ESTIMATES OF NUTRIENT STREAMLOAD IN THE SWAN-CANNING CATCHMENT 1987 - 1992

Swan River Trust
Report No. 20
December 1994

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SUMMARY

1. BACKGROUND AND THE MONITORING NETWORK

Eutrophication has been identified as the greatest threat to estuarine ecosystem health in the south west of Australia. As eutrophication proceeds the ecology of the systems is disrupted and the natural community of plants and animals may be replaced by less desirable groups. In the south west estuaries, the availability of phosphorus is thought to limit primary productivity although nitrogen limitation may be important seasonally. The biological symptoms of eutrophication have been observed in the Swan-Canning estuary for many years.

In 1987, the Swan River Trust (SRT) began monitoring nutrients in 15 major tributaries to the Swan-Canning estuary. The program of monitoring was carried out during the winter wet period, with a grab sample collected once a week from each of the sample sites. The aims of the monitoring were to estimate the total external load of nutrients from surface drainage to the Swan-Canning estuary, to identify the major contributing sub-catchments to the total annual load, and to show changes, if any, in the levels of nutrients in the monitored streams.

This report presents estimates of mass loading of phosphorus and nitrogen to the estuary based on data collected between 1987 and 1992.

2. RESULTS OF MONITORING FOR NUTRIENTS

In the period 1987 to 1992, an annual average of 580 million cubic metres of water was discharged to the Swan-Canning estuary, with about 740 tonnes of nitrogen and 70 tonnes of phosphorus. The external loading of the estuary with nutrients was closely related to annual discharge. Ellen Brook and the Avon River were the major contributors of nutrients to the estuary.

Of the total estimated load of nitrogen, over 50 percent came from the Avon River catchment while Ellen Brook (10%) and Southern River (5%) were the largest contributing catchments on the Swan Coastal Plain. The annual nitrogen loads in the Swan-Canning were closely correlated with discharge in all streams, except the Helena River. Total nitrogen loads increased over the monitoring period in the Avon River, Ellen Brook, Bannister Creek, Bennett Brook, Bayswater Main Drain and South Belmont Main Drain. At the sites on the Canning River, Southern River, Jane Brook, Yule Brook and Claisebrook Main Drain the estimates of annual nitrogen streamload varied between years with no indication of trend. Loads in Helena River also varied over time but independently of stream discharge. Ellen Brook and the Mills Street Drain contained the highest nitrogen flow-weighted mean concentrations (> 0.2 mg/L). Only two streams, Helena River and Jane Brook, contained less than 1 mg/L of nitrogen on average.

About 35 percent of the external phosphorus load to the estuary came from Ellen Brook, 30 percent from the Avon River, 10 percent from the Southern River and the Bayswater Main Drain contributed an average of about 5 percent every year. The magnitude of loads was related to total stream discharge and phosphorus concentration. The flow-weighted mean concentration of phosphorus in Ellen Brook was very high (0.7 mg/L). Bayswater Main Drain, Southern River, Mills Street Main Drain, South Belmont Main Drain also contained high concentrations of phosphorus (FWCs > 0.2 mg/L). The estimates of nitrogen flow-weighted mean concentration were remarkably stable between years in most of the sub-catchments monitored. The FWC of nitrogen increased in only the Mills Street Main Drain and Jane Brook .

In most streams, between 50 and 60 percent of phosphorus was transported in association with coarse particulate matter. In the Bayswater Main Drain nearly all the phosphorus present was in association with coarse particulate matter, possibly organics. In Ellen Brook, however, most of the phosphorus load was associated with very fine particulate matter, probably dissolved phosphates. The inorganic nitrogen loads in the Swan-Canning varied widely between the streams. In most, the inorganic nitrogen loads were greater than 40 percent of the estimated total nitrogen load and, in the Canning River, they were 66 percent of the total load. In the Avon River, Bannister Creek, Bennett Brook and Ellen Brook the inorganic nitrogen loads were less than about 35 percent of the total nitrogen streamloads.

Phosphorus loads tended to increase over the period 1987-1992 in Ellen Brook, Bannister Creek, Bennett Brook and South Belmont Main Drain. Annual phosphorus loads fluctuated between years with no trend in Blackadder Creek, Jane Brook, Mills Street Main Drain, Southern River, Susannah Brook and Yule Brook with changes in annual discharge. In the Avon, Canning, and Helena Rivers, there was a decrease in annual streamload between 1987 and 1992. In these streams, the estimates of load were independent of changes in annual discharge. Annual loads in the Bayswater Main Drain fell over the monitoring period as the concentration of phosphorus in the drain declined.

3. DISCUSSION

The export of nutrients from a catchment depends on land use, soil type, vegetation cover, drainage density, influence of ground water and the contribution from point sources. In the Swan-Canning, the variability in loads, flow-weighted concentrations, fractions and temporal patterns reflects the diversity of these attributes in the sub-catchments of the system. The sub-catchments range from rural areas, such as Ellen Brook, where the dominant land use is grazing, to catchments such as Bayswater or Claisebrook Main Drains which are predominantly urban. Soils in the sub-catchments of the Swan-Canning include areas of grey sands with little capacity to retain phosphorus on the coastal plain and lateritic soils that have a good ability to retain nutrients in the hills. Some stream waters, such as those in the low lying areas of Ellen Brook, are probably derived mostly from sub-surface flow.

The temporal and spatial variation in nutrient loads that is observed in the sub-catchments of the Swan-Canning system comes from two sources: that variation which is present because of actual differences between catchments and between years, and that variation introduced by extrinsic factors, mainly error, or bias in the streamload estimate.

Bias in load estimation is introduced through the reliance on infrequent fixed-interval sampling. Fixed-frequency sampling regimes, like the one that has been used during this project, produce biased and extremely imprecise estimates of mass load. Based on the levels of bias reported in the literature the estimates of nutrient load significantly underestimate the actual annual loads in the monitored streams. The estimates of filterable reactive phosphorus and inorganic nitrogen streamloads were probably less affected by bias than were the total estimates. Therefore the proportions of dissolved nutrients in the total loads were probably too high. It is also likely, based on studies reported in the literature, that the estimates of phosphorus streamload were more biased than the estimates of nitrogen streamload.

CONCLUSIONS

The fixed-interval sampling regime employed to sample the streams between 1987 and 1992 is not appropriate for the estimation of mass loads. It results in bias and imprecise loading estimates and can potentially result in spurious conclusions of spatial differences and temporal trends.

It is clear nevertheless that most of the phosphorus discharged to the Swan-Canning estuary is derived from the relatively small area of the Swan Coastal Plain. The Avon River, Ellen Brook and the Southern River were identified as the major contributors of nitrogen to the estuary. Ellen Brook, the Southern River and the Bayswater Main Drains were also shown to carry large quantities of phosphorus. There were a number of other monitored streams that contained high concentrations of phosphorus and nitrogen.

A large proportion of the nitrogen loading to the estuary was derived from the Avon River catchment due primarily to large annual discharge. Ellen Brook and the Mill Street Main Drain were also significant sources of nitrogen to the estuary but their total contributions were relatively minor because of their relatively small annual discharge compared to the Avon River.

1. INTRODUCTION

The excessive input of plant nutrients has been identified as the greatest threat to the health of estuarine ecosystems in the south west of Western Australia (GWA 1992). The process of enrichment of aquatic systems with nutrients, called eutrophication, is normally a slow process that occurs naturally as waterbodies age. Human activity in catchments can increase the export of nutrients to rivers and streams, and accelerate the rate of eutrophication of receiving waterbodies (Likens and Borman 1974; Sharpley *et al.* 1994). Nitrogen and phosphorus have been shown to be the most important nutrients in the eutrophication of natural waters.

Phosphorus is regarded as the primary limiting nutrient in fresh waters while, in marine waters, nitrogen is considered to be more important. Which of the macro-nutrients controls growth can depend on the plant groups being considered and on other factors such as season and salinity. Blue-green algae are able to 'fix' nitrogen so their populations are more limited by phosphorus. Phosphorus is widely regarded as the usual limiting nutrient in estuaries of the south west of Western Australia (McComb and Davis 1993).

1.1 Ecosystem Response to Nutrient Enrichment

The photosynthetic algae and plants — seaweeds, seagrasses and microscopic planktonic algae - are the groups most obviously affected by a change in nutrient status. For example, an increase in the biomass and a change in species composition of macroalgal communities is a common response to nutrient enrichment. The macrophyte communities in healthy estuaries contain a diversity of species, usually a mix of red, brown and green algae. In eutrophic aquatic systems however, the green algae such as *Ulva, Cladophora, Chaetomorpha* and *Enteromorpha*, which are advantaged by nutrient enrichment, may dominate the macroalgae community.

Nutrient enrichment can also cause often unpredictable changes in the distribution and biomass of higher plant groups. For example, the biomass of the aquatic plant *Ruppia megacarpa* has been observed to increase following the mild enrichment of salt lakes and estuaries, but has virtually disappeared from severely eutrophic systems (McComb and Davis 1993). Nutrient enrichment has led to the loss of seagrasses over large areas in some estuaries in WA. These losses have been attributed to decreased water clarity and smothering due to increases in algae biomass.

Frequent seasonal blooms of phytoplankton are another common response to enrichment in rivers, lakes and estuaries. The decay of organic material following the collapse of these blooms can cause anoxia in bottom waters. The lack of oxygen has major implications for the health of the estuary. It can cause the death of worms, crabs and other bottom living invertebrates (McComb and Davis 1993) which are important prey for fish and other high-order predators like waterbirds.

1.2 Trophic Status of the Swan-Canning Estuary

There has been evidence of nutrient enrichment in the Swan-Canning estuary for some time (Hodgkin and Hamilton 1993). For many years, massive accumulations of green algae fouled estuary beaches and had to be removed. Many urban wetlands in the catchments of the estuary have been showing signs of enrichment with nutrients and are characterised by large populations of blue-green algae, *Anabaena* and *Microcystis* . The excessive growth of macroalgae in the Swan-Canning estuary was originally linked to the discharge of sewage effluent to the estuary, however the problems continued after these sources were controlled. The estuary is still enriched with nutrients but they are thought to be coming from diffuse sources in urban and agricultural areas.

In the mid to late 1980s there was a general recognition that the problems in the estuary were due to the export of nutrients and organic material from the catchment. In 1987, the Swan River Trust (SRT) switched the focus of its monitoring activity from the estuary itself to the major

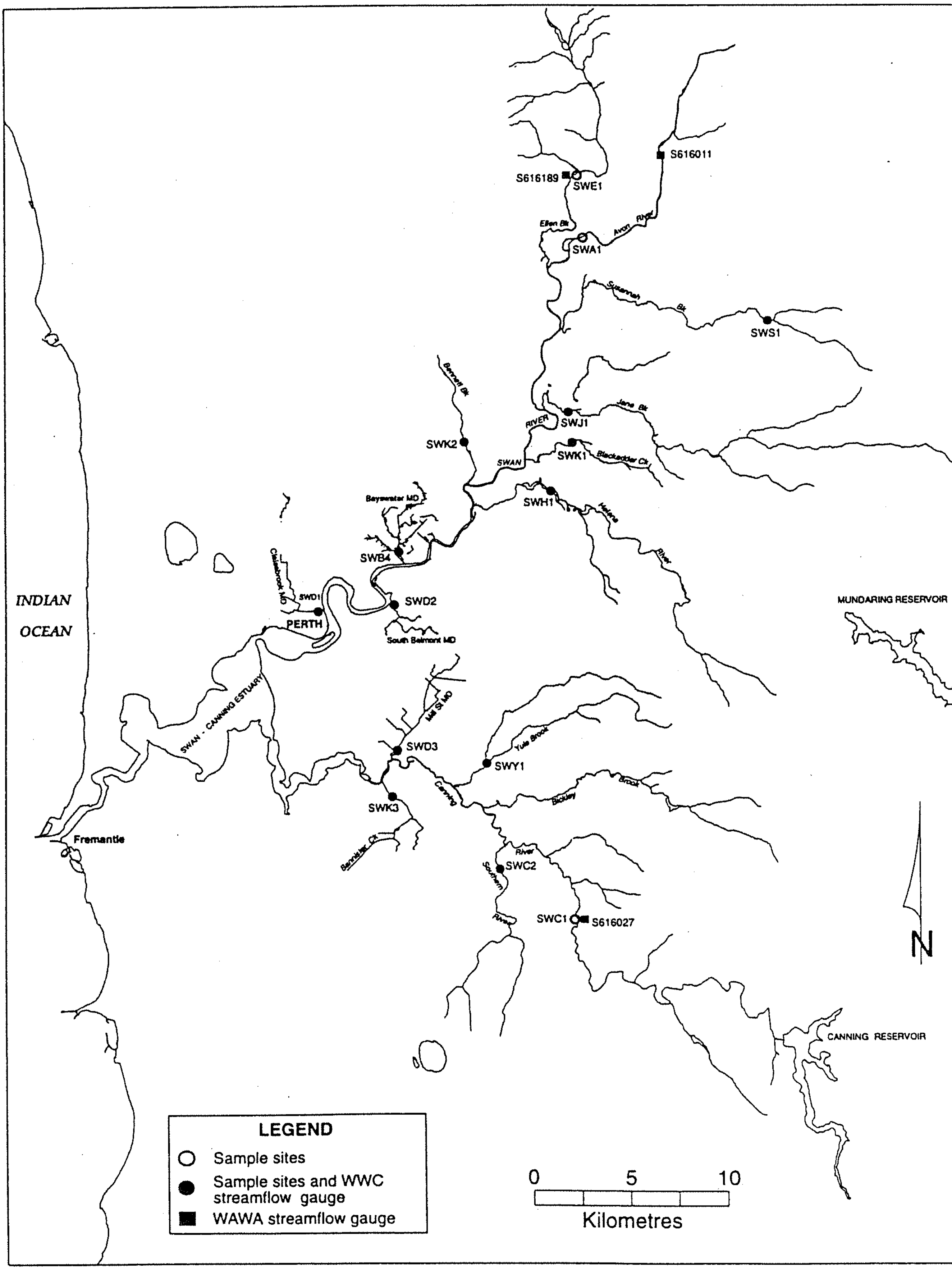


FIGURE 1 : Location of sample sites and WAWA streamflow gauges.

tributary inflows in the catchment (Figure 1). The SRT continues to monitor nutrient concentrations in the major inflows to the estuaries.

This initial report presents estimates of mass loading of phosphorus and nitrogen to the estuary, for two main reasons. The first is that mass loads of nutrients have been shown to be of use in the definition of estuarine trophic status (McComb and Davis 1993). Secondly, there is significant demand for information on mass loads of nutrients in streams and to estuaries in the south west of WA.

1.3 Aims and Objectives

The primary aims of the nutrient monitoring program were to:

1) estimate the total external load of nutrients to the Swan-Canning estuary;
2) identify the major contributing sub-catchments to the total annual load;
3) identify trends, if any, in the levels of nutrients in the monitored streams.

2. MATERIALS AND METHODS

In the period 1987 to 1992, the Waterways Commission monitored the concentrations of nutrients in 15 of the major tributaries to the Swan-Canning estuary (Figure 1). Appendix 1 contains details of the monitoring program as well as maps of the individual monitored sub-catchments.

2.1 Sampling Regime and Analysis

A single grab sample was collected from each site once a week during the winter wet period. The sampling period began with the first winter rains, usually in late May to early June, and continued until the start of the summer dry period around November of every year. No samples were collected during the summer months. Each sample was analysed for concentration of ammonium-nitrogen (NH_3-N), nitrate-nitrogen (NO_3-N), total nitrogen (TN), filterable reactive phosphorus (FRP) and total phosphorus (TP). Inorganic nitrogen (IN) was calculated as the sum of NH_3-N and NO_3-N concentrations.

2.2 Calculation of Annual Mass Load

For each monitored stream, estimates of daily load were computed as the product of daily stream discharge and nutrient concentration. Nutrient concentrations for those days when samples were not collected were obtained by linear interpolation between the observed weekly concentrations. This assumes therefore that the concentration from a single grab sample is representative of nutrient concentrations during the intervening period. Stream discharge was measured continuously at each of the sampling sites.

Estimates of the annual streamload were derived by integrating daily total loads for every day of the year. Annual flow-weighted concentrations (FWC) were calculated by dividing the total annual load estimate by the total annual stream discharge volume.

The total external load to the estuary was calculated by summing the annual loads from each site plus an estimate of nutrient export from the areas in the catchment that were not gauged. Methods of estimating the contribution from the ungauged areas are given in Appendix 1.

2.3 Terminology

A mass load has been defined as the total flux of a nutrient that passes a particular point of measurement in the period of interest (Richards and Holloway 1987). For this report, the mass load of nutrients may be termed nutrient 'streamload'. Unless the context indicates otherwise, all references to streamload refer to nutrient mass load over an annual period.

The terms 'stream discharge' and 'streamflow' will be used interchangeably and refer to the total volume of water that passed the sampling point in each year.

3. RESULTS

3.1 The Avon River

Over the monitoring period, annual total discharge in the Avon River increased from 210 million cubic meters ($x10^6$ m^3) in 1987 to $620x10^6$ m^3 in 1992 (Figure 2; see Appendix 2), and averaged $362x10^6$ m^3 per year (Table 1).

Over this period, the estimates of annual phosphorus streamload in the Avon River decreased from an estimated 25 tonnes in 1987 to 11 and 20 tonnes in 1991 and 1992 (Figure 2A). The average streamload estimate at the Avon River site was 20 tonnes per annum (Table 1). The annual FWC of phosphorus in the Avon River decreased over the six years of monitoring, falling from 0.1 mg/L in 1987 to 0.03 mg/L in 1992, and averaged 0.06 mg/L per year. The proportion of the total annual streamload that was FRP increased over the monitoring period, from about 10 per cent in 1987 to 35 per cent in 1992. Between 1987 and 1992, the FRP streamload in the Avon River averaged about 25 per cent of the TP streamload.

The annual nitrogen streamloads in the Avon River also increased between 1987 and 1992, from an estimated 188 tonnes in 1987 to 709 tonnes in 1992 (Figure 2B), and averaged 407 tonnes between 1987 and 1992 (Table 2). The annual FWC of nitrogen fluctuated between years but generally trended upward, from a low of 0.85 mg/L in 1987 to 1.34 mg/L in 1989 and 1.14 mg/L in 1992. The average FWC of nitrogen in the Avon River was 1.1 mg/L. The inorganic nitrogen load averaged 26 per cent of the total nitrogen load, and ranged between 20 and 40 per cent of total. The loads of NH_3-N varied between years and ranged between 20 and 30 per cent of the inorganic load (Figure 2B).

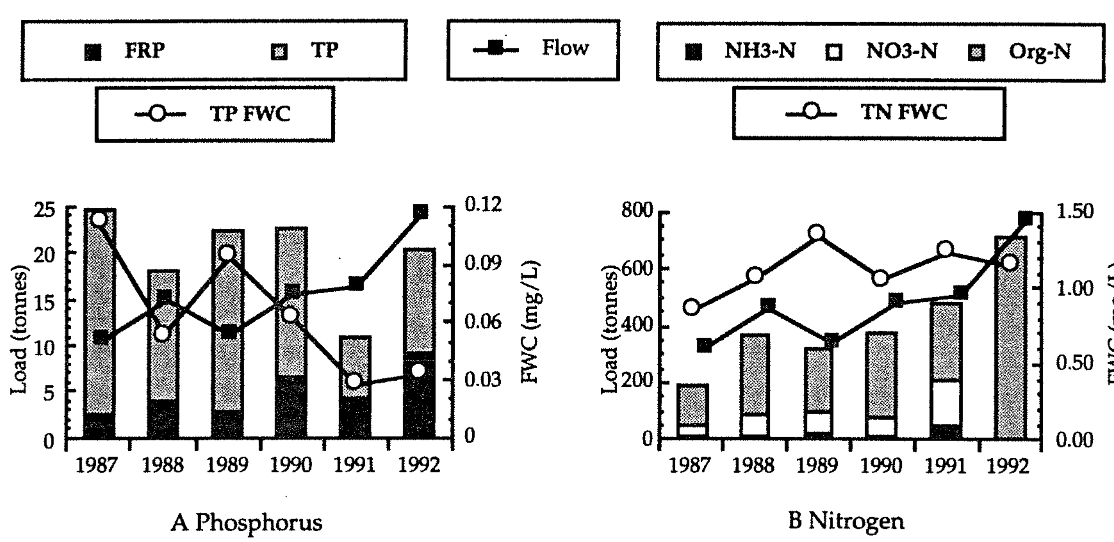


FIGURE 2 : Estimated annual phosphorus and nitrogen streamloads in the Avon River between 1987 and 1992. The concentrations of NO3-N and NH3-N were not measured in 1992. The plot of annual discharge has no reference scale and is intended only to demonstrate relative changes in flow from one year to the next. Key abbreviations are:

PP = Particulate Phosphorus;	Inorg-N = Inorganic Nitrogen;
FRP = Filterable Reactive Phosphorus;	Org-N = Organic Nitrogen;
NH3-N = Ammonium Nitrogen;	FWC = Flow-weighted mean concentration.

TABLE 1: Average loads and concentrations of phosphorus in the 15 monitored waterways in the Swan-Canning catchment. The numbers in brackets show the proportional contribution of each stream to the stream discharge and total external streamload to the estuary. The column headed FRP/TP is the average proportion of the total phosphorus load that was filterable.

Sub-catchment	Area (ha)	Discharge (10^6 m^3)	Filterable Reactive Phosphorus		Total Phosphorus		FRP/TP (%)
			Load (tonnes)	FWC (mg/L)	Load (tonnes)	FWC (mg/L)	
Ellen Brook	66423	37 (6)	19	0.51	26 (36)	0.69	73
Avon River	11903515	362 (62)	5	0.01	20 (28)	0.06	25
Southern River	14888	21 (4)	3.5	0.16	5.7 (8)	0.27	63
Bayswater MD	26200	12 (2)	0.2	0.02	3.3 (5)	0.29	8
Bannister Creek	2300	9.2 (1.6)	0.7	0.07	1.2 (2)	0.12	58
Mills St MD	1152	4.9 (1)	0.5	0.1	1.1 (2)	0.23	43
Yule Brook	5301	13 (2)	0.4	0.03	1.0 (1)	0.08	39
Bennett Brook	9852	10 (1.8)	0.4	0.03	0.9 (1)	0.09	40
Canning River	16283	17 (3)	0.3	0.02	0.8 (1)	0.05	33
Claisebrook MD	1604	5.4 (1)	0.1	0.02	0.5 (0.7)	0.09	27
South Belmont MD	975	3 (0.5)	0.2	0.07	0.5 (0.7)	0.16	42
Helena River	16065	10 (2)	0.2	0.02	0.4 (0.5)	0.04	41
Blackadder Creek	1258	3 (0.5)	0.1)	0.03	0.2 (0.3)	0.06	45
Jane Brook	13538	2.3 (0.4)	0.03	0.01	0.07 (0.1)	0.03	51
Susannah Brook	1901	0.4 (0.1)	0.01	0.03	0.02 (0.03)	0.05	49

3.2 Bannister Creek

Discharge in Bannister Creek averaged 9.2x10^6 m^3 per year between 1987 and 1992 (Table 1), and varied from a minimum discharge of 6x10^6 m^3 in 1990 and a maximum of 16x10^6 m^3 in 1992 (Figure 3; Appendix 2).

The estimates of phosphorus streamload in Bannister Creek averaged 1.2 tonnes per year (Table 1). Annual streamloads varied from a minimum of 0.5 tonnes in 1990 and 2 tonnes in 1992 (Figure 3A). There was no trend in loads over the monitoring period although they increased sharply after 1990. The proportion of FRP streamload to TP load ranged between 50 and 60 per cent of the TP streamload (Figure 3A). The estimated average FWC of phosphorus was 0.12 mg/L between 1987 and 1992, and was relatively stable between years varying from a minimum of 0.09 mg/L to a maximum of 0.16 mg/L in 1991.

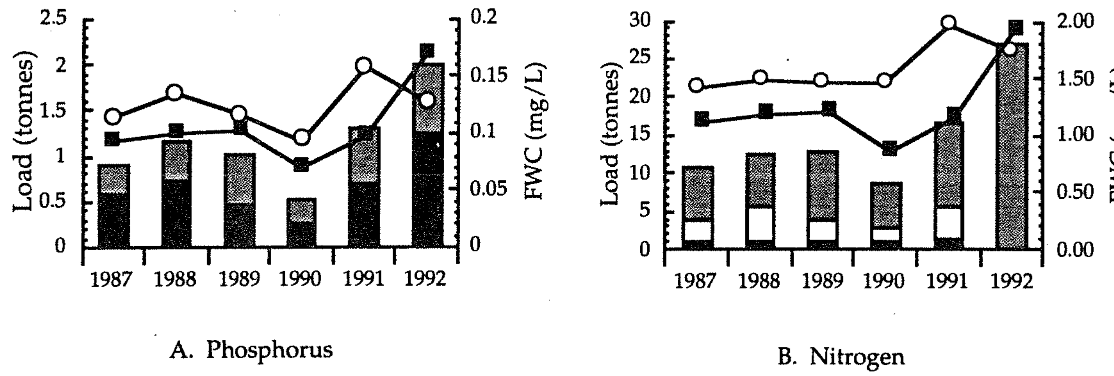


FIGURE 3: Estimated annual phosphorus and nitrogen streamloads in Bannister Creek between 1987 and 1992. See Figure 2 for a key to the graph. The key does not apply to 1992.

The nitrogen streamload in Bannister Creek averaged 15 tonnes (Table 2) and varied between a minimum of 8 tonnes in 1990 and a maximum of 27 tonnes in 1992 (Figure 3B). The inorganic nitrogen load averaged about 35 per cent of the total nitrogen load and varied between 30 and 45 per cent. In 4 of the 5 years the fraction was measured the inorganic load was between 31 and 33 per cent of total. Between 20 and 30 per cent of the dissolved load was ammonium-nitrogen. The FWC of nitrogen in Bannister Creek did not vary between 1987 and 1990 being always between 1.42 mg/L and 1.48 mg/L. In 1991 and 1992 the FWC were marginally higher, 1.96 mg/L and 1.73 mg/L respectively.

3.3 Bayswater Main Drain

Total annual stream discharge in the Bayswater Main Drain averaged 12×10^6 m^3 per year between 1987 and 1992 (Table 1). Discharge trended up over this period from a minimum of 10×10^6 m^3 in 1987 to 17×10^6 m^3 in 1992 (Figure 4; Appendix 2).

Over the monitoring period, the estimates of annual total phosphorus load averaged 1.2 tonnes per year. The annual estimates of streamload in Bayswater Main Drain decreased over the period of monitoring, from a maximum of 6 tonnes in 1987 to between 2 and 3.5 tonnes from 1988 to 1992 (Figure 4A). The estimates of FRP streamload in Bayswater Drain averaged 8 per cent (Table 1) and varied little between years, from 3 to 10 per cent of the annual TP loads. The estimates of annual phosphorus FWC in Bayswater Main Drain averaged 0.29 mg/L per year but decreased overall from over 0.6 mg/L in 1987 to about 0.2 mg/L between 1990 - 1992 (Figure 4A).

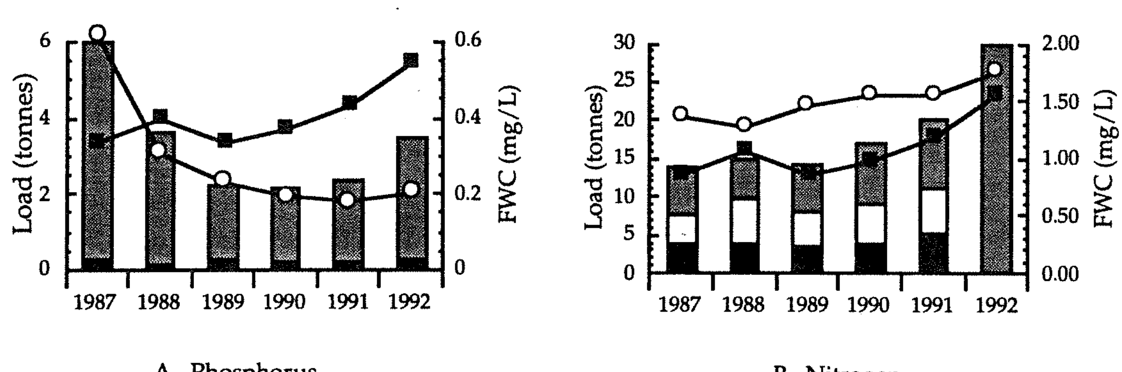
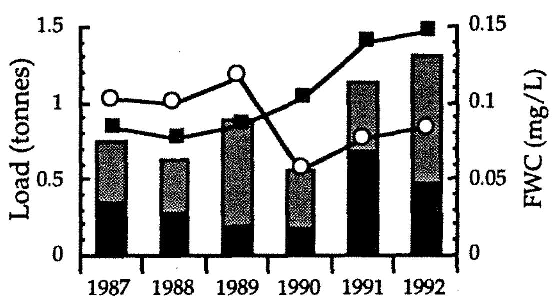


FIGURE 4: Estimated annual phosphorus and nitrogen streamloads in the Bayswater Main Drain between 1987 and 1992. See Figure 2 for a key to the graph. The key does not apply to 1992.

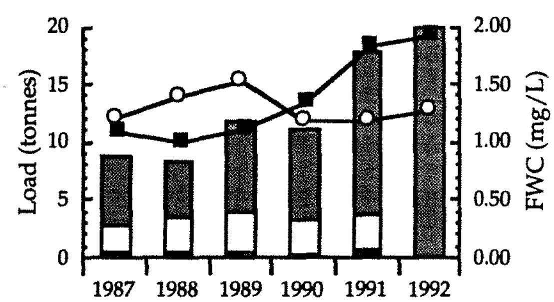
The streamloads of nitrogen in Bayswater Main Drain averaged 18 tonnes per year (Table 2). The annual streamload estimates increased over the monitoring period from 13 tonnes in 1987 to 30 tonnes in 1992 (Figure 4 B). The annual inorganic nitrogen loads averaged nearly 60 per cent of the total loads, ranging between 53 and 65 per cent in any year. The NH_3-N loads averaged nearly 45 per cent of the inorganic load and varied little between 41 and 47 per cent of the inorganic load. The estimates of annual nitrogen FWC in the Bayswater Drain averaged 1.49 mg/L per year. The estimates of nitrogen FWC increased slightly over the monitoring period, from 1.4 mg/L in 1987 to 1.8 mg/L in 1992 (Figure 4B).

3.4 Bennett Brook

Total annual stream discharge averaged $10x10^6$ m^3 between 1987 and 1992 (Table 1). Annual discharge increased over the monitoring period from a minimum of $7x10^6$ m^3 in 1987 to a maximum of $16x10^6$ m^3 in 1992 (Figure 5; Appendix 2).



A. Phosphorus



B. Nitrogen

FIGURE 5: Estimated annual phosphorus and nitrogen streamloads in Bennett Brook between 1987 and 1992. See Figure 2 for a key to the graph. The key does not apply to 1992.

Phosphorus streamloads in Bennett Brook averaged 0.9 tonnes per year between 1987 and 1992 (Table 1), and ranged between 0.6 tonnes in 1990 and 1.3 tonnes in 1992 (Figure 5A). The FRP fraction of the annual total phosphorus loads was variable, ranging between 20 and 60 per cent of the total. The annual FWC of phosphorus varied over a relatively small range during the monitoring from a minimum of 0.06 to a maximum of 0.12 mg/L/yr. There was evidence of a slight step-change in the FWC of phosphorus between 1989 and 1990. In the three years 1987 - 1989 the FWC averaged about 0.11 mg/L which decreased to a three year average of 0.07 mg/L between 1990-92.

The estimates of annual nitrogen streamload increased over the study period from about 9 tonnes per year in 1987-88 to almost 20 tonnes in 1992 (Figure 5B). The levels of inorganic nitrogen in Bennett Brook were generally between 30 and 40 per cent of total. In 1991, the proportion of inorganic to total fell to 20 per cent. Ammonia nitrogen was between about 10 and 20 per cent of the inorganic streamload. The FWC of TN varied over a relatively small interval ranging between 1.18 mg/L and 1.53 mg/L (Figure 5B). The step-change found in TP FWC was also present in the FWC of nitrogen although not as marked as that found with phosphorus. The average nitrogen FWC between 1987-89 was 1.4 mg/L and between 1990-92 it was 1.2 mg/L.

3.5 Blackadder Creek

The total annual discharge in Blackadder Creek averaged 2.9x10^6 m^3 per year between 1989 and 1992 (Table 1), and increased from 1.9x10^6 m^3 in 1989 to 4.0x10^6 m^3 in 1992 (Figure 6; Appendix 2).

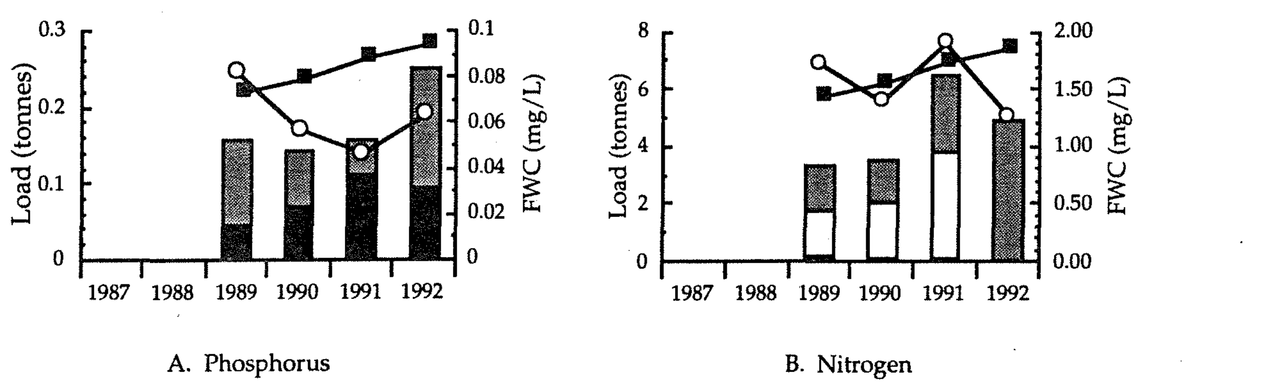


FIGURE 6: Estimated annual phosphorus and nitrogen streamloads in the Blackadder Creek between 1987 and 1992. See Figure 2 for a key to the graph. The key does not apply to 1992.

The estimates of annual phosphorus load in Blackadder Creek were small in all years, averaging 0.2 tonnes per year (Table 1), and varied between 0.1 and 0.2 tonnes per year (Figure 6A). The FRP streamload fluctuated widely between about 30 and 70 per cent of total, and averaged 45 per cent of the TP load. The FWC in Blackadder Creek was low in all years, and varied in a narrow range between 0.05 mg/L and 0.08 mg/L per year.

The annual estimates of nitrogen streamload in Blackadder Creek averaged 4.5 tonnes per year (Table 2) and varied at random in the range between 3.2 tonnes in 1989 and 6.5 tonnes in 1990 (Figure 6B). In the three years it was measured, the estimated inorganic nitrogen load averaged 55 per cent of the total nitrogen load. The variation in this proportion was low between years. The NH_3-N streamload varied between 4 and 9 per cent of the inorganic load. The estimates of annual nitrogen FWC averaged 1.6 mg/L (Table 2), and varied over a small range from a minimum of 1.24 mg/L in 1992 and to a maximum of 1.91 mg/L in 1991 (Figure 6B).

3.6 The Canning River

Over the monitoring period, annual discharge in the Canning River averaged 17x10^6 m^3 (Table 1). Annual discharge varied randomly between a minimum of 11x10^6 m^3 in 1989 and a maximum of 23x10^6 m^3 in 1992 (Figure 7; Appendix 2).

The annual estimates of phosphorus streamload in the Canning River trended downward from a maximum of 1.8 tonnes in 1987 to a minimum of about 0.3 tonnes in 1989 (Figure 7A). The estimated phosphorus load in the Canning River averaged 0.8 mg/L between 1987 and 1992 (Table 1). The annual FWC of phosphorus in the river decreased from 0.13 mg/L to 0.03 mg/L in 1992, and averaged 0.05 mg/L. The annual estimates of FRP load averaged 33 per cent of the total load and varied usually within a range from about 25 to 35 per cent. In 1992, the FRP load was nearly 55 per cent of the total phosphorus load.

The annual nitrogen streamloads in the Canning River averaged 21 tonnes per year (Table 2) and varied randomly between 13 and 35 tonnes per year (Figure 7B). The estimates of annual nitrogen FWC in the Canning River varied between years but trended down overall, from 1.32 mg/L in 1987 to 0.99 mg/L in 1992. Over the monitoring period, the FWC of nitrogen in the

Canning River averaged 1.2 mg/L. The inorganic nitrogen streamloads in the Canning River trended upward over the monitoring period as a proportion of the total nitrogen load, from about 50 per cent in 1987 to 75 per cent in 1991. The inorganic loads averaged 65 per cent. of total nitrogen streamloads. In every year NO_3-N was a very large component of the inorganic load, varying between 92 and 98 per cent (Figure 7B).

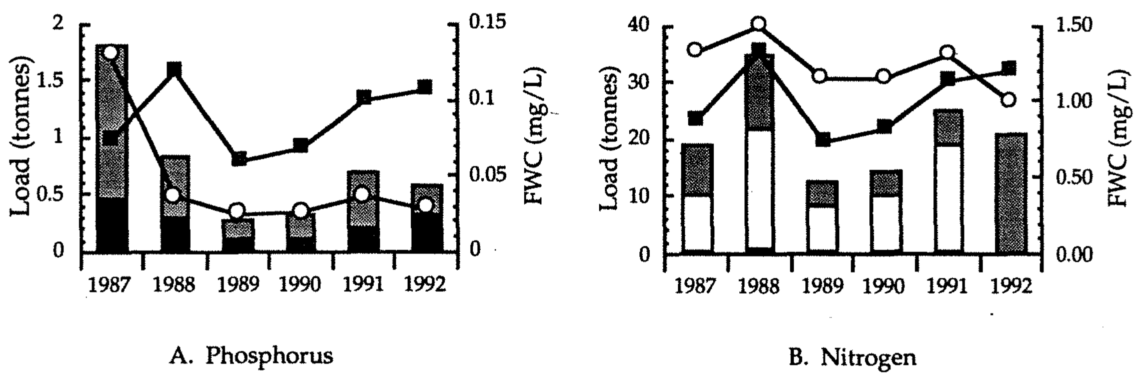


FIGURE 7: Estimated annual phosphorus and nitrogen streamloads in the Canning River between 1987 and 1992. See Figure 2 for a key to the graph. The key does not apply to 1992.

3.7 Claisebrook Main Drain

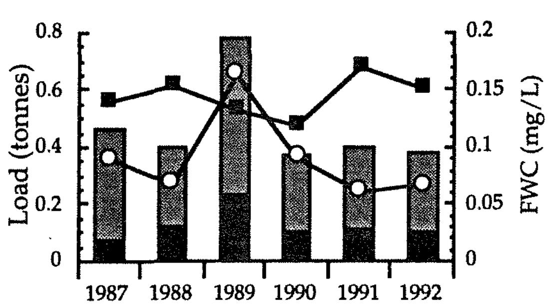
The total annual volume of streamflow in Claisebrook Main Drain averaged 5.4×10^6 m^3 (Table 1), and varied between a minimum of 4.1×10^6 m^3 in 1990 and a maximum of 6.7×10^6 m^3 in 1991 (Figure 8; Appendix 2).

The estimates of annual phosphorus streamload in the Claisebrook Drain averaged 0.5 tonnes per year (Table 1) over the monitoring period. The variability in loads between years was low. In 5 of the 6 years of monitoring the streamload was 0.4 or 0.5 tonnes. In 1989, the annual load was relatively high, 0.8 tonnes. The FRP streamload was usually about 30 per cent of the total load, except in 1987 when it was 16 per cent (Figure 7A). Except for 1989, when the annual phosphorus FWC was 0.16 mg/L, the annual FWCs varied in a narrow range between 0.06 mg/L and 0.09 mg/L (Figure 8A).

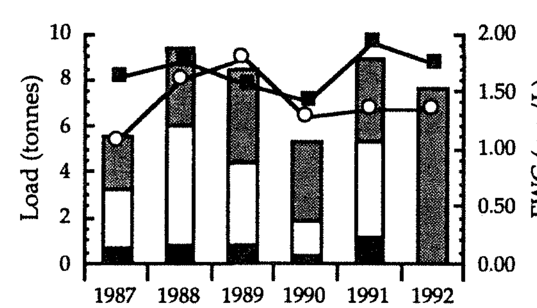
The estimates of annual nitrogen streamload in the drain averaged 7.1 tonnes per year over the monitoring period (Table 2), and ranged from a minimum of 5.3 tonnes in 1987 to a maximum of 9.4 tonnes in 1988 (Figure 8B). The loads of inorganic nitrogen averaged 53 per cent of the total load, however this proportion varied between 35 to 64 per cent per year. The NH_3-N streamload averaged 18 per cent of the inorganic load varying between 14 and 22 per cent (Figure 8B). The estimated average FWC of nitrogen in Claisebrook Main Drain was 1.4 mg/L and varied little between 1.1 mg/L in 1987 and 1.8 mg/L in 1989 (Figure 8B).

TABLE 2: Average annual loads and annual FWCs of ammonia nitrogen, nitrate nitrogen and total nitrogen for each of the monitored waterways in the Swan-Canning catchment. The bracketed figures are the per centage contribution of each site to the total external load of nitrogen to the estuary.

Sub-catchment	Ammonium nitrogen		Nitrate nitrogen		Total nitrogen		IN/TN (%)	NH3/IN (%)
	Load (tonnes)	FWC (mg/L)	Load (tonnes)	FWC (mg/L)	Load (tonnes)	FWC (mg/L)		
Avon River	24	0.08	80	0.25	407 (54)	1.11	29	23
Bannister Creek	1.1	0.15	3.3	0.41	15 (2)	1.59	35	25
Bayswater MD	4	0.37	5	0.46	18 (2)	1.49	58	44
Bennett Brook	0.4	0.05	3	0.35	13 (2)	1.29	31	13
Blackadder Creek	0.1	0.05	2.4	0.88	4.5 (0.6)	1.56	56	6
Canning River	0.6	0.04	13	0.80	21 (3)	1.23	66	5
Claisebrook MD	0.8	0.14	3.4	0.62	7.1 (0.9)	1.40	54	18
Ellen Brook	4	0.13	5	0.16	77 (10)	2.07	14	46
Helena River	0.6	0.07	3.9	0.39	9.3 (1)	0.91	49	15
Jane Brook	0.1	0.04	0.9	0.37	1.7 (0.2)	0.71	58	9
Mills St MD	2.1	0.46	2.5	0.51	10 (1)	2.08	47	47
South Belmont MD	0.5	0.19	0.9	0.35	3.6 (0.5)	1.21	45	35
Southern River	1.6	0.08	13	0.67	37 (5)	1.76	42	11
Susannah Brook	0.02	0.04	0.3	0.79	0.6 (0.1)	1.42	57	5
Yule Brook	0.8	0.07	6.1	0.51	16 (2)	1.24	45	12



A. Phosphorus



B. Nitrogen

FIGURE 8: Estimated annual phosphorus and nitrogen streamloads in the Claisebrook Main Drain between 1987 and 1992. See Figure 2 for a key to the graph. The key does not apply to 1992.

3.8 Ellen Brook

Total annual discharge averaged 37x10^6 m^3 over the 6 years of monitoring (Table 1). Total streamflow varied between years from a minimum of 19x10^6 m^3 in 1989 which increased to a maximum of 56x10^6 m^3 in 1991 (Figure 9; Appendix 2).

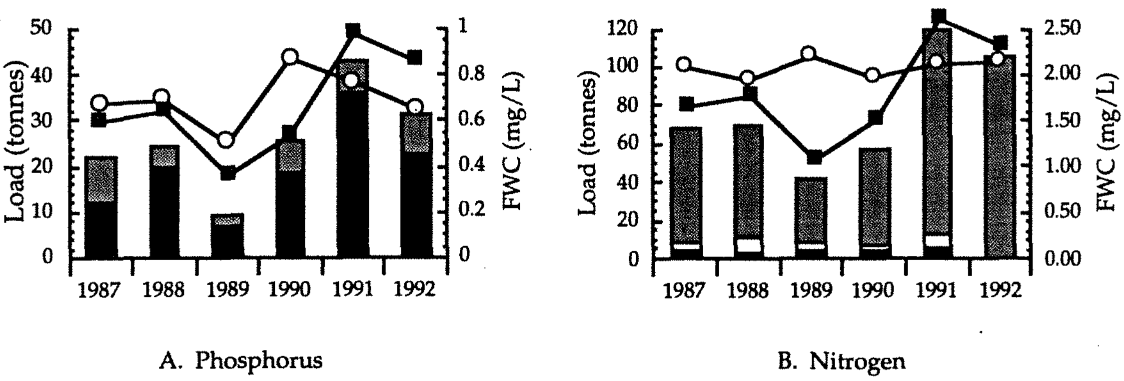


FIGURE 9: Estimated annual phosphorus and nitrogen streamloads in Ellen Brook between 1987 and 1992. See Figure 2 for a key to the graph. The key does not apply to 1992.

The estimates of annual phosphorus streamload in Ellen Brook averaged 26 tonnes between 1987 and 1992 (Table 1). Streamloads varied widely between years, ranging from a minimum of 9 tonnes in 1989 to a maximum of 43 tonnes in 1991 (Figure 9A). Between 1987 and 1992, the estimates of annual phosphorus FWC averaged 0.69 mg/L per year. There was no indication of a trend in annual phosphorus FWC in Ellen Brook over the monitoring period, between year variation was random within a range of 0.5 mg/L in 1990 to 0.9 mg/L in 1989. The annual FRP load averaged 73 per cent of the total phosphorus load between 1987 and 1992. In 5 of the 6 years, the FRP load ranged between 72 and 84 per cent of total. In 1987, this fraction was relatively low at 48 per cent of total.

The estimates of annual nitrogen streamload in Ellen Brook averaged 77 tonnes between 1987 and 1992 (Table 2). The annual loads were highly variable between years ranging from 41 tonnes in 1989 to nearly 120 tonnes in 1991 (Figure 9B). The estimates of IN streamload averaged about 15 per cent of the total nitrogen loads between 1987 and 1991. The variability from one year to the next was low, fluctuating between 11 and 19 per cent of total The relative proportions of the NO_3-N and NH_3-N loads to the IN load varied between years, but the estimated annual loads of NH_3-N were always relatively high, ranging between about 30 and 65 per cent of the estimates of IN load. The annual FWC of nitrogen averaged 2.0 mg/L, and varied little from year to year ranging from a minimum of 1.95 mg/L in 1988 to a maximum of 2.19 mg/L in 1991.

3.9 Helena River

Between 1987 and 1992, discharge in the Helena River averaged 10.3x10^6 m^3 per year (Table 1), and varied from a minimum annual flow of 8x10^6 m^3 in 1987 to a maximum flow of 13x10^6 m^3 in 1992 (Figure 10; Appendix 2).

Over the study period, the estimates of annual phosphorus streamload in the Helena River averaged 0.4 tonnes per year (Table 1). The phosphorus loads decreased over the period, due to a step-change in load estimates between 1989 and 1990 (Figure 10A). In the period 1987 to 1989, the phosphorus load in the Helena River averaged 0.5 tonnes per year which decreased to 0.3 tonnes in the three years 1990-1992. The estimates of annual phosphorus FWC averaged 0.04 mg/L, and also decreased over the monitoring period. Like that for the annual total loads, the overall decrease was due to a step-change in average FWC between 1989 and 1990. In the first three years of monitoring the phosphorus FWC averaged 0.06 mg/L and, between 1990 and 1992, 0.02 mg/L. The FRP load averaged 52 per cent of the total load between 1987 and 1992, and varied between 50 and 67 per cent in 5 of the 6 years. In 1989, the FRP was only 17 per cent of the total phosphorus load (Figure 10A).

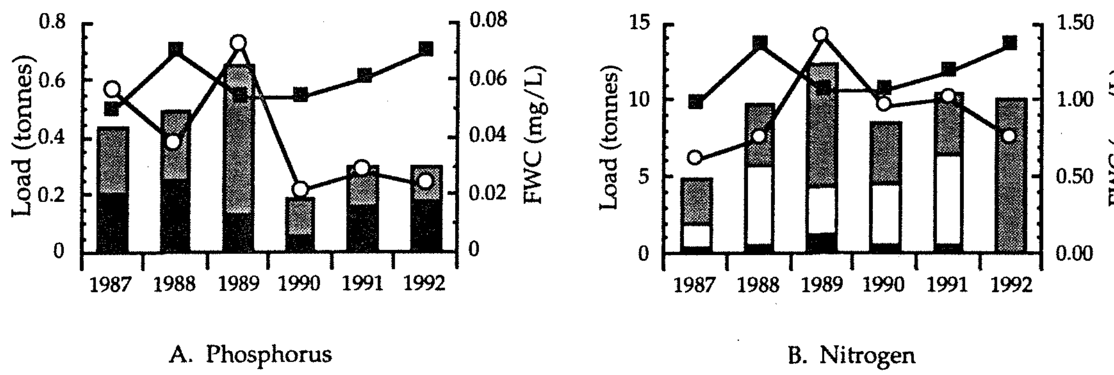


FIGURE 10: Estimated annual phosphorus and nitrogen streamloads in Helena River between 1987 and 1992. See Figure 2 for a key to the graph. The key does not apply to 1992.

Estimates of annual nitrogen streamload averaged 9.3 tonnes per year (Table 2) and varied randomly between 5 tonnes in 1987 and 13 tonnes in 1989 (Figure 10B). The estimates of nitrogen FWC averaged 0.9 mg/L, and varied between about 0.6 and 1.4 mg/L. The annual IN averaged about 47 per cent of the total load. Variability in the proportion was high from one year to the next, fluctuating in the range 35 per cent to 60 per cent of total streamload. In all years, about 90 per cent of the dissolved fraction was composed of NO_3-N.

3.10 Jane Brook

The annual discharge in Jane Brook averaged 2.3x10^6 m^3 over the monitoring period (Table 1) and varied randomly between 2.1x10^6 m^3 in 1990 and 3.7x10^6 m^3 in 1991 (Figure 11; Appendix 2).

The estimates of annual phosphorus streamload were relatively small in all years, ranging between 0.06 tonnes and 0.14 tonnes per year (Figure 11A). The proportion of phosphorus that was filterable increased from about 30 per cent in 1988 to 40 per cent in 1989-90 and reached over 60 per cent of total in 1991-92. The FWC of phosphorus in Jane Brook were very low in all years ranging between 0.02 and 0.04 mg/L per year since 1988 (Figure 11A). There was no evidence of an increasing or decreasing trend in the concentrations.

Estimated annual loads of nitrogen varied between 1.5 tonnes and 3.4 tonnes per year (Figure 11B). The inorganic nitrogen levels were high, as a proportion of total, ranging between 50 and 70 per cent in the four years it was monitored. In all years the levels of ammonia nitrogen were very low and varied within a narrow range between 6 and 10 per cent of the inorganic load. The FWC of nitrogen in Jane Brook was low in all years but increased slightly over the period of monitoring, climbing from 0.53 mg/L in 1988 to 0.92 mg/L in 1992 (Figure 11B).

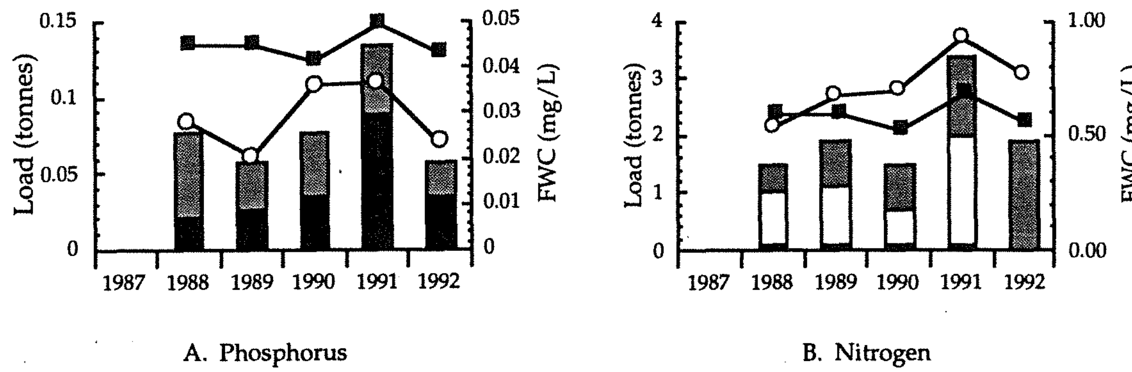


FIGURE 11: Estimated annual phosphorus and nitrogen streamloads in Jane Brook between 1988 and 1992. See Figure 2 for a key to the graph. The key does not apply to 1992.

3.11 Mills Street Main Drain

Over the period of monitoring, stream discharge in Mills Street Main Drain averaged $4.9x10^6$ m^3 (Table 1) and ranged between $3.8x10^6$ m^3 in 1989 and $6.2x10^6$ m^3 in 1992 (Figure 12; Appendix 2).

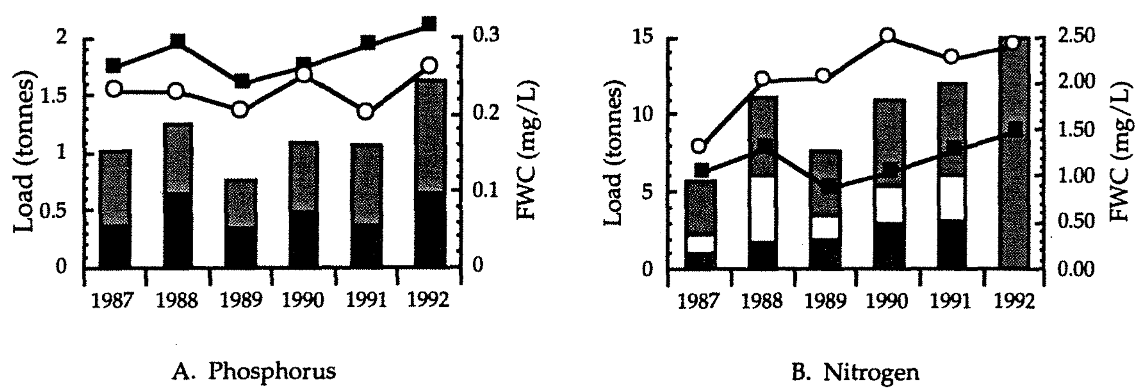


FIGURE 12: Estimated annual phosphorus and nitrogen streamloads in Mills Street Main Drain between 1987 and 1992. See Figure 2 for a key to the graph. The key does not apply to 1992.

The annual phosphorus streamload in the drain between 1987 and 1992 was 1.1 tonnes per year. Streamloads varied between a minimum of 0.8 tonnes in 1989 and a maximum of 1.6 tonnes in 1992 (Figure 12A). The FRP streamload averaged 43 per cent of the TP load (Table 1), and was relatively stable between years fluctuating from 35 to 50 per cent of total phosphorus load between years. The estimates of annual phosphorus FWC in Mills Street Drain averaged 0.23 mg/L per year (Table 1) and were stable between years generally hovering between 0.2 mg/L and 0.26 mg/L per year (Figure 12A).

Annual streamloads of nitrogen in Mills Street Main Drain averaged 10 tonnes per year (Table 2) and trended upward from 6 tonnes in 1987 to 15 tonnes in 1992 (Figure 12B). The inorganic nitrogen streamloads averaged 47 per cent of the total load (Table 2). The proportion of inorganic to total was stable between years varying between 40 to 50 per cent of total nitrogen (Figure 12B). The estimates of NH_3-N loads averaged 47 per cent of the inorganic load and varied between 30 and 55 per cent of the inorganic load. The estimates of nitrogen FWC in the drain increased over the first four years of monitoring from 1.3 mg/L in 1987 to 2.5 mg/L in 1990 and thereafter fluctuated between 2.2 and 2.4 mg/L (Figure 12B).

3.12 South Belmont Main Drain

Streamflow in South Belmont Main Drain averaged 2.9 x106 m^3 per year between 1987 and 1992 (Table 1). Streamflow increased over the monitoring period from a minimum of $2x10^6$ m^3 in 1987 to a maximum of $3.9x10^6$ m^3 in 1992 (Figure 13; Appendix 2).

Annual estimates of phosphorus streamload in the South Belmont Main Drain averaged 0.5 tonnes per year between 1987 and 1992 (Table 1), and ranged between 0.3 tonnes and 0.8 tonnes over the six years monitoring (Figure 13A). There was no sign of a significant trend in the annual loads over time but the 1992 load appeared to be high relative to those in the other years. The FRP load averaged 42 per cent of the TP streamload. The between year variability in the proportion was low, fluctuating between 32 and 49 per cent of total. The estimates of annual phosphorus FWC in the Belmont drain averaged 0.16 mg/L per year over the monitoring period (Table 1) and varied little from a minimum of 0.12 mg/L in 1991 and maximum of 0.20 mg/L in 1992.

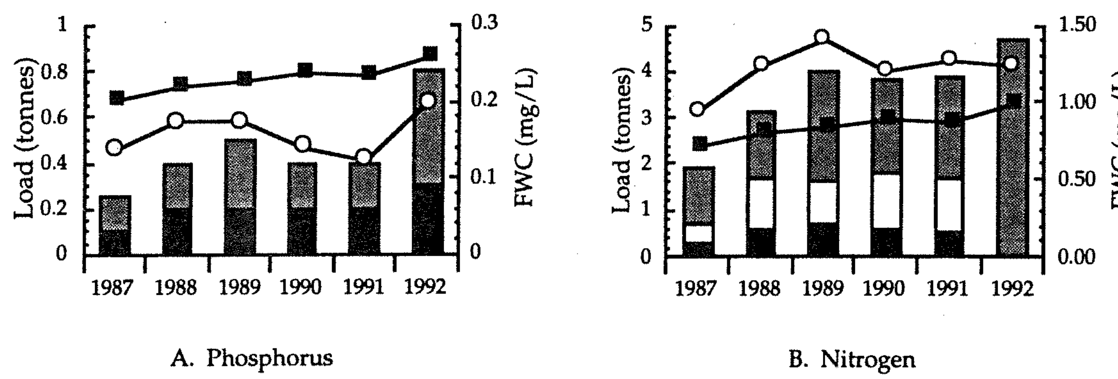


FIGURE 13: Estimated annual phosphorus and nitrogen streamloads in South Belmont Main Drain between 1987 and 1992. See Figure 2 for a key to the graph. The key does not apply to 1992.

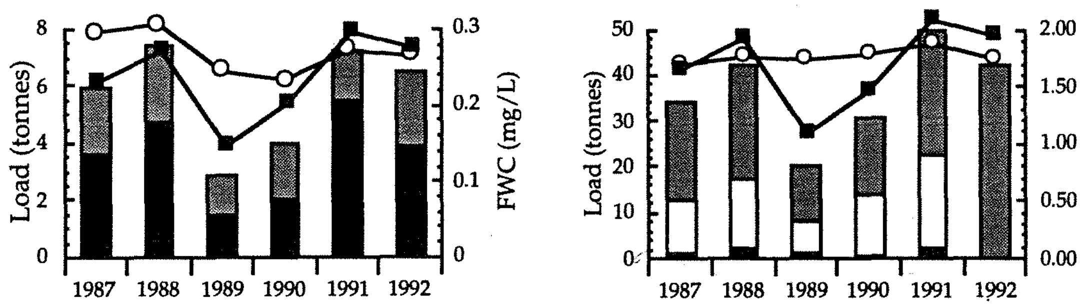
Annual estimates of nitrogen streamloads in the Belmont drain averaged 3.6 tonnes per year (Table 2). Annual nitrogen streamloads increased over the monitoring period from a minimum of 1.9 tonnes in 1987 to a maximum of 4.7 tonnes in 1992 (Figure 13B). The inorganic nitrogen load averaged 45 per cent of the TN loads over the period of monitoring and fluctuated between about 40 and 55 per cent. The estimates of NH_3-N streamloads averaged about 35 per cent of the inorganic loads and varied between 30 and 40 per cent. The estimates of annual nitrogen FWC averaged 1.21 mg/L in Belmont Main Drain and varied between 0.94 mg/L in 1987 and 1.41 mg/L in 1989.

3.13 Southern River

Discharge in the Southern River averaged about $21x10^6$ m^3 per year (Table 1) and, between years, varied randomly (Figure 14) from a minimum of $12x10^6$ m^3 in 1989 to a maximum of $27x10^6$ m^3 in 1991.

The annual phosphorus load in Southern River averaged 5.7 tonnes per year (Table 1) and varied in a range from a minimum of 2.9 tonnes in 1989 and a maximum of 7.4 tonnes in 1989 (Figure 14A). The annual FRP load was on average 63 per cent of the total phosphorus streamload. The FRP load varied randomly between about 50 and 75 per cent of the total load in the river. The annual FWC of phosphorus in Southern River averaged 0.27 mg/L per year over the period of monitoring. The estimates of FWC varied little between years, ranging between 0.31 mg/L in 1988 to 0.23 mg/L in 1989.

Between 1987 and 1992, the estimates of annual nitrogen streamload averaged 37 tonnes per year (Table 2) and ranged from 20 to 50 tonnes per year (Figure 14B). In the Southern River, the six year average FWC of nitrogen was estimated to be 1.8 mg/L. The nitrogen FWC varied little between years from a minimum of 1.7 mg/L in 1987 and a maximum 1.9 mg/L in 1991. The estimated IN load varied in a narrow range between 38 and 45 per cent of the total nitrogen streamload. The NO_3-N load was between 83 and 94 per cent of the IN load.

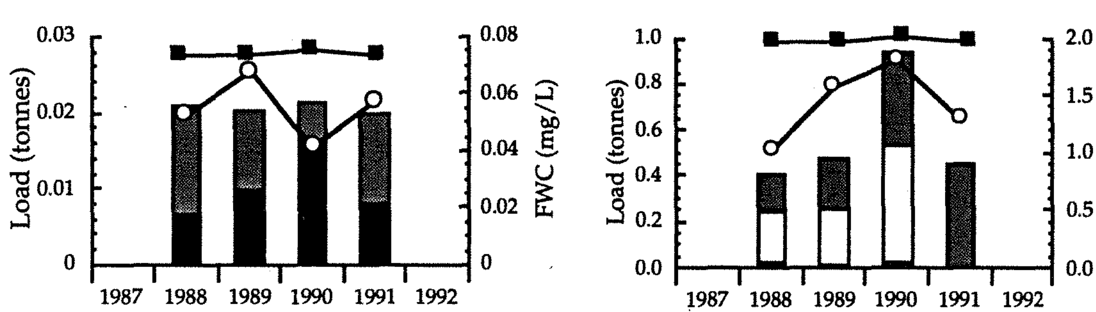


A. Phosphorus B. Nitrogen

FIGURE 14: Estimated annual phosphorus and nitrogen streamloads in Southern River between 1987 and 1992. See Figure 2 for a key to the graph. The key does not apply to 1992.

3.14 Susannah Brook

The estimates of annual stream discharge at the Susannah Brook sampling site averaged $0.4x10^6$ m^3 between 1988 and 1991 (Table 1). The annual streamflow estimates increased between 1988 and 1991 from a minimum of 1.9 x 106 m^3 in 1988 to a maximum of $4x10^6$ m^3 in 1991 (Figure 15; Appendix 2).



A. Phosphorus B. Nitrogen

FIGURE 15: Estimated annual phosphorus and nitrogen streamloads in Susannah Brook between 1987 and 1992. See Figure 2 for a key to the graph. The key does not apply to 1992.

The estimates of annual phosphorus streamload in Susannah Brook averaged 0.02 tonnes per year (Table 1) and varied very little between years (Figure 15A), hovering around 0.02 tonnes since monitoring began in 1988. The FWC streamloads averaged 49 per cent of the total loads. The proportion was highly variable however, ranging between 30 and 75 per cent. The estimates of phosphorus FWC averaged 0.05 mg/L and varied at random from year to year between 0.04 mg/L and 0.07 mg/L.

The annual estimates of nitrogen streamload averaged 0.6 tonnes per year in the monitoring period and varied between 0.41 tonnes in 1988 and 0.94 tonnes in 1991 (Figure 15B). The inorganic streamloads were on average about 60 per cent of the TN loads, and varied between 47 and 68 per cent of total from year to year. The NH_3-N streamloads averaged about 10 per cent of the inorganic loads varying between 7 and 11 per cent. The annual FWC of nitrogen in Susannah Brook averaged 1.42 mg/L and varied over a small range between 1.03 and 1.8 mg/L.

3.15 Yule Brook

Annual stream discharge in Yule Brook averaged 12.7×10^6 m^3 between 1987 and 1992 (Table 1). Discharge in Yule Brook ranged between a minimum of 8×10^6 m^3 in 1989 and a maximum of 17×10^6 m^3 in 1991 (Figure 16A).

Over the period of monitoring, the estimates of phosphorus streamload averaged 1 tonne per year (Table 1) and varied between 0.5 tonnes in 1990 and 2 tonnes in 1988 (Figure 16A). The FRP streamload averaged about 40 per cent of the total load (Table 1), but was highly variable between years, ranging between 36 per cent of total in 1988 and 70 per cent in 1991 (Figure 16A). There was a step-change in the estimates of phosphorus FWC between 1989 and 1990. In the three years 1987-89, the FWC averaged 0.11 mg/L whereas between 1990-92 the average was 0.06 mg/L (Figure 16A).

The estimates of nitrogen streamload in Yule Brook averaged 16 tonnes per year over the monitoring period (Table 2). The nitrogen loads varied from a minimum of 10 tonnes in 1987 to a maximum 22 tonnes in 1987 (Figure 16B). Inorganic nitrogen averaged 44 per cent of the total nitrogen load and varied between years within a relatively narrow range from 37 to 53 per cent of total . Between 4 and 10 per cent of the inorganic load was composed of NH3-N. The annual FWC of nitrogen in Yule Brook varied randomly in a small range between 1.01 mg/L and 1.58 mg/L (Figure 16B).

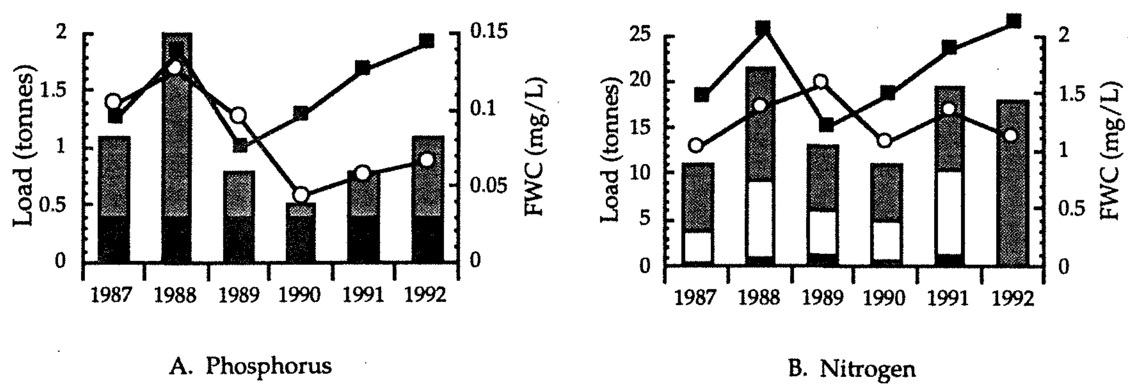


FIGURE 16: Estimated annual phosphorus and nitrogen streamloads in Yule Brook between 1987 and 1992. See Figure 2 for a key to the graph. The key does not apply to 1992.

4. TOTAL EXTERNAL LOAD TO SWAN-CANNING ESTUARY

An average of about $580x10^6$ m^3 of fresh water enters the Swan-Canning estuary every year, which contributes about 740 tonnes of nitrogen and 70 tonnes of phosphorus, on average, annually (Appendix 1; Table 3).

The estimated total annual flow and total nutrient loads to the estuary are shown in Figure 17. The annual total load of phosphorus to the estuary varied from about 50 tonnes in 1989 to about 90 tonnes in 1991. The total load of nitrogen to the estuary increased over the period of monitoring from about 420 tonnes in 1987 to over 1000 tonnes in 1992. High annual nutrient loads coincided with high streamflows. The correlation with annual discharge was closer with nitrogen loads than it was with estimates of annual phosphorus streamload.

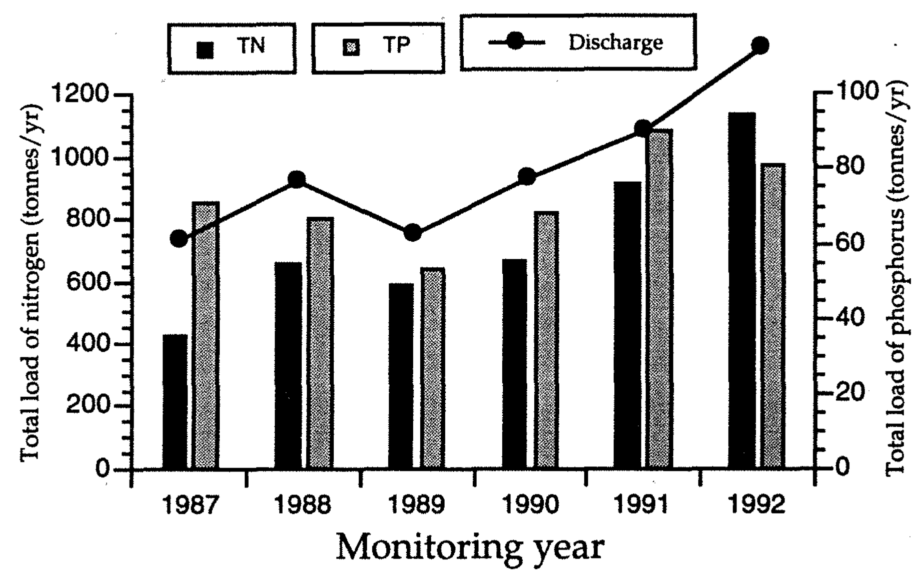


FIGURE 17: Estimates of the total annual external loads of phosphorus and nitrogen to the Swan-Canning estuary, 1987-92

5. DISCUSSION OF RESULTS

The total quantity of nutrients in streams is the sum of contributions from point sources and those from non-point sources. Nutrients are also carried in groundwater inputs and deposited on catchments in fine dusts and rain water. Variation in these inputs from one catchment to the next and changes in their magnitude over time, determined the observed variation in nutrient export from the sub-catchments of the Swan-Canning system from 1987 to 1992. However, bias and imprecision were probably a significant source of variation in the streamload estimates presented in this report. The following discussion will canvas some of the issues related to error in load estimates based on fixed-interval sampling regimes, before going on to discuss the results in Section 4.

Bias in estimates of nutrient mass load is the difference between the *actual* load of nutrients carried by a stream and the *estimate* of streamload. Streamload estimates are imprecise if the level of bias between catchments and between time periods also varies. When the estimates are very imprecise, observed variation in streamloads may be largely an artefact of uncontrolled bias rather than a true reflection of reality. A number of studies have looked at bias and precision associated with estimates of mass load in streams using a variety of sampling strategies

(Rekolainen *et al.* 1991, Burn 1990, Preston *et al.* 1989; Richards and Holloway 1987, Yaksich and Verhoff 1983; Cullen and Rosich 1982; Ongley 1982b; Barrett and Loh 1981). This research has shown convincingly that fixed-frequency sampling regimes, like the one that has been used during this monitoring program, produce extremely biased and imprecise estimates of annual nutrient streamload.

Fixed-interval sampling regimes do not allow for the fact that nutrient concentrations in streams vary markedly with changes in stream discharge. In streams, most of the annual load of nutrient is mobilised during storms, when high flows erode material from the stream channel and wash nutrients from the catchment in runoff (Sharpley *et al.* 1994; Cullen *et al.* 1988). However, fixed-interval sampling regimes concentrate sampling effort in the low to medium flow periods between storm events (Peters 1994). As a result, the largest component of the annual nutrient flux is not sampled and the resulting estimate of streamload severely underestimates the *actual* load. In any year the number of samples collected during storms is a matter of chance, and is invariably different from one year to next. Therefore the levels of bias variy and the estimates are imprecise over time.

The level of bias is dependant on the frequency of sampling relative to the in-stream variability of the measured substance, that is, on the magnitude and nature of the flow-response of the material. The more variable the substance in the period *between* sampling occasions the higher the levels of bias (Richards and Holloway 1987). The flow-response of material, and the bias in estimates of load, is a function of catchment size, rainfall intensity and the length of the inter-event period, soil erosion risk and nutrient status. It follows that the levels of bias in estimates of streamload are also related to the material being considered. It has been demonstrated for example that the most flow-responsive material is particulate matter, followed by total phosphorus and total nitrogen (Preston *et al.* 1989; Richards and Holloway 1987). Dissolved fractions tend to be less responsive to changes in streamflow.

The levels of bias in estimates of phosphorus streamload have been shown to be substantial in some cases. For example, when relatively infrequent fixed-interval sampling has been used, the reported levels of bias in estimates of phosphorus streamload vary anywhere between 20 and 1000 per cent. The levels of bias in the estimates presented here for the streams of the Swan-Canning were not known, but the feeling was that they were underestimations of between about 30 and 90 per cent depending on the sub-catchment and time period. Overestimates can occur, but are less common than under-estimates and tend to be smaller.

In this monitoring program, the sampling period began with the onset of winter rains so no samples were collected in the summer months. As a result, some summer storms were not sampled. In addition, it proved difficult to predict the onset of the winter wet period and therefore the 'first flush' of the year was not sampled in most years. These omissions from the annual nutrient flux would tend to worsen the probable underestimates of the presented loads.

5.1 Streamloads in the Swan-Canning System

Of the 15 monitored streams, two stood out as sources of nutrients to the Swan-Canning estuary. These were the two largest streams, Ellen Brook and the Avon River, both of which drain to the upper Swan River estuary. Between them, they delivered an annual average of just over 45 tonnes of phosphorus and nearly 500 tonnes of nitrogen over the monitoring period. This is about 65 per cent of the external load of phosphorus and nitrogen to the estuary (Table 1).

The average loads of nutrients that were carried by the streams tended to reflect their average flows. Nitrogen streamloads were more closely correlated with stream discharge, than were the phosphorus loads (Figure 18).

The scatter in the phosphorus plot was due to the high variability in phosphorus concentration between sites. The flow-weighted phosphorus concentrations ranged from a minimum of 0.03 mg/L in Jane Brook to a maximum of 0.7 mg/L in Ellen Brook. Streams that contained relatively high concentrations of phosphorus plotted to the left of the line. The effect of high concentrations in Ellen Brook was to produce very high loads relative to its size. Bayswater Main Drain, Southern River, Mills Street Main Drain and South Belmont Main Drain all had moderately high concentrations of phosphorus. Relatively low concentrations of phosphorus were found in the Avon River, Helena River, Canning River, Susannah Brook, Blackadder Creek and Jane Brook.

In contrast, the lower level of variability in the concentrations of nitrogen between the streams produced a plot with much less scatter (Figure 18). A total of 11 streams had average flow-weighted nitrogen concentrations between 1.1 mg/L and 1.8 mg/L. Only Helena River and Jane Brook contained less than 1 mg/L of nitrogen on average and only Ellen Brook and Mills Street Main Drain contained over 2 mg/L on average (Table 2).

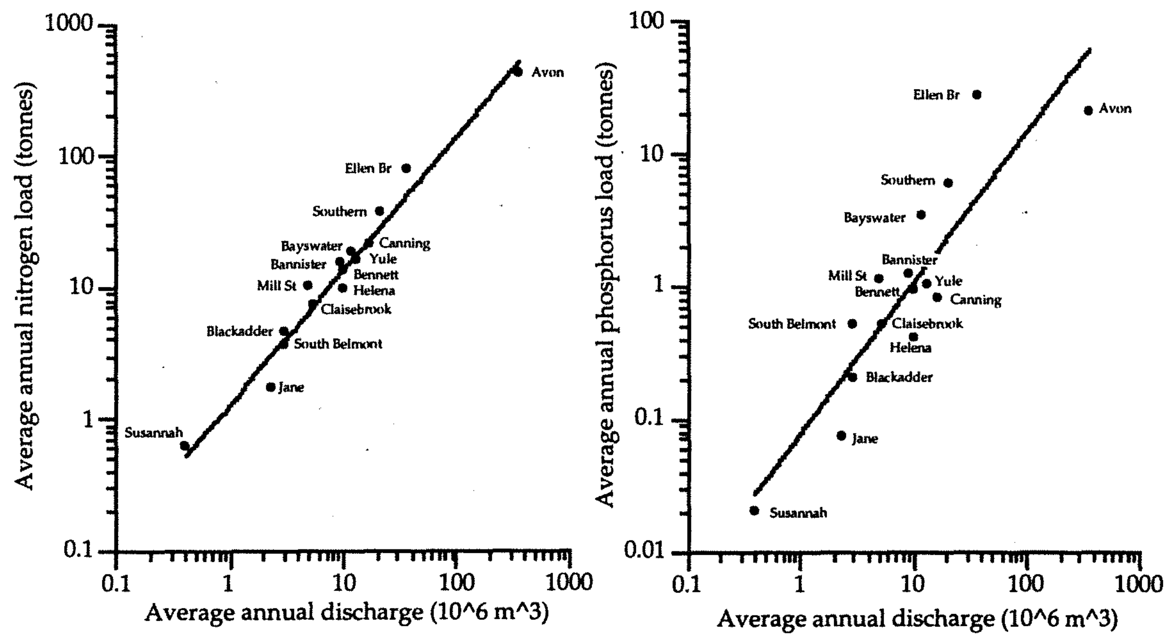


FIGURE 18: Dependence of average loads on average stream discharge. The axes are logged. *The plotted line is a power function fitted as a reference for site comparison. It is not intended to model process relationships between annual loads and discharge.*

In most of the monitored streams, between about 40 and 50 per cent of the total phosphorus load was filterable. In Ellen Brook, Southern River and Bannister Creek the filterable phosphorus streamloads were greater than 60 per cent of the total loads. That is, a high proportion of the phosphorus discharged to the estuary is readily available for plant growth. In the Avon River and Claisebrook Main Drain the filterable load was only about 30 per cent of the total load. In the Bayswater Main Drain, 10 per cent of the annual flux of phosphorus was filterable.

The inorganic nitrogen loads varied widely between streams. At most sites, average inorganic loads exceeded 42 per cent of total loads and ranged up to 66 per cent in the Canning River (Table 2). The large inorganic component in the Canning River was probably a site effect and not representative of the river. Fertiliser application on an orchard adjacent to the sample site probably influenced the measured levels of nitrate-nitrogen and the resulting mass loads (Gerritse and Adeney 1992). Groundwater seepage has been observed entering the river from the orchard side. Only the Avon River, Bannister Creek, Bennett Brook and Ellen Brook had inorganic nitrogen streamloads that were less than 35 per cent of their total nitrogen loads. Ellen Brook contained the lowest ratio of inorganic streamload to total of the 15 sites, only about 15 per cent on average. Much of the nitrogen in the brook is bound in organic complexes, presumably from relic organic groundwater storages in the catchment (Gerritse 1993).

There were four streams that contained very high proportions of ammonium-nitrogen streamloads in the inorganic loading fraction. Ellen Brook, Bayswater Main Drain, South Belmont Main Drain and Mills Street Main Drain all had ammonium-nitrogen loads greater than 35 per cent of the inorganic streamloads (Table 2). This suggests high organic loads to the streams. The Bayswater Drain also had high loads of phosphorus associated with coarse particulate matter (Figure 4A) which, considering the ammonium-nitrogen in the stream, was probably mostly organic. The riparian areas of Ellen Brook are not fenced and are grazed to the water line. The presence of cattle in the stream near the sampling site may explain the high proportion of ammonium-nitrogen in the inorganic loads in Ellen Brook, which were over 45 per cent of the inorganic load on average (Table 2) and often much higher (Figure 9B).

The magnitude of bias in estimates of mass load varies with the substance under consideration. Estimates of total nitrogen streamload are probably therefore more biased than dissolved fractions (Ongley 1982b). Therefore the proportions of the total nitrogen load that were inorganic are probably overestimated in all the monitored streams.

Speculations concerning the observed variation in streamloads must consider the connection between the sampling regime employed to characterise nutrient concentrations in the streams, and the processes that govern the quantity, mobility and fate of nutrients in catchments. There are two main modes of transportation of nutrients to surface water — overland in runoff and as solutes in shallow ground waters (Marston 1989). In the sandy soils of the coastal plain, a large proportion of the flow in streams may be due to groundwater influx. It has been estimated that, in deep grey sands, 60 per cent of the phosphorus load may be transported in relatively shallow sub-surface water (Ruprecht and George 1993). The concentration of phosphorus in the interflow varies, depending mostly on the capacity of the soil to retain phosphorous and the quantity of phosphorus applied to the catchment surface as fertiliser. The main sources of nitrogen to ground water in urban areas in Western Australia are thought to be seepage from septic tanks and nitrogenous fertiliser applied to grassed parklands and domestic gardens (Appleyard 1992).

Phosphorus concentrations in deeper ground waters in the Perth region are generally low. It has been suggested therefore that most of the phosphorus is held weakly as phosphate in the unsaturated zones of the soil profile. During the winter wet period, and when sampling occurred, sub-surface flow through these zones may mobilise phosphate from saturated soil stores, or 'hot spots' (Appleyard 1992). This is primarily speculative and more work is required on the transport of phosphates through soils to groundwater and surface drainage (Gerritse 1992). It has been shown elsewhere that, in medium to low flow periods, dissolved nutrients (mainly orthophosphate, nitrate and ammonia) in shallow ground waters largely determine the concentration of nutrients in surface streams (Sharpley *et al.* 1994; Marston 1989).

By concentrating sampling in the low to medium flow periods, the estimates of streamload presented in this report probably reflect differences between catchments in shallow groundwater nutrient concentrations. The streamload estimates could better be defined as estimates of annual nutrient loads carried by streams during low to medium flow periods.

The sandy soils of the coastal plain have a poor capacity to absorb and retain phosphorus. The ability of the better duplex soils in the region to store applied phosphorus decreases with time as available binding sites are exhausted. Therefore the history of land use in each of the sub-catchments is important in determining nutrient flux to surface drainage and annual streamloads (Weaver *et al.* 1994). This is especially critical with loads that reflect soil storage. Analysis is complicated by changes brought about by urbanisation. For example, large areas have been amended to improve the soils for domestic gardens and lawns. The effect on a catchment scale will be a mosaic of soils with differing capacities to bind applied nutrients and therefore in their ability to modify phosphorus levels in surface streams. Paved areas are effectively isolated from soils.

Nitrogen is leached from catchments mainly as inorganic nitrogen from the breakdown (mineralisation) of organic nitrogen, or from applied inorganic fertilisers. The most soluble, mobile and readily leached form is nitrate (Khanna 1981; Marston 1989). Soil conditions in many areas of the coastal plain are ideal for microbial denitrification and a large proportion of the nitrogen applied to catchments is probably lost from the system (Gerritse *et al.* 1990). Potentially, such losses may be significant and denitrification will act as a mechanism of equilibrium between catchments and reduce the variability of nitrogen concentrations between streams (Appleyard 1992). The similarity of nitrogen concentrations in the monitored streams may in part be due to such a regional process.

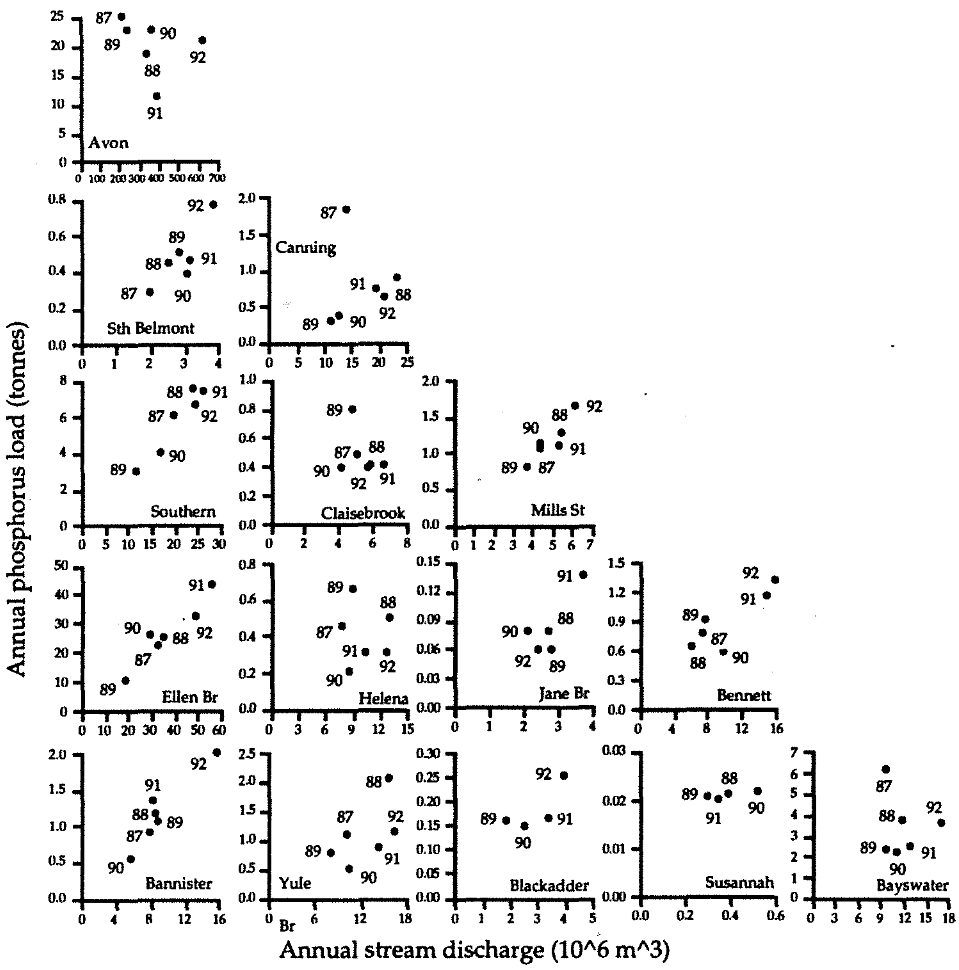


FIGURE 19: Dependence of annual phosphorus streamloads on annual stream discharge.

Many of the steams in the Swan-Canning carried relatively high loads of organic nitrogen during the low flow periods in which sampling effort was focused. This was inconsistent with the fact that most nitrogen is leached as inorganic solutes. However, ground water on the coastal plain has been shown to contain relatively high levels of organic nitrogen, probably in association with dissolved organic carbon (Gerritse 1993). The sampling regime was biased towards resolving any groundwater influence on nutrients in surface streams.

5.2 Temporal Patterns of Nutrient Flux

The loads of nutrients in streams will vary between years in response to changes in a number of factors. The processes that control the mobility and fate of nutrients, some of which are discussed above, will also influence variation in streamloads from year to year. Usually however, the major proportion of the variance in streamloads over time is due to changes in annual stream discharge. More nutrients are mobilised in wet years which results in a positive correlation between estimates of total annual load and discharge.

The other cause of variation in nutrient loads between years is change in the concentrations of nutrients. Nutrient levels in streams may change from one year to the next because of a large number of factors, for example, a change in quantity of fertiliser used in the catchment, the arrival or exhaustion of a groundwater pollution plume to surface drainage, or a run down over time in the nutrient soil store. Changes over time in the quantity of nutrients from point sources will also affect total loads in streams. Increasing development and clearing of vegetation in catchments may alter the hydrology of catchments, and the concentration of nutrients in surface drainage over time. All changes in nutrient concentration that are unrelated to annual discharge volume weaken the correlation between annual load and streamflow.

As has been discussed, imprecision may also be a major source of variation in estimates of annual streamload. The poor precision of streamload estimates calculated using data collected in fixed intervals of time has several ramifications. The most important is that the observed changes in streamloads from one year to the next may reflect bias rather than real changes in nutrient loads. For example, at the Avon, Canning, and Helena River sites, the estimates of annual phosphorus streamload, and flow-weighted concentration, decreased from 1987 to 1992. It could be concluded therefore that the levels of phosphorus in the rivers was declining in the period. However, no such conclusion could be made based on the time-series of the raw concentration data. These data clearly show that there has been no real change in the concentrations of phosphorus in these streams (Appendix 3). Significantly there were differences however in the spread, or distribution, of the raw sample phosphorus concentrations.

In the Avon River, the decrease in the estimates of annual phosphorus streamload were largely independent of annual streamflows, which generally increased over the period of monitoring (Figure 19). The highest streamloads coincided with those years in which the spread in the phosphorus concentrations was greatest, that is, in 1987, 1989 and 1990 (Appendix 3). The presence of outliers at the high end of the data distribution is typical of water quality data and often reflects a flow response (Ward *et al.* 1992). It is probable that the high concentrations coincided with high flows and produced relatively large streamload estimates in 1987, 1989 and 1990 (Figure 19). The increase in the filterable component in the Avon River over the monitoring period implies that the coarse particulate fraction was increasingly underestimated as streamflow increased (Figure 2).

The impression of falling annual phosphorus streamloads in the Canning River was due primarily to the very high streamload estimate in 1987 (Figure 7). In this year, a sample was collected at the peak of a storm. This sample reflected a positive flow-response and returned a very high phosphorus concentration, which greatly elevated the estimate of streamload. This single event mobilised nearly 80 per cent of the estimated total annual phosphorus load in that year. The elevated load occurred mostly in the coarse particulate fraction of phosphorus which is to be expected during storm flow (Figure 7). Similarly, the step-change in loads and phosphorus flow-weighted concentration in the Helena River (Figure 10), reflected a change in the spread of the raw data in the last three years of monitoring (Appendix 3).

These observed patterns of phosphorus loading occurred as a consequence of relatively infrequent sampling in fixed intervals of time, and probably did not reflect real changes in the monitored streams over time.

The flow-weighted mean concentrations of phosphorus in Ellen Brook, Bannister Creek and the South Belmont Main Drain varied between years with no trend. In Bennett Brook, the estimates of annual flow-weighted concentrations of phosphorus decreased between 1987 and 1992. The change occurred as a step-change between 1989 and 1990 (Figure 5). The spread of the raw sample concentrations was greater in 1987 and 1989, which may have affected the levels of bias in the estimates of load compared to 1990 to 1992 (Appendix 3).

In Ellen Brook, Bannister Creek, Bennett Brook and South Belmont Main Drain the estimates of phosphorus streamload increased over the period of monitoring. In Blackadder Creek, Jane Brook, Mills Street Main Drain, Southern River, Susannah Brook and Yule Brook annual phosphorus loads fluctuated between years with no observed trends. There was a good correlation between stream discharge and phosphorus streamloads in these streams (Figure 18). In the Southern River, the process of developing estimates of mass load may have masked the trend of decreasing phosphorus concentration that was evident in the raw sample concentrations between 1987 and 1990 (Appendix 3).

Variations in the estimates of phosphorus streamload over time in the Bayswater Main Drain and Claisebrook Main Drain were independent of fluctuations in streamflow (Figure 19). In the Claisebrook drain, there was a marked pulse in total streamload in 1989 that was not found in the annual flow record (Figure 8). In the other years, the streamload estimates were similar, hovering consistently around 0.4 tonnes/yr. The loads in the Claisebrook drain were determined by changes in phosphorus concentration which may have been due to the influence of point sources in this urban catchment (Appendix 3).

Changes in the level of phosphorus in Bayswater Main Drain were also the main factor controlling annual loads between 1987 and 1992. The phosphorus flow-weighted mean concentration in the drain trended downward over the monitoring period, from about 6 mg/L in 1987 to about 2 mg/L in 1992. Changes in phosphorus concentration were the main reason for the poor relationship between streamload and discharge (Figure 4). The falling trend present in the estimates of streamload and flow-weighted mean concentration can also be seen in the raw sample concentration data (Appendix 3). The reasons for the downward trend in phosphorus concentration in the drain are unknown.

Generally, the estimates of annual nitrogen streamload were closely correlated with the changes in streamflow from year to year (Figure 20). The estimates of nitrogen streamload increased over the monitoring period in 6 of the 15 sites — Avon River, Ellen Brook, Bannister Creek, Bennett Brook, Bayswater Main Drain and South Belmont Main Drain. In the Avon River, Bannister Creek, Bayswater Main Drain and the Belmont Drain, the flow-weighted mean concentration also increased with time. The increases were small however and were not evident in the sample concentrations. The flow-weighted concentration of nitrogen in Ellen and Bennett Brooks did not change. At the sites on the Canning River, Southern River, Helena River, Jane Brook, Yule Brook and Claisebrook Main Drain the estimates of annual nitrogen streamload, and flow-weighted concentration, varied between years with no indication of trend.

The estimates of annual nitrogen streamload in the Helena River were not as closely related to changes in annual stream discharge (Figure 20). The flow-weighted mean concentrations and the raw sample concentrations from the Helena River were variable compared to some of the other sites. Changes in the concentration of nitrogen in the river appear to be determining annual loads rather than streamflow volumes.

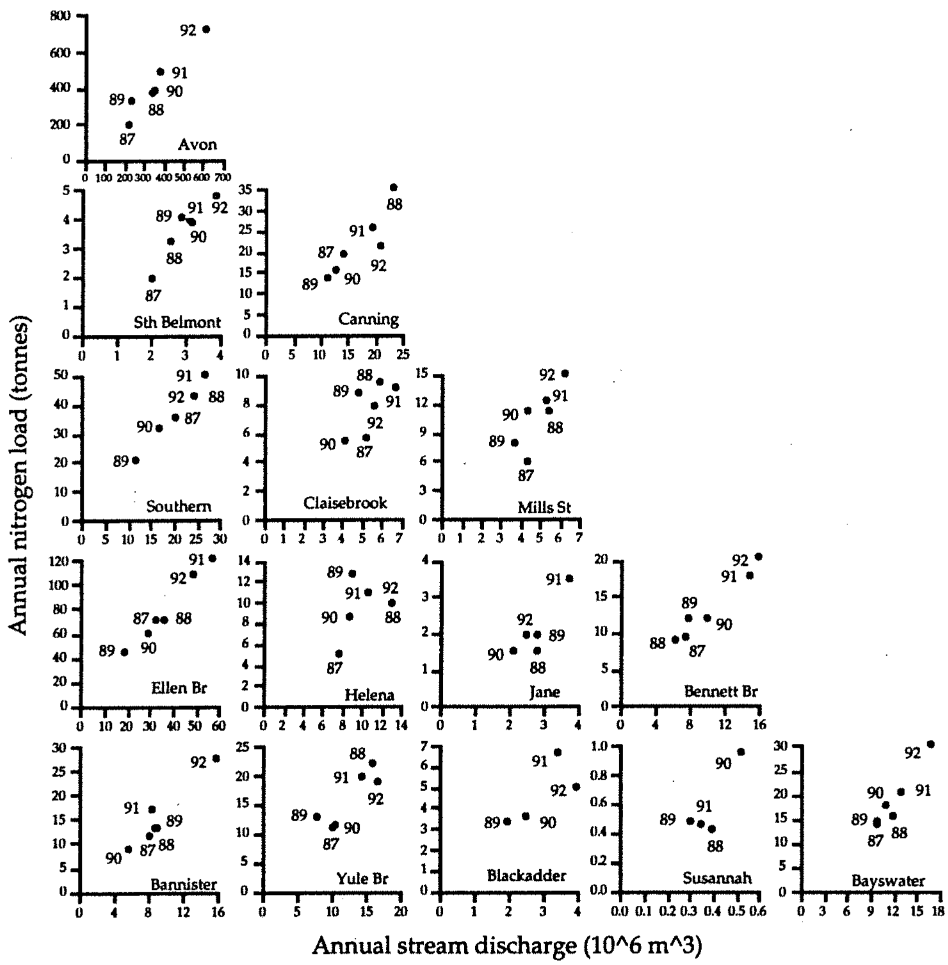


FIGURE 20: Dependence of annual nitrogen streamloads on annual stream discharge.

6. CONCLUSIONS

The estimates of streamload presented identify the Avon River, Ellen Brook and Southern River as major sources of phosphorus to the Swan-Canning estuary. The loads in the Avon River were large because of its relatively large catchment area and streamflow volume. Ellen Brook and the Southern River are much smaller catchments that contained high concentrations of phosphorus. Ellen Brook and the Avon River are important sources of nitrogen to the Swan estuary. Management should focus remedial efforts in these areas.

The Swan-Canning system was extremely diverse in terms of nutrient levels and fractions. The variability is a result of the mix of land uses, which include rural agricultural and urban, within the sub–catchments. The urban catchments include residential areas as well as areas of light and heavy industry. Large areas in some catchments support grazing at a range of stocking rates. Animal wastes are potentially important contributors to nutrient loads and represent potential point sources to the Swan-Canning estuary.

The sampling regime used in the monitoring program concentrated the sampling effort in the low to medium flow strata. Therefore the estimates of total load probably underestimated the actual loads which should include the loads associated with storm flows. The streamloads probably reflect nutrient storages in the catchments in soils and concentrations in interflow. Imprecision in the estimates is introduced by the occasional chance sampling of storm flows.

The fixed-interval regime of sampling employed during this monitoring program was inappropriate for the estimation of accurate and precise estimates of total annual nutrient flux to the Swan-Canning estuary. The estimates of total external loading of the estuary with nutrients were probably significant underestimates of the true load. The estimates were probably better defined as streamloads carried in low to medium flow periods between storm events.

The utility of estimates of mass streamloads to management is determined by the ability of monitoring programs to discern differences between catchments and differences between years. Studies to quantify bias in load estimates and to design a sampling regime that will result in accurate and precise load estimates are needed. Ideally, they should be based on observed data collected from the system to be monitored. For the design of appropriate monitoring regimes it is critical that the system is sampled intensively initially (Richards and Holloway 1987).

In recent years, regular blooms of phytoplankton and seasonal oxygen depletion have replaced macroalgae as the main symptom of eutrophication in the Swan-Canning estuary. Measurements have shown that much of the upper Swan estuary has very low concentrations of dissolved oxygen in summer. Several fish kills have occurred in the upper estuarine reaches of the Swan River in recent years. The fresh water sections of the Canning River have recently been experiencing blooms of toxic blue-green algae. These problems in the upper Swan estuary and Canning River may be linked to high levels of nutrients from Ellen Brook, the Avon and Southern Rivers.

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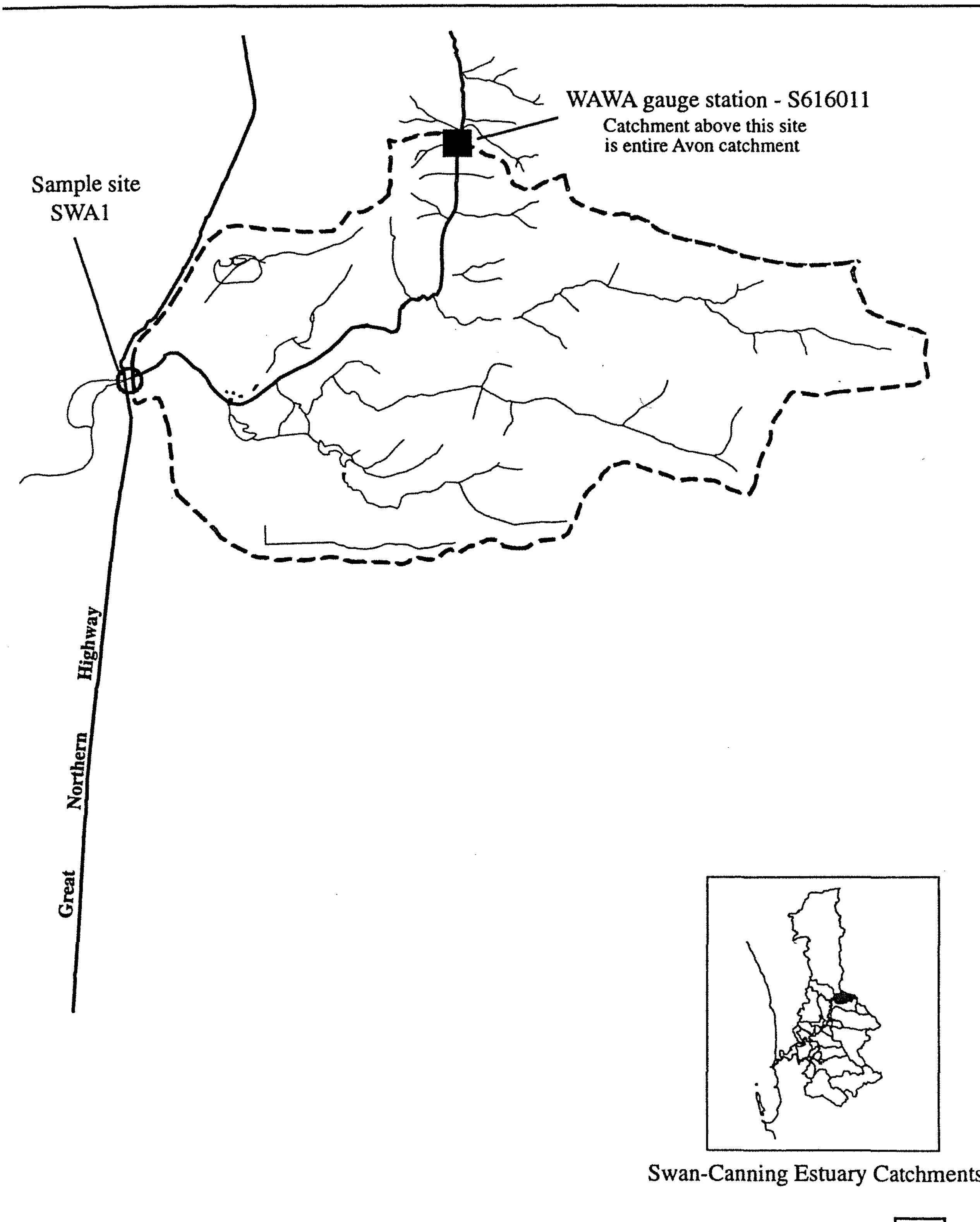
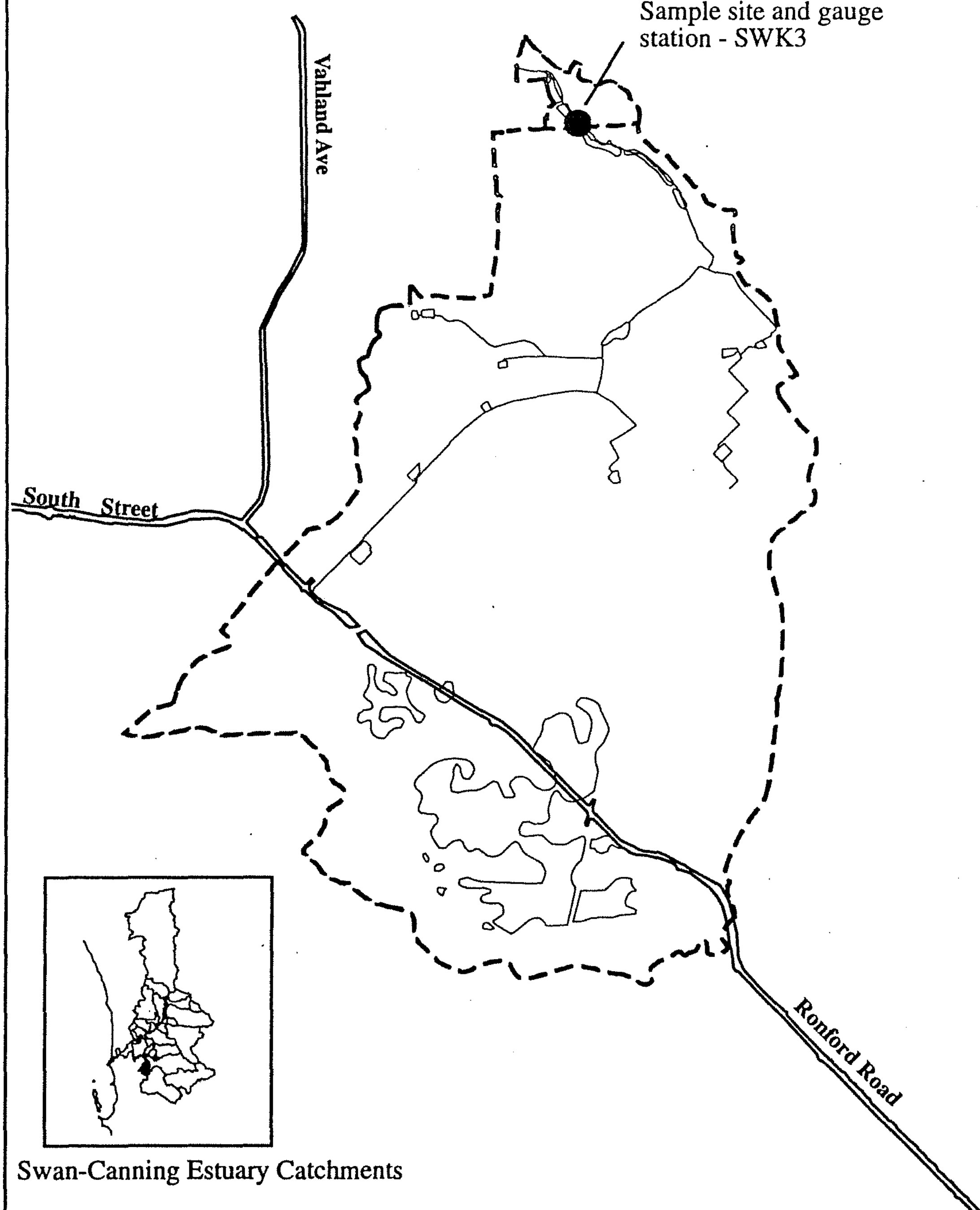
APPENDICES

APPENDIX 1 : CATCHMENT MONITORING MAPS



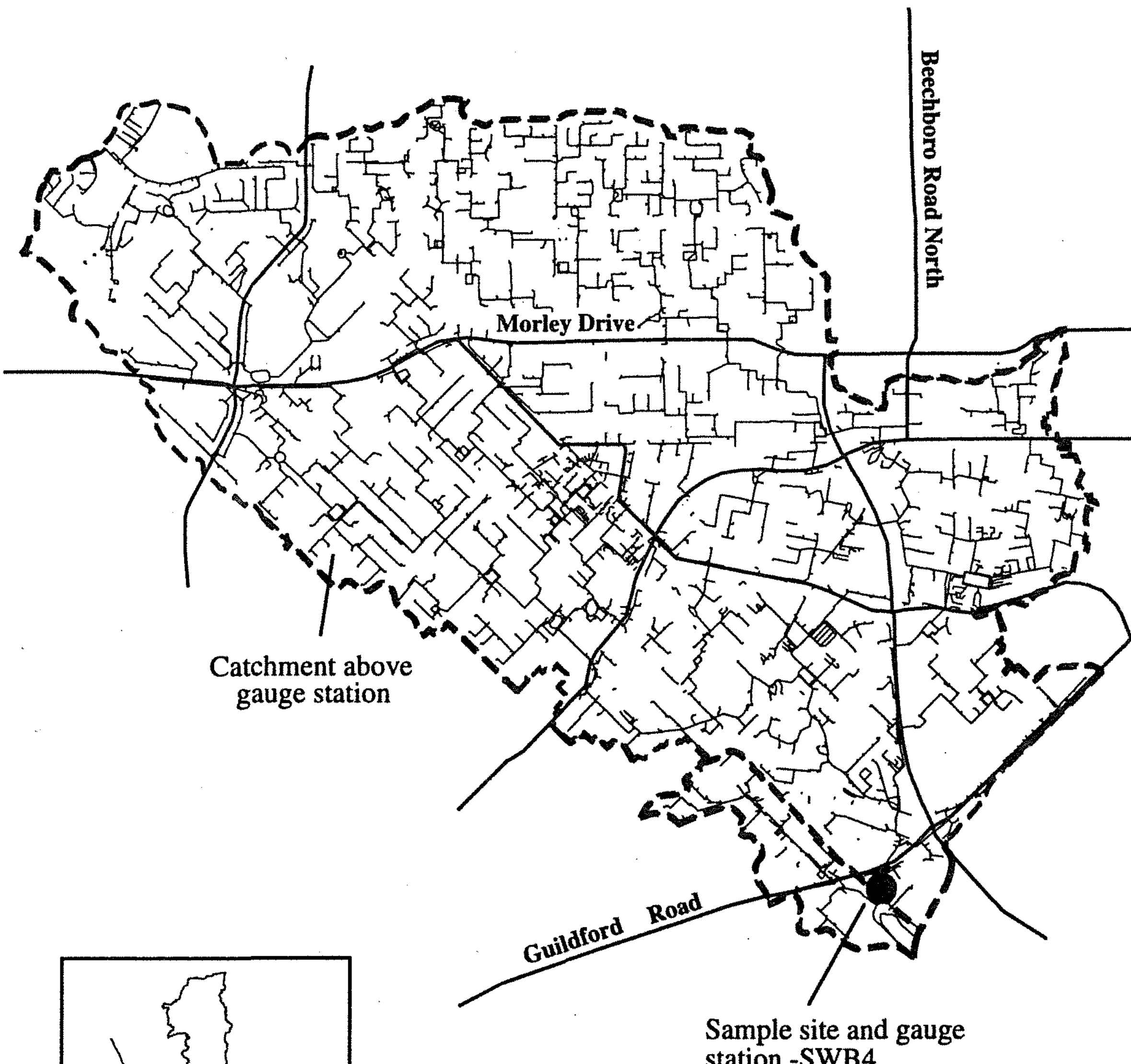
Avon River Catchment

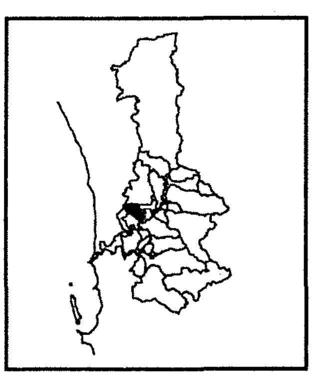


Swan-Canning Estuary Catchments

Bannister Creek Catchment

SWAN RIVER TRUST





Swan-Canning Estuary Catchments

Bayswater Main Drain Catchment

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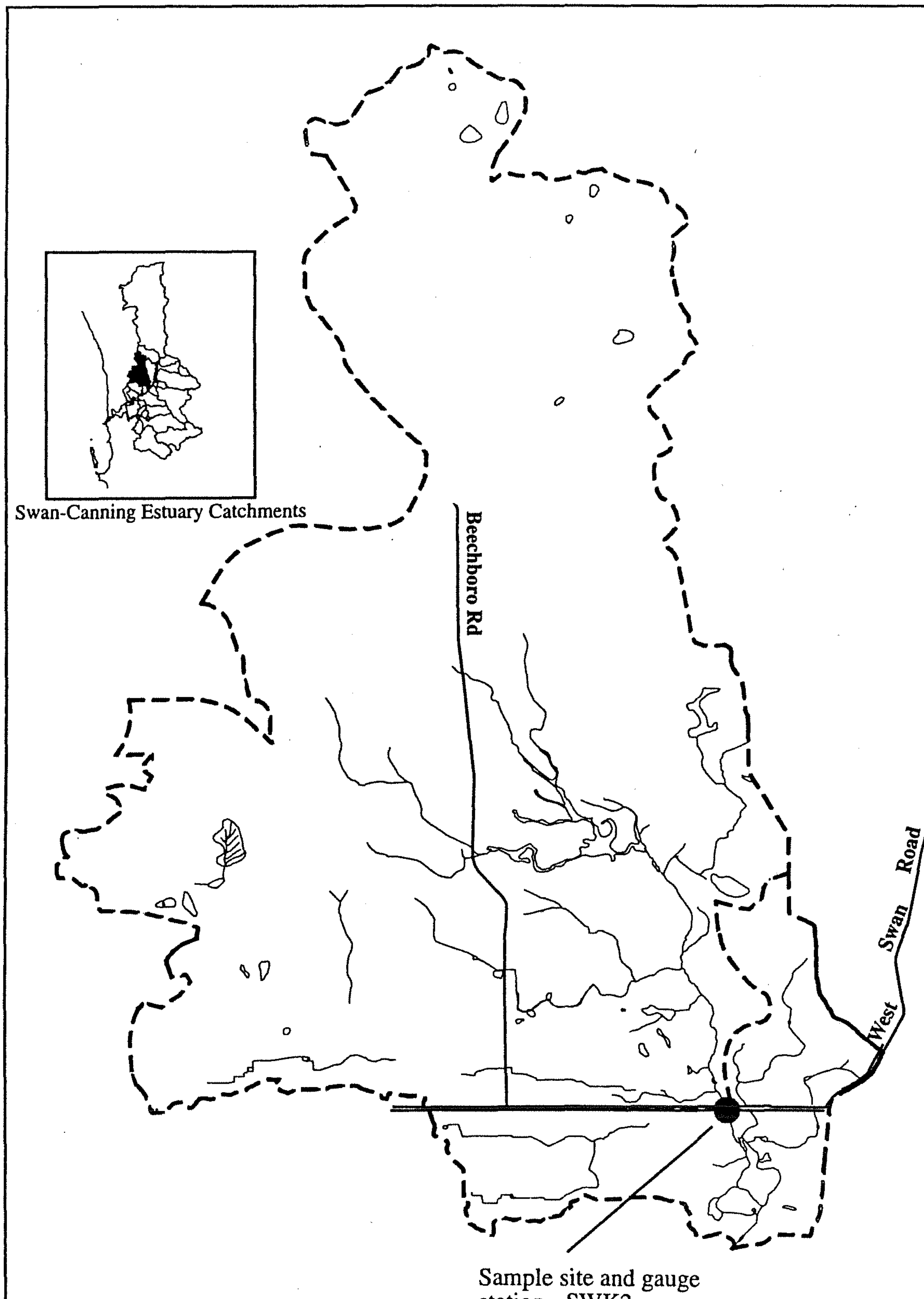

Bennett Brook Catchment

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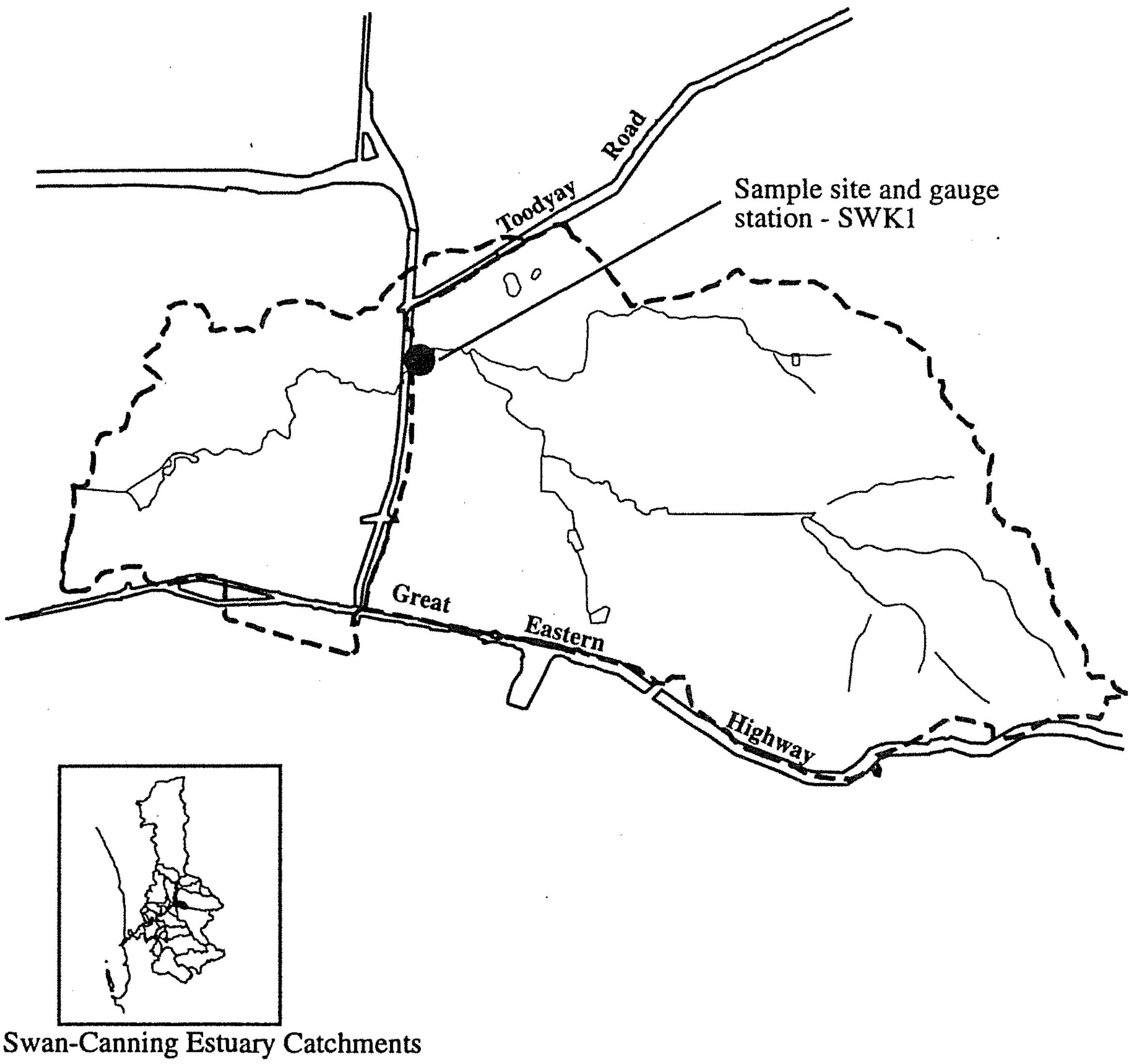
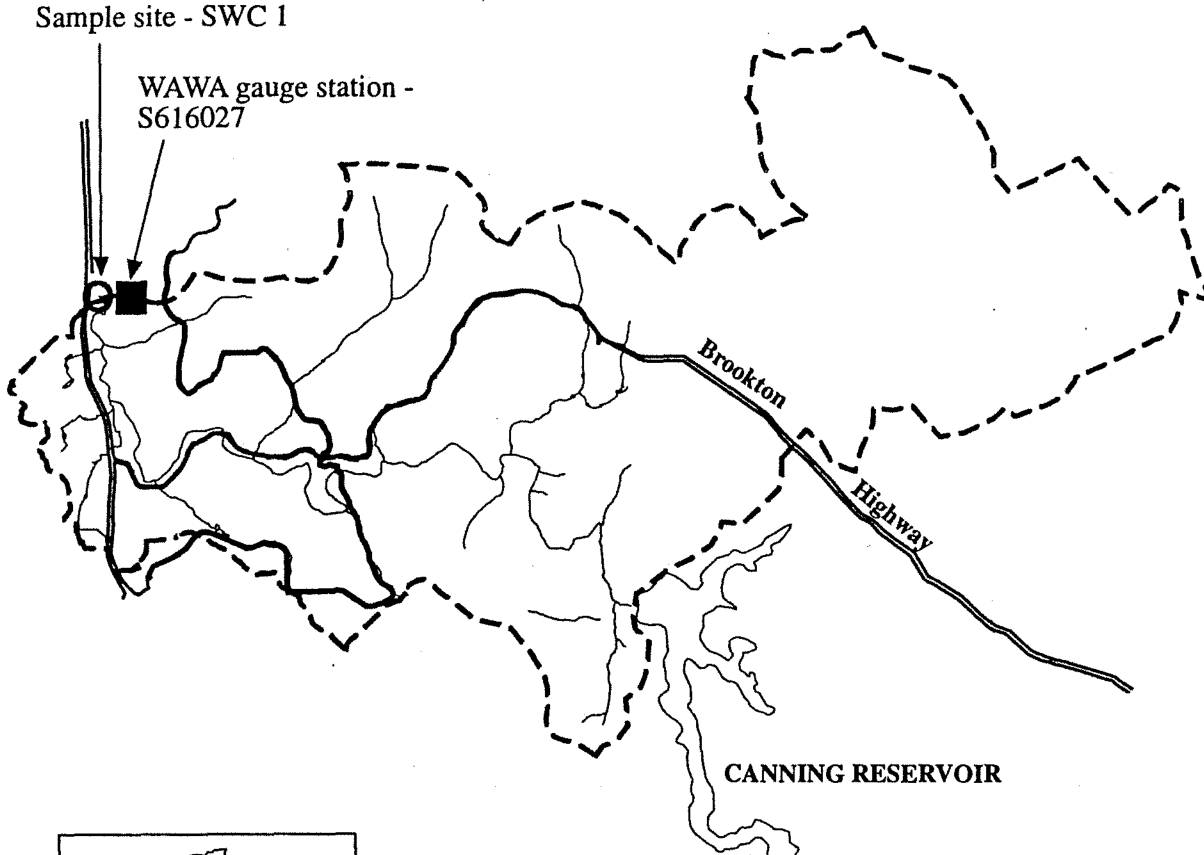
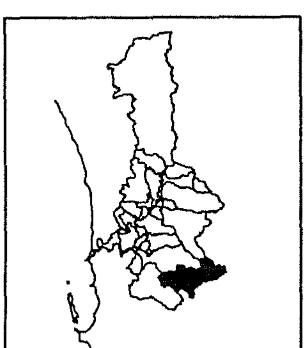


Blackadder Creek Catchment

Canning River Catchment





Swan-Canning Estuary Catchments

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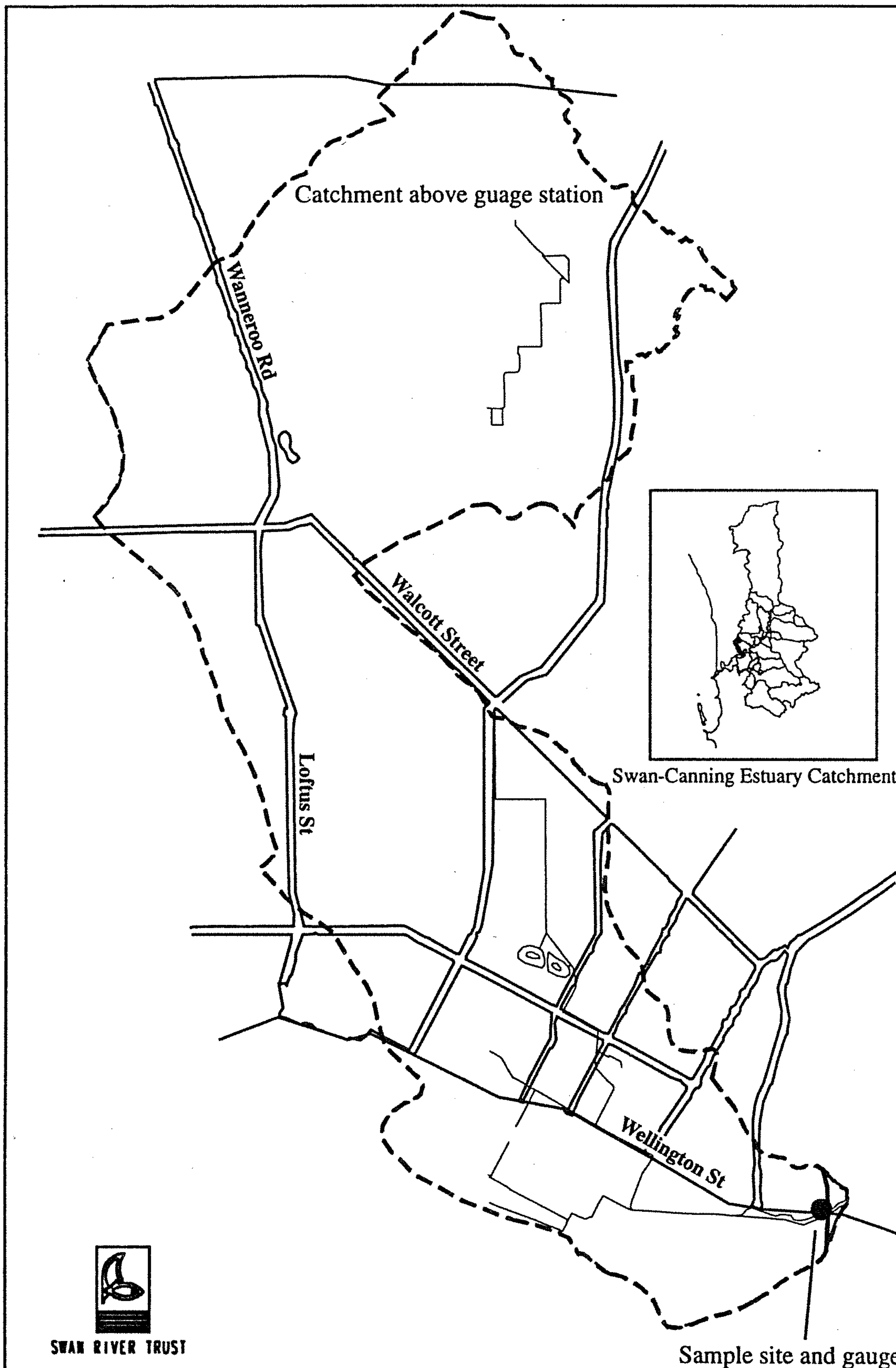
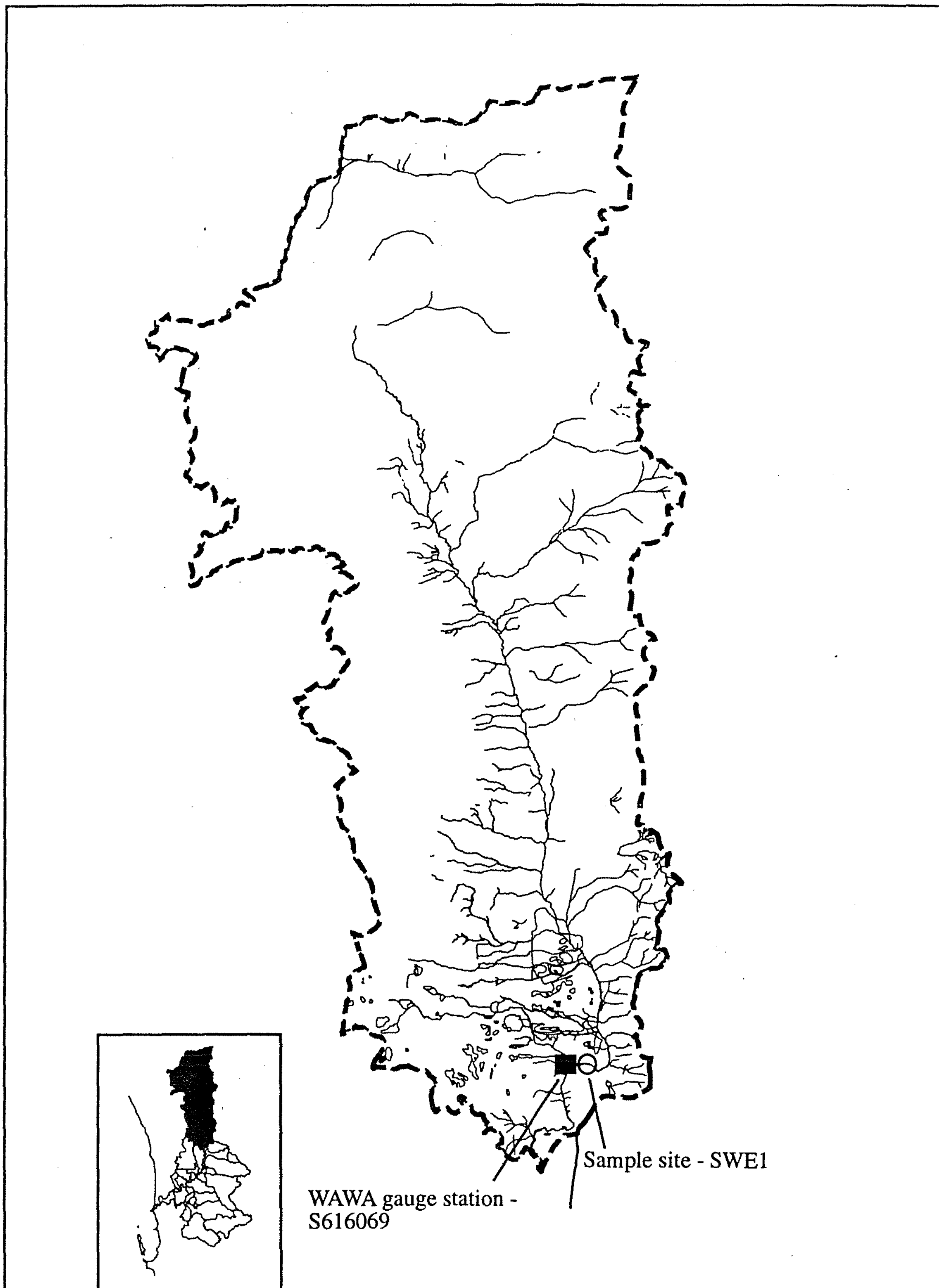
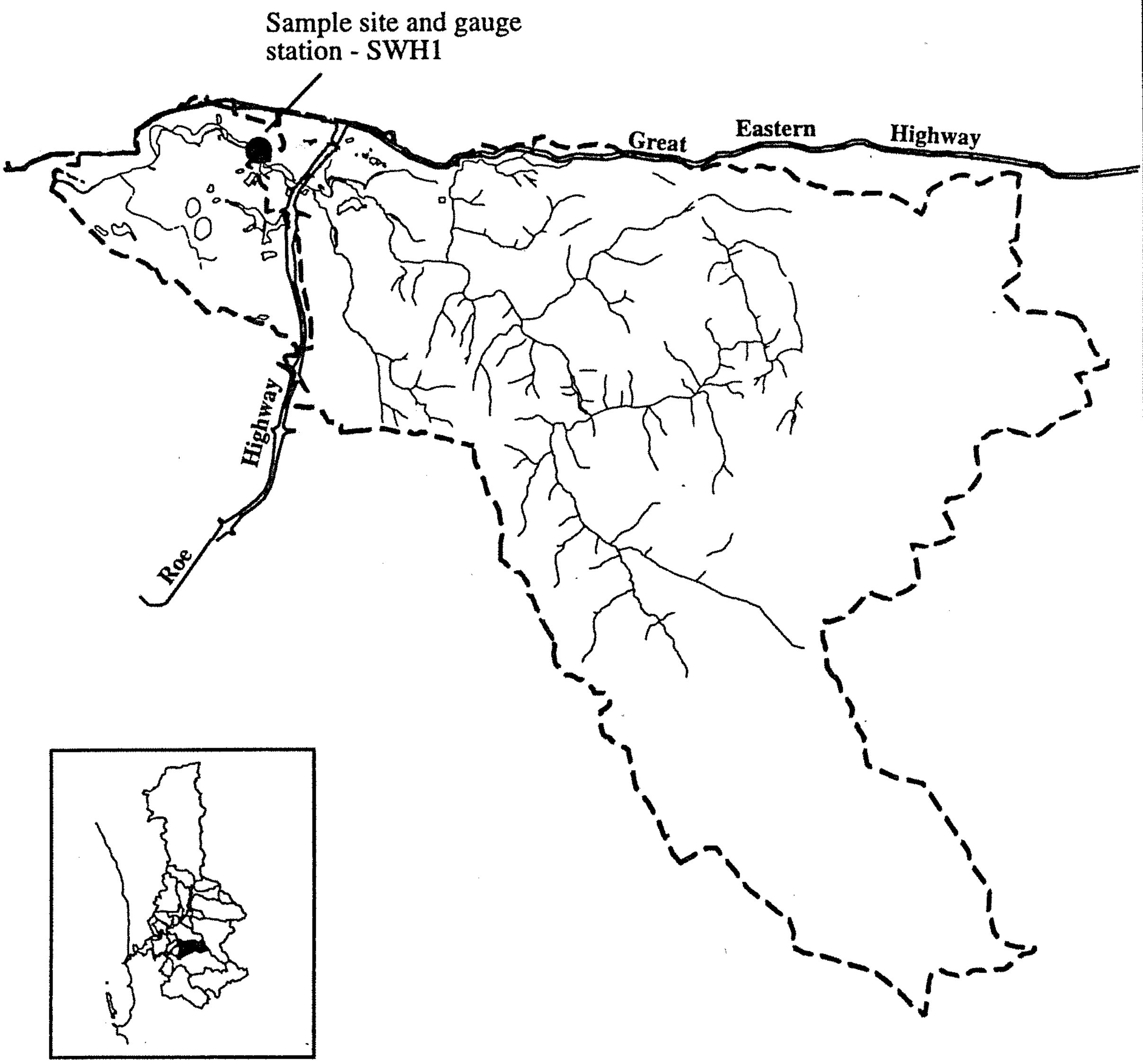


Claisebrook Main Drain Catchment



Ellen Brook Catchment



Swan-Canning Estuary Catchments

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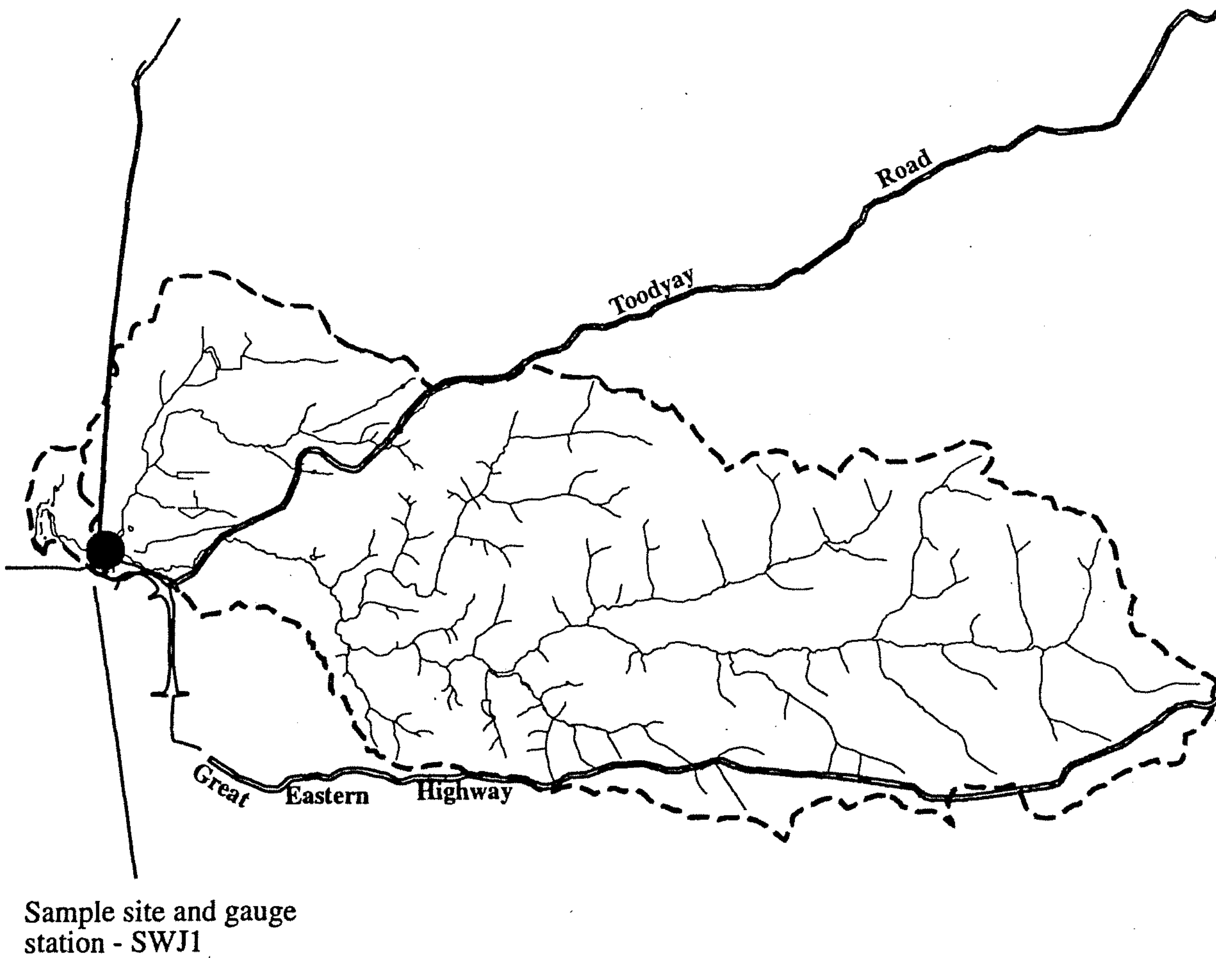
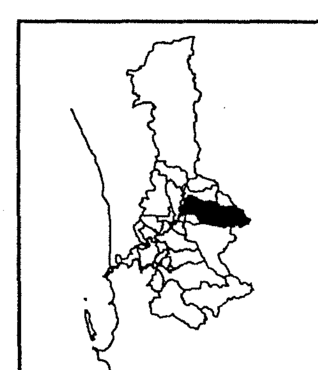
Helena River Catchment





Swan-Canning Estuary Catchment

Jane Brook Catchment

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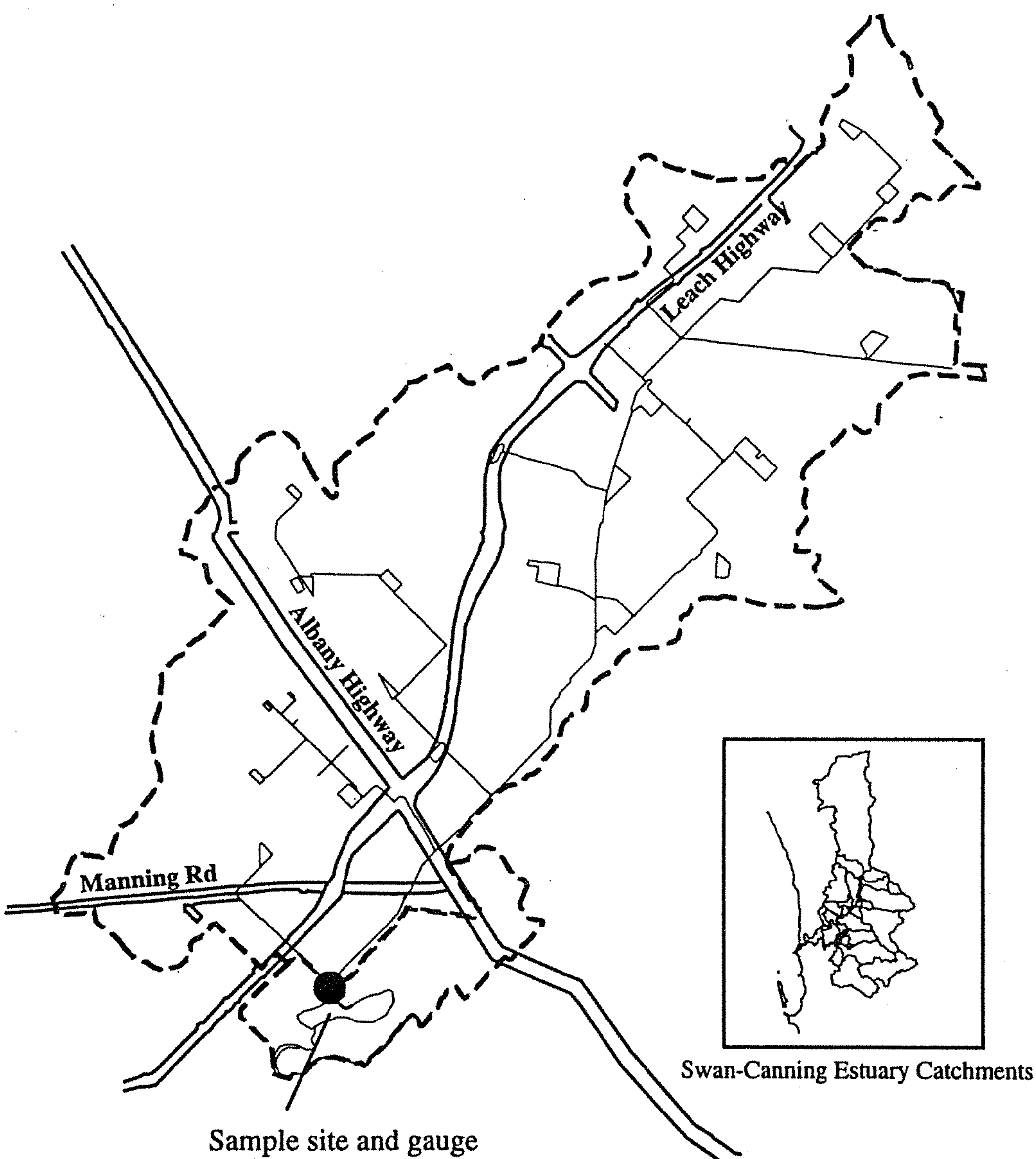

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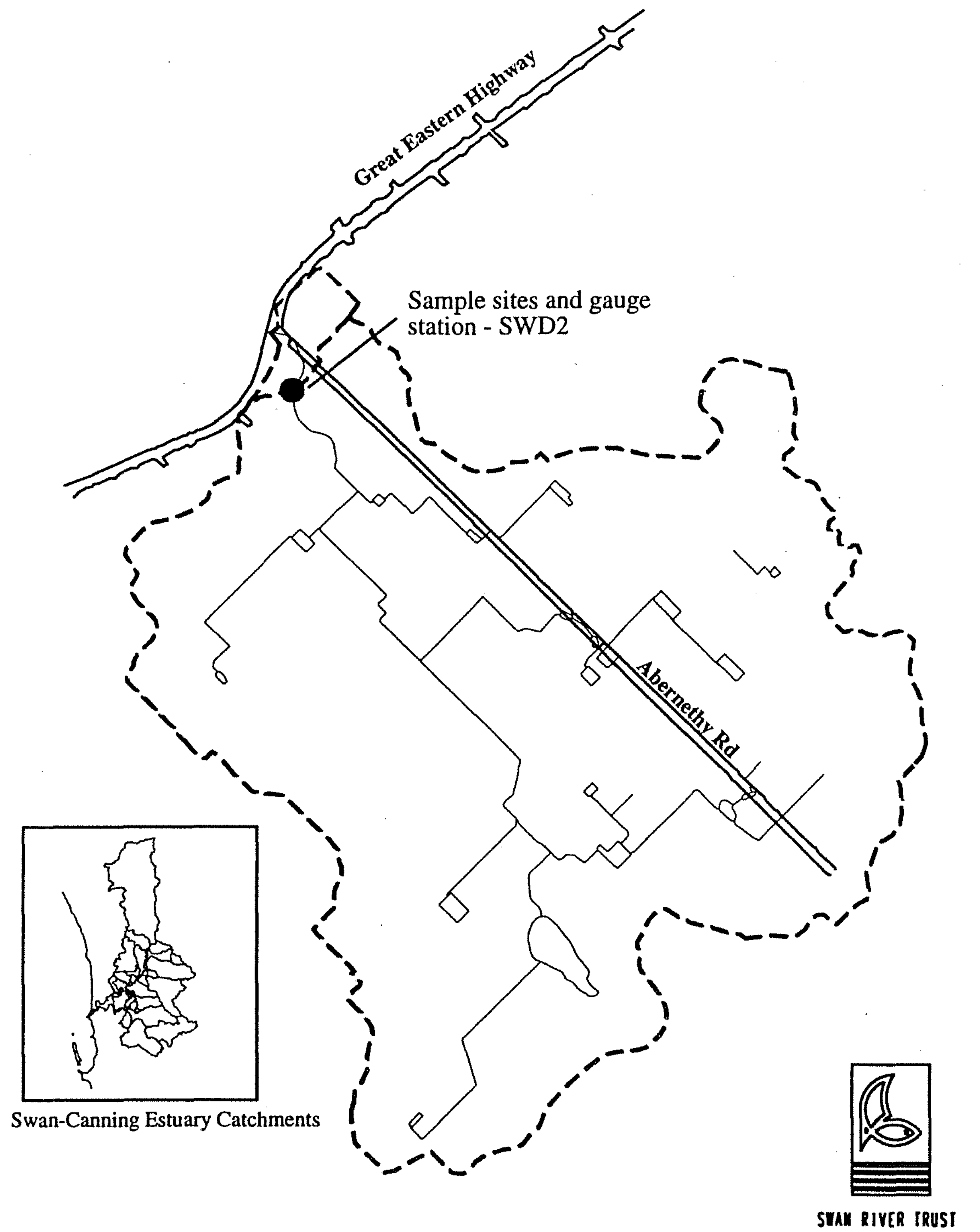
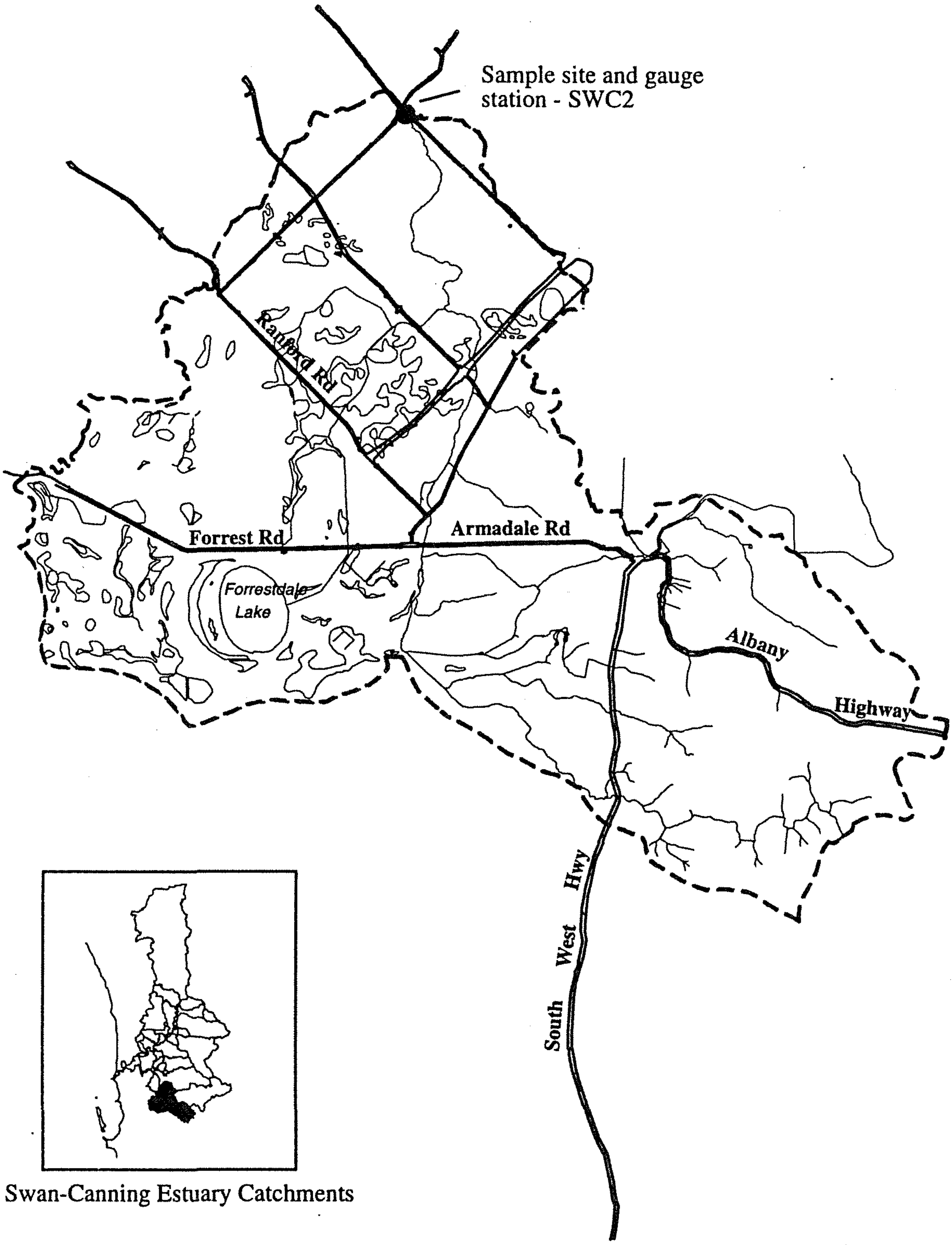
Mills Street Main Drain Catchment

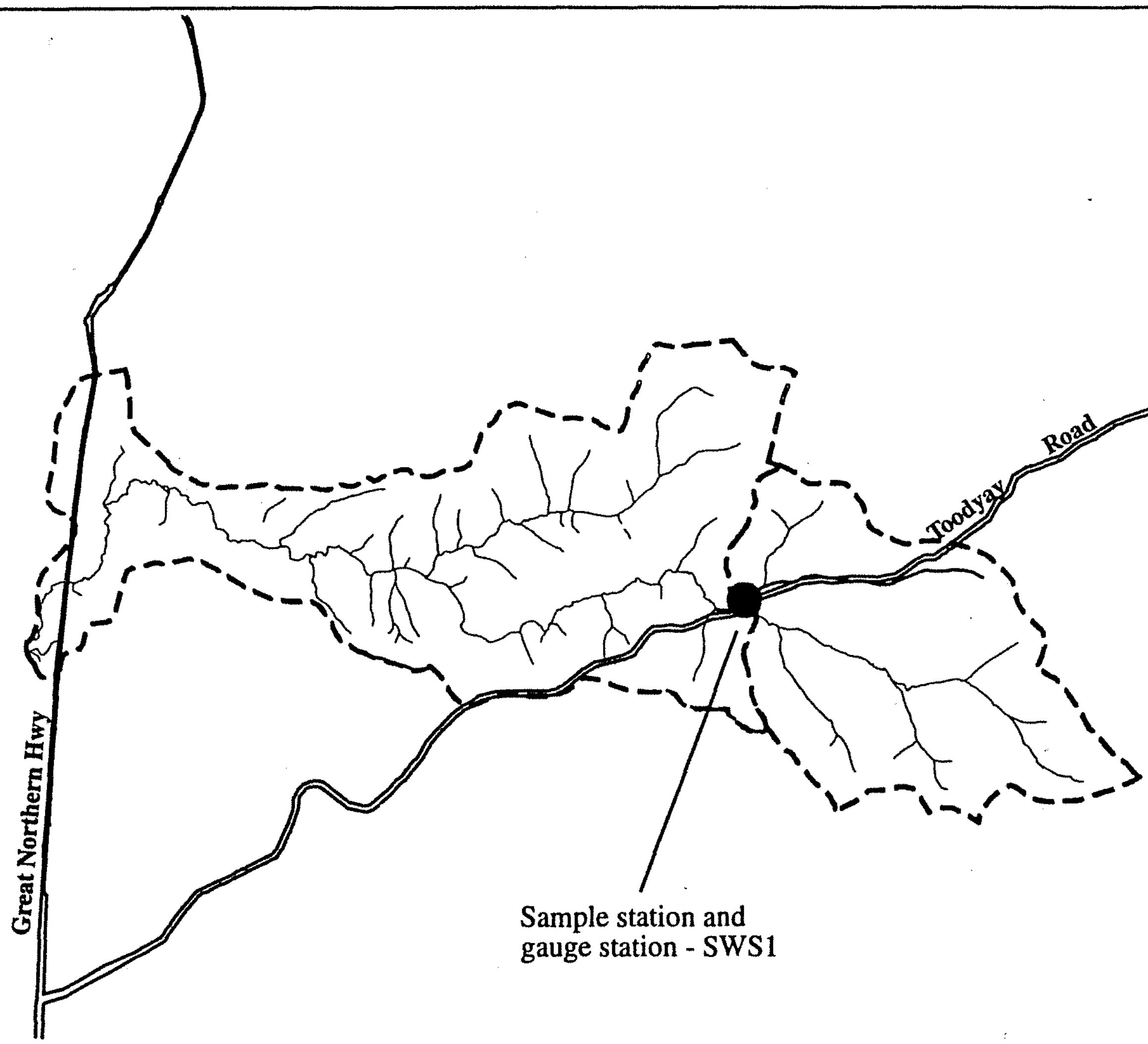


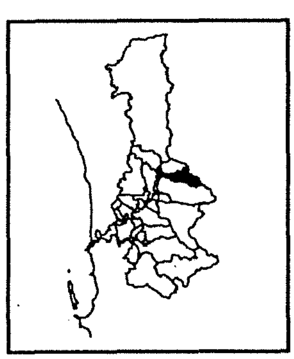
South Belmont Main Drain Catchment



Swan-Canning Estuary Catchments

Southern River Catchment

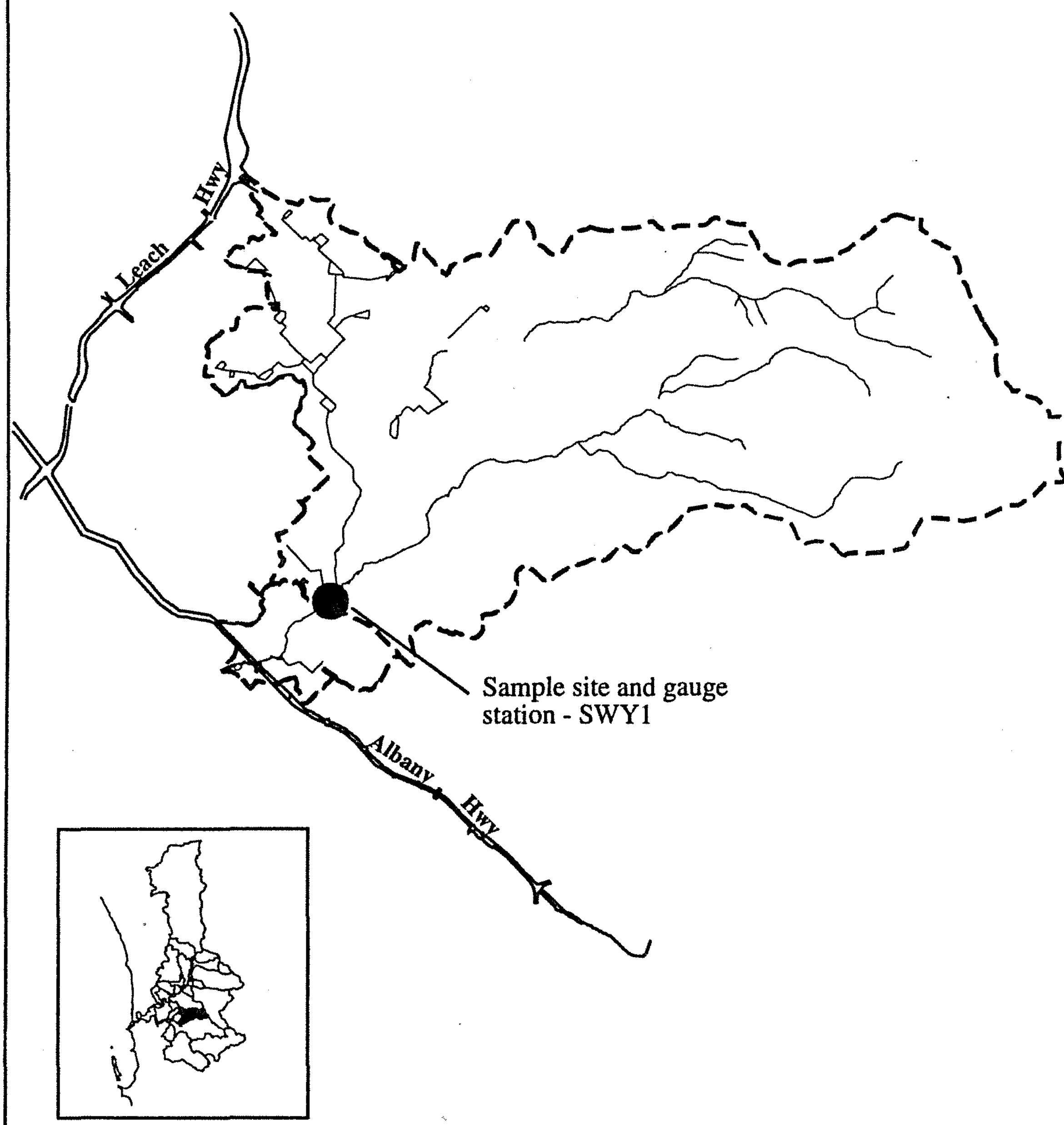




Swan-Canning Estuary Catchments

Susannah Brook Catchment

SWAN RIVER TRUST



Swan-Canning Estuary Catchmnets

Yule Brook Catchment

SWAN RIVER TRUST

DETAILS OF MONITORING NETWORK AND METHODS

1. THE NETWORK

The Swan River Trust has been regularly monitoring nutrients in the major tributary inflows to the Swan-Canning estuary since 1987. The data considered in this report is that collected between 1987 and 1992 from a network of 15 sampling sites in the Swan-Canning catchment (Figures 1 to 15). One of the main aims of the monitoring program was the calculation of mass loading estimates to the estuary. To this end, all sampling sites were located at the 'bottom end' of the respective sub-catchments as close as possible to stream confluence with the estuary waters. Details of the monitoring network are contained in Table 1.

TABLE 1: Details of the monitoring network.

Stream	Monitoring period	Site code	Location	Gauging station	Agency	Area (km^2)	Map Ref.
Bannister Creek	1987-92	SWK3	Hyranthus Road	SWK3	WWC	23	N 6454650 E 397625
Bayswater Main Drain	1987-92	SWB4	Slade Street	SWB4	WWC	26	N 6467300 E 397950
Bennett Brook	1987-92	SWK2	Benara Road	SWK2	WWC	99	N 6472750 E 401300
Blackadder Creek	1989-92	SWK1	Francis Street	SWK1	WWC	1.3	N E
Canning River	1987-92	SWC1	McKenzie Grove	S616027	WAWA	162	N 6448425 E 407005
Claisebrook Main Drain	1987-92	SWD1	Trafalgar Road	SWD1	WWC	16	N 6464200 E 394000
Ellen Brook,	1987-92	SWE1	Railway Parade	S616189	WAWA	664	N 6486600 E 407500
Helena River	1987-92	SWH1	Whiteman Road	SWH1	WWC	161	N 6470350 E 404700
Jane Brook	1987-92	SWJ1	Great Northern Highway	SWJ1	WWC	135	N 6474200 E 406600
Mills Street Main Drain	1987-92	SWD3	Mills Street, Palm Place	S616043	WWC	12	N 6457150 E 397600
South Belmont Main Drain	1987-92	SWD2	Great Eastern Highway	SWD2	WWC	10	N 6464350 E 397700
Southern River	1987-92	SWC2	Fremantle Road	SWC2	WWC	149	N 6451500 E 402900
Susannah Brook	1989-91	SWS1	Roland Road	SWS1	WWC	1.9	N 6478900 E 417450
Swan River	1987-92	SWC2	Walyunga	S616011	WAWA	119035	N 6486200 E 411600
Yule Brook	1987-92	SWY1	Brixton Road	S616042	WAWA	53	N 6456100 E 402300

2. SAMPLING REGIME AND ANALYSIS

A single grab sample was collected from each site once a week during the winter wet period. The sampling period began with the first winter rains, beginning usually in late May to early June, and continued until the start of the summer dry period, about November of every year. No samples were collected during the summer months. In practice it proved difficult to predict the onset of the winter wet period and therefore the 'first flush' of the year was not sampled in most years.

All samples were collected into new high density polyethylene screw capped bottles. Each sample bottle was rinsed with river water immediately prior to sample collection. Samples for FRP analysis were filtered on site through 0.45 µm cellulose nitrate filters. Samples were cooled on ice or frozen and transported to the Chemistry Centre of Western Australia (CCWA) for analysis. Inorganic nitrogen was calculated as the sum of NH_3-N and NO_3-N concentrations (Table 2).

TABLE 2: Nutrients measured in samples collected from each site. Details of analytical method can be obtained from the CCWA. See also Greenberg et al. (1992) for standard methods of analysis as well as a discussion of environmental significance.

Determinant	Chemical Symbol	Units of measurement	CCWA analytic method: Reference No.
Ammonia nitrogen	NH3-N	mg/L	iAMMN1WAAA
Nitrate nitrogen	NO3-N	mg/L	iNTAN1WAAA
Total nitrogen	TN	mg/L	iNP1WTCO
Filterable reactive phosphorus	FRP	mg/L	iP1WTCO
Total phosphorus	TP	mg/L	iPP1WTCO

3. CALCULATION OF ANNUAL MASS LOAD

Daily estimates of mass load for each variable at each of the sampling sites were computed as the product of daily stream discharge and nutrient concentration. Stream discharge was measured continuously at each site using standard streamflow gauging techniques. It was assumed that the concentration of nutrients in the sample was representative of that particular day's nutrient level.

Nutrient concentrations for those days when samples were not collected were obtained by simple linear interpolation between the observed weekly concentrations. Estimates of the load of nutrients that pass the sample point in a year were derived by integrating daily total loads for every day of the year. Annual flow-weighted concentrations (FWC) were calculated by dividing the total annual load estimate by the total annual stream discharge volume.

The total external load to the estuary was estimated by summing the annual loads from each site plus an estimate of nutrient export from the areas in the catchment that were not gauged.

That is:

$$\text{Annual load} = \sum_{i=1}^{365} Q_1 C_1$$

where: Q_1 = total daily discharge on day 1
C_1 = nutrient concentration on day 1

Estimates of annual flow-weighted mean concentration at each site was calculated by dividing the total annual load estimate by the total annual stream discharge.

4. MEASURING STREAMFLOW

To measure flow at the nutrient sampling sites, fourteen of the fifteen sites were gauged using standard metering techniques. These are listed in Table 1 along with their locations. Discharge at the Blackadder Creek was not gauged and had to be estimated using a data collected from a neighbouring catchment, that drained by Yule Brook. Discharge at the sampling site SWK1 was transferred from Yule Brook catchment on a per hectare basis.

5. ESTIMATION OF CONTRIBUTION FROM THE UNGAUGED CATCHMENT

The sample sites needed to be located far enough upstream to be outside the influence of tidal intrusions into the tributaries. The low gradient of the coastal plain meant the sites were situated some distance from the estuary which left an area of about 10,000 hectares in the catchment ungauged. The contribution from these areas to discharge and nutrient loads were estimated using the rational method outlined by Pilgrim (1987, ch 5).

The technique uses observed rainfall and estimated percent runoff coefficients to derive discharge. The loads are estimated as the product of discharge and approximated flow-weighted concentrations (Table 3).

TABLE 3: Estimates of total external nutrient load to the Swan-Canning estuary. The contribution from the ungauged section of the catchment was derived using typical percent rainfall runoff from areas with similar land uses, and estimates of the concentration of nutrients contained in the runoff. Parameter settings are provided along with estimates of load from the gauged and ungauged sections of the catchment.

Year	Rain	Parameter settings			Ungauged contribution			Total export to estuary		
		Runoff (%)	TP fwc (mg/l)	TN fwc (mg/l)	Flow (10^6 m^3)	TN (tonnes)	TP (tonnes)	Flow (10^6 m^3)	TN (tonnes)	TP (tonnes)
1987	757	20	0.12	1.1	51	56	6	394	426	71
1988	727	20	0.12	1.1	49	54	6	548	657	67
1989	820	25	0.15	1.5	69	104	10	410	589	53
1990	809	25	0.15	1.5	69	103	10	552	668	68
1991	1003	30	0.20	1.9	102	194	20	677	989	90
1992	901	25	0.15	1.5	76	115	11	890	1132	81
Total	5017				417	626	65			
Mean	836				70	104	11	579	744	72

6. TOTAL ANNUAL EXTERNAL LOAD TO THE ESTUARY

The total load of nutrients entering the estuary in a year was estimated by summing the estimates of total annual load for all of the major tributary inflows in each year. The estimated contribution from the ungauged catchment was added to this sum to derive an estimated total load into the estuary.

The contribution from the ungauged catchment was derived using estimates of percent runoff and observed rainfall data. The nutrient levels in runoff were estimated using guesstimates of typical FWC values. The total contribution to annual external nutrient loads was estimated as the product of estimated discharge and estimated nutrient concentration. Parameter settings and results are shown in Table 3.

APPENDIX 2 : ESTIMATED NUTRIENT STREAMLOADS, 1987-1992.

Avon River

Year	Rain (mm)	Discharge (10^6 m^3)	Load (tonnes)				
			NH3-N	NO3-N	TN	FRP	TP
1987	662	221	16	33	188	2	25
1988	571	344	17	74	364	4	18
1989	522	239	18	77	320	3	22
1990	733	362	17	62	381	7	23
1991	823	389	53	155	481	4	11
1992		619			709	9	20
Mean	662	362	24	80	407	5	20

Year	Catchment Area (ha)	Runoff (mm)	FWC (mg/L)				
			NH3-N	NO3-N	TN	FRP	TP
1987	11903515	19	0.07	0.15	0.8	0.01	0.11
1988		29	0.05	0.22	1.1	0.01	0.05
1989		20	0.07	0.32	1.3	0.01	0.09
1990		30	0.05	0.17	1.1	0.02	0.06
1991		33	0.14	0.40	1.2	0.01	0.03
1992		52			1.1	0.01	0.03
Mean		30	0.08	0.25	1.1	0.01	0.06

Bannister Creek

Year	Rain (mm)	Discharge (10^6 m^3)	Load (tonnes)				
			NH3-N	NO3-N	TN	FRP	TP
1987	757	8	0.9	2.8	11	0.6	0.9
1988	727	9	1.2	4.3	13	0.7	1.1
1989	820	9	1.0	3.0	13	0.5	1.0
1990	809	6	0.9	1.9	8	0.3	0.5
1991	1003	8	1.3	4.2	16	0.7	1.3
1992	901	16			27	1.3	2.0
Mean	836	9	1.1	3.3	15	0.7	1.2

	Catchment Area (ha)	Runoff (mm)	FWC (mg/L)				
			NH3-N	NO3-N	TN	FRP	TP
1987	2300	344	0.11	0.36	1.42	0.07	0.11
1988		372	0.14	0.50	1.48	0.09	0.13
1989		388	0.12	0.34	1.47	0.05	0.12
1990		248	0.16	0.34	1.47	0.05	0.09
1991		365	0.16	0.51	1.96	0.08	0.16
1992		683			1.73	0.08	0.13
Mean		400	0.14	0.41	1.59	0.07	0.12

Bayswater Main Drain

Year	Rain (mm)	Discharge (10^6 m^3)	Load (tonnes)				
			NH3-N	NO3-N	TN	SRP	TP
1987	757	9.8	3.7	4.1	13	0.3	6.1
1988	727	11.9	4.0	5.8	15	0.1	3.6
1989	820	9.8	3.6	4.5	14	0.3	2.3
1990	809	11.0	3.8	5.3	17	0.2	2.1
1991	1003	13.0	5.3	5.8	20	0.2	2.3
1992	901	16.9			30	0.3	3.5
Mean	836	12.1	4.1	5.1	18	0.2	3.3

Year	Catchment Area (ha)	Runoff (mm)	FWC (mg/L)				
			NH3-N	NO3-N	TN	SRP	TP
1987	26200	37	0.37	0.42	1.35	0.03	0.62
1988		45	0.34	0.49	1.27	0.01	0.31
1989		37	0.37	0.47	1.46	0.03	0.23
1990		42	0.35	0.48	1.55	0.02	0.19
1991		50	0.40	0.44	1.55	0.02	0.18
1992		65			1.76	0.02	0.20
Mean		46	0.37	0.46	1.49	0.02	0.29

Bennett Brook

Year	Rain (mm)	Discharge (10^6 m^3)	Load (tonnes)				
			NH3-N	NO3-N	TN	FRP	TP
1987	757	7	0.4	2.3	9	0.3	0.8
1988	727	6	0.5	2.9	9	0.3	0.6
1989	820	8	0.4	3.5	12	0.2	0.9
1990	809	10	0.2	3.0	12	0.2	0.6
1991	1003	15	0.6	3.2	17	0.7	1.1
1992	901	16			20	0.5	1.3
Mean	836	10	0.4	3.0	13	0.4	0.9

Year	Catchment Area (ha)	Runoff (mm)	FWC (mg/L)				
			NH3-N	NO3-N	TN	FRP	TP
1987	9852	75	0.06	0.31	1.21	0.05	0.10
1988		64	0.08	0.47	1.39	0.04	0.10
1989		77	0.05	0.45	1.53	0.02	0.12
1990		99	0.02	0.31	1.18	0.02	0.06
1991		151	0.04	0.22	1.18	0.05	0.08
1992		159			1.27	0.03	0.08
Mean		104	0.05	0.35	1.29	0.03	0.09

Blackadder Creek

Year	Rain (mm)	Discharge (10^6 m^3)	Load (tonnes)				
			NH3-N	NO3-N	TN	SRP	TP
1987							
1988							
1989	0	1.9	0.2	1.6	3.2	0.04	0.2
1990	0	2.5	0.1	1.9	3.5	0.07	0.1
1991	0	3.4	0.1	3.7	6.5	0.11	0.2
1992	0	4.0			4.9	0.09	0.2
Mean	0	2.9	0.1	2.4	4.5	0.08	0.2

Year	Catchment Area (ha)	Runoff (mm)	FWC (mg/L)				
			NH3-N	NO3-N	TN	SRP	TP
1987	1258						
1988							
1989		151	0.09	0.83	1.71	0.02	0.08
1990		199	0.03	0.76	1.39	0.03	0.06
1991		273	0.04	1.06	1.91	0.03	0.05
1992		314			1.24	0.02	0.06
Mean		234	0.05	0.88	1.56	0.03	0.06

Canning River

Year	Rain (mm)	Discharge (10^6 m^3)	Load (tonnes)				
			NH3-N	NO3-N	TN	FRP	TP
1987	757	14	0.6	9.4	19	0.5	1.8
1988	727	23	0.9	21.0	35	0.3	0.8
1989	820	11	0.7	7.8	13	0.1	0.3
1990	809	13	0.3	10.1	15	0.1	0.3
1991	1003	19	0.7	18.2	25	0.2	0.7
1992	901	21			21	0.3	0.6
Mean	836	17	0.6	13.3	21.2	0.3	0.8

Year	Catchment Area (ha)	Runoff (mm)	FWC (mg/L)				
			NH3-N	NO3-N	TN	FRP	TP
1987	16283	86	0.04	0.67	1.32	0.03	0.13
1988		143	0.04	0.90	1.50	0.01	0.04
1989		70	0.06	0.69	1.15	0.01	0.02
1990		79	0.02	0.78	1.14	0.01	0.03
1991		119	0.04	0.94	1.30	0.01	0.04
1992		128			0.99	0.02	0.03
Mean		104	0.04	0.80	1.23	0.02	0.05

Claisebrook Main Drain

Year	Rain (mm)	Discharge (10^6 m^3)	Load (tonnes)				
			NH3-N	NO3-N	TN	FRP	TP
1987	757	5	0.7	2.5	5.5	0.1	0.5
1988	727	5.8	0.8	5.2	9.4	0.1	0.4
1989	820	4.8	0.8	3.6	8.5	0.2	0.8
1990	809	4.1	0.3	1.6	5.3	0.1	0.4
1991	1003	6.7	1.2	4.1	9.0	0.1	0.4
1992	901	5.7			7.6	0.1	0.4
Mean	836	5.4	0.8	3.4	7.5	0.1	0.5

Year	Catchment Area (ha)	Runoff (mm)	FWC (mg/L)				
			NH3-N	NO3-N	TN	FRP	TP
1987	1604	323	0.14	0.48	1.05	0.01	0.09
1988		364	0.15	0.89	1.60	0.02	0.07
1989		297	0.17	0.76	1.79	0.05	0.16
1990		257	0.07	0.38	1.28	0.03	0.09
1991		415	0.18	0.62	1.35	0.02	0.06
1992		355			1.33	0.02	0.07
Mean		335	0.14	0.62	1.40	0.02	0.09

Ellen Brook

Year	Rain (mm)	Discharge (10^6 m^3)	Load (tonnes)				
			NH3-N	NO3-N	TN	FRP	TP
1987	771	33	3.9	4.3	68	12	22
1988	489	35	3.4	8.4	69	20	24
1989	347	19	4.0	3.9	41	7	9
1990	706	29	4.6	2.7	57	19	25
1991	1061	56	5.0	7.6	119	36	43
1992	1061	49			106	23	32
Mean	739	37	4	5	77	19	26

Year	Catchment Area (ha)	Runoff (mm)	FWC (mg/L)				
			NH3-N	NO3-N	TN	FRP	TP
1987	66423	49	0.12	0.13	2.08	0.36	0.67
1988		53	0.10	0.24	1.95	0.55	0.69
1989		28	0.21	0.20	2.19	0.37	0.50
1990		44	0.16	0.09	1.97	0.64	0.87
1991		85	0.09	0.14	2.11	0.64	0.76
1992		74			2.15	0.46	0.65
Mean		56	0.13	0.16	2.07	0.51	0.69

Helena River

Year	Rain (mm)	Discharge (10^6 M^3)	Load (tonnes)				
			NH3-N	NO3-N	TN	FRP	TP
1987	757	8	0.3	1.6	5	0.2	0.4
1988	727	13	0.6	5.1	10	0.3	0.5
1989	820	9	1.2	3.1	13	0.1	0.6
1990	809	9	0.5	4.0	8	0.1	0.2
1991	1003	11	0.6	5.8	11	0.2	0.3
1992	901	13			10	0.2	0.3
Mean	836	10	0.6	3.9	9.3	0.2	0.4

Year	Catchment Area (ha)	Runoff (mm)	FWC (mg/L)				
			NH3-N	NO3-N	TN	FRP	TP
1987	16065	48	0.03	0.21	0.62	0.03	0.06
1988		81	0.05	0.39	0.75	0.02	0.04
1989		56	0.13	0.35	1.40	0.01	0.07
1990		55	0.06	0.46	0.95	0.01	0.02
1991		66	0.06	0.55	1.01	0.01	0.03
1992		80			0.75	0.01	0.02
Mean		64	0.07	0.39	0.91	0.02	0.04

Jane Brook

Year	Rain (mm)	Discharge (10^6 m^3)	Load (tonnes)				
			NH3-N	NO3-N	TN	FRP	TP
1987	757						
1988	727	2.8	0.1	0.9	1.5	0.02	0.08
1989	820	2.8	0.1	1.0	1.9	0.03	0.06
1990	809	2.1	0.1	0.6	1.5	0.03	0.08
1991	1003	3.7	0.1	1.9	3.4	0.09	0.14
1992	901	2.5			1.9	0.04	0.06
Mean	836	2.3	0.1	0.9	1.7	0.03	0.07

Year	Catchment Area (ha)	Runoff (mm)	FWC (mg/L)				
			NH3-N	NO3-N	TN	FRP	TP
1987	13538						
1988		21	0.04	0.32	0.53	0.01	0.03
1989		21	0.04	0.35	0.67	0.01	0.02
1990		16	0.03	0.30	0.70	0.02	0.04
1991		27	0.04	0.50	0.92	0.02	0.04
1992		18			0.76	0.01	0.02
Mean		21	0.04	0.37	0.71	0.01	0.03

Mills Street Main Drain

Year	Rain (mm)	Discharge (10^6 m^3)	Load (tonnes)				
			NH3-N	NO3-N	TN	FRP	TP
1987	757	4.4	1.0	1.2	5.7	0.4	1.0
1988	727	5.5	1.7	4.3	11.1	0.6	1.3
1989	820	3.8	1.9	1.5	7.7	0.4	0.8
1990	809	4.4	2.9	2.4	10.9	0.5	1.1
1991	1003	5.3	3.2	2.9	12.1	0.4	1.1
1992	901	6.2			14.9	0.7	1.6
Mean	836	4.9	2.1	2.5	10.4	0.5	1.1

Year	Catchment Area (ha)	Runoff (mm)	FWC (mg/L)				
			NH3-N	NO3-N	TN	FRP	TP
1987	1152	385	0.23	0.26	1.30	0.09	0.23
1988		474	0.31	0.78	2.03	0.12	0.23
1989		327	0.49	0.40	2.04	0.09	0.21
1990		382	0.65	0.54	2.47	0.11	0.25
1991		464	0.60	0.55	2.26	0.07	0.20
1992		539			2.40	0.11	0.26
Mean		428	0.46	0.51	2.08	0.10	0.23

South Belmont Main Drain

Year	Rain (mm)	Discharge (10^6 m^3)	Load (tonnes)				
			NH3-N	NO3-N	TN	FRP	TP
1987	757	2.0	0.3	0.4	1.9	0.1	0.3
1988	727	2.5	0.6	1.1	3.1	0.2	0.4
1989	820	2.8	0.7	0.9	4.0	0.2	0.5
1990	809	3.2	0.6	1.2	3.8	0.2	0.4
1991	1003	3.1	0.5	1.2	3.9	0.2	0.4
1992	901	3.9			4.7	0.3	0.8
Mean	836	2.9	0.5	1.0	3.6	0.2	0.5

Year		Runoff (mm)	FWC (mg/L)				
			NH3-N	NO3-N	TN	FRP	TP
1987		208	0.14	0.22	0.94	0.06	0.14
1988		262	0.24	0.45	1.23	0.09	0.17
1989		290	0.24	0.33	1.41	0.07	0.17
1990		325	0.18	0.38	1.20	0.07	0.14
1991		314	0.17	0.39	1.27	0.06	0.12
1992		395			1.23	0.07	0.20
Mean		299	0.19	0.35	1.21	0.07	0.16

Southern River

Year	Rain (mm)	Discharge (10^6 m^3)	Load (tonnes)				
			NH3-N	NO3-N	TN	FRP	TP
1987	757	20	1.0	12	34	3.6	5.9
1988	727	24	2.4	15	42	4.8	7.4
1989	820	12	1.4	7	20	1.4	2.9
1990	809	17	0.7	13	31	2.1	4.0
1991	1003	27	2.4	20	50	5.5	7.2
1992	901	24			42	3.9	6.5
Mean	836	21	1.6	13.4	36.5	3.5	5.7

Year	Catchment Area (ha)	Runoff (mm)	FWC (mg/L)				
			NH3-N	NO3-N	TN	FRP	TP
1987	14888	135	0.05	0.61	1.70	0.18	0.29
1988		163	0.10	0.63	1.75	0.20	0.31
1989		78	0.12	0.62	1.74	0.12	0.25
1990		115	0.04	0.76	1.79	0.12	0.23
1991		178	0.09	0.74	1.87	0.21	0.27
1992		164			1.73	0.16	0.27
Mean		139	0.08	0.67	1.76	0.16	0.27

Susannah Brook

Year	Rain (mm)	Discharge (10^6 m^3)	Load (tonnes)				
			NH3-N	NO3-N	TN	SRP	TP
1987							
1988	0	0.4	0.02	0.22	0.41	0.01	0.02
1989	0	0.3	0.01	0.25	0.47	0.01	0.02
1990	0	0.5	0.02	0.51	0.94	0.02	0.02
1991	0	0.3			0.45	0.01	0.02
1992							
Mean	0	0.4	0.02	0.3	0.6	0.01	0.02

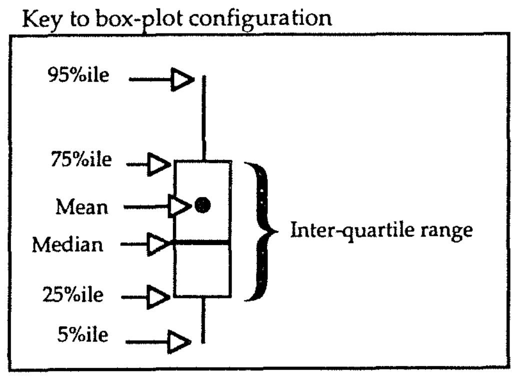
Year	Catchment Area (ha)	Runoff (%)	FWC (mg/L)				
			NH3-N	NO3-N	TN	SRP	TP
1987	1901						
1988		21	0.05	0.55	1.03	0.02	0.05
1989		16	0.04	0.83	1.56	0.03	0.07
1990		27	0.04	0.98	1.80	0.03	0.04
1991		18			1.30	0.02	0.06
1992							
Mean		20	0.04	0.79	1.42	0.03	0.05

Yule Brook

Year	Rain (mm)	Discharge (10^6 m^3)	Load (tonnes)				
			NH3-N	NO3-N	TN	FRP	TP
1987	1017	10	0.3	3.6	10	0.4	1.1
1988	570	16	0.8	8.6	22	0.5	2.0
1989	931	8	1.2	4.9	13	0.2	0.8
1990	880	11	0.5	4.5	11	0.3	0.5
1991	1198	14	1.2	9.1	19	0.6	0.8
1992		17			18	0.5	1.1
Mean	919	13	0.8	6.1	16	0.4	1.0

	Catchment Area (ha)	Runoff (mm)	FWC (mg/L)				
			NH3-N	NO3-N	TN	FRP	TP
1987	5301	194	0.03	0.35	1.01	0.04	0.10
1988		301	0.05	0.54	1.37	0.03	0.13
1989		151	0.15	0.61	1.58	0.03	0.09
1990		199	0.05	0.43	1.07	0.03	0.04
1991		273	0.09	0.63	1.34	0.04	0.06
1992		314			1.10	0.03	0.07
Mean		239	0.07	0.51	1.24	0.03	0.08

APPENDIX 3 : RAW SAMPLE CONCENTRATIONS, 1987-1992.



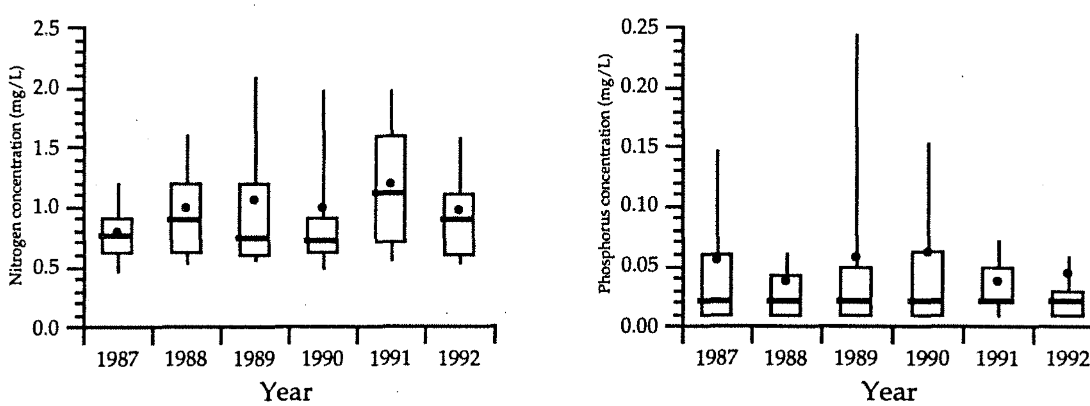


FIGURE 1: Nitrogen and phosphorus concentration in the Avon River, 1987 - 1992.

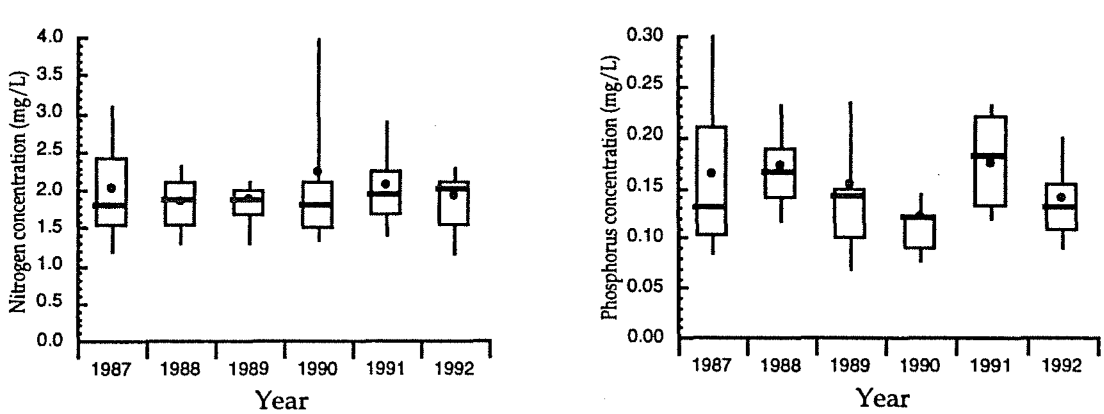


FIGURE 2: Nitrogen and phosphorus concentration in Bannister Creek 1987 - 1992.

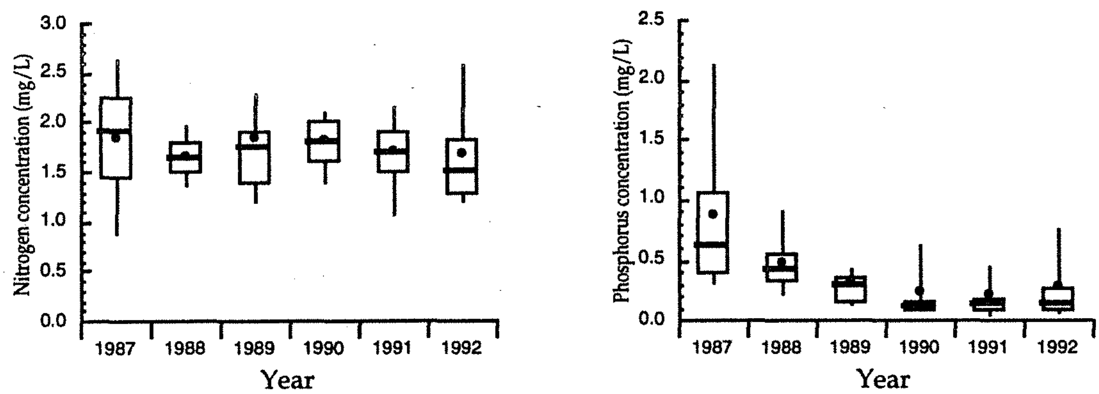


FIGURE 3: Nitrogen and phosphorus concentration in the Bayswater Main Drain, 1987 - 1992.

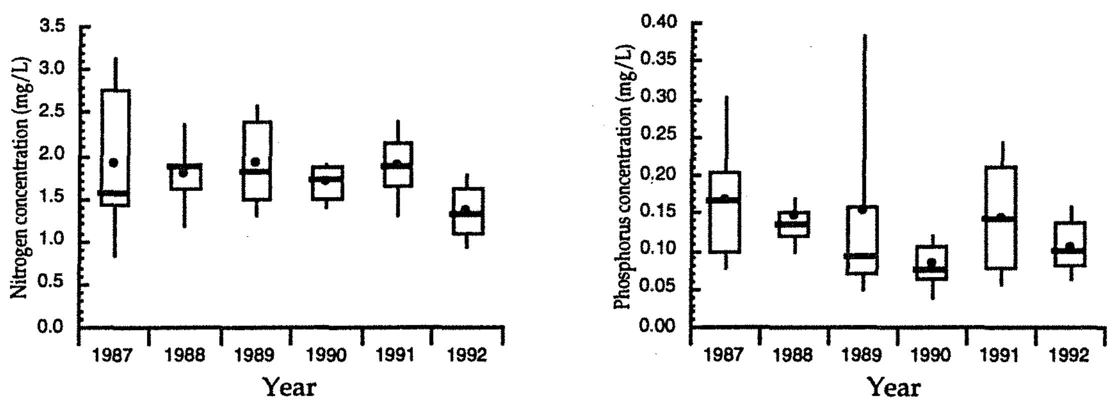


FIGURE 4: Nitrogen and phosphorus concentration in Bennett Brook, 1987 - 1992.

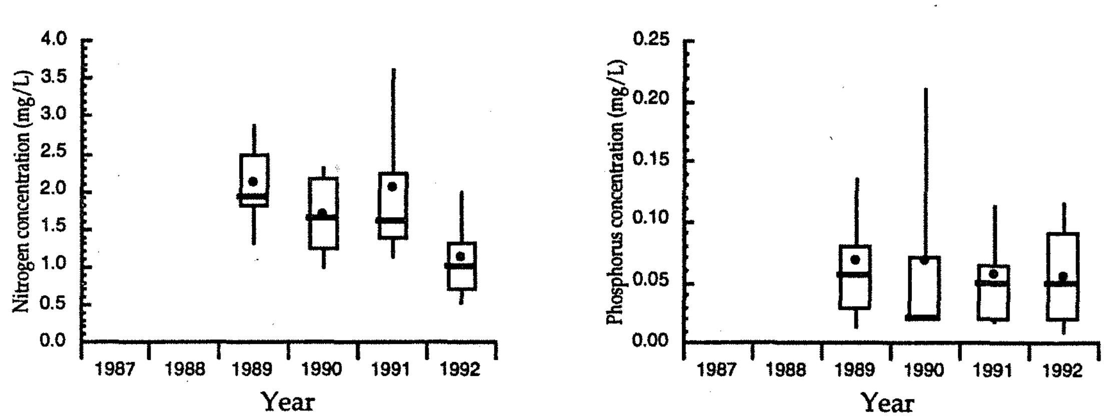


FIGURE 5: Nitrogen and phosphorus concentration in Blackadder Creek, 1989 - 1992.

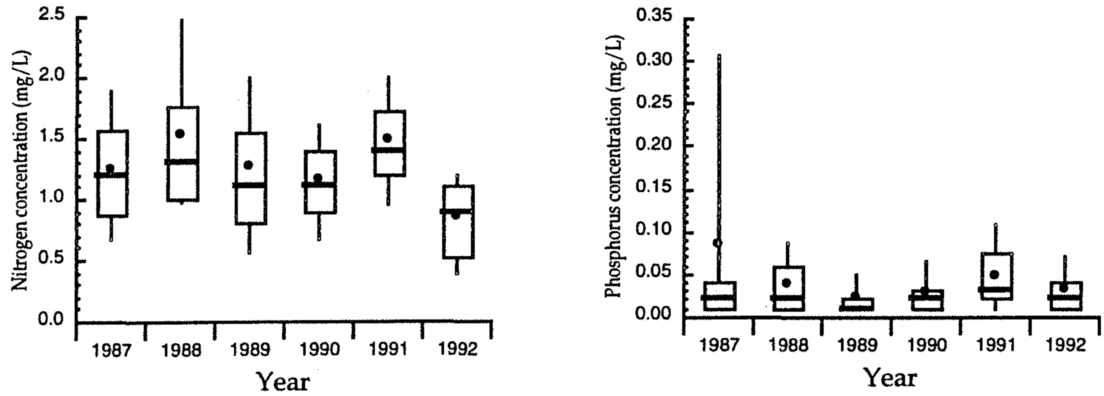


FIGURE 6: Nitrogen and phosphorus concentration in the Canning River, 1987 - 1992.

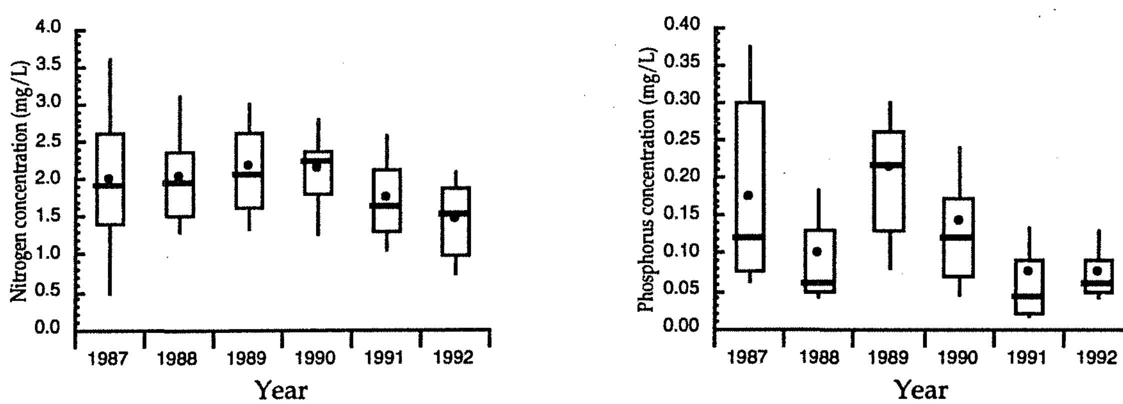


FIGURE 7: Nitrogen and phosphorus concentration in the Claisebrook main drain, 1987 - 1992.

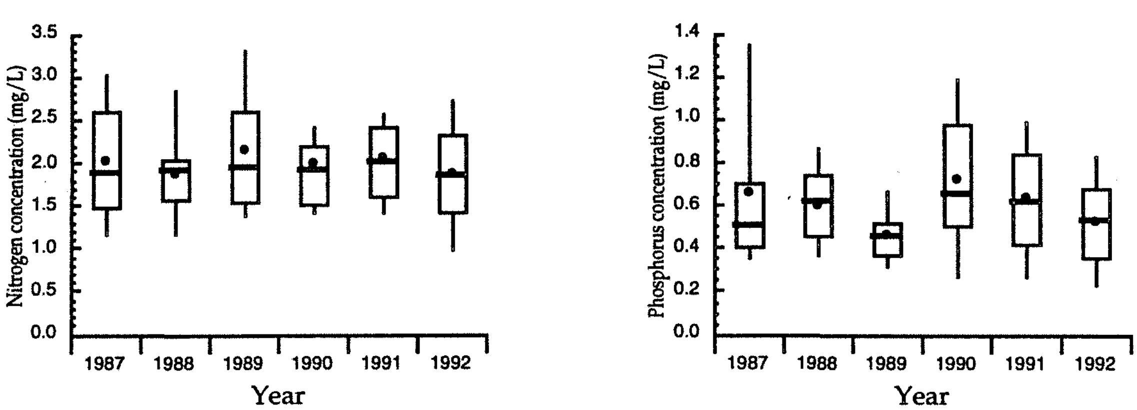


FIGURE 8: Nitrogen and phosphorus concentration in Ellen Brook, 1987 - 1992.

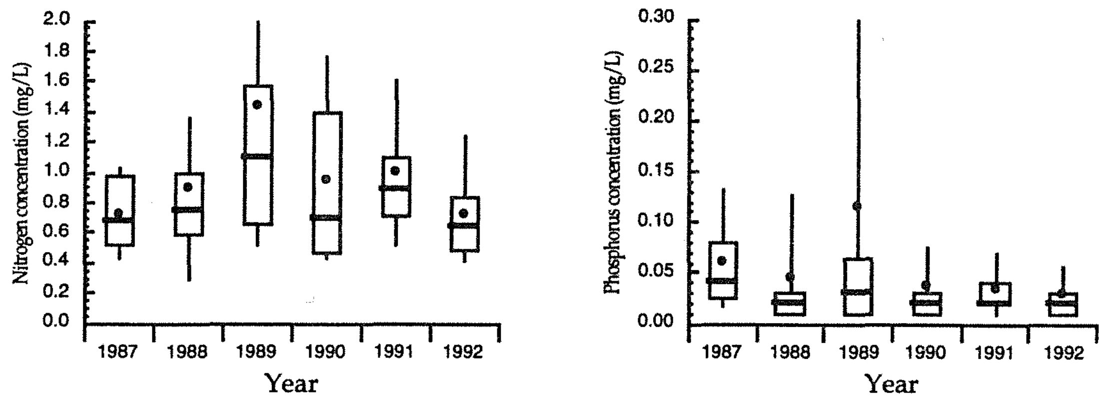


FIGURE 9: Nitrogen and phosphorus concentration in the Helena River, 1987 - 1992.

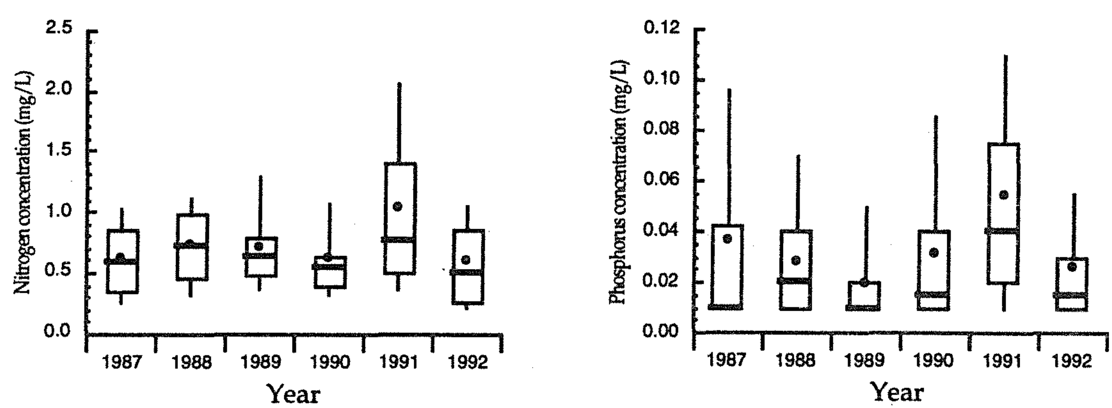


FIGURE 10: Nitrogen and phosphorus concentration in Jane Brook, 1987 - 1992.

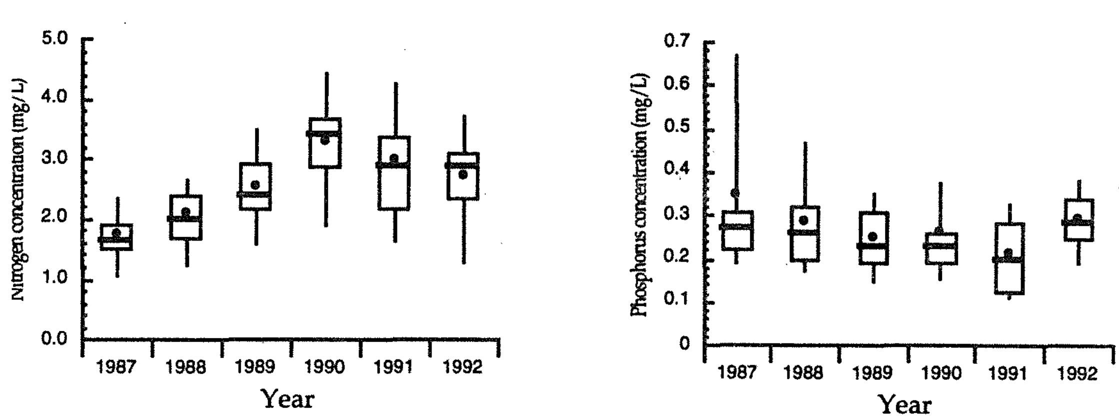


FIGURE 11: Nitrogen and phosphorus concentration in the Mills Street Main Drain, 1987 - 1992

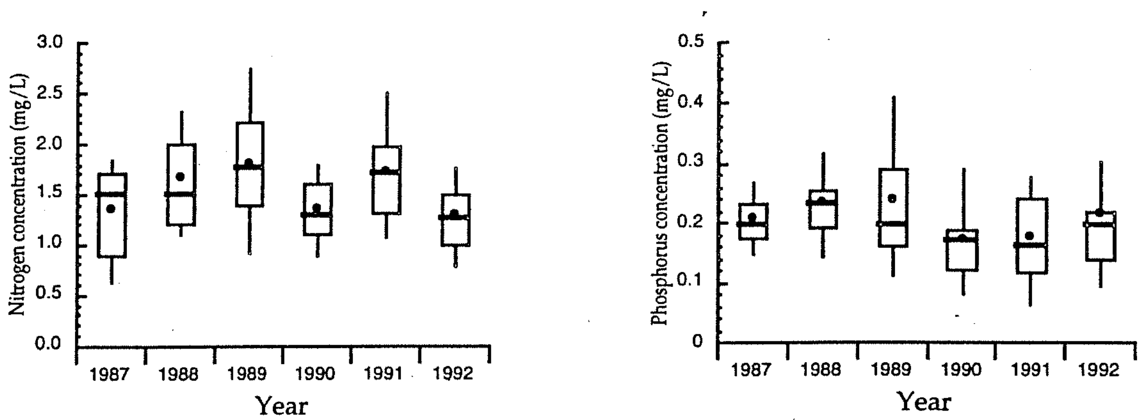


FIGURE 12: Nitrogen and phosphorus concentration in the South Belmont Main Drain, 1987 - 1992.

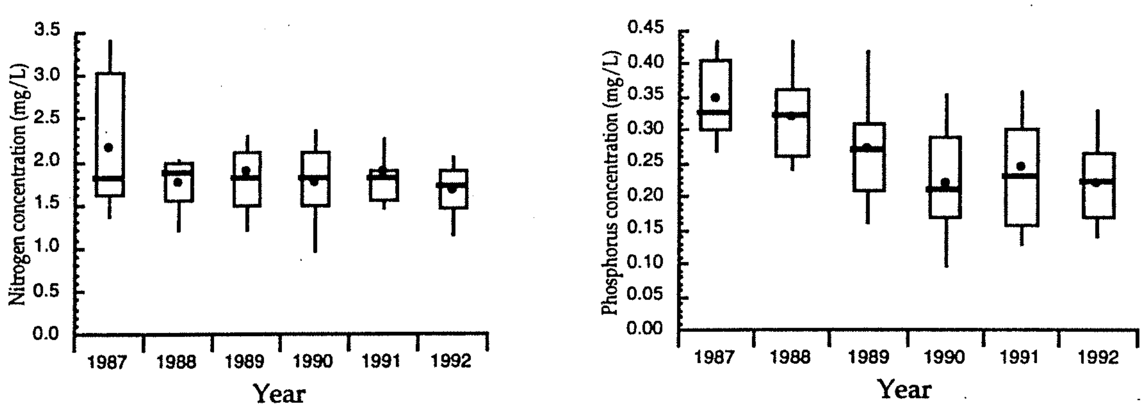


FIGURE 13: Nitrogen and phosphorus concentration in Southern River, 1987 - 1992.

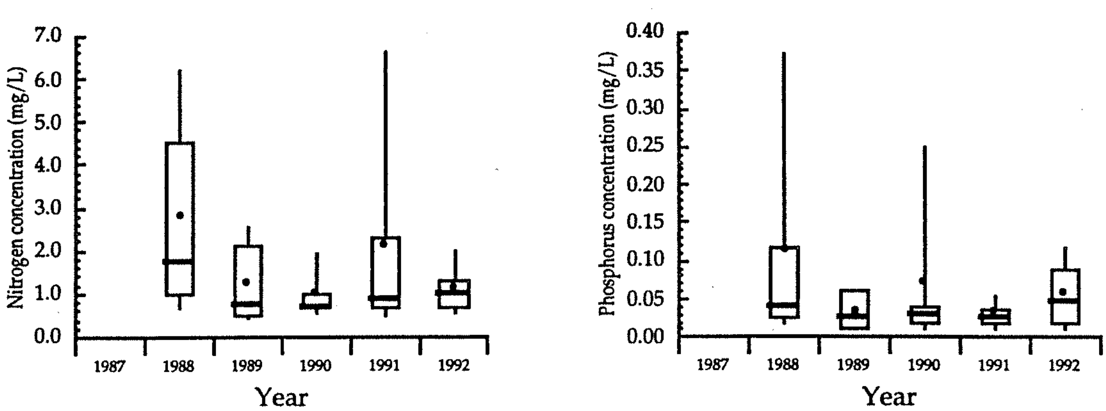


FIGURE 14: Nitrogen and phosphorus concentration in Susannah Brook, 1988 - 1992.

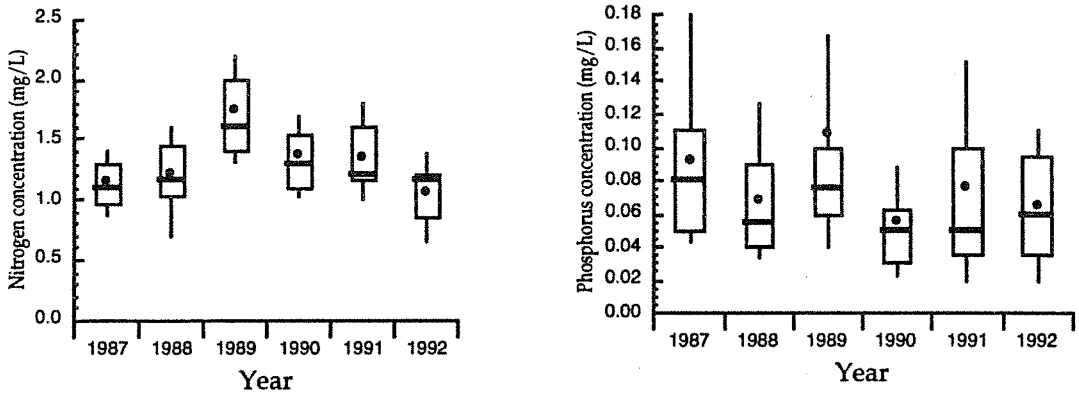


FIGURE 15: Nitrogen and phosphorus concentration in Yule Brook, 1987 - 1992.