Estimated Annual Loads of Nutrients to the Leschenault Estuary, 1984 - 1992

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1. INTRODUCTION

The Leschenault Estuary is of significant environmental and economic value to the south west of Western Australia. The waterway and its surrounds are the hub of recreational activity in the Leschenault region. It has safe protected waters most of which are freely navigable by small pleasure craft. Much of its popularity is due to its quality as a recreational fishing and crabbing area (Thurlow 1990). It contains a diversity of ecologically important habitats including seagrass beds, tidal mud and sand flats, salt marshes, and fringing sedge lands, heathlands and *Melaleuca* forest vegetation, along with their associated biodiversity (Pen 1992; Van de Weile 1987). It also contains small remanent stands of the white mangrove, *Avicennia marina*. The areas of aquatic vegetation and mangroves are nursery areas for fish, many of which are important to the recreational fishing industry (WWC 1990).

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 natural waters.

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, can come to 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 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 (WWC 1989).

1.2. Monitoring for Nutrients

Recognition that problems of eutrophication in the Peel-Harvey and Vasse-Wonnerup estuaries were linked to nutrients coming from the coastal plain, prompted management authorities to begin monitoring in the Leschenault catchment. In 1984, monitoring commenced in four of the major tributaries to the estuary. Every year between 1984 and 1993, weekly grab samples were collected from sites on the Brunswick River, Collie River, Ferguson River and Preston River during the winter wet period. Monitoring of the Wellesley River, a large tributary of the Brunswick River, began during the winter of 1990 (Figure 1).

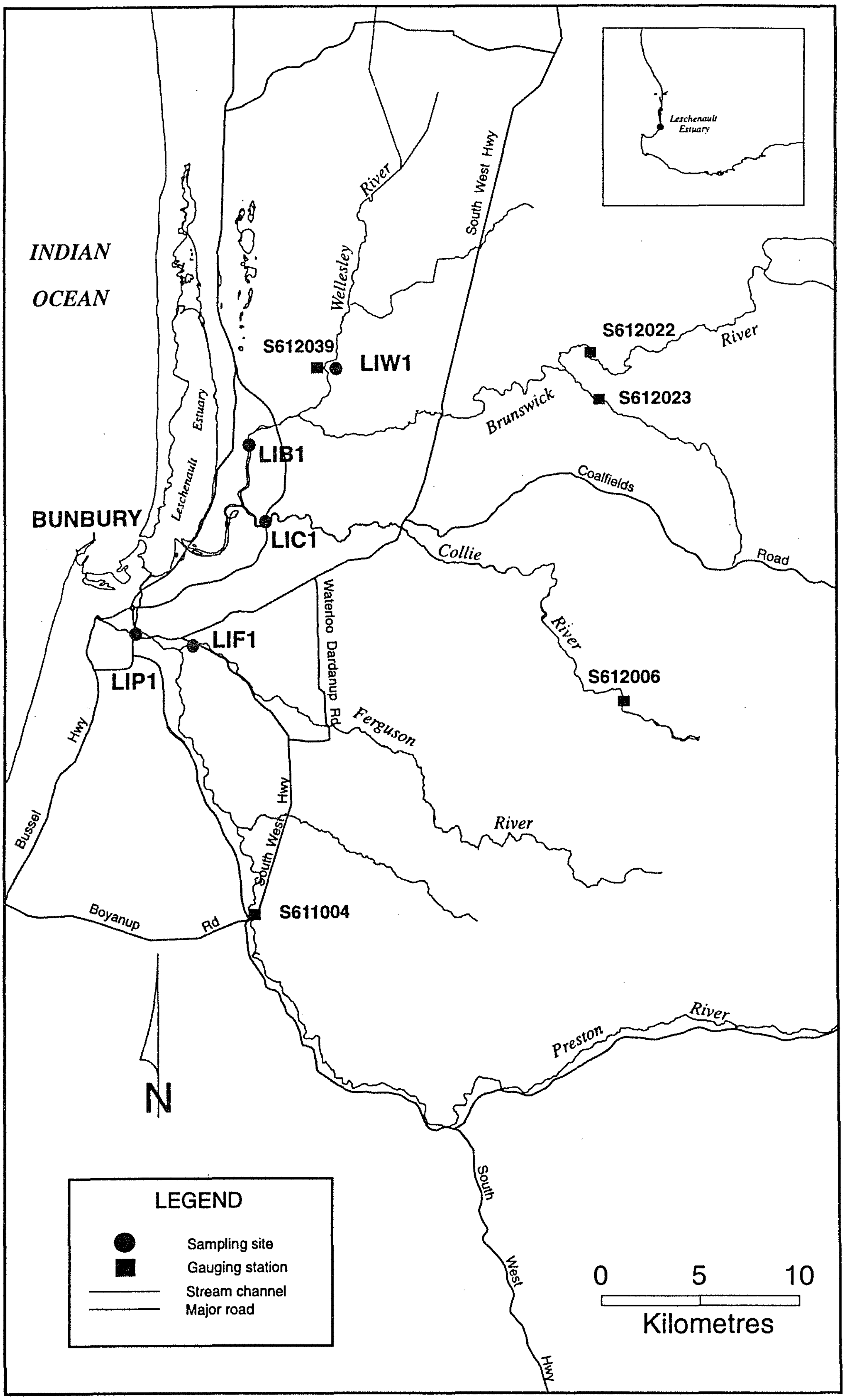

FIGURE 1 : Location of sample sites and flow gauging stations.

Each sample was analysed for ammonium-nitrogen, nitrate-nitrogen, total nitrogen, filterable reactive phosphorus and total phosphorus. Mass loads of nutrients have been shown to be of use in the definition of estuarine trophic status. Therefore, the data from the monitoring program were used to estimate the total annual load of nutrients carried by each of the streams. A mass nutrient load is defined as the total flux of a nutrient that passes a particular point of measurement over the period of interest (Richards and Holloway 1988). The total external load of nutrients to a receiving waterbody is the sum of all inputs from all sources. Annual loads were calculated here as the product of nutrient concentration and stream discharge (details of method are provided in Appendix 1).

This report presents the resulting estimates of mass loading of phosphorus and nitrogen to the Leschenault Estuary between 1984 and 1992. For the purposes of this report, the mass load of nutrients will be termed nutrient 'streamload'. The terms 'stream discharge' and 'streamflow' will be used interchangeably and refer to the total volume of water that passed the sampling point each year.

1.3. Aims of the Monitoring

The primary aims of the nutrient monitoring program were to:

1. estimate the total external load of nutrients to the Leschenault Estuary;
2. identify the major contributing catchments to the total annual load;
3. identify trends, if any, in the levels of nutrients in the monitored streams.

2. CATCHMENT DESCRIPTION

The Leschenault Estuary is a long, narrow interdunal lagoon separated from the sea by a slender peninsula of sand dunes. It is approximately 16 km long and 2.4 km wide, and has a surface area of approximately 25 square kilometres.

Over most of this area the estuary is shallow (about 1.5 metres deep at low water), especially on the eastern shore where extensive areas of sand flats are exposed during low tides. The deepest areas are found around mid-estuary at the southern end, where the estuary is about 3 m deep. The estuary is connected to the ocean by an artificial channel at its southern end (Figure 1).

TABLE 1: Summary statistics on surface drainage for the monitored sub-catchments of the Leschenault Estuary.

Catchment	Area (km^2)	Cleared (km^2)	% Cleared	Drainage length (km)	Drainage density (km/km^2)
Wellesley	210	160	76	537	2.56
Brunswick	262	82	31	322	1.23
Well/Bruns	471	241	51	860	1.82
Collie	254	131	52	398	1.56
Ferguson	167	95	57	270	1.62
Preston	952	517	54	1554	1.63
Whole (+ ungauged)	1981	953	48	3318	1.67

2.1 Surface Hydrology

The natural drainage network of the Leschenault catchment comprises five main drainage systems: the Wellesley, Brunswick, Collie, Preston and Ferguson river systems. The drainage systems converge on the coastal plain, and only the Preston and Collie Rivers discharge into the Leschenault Estuary (Figure 1).

There is a substantial artificial drainage network in the catchment which was constructed to remove water quickly from the low lying and seasonally water logged agricultural areas. The Wellesley River in particular receives runoff from artificial drains in the Harvey area. This network adds significantly to the average density of drainage in that catchment (Table 1).

In 1960, the Collie River was regulated with the construction of the Wellington Dam, which decreased total volumes of freshwater flow to the estuary and shortened the duration of storm flows (Schwinghammer 1982). The reservoir behind the dam now acts as a sink, intercepting and storing nutrients coming from the upper Collie River catchment. Nutrients from the reservoir will be mobilised and move downstream as pulses associated with releases of water from the dam.

2.2 Soils of the Region

The catchment of the Leschenault Estuary spans two main regions, the Swan Coastal Plain and the Darling Plateau to the east. The statistics on soil types, given in Table 2, illustrate the geographic extent of the monitored sub-catchments. The catchment of the Wellesley River for example is confined to the coastal plain and its soil types reflect this restriction. Generally, the rivers that drain the middle and southern regions of the Leschenualt catchments, that is the Collie, Ferguson and Preston River catchments, extend further east onto the plateau and contain a more diverse mosaic of soil types.

The soils on the coastal plain consist of a series of distinct geomorphic elements, the most significant of which is a series of dunes that run more or less parallel to the coast. Nearest to the coast are the Quindalup dunes that separate the estuary from the ocean. These dunes are composed of aeolian calcareous sands and are naturally low in nutrients. Bounding the estuary to the east are the Yoongarillup plains. Directly east of the Yoongarillups is the Karrakatta plain. These two systems are collectively referred to as the Spearwood dune system. The plains consist of low ridges and swales of leached deep yellow podsolic sands overlaying a limestone base.

East of the Spearwood association are the Bassendean sand plains. These soils are deep grey sands formed into broad low dunes with occasional swamps in the swales. They are mainly humic podsols with between 1 and 2 metres of leached sand overlying an organic hard pan. They are naturally poor in nutrients. The Southern River sand plains lie south of the Bassendean and arch inland broadly following the line of the Preston River. The Southern River unit is characterised by peaty podsols commonly with a clay base in the swampy areas.

Between the Bassendean complex and the Darling Scarp are the medium textured deposits of the Guildford plains. These plains run along the eastern fringe of the coastal plain and consist generally of older deposits of alluvial material. The Guildford soils are classified as yellow duplex soils. The Guildford plain is bisected by the valleys of the Collie, Brunswick and Preston Rivers. These river valleys contain alluvial red earths and duplex soils. Further north, alluvial material deposited by the Wellesley River system has formed well developed fans with dark brown loamy soils below the Darling Scarp.

TABLE 2: Soils in the monitored sub-catchments. Shown is the area of each soil in km^2 and the proportion (%) of each soil type in each sub-catchment. *NOTE: The data relate only to the area of the catchments that have been cleared of natural vegetation.*

Soil/Association	Wellesley	Brunswick	Collie	Ferguson	Preston
Bassendean sands	10 (5)	3 (1)	5 (2)	17 (10)	95 (10)
Serpentine sands	63 (30)			8 (5)	
Guildford sands	84 (40)	52 (20)	122 (48)	42 (25)	48 (5)
Scarp	50 (24)	52 (20)	64 (25)	42 (25)	95 (10)
Swan	2 (1)	13 (5)	13 (5)		
Lowdon		131 (50)	38 (15)	42 (25)	571 (60)
Yarragil/Dwellingup		10 (4)	13 (5)		
Cartis				8 (5)	10 (1)
Preston/Dwellingup				8 (5)	105 (11)
Mumballup					29 (3)

2.3 Land Use

Table 3 shows the total area and proportion of each catchment which is exploited for each major category of land use. The catchment on the Swan Coastal Plain has been extensively cleared for agriculture although substantial areas of remnant vegetation remain in the CALM estate, mainly in the upper areas of the Brunswick, Ferguson and Preston River catchments.

The Guildford, Serpentine and Bassendean sand plains have been extensively cleared, drained and planted to pasture, mainly for intensive dairy and beef cattle. This type of land use is largely confined to the coastal plain areas. Significant areas rely on irrigation to maintain production during the dry summer months. Relatively large areas are irrigated in the Wellelsey River catchment in comparison to the other catchments (Table 3).

The alluvial terraces of the Preston River valley support orchards and market gardens with some areas of pasture. Urban and industrial areas are largely confined to the eastern and southern shores of the estuary, in and around the township of Bunbury. To the north of the estuary, market gardens operate in the catchment of the Parkfield Drain. The catchment of the estuary contains a number of possible point sources for nutrients such as refuse disposal sites, factories, waste water treatment plants and stock holding yards.

TABLE 3: Land use in the Leschenault catchment. The table shows the area (km^2) in each of the monitored sub- catchments used for the land use classifications. The figures in brackets show the proportion (%) of the catchment used for each land use.

Land use	Parkfield	Wellesley	Brunswick	Collie	Ferguson	Preston	Total
Grazing	15 (45)	63 (30)	52 (20)	51 (20)	84 (50)	429 (45)	693 (35)
Irrigated	0	94 (45)	26 (10)	64 (25)	17 (10)	0	200 (10)
Market gardens	2 (7)	0	0	0	0	0	2 (0.1)
Orchard	0	0	0	0	0	95 (10)	95 (5)
Urban/Industrial	0	0	3 (1)	3 (1)	0	0	5 (0.2)
Vegetation	15 (47)	52 (25)	181 (69)	137 (54)	67 (40)	429 (45)	881 (42)

3. RESULTS

3.1 Wellesley River

The Wellesley River was monitored for only three years, 1990 to 1992 and the limited length of the data series means that results should be viewed with caution. In the monitoring period, discharge in the Wellesley River averaged 88 million cubic metres ($x10^6$ m^3) per year (Table 4), and varied between a minimum of $56x10^6$ m^3 in 1990 and a maximum of 112 $x10^6$ m^3 in 1991 (Figure 2).

Over the same period, the estimates of phosphorus streamload in the Wellesley averaged 16 tonnes per year (Table 4), and varied between a minimum of 9 tonnes in 1990 and a maximum of about 20 tonnes in both 1991 and 1992 (Figure 2). The FRP streamloads averaged 7 tonnes per year and averaged 44 percent of the total annual loads. They varied between 5 and 12 tonnes, or about 30 and 60 percent of total. The estimates of annual phosphorus flow-weighted concentration averaged 0.18 mg/L and varied little between a minimum of 0.17 mg/L in 1990 to a maximum of 0.20 mg/L in 1992 (Figure 2).

The estimates of nitrogen streamloads averaged 137 tonnes per year, between 1990 and 1992 (Table 5), and varied between 82 tonnes in 1990 and 177 tonnes in 1991 (Figure 2). The inorganic load of nitrogen in the Wellesley River averaged 31 tonnes per year, or 22 percent of the total nitrogen streamloads over the period of monitoring, and varied between 18 and 45 tonnes, or about 20 to 25 percent of total. The annual ammonium-nitrogen streamloads averaged 33 percent of the inorganic load, varying between 25 and 38 percent. The estimates of annual total nitrogen flow-weighted concentration averaged 1.55 mg/L between 1984 and 1992 and varied between 1.46 and 1.59 mg/L.

3.2 Brunswick River

Over the period 1984-92, the estimates of stream discharge in the Brunswick River at the sampling site averaged $281x10^6$ m^3 per year (Table 4), and varied between a minimum of $91x10^6$ m^3 in 1987 and a maximum of $412x10^6$ m^3 the following year (Figure 2). Based on stream gauging in the period 1990 - 1992, between 20 and 30 percent of the flow volume at the Brunswick River sampling site originated from the Wellesley River catchment.

TABLE 4: Average annual loads and concentrations of phosphorus in the monitored streams. The proportional contribution to total external load to the estuary is shown in brackets. The column headed FRP/TP is the average ratio of FRP load to total load expessed as a percentage. The Brunswick River contribution minus that from the Wellesley (1990-92) is presented in the upper part of the table. The bottom part of the table contains data averaged over the period 1984-92.

Sub-catchment	Area (km^2)	Discharge (10^6 m^3)	Filterable Reactive Phosphorus		Total Phosphorus		FRP/TP (%)
			Load (tonnes)	FWC (mg/L)	Load (tonnes)	FWC (mg/L)	
Wellesley River	210	88 (11)	7	0.08	16 (33)	0.18	44
Brunswick River	262	233 (29)	5	0.01	16 (35)	0.07	38
Well/Bruns.	471	281(42)	17	0.05	34 (68)	0.13	48
Collie River	254	214(34)	1.7	0.01	4.4 (11)	0.02	35
Ferguson River	167	29(4.2)	0.9	0.03	2.4 (5)	0.09	34
Preston River	952	136 (19)	2.3	0.02	7.1 (15)	0.06	30

The estimates of phosphorus streamload in this period averaged 34 tonnes per annum in the Brunswick River (Table 4), and varied widely between a 1986 minimum of 15 tonnes and a maximum of 67 tonnes in 1988 (Figure 2). The estimates of annual FRP streamloads averaged 17 tonnes per year which was about 48 percent of the total phosphorus streamloads. The loads of FRP varied between 4 and 37 tonnes, or between 30 and 80 percent of the total load estimates. The estimates of total phosphorus flow-weighted concentration averaged 0.13 mg/L over the monitoring period, and varied between 0.07 and 0.21 mg/L.

Streamload estimates of total nitrogen varied between 95 tonnes in 1987 and 435 tonnes in 1991 (Figure 2), and averaged 280 tonnes per year over the period (Table 5). The estimates of annual inorganic nitrogen loads ranged between 29 and 211 tonnes per year and averaged 86 tonnes per year. The inorganic loads were between about 30 and 50 percent of the total nitrogen loads and averaged 33 percent over the monitoring period. The ammonium-nitrogen loads ranged between 15 and 35 percent of the inorganic loads in averaging 25 percent over the period. The estimates of total nitrogen flow-weighted concentration varied randomly between 0.82 and 1.17 mg/L, and averaged 0.99 mg/L (Figure 2).

3.3 Collie River

In the period 1984-92, the estimates of discharge in the Collie River averaged 214×10^6 m^3 per year at the sampling site (Table 4), and varied between a minimum of 91×10^6 m^3 in 1987 and a maximum of 327×10^6 m^3 in 1991 (Figure 2).

The estimates of phosphorus streamload in this period averaged 4.4 tonnes per annum (Table 4), and varied widely between a minimum of 1.5 tonnes in 1987 and a maximum of 9.3 tonnes in 1991 (Figure 2). The estimates of annual FRP streamloads averaged 1.7 tonnes per year, or about 35 percent of the total phosphorus streamloads. The loads of FRP varied between 0.4 and 3.4 tonnes, or over a wide range between 14 and 70 percent of the total load estimates. The estimates of total phosphorus flow-weighted concentration averaged 0.02 mg/L over the monitoring period, and varied little between 0.02 and 0.05 mg/L.

The estimates of total nitrogen streamload varied between 28 tonnes in 1987 and 221 tonnes in 1991 (Figure 2), and averaged 116 tonnes per year over the period (Table 5). The estimates of annual inorganic nitrogen load ranged between 9 and 87 tonnes per year and averaged 44 tonnes per year.

The inorganic loads were between about 30 and 60 percent of the total nitrogen loads and averaged 40 percent over the monitoring period. The ammonium-nitrogen loads ranged between 10 and 30 percent of the inorganic loads in averaging 20 percent over the period. The estimates of total nitrogen flow-weighted concentration varied between 0.31 and 0.73 mg/L, and averaged 0.50 mg/L over the period of monitoring.

3.4 Ferguson River

Between 1984 and 1992, discharge in the Ferguson River averaged an estimated 29 Mm^3 per year at the sampling site (Table 4), and varied between a minimum of 8 Mm^3 in 1987 and a maximum of 42 Mm^3 in 1991 (Figure 2).

Annual phosphorus streamload estimates averaged 2.4 tonnes per annum in the Ferguson River (Table 4), and varied randomly over the monitoring period between a minimum of 1.1 tonnes in 1987 and a maximum of 3.7 tonnes in 1992 (Figure 2). The estimates of annual FRP streamloads averaged 0.9 tonnes per year, or about 34 percent of the total phosphorus streamloads. Annual FRP streamloads varied between 0.2 and 1.5 tonnes, between about 20 and 50 percent of the total load estimates. The estimates of total phosphorus flow-weighted concentration averaged 0.09 in the Ferguson River over the monitoring period, and were relatively variable ranging between 0.06 and 0.14 mg/L.

The estimates of total nitrogen streamload in the Ferguson River varied between 8 tonnes in 1987 and 74 tonnes in 1991 (Figure 2), and averaged 43 tonnes per year (Table 5). The estimates of annual inorganic nitrogen load ranged between 4 and 37 tonnes per year and averaged 20 tonnes per year over the period of monitoring.

The estimates of inorganic nitrogen loads were between about 40 and 75 percent of the total nitrogen loads and averaged 52 percent of total loads over the monitoring period. The ammonium-nitrogen loads ranged mostly between 6 and 30 percent of the inorganic loads and averaged 13 percent over the period. In 1987, the estimated ammonium-nitrogen streamload was relatively high at nearly 30 percent of the inorganic load. The estimates of total nitrogen flow-weighted concentration varied little between a minimum of 1.0 mg/L and 1.8 mg/L, and averaged 1.4 mg/L over the period of monitoring.

3.5 Preston River

In the 9 years of gauging 1984-92, the estimates of discharge in the Preston River at the sampling site averaged 136×10^6 m^3 per year (Table 4), and varied between a minimum of 38×10^6 m^3 in 1987 and a maximum of 206×10^6 m^3 in 1988 (Figure 2).

The estimates of phosphorus streamload averaged 7 tonnes per annum in the period (Table 4), and varied widely between a minimum of 3 tonnes in 1987 and a maximum of 12 tonnes in 1991 (Figure 2). The estimates of annual FRP streamloads averaged 2.3 tonnes per year, or about 30 percent of the total phosphorus streamloads. The loads of FRP in the Preston River varied between 0.3 and 3.9 tonnes, or between 10 and 45 percent of the estimated total nitrogen load. The estimates of total phosphorus flow-weighted concentration averaged 0.06 mg/L in the Preston River over the monitoring period, and varied little between 0.03 and 0.10 mg/L.

The estimates of total nitrogen streamload varied between 42 tonnes in 1986 and 311 tonnes in 1991 (Figure 2), and averaged 207 tonnes per year over the monitoring period (Table 5). The estimates of annual inorganic nitrogen load ranged between 18 and 326 tonnes per year and averaged 110 tonnes. The inorganic loads were between about 40 and 80 percent of the total nitrogen loads and averaged 60 percent over the monitoring period. The ammonium-nitrogen loads ranged between 3 and 25 percent of the inorganic loads in averaging 12 percent over the period. The estimates of total nitrogen flow-weighted concentration varied randomly between 0.94 and 2.00 mg/L, and averaged 1.43 mg/L over the 9 years of monitoring.

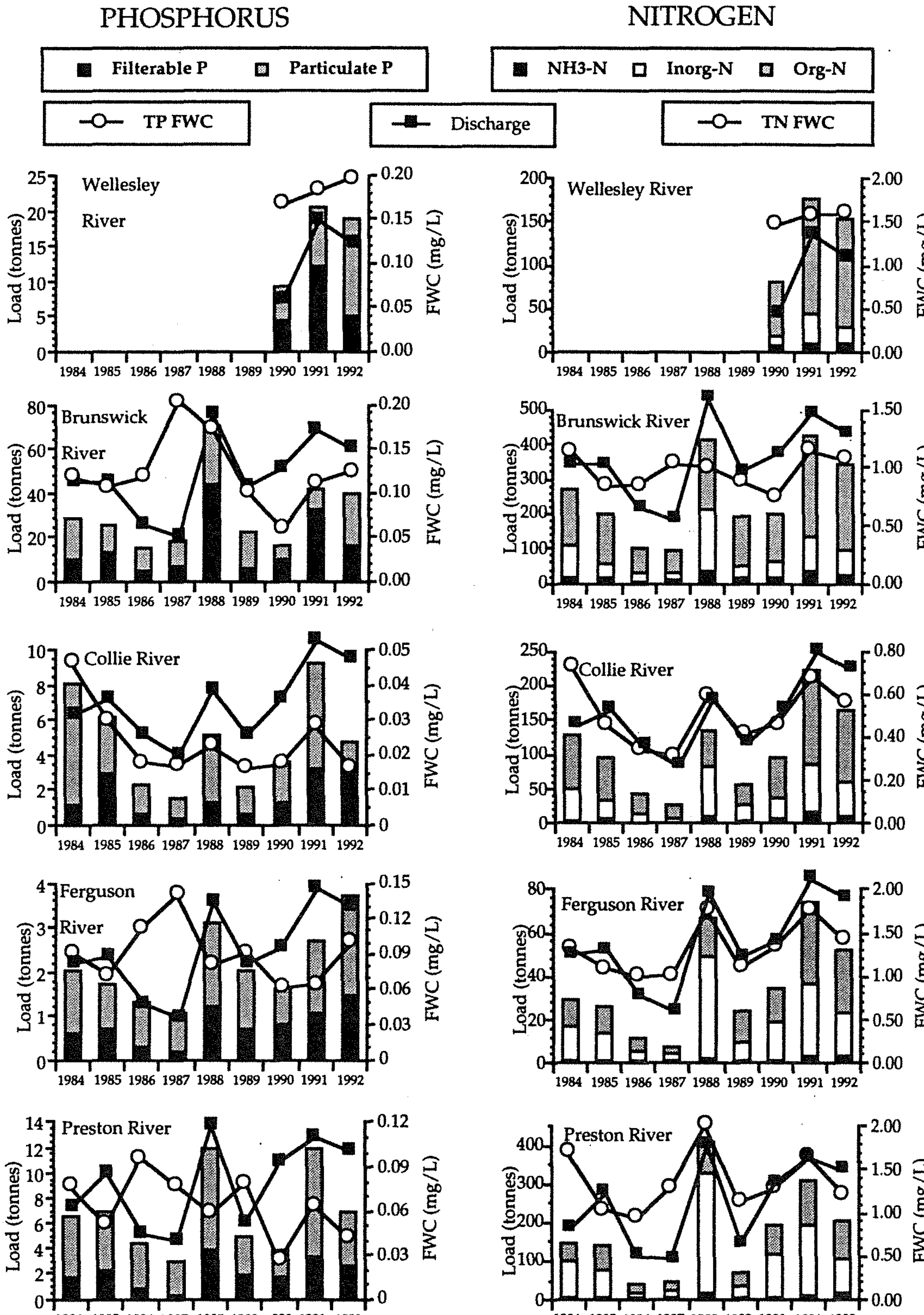

FIGURE 2: Estimated annual loads of nitrogen and phosphorus in the monitored streams. *NOTE: the plot showing stream discharge has no reference scale and is provided only to show relative differences in streamflow between years.*

TABLE 5: Average annual loads and FWCs of ammonium-nitrogen, nitrate-nitrogen and total nitrogen for each of the monitored waterways. The bracketed figures are the percentage contribution of each site to the estimated total external load of nitrogen to the estuary. The caption to Table 4 contains further explanations of the table format.

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)		
Wellesley River	10	0.11	21	0.23	137 (16)	1.55	22	33
Brunswick River	15	0.05	51	0.24	218 (26)	0.92	30	22
Well/Bruns.	23	0.09	77	0.25	280 (39)	0.99	33	25
Collie River	9.2	0.04	41	0.17	116 (17)	0.50	40	20
Ferguson River	2.5	0.09	21	0.65	43 (6)	1.40	52	13
Preston River	12	0.10	123	0.78	207 (26)	1.43	57	12

3.6 Total External Load of Nutrients to the Estuary

It was estimated that in the period 1984 to 1992 an average of 624×10^6 m^3 of fresh water was discharged to the Leschenault Estuary by the Collie and Preston Rivers per year (Appendix 2, Table 6). The estimates of total discharge to the estuary varied between years from a minimum of 248×10^6 m^3 in 1987 to a maximum of 957×10^6 m^3 in 1991 (Figure 3). About 40 percent of inflows originated from the Brunswick River catchment (Table 4). The gauging between 1990 and 1992 showed that about 10 percent of flow comes from the catchment of the Wellesley River and about 30 percent from the Brunswick River arm of the system. The catchment of the Collie River supplied about 35 percent of the total inputs, the Ferguson River catchment about 4 percent and the Preston River catchment about 20 percent.

The estimates of total external loading of the estuary with phosphorus averaged 51 tonnes per year in the monitoring period (Figure 3). External loading estimates varied between a minimum of 28 tonnes in 1986 and a maximum of 94 tonnes in 1988. Of the total external phosphorus load, nearly 70 percent was contributed by the Brunswick River (Table 4). It was estimated that in the period 1990 and 1992, the Wellesley and Brunswick River arms of the catchment each contributed about 35 percent of the total external loading to the estuary (see Figure 1). In the monitoring period the Collie River supplied an average of about 10 percent of the external load of phosphorus to the estuary, the Ferguson River contributed 5 percent and the Preston River 15 percent.

The estimates of annual external loading of the estuary with nitrogen averaged 610 tonnes per year (Figure 3). External nitrogen loading varied between a minimum of 215 tonnes in 1987 and a maximum of 1090 tonnes in 1991 (Figure 3). Of the total external nitrogen load, nearly 46 percent was contributed by the Brunswick River. In the period 1990 to 1992, the Wellesley River contributed 17 percent of the external load to the estuary and the Brunswick supplied 25 percent. The Collie River contributed an average of about 20 percent of the external load of nitrogen to the estuary, the Ferguson River about 6 percent and the Preston River about 30 percent.

The flow-weighted average concentration of phosphorus in inflows to the estuary, estimated across the monitored streams, averaged 0.08 mg/L and varied between a minimum of 0.05 mg/L in 1990 and a maximum of 0.12 mg/L in 1987. The flow-weighted average concentration of nitrogen in the inflows, estimated across the streams, averaged 0.94 mg/L, and varied between a minimum of 0.73 mg/L in 1986 and a maximum of 1.16 mg/L in 1988.

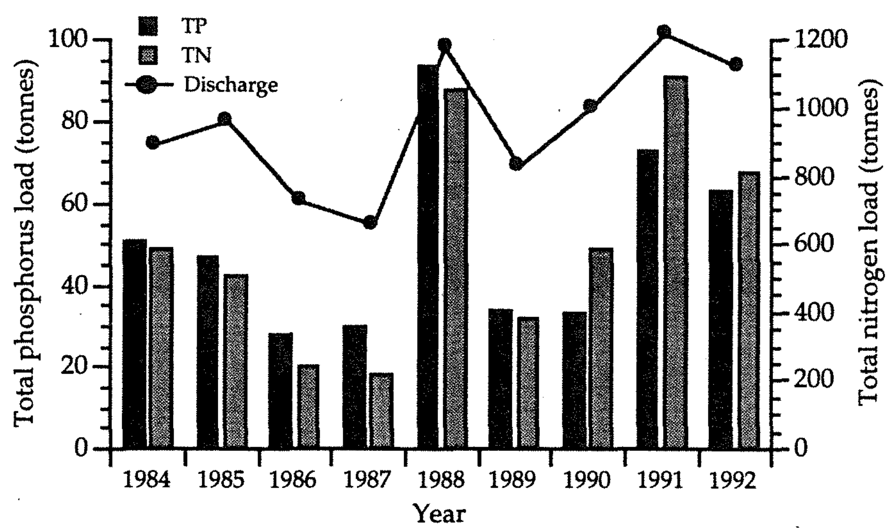

FIGURE 3: Estimated total external load of nitrogen and phosphorus discharged to the Leschenault Estuary in each year of monitoring.

4. 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 ground water 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 Leschenault system from 1984 to 1992. However, bias and imprecision were probably also 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 of monitoring in Section 4.1.

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 1982, 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 concentration in streams varies 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 in dissolved and particulate forms from the catchment (Sharply *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 part of the annual nutrient flux is not sampled and the resulting estimate of streamload significantly under estimates 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 vary 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, or 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 erodability and nutrient status of the soil. 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 based on fixed-interval sampling have been shown to be substantial. For example, when relatively infrequent sampling has been used, the reported levels of bias in estimates of phosphorus streamload vary between 20 and 1000 percent. Bias in the streamload estimates presented here is not known but they are almost certainly underestimated and imprecise over time. Overestimates can occur with fixed-interval sampling, but are less common than underestimates and tend to be smaller.

4.1 Phosphorus Loads

In the Leschenault catchment, much of the diffuse source phosphorus (and nitrogen) will come from animal wastes and that applied originally as fertiliser. There are two main modes of transportation of nutrients from catchments to surface water — overland in runoff and as dissolved fractions in shallow ground waters, or interflow.

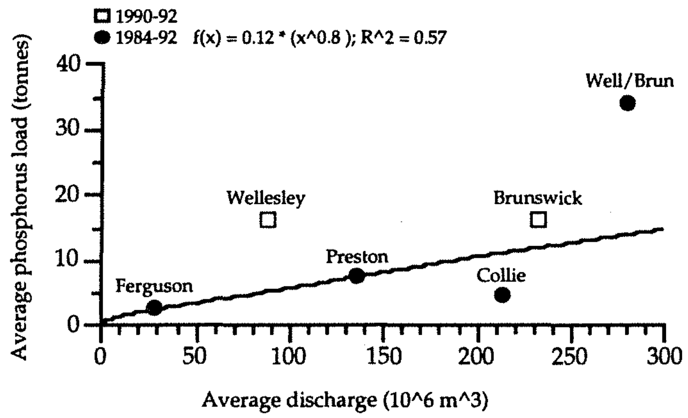

FIGURE 4: Average annual load of phosphorus plotted against average annual stream discharge. *The line is a power fit against data collected between 1984 and 1992. It is provided only as a reference for comparison and is not intended to imply process .*

Dissolved nutrients (mainly orthophosphate, ammonia and nitrate) contained in shallow ground waters contribute significantly to the concentration of nutrients in streams during low to medium flow conditions (Marston 1989). Since the fixed-interval sampling regime concentrated sampling in these flows, the phosphorus and nitrogen loads in streams of the Leschenault probably reflect differences in nutrients contained in shallow ground waters and stored in soils, more than differences in fertilisers applied during the current year (Ruprecht and George 1993).

The estimates of phosphorus streamload varied widely between the monitored sub-catchments. The highest average phosphorus streamloads were found at the Brunswick River site, which averaged about 35 tonnes per year over the monitoring period, or nearly 70 percent of the estimated external load to the estuary. The Collie, Ferguson and Preston Rivers carried less than half the average streamloads of the Wellesley and Brunswick Rivers (Table 4). The patterns of variation in the filterable phosphorus streamloads were similar to those found in the total phosphorus loads (Figure 2). There was little difference in the proportion of filterable phosphorus to total between the streams, with between 30 and 45 percent of the total phosphorus loads in streams of the Leschenault being filterable (Table 4). The proportion of filterable phosphorus has probably been overestimated because the particulate fractions during storms were not sampled (Ongley 1982).

Nutrient streamloads are a function of discharge and in-stream concentration. Some of the observed variation in streamloads between streams was explained by differences in streamflow (Figure 4). However, the scatter in the plot reflects the differences in phosphorus concentration between streams. For example, the estimates of streamload in the Brunswick River were higher than expected based on differences in average streamflow volume. About half of the phosphorus measured at the Brunswick River site originated from the Wellesley River (Figure 1), according to the data collected between 1990 and 1992 (Table 4). When the loads at the Brunswick site were corrected for the Wellesley contribution, they became closer to those suggested by streamflow volume alone (Figure 4).

The phosphorus loads in the Wellesley River were high relative to its average streamflow volume (Figure 4). The Wellesley River, which contributed only 10 percent of the streamflow volume to the estuary, carried nearly 35 percent of the total phosphorus load, or about 16 tonnes per year on average (Table 4). The high loads were due to the high concentration of phosphorus in the river. The average phosphorus flow-weighted concentration in the Wellesley was about 0.2 mg/L, while in each of the other monitored streams it was less than 0.1 mg/L on average (Table 4). In every year, the Collie River contained very low concentrations of phosphorus, averaging about 0.02 mg/L and had correspondingly small total annual streamloads. The reason for the low phosphorus levels in the Collie River were not known but the Wellington Dam reservoir would be intercepting and storing some nutrients.

At each site, the variation in the phosphorus load estimates between years was high with little indication of trend (Figure 2). The flow-weighted concentration of phosphorus also varied at all sites with no sign of trend. Between 60 and 80 percent of the variation in the estimates of phosphorus streamload were determined by annual streamflow (Figure 5). Large estimates of streamload generally coincided with high discharge years. However, the scatter suggests that factors other than discharge were important determinants of annual load, primarily changes in the concentration of phosphorus between years. Bias in the estimates of load was probably also an important variable responsible for the observed temporal patterns.

There is a combination of factors that could explain the high phosphorus concentrations in the Wellesley River. Over 75 percent of the Wellesley catchment has been cleared of natural vegetation compared to an average of about 50 percent cleared in the other catchments. Most of this area is used for the grazing of dairy and beef cattle. Nearly 45 percent of the area relies on irrigation during the dry summer period, compared to between 10 and 20 percent in the other catchments. Therefore, the average soil moisture levels in the Wellesley were probably higher than in the other catchments. The degree to which nutrients in groundwater influence stream concentrations depends on the rate of inflow. This increases with increasing drainage density and soil moisture (Ruprecht and George 1993; Birch 1985). The catchment of the Wellesley River has nearly twice the drainage density of the other sub-catchments (Table 1).

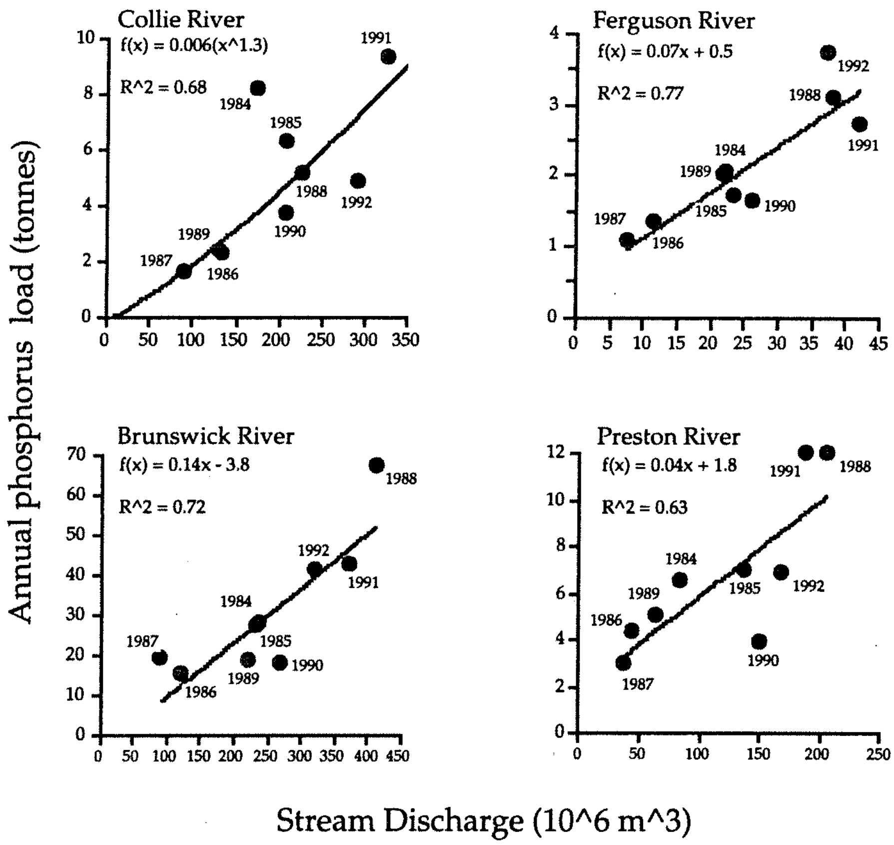

FIGURE 5: Estimates of annual phosphorus streamload plotted against annual total stream discharge. *The line plots are for reference only and are not intended to model process relationships between discharge and phosphorus load.*

It has been estimated that 90 percent of the phosphorus lost to the Peel-Harvey Estuary comes from the coastal plain, mainly through the leaching of fertilisers applied to the grey sands of the Bassendean complexes. Table 2 shows that almost all of the Wellesley River catchment lies on the coastal plain. Essentially it contains only the Bassendean and Serpentine sands and the deposits of the Guildford associations to the east. About 35 percent of the cleared area in the catchment lies on the poor sands of the Bassendean and Serpentine soil complexes compared to less than 15 percent in the other catchments.

4.2 Nitrogen Loads

Most nitrogen in catchments is present as organic nitrogen. Organic nitrogen is relatively immobile and is probably only lost to surface drainage in runoff associated with intense storms. Nitrogen is leached from catchments mainly as inorganic nitrogen which comes from the breakdown, or mineralisation, of organic nitrogen, and from applied inorganic fertilisers, mainly ammonia and nitrate. The most mobile and readily leached form of nitrogen is nitrate, which is highly soluble (Khanna 1981; Marston 1989). Like orthophosphate concentrations, nitrate in sub-surface seepage probably determines the concentration of nitrogen in streams during low to medium flow conditions when the majority of samples were collected (Marston 1989).

The estimates of annual nitrogen streamload varied widely between the streams and over time between 1984 and 1992, with the larger streams tending to carry greater loads (Figure 6). Streamloads in the Leschenault catchment ranged from over 200 tonnes per year in the Brunswick and the Preston Rivers on average, to 45 tonnes in the Ferguson River. The Brunswick and the Preston Rivers supplied nearly 65 percent of the nitrogen discharged to the Leschenault Estuary. Between 1990 and 1992, the Wellesley River contributed about 40 percent of the nitrogen measured at the Brunswick River. The estimates of nitrogen streamload in the Collie River were low relative to its size (Figure 6). The small loads in the Collie occurred because it contained low concentrations of nitrogen, only 0.50 mg/L per year on average (Table 5).

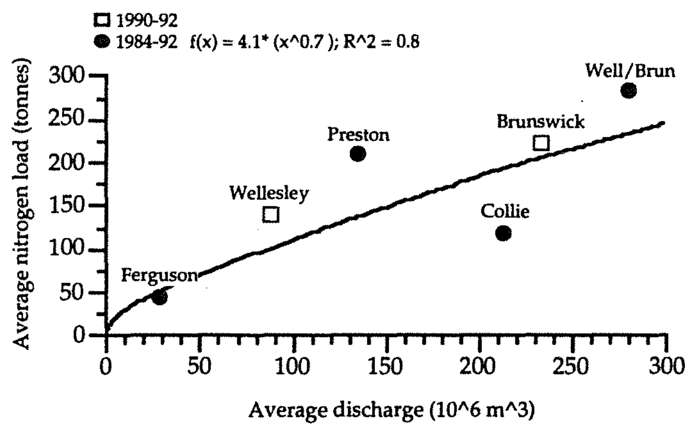

FIGURE 6: Average annual load of nitrogen plotted against average stream discharge. The line is a power curve fitted against data collected between 1984 and 1992.

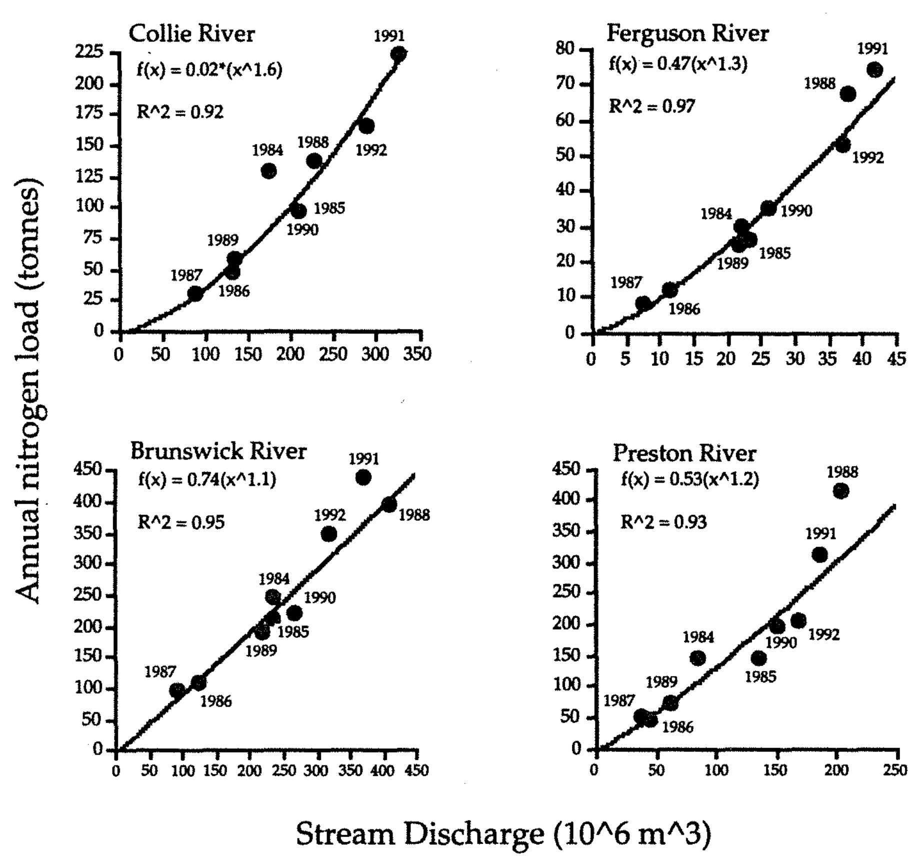

FIGURE 7: Estimates of annual nitrogen streamload plotted against annual total stream discharge. For each site, a power function provided the best fit to the relationship between annual stream discharge and annual nitrogen load.

At all sites, variation in the estimates of nitrogen streamload between years was high. There was no sign of a trend at any of the sampling sites (Figure 2). The estimates of nitrogen streamload were closely related to changes in stream discharge between years (Figure 7). High estimates of streamload occurred in years in which there was a high annual discharge. The close dependence of load on annual streamflow was due to the overwhelming influence of discharge in the equation. It also reflects the relative stability of nitrogen concentration in the low to medium flow periods in which most samples were collected. There was no observed trend in the estimates of nitrogen flow-weighted concentration at any of the sites (Figure 2).

There were differences in nitrogen concentration between the monitored streams. The estimates of annual flow-weighted concentration ranged between 0.5 mg/L in the Collie River and 1.5 mg/L in the Wellesley River. However, the variation was small compared to the variation in phosphorus concentrations. This reflects the fact that phosphorus remains in the system whereas nitrogen can be lost to the atmosphere. Soil conditions in the grey sands of the coastal plain are thought to be ideal for denitrification (Gerritse, RG and Adeney, JA 1992). Presumedly therefore, a proportion of the nitrogen applied to the surface of the catchments is lost. If these are significant, denitrification will act as an mechanism of equilibrium between catchments, and result in the relatively low levels of variation in nitrogen concentrations between catchments in the Leschenault.

About 80 percent of the nitrogen in the Wellesley River was organic compared to only about 40 to 50 percent in the Ferguson and Preston Rivers (Figure 2). The high organic component in the Wellesley River may have been due to the greater uptake, or immobilisation, of nitrate by phytoplankton and attached algae than was the case in the other streams. The concentration of phosphorus was relatively high in the Wellesley River compared to the other monitored streams and may have promoted greater productivity and uptake of nitrate by plants (Table 4). In addition, the Wellesley River sampling site was not far downstream of a dairy and the input of animal wastes may have elevated the organic component. The ammonium-nitrogen load in the Wellesley was a relatively large component of the inorganic fraction (Table 5), which also suggests the presence of an organic source of nitrogen near the Wellesley sample site (Marston 1989; Khanna 1981).

In all years, the inorganic loads in the Ferguson and Preston Rivers were similar to the other streams. The inorganic loads were comprised mostly of nitrate-nitrogen (Figure 2). The flood plains of the Ferguson and Preston Rivers support a high number of orchards and market gardens compared to the other catchments. These activities have a large demand for nitrogenous fertilisers. Since nitrogen applied as fertiliser is easily leached as nitrate (Khanna 1981) this would explain the large nitrate loads in these streams. The fixed-interval sampling would emphasise this difference. The reasons for the low concentrations of nitrogen in the Collie are not known, however the regulated nature of the river may have been a contributing factor.

5. CONCLUSIONS

Generally, the levels of nutrients in streams of the Leschenault Estuary catchment were low when compared to other monitored catchments in the south west of WA. Of the five monitored streams, the Wellesley River contained the highest concentrations of both phosphorus and nitrogen, and the Collie River contained the lowest. The monitoring indicated that the Wellesley, Ferguson and Preston Rivers contained moderately high concentrations of nitrogen. The higher levels of phosphorus in the Wellesley River were related to differences in the intensity and nature of land uses in the catchment. It has a larger area cleared of native vegetation, a high density of surface drainage and a large area is irrigated. These factors, combined with the catchment's poor soils, could have resulted in the higher levels of nutrients in the surface drainage of the Wellesley River catchment. Management authorities need to be aware that there is evidence of enrichment with phosphorus in the system, especially in the Wellesley River.

Between 1984 and 1992, the estimates of nutrient flow-weighted concentration showed that the levels of nutrients in the streams have not changed over this period. However, imprecision in the estimates may have masked possible changes. Nevertheless, relative stability of nutrient levels in the streams could be expected given the lack of catchment-wide changes in land management practices. The probability exists also that the sampling regime was unable to detect differences in applied nutrients in the current year, and was in effect reflecting nutrients stored in the catchment's soils.

Currently, in the Leschenault Estuary, a high proportion of the total macrophyte biomass is a healthy mix of seagrass (> 30 % on average) and macroalgae. To date, there have been no problems with excessive macrophyte accumulations in these areas. On the whole, the structure of the macrophyte communities is consistent with the view that the water quality in the Leschenault Estuary itself is good, especially in comparison to the Peel-Harvey and Swan-Canning Estuaries (Lukatelich 1989).

The less flushed northern sections of the estuary are slightly more productive than the lower sections, and support a larger mass of algae, which is a mixture of brown and green algae (Lukatelich 1989; Van de Weile 1987). The biomass and distribution of macroalgae in these sections of the estuary have been shown to be variable from year to year. These fluctuations have led to concerns that the estuary may be beginning to respond to greater levels of nutrients. There have also been some biological indications of eutrophication in the estuarine reaches of the Collie River. These have included large summer blooms of dinoflagellates (red tides) and diatoms (Hosja and Deeley 1994). Monitoring in the catchment over the last decade suggests that the relatively high export of nutrients from the Wellesley River catchment may be a contributing factor.

Studies show that the fixed-interval regime of sampling used during this monitoring program was inappropriate for the estimation of accurate and precise estimates of total annual nutrient flux. Sampling effort was concentrated in the periods of low to medium flows. Streamloads probably reflect therefore nutrients in sub-surface water and streamloads carried in low to medium flows and the streamloads were probably significant underestimations of the actual annual loads. Because the errors are systematic the long-term average estimates of external load will continue to underestimate the true load regardless of the length of record.

It is apparent from the literature that the 'dissolved' fractions of phosphorus and nitrogen contain less bias than the total nutrient loads. Therefore the filterable components of phosphorus and the inorganic fractions of nitrogen are probably overestimated as a fraction of total.

The utility of estimates of mass streamloads to management is determined by the ability of monitoring programs to discern differences in nutrient export between catchments and between years. Although the estimates of streamload are of low quality they have identified the major contributing catchments to the estuary. However, in terms of identifying trends in loads they need to be viewed with caution. For the design of appropriate monitoring regimes it is critical that the system is initially sampled intensively so an efficient sampling regime can be designed, probable errors assessed and means by which bias can be controlled developed (Richards and Holloway 1987). This will involve a regime based on sampling during storm events.

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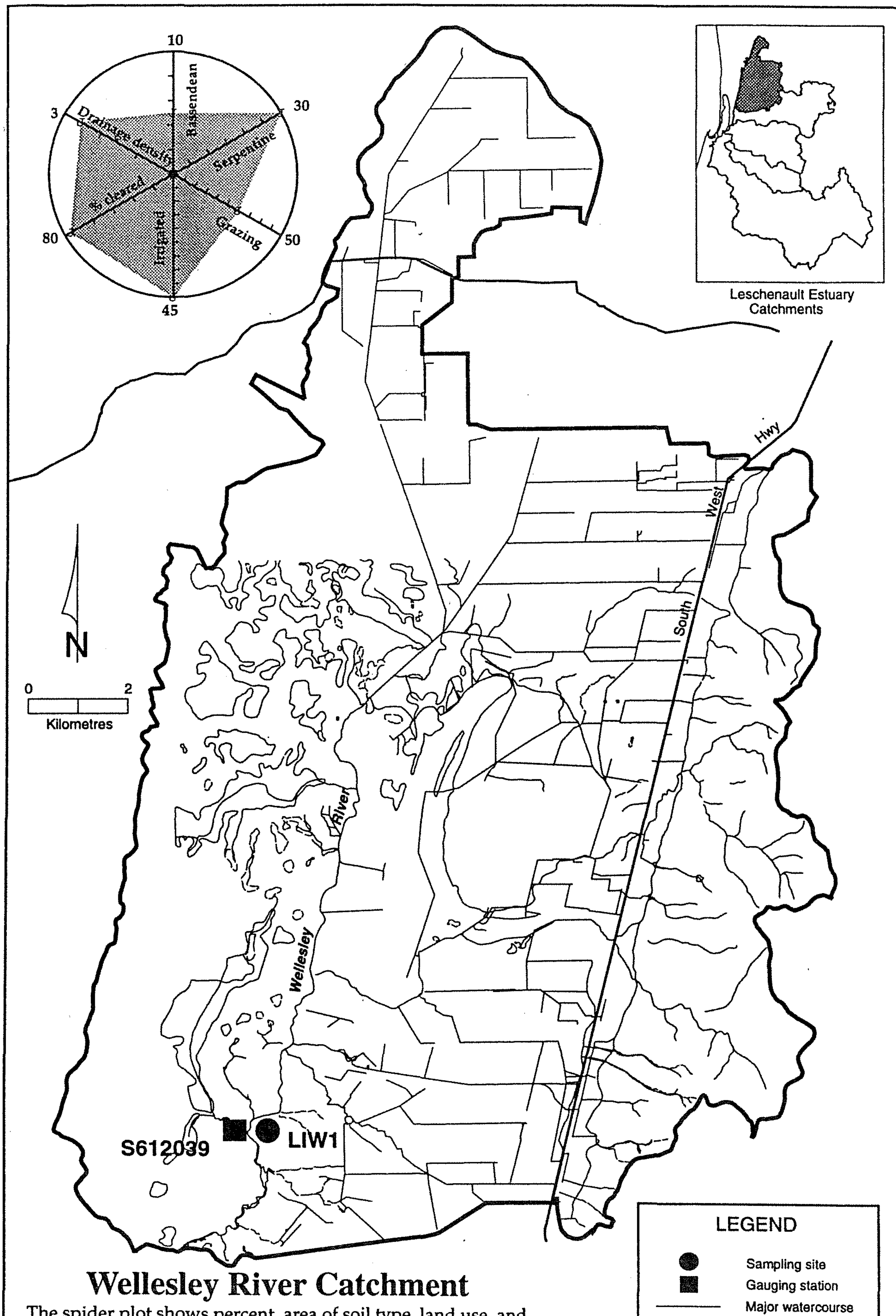
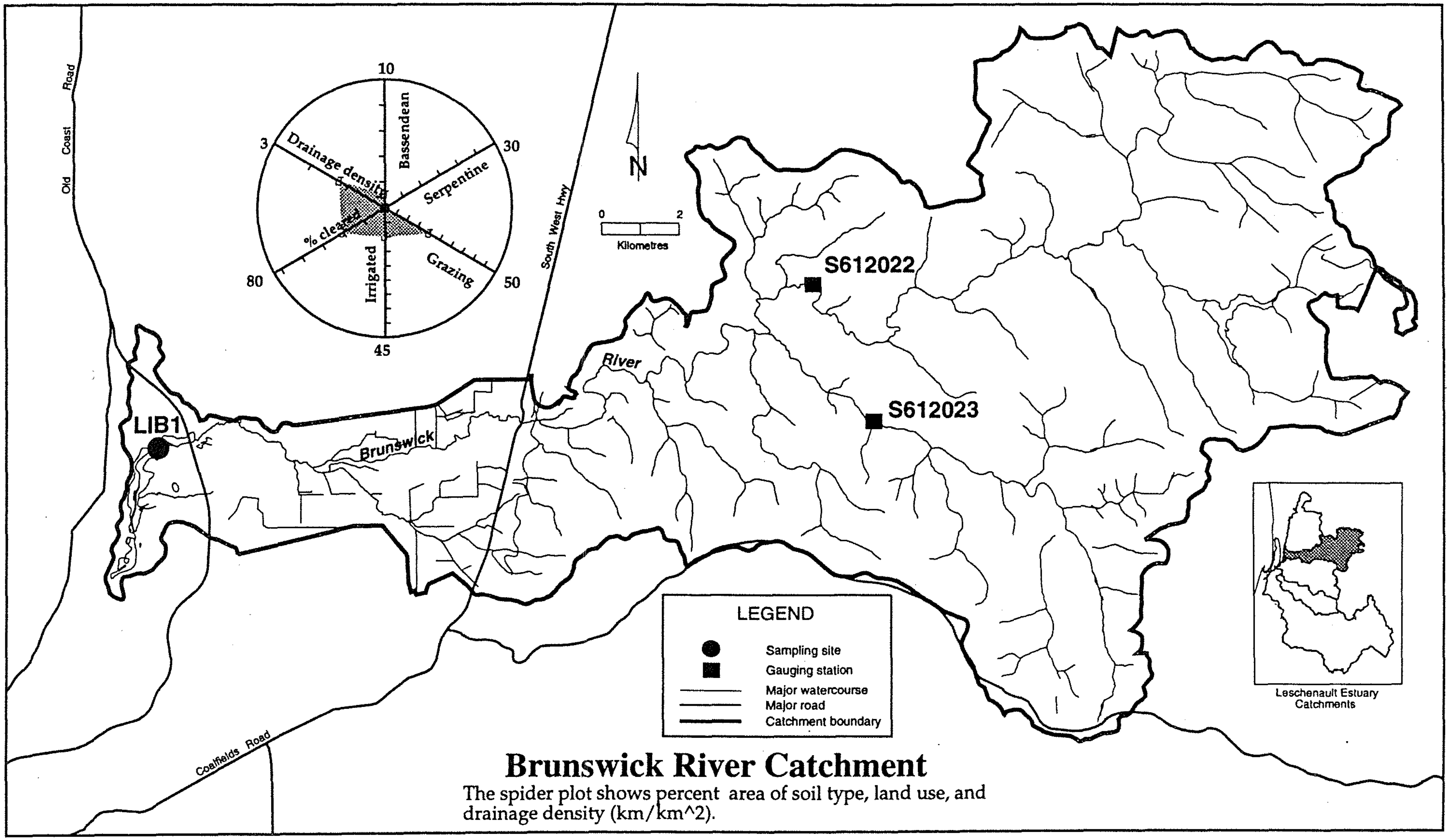
APPENDICES

APPENDIX 1 : CATCHMENT MAPS



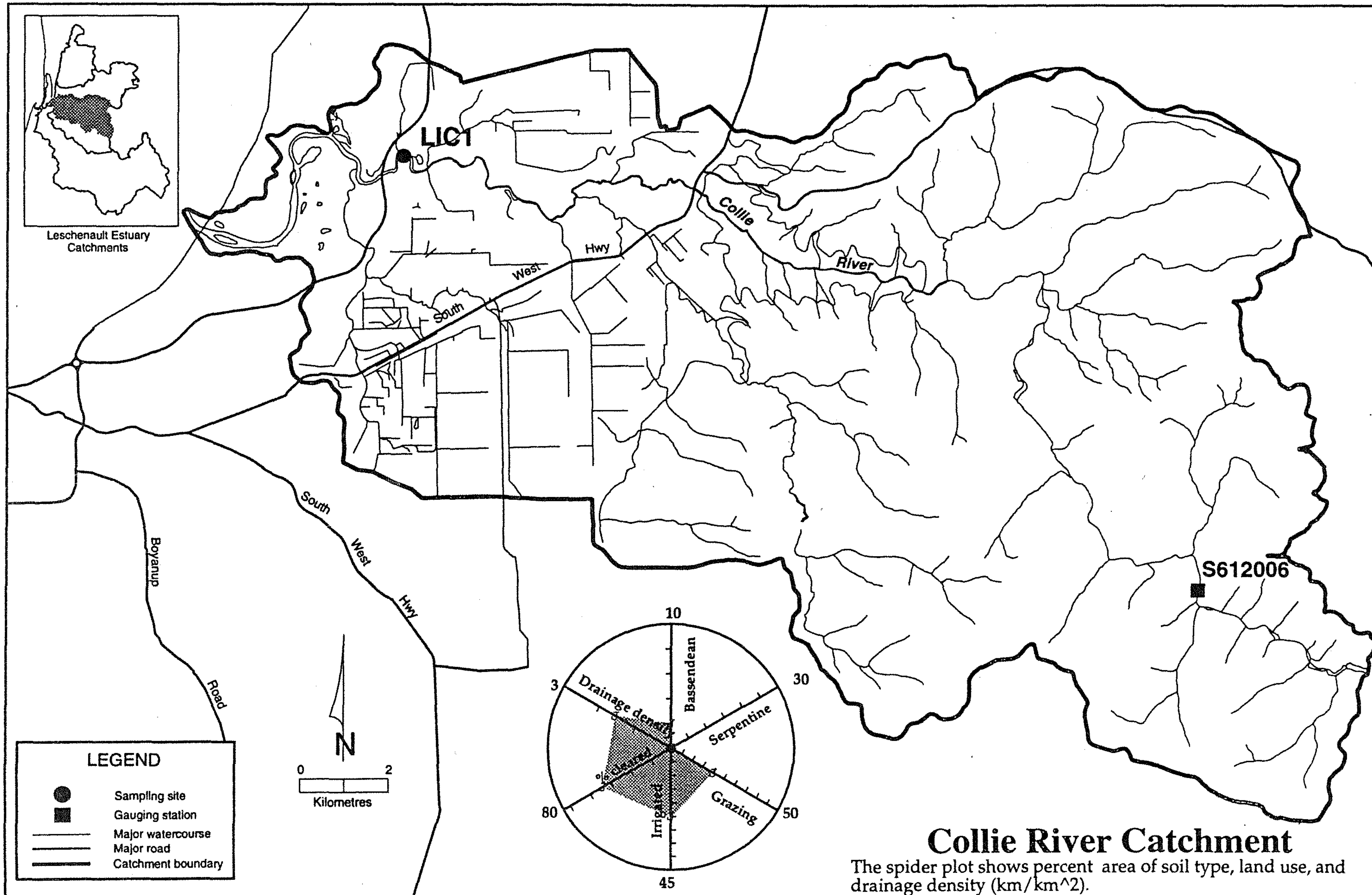
Wellesley River Catchment

The spider plot shows percent area of soil type, land use, and drainage density (km/km^2).



Brunswick River Catchment

The spider plot shows percent area of soil type, land use, and drainage density (km/km^2).

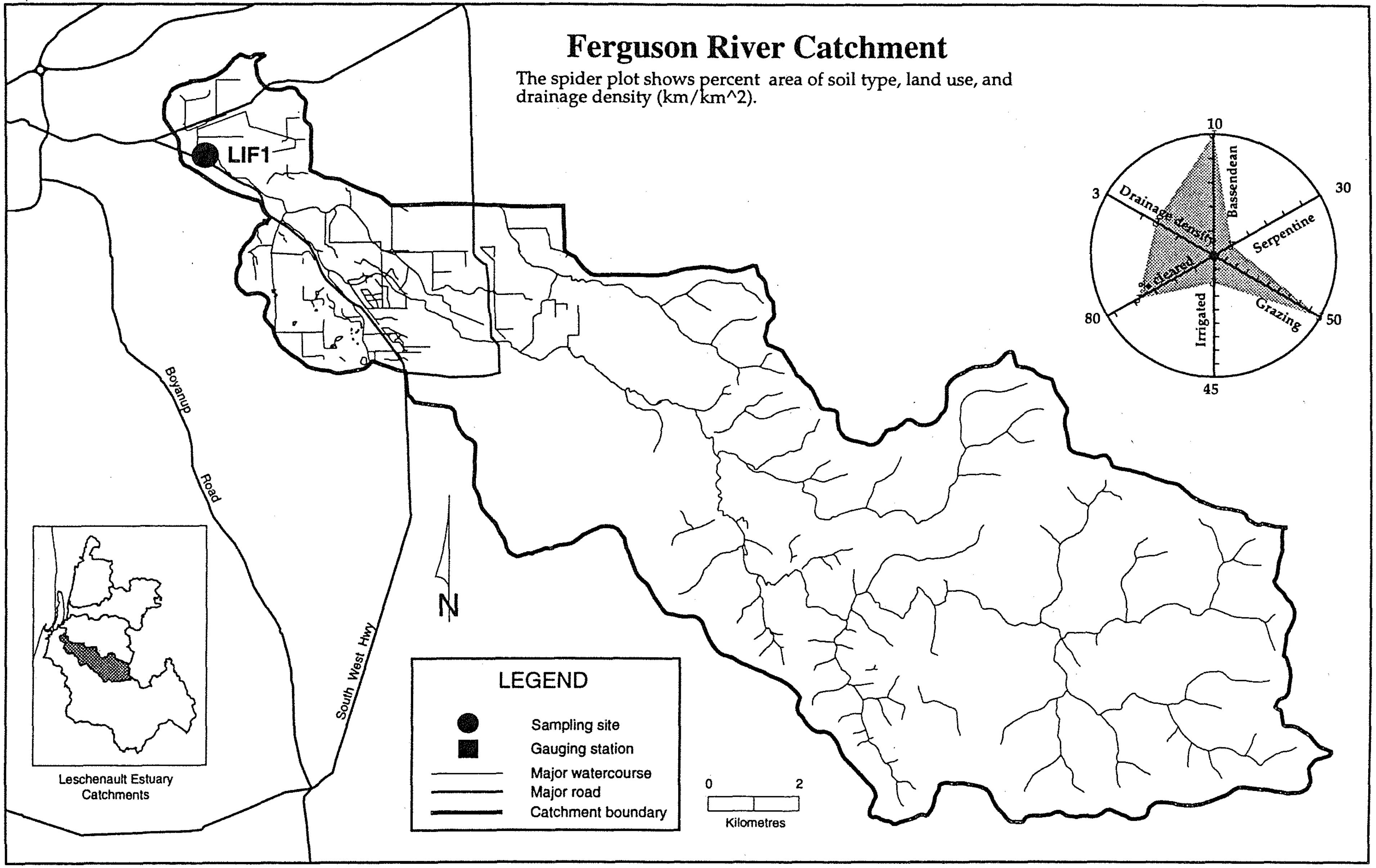


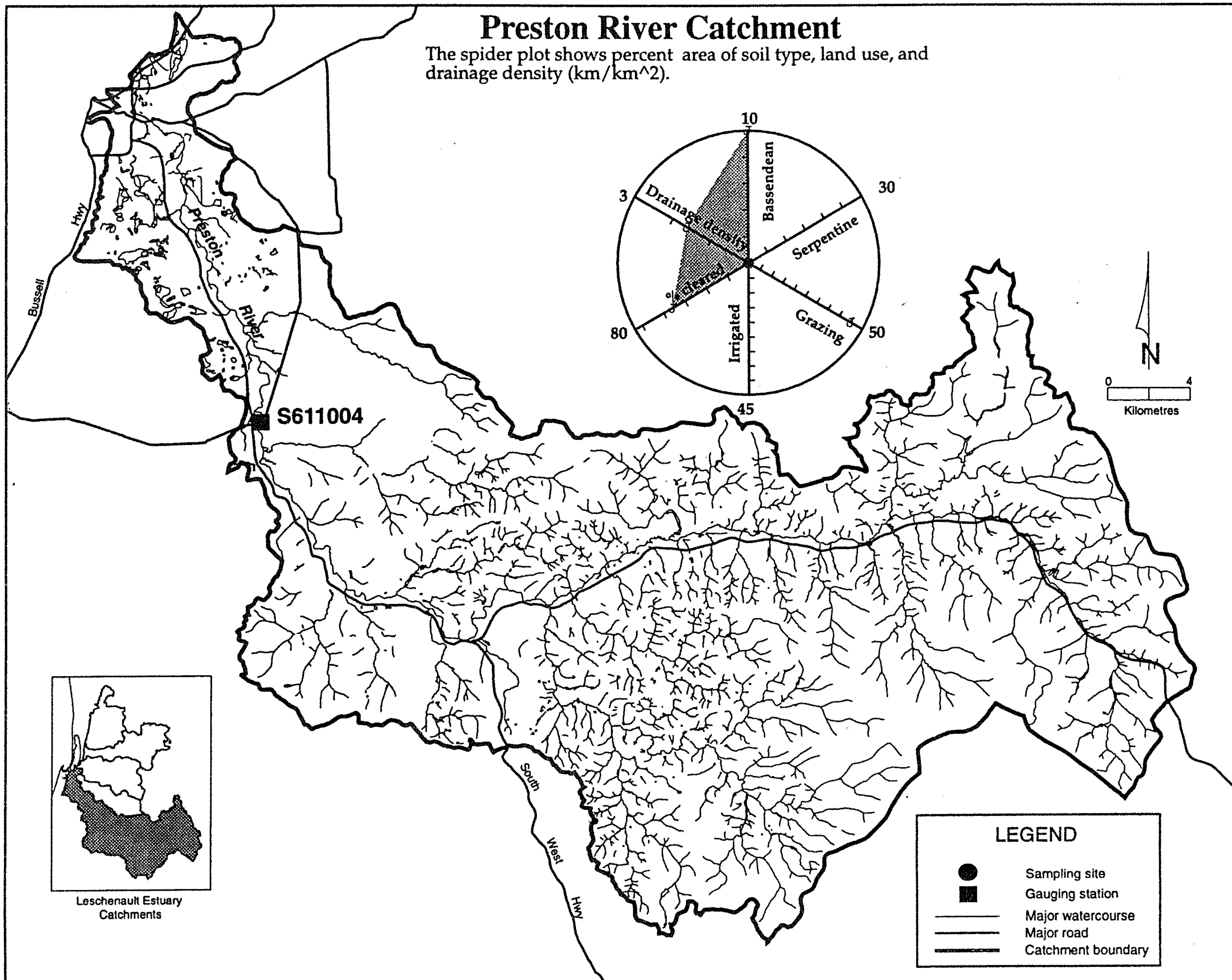
Collie River Catchment

The spider plot shows percent area of soil type, land use, and drainage density (km/km^2).

Ferguson River Catchment

The spider plot shows percent area of soil type, land use, and drainage density (km/km^2).




Preston River Catchment
The spider plot shows percent area of soil type, land use, and drainage density (km/km^2).
10
30
50
45
80
3
Bassendean
Serpentine
Grazing
Irrigated
% cleared
Drainage density
N
0
4
Kilometres
S611004
Preston
River
Bussell
Hwy
South
West
Hwy
Leschenault Estuary Catchments
LEGEND
Sampling site
Gauging station
Major watercourse
Major road
Catchment boundary

MATERIALS AND METHODS

1. MONITORING PERIOD

From 1984 to 1993, the Waterways Commission has been measuring the concentration of nutrients in the major tributary inflows into the Leschenault Estuary. These data were used with measurements of stream discharge to derive estimates of annual mass load of nutrients passing the points of sampling, as well as to estimate the total load of nutrients entering the Leschenault Estuary near Bunbury. The maps show details of each of the monitored sub-catchments (Figures 1 to 5).

From 1984 to 1989, the Brunswick, Collie, Ferguson and Preston Rivers were monitored. In 1990, the WWC and WAWA began monitoring water quality in the Wellesley River, a major tributary of the Brunswick River that drains the northern areas of the Leschenault catchment. The sample site on the Brunswick River was located a short distance downstream of the Brunswick-Wellesley confluence and the Wellesley River sample site. Flow and chemical load data at the Brunswick site therefore include the separate contributions from the Wellesley and Brunswick drainage systems.

2. SAMPLE COLLECTION AND ANALYSIS

Over the nine years of monitoring, grab samples were collected from each of the sites at regular intervals. The sampling frequency was nominally once per week during the winter wet period. In practice, the period between sample collection varied from about four to seven days. The regime was stratified by season to take advantage of the pronounced seasonality of streamflow in WA. The sampling period began with the onset of winter rains, usually May/June, and finished in October/November with the onset of the summer dry period. No samples were collected during the dry summer months.

All samples were collected into new high density polyethylene screw capped bottles. Each sample bottle was rinsed with river water prior to final sample collection. Samples for FP analysis were filtered on site using 0.45 µm cellulose nitrate filters. Samples were cooled in ice or frozen and transported to the Chemistry Centre of Western Australia (CCWA) for analysis. The nutrients that were considered are shown in Table 1.

TABLE 1: Nutrients measured in samples collected from each site. Details of analytical method can be obtained from the CCWA. See also Greenberg e. at., (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 phosphorus	FP	mg/L	iP1WTCO
Total phosphorus	TP	mg/L	iPP1WTCO

3. ESTIMATION OF STREAMFLOW AT NUTRIENT SAMPLING SITES

The estimation of loads required that stream discharge was known at the point where water samples were collected for nutrient analysis. Unfortunately many of the gauging stations in the catchment of the Leschenault Estuary were located at the edge of the Darling Scarp, some distance from the nutrient sampling sites (Figure 1).

To estimate the flow gain from the Scarp to the sampling sites the Water Authority of Western Australia established temporary flow gauges on the coastal plain near the estuary in 1984. Using weekly measurements of flow from the Collie and Brunswick Rivers step-wise linear relationships were derived between the weekly observations taken on the coastal plain and the permanent gauging stations near the Scarp. The daily streamflow volumes were estimated from the gauging stations to the coastal plain sampling sites using these regression models (Salim 1985).

A total of five gauging stations were used in this project to estimate flow at the nutrient sampling sites. These are listed in Table 2 along with their locations. Details of methodology and formula used for the estimation of flow at each of the sampling sites are provided in the following sections.

Wellesley River 1990-1992

A flow gauging station was established on the Wellesley River at the sampling site in May 1990. For the calculation of daily loads from January to May 1990 it was assumed that flow was minimal.

Brunswick River 1984-1992

In 1990, a gauging station was established on the Brunswick River at the sampling site on the bypass road bridge. This allowed the flow relationship developed by Salim (1985), for the flow gauging station near the Scarp and weekly instantaneous measurements of flow taken near the estuary, to be validated against observed data. In 1991, it was found that the Salim model underestimated annual total volume of flow in the Brunswick by 50 percent. It was decided therefore to use auto-regressive techniques to develop a new relationship between the new gauging station and the gauging stations near the scarp (Young and Benner 1991).

TABLE 2: Flow gauging stations used to estimate discharge at the nutrient sampling sites.

Station name	WAWA Gauge No.	Gauged Area (km^2)	Map reference (Aust. Metric Grid)
Preston River, Preston Bridge	S611004	830	N 6294850 E 382100
Collie River, Mount Lennard	S612006	2900	N 6309250 E 397300
Brunswick River, Sandalwood	S612022	115	N 6323700 E 399400
Lunenburgh River, Silver Springs	S612023	57.5	N 6320750 E 400400
Wellesley River. Juegenup	S612039	147	N 6323050 E 385900

The transfer function so developed resulted in a five percent overestimation of total annual flow compared to observed, and estimates of mass nutrient loads virtually identical to those calculated using the observed gauged flow. On this basis, it was decided to use the transfer function below to estimate flow at the Brunswick River sampling site from 1984 to 1989. Data from the gauging station were used after this date.

The transfer function used was:

$$y(k) = 0.64434\, y(k-1) + 6.81151\, \mu(k) - 4.56388\, \mu(k-1)$$
(Coefficient of Determination = 0.8)

where:

$y(k)$ = estimated total daily flow volume at sampling station LIB1
$\mu(k)$ = sum of total daily flow volume measured at stations S612022 and S612023

Collie River 1984 - 1992

Flow at the sampling site LIC1 was estimated using the step-wise regression model developed by Salim (1985). The formula was:

If flow at S612006 < 492480 m^3/day
then flow at LIC1 = 1.32 x S612006
If flow at S612006 > 492480 but < 578880 m^3/day
then flow at LIC1 = 1.54 x S612006
If flow at S612006 > 578880 but < 1097280 m^3/day
then flow at LIC1 = 1.34 x S612006
If flow at S612006 > 1097280 m^3/day
then flow at LIC1 = 1.26 x S612006

Ferguson River 1984 - 1992

Streamflow volume at the sampling site was estimated as a function of the combined discharge at gauges S612022 and S612023. The formula used, as devised by Salim (1985), was:

Let 'Sumflow' = Σ (S612022 & S612023)

If 'Sumflow' < 15002
then flow at LIF1 = 0
else flow at LIF1 = 0.734 x 'Sumflow' - 11010

Preston River 1984 - 1992

Streamflow at the Preston River sampling site was estimated by transferring a water yield coefficient from the gauged portion of the catchment to the lower ungauged section (Salim 1985). The resulting formula was:

Flow at LIP1 = 1.091 x S611004

Estimation of Annual Mass Load

Daily loads were computed as the product of total daily stream discharge (in litres/day) and daily nutrient concentration. Daily concentrations of nutrients were obtained by linear interpolation between the observed weekly concentrations. This method assumes that the weekly observations are indicative of water conditions between sampling. The annual estimates of mass load for each site were derived by summing the daily total loads for every day of the year.

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

Areal export rates were calculated by dividing the annual mass load at each site by the area of gauged catchment. *(These were calculated and provided here for information only. They are not considered or interpreted in this report. Export coefficients provide little new information on water quality, and are open to misinterpretation, especially in large catchments containing a range of geomorphic elements and land uses).*

Annual flow-weighted concentrations on the other hand are good indicators of average water quality over the year. They are calculated by dividing the total annual load estimate by the total annual stream discharge.

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 was 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.

Total Mass Load into the Estuary

The total load of nutrients entering the estuary in a year was estimated by summing the estimates of total annual load for the Brunswick, Collie, Ferguson and Preston Rivers in each year. The estimated contribution from the ungauged catchment was added to this sum to derive an estimated total load into the estuary.

APPENDIX 2 : ESTIMATES OF MASS LOAD

Table 1: Brunswick River.

Year	Rainfall (mm)	Discharge (10^6 m^3)	Annual Mass Load (tonnes)				
			NH_3-N	NO_3-N	TN	FP	TP
1984	1207	237	16	71	243	12	28
1985	1099	236	16	40	210	13	27
1986	919	124	8	23	107	5	15
1987	785	91	12	18	95	4	19
1988	1288	412	32	163	395	37	67
1989	1011	220	15	35	188	7	19
1990	813	268	17	55	219	6	18
1991	1252	372	38	121	435	33	42
1992	1057	321	24	70	346	17	41
Mean	1034	281	23	77	280	17	34
		Runoff (mm)	Catchment Export (kg/ha/yr)				
			NH_3-N	NO_3-N	TN	FP	TP
1984		503	0.33	1.51	5.15	0.25	0.60
1985		500	0.34	0.85	4.45	0.28	0.57
1986		263	0.17	0.49	2.27	0.10	0.32
1987		193	0.25	0.39	2.03	0.07	0.40
1988		874	0.67	3.46	8.38	0.80	1.42
1989		468	0.33	0.73	3.98	0.15	0.40
1990		569	0.36	1.16	4.64	0.14	0.38
1991		789	0.80	2.56	9.24	0.69	0.90
1992		681	0.51	1.48	7.34	0.35	0.87
Mean		595	0.49	1.63	5.93	0.37	0.73
			Flow-weighted Concentration (mg/L)				
			NH_3-N	NO_3-N	TN	FP	TP
1984			0.07	0.30	1.02	0.05	0.12
1985			0.07	0.17	0.89	0.06	0.11
1986			0.06	0.19	0.86	0.04	0.12
1987			0.13	0.20	1.05	0.04	0.21
1988			0.08	0.40	0.96	0.09	0.16
1989			0.07	0.16	0.85	0.03	0.08
1990			0.06	0.20	0.82	0.02	0.07
1991			0.10	0.32	1.17	0.09	0.11
1992			0.07	0.22	1.08	0.05	0.13
Mean			0.09	0.25	0.99	0.05	0.13

Table 2: Preston River

Year	Rainfall (mm)	Discharge ($10^6 m^3$)	Annual Mass Load (tonnes)				
			NH_3-N	NO_3-N	TN	FP	TP
1984	1207	85	3	94	145	1.6	6.5
1985	1099	137	5	69	142	2.2	6.9
1986	919	45	4	15	42	0.8	4.3
1987	854	38	6	19	50	0.3	3.0
1988	1422	206	17	309	412	3.9	11.9
1989	999	64	6	27	71	2.0	5.0
1990	1219	151	9	110	194	1.7	3.8
1991	1487	188	12	181	311	3.4	12.0
1992	1253	169	19	88	204	2.6	6.9
Mean	1196	136	12	123	207	2.3	7.1
		Runoff (mm)	Catchment Export (kg/ha/yr)				
			NH_3-N	NO_3-N	TN	FP	TP
1984		155	0.06	1.70	2.63	0.03	0.12
1985		249	0.10	1.25	2.58	0.04	0.13
1986		82	0.07	0.27	0.77	0.02	0.08
1987		70	0.12	0.35	0.90	0.01	0.05
1988		374	0.30	5.63	7.50	0.07	0.22
1989		116	0.11	0.50	1.30	0.04	0.09
1990		275	0.16	2.00	3.54	0.03	0.07
1991		343	0.22	3.30	5.65	0.06	0.22
1992		307	0.35	1.61	3.72	0.05	0.13
Mean		247	0.21	2.23	3.77	0.04	0.13
			Flow-weighted concentration (mg/L)				
			NH_3-N	NO_3-N	TN	FP	TP
1984			0.04	1.10	1.69	0.02	0.08
1985			0.04	0.50	1.03	0.02	0.05
1986			0.08	0.33	0.94	0.02	0.10
1987			0.17	0.50	1.29	0.01	0.08
1988			0.08	1.50	2.00	0.02	0.06
1989			0.09	0.43	1.12	0.03	0.08
1990			0.06	0.73	1.29	0.01	0.03
1991			0.06	0.96	1.65	0.02	0.06
1992			0.11	0.52	1.21	0.02	0.04
Mean			0.10	0.78	1.43	0.02	0.06

Table 3: Ferguson River.

Year	Rainfall (mm)	Discharge ($10^6 m^3$)	Annual Mass Load (tonnes)				
			NH_3-N	NO_3-N	TN	FP	TP
1984	1207	22	1.2	16	30	0.6	2.0
1985	1099	24	1.3	12	26	0.7	1.7
1986	919	12	0.8	5	12	0.3	1.3
1987	854	8	1.1	3	8	0.2	1.1
1988	1422	38	2.9	46	67	1.2	3.1
1989	999	22	1.8	8	24	0.7	2.0
1990	1219	26	1.6	18	35	0.8	1.6
1991	1487	42	3.9	33	74	1.0	2.7
1992	1253	37	3.8	20	53	1.5	3.7
Mean	1196	29	2.5	21	43	0.9	2.4
		Runoff (mm)	Catchment Export (kg/ha/yr)				
			NH_3-N	NO_3-N	TN	FP	TP
1984		136	0.07	0.98	1.81	0.04	0.12
1985		144	0.08	0.74	1.59	0.04	0.10
1986		70	0.05	0.28	0.70	0.02	0.08
1987		47	0.07	0.18	0.47	0.01	0.07
1988		233	0.17	2.81	4.09	0.07	0.19
1989		135	0.11	0.47	1.49	0.04	0.12
1990		159	0.10	1.08	2.13	0.05	0.10
1991		256	0.24	1.99	4.51	0.06	0.16
1992		227	0.23	1.20	3.22	0.09	0.23
Mean		176	0.15	1.29	2.65	0.05	0.14
			Flow-weighted concentration (mg/L)				
			NH_3-N	NO_3-N	TN	FP	TP
1984			0.05	0.72	1.33	0.03	0.09
1985			0.06	0.51	1.10	0.03	0.07
1986			0.07	0.40	1.00	0.03	0.11
1987			0.14	0.39	1.02	0.02	0.14
1988			0.07	1.20	1.75	0.03	0.08
1989			0.08	0.35	1.11	0.03	0.09
1990			0.06	0.68	1.34	0.03	0.06
1991			0.09	0.78	1.76	0.02	0.06
1992			0.10	0.53	1.42	0.04	0.10
Mean			0.09	0.65	1.40	0.03	0.09

Table 4 : Wellesley River

Year	Rainfall (mm)	Discharge (10^6 m^3)	Annual Mass Load (tonnes)				
			NH_3-N	NO_3-N	TN	FP	TP
1990	813	56	7	11	82	5	9
1991	963	112	11	34	177	12	20
1992	855	96	11	17	153	5	19
Mean	877	88	10	21	137	7	16
		Runoff (mm)	Catchment Export (kg/ha/yr)				
			NH_3-N	NO_3-N	TN	FP	TP
1990		267.1	0.3	0.5	3.9	0.2	0.4
1991		532.6	0.5	1.6	8.4	0.6	1.0
1992		456.5	0.5	0.8	7.3	0.2	0.9
Mean		418.7	0.5	1.0	6.5	0.3	0.8
			Flow-weighted concentration (mg/L)				
			NH_3-N	NO_3-N	TN	FP	TP
1990			0.13	0.21	1.46	0.08	0.17
1991			0.10	0.30	1.59	0.11	0.18
1992			0.11	0.18	1.59	0.05	0.20
Mean			0.11	0.23	1.55	0.08	0.18

Table 5: Collie River

Year	Rainfall (mm)	Discharge ($10^6 m^3$)	Annual Mass Load (tonnes)				
			NH_3-N	NO_3-N	TN	FP	TP
1984	1207	175	5.3	43.7	128	1.1	8.1
1985	1099	209	8.1	27.3	95	2.9	6.2
1986	919	132	2.9	10.6	45	0.7	2.3
1987	854	91	2.6	6.6	28	0.4	1.5
1988	1422	228	10.6	70.6	135	1.3	5.1
1989	999	136	6.0	20.0	56	0.7	2.2
1990	1219	209	7.2	29.5	96	1.3	3.7
1991	1487	327	16.3	70.5	221	3.2	9.3
1992	1253	292	12.4	47.5	163	3.4	4.8
Mean	1196	214	9.2	40.8	116	1.7	4.4
		Runoff (mm)	Export (kg/ha/yr)				
			NH_3-N	NO_3-N	TN	FP	TP
1984		730	0.22	1.83	5.33	0.05	0.34
1985		874	0.34	1.14	3.98	0.12	0.26
1986		553	0.12	0.44	1.89	0.03	0.10
1987		380	0.11	0.27	1.19	0.02	0.06
1988		951	0.44	2.95	5.63	0.06	0.21
1989		567	0.25	0.83	2.33	0.03	0.09
1990		873	0.30	1.23	4.00	0.05	0.15
1991		1365	0.68	2.94	9.24	0.13	0.39
1992		1219	0.52	1.98	6.81	0.14	0.20
Mean		892	0.38	1.70	4.87	0.07	0.19
			Flow-weighted concentration (mg/L)				
			NH_3-N	NO_3-N	TN	FP	TP
1984			0.03	0.25	0.73	0.01	0.05
1985			0.04	0.13	0.46	0.01	0.03
1986			0.02	0.08	0.34	0.01	0.02
1987			0.03	0.07	0.31	0.005	0.02
1988			0.05	0.31	0.59	0.01	0.02
1989			0.04	0.15	0.41	0.01	0.02
1990			0.03	0.14	0.46	0.01	0.02
1991			0.05	0.22	0.68	0.01	0.03
1992			0.04	0.16	0.56	0.01	0.02
Mean			0.04	0.17	0.50	0.01	0.02

Table 6: Estimates of total external nutrient loads

Year	Discharge (10^6 m^3)	Total Nitrogen		Total Phosphorus	
		Load (tonnes)	FWC (mg/L)	Load (tonnes)	FWC (mg/L)
1984	546	589	1.08	51	0.09
1985	628	511	0.81	47	0.08
1986	335	244	0.73	28	0.08
1987	248	215	0.87	30	0.12
1988	911	1057	1.16	94	0.10
1989	466	380	0.82	34	0.07
1990	680	589	0.87	33	0.05
1991	957	1090	1.14	73	0.08
1992	844	810	0.96	63	0.07
Total	5615	5486	n/a	455	n/a
Mean	624	610	0.94	51	0.08