu loads in 1980 were low in the Mordialloc Main Drain and high in the Patterson River, which is consistent with the upstream discharge record and the practice of switching high flows to the Patterson River. However, elevated loads of both variables were observed in 1981 with increased flows, which indicates that higher flows were occurring in both watercourses.

The relationship between rainfall and flow has also been further examined. Regression analysis of rainfall versus the combined flow at these three sites did not prove to be particularly effective. Although rainfall on the day of sampling and the six days before sampling were all shown to be significant, the R^2 value for this regression equation was only 0.343. This relatively poor relationship between daily rainfall and combined flow is apparent when the data is plotted as a time series (Figure 15), and can probably be attributed to the size of the catchment and the varied land-uses within the catchment.

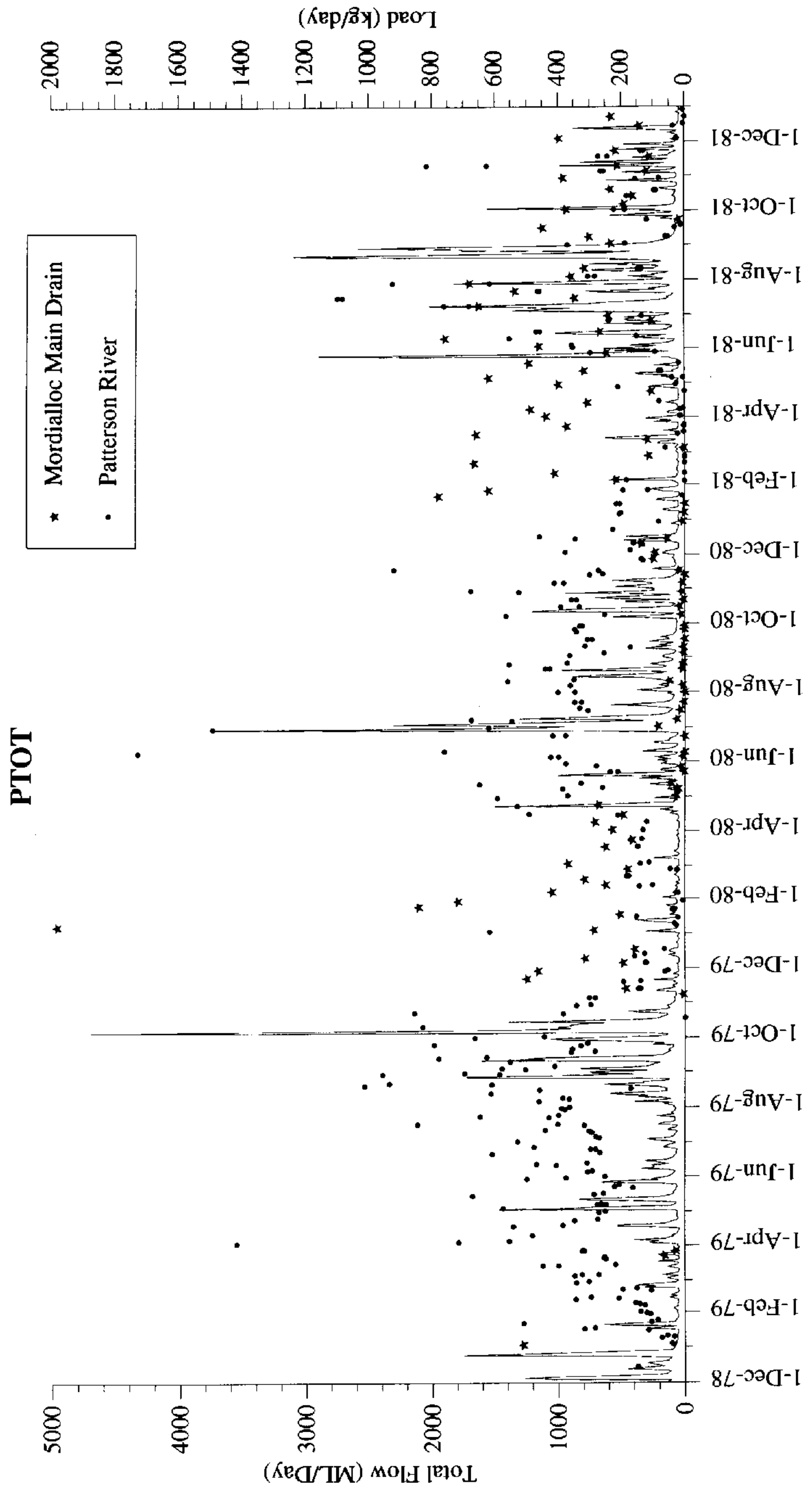

Figure 13. Total flow (ML/day) at Dandenong, Mile and Eumemmering creeks and total P loads (kg/day) for Patterson River and Mordialloc Main Drain

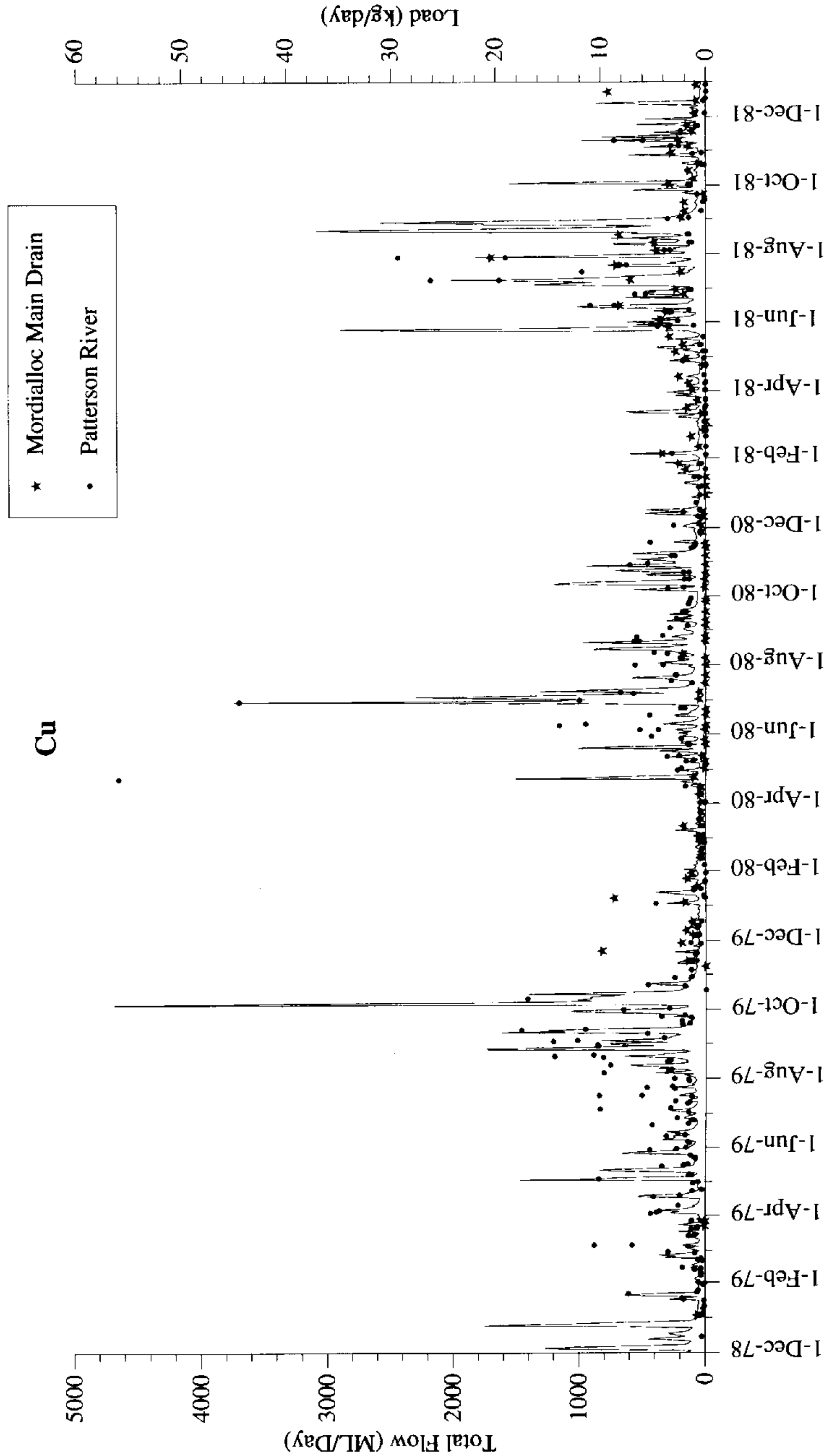

Figure 14. Total flow (ML/day) at Dandenong, Mile and Eumemmering creeks and total Cu loads (kg/day) for Patterson River and Mordialloc Main Drain

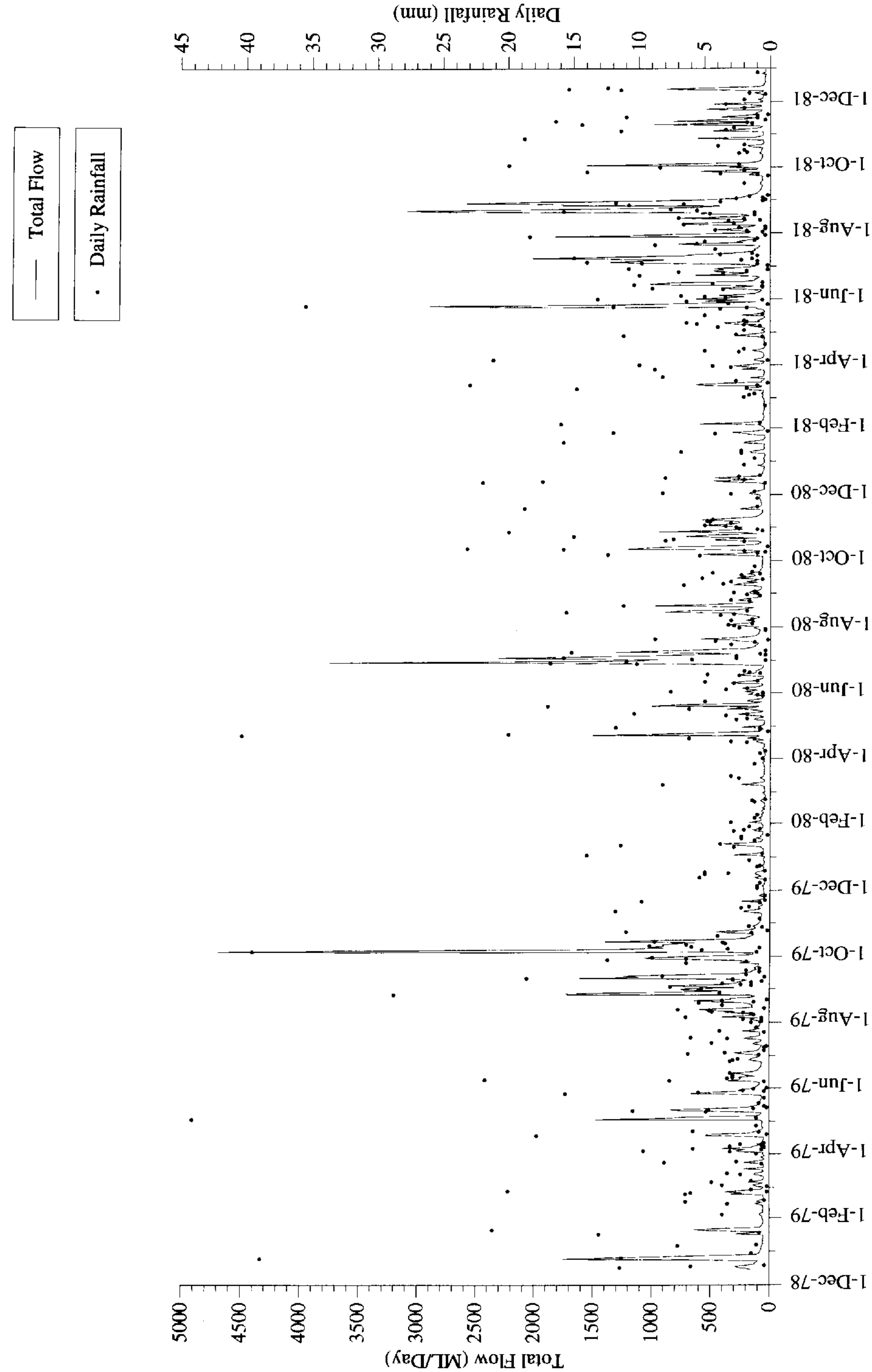

Figure 15. Total flow (ML/day) at Dandenong, Mile and Eumemmering creeks and daily rainfall (mm) at Dandenong

5. CONCLUSIONS & RECOMMENDATIONS

The data resulting from EPA's 1979-81 sampling and analytical program has allowed reasonable estimates to be made of flow, suspended particulate matter, nutrients and inorganic toxicants entering the Bay from more than 100 streams and drains. Inputs are dominated by a small number of sites. Although not necessarily the same when ranked in order of inputs, the ten highest-ranking sites for each variable contribute between 75 and 94% of the loads entering the Bay (excluding the Yarra River, the WTC and EPA-licensed discharges).

The same database has been used to estimate loads entering the Bay from the Yarra River. When these are included in the total load calculations, non-Yarra River inputs into the Bay (excluding the Werribee Treatment Complex and other EPA-licensed discharges) account for 36% of the flow and 27% (NFR) to 77% (total P) of pollutant loads. In particular, contributions of inorganic toxicants range from 31% (Ni) to 55% (Cu). When the metal loads (excluding Fe) are summed, the non-Yarra contribution is 45% of the total input.

Of these non-Yarra River inputs, Patterson River is the major single contributor of water, nutrients and suspended particulate matter, while the Mordialloc Main Drain, Mordialloc Settlement drain and Patterson River (all of which are hydrologically linked) are the major contributors of most metals. When input loads are summed, these three sources contributed 64% of the total P, 62% of the Kjeldahl N, 67% of the oxidised N, 61% of the NFR and 46% of the surfactants entering the Bay from surface sources (excluding the Yarra River and EPA-licensed discharges) during the sampling period. In terms of inorganic toxicants (Pb, Hg, Zn, Cd, Cu, As, Cr(t) and Ni), these same three sources contributed between 35 and 75% of input loads. When the individual metal loads from all sources are summed, the contribution from these sources is 60%.

Other major non-Yarra inputs which feature prominently in the ten highest-ranked sites for each variable are Kororoit Creek, Kananook Creek, Heatherton Road Drain, Cowderoy Street drain, and Cowies Creek.

Although the data on which these findings are based is over 12 years old, comparison with more recent data indicates that water quality has not changed substantially. However, cessation of the discharge from Melbourne Water's Wastewater Treatment Plant at Dandenong in the near future will presumably result in decreased loads of some variables, particularly nutrients, entering the Bay via the Patterson River/Mordialloc Main Drain system.

In terms of modelling inputs into the Bay, direct relationships between loads and rainfall generally offer only limited predictive capabilities. A more promising predictive tool is that offered by linear regressions of natural log-transformed daily flow and pollutant load estimates. These relationships demonstrate that a good estimate of daily loads can be obtained from flow measurements. The relationship between flow and rainfall is not as clear, which is not surprising given the often complex hydrological characteristics of these catchments.

As a result of these findings, the following recommendations can be made:

- Non-Yarra River sources should be accounted for in any consideration of surface inputs into Port Phillip Bay.

- The focus of these non-Yarra River sources should be on the Patterson River, Mordialloc Main Drain and Mordialloc Settlement drain.

- If resources allow, validation of the predictive capabilities of flow measurements in the Patterson River/Mordialloc Main Drain system should be considered given that the main sampling program was undertaken over twelve years ago. This would need to take into account:

  - Flow control in the system below the existing stream gauging stations.
  - Inflows from the Mordialloc Settlement drain below the sampling sites used in the 1979-81 study.
  - Possible changes in flow quality and quantity since the 1979-81 study and the anticipated cessation of discharges from the Wastewater Treatment Plant at Dandenong.

  Two possible approaches to such a program are either long-term sampling or a number of intensive flow-related sampling exercises at each of the three sites. Considering the latter, temporary gauging stations could be established at each site to provide flow estimates and the subsequent confirmation of load/discharge relationships.

- Other surface inputs which should be considered in any assessment of surface inputs into Port Phillip Bay are Kororoit Creek, Kananook Creek, Heatherton Road drain, Laverton Creek, Cowderoy Creek drain, Earimil Creek and Cowies Creek. These represent the four highest-ranking inputs for all the variables examined (in addition to the Patterson River/Mordialloc Main Drain system and Mordialloc Settlement drain).

- Access to stream flow data should be pursued to provide a predictive capability for surface inputs entering Port Phillip Bay.

- Consideration should be given to assessment of EPA-licensed discharges, possible sources of organic contaminants, and other potentially-significant sources not included in the main database. This could be by review of other existing data or by undertaking a sampling and analytical program.

6. ACKNOWLEDGEMENTS

This report was prepared in association with the Water Studies Center, Monash University, Melbourne.

The cooperation of a number of State Government agencies involved in the water industry is gratefully acknowledged. The Environment Protection Authority - Catchment and Marine Studies Unit provided the initial data and supporting information, while other agencies which contributed include Melbourne Water, the National Climate Centre, and the State Water Laboratories.

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