13

SWAN RIVER TRUST

Nutrient loads in surface drainage from Ellen Brook from 1987 to 1992

Swan River Trust
Report No 13
1993

Swan River Trust

216 St Georges Terrace
PERTH WA 6000

Telephone: (09) 3279700
Fax. : (09) 3279770

Nutrient loads in surface drainage from Ellen Brook from 1987 to 1992

Report to the Swan River Trust

David M Deeley, Robert Donohue and Geoff Parsons

Swan River Trust
216 St Georges Tce
PERTH WA 6000

SWAN RIVER TRUST
REPORT No 13
SEPTEMBER 1993

ISBN 0 7309 5944 9

ISSN 1033-9779

Acknowledgments

The Water Authority of Western Australia supplied the flow record for the bottom end audit of Ellen Brook. Thanks also to the Chemistry Centre of Western Australia for analysing all water samples.

CONTENTS

List of Figures

List of Tables

1 Introduction

The upper reaches of the Swan River are currently experiencing seasonal phytoplankton blooms (chlorophytes, dinophytes) with peak cell densities in excess of 1 billion cells (10^9) per litre (Hosja and Deeley 1993). Extensive periods of severe summer oxygen stress in bottom waters are now common especially under stratified conditions. Significant kills of fish and benthic invertebrates have also been experienced.

The Swan River Trust has been monitoring water quality of surface drainage in the Swan-Canning catchment for a number of years (Henderson *et al* 1983, Atkins 1985, Thurlow *et al* 1986, Deeley *et al* 1993) . The nutrient enrichment of the upper reaches of the Swan estuary has followed many years of excessive nutrient inputs from inappropriate waste disposal and from polluted surface runoff. Discharges of secondary treated sewerage have mostly been diverted to ocean outfalls, but nutrient loads in surface runoff continue to remain at very high levels (>70 tonnes of total phosphorus per annum).

The contribution of nutrients from groundwater to the estuary have also been investigated (Appleyard 1992). Significant inputs of nitrogen have been identified in groundwater accession to the Swan estuary. Phosphorus loads in groundwater discharges are relatively low (<6 tonnes TP/yr) .

Ellen Brook has been identified as having the highest concentration of phosphorus of the streams discharging to the Swan-Canning estuary (Deeley *et al* 1993a). The averge flow-weighted concentration of total phosphorus for Ellen Brook from 1987 to 1992 was 0.70 mg/L. This compares to an average of 0.24 mg/L for the Harvey River over the same period. The Harvey River has been identified as contributing the largest quantity of phosphorus to the eutrophic Peel-Harvey estuarine system (Deeley *et al* 1993b, Kinhill 1985).

Most of the Ellen Brook catchment has been cleared for agriculture and there are extensive areas of annual clover-based pastures on low lying Bassendean sands. These soil types have very low phosphorus binding capacities and, in the Peel-Harvey estuary, have been identified as major source areas for phosphorus (Kinhill 1985, Schofield *et al* 1985, Gerritse and Schofield 1989). A number of point sources of nutrients and runoff from the areas of Bassendean sand are thought to contribute much of the nutrient load in Ellen Brook. Intensive horticultural enterprises are generally located on the heavier soils on the eastern side of the Ellen Brook catchment which have a greater capacity to bind phosphorus.

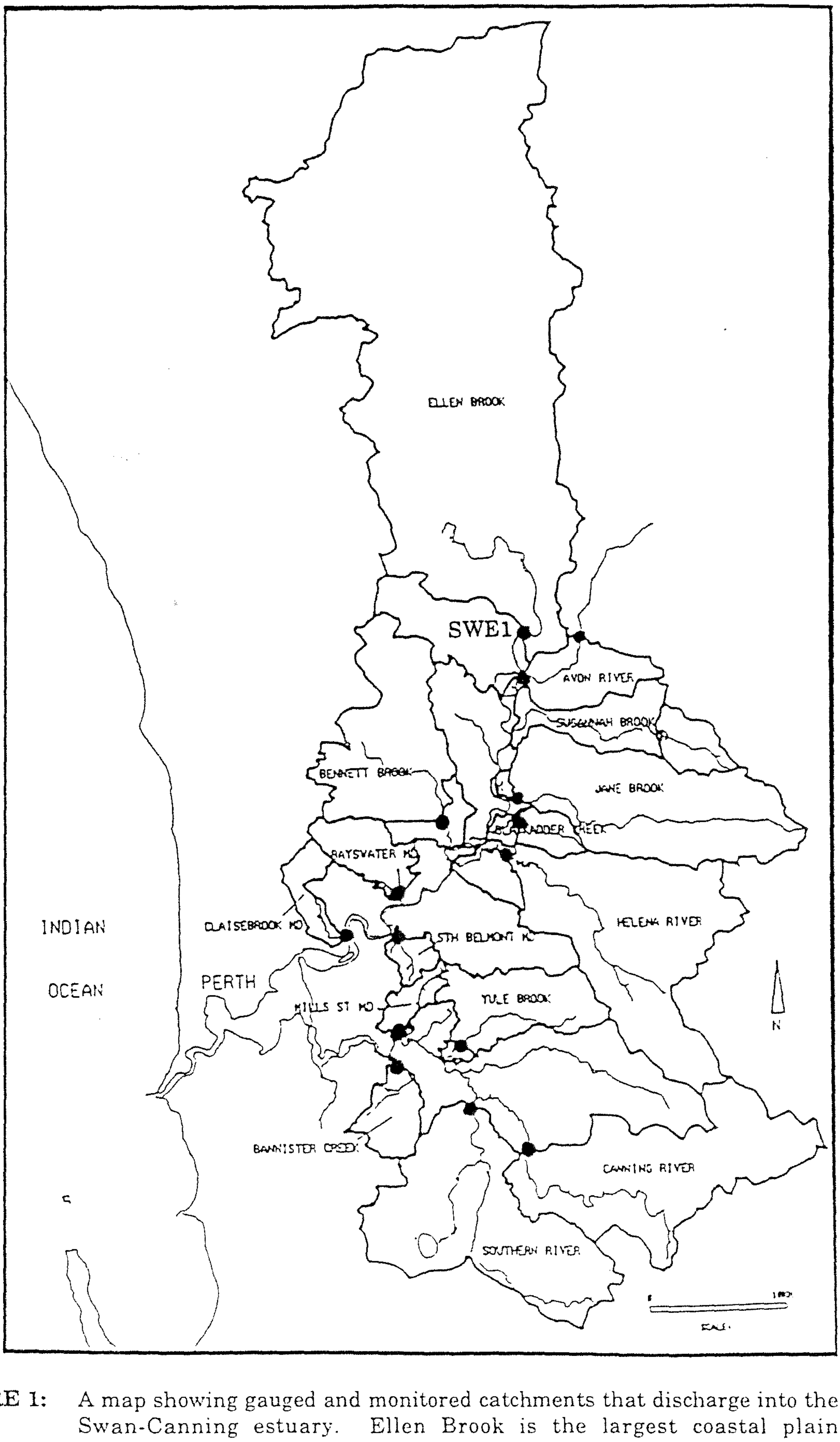

FIGURE 1: A map showing gauged and monitored catchments that discharge into the Swan-Canning estuary. Ellen Brook is the largest coastal plain catchment. The small circles show the location of the sample sites.

2. Methods

The Swan River Trust investigated water quality in Ellen Brook between 1987 and 1992 in three related investigations discussed in more detail below, they include:

i) an ongoing bottom end water quality audit, 1987 to 1992;
ii) an annual audit of three sub-catchments within the catchment of Ellen Brook, 1992;
iii) a once only snap-shot of water quality down the length of Ellen Brook over a major storm and flow event on the 4th September 1992.

Nutrient loads can be defined as the total amount of nutrient passing the point of measurement, and are only estimates of the 'true load' carried by streams. The high degree of variability in the sediment and nutrient carrying capacity along the length of a stream means that loads are subject to errors depending on the frequency and location of sampling sites and calculational methods. Errors associated with the calculation of loads have been discussed in detail by Richards and Holloway (1986) and Birch and Forbes (1985). Typical errors associated with loads may lead to underestimates in the order of 30%.

Comparison of nutrient export co-efficients between catchments must proceed with extreme caution because of the unsystematic nature of load errors and differences between catchments in source and non-contributory areas. Past comparisons of loads and export co-efficients have assumed that all areas within a catchment contribute equally to the total load. Clearly this is not the case, some areas in the catchment contribute large amounts of nutrients (source areas) and other areas very little.

Runoff from the critical source areas that determine nutrient loads rather than the average catchment condition. It has been shown that export co-efficients from other places, land uses and hydrologic regimes are limited in their use (Cullen *et al* 1988). Given these concerns nutrient loads and export co-efficients presented in this report should be interpreted with caution and only compared to reports from other catchments with a full appreciation of errors associated in studies being compared.

2.1 Bottom end water quality audit, 1987 to 1992

This investigation was based around the WA Water Authorities flow gauging station at West Swan Road (Figure 1; site code SWE1). Discharge was measured continuously and nutrient samples were collected on a weekly fixed frequency basis with some flow stratified opportunistic sampling on major flow events. Samples were collected into new high density polyethylene screw-capped bottles, chilled or frozen and analysed for nitrate-nitrogen (NO_3-N+NO_2-N), ammonium-nitrogen, total persulphate nitrogen, soluble reactive phosphorus (-0.45µm) and total persulphate phosphorus.

Nutrient loads were computed as the product of daily discharge and linearly interpolated daily nutrient concentrations. Flow weighted mean concentrations were computed by dividing total annual load by total annual discharge expressed as milligrams per litre. Areal nutrient export was computed by dividing total annual load by total catchment area expressed as kilograms per hectare per year.

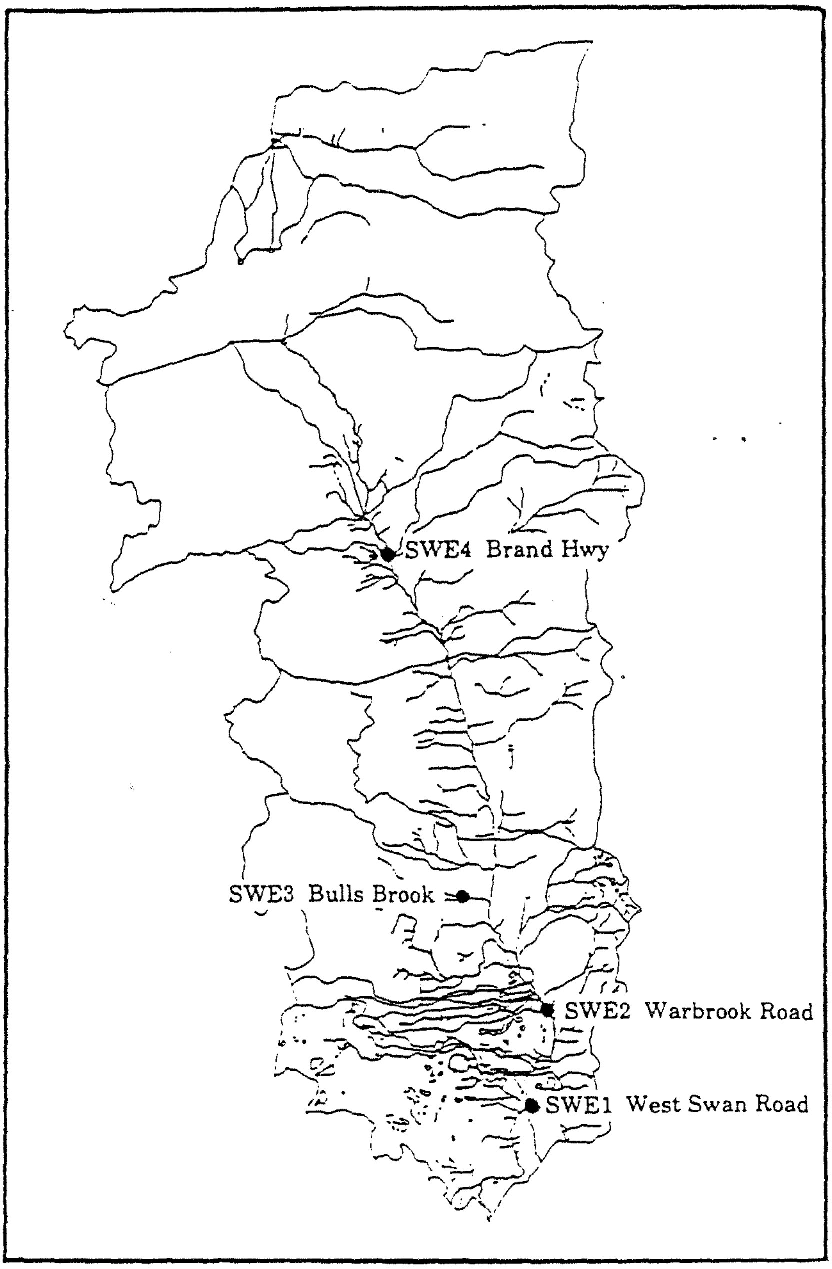

FIGURE 2: Location of sampling sites SEW1, SWE2, SWE3 and SWE4.

2.2 Annual audit of three Ellen Brook sub-catchments

This investigation commenced in 1992 and was conducted in the same manner as the longer term bottom end water quality described above.

Sample sites included Ellen Brook at Warbrook Road (SWE2), Bullsbrook (SWE3) and Chandala Brook (SWE4) at Brand Highway (Figure 2). Continuous streamflow was measured at SWE3 and SWE4. Streamflow for SWE2 was simply computed from SWE1 on a catchment area basis. Nutrient samples and loads were computed for each site.

2.3 Water quality snapshot on a major flow event

This investigation consisted of a transect down the length of the Ellen Brook catchment. Instantaneous discharge and nutrient samples were collected from fifteen sites (Figure 3). Instantaneous discharge was measured for all sites using standard hydrographic techniques of determining cross sectional areas combined with appropriate current metering.

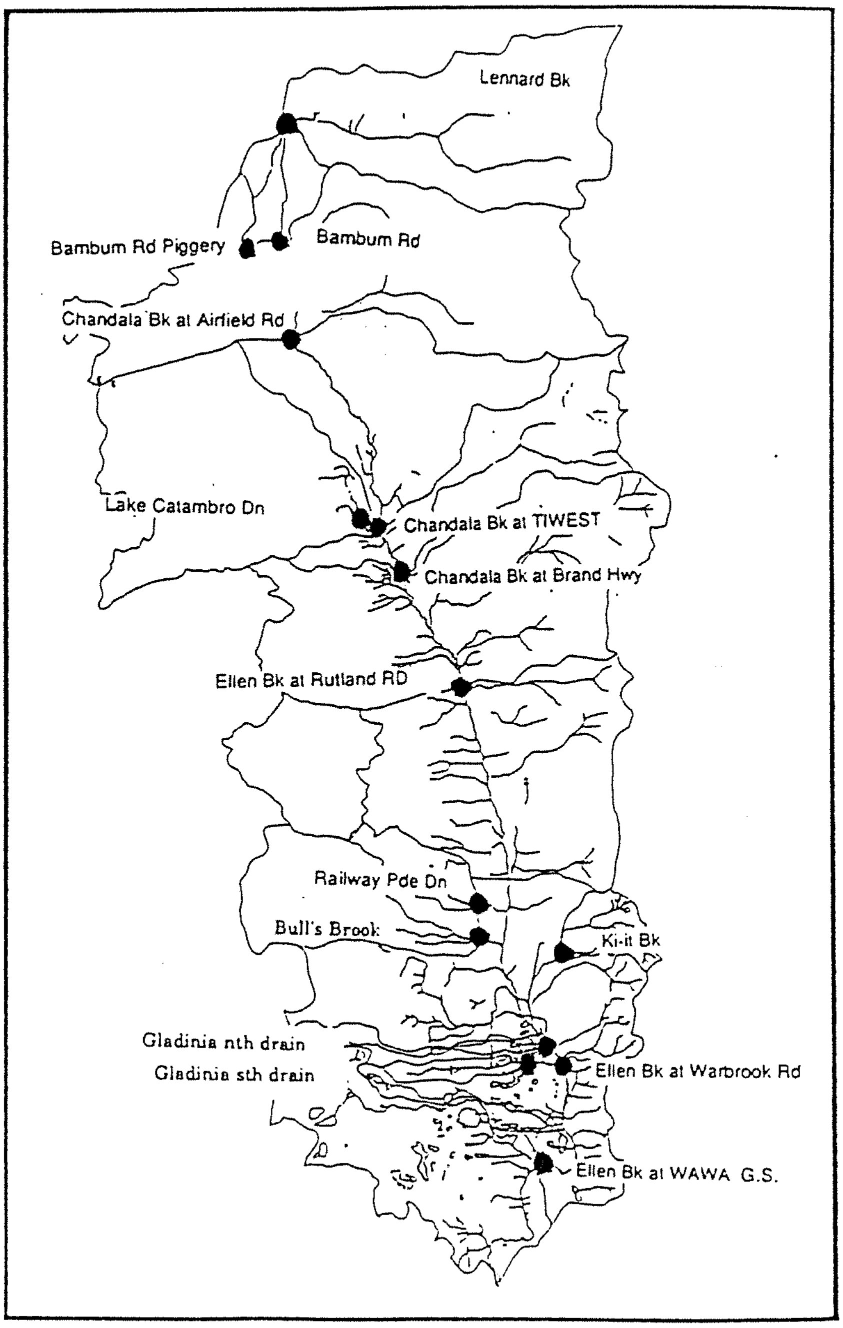

FIGURE 3: Location of sample sites during 'snap-shot' on 4th September 1992.

3 Summary of results

The average flow-weighted concentrations for the bottom end water quality audit of the major catchments discharging into the Swan-Canning estuary are reproduced from Deeley *et al* 1993 and presented in Table 1. These results clearly show the very high annual average concentrations of phosphorus found in Ellen Brook.

TABLE 1 Average annual flow-weighted concentrations (mg/L) of ammonia nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), total nitrogen (TN), soluble reactive phosphorus (SRP) and total phosphorous (TP) in streams draining major catchments in the Swan/Canning system for the period 1987 to 1991 (After Deeley *et al* 1993).

Sub-catchment	NH4-N	NO3-N	TN	SRP	TP
Avon River	0.05	0.20	1.04	0.01	0.07
Bayswater main drain	0.48	0.60	1.69	0.04	0.49
Canning River	0.05	0.86	1.35	0.02	0.08
Southern River	0.08	0.68	1.69	0.17	0.29
Claisebrook main drain	0.18	0.84	1.88	0.04	0.17
South Belmont main drain	0.26	0.42	1.44	0.11	0.21
Mills Street main drain	0.49	0.56	2.19	0.12	0.26
Ellen Brook	**0.17**	**0.15**	**1.97**	**0.43**	**0.71**
Helena River	0.10	0.49	1.17	0.02	0.08
Jane Brook	0.04	0.37	0.79	0.01	0.04
Blackadder Creek	0.36	1.25	1.16	0.03	0.06
Bennett Brook	0.06	0.55	1.59	0.04	0.14
Bannister Creek	0.15	0.45	1.54	0.07	0.13
Susannah Brook	0.10	0.68	1.55	0.03	0.12
Yule Brook	0.07	0.53	1.30	0.03	0.11

3.1 Annual bottom end water quality audit, 1987 to 1992

Results for the audit are summarised in Table 2. It can be seen that there is considerable annual variation in rainfall, streamflow and nutrient load. The variation appears to increase in the order of rainfall < discharge < TN < TP with standard deviations expressed as a percentage of the mean being 9 < 37 < 39 < 44 percent respectively.

The relationships between nutrient loads and streamflow are summarised in Figure 4. This figure also shows the relatively low proportion of dissolved inorganic nitrogen (NO3-N + NH3-N) and high proportion of soluble reactive phosphorus in Ellen Brook runoff.

Total nitrogen loads average 77 t/yr compared to 26 t/yr for phosphorus. This corresponds to an average nitrogen to phosphorus (N/P) ratio of 6. This very low N to P ratio is considerably below the idealised Redfield ratio of 15 for optimum growth of green plants, and highlights the very large phosphorus loads in Ellen Brook. Discharges with very low N to P ratios and high nutrient loads favour the growth of nitrogen fixing blue-green algae.

Table 2 Results of monitoring nutrients in Ellen Brook between 1987-1992. The data are presented as annual load in tonnes, as areal nutrient export in kg/ha/yr, and as flow-weighted mean concentrations.

Year	Rain (mm)	Discharge (million m^3)	Load (tonnes/yr) NH4-N	NO3-N	TN	SRP	TP
1987	771	33	3.9	4.3	68	12	22
1988	928	35	3.4	8.4	69	20	24
1989	820	19	4.0	3.9	41	7	9
1990	913	29	4.6	2.7	57	19	25
1991	969	56	5.0	7.6	119	36	43
1992		49			106	23	32
Mean	734	37	4	5	77	19	26
		Water Yield (m^3/ha)	Export (kg/ha/yr) NH4-N	NO3-N	TN	SRP	TP
1987		493	0.06	0.07	1.02	0.18	0.33
1988		534	0.05	0.13	1.04	0.29	0.37
1989		285	0.06	0.06	0.62	0.11	0.14
1990		439	0.07	0.04	0.86	0.28	0.38
1991		849	0.08	0.11	1.79	0.55	0.65
1992		739			1.59	0.34	0.48
Mean		556	0.06	0.08	1.16	0.29	0.39
			Flow-weighted concentration (mg/L) NH4-N	NO3-N	TN	SRP	TP
1987			0.12	0.13	2.08	0.36	0.67
1988			0.10	0.24	1.95	0.55	0.69
1989			0.21	0.20	2.19	0.37	0.50
1990			0.16	0.09	1.97	0.64	0.87
1991			0.09	0.14	2.11	0.64	0.76
1992					2.15	0.46	0.65
Mean			0.13	0.16	2.07	0.51	0.69

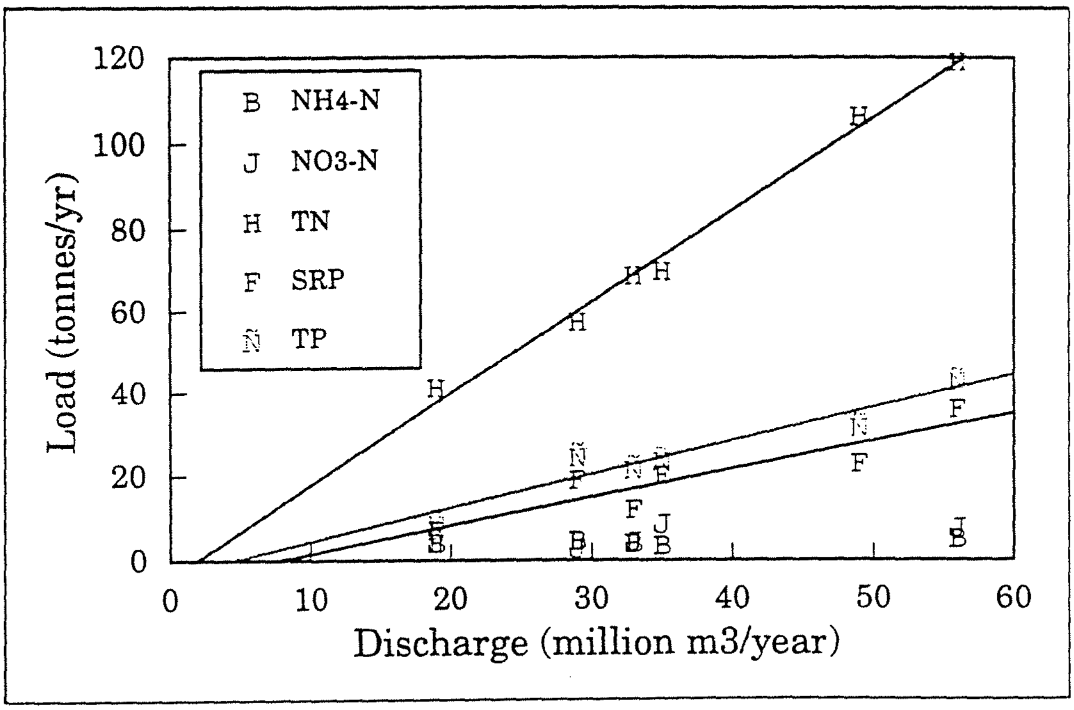

FIGURE 4 Relationships between annual discharge and annual nutrient loads. There is a good linear relationship between discharge and load of TN (R^2=0.99), SRP (R^2=0.83) and TP (R^2=0.92). The loads of NO_3-N (R^2=0.43) and NH_4-N (R^2=0.28) appear to be less influenced by discharge.

Blue-green algae are currently a regular but relatively unimportant component of the phytoplankton community in the upper Swan River (Hosja and Deeley 1993). There is a danger however that the low N/P ratio and magnitude of Ellen Brook nutrient loads may encourage a shift in phytoplankton community structure to one dominated by blue-greens.

The large phosphorus loads are reflected in the high average areal export rates of 0.4 kg/ha/yr. Flow weighted mean concentrations of 2 and 0.7 mg/L for total nitrogen and total phosphorus are also high. The high FWC for ammonium nitrogen of 0.13 mg/l indicates the presence of either faecal material or leachate from decaying animal or vegetable material. There are several possible point sources for nutrients in Ellen Brook including sewage treatment plants and piggeries.

3.2 The annual audit of three Ellen Brook sub-catchments

The results for the three Ellen Brook sub-catchments are compared with the main bottom-end site (SWE1) in Table 3. The pattern of very high phosphorus loads relative to nitrogen loads observed for SWE1 from 1987 to 1992, and the very high proportion of SRP were also evident within the three sub-catchments. Nitrogen to phosphorus ratios for SWE2, SWE3 and SWE4 were 8, 8 and 7 respectively. Proportion of SRP to TP were 74%, 87% and 68%.

TABLE 3 Total annual nutrient loads, areal nutrient export, and flow-weighted mean nutrient concentrations for sub-catchments located within the Ellen Brook catchment for 1992. Data for the three sub-catchments, Ellen Brook at Warbrook Road (SWE2), Bullsbrook (SWE2) and Chandala Brook at Brand Highway (SWE4) are compared with the main bottom-end site, Ellen Brook at West Swan Road (SWE1). (see Figure 3 for the location of these sites). Samples were not analysed for NH_4-N and NO_3-N in 1992.

Site code	Area (ha)	Discharge (tonnes/yr)	Load (tonnes/yr)		
			TN	SRP	TP
SWE1	62800	49	106	23	32
SWE2	60720	47	128	25	34
SWE3	3080	2	5.0	1.3	1.5
SWE4	39230	19	39	8.1	12
		Water Yield (m3/ha/yr)	Export (kg/ha/yr)		
			TN	SRP	TP
SWE1		739	1.59	0.34	0.48
SWE2		781	2.10	0.41	0.56
SWE3		761	1.61	0.41	0.50
SWE4		475	1.00	0.21	0.30
			FWC (mg/L)		
			TN	SRP	TP
SWE1			2.15	0.46	0.65
SWE2			2.69	0.52	0.71
SWE3			2.11	0.54	0.66
SWE4			2.10	0.43	0.63

It should be noted that much of the SRP as measured in a 0.45μm filtrate may not be as readily plant available as forms of orthophosphate ($H_2PO_4^-$, HPO_4^{-2}, PO_4^{-3}). Much of the phosphate in a 0.45μm filtrate may be associated with dissolved organic molecules (fulvic acids; Allen 1986) or adsorbed onto fine colloidal clay material smaller than 0.45μm in size.

Areal nutrient export rates in Table 3 are for the catchments above the particular sampling sites and show high levels of phosphorus and nitrogen export. The flow-weighted mean concentrations show very high concentrations of TN, SRP and TP at all sampling sites.

The pattern and relative magnitudes of discharge for SWE1, SWE3 and SWE4 are summarised in Figure 5. The figure illustrates the strong seasonality of flow typical of streams in the south west of WA where little streamflow occurrs outside June to September. The spike in the hydrograph in early February for SWE1 shows that unseasonal summer rainfall can cause a runoff event. These unseasonal events are thought to be significant in terms of their nutrient inputs to the estuary when phytoplankton growth potential is at its highest.

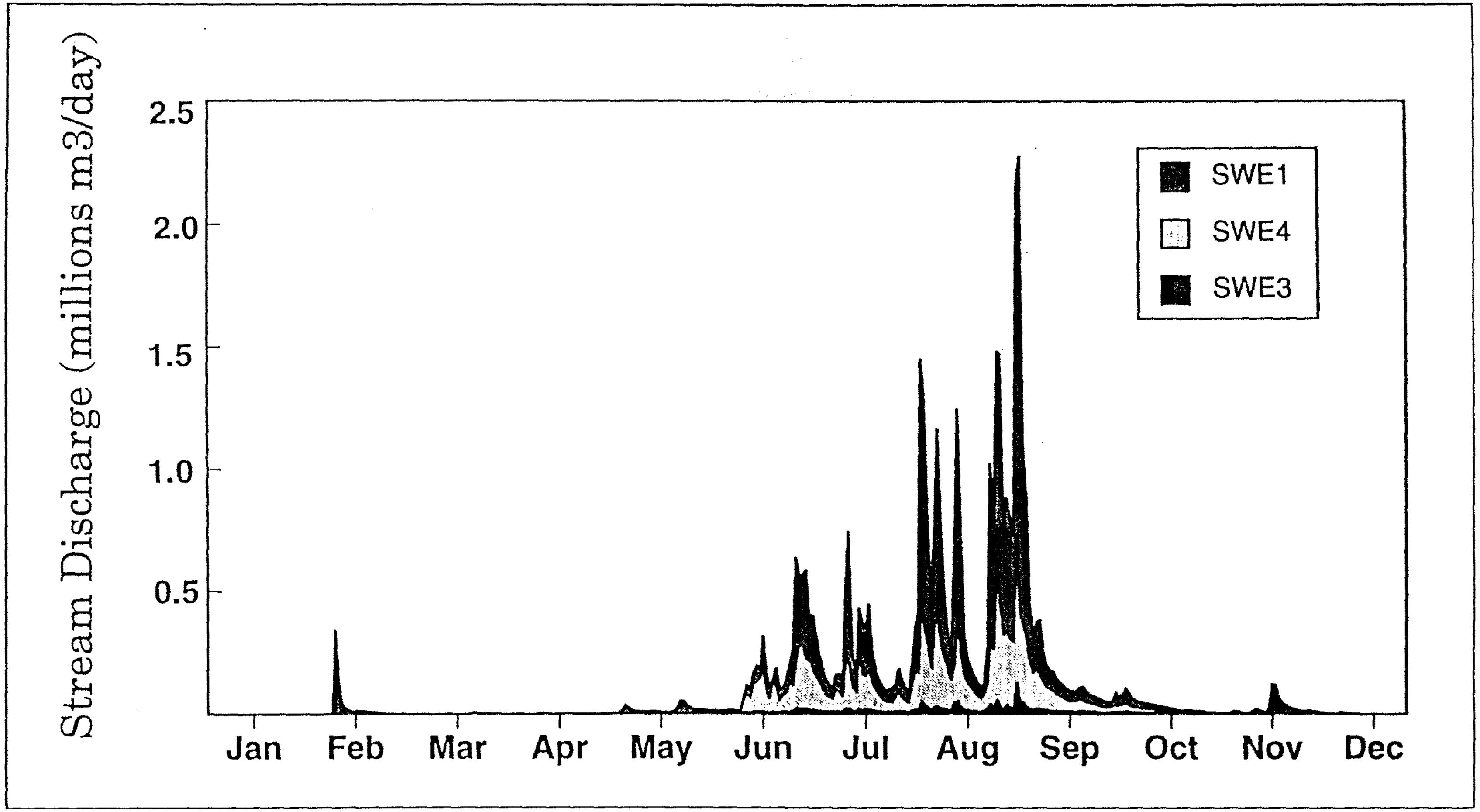

FIGURE 5: Daily discharge for Ellen Brook at West Swan Road (SWE1), at Bull's Brook (SWE3) and Chandala Brook at Brand Highway (SWE4). Discharge at SWE3 and SWE4 was not measured during the early and latter parts of the year so the minor flow events in Febuary and November were not recorded for these sites. Flow for Ellen Brook at Warbrook Road (SWE2) was calculated from SWE1 on an areal basis and is therefore not presented.

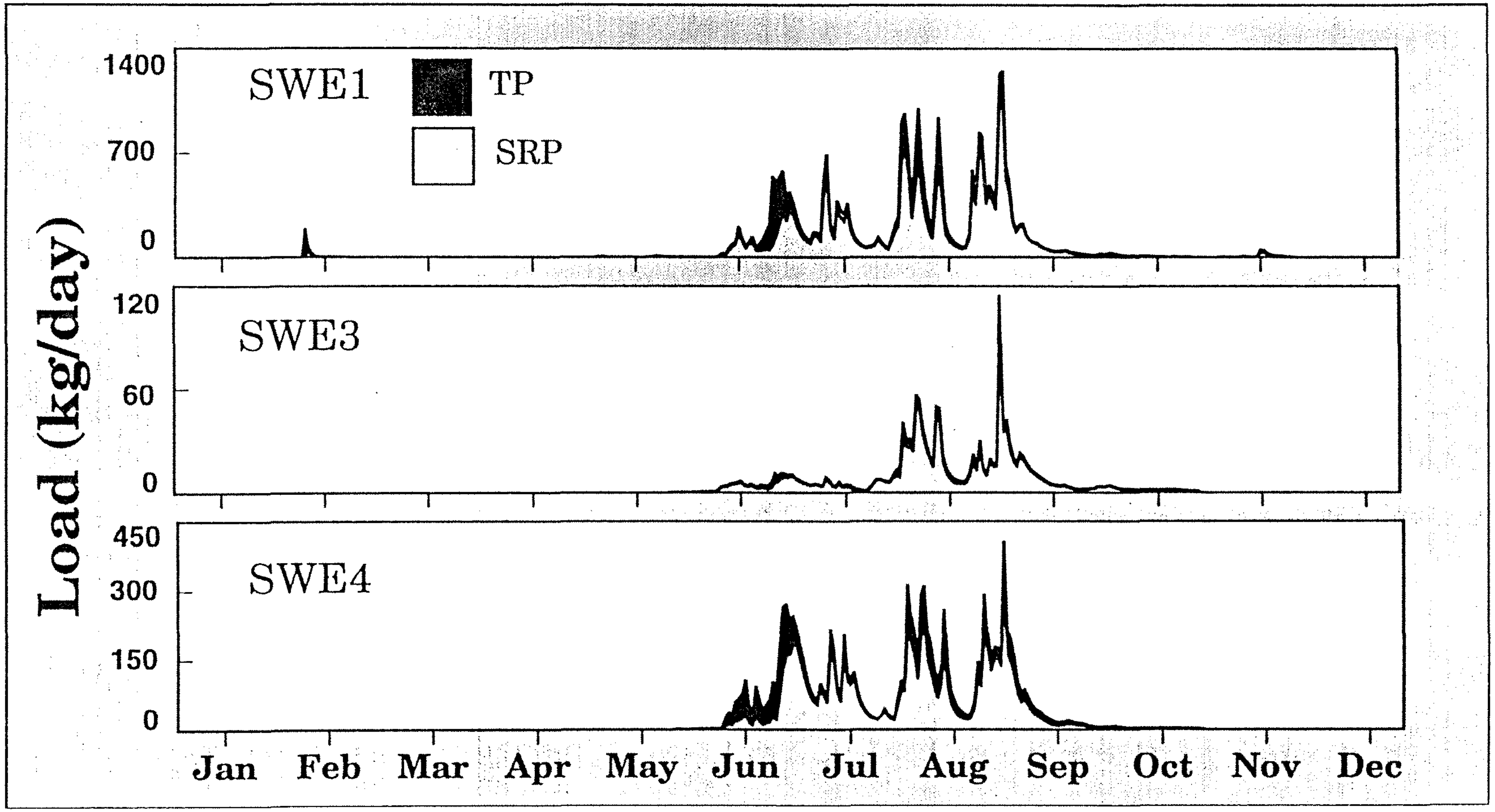

FIGURE 6: Daily loads of soluble reactive phosphorus (-0.45μm) (SRP) and total phosphorus (TP) for Ellen Brook at West Swan Road (SWE1), at Bull's Brook (SWE3) and Chandala Brook at Brand Highway (SWE4).

The seasonal pattern of nutrient discharge for the sub-catchments is shown in Figure 6. The series of graphs clearly shows a first flush effect where the proportion of particulate phosphorus (TP minus SRP) was highest in the first event of the year. This may have been caused by a displacement of silt and organic material accumulated in stream channels and rills over the drier summer months. At this time of the year runoff came from wet low lying areas and there was little runoff from broad paddock areas. The normal pattern of very high percentage of SRP was evident for the following runoff events. The seasonal pattern of total nitrogen discharge was similar to that for total phosphorus.

3.3 The water quality snapshot on a major flow event

The aim of the snapshot was to capture a major flow event and to partition the streamflow and nutrient movement within the Ellen Brook catchment. It was fortunate that the snapshot was undertaken on the largest single flow event for 1992. Figure 7 shows the magnitude of the flow event and the timing of the snapshot. At this time the Ellen Brook catchment was highly saturated and there was extensive sheet movement of water across much of the low lying sandy soils.

Infiltration rates in unsaturated sandy soils lead to the impression that runoff from these soils may be rare and that groundwater flows may predominate. This was certainly not the case for the 4th of September 1992.

Figure 3 shows that there was a good spread of sites along the main channel of Ellen Brook from the top of the catchment to the bottom as well as sites located on tributary inflows. Lennard Brook (1) and Ki-it Brook (11) drain the sand over laterite and laterite soils of the eastern part of the catchment. Lake Catambro Drain (5), Railway Parade Road (9), and Bull's Brook (10) or (SWE3) drain very sandy soils on the western side of the catchment. Bambum Road Piggery (2), and the Gladinia North (12) and South (13) drains collect runoff from properties running pigs on sandy soils. The remaining sites, Bambum Road (3), Chandala Brook at Airfield Road (4), Chandala Brook at TIWEST (6), Chandala Brook at Brand Highway (7) or (SWE4), Ellen Brook at Rutland Road (8), Ellen Brook at Warbrook Road (14) or (SWE2) and Ellen Brook at West Swan Road (SWE1) are all along the length of the main stream channel.

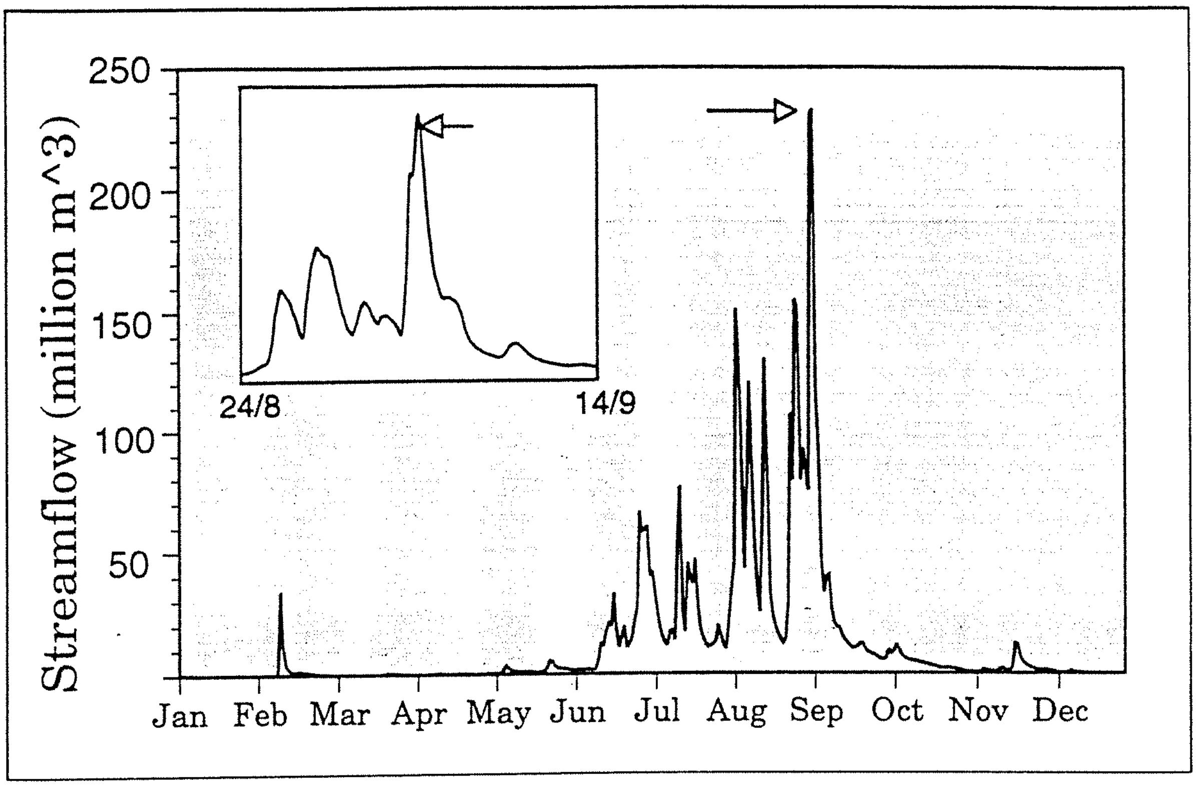

FIGURE 7: Hydrograph of Ellen Brook at the WAWA gauge at West Swan Road (sampling site SWE1), showing the timing of the snapshot relative to stream discharge. The arrows show when the snapshot was undertaken.

The sub-catchment areas, instantaneous streamflow, and results of the nutrient analyses for the fifteen snapshot sampling sites are summarised in Table 4. Water yields show that the Bambum Road piggery drain, Bull's Brook and the Gladinia North and South drains have very high water yields in excess of 1.3 M^3/Ha/hr.

Suspended solids concentrations (SS) were very low for all sites except Ki-it Brook which had a concentration of 50 mg/L (Table 4). This site drains lateritic soils to the east and milky colloidal clay material was clearly evident in the streamflow. It is interesting to note that the trace of suspended solids was also observed immediately downstream in the main channel of Ellen Brook at Warbrook Road. This was not observed at the bottom end of Ellen Brook at West Swan Road however.

Measured total phosphorus concentrations were very high at all sites except Lennard and Ki-it Brooks (Table 4). High concentrations were found in the Gladinia drains and the stream draining Bambum Road. All three of these small sub-catchments contain piggeries which may be contributing to nutrient loads. Concentrations of TP, and SRP were very low for Lennard Brook and Ki-it Brook which is consistent with the considerable phosphate retention capacity of lateritic soils in their catchments. The very low concentrations of phosphorus found in Ki-it Brook combined with the very large sediment load indicate very little sediment bound phosphorus. This suspended load may have had considerable ability to absorb phosphorus after mixing with the dissolved phophorus rich waters of Ellen Brook.

TABLE 4 Instaneous streamflow, sub-catchment area, water yield, suspended solids and nutrient concentrations for the sites sampled during the snapshot on the 4 September 1992.

Site no.	Site location	Area (ha)	Discharge (m^3/sec)	Water yield (m^3/ha/hr)	Observed Concentration (mg/L)					
					SS	NH4-N	NO3-N	TN	SRP	TP
1	Lennard Brook	6240	0.45	0.26	1	0.03	1.00	2.3	0.09	0.16
2	Bambum Road Piggery	540	0.20	1.33	1	0.02	0.02	2.1	0.97	1.20
3	Bambum Road	690	0.05	0.26	1	0.04	0.04	2.5	0.58	0.69
4	Chandala Brook @ Airfield Rd	18880	1.02	0.19	1	0.03	0.05	1.8	0.31	0.45
5	Lake Catambro Drain	7290	0.28	0.14	1	0.02	0.04	1.6	0.12	0.23
6	Chandala Road @ TIWEST	30200	2.62	0.31	1	0.03	0.02	2.1	0.53	0.72
7	Chandala Brook @ Brand Hwy	39230	4.60	0.42	1	0.02	0.02	1.9	0.48	0.63
8	Ellen Brook @ Rutland Road	49580	12.80	0.93	1	0.07	0.02	1.8	0.39	0.59
9	Railway Parade Road	1200	0.10	0.30	1	0.02	0.02	1.6	0.36	0.43
10	Bull's Brook	3080	1.67	1.95	1	0.02	0.02	1.9	0.43	0.71
11	Ki-it Brook	680	0.14	0.74	50	0.02	0.11	0.8	0.03	0.07
12	Gladinia north drain	730	0.38	1.87	1	0.05	0.03	2.6	0.70	1.90
13	Gladinia south drain	450	0.17	1.36	1	0.03	0.03	2.4	2.40	2.80
14	Ellen Brook @ Warbrook Rd	60720	18.10	1.07	5	0.02	0.02	1.7	0.18	0.59
15	Ellen Brook @ West Swan Rd	62800	18.80	1.08	1	0.03	0.02	1.7	0.42	0.60

Total phosphorus concentrations for all sites along the main channel (Sites 3, 4, 6, 7, 8, 14, 15) were remarkably consistent varying little from an average of 0.61 mg/L with a standard deviation of only 14% of the mean (Table 4). The proportion of soluble phosphorus found at site 14 at Warbrook Road was low compared to the other sites. The phosphorus poor suspended sediment load from Ki-it Brook may have bound the dissolved phosphorus present in Ellen Brook possibly resulting in the higher than average particulate fraction of phosphorous found at Warbrook Road.

Total nitrogen concentrations were high with very little difference between sites. The measured dissolved fractions of nitrogen were generally low relative to total (Table 5). Nitrate nitrogen concentrations were greater in the streams draining the eastern side of the catchment, Lennard and Ki-it Brooks.

TABLE 5: Partitioning of the forms of nitrogen into concentrations of dissolved inorganic nitrogen (DIN) calculated as NH4-N + NO3-N, particulate plus dissolved organic N (DON) calculated as TN - DIN. Also shown are the inorganic, total and particulate nitrogen to phosphorus ratios. (See Table 3.1 for key to site numbers)

Site no.	Concentrations			Ratios		
	DIN	PN+DON	%DIN	DIN/SRP	TN/TP	PN/PP
1	1.03	1.3	44.8	11.44	14.4	18.1
2	0.04	2.1	1.9	0.04	1.8	9.0
3	0.08	2.4	3.2	0.14	3.6	22.0
4	0.08	1.7	4.4	0.26	4.0	12.3
5	0.06	1.5	3.8	0.50	7.0	14.0
6	0.05	2.1	2.3	0.09	2.9	10.8
7	0.04	1.9	2.1	0.08	3.0	12.4
8	0.09	1.7	5.0	0.23	3.1	8.6
9	0.04	1.6	2.4	0.11	3.7	22.3
10	0.04	1.9	2.1	0.09	2.7	6.6
11	0.13	0.6	17.1	4.33	10.9	15.8
12	0.08	2.5	3.1	0.11	1.4	2.1
13	0.06	2.3	2.5	0.03	0.9	5.9
14	0.04	1.7	2.4	0.22	2.9	4.0
15	0.05	1.7	2.9	0.12	2.8	9.2

The total loads of TP, SRP and TN generally increased from the top to the bottom of the catchment (Figures 8, 9 and 10) consistent with the increase in discharge at each downstream sampling site (Table 4). During the flow event, the largest of the year, less than one kilogram of phosphorous per hour was carried by the streams at the headwaters of the catchment. This increased to about 30 kg/hr at the Rutland Road about half way down the catchment to some 40 kg/hr at the confluence of Ellen Brook with the Swan River (Figure 8). Ellen Brook contributed about 30 kilograms of soluble P to the Swan River every hour during the sampling period (Figure 9). Total nitrogen loads showed a similar pattern of change with distance downstream. Somewhere between 3.7 and 0.5 kg/hr of total nitrogen were discharged by the upper catchment streams which increased to 80 kg/hr half way down the catchment. About 100 kilograms of nitrogen were delivered to the Swan River during the high flow conditions (Figure 10).

The loads of nitrate and ammonia nitrogen did not increase with flow volume and distance downstream (Figures 11 and 12). This finding is consistent with the poor relationship found between annual total discharge and annual load of nitrate and ammonia identified during the annual audit of Ellen Brook 1987-1992 (see Figure 4).

There was some inconsistency between discharge and nutrient loads measured at the Lennard Brook site and the downstream Bambum Road site (Figures 8 to 12). For example, the TN load decreases substantially from 3.7 kg/hr at Lennard Brook to only 0.5 kg/hr downstream at Bambum road (Figure 10). The concentration of TN at the sites were similar so the differences are primarily a function of flow volume rather than instream losses. The surface drainage lines in the upper portion of the Ellen Brook catchment are poorly defined and some water from Lennard Brook may flow north into Gingin Brook.

Areal export rates for the catchments above each of the sample sites are presented in Table 6. The data confirm Bambum Road and the Gladinia drains as significant sources of phosphorus and nitrogen to Ellen Brook. Bull's Brook also contributes relatively large quantities of nutrients. Partition of the sites according to effective area of water catchment suggests that the catchment above the TIWEST and Rutland road sites may contribute disproportionate amounts of phosphorus and nitrogen

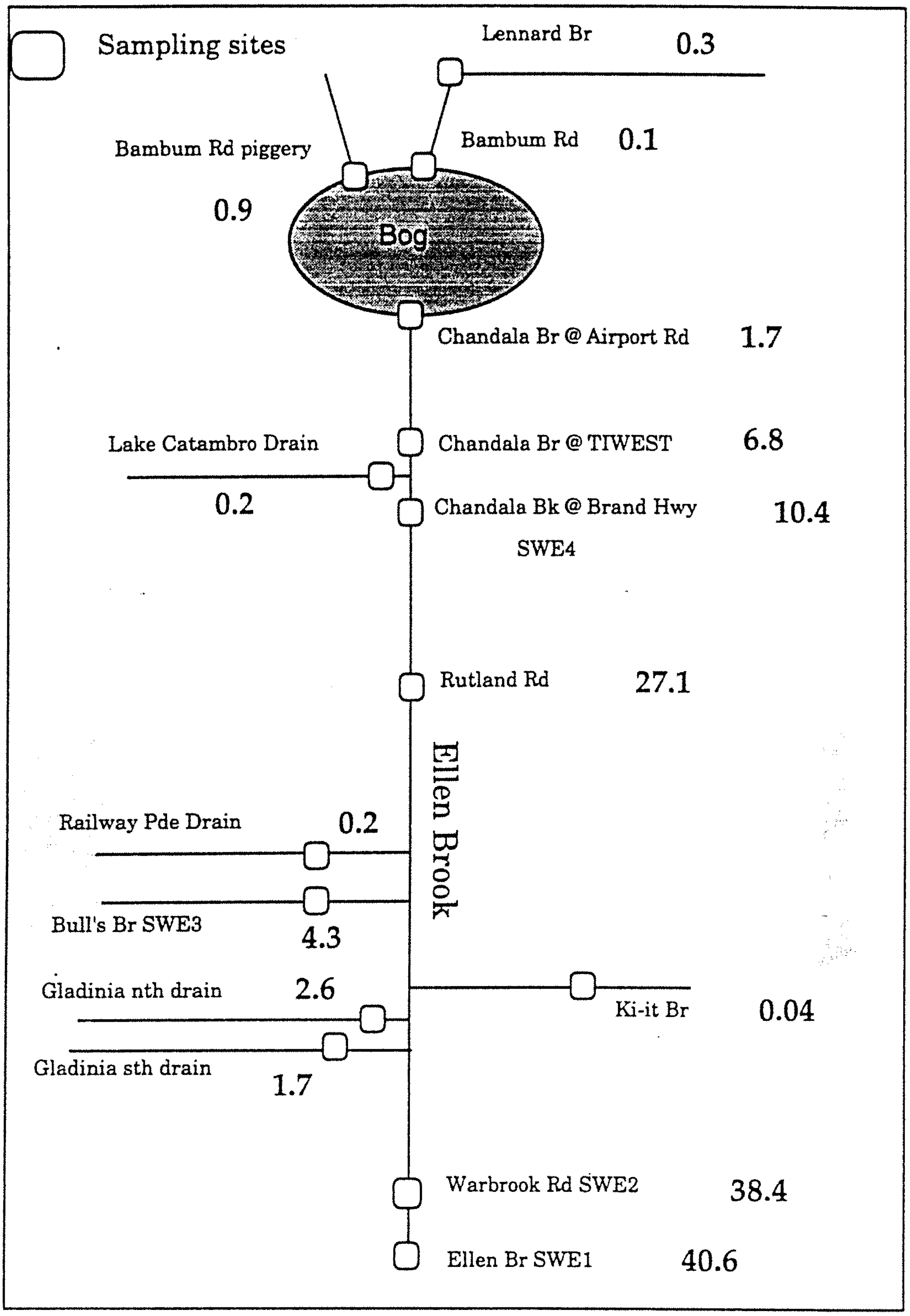

FIGURE 8 Conceptual model of Ellen Brook showing snapshot sampling sites and instantaneous **total phosphorus** loads (kg/hr).

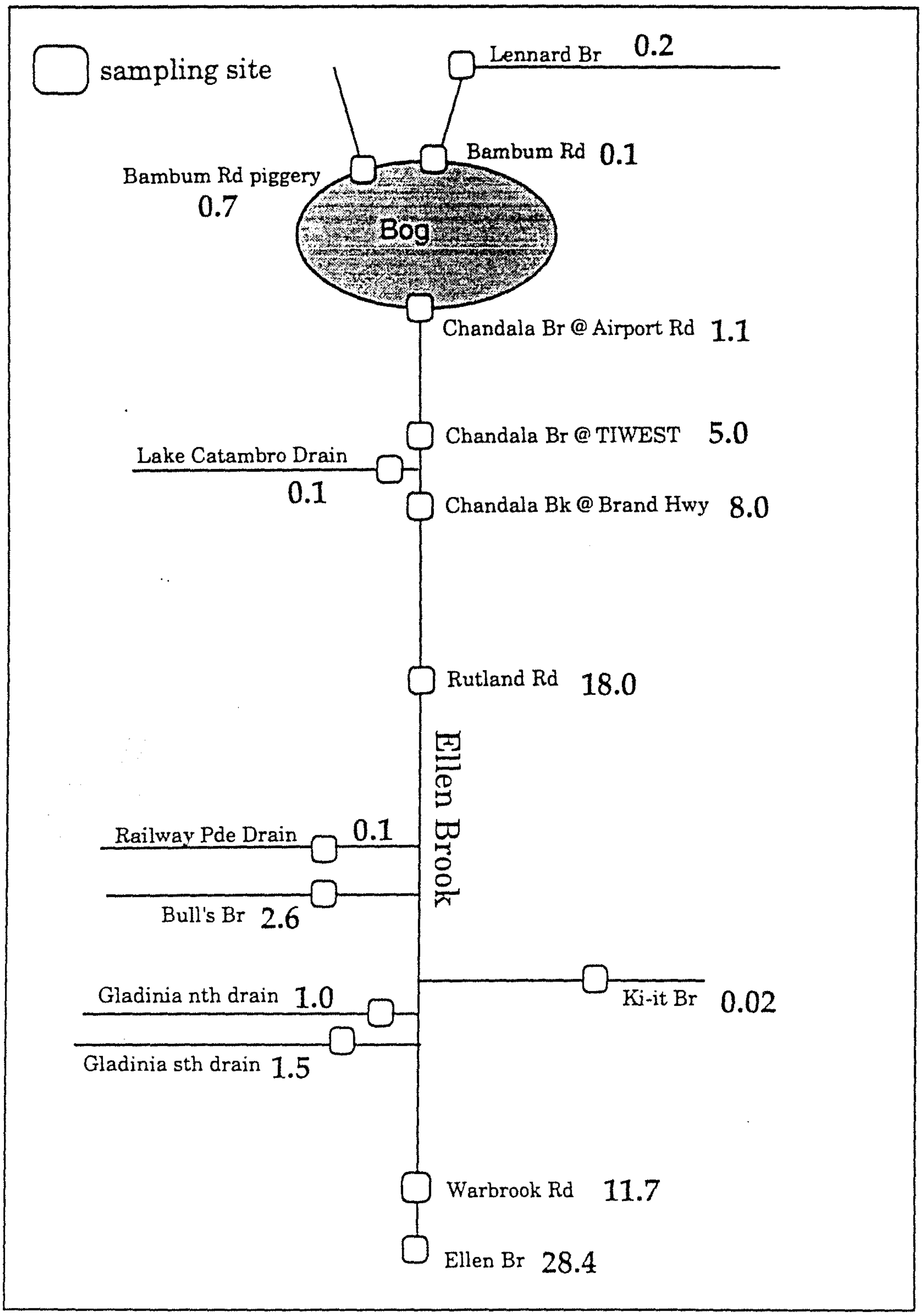

FIGURE 9 Conceptual model of Ellen Brook showing snapshot sampling sites and instantaneous **soluble reactive phosphorus** loads (kg/hr).

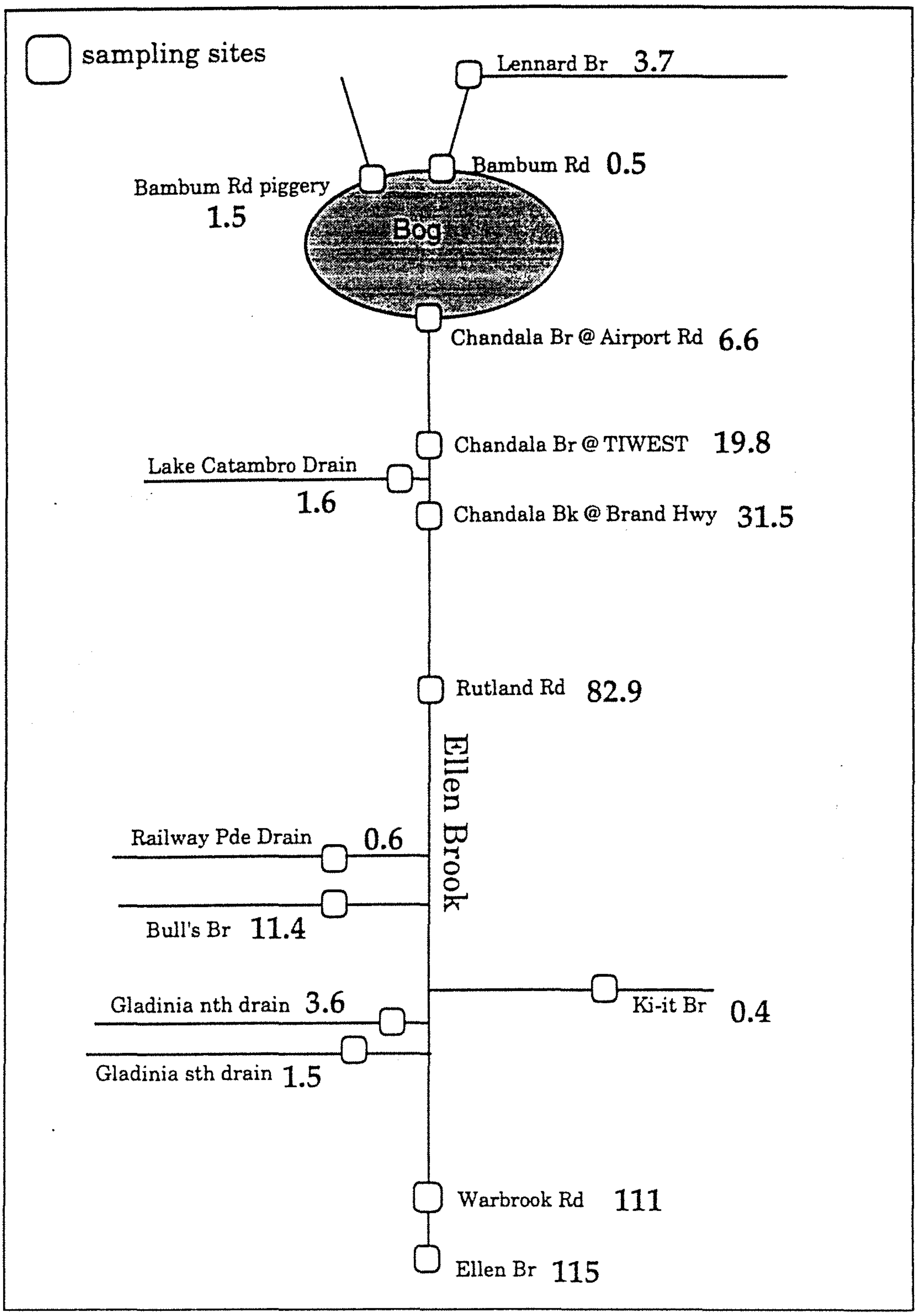

FIGURE 10 Conceptual model of Ellen Brook showing snapshot sampling sites and instantaneous **total nitrogen** loads (kg/hr).

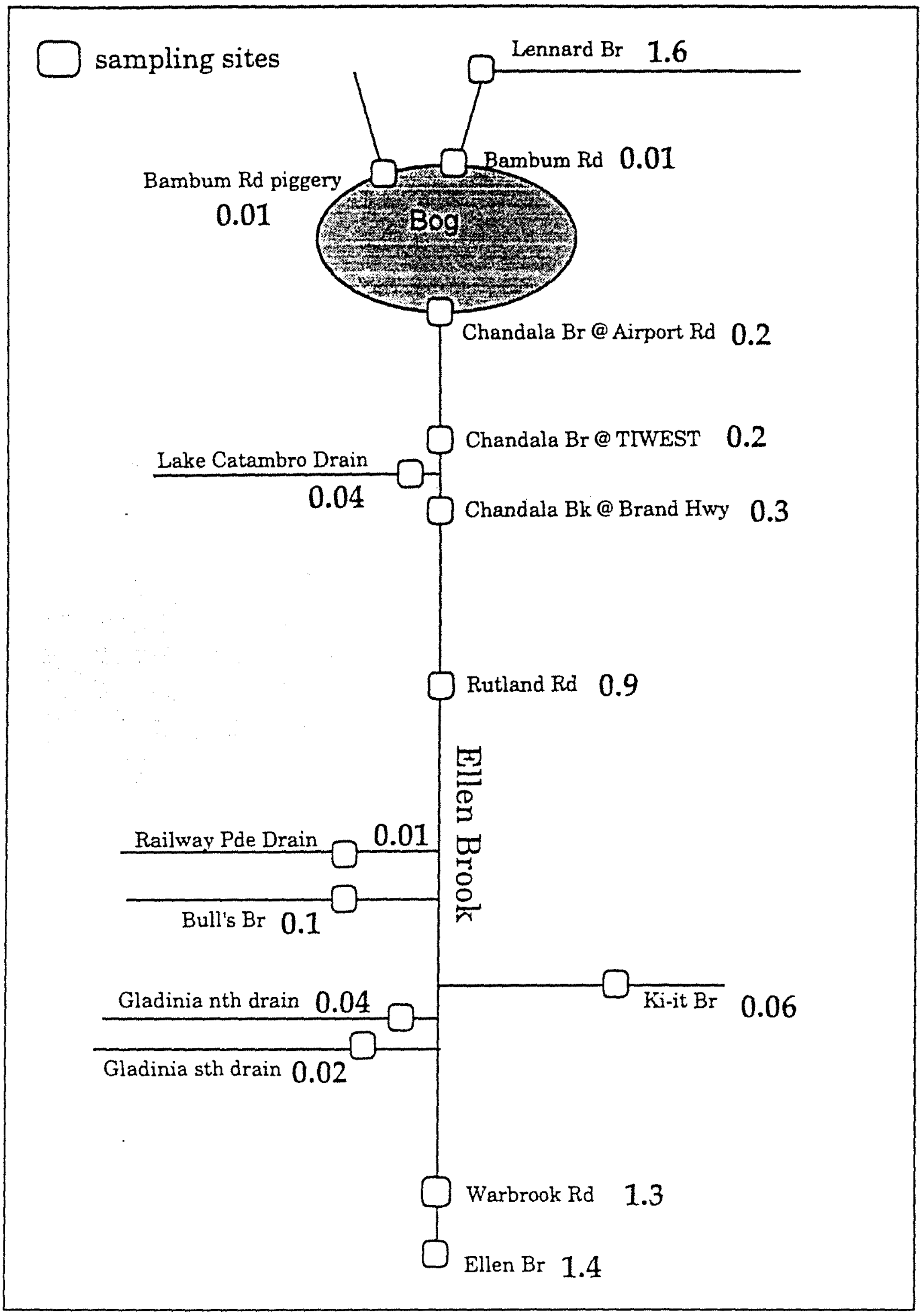

FIGURE 11 Conceptual model of Ellen Brook showing snapshot sampling sites and instantaneous **nitrate nitrogen** loads (kg/hr).

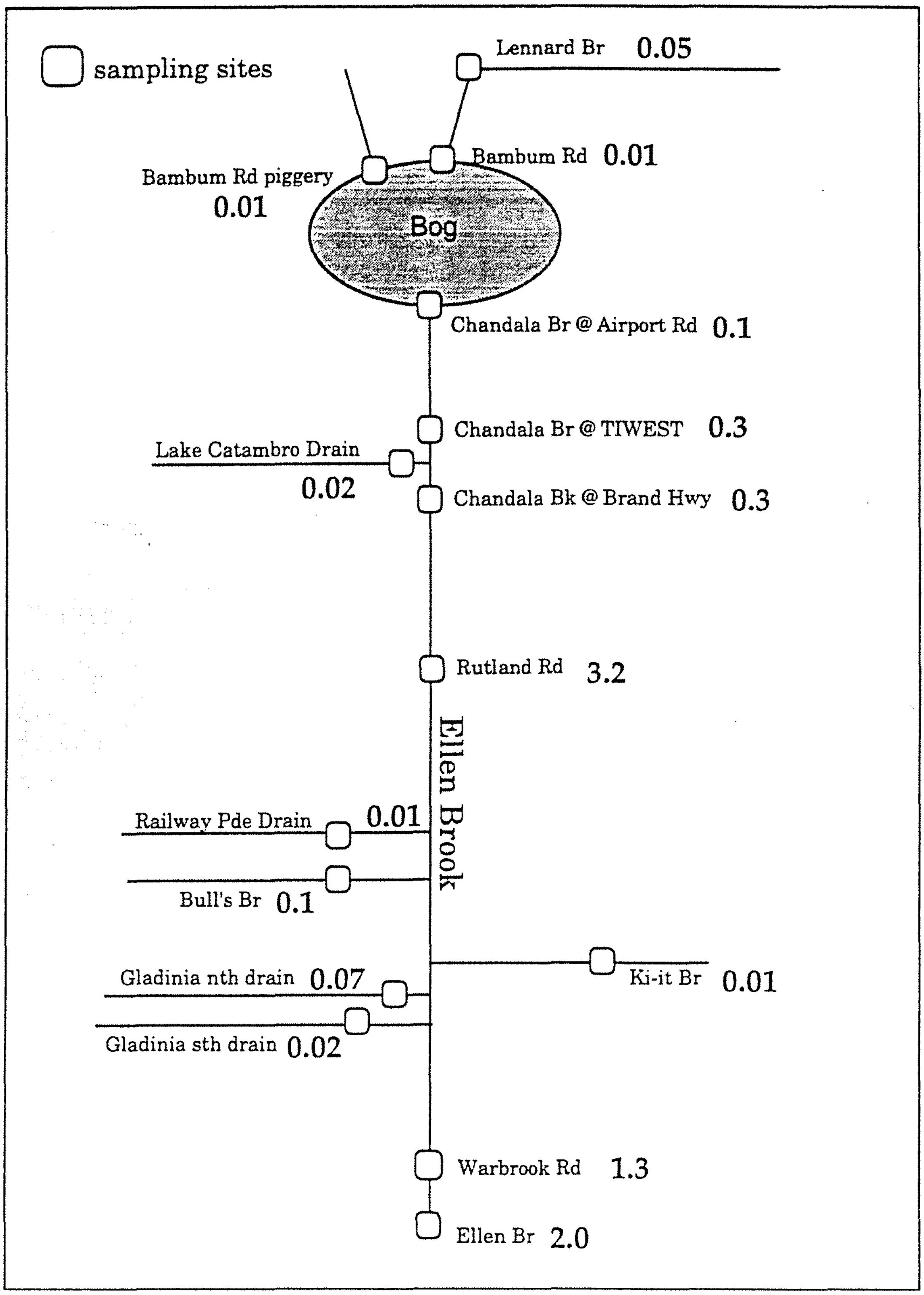

FIGURE 12 Conceptual model of Ellen Brook showing snapshot sampling sites and instantaneous **ammonia nitrogen** loads (kg/hr).

TABLE 6 Areal export of suspended solids (SS) and nutrients as measured at each of the sampling sites. Areal export rates for catchments between sites along the main channel (bolded) have been calculated by difference. Negative values may indicate instream losses or errors in the method of sampling and load estimations. See table 3.1 for key to site numbers.

Site no.	Export (g/ha/hr)						Partitioned Export (g/ha/hr)					
	SS	NH4	NO3	TN	SRP	TP	SS	NH4	NO3	TN	SRP	TP
1	0.23	0.01	0.26	0.60	0.02	0.04	0.23	0.01	0.26	0.60	0.02	0.04
2	1.20	0.03	0.03	2.80	1.29	1.60	1.20	0.03	0.03	2.80	1.29	1.60
3	0.23	0.01	0.01	0.65	0.15	0.18	0.23	0.01	0.01	0.65	0.15	0.18
4	0.18	0.01	0.01	0.35	0.06	0.09	**0.09**	**0.00**	**-0.13**	**0.08**	**0.02**	**0.04**
5	0.12	0.00	0.01	0.22	0.02	0.03	0.12	0.00	0.01	0.22	0.02	0.03
6	0.28	0.01	0.01	0.66	0.17	0.22	**1.06**	**0.04**	**-0.01**	**2.87**	**0.93**	**1.22**
7	0.38	0.01	0.01	0.80	0.20	0.27	**0.71**	**0.01**	**0.02**	**1.29**	**0.33**	**0.40**
8	0.84	0.07	0.02	1.67	0.36	0.55	**2.57**	**0.28**	**0.06**	**4.97**	**0.97**	**1.62**
9	0.27	0.01	0.01	0.48	0.11	0.13	0.27	0.01	0.01	0.48	0.11	0.13
10	1.76	0.04	0.04	3.71	0.84	1.39	1.76	0.04	0.04	3.71	0.84	1.39
11	37	0.01	0.08	0.56	0.02	0.05	37	0.01	0.08	0.56	0.02	0.05
12	1.69	0.09	0.06	4.87	1.31	3.56	1.69	0.09	0.06	4.87	1.31	3.56
13	1.22	0.04	0.04	3.26	3.26	3.81	1.22	0.04	0.04	3.26	3.26	3.81
14	5.37	0.02	0.02	1.82	0.19	0.63	**50**	**-0.43**	**0.03**	**2.08**	**-2.28**	**0.50**
15	0.97	0.03	0.02	1.83	0.45	0.65	**-127**	**0.35**	**0.02**	**2.06**	**8.03**	**1.04**

4. Conclusions

Ellen Brook was found to have been discharging large amounts of nutrients, particularly phosphorus, to the Swan River. The very low average nitrogen to phosphorus ratio of 6:1 favours the growth of potentially toxic blue-green algal species.

To date there have been large blooms of phytoplankton in the upper reaches of the Swan River during the summer months but they have been non-toxic species. The Swan River Trust is concerned that continued discharges of phosphorus rich runoff from Ellen Brook and similar catchments may cause a shift in Swan River phytoplankton communities toward a seasonal dominance by blue-green species, and possibly result in problems similar to those being experienced in the Peel-Harvey estuary, or the Murray-Darling river system in the eastern states.

The high levels of phosphorus appear to be originating in areas associated with intensive animal industries and from agricultural enterprises on the low lying grey sandy soils. More than 70 percent of the phosphorus loads in Ellen Brook are classified as being in a reactive form. This means that little of the phosphorus is associated with sediment particles.

There is also a significant amounts of nitrogen coming from Ellen Brook. A small proportion of this nitrogen is in dissolved forms such as nitrate and ammonium. The slightly elevated levels of ammonia nitrogen indicate faecal contamination or decaying vegetable and animal wastes. The low proportion of inorganic dissolved nitrogen and the low levels of suspended sediment indicate that much of the nitrogen is present in dissolved fractions not measured in this study. The highly coloured waters of Ellen Brook suggest the presence dissolved organic compounds rich in nitrogen.

5. References

Allen, D.G. (1989). Organic phosphorus in soils of the Peel Harvey catchment area. Report by the Government Chemical Laboratories.

Appleyard, S.J. (1992). Estimated nutrient loads discharged into the Swan-Canning estuary from groundwater. Geological Survey of Western Australia. *Hydrogeology Report No. 1992/20.*

Atkins, R. P. (1985). Nutrient enrichment of the Canning River. *Waterways Commission. Report No. 7.*

Cullen, P.; Farmer, N. and O'Loughlin, E. Estimating nonpoint sources of phosphorus to lakes. *Verh. Internat. Verein. Limnol. Vol 23: 588-593.*

Deeley, D.; Parsons, G.W. and Donohue, R.B. (1993a). Water quality monitoring in the Swan-Canning catchment: Interim results. In: *Workshop Proceedings- Swan River-The Future.* Swan River Trust. Report no. 8.

Deeley, D.; Donohue R.B. and Parsons, G.W. (1993b). Nutrient audit of the Peel-Harvey catchment 1990-1992. In prep.

Forbes, G. G. and Birch, P. B. (1987). Nutrient loading into the Peel-Harvey Estuary from the Harvey, Murray and Serpentine Rivers (1977-1984). *Environmental Protection Authority Technical Series No. 13.* Perth, Western Australia.

Gerritse, R.G. and Schofield, N.J. (1989). The movement of phosphate in a catchment with a shallow ephemeral water table. *Journal of Contaminant Hydrology* 4:313-331.

Henderson, A.; Humphries, R.B.; and Hosja, H. (1983). Time series plots of the Swan-Canning estuarine system: Phsico-chemical data, 1944-1980. *Waterways Commission, Report No. 1.*

Hosja, V. and Deeley, D. (1993). Phytoplankton distribution in the upper reaches of the Swan estuary: Influence of physical properties. Swan River Trust Report. In prep.

Kinhill, S. (198). Peel-Harvey Estuarine System Study: Report on the Mandurah Attitudinal Survey. *DCE Bulletin No. 235.*

Richards, R. P. and Holloway, J. (1987). Monte Carlo studies of sampling strategies for estimating tributary loads. *Water Resources Research. Vol. 23, No. 10, 1939-1948.*

Schofield, N.J.; Bettenay, K.W.; McAlpine, K.W.; Height, D.H.; Hurle, D.H.; Ritchie, G.S.P.; Birch, P.B. (1985). Water and phosphorus transport processes in permeable grey sands at Talbot's site near Harvey, Western Australia. *Department of Conservation and Environment, Bulletin 209.* Perth, WA.

Thurlow, B.H; Chambers.J. and Klemm, V.V. (1986). *Swan-Canning Estuarine System: Environment, Use and the Future.* Waterways Commission. Report No. 9.