GOVERNMENT OF WESTERN AUSTRALIA

NUTRIENTS IN TRIBUTARY INFLOWS TO THE ALBANY HARBOURS, WESTERN AUSTRALIA

WATER RESOURCE TECHNICAL SERIES

WATER AND RIVERS COMMISSION REPORT WRT 18
1999

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Cover Photograph: Aerial view of the Kalgan River discharging to Oyster Harbour (Photo by Simon Neville)

Nutrients in Tributary Inflows to the Albany Harbours, Western Australia

by

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Summary

Water quality sampling for nutrients has occurred in the Albany catchment for a number of years primarily as a result of observed declines in seagrass populations in Oyster and Princess Royal harbours. As a result early sampling was focussed on estimation of Nitrogen and Phosphorus loads entering the Albany Harbours. Most of the obvious point sources of nutrients have been reduced or eliminated and focus is now on reducing diffuse sources of nutrients. More detailed information is required on catchment condition so that management action can be directed efficiently within the catchment. Establishing catchment condition and changes in catchment status in terms of water quality data will require different sampling and analysis strategies than those used in the past.

Existing nutrient data from catchment sampling programs has been analysed to determine the best use to which those data can be put in answering both questions about loading to the estuaries and the nature of nutrient sources in the catchment. This analysis also provides the basis for determining sampling requirements in the future once the information objectives of any future program have been clearly defined.

Existing data have been used to:

- Compare among sites (streams);
- Compare among seasons;
- Show relationships between concentration and flow;
- Establish classification of streams based on nutrient concentrations;
- Describe changes in time.

Evidence of slight enrichment is to be expected in the monitored tributaries since most of the catchments are cleared and support urban centres, industrial areas and broad-scale agriculture. The catchment is therefore subject to a net export of nutrients in fertilisers from urban gardens and parklands, industrial discharges or from pasture and crops in agricultural regions.

Nutrient concentrations varied seasonally at each monitored site. Peak nutrient concentrations were typically observed in late winter coinciding with peak rainfall and water discharged from the Albany Harbours tributaries. Maximum concentrations of inorganic nitrogen were found in samples collected in the first storm events (May / June) which flush dissolved nitrogen from the catchments' soils. Peak inorganic phosphorus concentrations occurred later in the year (August / September). Inorganic phosphates were probably derived from fertiliser leachates in agricultural soils plus runoff from industrial areas in Albany.

Analyses of the nutrient data show that nitrogen and phosphorus concentrations in Munster Hill Drain were high between 1995 and 1997. There are several possible point sources of nutrients to the drain including a fertiliser manufacturer and refuse dump. The catchment is low lying and flows in the drain are strongly influenced by groundwater discharges, which is the most likely transport mechanism of contaminants to the drain. In any case, the weekly fixed-interval sampling generally collects samples primarily from base flows when groundwater discharge is the primary source of water.

The Kalgan River, which drains to the Oyster Harbour, has relatively low concentrations of nitrogen and phosphorus. None the less, the total load of nutrients it carries annually may be relatively large because of its high annual total water discharge. Frequent high nitrogen concentrations in the upper reaches of Yakamia Creek may reflect septic tank leakage from residential areas or generally poor waste management practices.

Nutrient concentrations in the monitored inflows to the Princess Royal and Oyster harbours varied with variation in base flows. This suggests that groundwater plays an important role in determining nutrient concentrations. Therefore, nutrients in groundwater may influence estuarine ecology in the harbours (Jordan *et al.* 1997, Turner *et al.*, *in prep*).

It is unlikely however, that the growth of macro-algae species is solely dependent on inorganic forms of nutrients entering the harbours, and is likely that other estuarine processes would enhance the supply of bio-available nutrient forms. For a majority of monitored tributaries the organic component of both nitrogen and phosphorus remained the dominant fraction discharged to the harbours throughout the year.

Thus a majority of the nutrients being delivered to the harbours is organic (ie. plant material and animal waste). Biochemical processes occurring within the estuary, such as ammonification processes for nitrogen and dissimilation processes for phosphorus (Heathwaite *et al.* 1996), convert organic forms to an inorganic form. The rate of mineralisation of organic material in the harbours will influence macro-algae populations, but by how much is unknown. The cycling of nutrients from internal sediment stores within Albany Harbours is also an important source of nutrients for algae (WRC 1995, Lords *et al.* 1997).

Estimates in nutrient loading were found to be imprecise due to an inadequate sampling of storm events and errors in rating curves used for calculation of loads. Compared to the intensive sampling efforts and equipment required for measuring loads accurately, detecting spatial and temporal variation in ambient nutrient data series requires infrequently, but regularly, collected grab samples. Recognising the existing need for loading information a programmable autosampler has been commissioned on the Kalgan River, however data is not available from this installation.

It is recommended that fixed-interval sampling of nutrients in the tributaries to Albany Harbours be continued for the purpose of establishing trend with time in nutrient concentrations. This approach allows for classification of stream status and the ability to measure against targets. Samples should be collected from the existing sites once every two weeks. Five years of data at this sampling frequency are required to establish trends. For most sites three years of data already exist at the appropriate frequency. The data will be analysed statistically for temporal trends in ambient nutrient concentration every three years. By identifying degrading systems this information will help managers of the Albany Harbours to allocate resources where they are most needed.

1. Introduction

1.1 Background

The Albany basin has a Mediterranean climate, with cool wet winters and dry, temperate summers. Rainfall ranges from 400 millimetres in the north east of the basin to 1200 millimetres near the coast. A majority of rainfall occurs between April to October with an average of 180 rain days each year (Weaver and Reed 1998).

Monitoring nutrient concentrations in inflows to the Albany Harbours commenced in response to concerns that seagrass meadows have been degrading in both Princess Royal and Oyster harbours. More than 80 percent of the seagrass meadows have been lost since the 1960's, which has changed the estuaries' primary productivity and the Harbour's recreational and aesthetic qualities (Environmental Protection Authority, 1988). The main sources of nutrients to the Albany Harbours were from agricultural fertilisers, plant material, animal waste, industrial wastes, and stormwater runoff from urban areas (Environmental Protection Authority, 1990). Applied nutrients may be mobilised in stormwater runoff or leached to groundwaters and either discharged directly to the estuaries or lost from the catchment in surface drainage.

The catchments of the Princess Royal Harbour and Oyster Harbour have been had about 80 to 90 percent of natural vegetation cleared for agricultural purposes (WRC 1997). Annual application of fertiliser is needed to maintain the productivity of the naturally infertile soils and, combined with the poor nutrient retention in the sandy soils, has resulted in high nutrient runoff (Weaver and Reed 1998). Land use in the Princess Royal Harbour basin consists of intensive horticulture, cattle and sheep grazing, and residential, commercial and industrial zones closer to the town of Albany. Land use in the Oyster Harbour basin almost exclusively consists of cattle and sheep grazing, with some horticulture, viticulture and urban areas (Environmental Protection Authority, 1990, Water & Rivers Commission, 1995).

Seagrass losses have been attributed to the growth of macro-algae species caused by increases in nutrients from the catchments, which has inhibited light penetration and smothered seagrasses. Changes in the amount of nutrients entering the harbours every year will modify the spatial distribution and density of macro-algae populations (Simpson and Masini 1990). Surveys carried out by the Water and Rivers Commission (Marine & Freshwater Research Laboratory, 1996), showed that seagrass losses appear to have stopped and there is evidence of regrowth, especially in areas where macro-algae is consistently removed by wind shear and strong tidal flows.

Nutrient monitoring in the Albany Harbours catchment has been in place since 1987 and most of the early data has been described elsewhere (Environmental Protection Authority, 1990). Currently nine tributary inflows are monitored; seven of which drain the Oyster Harbour basin and two that drain the Princess Royal Harbour basin (Figure 1). The size of the tributaries' catchments vary widely, from the extensive Kalgan River catchment (~2375km^2) to the smaller drains of the Albany township (<10km^2).

It was originally intended to analyse the data from 1987 to 1998, however much of the early data series for many sites could not be located. Due to poor data management in the past, only the more recent Water and Rivers Commission data (since 1995) was analysed for this report, although reliable historical data from Agriculture WA was used for both Chelgiup Creek and Kalgan River. Once the rest of the historical data has been obtained and verified, an additional analysis will be performed to allow comparisons over time.

1.2 Purpose of this report

After many years of monitoring in the Albany Harbours catchment using varying sampling regimes, sampling intervals and sites, there was a need to evaluate the overall sampling program in the context of current information objectives. The focus in the past has been to quantify nutrient loading to the harbours, rather than to measure catchment condition as expressed by tributary water quality.

This report discusses how data collected by fixed-interval, fixed-site sampling can be used and makes some comments on the data requirements for load calculations where they are required.

Therefore this report should be used as a basis for discussion when assessing the state of the current monitoring program. The challenge should be to design an optimal sampling program to meet current (as yet not fully developed) information objectives with a limited budget.

1.3 Information objectives

Sampling for nutrients in the catchment to date aimed at obtaining annual nutrient loading estimates for the major tributary inflows of both Princess Royal and Oyster harbours (Figure 1). Samples were collected from fixed-sites in (approximately) weekly intervals and analysed for total nitrogen, total phosphorus and their inorganic fractions. However, weekly fixed-interval sampling is generally recognised to be an inadequate strategy for estimating mass loads because misalignment of sampling to nutrient fluxes produces unquantifiable uncertainties (Richards and Holloway 1987, Littlewood 1992).

Information objectives are now changing from quantifying nutrient loads delivered to estuaries to those that assess changes in tributary water quality. The need is to develop an understanding of catchment condition that will guide management activity. The detection of trends in nutrients within tributaries has proven to be a sensitive and widely accepted measure of catchment degradation or improvement (Sanders *et al* 1987, Heathwaite *et al.* 1996; Robson and Neal 1996; Lettenmaier *et al.* 1991) and can be used as an effective quantitative management tool. This approach places emphasis on removing natural background sources of variation from the time series (such as seasonal and flow components), so variation in nutrient levels due to human activity can be identified. Changes in the residual concentrations of nutrients (after seasonal and flow components have been removed) will probably indicate a change in mass loading. Existing data have therefore been analysed to determine their compatibility with trend detection.

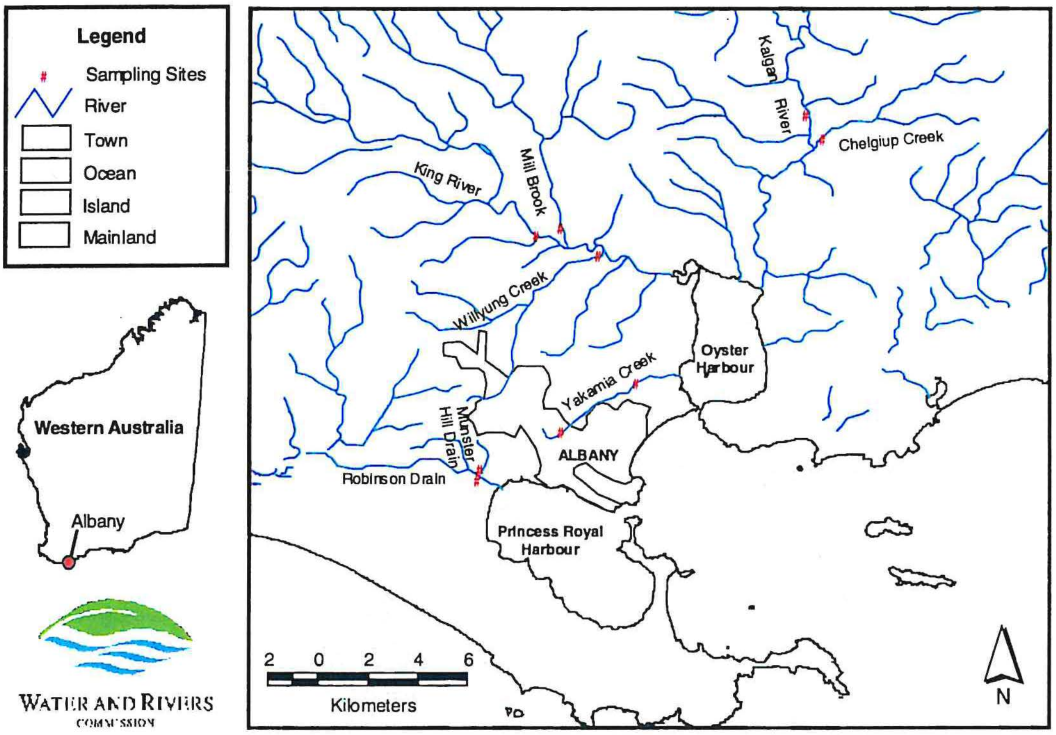


Figure 1. Albany Harbours and its monitored tributaries.

1.4 Data coverage and adequacy

The results of Albany Harbours nutrient monitoring are shown in Figures 2 and 3 in terms of when samples were collected and which nutrient parameters were sampled. They also indicate that there are many gaps in the data series. In a well managed program the data should be collected over the entire year of a tributary's flow period to ensure a representative historic record. Methods of analysis that are not affected by missing data can be used, however the information that the data contains cannot be recovered. All data series will contain missing values but if the level of missing data is too high the information content of the data series becomes severely compromised. Most monitored tributaries in the Albany region are perennial so with uninterrupted sampling throughout the year a total of 52 samples should be collected.

Table 1 shows the percentage of flow weeks actually sampled in each year at each site. Of those years where weekly fixed-interval sampling appears to have been used, many of the monitored sites only had between 30 and 40 percent missing, indicating a somewhat erratic sampling program. In 1997, most monitored sites complied with the intended fortnightly fixed-interval sampling regime (50 percent of flow weeks sampled in the year), with the exception of both Chelgiup Creek and the Kalgan River where monitoring commenced late in the year. In some very dry years the smaller streams ceased to flow (see hydrographs in Figures 2 and 3). For example, Upper Yakamia Creek stopped flowing in 1995 but was otherwise permanent for 1996 and 1997.

Trend detection requires a single observation per period (one per week for example). Multiple samples per period generally serve no purpose and represent wasted resources. For this analysis additional samples within the sample were removed prior to calculating the level of missing data (shown in Table 1). Many extra weekly samples were taken for both Chelgiup Creek and Kalgan River during 1992 and 1993, which may have been a result of a sampling regime designed to suit loading information objectives. Simulation studies on optimal timing of fixed-interval monitoring has demonstrated that samples collected at intervals less than fortnightly are not independent (they are correlated) and yield less information per sample (Smith and McBride 1990).

Figure 4 provides a graphical representation of where samples were collected in relation to three years of flow in Robinson Drain. It shows there were extensive periods when no samples were collected, especially in for example 1995 and 1996. Many of the samples collected during these years appear to have been collected in response to a storm event (high flows) suggesting opportunistic sampling. This method of inconsistent sampling creates multiple observations in data series and complicates the detection of trends in ambient nutrient concentrations. Opportunistic sampling appears to have been replaced in late 1996 for more regular fixed sampling intervals. As shown in Figure 4 most samples were collected during low to medium flow periods which is usually the case for fixed-interval regimes.

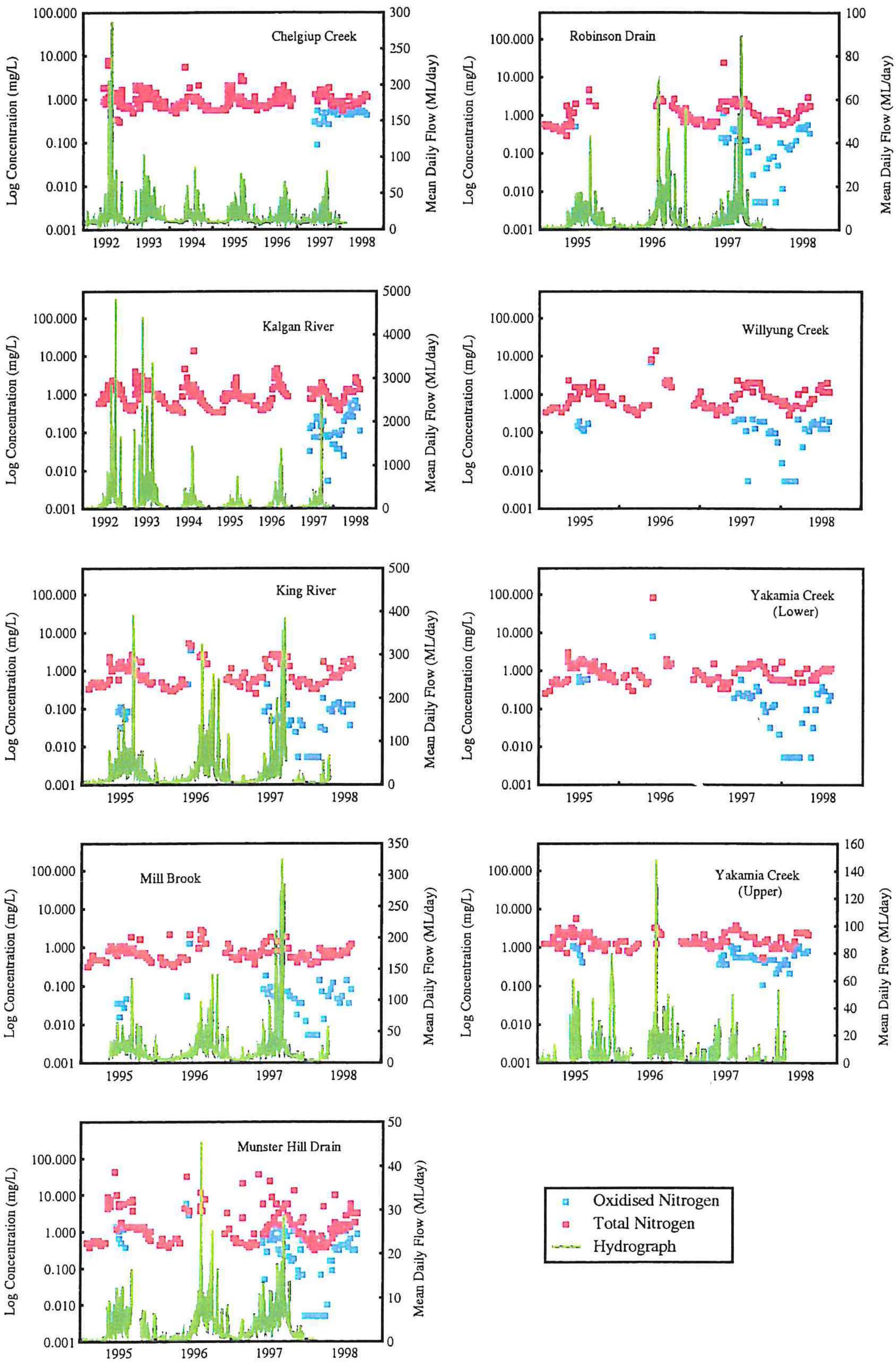


Figure 2. Nitrogen species concentration compared to tributary flow.

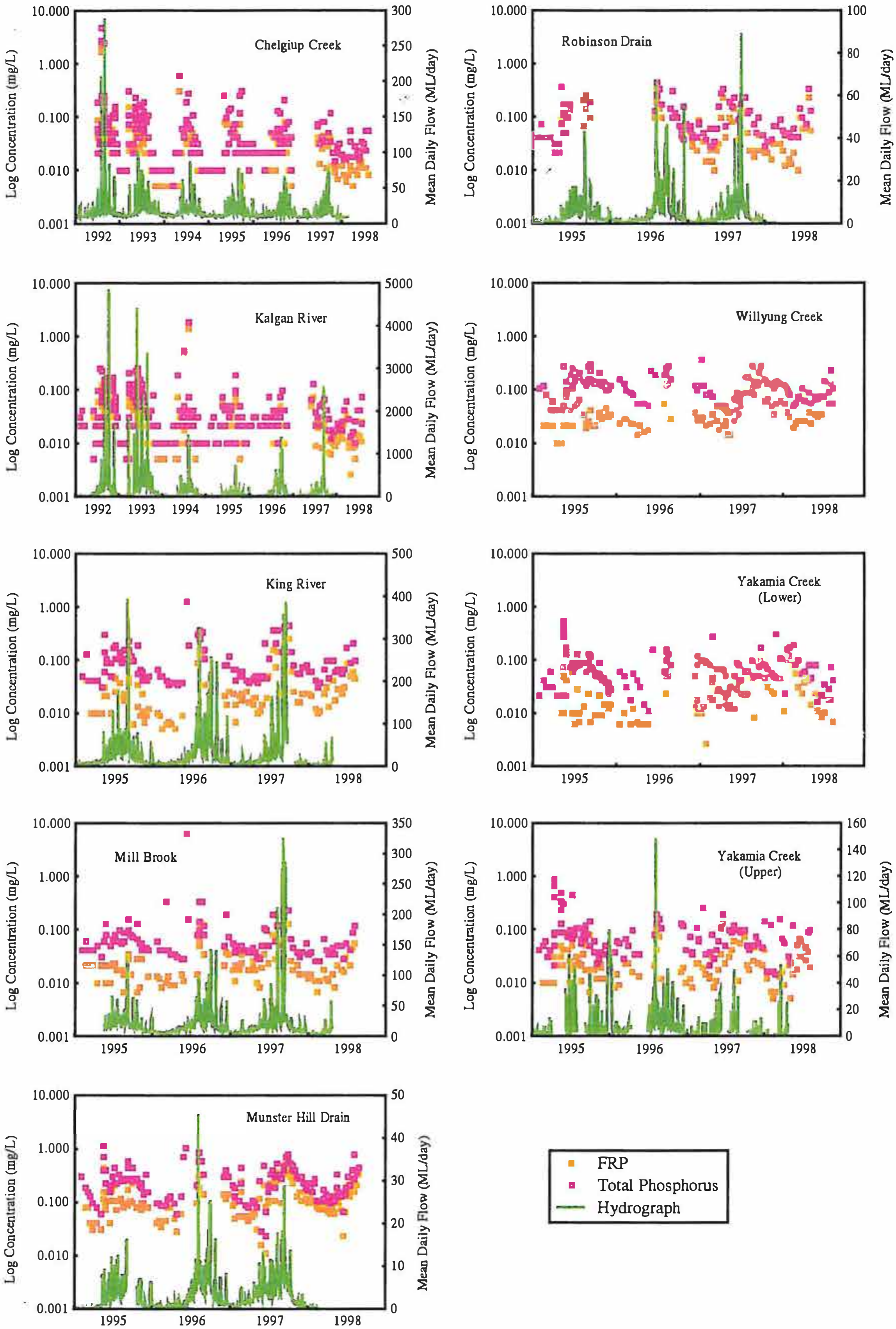


Figure 3. Phosphorus species concentration compared to tributary flow.

Table 1. Percentage of missing samples using the sampling interval for each year.

Compliance with the sampling program would result in 0 percent missing data. Any difference from this sampling goal is a measure of how well the sampling was performed in relation to the sampling program at the time.

Site	Year	Sampling Interval	Weeks of Flow per Year	Samples Taken per Year	Multiple Samples per Period	Missing data (%)
Chelgiup Creek	1992	Weekly	52	27	20	48%
	1993	Weekly	52	34	16	35%
	1994	Weekly	52	32	0	38%
	1995	Weekly	52	37	3	29%
	1996	Weekly	52	31	4	40%
	1997	Fortnightly	52	15	0	42%
Kalgan River	1992	Weekly	52	36	21	31%
	1993	Weekly	52	33	20	37%
	1994	Weekly	52	34	0	35%
	1995	Weekly	52	34	4	35%
	1996	Weekly	52	31	5	40%
	1997	Fortnightly	52	15	0	42%
King River	1995	Weekly	52	33	2	37%
	1996	Indeterminate	52	19	0	64%
	1997	Fortnightly	52	26	3	0%
Mill Brook	1995	Weekly	52	32	2	38%
	1996	Indeterminate	52	20	0	62%
	1997	Fortnightly	52	26	3	0%
Munster Hill Drain	1995	Weekly	52	32	2	38%
	1996	Indeterminate	52	19	0	62%
	1997	Weekly	52	43	0	17%
Robinson Drain	1995	Weekly	52	19	2	64%
	1996	Indeterminate	52	16	3	69%
	1997	Fortnightly	52	26	3	0%
Willyung Creek	1995	Weekly	N/A	33	3	N/A
	1996	Indeterminate	N/A	20	0	N/A
	1997	Fortnightly	N/A	26	3	N/A
Yakamia Creek (Lower)	1995	Weekly	N/A	33	2	N/A
	1996	Indeterminate	N/A	18	0	N/A
	1997	Fortnightly	N/A	26	3	N/A
Yakamia Creek (Upper)	1995	Weekly	48	34	2	35%
	1996	Indeterminate	52	19	0	64%
	1997	Fortnightly	52	26	3	0%

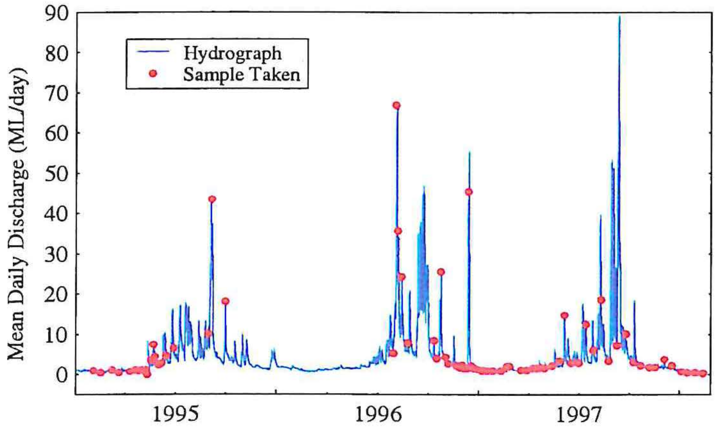


Figure 4. An example of a time series analysis of Robinson Drain showing sampling frequency in relation to the hydrograph.

2. Ambient nutrient concentrations at the monitored sites

2.1 Introduction

Existing analytical data were collated, verified and matched with the flow record. The data was examined to determine the types of information that could be obtained using recognised statistical approaches.

These analyses have allowed:

- Comparison among sites (streams);
- Comparison among seasons;
- Show relationships between concentration and flow;
- Establishment of classification of streams based on nutrient concentrations.

Description of changes with time was not possible since only three years of data were available at the correct frequency. Loading calculations were also made using simulation software developed by the Water & Rivers Commission River and Estuary Investigations section.

In order to assist in interpretation of this report common terms and conventions are described in the following section.

2.2 Describing data – means, medians and percentiles

The result of sampling a river over a period of time is set of data containing a range of values, some of which will be relatively high, some low, and the rest in between (Figure 5). The number of values within any particular concentration range is diagnostic and characteristic of the sampled river. The **spread** of the data between a concentration range is called the data distribution (Figure 5). The distribution of the data hopefully approximates the distribution of phosphorus in the sampled river. It shows that all of the data values lie between the minimum and maximum concentration, or the spread of the distribution. Most of the data lies between 0.1 and 0.4 mg/L. In the distribution shown, five percent of the data lies below 0.04 mg/L and five percent greater than 0.65 mg/L (Figure 5).

A point of interest is the measure of ***central tendency*** of the distribution. Measures of central tendency include the average (mean) and the median concentration (Figure 5). The average concentration tends to be sensitive to extreme values, so infrequent high values may disproportionately affect the average concentration, for example the average of 0.28 mg/L in Figure 5 is probably a biased estimate of central tendency of phosphorus in the Harvey River. The median concentration is insensitive to outliers and is therefore the preferred measure of central tendency for hydrologic data (Figure 5).

Other summary descriptors of the data distribution are ***percentile concentrations***. Percentiles refer to the proportion of results (of the data distribution) that fall above or below a concentration value. For example, stating that a 95 percentile nitrogen concentration from a set of data is 0.66 mg/L means that only five percent of the samples contained more than 0.66 mg/L.

A data set from a pristine river will have a different distribution than one from an impacted river. Measures of central tendency are often used to compare differences in water quality between sites. The difference may be best observed using a measure of central tendency, or using a percentile from the lower end or the upper end of the distribution. Changes in a river's water quality will be reflected in the distribution of the sampled data. For example, as water quality improves the distribution in Figure 5 will shift left and if water quality degrades the distribution will shift right.

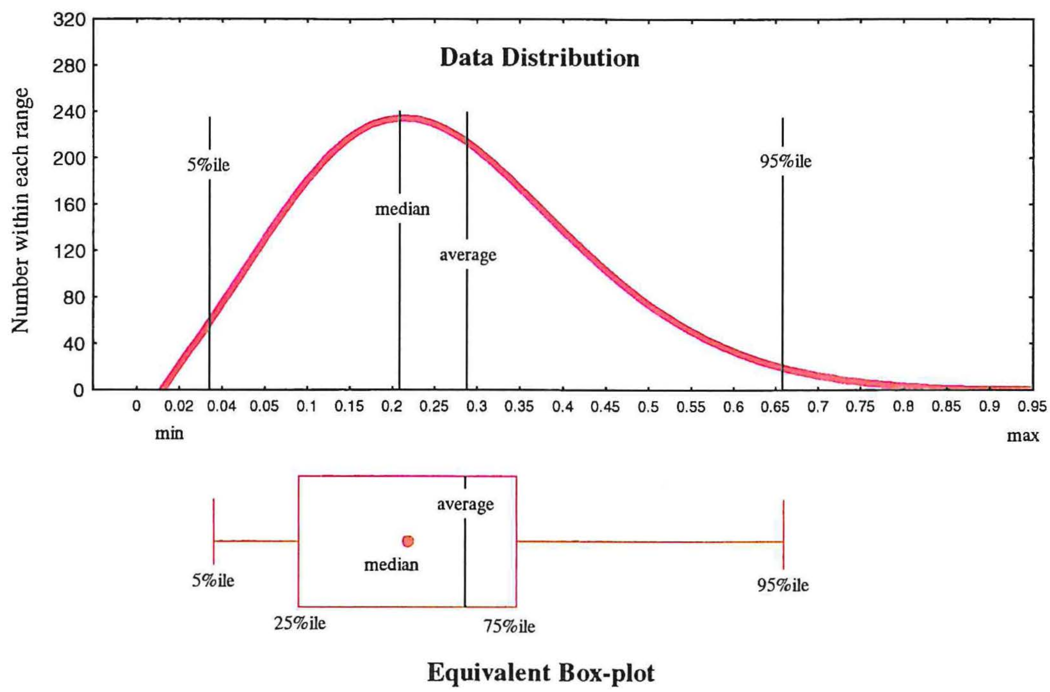


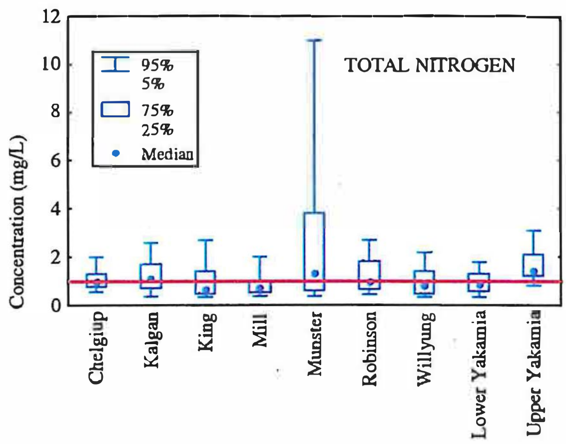
Figure 5. An example of a data distribution of phosphorus concentrations from 10 years of monitoring in the Harvey River. The lower plot shows a box plot of the same data set.

As the entire distribution of data moves along the x-axis, any measures of central tendency may also shift; that is, the median or average concentration wirl change. In this way measures such as averages or medians are often used to compare water quality between sites and over time. Changes in water quality may be less general and, for example, result in fewer high concentrations only. Such a situation will be reflected not by changes in central tendency (which may not move) but by a decrease in the upper percentiles of the distribution. To describe improvements that decrease the frequency of high concentrations, upper percentiles of the data distributions will be the most sensitive statistic to compare.

Long-term trends in nutrient data distributions between years can reveal changes in hydrology or land use, such as improvements in land management practises (Evans *et al* 1998). However, changes in nutrient concentrations between years may simply reflect variation in rainfall and river flows between years (Helsel *et al* 1992) and subsequently need to be removed prior to trend analyses. Seasonal variation in nutrient concentration can also influence the choice of analytical procedures to detect trends in a data series (Esterby 1996). Measures of central tendency and percentile limits can also be utilised to develop water quality classification schemes and to determine river compliance with water quality targets (Ellis 1989).

2.3 Spatial comparison in nutrient concentration

Box-plots are used to examine differences in nutrient concentration between the monitored sites for both the Princess Royal and Oyster Harbour basins (Figure 6). Box-plots retain many of the features evident from the data distribution, including the location of central tendency, percentiles and the spread of the sampled population.



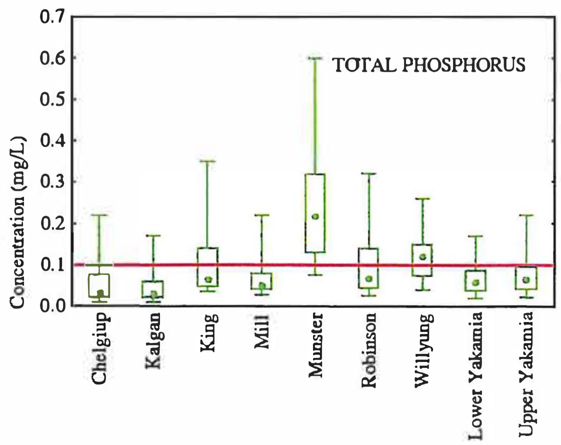


Figure 6. Total nitrogen and total phosphorus concentrations for sites in the Albany Harbours catchment using all available data.

Medians with 50 and 90 percent percentile ranges are given for each tributary's monitoring period. The red line indicates the guideline concentrations.

2.3.1 Nutrients in tributaries of Princess Royal Harbour

Only two monitoring sites are located in the catchment of the Princess Royal Harbour, located on both Munster Hill Drain and Robinson Drain (Figure 1). Robinson and Munster Hill drains drain water from the western regions of Albany. Both drains join prior to emptying into the Princess Royal Harbour.

Nitrogen

The plots indicate that the Munster Hill Drain is polluted with nitrogen (Figure 6). The concentration of nitrogen ranges between a minimum of 0.32 and a maximum of 45 mg/L, with a median nitrogen concentration of 1.4 mg/L. The higher percentile concentrations in the Munster Hill Drain were greater than found in the other monitored sites, but the lower percentile nitrogen concentrations were low and comparable to those found at the other monitored sites (Figure 6). The fixed-site weekly sampling cannot reveal catchment-scale variations or identify (with certainty) the source of nitrogen to the drain, but the shape of the sample distribution can provide clues. The skewed distribution toward the low concentrations suggests that the sources of nitrogen to the drain were episodic, reflecting a random coincidence of sampling with a plug of nitrogen-polluted water. Episodic nitrogen sources include, for example rainfall runoff from partial source areas, inputs from low lying waterlogged areas, or animal wastes in runoff from small areas such as stock yards. Discharges of nitrogen-rich industrial effluent can also be episodic.

Robinson Drain is the other monitored tributary that discharges to Princess Royal Harbour. Nitrogen concentrations were comparable to those from other monitored sites with a median concentration of 1.0 mg/L (Figure 6). Leaching of applied fertilisers and atmospheric nitrogen by leguminous pastures is thought to be an important source in the Robinson Drain. Animal wastes from grazing stock that have unrestricted access to the drain are also thought to contribute nitrogen.

Phosphorus

Munster Hill Drain is also polluted with phosphorus. The spread of the phosphorus distribution was from 0.22 to 1.0 mg/L with a median concentration of 0.23 mg/L (Figure 6). Both upper and lower percentiles were higher than for any other monitored site in the Albany Harbours basin suggesting a definite deviation from 'normal' conditions. The upward shift in the sampled phosphorus population suggests consistent sampling of polluted water. Continuous phosphorus sources include large groundwater nutrient plumes or large, permanent point or diffuse sources. These long-term sources will also produce a high measure of central tendency and increased low-percentile estimates.

Phosphorus concentrations in Robinson Drain were slightly elevated at the upper percentiles and had a low median concentration of 0.07 mg/L (Figure 6). The ranges of concentrations were similar to those attained by the King River and Willyung Creek in the Oyster Harbour basin. The slightly skewed distribution to favour low concentrations of phosphorus indicates that sources are episodic, ie. flushing events or large point sources.

2.3.2 Nutrients in the tributaries of Oyster Harbour

Other monitored tributaries drained the larger Oyster Harbour basin (Figure 1). These included the Kalgan River that drains approximately 80 percent of the basin and a major tributary (Chelgiup Creek) that extends to the eastern region of the basin. The King River also empties into the Oyster Harbour; monitored tributaries of which include Willyung Creek, which drains the south of the King catchment, and Mill Brook, which drains the north of the King catchment. Yakamia Creek drains both the northern and eastern sides of Albany and was sampled at upper and lower catchment sites. The upper site is located within the town of Albany while the lower site is located closer to its discharge point into Oyster Harbour.

Nitrogen

With the exception of the Upper Yakamia Creek site, most of the monitored sites in the Oyster Harbour basin had a similar nitrogen concentration distribution with median concentrations ranging from 0.7 to 1.1 mg/L (Figure 6). The similar-shaped data distributions suggest that similar types of land use might exist for the catchments. The major land use in the Oyster Harbour basin is cattle and sheep grazing, with some dairies, piggeries and residential areas. Nitrogen concentrations in these tributaries are slightly elevated compared to those observed in pristine rivers. Generally, 30 percent or more of the sampled population for these sites exceeded 1.0 mg/L. The slight upward shift in nitrogen concentration may be caused by a permanent diffuse source of nitrogen. The leaching of fertilisers and the fixing of atmospheric nitrogen by subterranean clover in agricultural soils is thought to contribute towards the diffuse source. Although the general shift in the nitrogen distributions observed for the sites is not large, it may indicate that further monitoring is needed since there are sources of nutrient inputs.

Nitrogen concentrations for the upper site on Yakamia Creek were elevated. The median nitrogen concentration was 1.4 mg/L and about 90 percent of the distribution exceeded 1.0 mg/L (Figure 6). The entire shift in the distribution compared to the other sites in the Oyster Harbour basin suggests that large sources of nitrogen may be present. The Upper Yakamia Creek site runs through the residential and commercial districts of Albany, so nitrogen sources from leaking septic tanks, commercial waste dumping or groundwater plumes are likely to impact the site. The lower site on Yakamia Creek had comparatively lower nutrient concentrations with a smaller spread in the data distribution. The apparent decrease in nutrient concentrations between the upper and lower sites on Yakamia Creek suggest that nutrients are either being diluted, consumed or stored as water moves towards Oyster Harbour. The contrast in the nitrogen distribution between upper and lower catchment sites highlights the limitations imposed on such spatial analyses. That is, it fails to take a tributary's flow or volume into account and is subsequently not reflecting the quantity of nutrients entering the harbours.

Phosphorus

Both the King River and Willyung Creek had elevated phosphorus concentrations comparable to that of the Robinson Drain in the Princess Royal basin. Both sites had the largest median phosphorus concentrations and the largest distribution spread of the monitored sites in the Oyster Harbour basin. The King River had a median phosphorus concentration of 0.07 mg/L, while Willyung Creek had a median concentration of 1.2 mg/L (Figure 6). A large spread in the upper percentiles of the distribution suggested that higher concentrations of phosphorus delivered to the King River were episodic (ie. flushing events or large point sources). Although the spread of the distribution was less for Willyung Creek, the distribution appeared slightly elevated suggesting a more consistent supply of phosphorus (ie. fertiliser leachate from agricultural soils or animal waste).

The Chelgiup, Kalgan, Mill and Upper and Lower Yakamia sites recorded similar phosphorus distributions. Median phosphorus concentrations typically ranged from 0.03 to 0.06 mg/L (Figure 6). Generally, not more than 25 percent of samples from these sites exceeded 0.1 mg/L. Most had distributions that were slightly skewed towards lower concentrations, suggesting that occurrence of elevated concentrations in the streams is infrequent. However, the slightly skewed distributions may also be a function of chance sampling or representative of the type of sampling strategy used.

Chance still plays an important role in collecting grab samples that form the representative data distribution. For example, opportunistic sampling may present a bias towards sampling during periods of high flow and subsequent high nutrient levels. It will result in a sampled distribution that does not accurately reflect the true distribution of concentrations in the tributary. Fixed interval sampling is non-biased and produces a sampled distribution that is representative of the true distribution of nutrients found in the monitored tributaries.

2.4 Seasonal patterns in nutrient concentration

Seasonal patterns in nutrient concentrations for tributaries have ecological implications for receiving waterbodies such as estuaries (Thompson 1998). Seasonality is observed to occur in most south-west rivers and is defined as a predictable change in a data series that occurs within a 12 month period. Seasonal cycles of nutrient delivery are important ecologically because nutrient (and fresh water) delivery to the harbours is predictable and the life cycle of some aquatic plants (eg. macro-algae) can be attuned with a reliable input of nutrients. Figures 7 and 8 show a 'least squares' smooth of seasonal variation in total nitrogen and total phosphorus and their respective organic and inorganic fractions over a typical year. Seasonal cycles in a data series also affect methods used to detect trends in water quality and thus need to be removed prior to analysis.

With the exception of Yakamia Creek (both upper and lower sites), most sites showed evidence of seasonality in the nitrogen series. Nitrogen concentrations remained low for much of summer and autumn, but gradually increased through winter to peak in August to September (Figure 7). Peak nitrogen concentrations coincided with periods of maximum rainfall and subsequent increased catchment flushing and tributary flow. Peak organic nitrogen flushed from the catchments occurred in August to September and can be attributed to increased transport of plant material or animal waste. Peak inorganic nitrogen concentrations occurred slightly earlier in the year coinciding with first flush events (ie. June). This suggests that NO_X and NH_3 species are readily available in the catchment soil and become highly soluble and mobile in saturated soil conditions. Therefore most inorganic nitrogen loss from the Albany Harbours basin would be attributable to leachates from agricultural soils commencing with soil saturation and surface water runoff (Heathwaite *et al.* 1996).

Most monitored tributaries also showed evidence of seasonal variation in phosphorus. Phosphorus concentrations generally increased from April or May to peak around August (Figure 8). Peak phosphorus concentrations occurred at a similar time to peak nitrogen concentrations, again coinciding with peak rainfall and flushing of the catchment. Both inorganic and organic components of phosphorus were also observed to peak at this time. The inorganic component of phosphorus was generally much lower in concentration than the organic component suggesting that soil particulates, plant debris and animal waste are the major sources of phosphorus input. However, both Kalgan River and Robinson and Munster Hill drains had months where the inorganic component of phosphorus was the dominant fraction. The leaching of fertilisers from agricultural soils is thought to be an important source of inorganic phosphorus in the Kalgan River catchment; while surface runoff from local industries are the most likely sources to have contributed to high concentrations in both Munster Hill and Robinson drains.

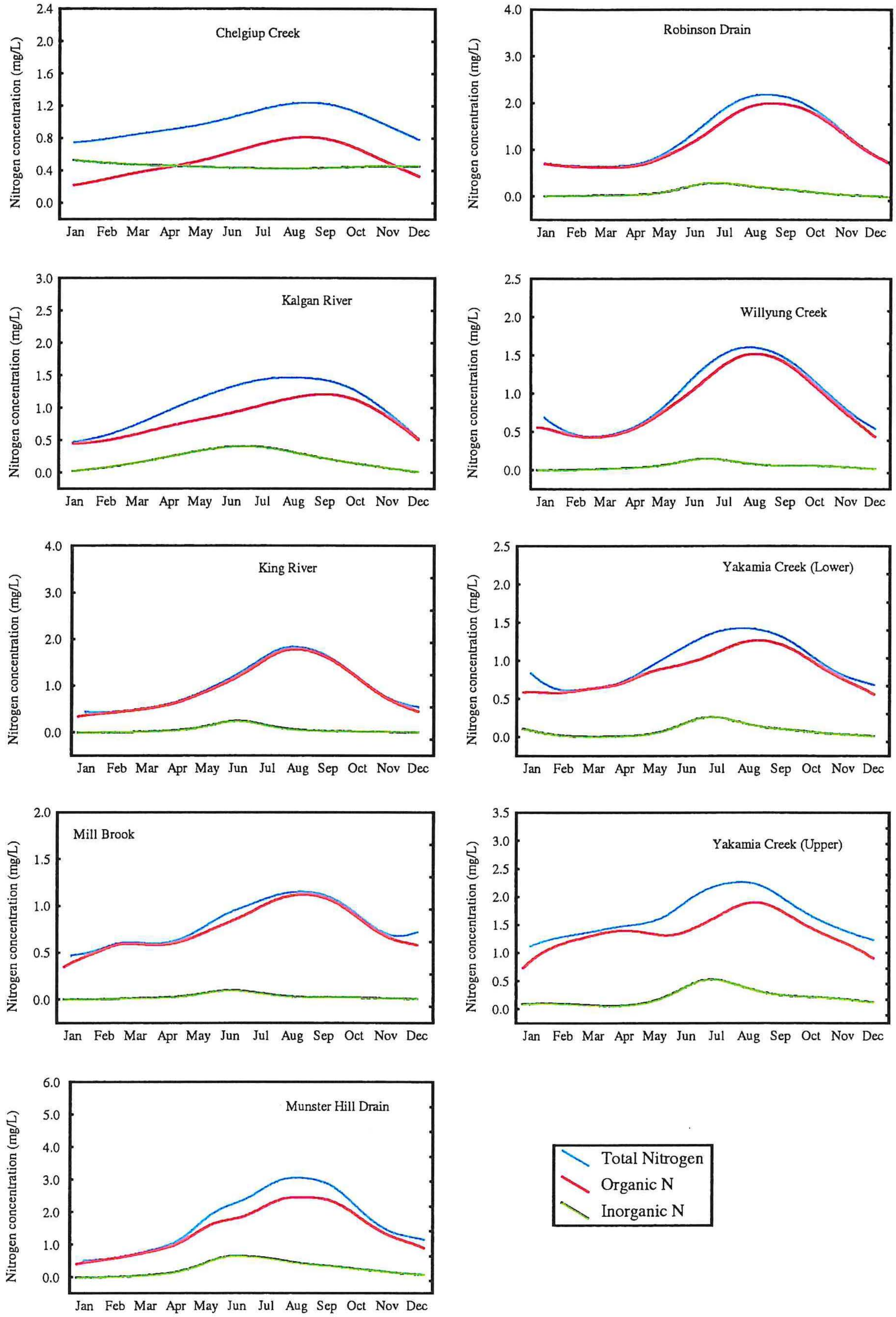


Figure 7. Seasonality pattern for total nitrogen and its fractions.

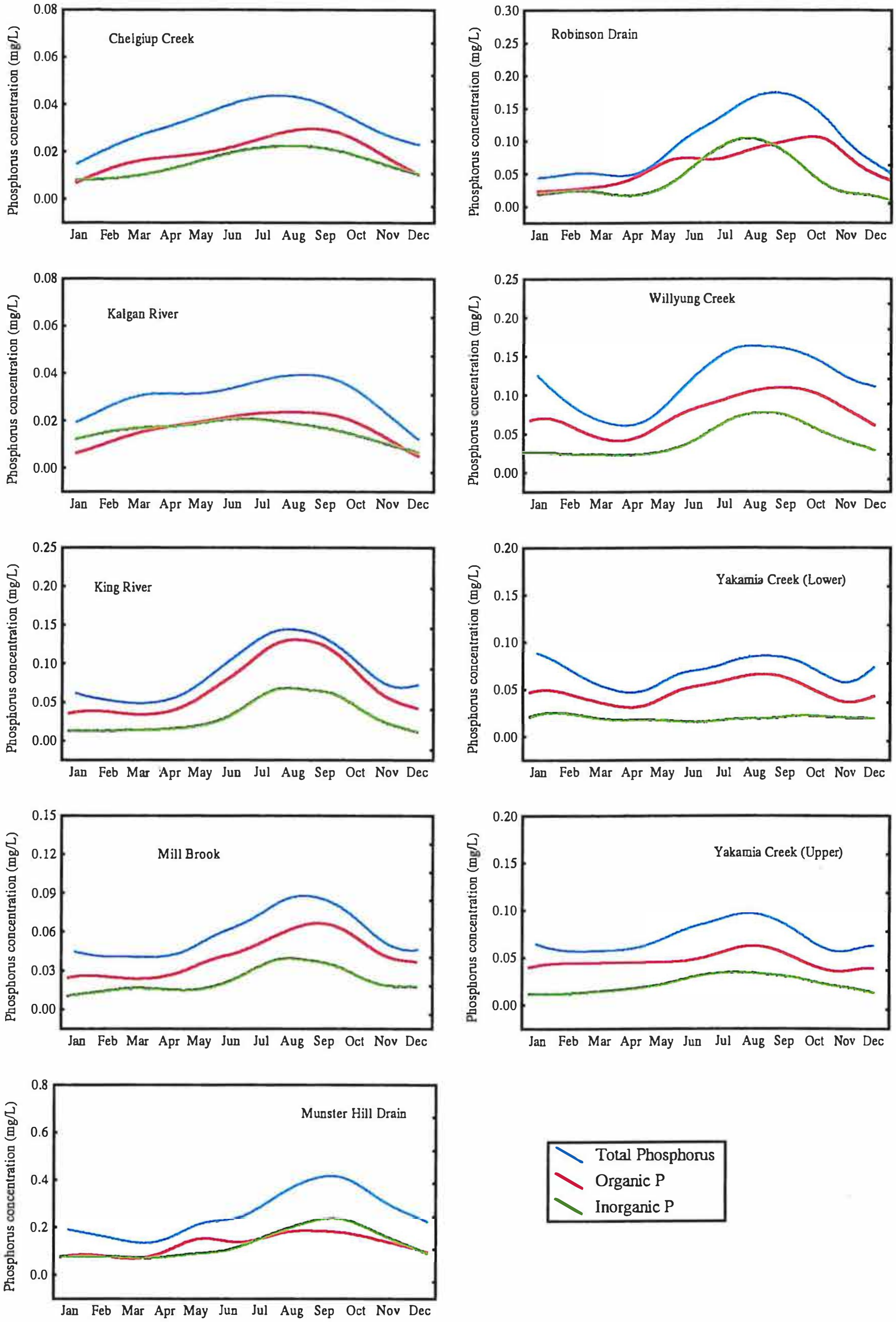


Figure 8. Seasonality pattern for total phosphorus and its fractions.

2.5 Relationships between concentration and flow

Modelling the flow response of nutrients can reveal general hydrological processes important in the delivery of nutrients to the tributary (Evans and Davies 1998). Samples collected during various stages of the hydrograph were categorised into rising limb samples (collected during periods of increasing flow), falling limb samples (collected during periods of decreasing flow), and inter-event samples (collected between storm events or base flows). Assigning limbs to samples enables the timing of the flux of nutrients to be examined with respect to various stages of storm events.

Figures 9 and 10 show most monitored tributaries have a positive flow response where an increase in flow results in an increase in nutrient concentrations (Johnson and East 1982). The plots for Robinson Drain provide a good example of positive flow responses, with a sharp increasing gradient in nutrient concentrations for base flows (inter-event) and a levelling off in concentration for higher flows (falling and rising limbs). This implies that Robinson Drain is dominated by base flows (ie. groundwater inputs) and that these sources are heavily polluted with nutrients. Flow responses can also be negative where sites are dominated by point sources (concentrations decrease with increases in flow), or they can exhibit independence between concentration and flow when multiple sources contribute nutrient input to the tributary.

Figure 9 shows the flow response for nitrogen at the monitored sites. Most sites appear to have a positive flow response for nitrogen. This means that as rainfall in the catchment increases, more nitrogen will be flushed from the catchment and tributary nitrogen concentrations will increase. As indicated by the large variation in nitrogen concentration during base flows, groundwater plays an important role in nutrient delivery to most monitored tributaries. However, in Upper Yakamia Creek and Munster Hill Drain the flow responses are not clear. The scatter evident in the tributaries flow responses suggests discharges of nitrogen are not necessarily related to changes in flow. The upper reaches of Yakamia Creek extend into Albany where many point sources of nitrogen from commercial and residential areas are likely. Munster Hill Drain runs through industrial areas where large point sources and contaminated runoff and groundwater inputs are likely.

Figure 10 shows the flow / concentrations response for phosphorus at the monitored sites. Positive flow responses were also observed in phosphorus for most monitored sites. The phosphorus flow response plots for Munster Hill Drain and Upper Yakamia Creek again indicate that they are likely to be impacted by various point sources. A large concentration variation observed during base flows suggests that groundwater also plays an important role in phosphorus delivery to the tributaries.

Flow / concentration responses tend to complicate the detection of trends in a data series and therefore need to be removed (Esterby 1996, Heathwaite *et al* 1996, Ward *et al* 1990, Hirsch and Slack 1984, Hirsch *et al* 1982). Flow effects on nutrient concentration are removed by fitting a LOWESS (Locally Weighted Scatterplot Smooth) model to the flow response. The residuals, or difference between the observed and modelled nutrient concentrations, can be considered as flow adjusted concentrations and can be utilised in trend detection methods (Gilbert 1987). This allows trends in nutrient concentrations to be quantified without simply reflecting a long-term change in tributary hydrology.

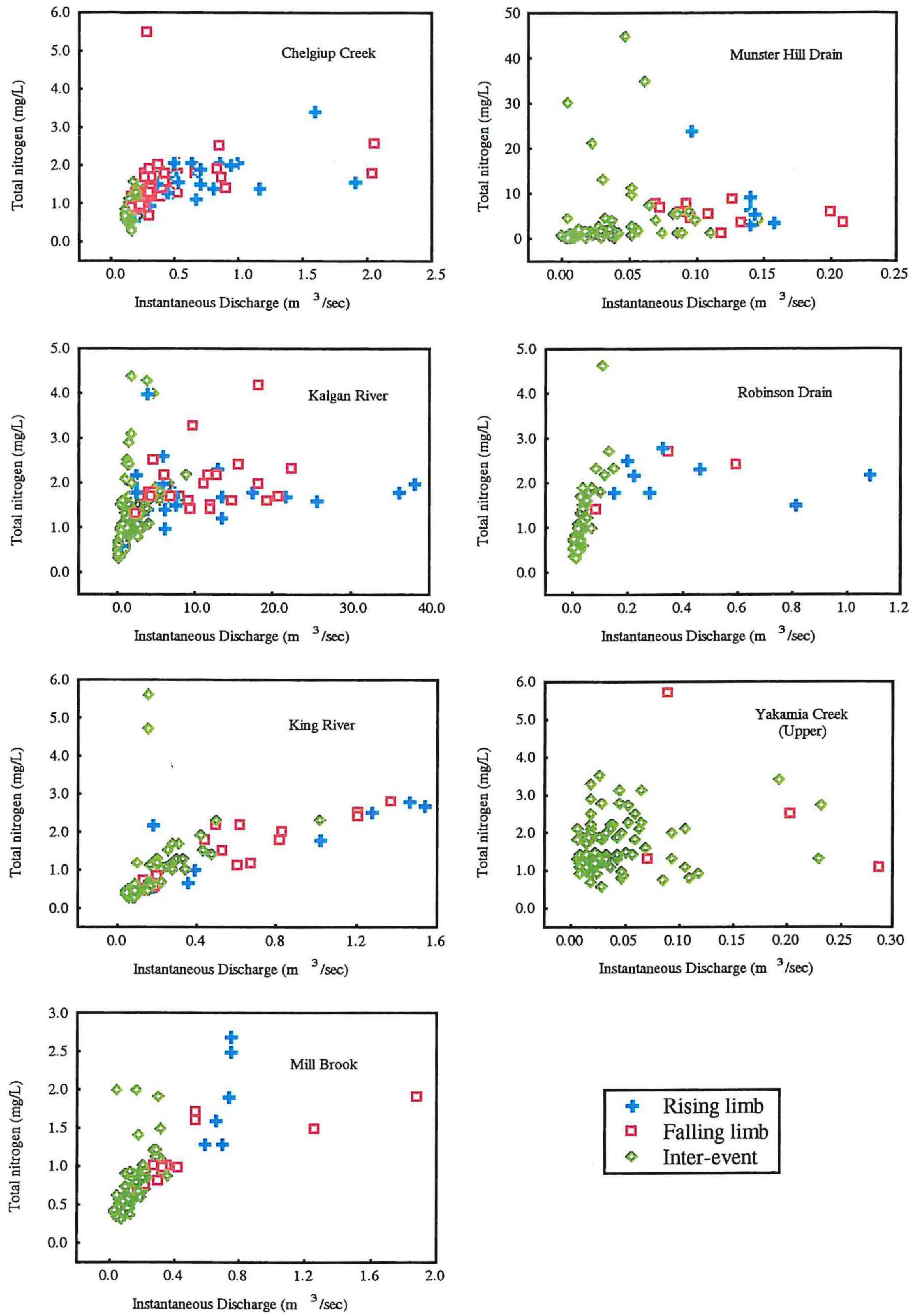


Figure 9. Flow responses for total nitrogen for monitored sites in the Albany catchment.

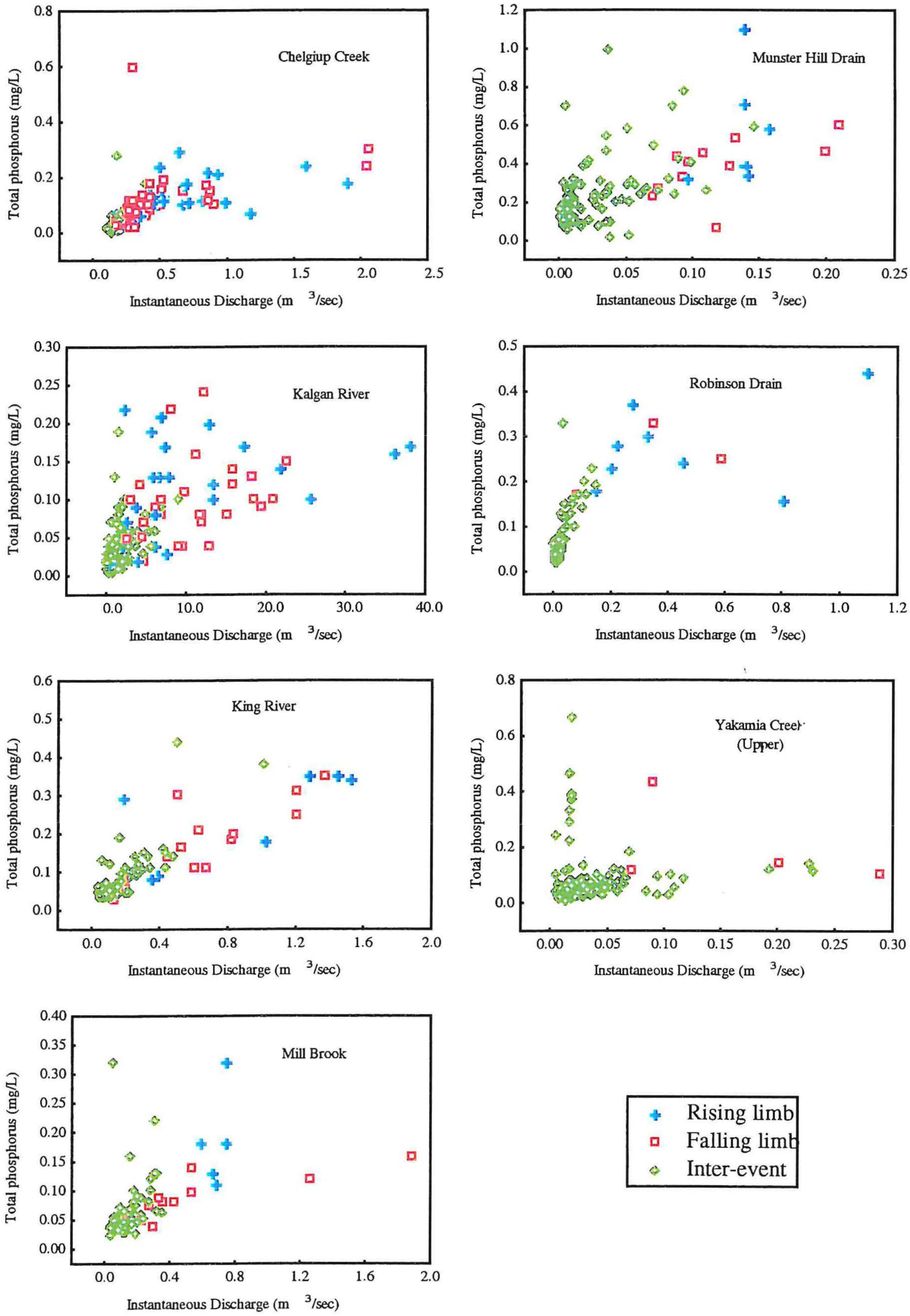


Figure 10. Flow responses for total phosphorus for monitored sites in the Albany catchment.

2.6 Temporal trends in nutrient concentration

The detection of trending periods in a nutrient data series is an accepted measure of degradation or improvement in surface water quality. For example, increasing trends can be associated with eutrophication related problems in ecological systems (Heathwaite *et al.* 1996; Robson and Neal 1996; Lettenmaier *et al.* 1991), while decreasing trends can be accredited to good management practices such as public education, improving riparian vegetation, fertiliser reduction initiatives, etc (Stoddard *et al.* 1996). With sampling frequencies that are at or near information saturation, five years of monitoring (or longer) is normally needed to detect trends (Smith and McBride 1990). Given that only three years of data were available for a majority of monitored sites at the time of this report, a statistical analysis of trending periods in nutrient concentration was not performed. Instead, historical sampling was used to recommend a nutrient monitoring program that will enable future trend information objectives to be met (Section 4).

When a sufficient amount of data becomes available non-parametric significance tests will be used to analyse for statistically significant trending periods. Non-parametric tests are useful, as they are robust when the data distribution is not normal, they are insensitive to extreme values and are not affected by missing values. Natural factors that are likely to interfere with trend detection must be recognised to determine the method of data analysis. Identification of seasonal patterns are important in ascertaining the intra-annual variation in nutrient concentration, which can be accounted for by using a Seasonal Kendall test (Gilbert 1987) or through seasonal decomposition of the data series. When the data series does not vary seasonally a Mann Kendall test can be used to test the statistical significance of observed trends. When variation in the nutrient data series is influenced by flow, the flow-adjusted series can also be analysed using the Mann Kendall test. Trends detected in this manner must be further evaluated with respect to the sampling error risks associated with a given sample size, concentration variation, and magnitude of the trend (Ward *et al.* 1990, Donohue *et al.* 1998).

2.7 Classification schemes

Classification schemes can also be used in a similar manner to spatial analysis techniques to categorise each site according to nutrient concentration. Classification methods can use either a measure of central tendency or percentiles of the data distribution to compare with classes of concentration ranges. Median concentrations are used when the distribution of data changes over time, whereas percentile concentrations are used when there is large variation at the ends of the distribution. While classification schemes can detect general changes in nutrient concentration over time, a trend analysis is necessary to statistically assess whether the change is due to chance or due to a change in concentration over time.

The Water and Rivers Commission has developed a classification system that categorises a tributary's median nutrient concentrations using five distinct concentration boundary concentrations (Table 2). Each of the monitored sites was classified in terms of their observed total nitrogen (Table 3) and total phosphorus (Table 4) median concentration over a three year running period. Three year running median periods were used to reduce the variation in nutrient concentrations due to differences in flow between years. A '90 percent confidence interval' of the median concentration is used to reduce the uncertainty associated with reclassifying a tributary's class (Ellis 1989). The class will change only when both the median and the associated confidence interval entirely move across a classification boundary concentration (Table 2); thus ensuring that there is 90 percent certainty that the running median nutrient concentration has indeed changed classes.

The nitrogen classifications for each of the monitored sites over time are shown in Table 3. Both Munster Hill Drain and Upper Yakamia Creek were consistently classed as having moderate median nitrogen concentrations over their entire monitoring periods. In the early stages of monitoring, the Kalgan River was classed as having moderate median nitrogen concentrations, but between 1994 to 1995 this changed to a low classification. This suggests a decreasing trend in nitrogen concentration, but this would need to be confirmed using trend analysis techniques to prove the change is not due to chance. Lower Yakamia Creek also changed in 1996 to 1997 from a moderate to a low nitrogen classification. The other monitored sites were consistently classed as having low median nitrogen concentrations.

The phosphorus classifications for each of the monitored sites over time are shown in Table 4. Munster Hill Drain was classed as having consistently high median phosphorus concentrations between 1995 – 1998. Willyung Creek was classed as having moderate median phosphorus concentrations over the same period, while other monitored sites were classified as having low median phosphorus concentrations. It appears that phosphorus concentrations did not vary at any of the monitored sites over their monitored periods.

Table 2. Possible classification ranges for nitrogen and phosphorus concentrations.

Classification	Total Nitrogen	Total Phosphorus
Low	< 1.0 mg/L	< 0.1 mg/L
Moderate	1.0 – 2.0 mg/L	0.1 – 0.2 mg/L
High	2.0 – 3.0 mg/L	0.2 – 0.3 mg/L
Very High	3.0 – 4.0 mg/L	0.3 – 0.5 mg/L
Extreme	> 4.0 mg/L	> 0.5 mg/L

Table 3. Classifications of total nitrogen in tributaries of the Albany Harbours catchment.
Because of the difference in length in the some data series, the scale was broken into two segments to accommodate for the different periods of analysis.

Waterway	1992	1992/93	1992-94	1993-95	1994-96	1995-97	1996-98
Chelgiup Creek	Low	Low	Low	Low	Low	Low	Low
Kalgan River	Moderate	Moderate	Moderate	Moderate	Low	Low	Low
				1995	1995-96	1995-97	1996-98
King River				Low	Low	Low	Low
Mill Brook				Low	Low	Low	Low
Munster Hill Drain				Moderate	Moderate	Moderate	Moderate
Robinson Drain				Low	Low	Low	Low
Willyung Creek				Low	Low	Low	Low
Yakamia Creek (Lower)				Moderate	Moderate	Moderate	Low
Yakamia Creek (Upper)				Moderate	Moderate	Moderate	Moderate

Table 4. Classifications of total phosphorus in tributaries of the Albany Harbours catchment.
Because of the difference in length in the some data series, the scale was broken into two segments to accommodate for the different periods of analysis.

Waterway	1992	1992/93	1992-94	1993-95	1994-96	1995-97	1996-98
Chelgiup Creek	Low	Low	Low	Low	Low	Low	Low
Kalgan River	Low	Low	Low	Low	Low	Low	Low
				1995	1995-96	1995-97	1996-98
King River				Low	Low	Low	Low
Mill Brook				Low	Low	Low	Low
Munster Hill Drain				High	High	High	High
Robinson Drain				Low	Low	Low	Low
Willyung Creek				Moderate	Moderate	Moderate	Moderate
Yakamia Creek (Lower)				Low	Low	Low	Low
Yakamia Creek (Upper)				Low	Low	Low	Low

2.8 Compliance testing of nutrients in rivers using targets

Compliance testing can be used to assess the progress of catchment management programs. Compliance testing will allow a tributary's performance to be assessed by using targets to make a simple 'pass' or 'fail' decision about its water quality. Water quality targets should be realistically achievable, they should be statistically testable and should be easily interpreted so managers can easily understand the technical requirements of the compliance monitoring scheme. The binomial distribution is used to determine a critical number of samples that is needed in a sampled population before the compliance test is deemed to have failed at the accepted error levels (ie. α=0.05). Compliance testing does not provide answers as to why a tributary passed or why it failed. However, with proper statistical analysis and incorporation of associated error risks it is certain that chance has little (if nothing) to do with the pass / fail decision (Ellis 1989, Ward et al. 1991).

The concentration ranges used in the classification of each tributary (as shown in Table 2) can be utilised to develop targets for total nitrogen and total phosphorus concentrations. It is reasonable to expect that, given enough time, effective management would result in all tributary inflows having a 'low' classification for both total nitrogen (less than 1.0 mg/L) and total phosphorus (less than 0.1 mg/L) concentrations. However, in all reality, this objective may only be achieved after many years of *effective* catchment management.

Consequently, short-term targets are needed to provide interim goals for reducing nutrients in those monitored tributaries with moderate, high, very high or extreme nutrient concentrations. Short-term (for example eight years) target concentrations of 2.0 mg/L for nitrogen and 0.2 mg/L for phosphorus should be used for those tributaries that need to improve to at least a 'moderate' classification. Those with a current 'low' classification need only maintain their present water quality condition. Compliance testing on each tributary can then be performed based on the proposed management term and the current water quality.

Compliance with a target concentration indicates that the nutrient variable should be at or below the target for a majority of the compliance period analysed, while those that fail the compliance test have nutrient concentrations that are greater than the target for a majority of time. Using the 1995-97 compliance period as an example (shown in Tables 5 and 6), all monitored Albany Harbour tributaries with a 'low' nitrogen or phosphorus classification were deemed to have passed the nominated long-term target concentrations and will be expected to maintain that water quality condition. Both Munster Hill Drain and Upper Yakamia Creek, with moderate nitrogen classifications, failed the long-term target but passed the short-term target, while Lower Yakamia Creek passed both long and short-term nitrogen targets. Munster Hill Drain had a high phosphorus classification and failed both long and short-term targets, while Willyung Creek had a moderate phosphorus classification and failed the long-term target only.

Table 5. An example of total nitrogen targets that could be used in the short-term (eg. until 2004) for each of the monitored inflows. The table shows how the compliance scheme would operate in the Albany Harbours catchment.

Waterway	1995–97 Classification	Short or Long Term Target	Target TN Concentration	Number of Samples	Fail Criteria	Number of Samples > Target	Outcome
Chelgiup Creek	Low	Long	1.0	86	51	33	Pass
Kalgan River	Low	Long	1.0	86	51	30	Pass
King River	Low	Long	1.0	82	48	32	Pass
Mill Brook	Low	Long	1.0	82	48	19	Pass
Munster Hill Drain	Moderate	Short	2.0	95	56	38	Pass
		Long	1.0	95	56	58	**Fail**
Robinson Drain	Low	Long	1.0	71	42	31	Pass
Willyung Creek	Low	Long	1.0	84	50	32	Pass
Yakamia Creek (Lower)	Moderate	Short	2.0	82	48	1	Pass
		Long	1.0	82	48	34	Pass
Yakamia Creek (Upper)	Moderate	Short	2.0	83	49	22	Pass
		Long	1.0	83	49	74	**Fail**

Table 6. An example of total phosphorus targets that could be used in the short-term (eg. until 2004) for each of the monitored inflows. The table shows how the compliance scheme would operate in the Albany Harbours catchment.

Waterway	1995–97 Classification	Short or Long Term Target	Target TP Concentration	Number of Samples	Fail Criteria	Number of Samples > Target	Outcome
Chelgiup Creek	Low	Long	0.1	86	51	10	Pass
Kalgan River	Low	Long	0.1	86	51	2	Pass
King River	Low	Long	0.1	82	48	32	Pass
Mill Brook	Low	Long	0.1	82	48	14	Pass
Munster Hill Drain	High	Short	0.2	96	56	59	**Fail**
		Long	0.1	96	56	79	**Fail**
Robinson Drain	Low	Long	0.1	71	42	25	Pass
Willyung Creek	Moderate	Short	0.2	84	50	13	Pass
		Long	0.1	84	50	51	**Fail**
Yakamia Creek (Lower)	Low	Long	0.1	82	48	14	Pass
Yakamia Creek (Upper)	Low	Long	0.1	83	49	19	Pass

3. Nutrient loading

When using a fixed-interval sampling regime, load estimation methods are a less effective measure of catchment condition than measuring changes in tributary nutrient concentration. However, nutrient loads are still required for nutrient budget assessments of both Princess Royal and Oyster harbours and serve as an indicator for catchment source. From an estuary point of view annual loads are in themselves not very informative unless the timing and frequency for nutrient delivery is also understood. Nutrient load estimates can be generated from fixed-interval data, although these estimates are likely to be biased and imprecise depending on many factors. In the interest of meeting the continuing need for accurate loading estimates to the Albany Harbours, autosamplers should be used on the monitored tributaries to provide information on nutrient flux at various stages of the hydrograph. Only then will estimates of nutrient loads be more accurate and contain a known precision.

Recognising the continued importance of load measurement a programmable autosampler was installed on the Kalgan River in 1998.

3.1 Load estimation method

Load estimates are calculated as the annual summed products of flow and concentration measurements. Flow in the monitored tributaries of Albany Harbours was measured continuously at gauging stations located at the point of sample collection. For this report, nutrient load estimates generated from fixed-interval sampling were modelled using the Beale Ratio Estimator method which calculates mean daily loading rate and multiplies it by the number of days in the year to obtain total annual nutrient loads (Richards and Holloway 1987, Littlewood 1992). This method was found to give the most precise load estimates from any load estimation strategy used. Linear interpolation was not a viable option for the calculation of annual loads in 1995 and 1996 due to large intervals of missing data for much of their annual flow periods. An inadequate representation of the entire flow / concentration relationship (especially for high flows) for most monitored sites meant the extrapolation method was also unsuitable for calculating loads. Littlewood (1992) discusses the benefits and disadvantages of using these various load calculation strategies.

Flow Weighted Concentrations (FWC's) were calculated as the ratio of load to volume of water discharged from the tributary and were used to remove the effect of flow from the load estimates.

3.2 Bias / precision errors in load measurements]

Where non-point sources are the major constituent of a nutrient load many factors conspire to produce imprecise and biased load estimates. As mentioned previously, measures to control or quantify these factors were not considered during the design of past monitoring programs. Richards and Holloway (1987) state that the reported estimates of nutrient loads are likely to be biased by differing amounts depending on the pattern and frequency of sampling, the calculation method used, the catchment size, and the behaviour of the chemical species being monitored. Hydrographic rating curve techniques used for generating flows from stage heights have also shown to be biased and are likely to generate variable systematic errors in nutrient load estimates (Dean and Marks 1995). Estimates of the errors are shown in Table 7 for the monitored Albany tributaries (WRC unpublished data).

Table 7. Percentage error estimates for the hydrographic rating curves at each of the monitored site's gauging stations (WRC, unpublished data).

Site	Error Estimates in Hydrographic Rating Table
Chelgiup Creek	5%
Kalgan River	7%
King River	30%
Mill Brook	20%
Munster Hill Drain	30%
Robinson Drain	5%
Yakamia Creek (Upper)	30%

Nutrient loads in rivers are difficult to quantify due to unpredictable timing of nutrient fluxes during relatively short periods of elevated flow and a strong serial correlation between concentration measurements within a runoff period (Richard and Holloway 1987). These effects are likely to be exacerbated in the case of small or flashy catchments (Cohn 1994) which are common in the Albany basin. Imprecision in the load estimates occurs due to the unpredictable alignment of fixed time interval sampling with nutrient fluxes and the hydrograph. Sampling patterns produce biased estimates where the sampling interval selectively misses storm events or where storm events are irregularly targeted.

The method chosen to calculate load estimates may also introduce variation in the loading estimates (Preston *et al.* 1989, Littlewood 1992). However, the Beale Ratio Estimator used in this analysis corrects for an underestimate in nutrient loads generated from fixed-interval sampling (Richards and Holloway 1987, Littlewood 1992), but the accuracy of the correction is unknown. Preliminary simulation analysis of errors in nutrient load discharged from Ellen Brook (a highly eutrophic, ground water dominated and slowly responding tributary to the Swan River) indicates that the magnitude of error in nutrient load estimates will severely restrict their use (WRC, Unpublished data).

3.3 Nutrient load estimates

Table 8 shows the results of the nutrient load estimates using the Beale Ratio Estimator method for the tributaries of Albany Harbours using fixed-interval data. Given that the amount of error in the estimates is unknown, only tentative conclusions regarding the relative contributions of nutrient load to Princess Royal and Oyster harbours can be made.

Munster Hill Drain was found to produce a higher nutrient loading than Robinson Drain in the Princess Royal Harbour basin, but given that both converge to a solitary drain they would deliver a large quantity of nutrients to the northern Princess Royal Harbour. The extensive Kalgan River contributed the bulk of the nitrogen and phosphorus delivered to Oyster Harbour. A large difference in nutrient loads for the Kalgan River between the periods 1992-94 and 1995-97 suggests a large decrease in the loads being discharged to Oyster Harbour. Whether the difference was the result of a change in sampling patterns, flows or an actual decrease in nutrients discharged is indeterminate and can only be determined through a trend analysis of the Kalgan River's ambient nutrient concentrations (detailed in Section 3.7).

In contrast, the much smaller King River contributed phosphorus loads comparable to those delivered to the Oyster Harbour by the Kalgan River for 1995 to 1997. These results should be carefully interpreted given the likely errors in the calculated loads and given that the King River catchment is at least five times smaller than the Kalgan River catchment and both share similar land uses. Focussed catchment monitoring in the King River catchment is required to determine sub-catchments where improvements in catchment management are needed.

FWCs calculated for the monitored tributaries did not reveal any consistent pattern for actual changes in nutrient load being discharged (Table 8). Flow weighted concentrations indicate that Munster Hill Drain consistently has the highest nitrogen and phosphorus annual average concentrations of the tributaries in the Albany Harbours catchment. This confirms the results obtained for the spatial analysis of ambient nutrient concentrations in Section 3.1.

Table 8. Loading estimates (tonnes) and flow weighted concentrations (FWC) for the major tributary inflows to the Albany Harbours.

Harbour	Site	Year	Nitrogen Loading		Phosphorus Loading	
			Mass (Tonnes)	FWC (mg/L)	Mass (Tonnes)	FWC (mg/L)
Princess Royal	Munster Hill Drain	1995	6.60	6.15	0.42	0.39
		1996	5.18	4.58	0.74	0.65
		1997	7.65	5.71	0.47	0.35
	Robinson Drain	1995	2.83	2.00	0.30	0.21
		1996	4.13	2.04	0.56	0.28
		1997	3.83	2.37	0.27	0.17
Oyster	Chelgiup Creek	1992	18.8	3.55	8.07	1.52
		1993	9.91	1.44	0.73	0.11
		1994	7.61	1.30	0.50	0.09
		1995	9.84	1.79	0.72	0.13
		1996	6.25	1.25	0.36	0.07
		1997	6.26	1.23	0.27	0.05
	Kalgan River	1992	117	1.62	8.80	0.12
		1993	214	2.26	12.6	0.13
		1994	169	4.63	18.9	0.52
		1995	30.4	1.28	1.47	0.06
		1996	84.0	2.04	1.66	0.04
		1997	44.9	1.33	1.54	0.05
	King River	1995	16.5	1.79	1.49	0.16
		1996	23.3	2.24	2.82	0.27
		1997	19.2	1.89	2.47	0.24
	Mill Brook	1995	7.00	1.18	0.59	0.10
		1996	19.1	3.02	2.40	0.38
		1997	8.89	1.15	0.73	0.09
	Yakamia Creek (Upper)	1995	3.93	1.80	0.28	0.13
		1996	5.06	1.42	0.57	0.16
		1997	2.52	1.75	0.14	0.10

4. Recommended monitoring program design

Currently, large unquantifiable errors in the methods used to calculate loads using fixed-interval data have generated nutrient load estimates that are biased and imprecise by variable amounts in different years. Analytical tools are currently being developed by the Water and Rivers Commission that will calculate the precision in nutrient load estimates using fixed-interval data. To meet the need for reliable estimates in nutrient loading to Oyster Harbour, a programmable autosampler has been installed to take samples at the Kalgan River gauging station at critical points in the storm hydrograph. This will allow the calculation of (comparatively) accurate nutrient load estimates together with an estimate of precision.

Ultimately, the aim of nutrient monitoring in the Albany catchment is the identification for trends in nutrient concentrations that reflect tributary changes could be of practical significance to environmental managers in the Albany Harbours catchment and would be a useful aim for any future nutrient monitoring. Based on results from similar trend analyses carried out on data series from the Swan Canning Estuaries and Wilson Inlet monitoring programs (Donohue *et al.* 1998, Donohue *et al.* in prep), it is recommended that similar information objectives should be used for the Albany Harbours monitoring program. More explicitly, the recommended information objective for monitoring of nutrient concentrations at inflows to the Albany Harbours is to detect, in a five year minimum period, a trend in nutrient concentration at least 1.32 times the standard deviation of the de-trended data series (using error risks of $\alpha = 0.05$ and $\beta = 0.1$). Alpha and beta represent the statistical error risks associated with falsely detecting a trend and failing to detect a trend respectively (Ward *et al* 1990).

In meeting these requirements, the monitoring program must be designed and implemented as efficiently as possible. This effectively means that a minimum number of samples should be collected to meet the monitoring program objectives. To detect a trend of magnitude 1.32 times the standard deviation of any de-trended data series requires that at least 74 independent samples be collected in any five year period (Donohue *et al.* 1998). There are two constraints in selecting the sampling interval to achieve the minimum number of samples in the period. They must be collected in intervals equal to fortnightly or greater to avoid serial correlation in the data series, and they must also be collected more frequently than once a month because too few samples will be available after five years. Given that most of the monitored tributaries in the Albany Harbours catchment are permanent and allowing some room for sampling error, this equates to fortnightly, fixed-interval samples taken throughout the year (Donohue *et al.* 1998).

A compliance monitoring scheme can be used to make a simple 'pass' or 'fail' assessment of each tributary's water quality in relation to nutrient target concentrations with both short and long-term management objectives in mind. Several factors need to be considered when designing the compliance test; including the number of samples in the population, the test to be considered, the critical number of samples allowed to exceed the target concentration, and the accepted statistical error risks. Ultimately, the long-term goal is for all monitored tributaries to reach a 'low' nutrient classification and consistently pass the compliance test using predetermined target concentrations.

Implementation of the recommended monitoring program will enable managers of the Albany Harbours catchment to best meet the current information requirements of the nutrient monitoring program from both nutrient loading and trend perspectives. Ultimately the program is designed to provide an efficient, informative and cost-effective means of analysing the nutrient data series. The results will provide an accurate measure of change in tributary's water quality and a better understanding of the impact that nutrient inputs has on macro-algae populations and seagrass stocks within Princess Royal and Oyster harbours.

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