# Relationships between the extent of conventional, broadscale agriculture and stream phosphorus concentration and phosphorus export in South-West Western Australia

Geoffrey Bott

Discussion Paper No. 2
March 1993

Office of Catchment Management, Perth, Western Australia

## Preface

Over the next twelve months the Office of Catchment Management will be preparing a number of public discussion papers in the interests of integrated catchment management to seek input on a range of issues, including the role and function of catchment groups, extent of local decision-making, options for funding, community involvement and so on. The papers will not usually be technical unless there is a very good reason. Even then, it is intended that they should be readily understandable and user friendly.

This particular paper is a little different and has arisen from the unique opportunity afforded to us by the temporary secondment of Mr Geoff Bott from the Environmental Protection Authority to the Office of Catchment Management. The State has invested a large amount of money over the years in various aspects of monitoring in many of the south west catchments. This has resulted in the collection of a great deal of information relevant to specific management issues in the catchment systems. Although the data collection side has been well supported, and the specific issues have been addressed (eg developing a management strategy for the Peel-Inlet and Harvey Estuary) the opportunity to revisit, process and interpret these data to uncover broader relationships have not been so well provided for. Given the large cost involved in the data collection, allocating some staff time to carry out this task was a high priority. Mr Bott's secondment provided a rare opportunity to add value to the State in this way.

Although relatively technical, the paper has been prepared in the interests of integrated catchment management and has been written so that the author's thinking can be easily followed. It is a "without prejudice" document. The paper represents the findings of the author and does not represent any agency position. Its intention is simply to document some interesting findings and to stimulate discussion of the assertions and issues it raises.

The findings have important ramifications for retention of vegetation, revegetation/rehabilitation of catchments, as well as for planning and environmental management of these systems. There is merit in further testing some of the findings by experimentation and field trials and proposals for this can be developed on a cooperative basis among agencies.

The material draws on information collected over a period of many years by a number of WA State Government agencies, including:

- the Department of Agriculture
- the Department of Conservation and Environment
- the Environmental Protection Authority
- the Water Authority of WA
- the Waterways Commission
- Public Works Department (prior to amalgamation into WAWA)

Published data have been cited and details of reports used are given in the references.

The discussion paper draws together and builds on ideas from many people over the years and thus represents an integrated look at catchment processes that can be of benefit to environmental managers in the State as a whole. The contribution made by these people is acknowledged.

Particular thanks go to the Environmental Protection Authority for making Mr Bott available for a period of secondment to the Office of Catchment Management. Special

thanks also go to Dr Bob Humphries of the WA Water Resources Council for his stringent review of the paper as it was being written.

It is planned to hold an informal workshop on the findings later in the year. Interested readers are invited to provide written comments or to contact the author and may have their views included in the workshop, either as a critique or as an invited speaker.

Please send your comments by 30 April 1993 to:


Mr Geoff Bott
Acting Principal Environmental officer
Office of Catchment Management
2nd Floor
25 Irwin Street
Perth
WA 6000


SALLY ROBINSON
A/DIRECTOR

March 1993

# Relationships between the extent of conventional, broadscale agriculture and stream phosphorus concentration and phosphorus export in South-West Western Australia.

**Geoffrey Bott**
*A/Principal Environmental Officer, Office of Catchment Management, 25 Irwin Street, Perth, WA 6000.*

**Abstract**

Many estuaries and wetlands in the South-West of Western Australia are eutrophic (nutrient enriched). Phosphorus, which is generally the algal growth-limiting nutrient in these waterbodies, is exceptionally scarce in the virgin soils of the region, consequently phosphatic fertilizers, such as superphosphate, are applied at high rates in order to attain satisfactory agricultural production. The proportion of this applied phosphorus that is lost to drainage is relatively small (<10%) but the catchments are expansive and the resultant phosphorus loads to the small, poorly-flushed estuaries and wetlands are often excessive and cause eutrophication.

Extensive land clearing has generated an excess of water in the landscape - a consequence of diminished catchment evapotranspiration due to the conversion of native vegetation to pasture. The need to remove this excess water, so as to prevent waterlogging, has resulted in the construction of myriad drains. These drains have not only promoted the movement of water but also of phosphorus from the land to the rivers. Evidence now suggests that catchment phosphorus export and stream phosphorus concentration increases rapidly when clearing of deep-rooted perennial vegetation (and the subsequent transition to agricultural activities) exceeds about 70% of the catchment. This finding has important implications for the environmental sustainability of surface water resources, and associated aquatic ecosystems, in the South-West of Western Australia and probably elsewhere.

## 1. Introduction

There is growing community concern regarding the apparent worldwide increase in the incidence of riverine and estuarine eutrophication (nutrient enrichment). This was evident last summer following the eruption of toxic algal blooms in Australia's longest river the Murray-Darling.

Reports of algal blooms in the rivers and estuaries of South-West Western Australia are not new, although some recent sightings represent previously unrecorded, or new, incidences. Many Western Australians will probably remember the extensive publicity campaigns which were initiated in the late-70's when blooms of the toxic blue-green alga, *Nodularia spumigena*, occurred in the Peel-Harvey Estuary. A recent analysis of stream data, some of which date back to this time, indicates that the catchment phosphorus export is likely to increase rapidly when broadscale agriculture exceeds about 70% of the catchment area (Government of Western Australia, 1992). In general, the incidence of eutrophication is likely to dramatically increase above this threshold, however permissible phosphorus loadings will largely depend on the flushing characteristics of the downstream waterway.

The Environmental Protection Authority of Western Australia (formerly the Department of Conservation and Environment) conducted extensive investigations into the causes of estuarine eutrophication in the South-West of Western Australia between 1977 and 1990. An integral part of these studies involved measuring the annual phosphorus loads of the streams discharging to the waterways. This monitoring was often conducted over a number of years to understand how the annual phosphorus loads and flows of these streams varied from year to year. The database arising from these investigations, and others conducted by the Water Authority of Western Australia and Agriculture Department of Western Australia, constitutes a comprehensive, long-term collection of stream phosphorus loads and concentrations (some 20,000 individual phosphorus concentrations from 36 catchments).

Previous analysis of these data has been primarily directed towards addressing estuarine eutrophication and water quality management issues - the reason for the monitoring programme in the first instance. However, it is felt that a sufficiently large quantity of reliable and spatially extensive information has now been gathered from a number of sources to enable the identification of regional and overall catchment trends and the physical and land use characteristics affecting stream phosphorus concentrations and catchment phosphorus export in the region.

Empirical methods have been employed to identify general trends between land use and catchment water quality, while consciously avoiding more complex (and confusing) mathematical approaches at this stage. Internationally, the use of empirical methods is now proving to be both a useful and popular tool in the analysis of area-typical, as opposed to site-typical, ecological data collected over an extended period of time (Hakanson, 1990).

## 3. Previous studies

Between 1972 and 1974 the United States Environmental Protection Agency conducted a nationwide survey (the National Eutrophication Survey) of non-point, or diffuse, sources of pollution. This survey entailed the measurement of nitrogen and phosphorus loads and concentrations from 928 nonpoint-source catchments across the mainland of the United States of America. The continental United States exhibits land use which varies from urban to agriculture to forestry; topography which varies from mountains to plains; soils which vary from infertile sands to rich volcanic earths and; climates which vary from desert to maritime to temperate. Despite such diversity, a good exponential relationship between land use and stream phosphorus concentration and export was identified (Omernik, 1976 & 1977; Figures 1a & b).

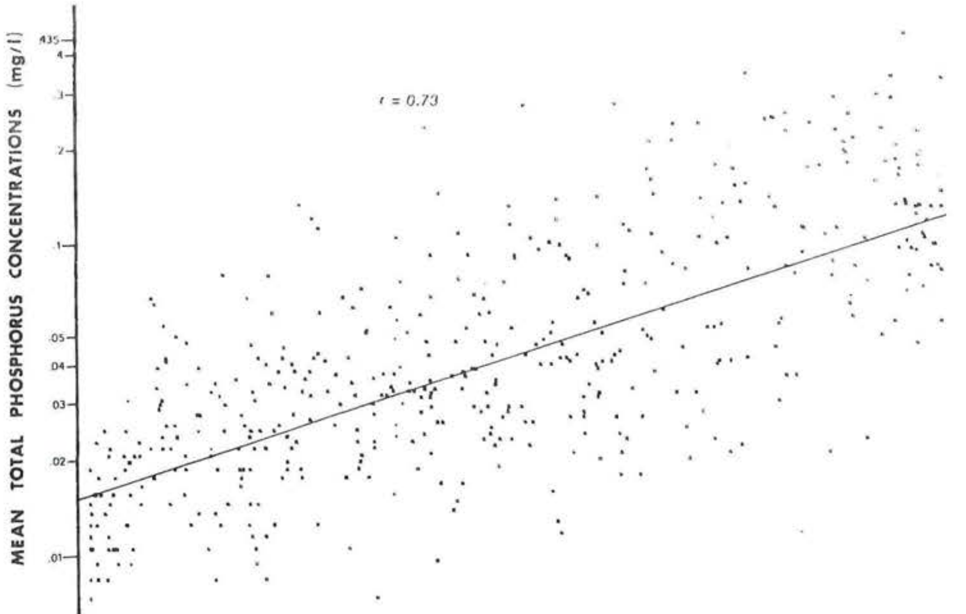



*Figure 1a: Scattergram of "contributing" land use types related to flow-weighted stream phosphorus concentrations in the United States of America (after Omernik, 1976 & 1977). (Note the logarithmic vertical axis).*

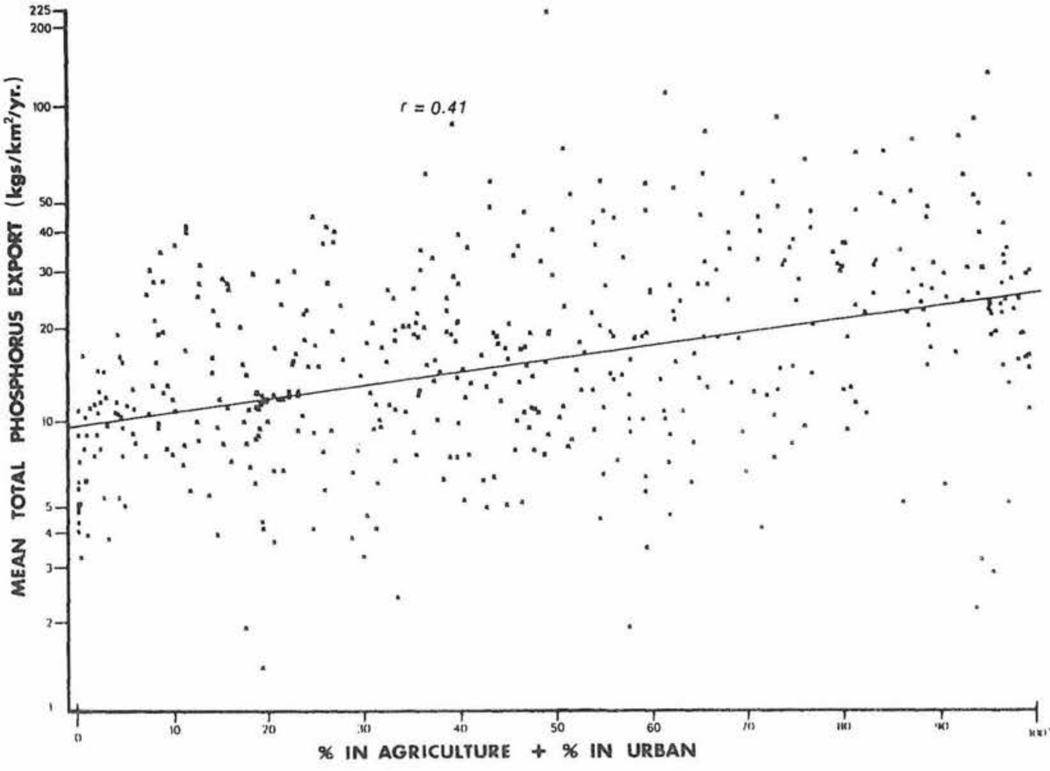



*Figure 1b: Scattergram of "contributing" land use types related to stream phosphorus export in the United States of America (after Omernik, 1976 ). (Note the logarithmic vertical axis).*

Following the work of Omernik (1976 & 1977) it is apparent that if the analysis is confined to catchments within an area that is climatically, topographically and lithologically homogeneous, or at least not grossly dissimilar, then one could reasonably expect the relationship between stream phosphorus concentration and export and landuse to be better defined. Indeed, within the National Eutrophication Survey data three discrete geographical sub-regions were identified, all of which exhibited a similar, but generally improved correlation, between land use and stream phosphorus concentration when compared with a similar regression based on all available data (Figure 2).

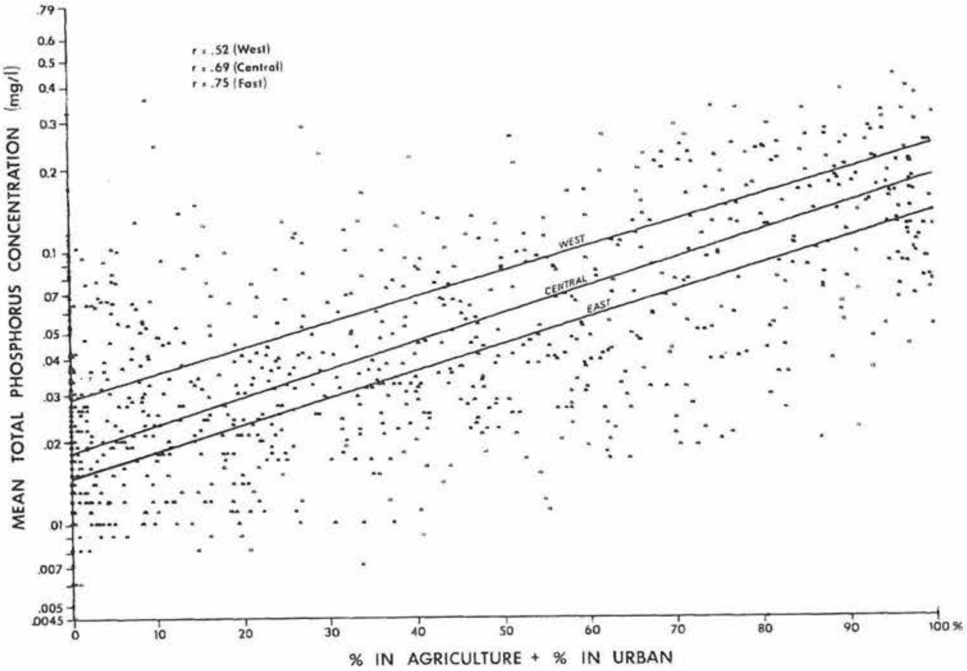



*Figure 2: Scattergram of "contributing" land use types related to the flow-weighted phosphorus concentration of streams from different regions of the United States of America (Omernik, 1977). (Note the logarithmic vertical axis).*

## 4. Case 1: The sub-catchments of the Murray River basin

Data collected by the Public Works Department in 1979 from the sub-catchments of the Murray River basin (Loh et al., 1981) in Western Australia was re-analysed in the light of Omernik's findings to assess if similar trends between land use and stream phosphorus concentration and export are evident for local catchments. The data collected from the Murray River basin were chosen for this analysis because:

- no point source (nutrient) discharges were evident within the catchments (Loh et al., 1981);
- the data were collected during a one year period (1979) and the sub-catchments are located in proximity to one another, hence variability between the catchments due to seasonal and climatic factors is reduced;
- urban development within the catchments is minor and unlikely to be a significant "contributing" land use to either stream phosphorus concentrations or exports;
- land use within the sub-catchments constitutes, almost exclusively, broadscale agricultural enterprises and forestry;
- there was a broad range in the percentage of land cleared in the sub-catchments; and
- reliable streamflows and phosphorus concentrations (and hence loads) were available (sampling was conducted three times weekly at most sites and once weekly at more remote sites in association with continuous stream gauging).

### 4.1 Land use or catchment clearing?

Omernik (1976) framed land use in terms of the percentage of the catchment being used for agriculture and urban pursuits. Generally, clearing in the South-West is conducted so that agricultural pursuits can occur on once forested land. For the purposes of this report, clearing of deep-rooted vegetation has been used as a measure of the extent of conventional and broadscale agricultural activity in a catchment.

### 4.2 Stream phosphorus concentration

In this report, stream phosphorus concentration has been expressed as an annual flow-weighted phosphorus concentration, rather than a mean concentration, and is calculated by dividing annual phosphorus load by annual flow:

$$\text{flow-weighted phosphorus concentration} = \frac{\text{annual phosphorus load}}{\text{annual streamflow}} \quad \frac{(\text{tonnes/yr})}{(10^6\ \text{m}^3/\text{yr})} = \text{mg/l}$$

It is important to note that the mean <u>concentration</u> of a stream is not necessarily indicative of the phosphorus <u>load</u> of that stream, particularly in semi-arid areas where infrequent floods with high phosphorus concentrations are prone to occur.

The annual flow-weighted phosphorus concentration is analogous to collecting the total flow of a stream for a year and then sampling the volume for a single, representative phosphorus concentration. By comparison, the mean of, say, weekly phosphorus concentrations obtained from the same stream over the same year is likely to differ from the annual flow-weighted phosphorus concentration for that stream. For example, the average annual phosphorus load of the Kalgan River, calculated by the average annual phosphorus concentration multiplied by the average annual streamflow, is 5.4 tonnes - whereas the true average annual phosphorus load for the same period is 18 tonnes (see Table 2).

### 4.3 Soil type considerations

Two of the Murray River basin study sub-catchments drain portions of the Swan Coastal Plain, and were excluded from the data analysis (Dirk Brook Lower and the Serpentine River) because they were believed to be lithologically and hydrologically dissimilar to the remainder of the sub-catchments to the east of the Darling Escarpment. Investigations have shown that most of the phosphorus entering the eutrophic Peel-Harvey Estuary comes from the Swan Coastal Plain which, although comprising only 28% of the total catchment area, contributes 85% of the phosphorus load to the estuary. The remaining 15% of the phosphorus load is derived from 72% of the catchment, being that portion located to the east of the Darling Escarpment. Clearly, the coastal plain soils are distinct from the scarp soils in terms of their ability to retain phosphorus and were consequently excluded from this analysis.

Soil variability is discussed later in this report, but differences in phosphorus export between the coastal plain and scarp catchments appears to be largely because of the differences in runoff and waterlogging regimes that exist rather than wholesale differences in soil type.

## 4.4 Rainfall and runoff considerations

Data collected from the catchments of South-West Western Australia, show that stream phosphorus load, and hence catchment phosphorus export, are strongly correlated with streamflow (Figure 3). As a result, rainfall and hence runoff will largely dictate the amount of phosphorus exported from the sub-catchments of the Murray River basin study. This variation in rainfall and runoff is likely to mask any underlying relationships between catchment land use and stream phosphorus export, but perhaps not between catchment land use and stream flow-weighted phosphorus concentration given the relatively static nature of this variable in the higher rainfall areas (see Figure 3). With this knowledge the scarp sub-catchments were broadly classified as either 'wet' or 'dry' based on 1979 runoff (Table 1).

The 'dry' sub-catchments are situated to the east and the 'wet' sub-catchments to the west of the Murray River basin. This reflects the average annual rainfall across the basin, which declines from 1300 mm in the west (near the Darling Escarpment) to 590 mm in the east. 'Dry' and 'wet' sub-catchments have been classified as those sub-catchments which experienced less than 10 mm or more than 70 mm runoff in 1979, respectively.

*Table 1: The scarp sub-catchments of the Murray River basin study (which excludes those draining the coastal plain) can be readily grouped into 'Wet' and 'Dry', based on 1979 runoff (data of Loh et al., 1981).*

| Murray River basin scarp sub-catchment | 1979 runoff (mm) | Sub-catchment group | 1979 phosphorus export (kg/ha) |
|---|---|---|---|
| Hotham River | 4.1 | Dry | 0.001 |
| Yarragil Brook | 4.7 | Dry | 0.0005 |
| Murray River | 6.5 | Dry | 0.0009 |
| Williams River | 8.4 | Dry | 0.002 |
| Little Dandalup River | 73.2 | Wet | 0.0076 |
| Little Dandalup Tributary | 87.6 | Wet | 0.0094 |
| Dirk Brook Upper | 126 | Wet | 0.013 |
| Marrinup Brook | 137 | Wet | 0.0147 |
| Marrinup Tributary | 244 | Wet | 0.056 |

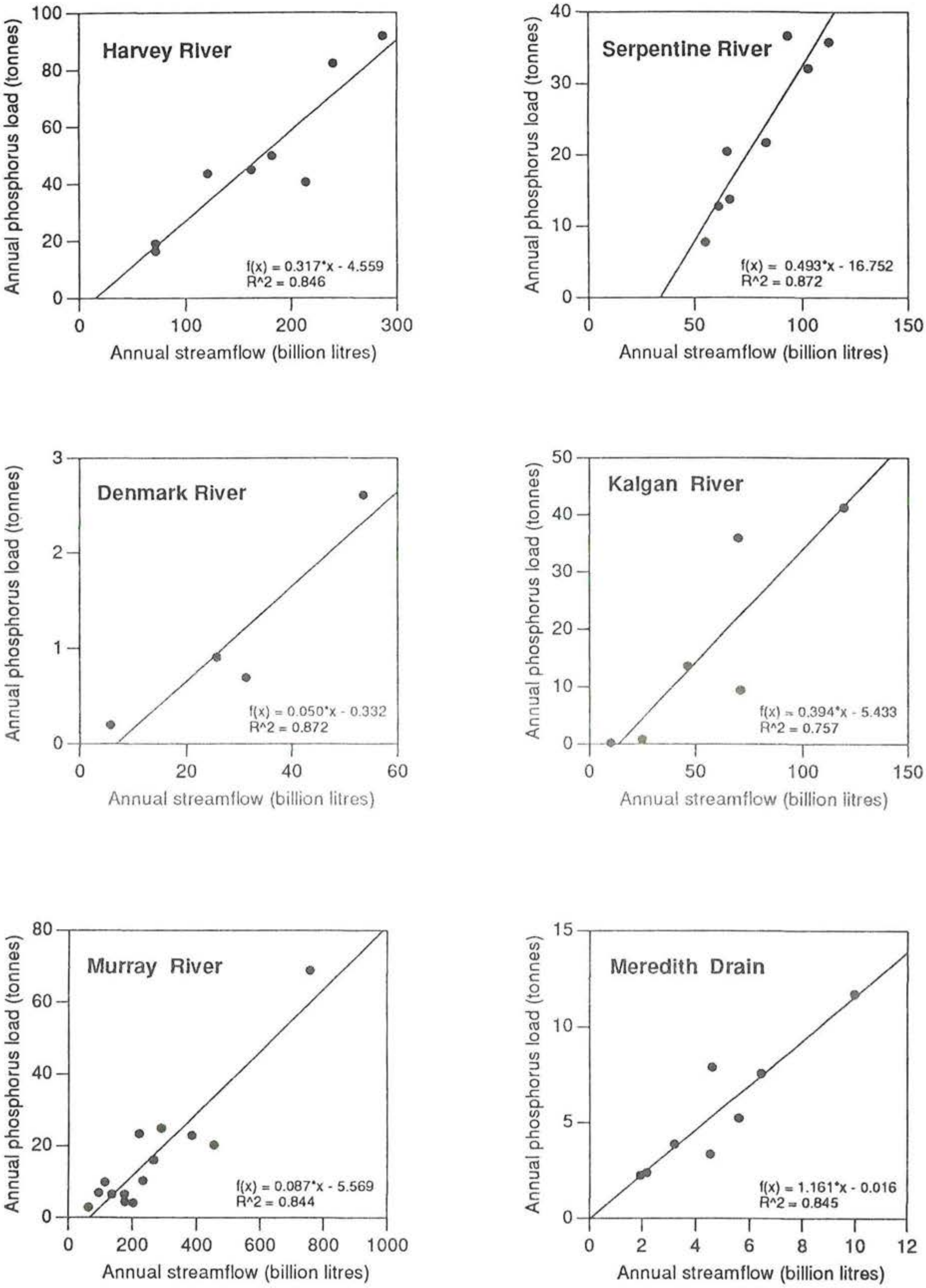



*Figure 3: As annual streamflow increases there is a corresponding increase in phosphorus exported by streams in the South-West of Western Australia.*

## 4.5 Results

Once obvious distinctions between the sub-catchments have been noted, in terms of runoff and soil type, relationships between land use and stream phosphorus export, similar to those identified by Omernik (1976 & 1977), become discernible (Figure 4). In all likelihood, if data from more sub-catchments were available then this trend would become more obvious. However, the overall correlation would not be as strong, given the variability of such factors as soil and climate evident between the scarp and the coastal plain (see Figure 1).

Interestingly, when catchment clearing is correlated with stream phosphorus concentration it is evident that partitioning of the data into 'wet' and 'dry' sub-catchments is not required (Figure 5). This is contrary to Omernik's findings (see Figure 2), but is not altogether unexpected, given the static nature of stream flow-weighted phosphorus concentrations in the region, the uniformly low rainfall experienced in 1979, extraction of the coastal plain data and the extreme variability of the catchments analysed by Omernik (1977).

Previous workers (Loh et al., 1981, and McComb, 1983) could not identify any obvious relationship between catchment clearing and phosphorus concentration for the streams in the Murray River basin. This has been attributed to the fact that during their analysis data from the scarp and coastal plain regions were 'lumped' together, as well as the data from the high and low runoff sub-catchments. This would have undoubtedly masked any underlying relationships between catchment clearing and stream phosphorus concentration and export.

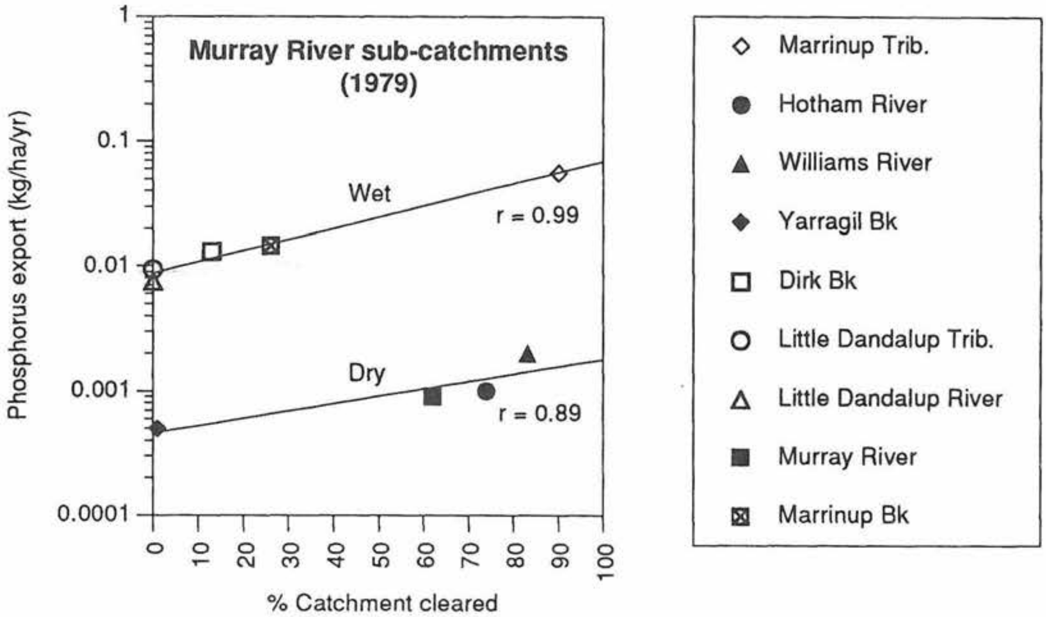



*Figure 4: The sub-catchments of the Murray River basin, located to the the east of the Darling Escarpment, show a strong exponential relationship between catchment clearing and phosphorus export when the data are separated into 'wet' and 'dry' sub-catchments (>70 mm and <10 mm runoff, respectively, as measured in 1979). (Note the logarithmic vertical axis). (Data from: Loh et al., 1981).*

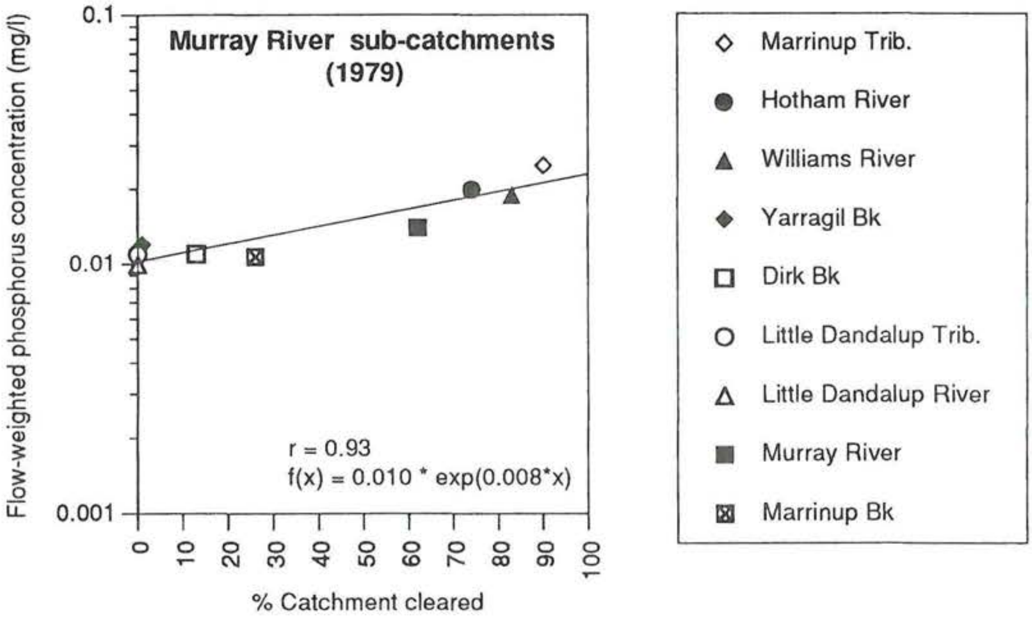



*Figure 5: The sub-catchments of the Murray River basin, located to the the east of the Darling Escarpment, show a strong exponential relationship between catchment clearing and stream phosphorus concentration. This conforms with earlier findings by Omernik (1976 & 1977) (see Figure 1). (Note the logarithmic vertical axis).*

## 5. Case 2: The South-West of Western Australia

As a result of the trends identified in the Murray River basin data, further analysis was conducted to determine if similar land use and stream phosphorus relationships could be identified on a regional scale for the South-West of Western Australia.

A preliminary comparison of data from the Peel-Harvey Estuary coastal plain catchment with that of the Moore River Estuary coastal plain catchment showed that, although these catchments exhibit essentially the same soil types and distributions, the streams draining the coastal plain areas exhibit markedly different phosphorus concentrations and hence annual phosphorus loads. The lower rainfall and runoff experienced by the Moore River Estuary coastal plain catchment alone is not sufficient to explain these differences. A conspicuous difference in the degree of agricultural development between these catchments, and the findings of Omernik (1976), gives rise to the suspicion that the covering of perennial, deep-rooted vegetation in a catchment plays a modifying role in determining stream phosphorus concentration and export from these catchments. This provided the basis for further investigation across the broader range of catchments in the South-West (Figure 6).

### 5.1 Catchment boundaries and clearing estimates

Catchment boundaries and estimates of land clearing in the Albany Harbours and Peel-Harvey Estuary catchments were kindly supplied by the Western Australian Department of Agriculture. These estimates are based on extensive ground-truthing and, in association with the high resolution colour, aerial photography mapping base used, are the most accurate available.

Elsewhere, estimates of catchment clearing were made by the Remote Sensing Applications Centre using remotely sensed data (Landsat Multispectral Scanner) collected during 1987 and 1988 which was then overlain on catchment boundaries mapped by Hodgkin and Clarke (1988-1990) as part of the Environmental Protection Authority's South Coast Estuaries Study. The smallest parcel of vegetation discernible by this method is 80 metres by 80 metres which, although being somewhat coarse, is deemed to be adequate resolution for the purposes of this study.

In the few instances where digital information was not readily available, estimates of catchment clearing were obtained from "The Impact of Agricultural Development on the Salinity of Surface Water Resources of South-West Western Australia" (Schofield et al., 1988). Failing this, catchment clearing was estimated visually from Landsat scenes and catchment boundaries collated in 1984 and presented in "Environmental Guidance for Land Use in Southern Western Australia" (EPA, 1988).

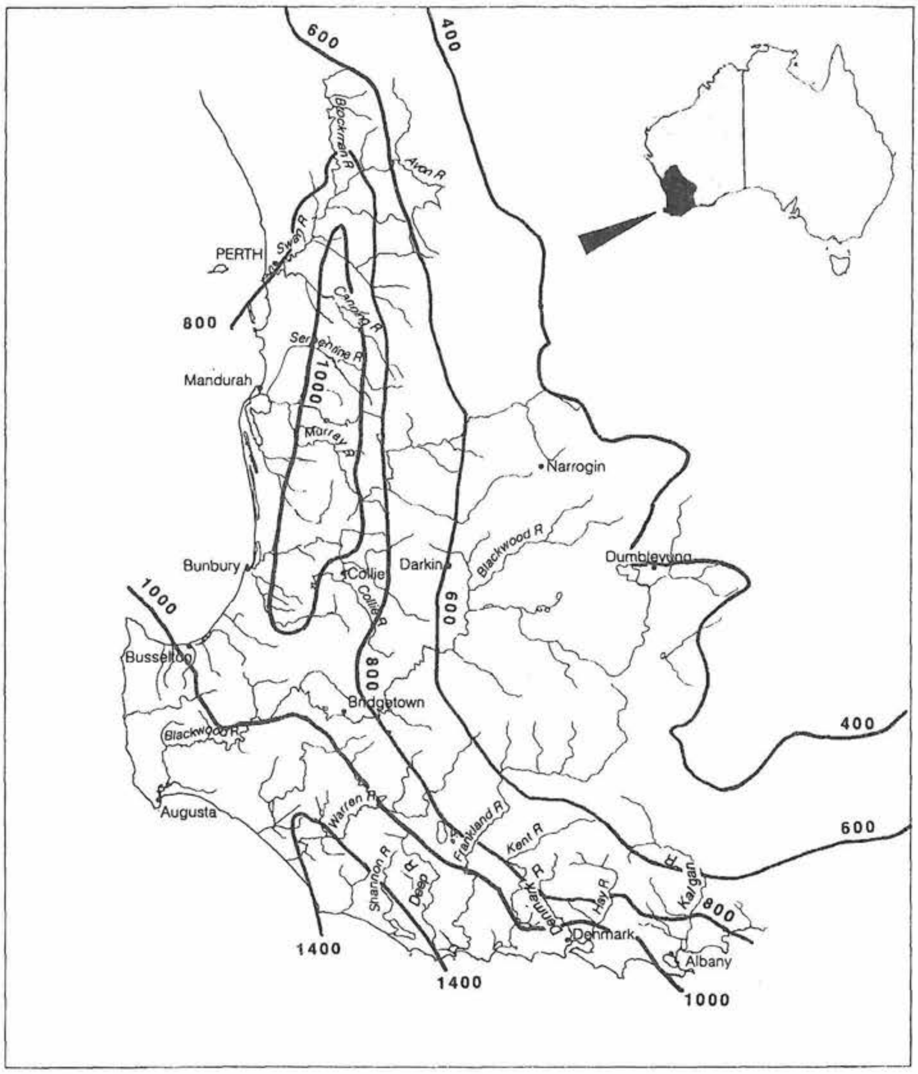



*Figure 6: Major rivers and rainfall isohyets in South-West Western Australia (Data source: Government of Western Australia, 1992).*

## 5.2 Regional considerations

### 5.2.1 Runoff variability

The 'wet' and 'dry' catchment runoff separation that was evident in the Murray River basin sub-catchment data suggests that a high degree of annual variability in stream phosphorus concentration and export can be expected from a region whose rainfall is as varied as that of the South-West. Although the average annual rainfall in the region ranges from 400 mm to 1400mm, there is considerable variation from year to year and from catchment to catchment in terms of both annual streamflow and phosphorus load. In order to compare catchments of differing size and annual streamflow regimes, streamflows were converted from volumetric values to areal values in the form of annual runoff (mm/yr):

$$\text{catchment runoff} = \frac{\text{annual streamflow}}{\text{catchment area}} \quad \frac{(10^6\ m^3/yr)}{(km^2)} \times 1000$$

Many Australian rivers do not have normally distributed annual flows, but rather these distributions tend to be strongly skewed (Finlayson and McMahon, 1988). This is particularly the case in the more arid areas where annual streamflows are generally low, but under flood conditions large nutrient loads may be delivered over a short period (typically 3-7 days). Under these circumstances a running flow-weighted phosphorus concentration has been used over the duration of the monitoring record. This has the advantage that, unlike using the average annual flow-weighted phosphorus concentration, it produces a value which is more representative of the long-term phosphorus concentration and load of the river in cases of both skewed and normally distributed annual streamflow (Table 2).

*Table 2: The Kalgan River, discharging to Oyster Harbour in Albany, exhibits strongly skewed streamflow and phosphorus load distributions. For this reason running flow-weighted phosphorus concentrations have been used in preference to the mean annual flow-weighted phosphorus concentration for catchments in the South-West. (1991 data source: Department of Agriculture, Albany).*

| Kalgan River | 1987 | 1988 | 1989 | 1990 | 1991 | Mean annual (std dev) (n) |
|---|---|---|---|---|---|---|
| Streamflow ($10^6 m^3$) | 10 | 119 | 25 | 46 | 70 | 54 (43) (5) |
| Phosphorus load (tonnes) | 0.33 | 41 | 1 | 14 | 36 | 18 (19) (5) |
| Mean annual phosphorus concentration (mg/l) (std dev) (n) | 0.03 (0.02) (13) | 0.23 (0.60) (28) | 0.04 (0.06) (44) | 0.15 (0.47) (22) | 0.17 (0.57) (39) | **0.10** (0.09) (5) |
| Flow-weighted phosphorus concentration (mg/l) | 0.03 | 0.35 | 0.04 | 0.30 | 0.52 | **0.25** (0.21) (5) |
| Running flow-weighted phosphorus concentration (mg/l) | 0.03 | 0.32 | 0.27 | 0.28 | 0.34 | **0.34** |

The running flow-weighted phosphorus concentration of a stream is calculated as follows:

Flow-weighted phosphorus concentration (mg/l) =

$$\frac{\text{sum (P load}_{\text{year 1}} + \text{P load}_{\text{year 2}} + \ldots \text{P load}_{\text{year n}})}{\text{sum}\supseteq(\text{streamflow}_{\text{year 1}} + \text{streamflow}_{\text{year 2}} + \ldots \text{streamflow}_{\text{year n}})} \quad \frac{(\text{tonnes})}{(10^6\ m^3)} = \text{mg/l}$$

This method has been used in this study to calculate the flow-weighted phosphorus concentration of streams in the South-West of Western Australia, some of which exhibit a high degree of skewness in terms of their annual streamflow distribution.

### 5.2.2 Catchment size

Plot and sub-catchment scale studies conducted in the Peel-Harvey Estuary catchment demonstrated that small-scale catchments have a propensity for higher water yields (runoff) than similar large-scale catchments (Schofield et al., 1984). This is presumably a result of the longer flow routing distances involved in the larger catchments. Runoff corrections, on the grounds of catchment scale, were not included in the analysis of the data because all catchments were deemed to be of medium to large size (30 - 28,000 $km^2$).

### 5.2.3 Soil type

In geomorphological terms, the catchments of the South-West consist of the same elements. Typically, they consist of a high rainfall, coastal fringe of recent sedimentary soils, which gives way to loamy soils in the low rainfall inland areas (associated with either the Albany-Fraser Orogen or the Yilgarn Block).

The coastal soils largely consist of aeolian and marine sediments with a very low capacity to retain phosphorus. This is a reflection of their low clay and iron and aluminium oxide compositions. In contrast, the inland soils generally exhibit higher phosphorus retention capacities as a result of their igneous and metamorphic origins; the parent rocks giving rise to the high iron and aluminium oxide (red) and loamy nature of the soils which characterize the inland areas. Sandy soils derived from riverine processes are generally confined to the valley floors and represent only a small percentage of the vast inland areas.

Most catchments, particularly the larger ones, are likely to be representative of the soils of the region because the catchments are transects of these soil groups as their rivers traverse from the inland to the sea.

### 5.2.4 Waterlogging

Surface runoff and waterlogging are believed to severely impair the capacity of a soil to retain phosphorus because the time and area of contact between phosphorus-rich runoff water and the soil is greatly reduced, thereby minimizing plant uptake and soil adsorption of phosphorus (Cosser, 1989). Indeed, the high phosphorus retention capacity of clay soils in the irrigation districts of the South-West appear to be nullified when these soils are subjected to flood irrigation and extensive draining (Water Authority of Western Australia, 1992b; Community Catchment Centre pers comm.).

Similarly, catchment phosphorus export and stream phosphorus concentrations are known to increase dramatically under high runoff (see Table 2). This is generally not because of high particulate phosphorus loads which are traditionally ascribed to floods - catchment phosphorus loads have not been directly correlated with turbidity and the occurrence of high turbidity/low phosphorus concentration waters in mid-late winter emphasizes the apparent independence of these variables (Birch et al., 1986). These facts, coupled with the widespread incidence of waterlogging in the agricultural areas of the South-West (Figure 7) and the uncommonly high proportion of soluble to total phosphorus (50-80% orthophosphate phosphorus) in the watercourses of the region, leads to the belief that surface runoff and the myriad of drains constructed to alleviate waterlogging are more important than soil type in determining phosphorus export from the agricultural soils in the region.

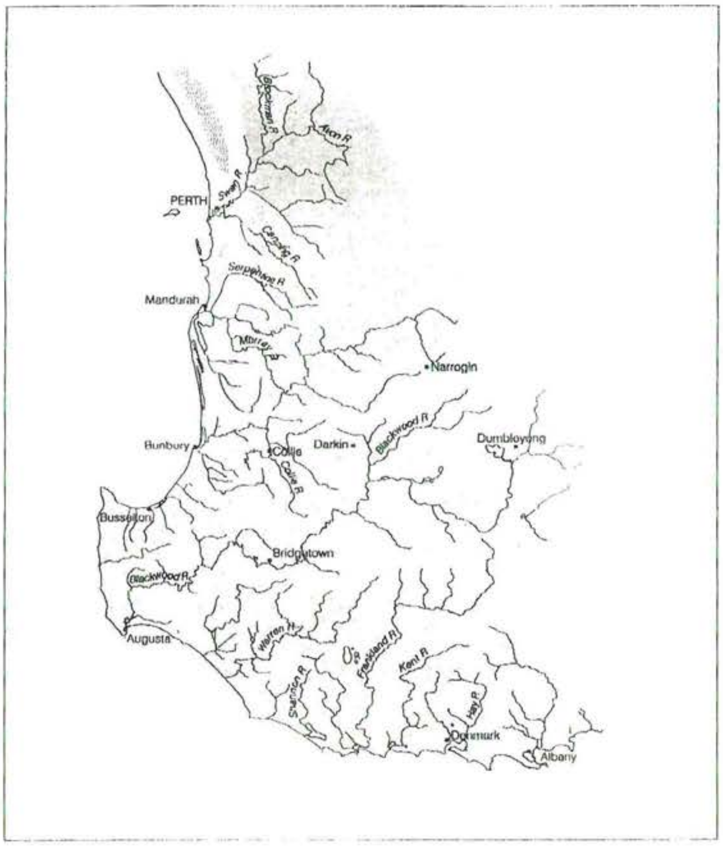



*Figure 7: The agricultural areas of the South-West are prone to waterlogging. It is believed that drains which are constructed to alleviate waterlogging also promote phosphorus export. Shading denotes areas prone to waterlogging and includes areas that may be subject to only infrequent waterlogging (after Government of Western Australia, 1992).*

#### 5.2.5 Catchment land use

Only a few large townships in the South-West could possibly be considered to be significant sources of phosphorus because the vastness of the catchments and the prolific use of fertilizers within these areas ensures most phosphorus is derived from agricultural activities. Coincidentally, all large urban centres are located on the coastal plain, well below the stream monitoring stations used in this analysis.

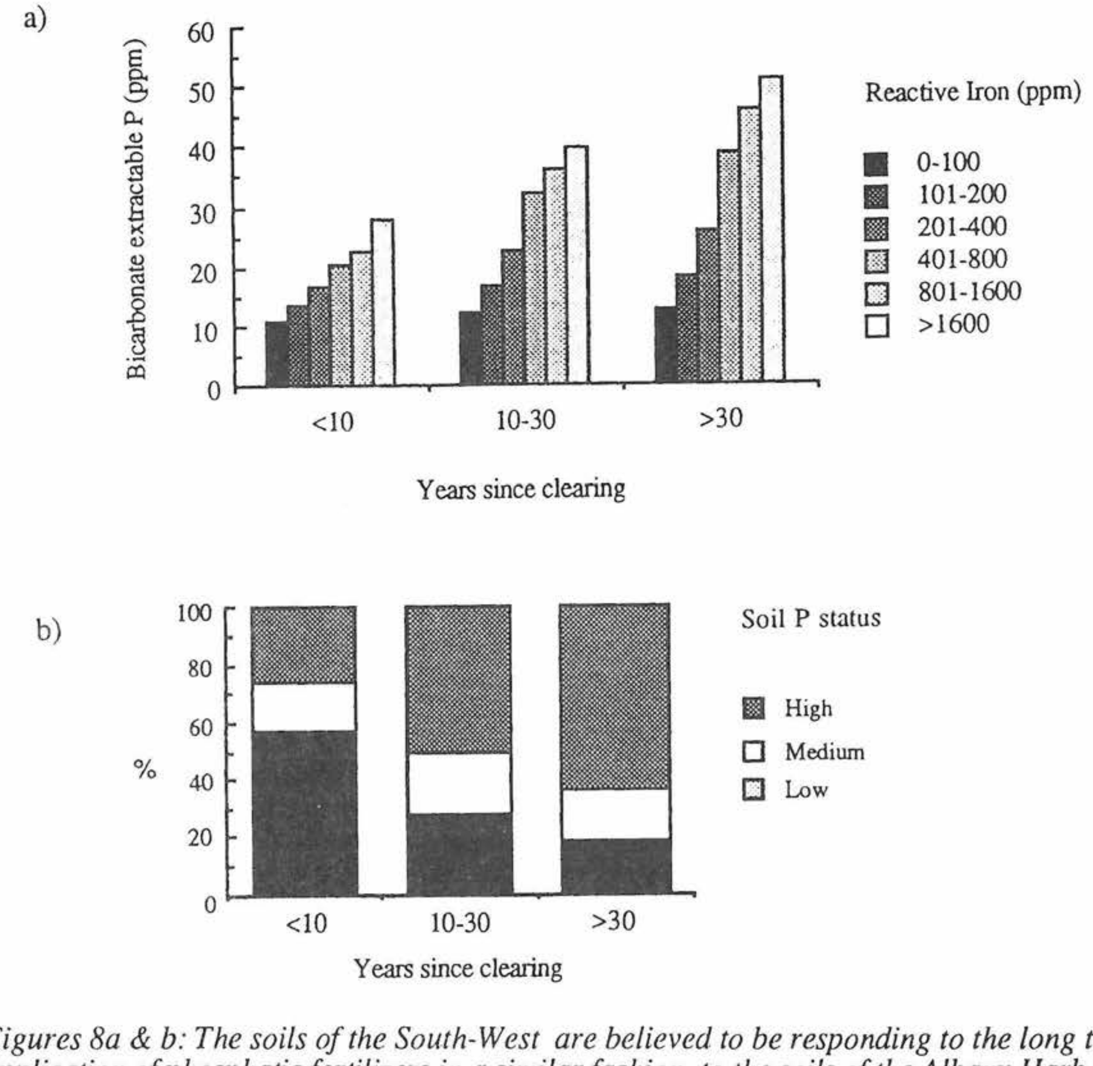
Industrial discharges, which are often sporadic and indeterminate, can hinder attempts to quantify the amount of phosphorus being derived from diffuse sources and may mask underlying relationships. Fortunately, industrial development in the South-West is in its infancy so these sources of phosphorus can be largely discounted.

Catchments which contain known, or suspected, point sources or appreciable tracts of nutrient intensive forms of agriculture have been expressly excluded from the analysis. These catchments are the Ludlow and Sabina Rivers near Busselton (mining and dairying activities; Mc Alpine et al., 1989), the lower reaches of the Serpentine River near Mandurah (piggeries, horticulture and sheepholding yards; Kinhill, 1988) and the Lake Sadie Drain near Denmark (potato growing; Lukatelich et al., 1984).

#### 5.2.6 Fertilizer history and fertilizer application rates

In general, only a small percentage of the phosphorus applied as fertilizer is lost to drainage (1-10%; South Coast Estuaries Project Group, 1992) and that the bulk of this phosphorus is derived from soil stores built up from previous applications of phosphorus (~70%) rather than from the current seasons fertilizer application (Schofield et al., 1984). More recently, it has been revealed that the discharge of organic and inorganic phosphorus from catchments is highly related to their soil phosphorus composition ($r^2 = 0.958$) and that when soils are cultivated mineralization of organic phosphorus enlarges the inorganic phosphorus pool (Vaithiyanathan and Correll, 1992).

Many of the soils in the South West were cleared between 1920 and 1960 (Schofield et al., 1988) and as such have long agricultural and fertilizer histories. Consequently, it is unlikely that large differences exist between the soils of the catchments in terms of soil phosphorus status. Indeed, soil surveys to date show that a majority (60-70%) of the agricultural soils in the South West do not require the addition of phosphate fertilizers for at least one year and that most soils exhibit high levels of bicarbonate extractable phosphorus in relation to plant growth requirements (Yeates et al., 1985; South Coast Estuary Project Group, 1992). Information also suggests that the soils in the region are all gradually becoming high phosphorus status soils under current fertilizer application practices in the region, irrespective of soil type or the reactive iron (phosphorus binding) content of the soil (South Coast Estuaries Project Group, 1992; Figures 8a & b).




*Figures 8a & b: The soils of the South-West are believed to be responding to the long term application of phosphatic fertilizers in a similar fashion to the soils of the Albany Harbours catchment. That is, there is a tendency for all soils to become high phosphorus status soils (a surplus of phosphorus with respect to plant growth requirements) over time. Figure a) - Effect of time and soil reactive iron level on average bicarbonate extractable phosphorus. Figure b) - Effect of time on the proportion of high, medium and low phosphorus status soils. (Figures from: South Coast Estuaries Project Group, 1992).*

The generally large size of the catchments used in the analysis (up to 28,000 km$^2$) serve to dampen the effects of individual farm fertilizer practices, soil variability and soil fertilizer histories (and soil phosphorus status) and are likely to be representative of the soils in the region. Furthermore, dryland grazing and cereal cropping are the dominant land uses in the

South-West and farm productivity and profitability dictates that application rates of phosphatic fertilizers lie between distinct ranges for these land uses, further reducing variability between the catchments that may otherwise arise.

# 6. Results

## 6.1 Factors affecting stream phosphorus concentration

The over-riding factors determining stream phosphorus concentrations in South-West Western Australia are runoff and the extent of agricultural development in the catchment.

When the catchment data are plotted it is apparent that low runoff catchments, which are predominantly the large inland catchments (eg Blackwood River), generally exhibit low stream phosphorus concentrations. However, under wet conditions the phosphorus concentration of these streams rise to levels which are more typical of the wetter catchments of the South-West. The best documented example of this behaviour is the Kalgan River which has an annual flow-weighted phosphorus concentration of about 0.03 mg/l when annual runoff is less than 10 mm, which then increases by an order of magnitude to 0.30 mg/l when annual runoff approaches 20 mm (see Table 2).

To further complicate matters, the extent of agricultural development in a catchment also influences stream phosphorus concentration. This fact is apparent when the annual flow-weighted phosphorus concentration is plotted against the extent of agriculture in the catchment (log transformation), and even more clearly when the running flow-weighted phosphorus concentration is plotted against the extent of agriculture in the catchment (Figures 9 & 10).

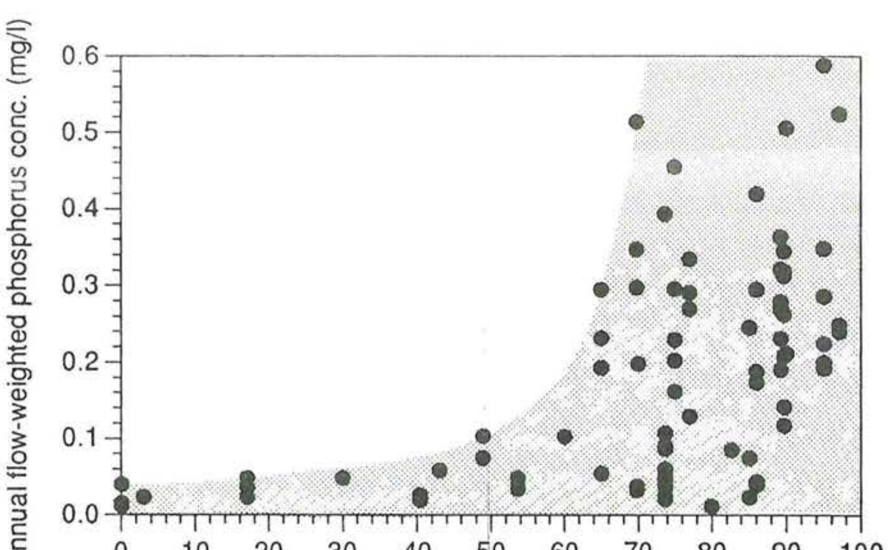



*Figure 9: The catchments of the South-West of Western Australia show a log-linear relationship between the extent of agriculture in the catchment and stream annual flow-weighted phosphorus concentration. The phosphorus concentration of some watercourses can be highly variable from year to year (vertically aligned points represent data from individual catchments). Notably, stream phosphorus concentration variability also increases with increased agricultural development of the catchment (shaded).*

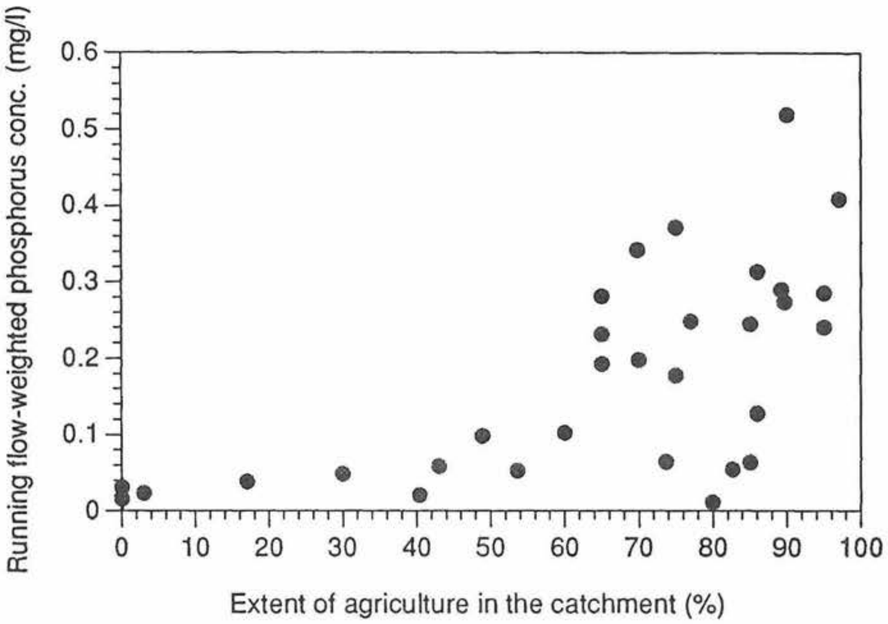



*Figure 10: The catchments of the South-West of Western Australia show a good log-linear correlation between the extent of agriculture in the catchment and (running) flow-weighted phosphorus concentration. Increasing variability with increasing parameter values is indicative of hetero-scedastic data.*

The result is that highly cleared and agriculturally developed catchments in the high rainfall zones of the South-West tend to exhibit high stream phosphorus concentrations almost all of the time, except in droughts. Conversely, the large, extensively cleared and agriculturally developed inland catchments tend to exhibit low phosphorus concentrations most of the time, except for floods. It is these infrequent floods at high phosphorus concentrations, yielding massive phosphorus loads, which are thought to be responsible for the eutrophication of Oyster Harbour in Albany.

Importantly, it appears that soil type has less of an influence on stream phosphorus concentrations in the greater South-West than first thought. This is presumably because of the small area of coastal plain (sandy) soils in relation to the remainder of the catchment and the subsequent dilution of this runoff as a result of "normal" low runoff conditions from the inland portion of the catchment. However, the coastal aspect of the sandy soils makes them more regular "contributors" of phosphorus from year to year. In short, the data suggest that sandy soils have considerably less of an influence on stream phosphorus concentrations regionally than the extent of agricultural development. However, the reverse can be said of stream phosphorus concentrations associated with the smaller, sandy catchments situated entirely on the coastal plains (see Figure 3 - Meredith Drain).

## 6.2 Factors affecting stream phosphorus export

There is a trend of catchment phosphorus export increasing with increasing streamflow (expressed as runoff) across the catchments of the South-West (Figure 11). This is despite other factors which may modify the annual phosphorus load of a stream, such as daily flow distribution, flood frequency, drainage density and soil type.

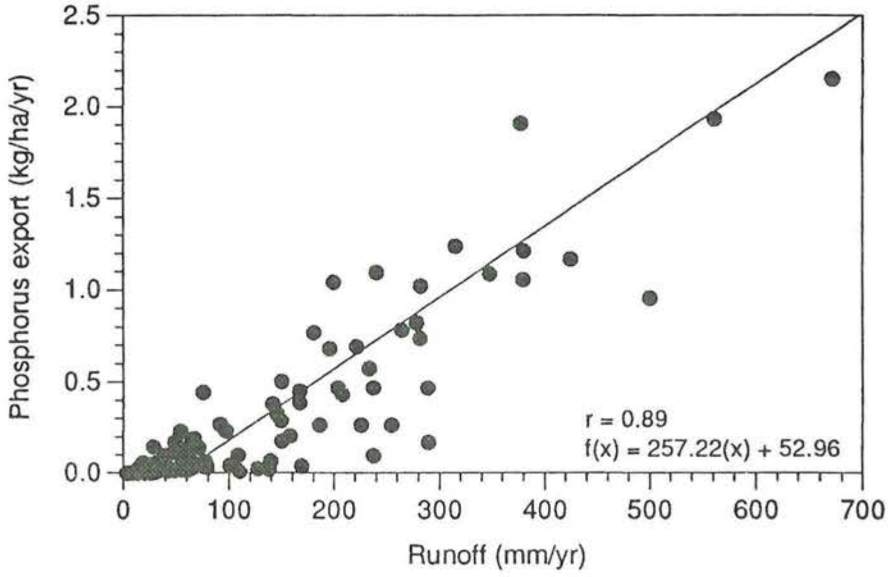



*Figure 11: The catchments of the South-West of Western Australia show a strong linear correlation between catchment runoff and phosphorus export.*

Overlaid on the relationship between runoff and phosphorus export is the effect of the extent of agriculture in a catchment. Data from all streams for all years were divided into three groups based on annual runoff (<50 mm, 50 - 150 mm, >150mm). These groupings were selected largely arbitrarily, however, the ten-fold increase in catchment phosphorus export exhibited by the Kalgan River in 1988 was used to define the initial 50 mm threshold (see Table 2). Within each runoff grouping it is apparent that the relationship between the extent of agriculture in a catchment and phosphorus export is approximately exponential, and that between the runoff groups phosphorus export also increases with increasing runoff (Figure 12). Even in the driest of catchments, it is apparent that the extent of agriculture influences stream phosphorus concentrations, though at a reduced level.

Interestingly, the wetter the catchment the stronger the relationship between the extent of agriculture in the catchment and phosphorus export becomes. Presumably this is because waterlogging and surface runoff promote phosphorus export which overcomes any inherent differences in soil composition between the catchments. The drier catchments (<50mm) exhibit widely varying phosphorus exports, which is probably caused by the greater importance of soil properties in retaining phosphorus at these low levels of runoff as a consequence of enhanced infiltration.

It must be stated that the runoff groups that have been used are artificial and a high degree of transition occurs between these groups. However, confidence in the general form of these relationships is not only evident by the coefficient of variation (up to 60% of the variability in phosphorus export can be explained by the extent of agriculture in the catchment alone) but also by the consistency in the slope of the log-linear regressions across runoff groups and the apparent similarity of these trends to those identified on a regional basis in the United States (see Figure 2).

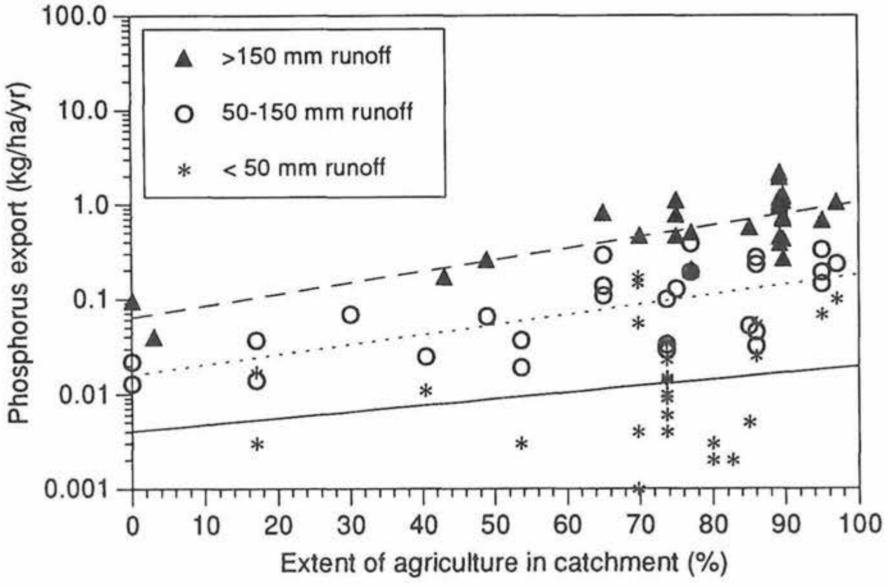



*Figure 12: The catchments of the South-West of Western Australia show a good log-linear correlation between phosphorus export and the extent of agriculture in the catchment. This relationship improves with increasing runoff, presumably because surface runoff down-plays the importance of soil type on phosphorus export (r = 0.77, r = 0.68 and r = 0.21 for >150 mm, 50-150 mm and <50 mm groups respectively).*

These relationships imply that catchment phosphorus export is likely to be greatest when agricultural development of a catchment exceeds about 70% of the catchment area and the catchment is situated in a high rainfall area. Intuitively, the single greatest factor currently inhibiting the occurrence of nuisance algal blooms in the Blackwood Estuary is the retention of native vegetation (State Forest) in the high rainfall (coastal) zone of the catchment, despite extensive clearing and agricultural development of the inland portion of the catchment.

## 7. What identifies a high-phosphorus exporting catchment? Where are they?

In the South-West, the 700 mm rainfall isohyet serves to differentiate between those catchments which produce <50 mm or >50 mm runoff annually under <u>normal</u> climatic conditions. The infrequent nature of floods from the normally 'dry' inland catchments (<50 mm runoff) and the relatively short duration of stream records has meant that information is scant on the behaviour of these catchments in high runoff conditions. However, data obtained from the Kalgan and Frankland Rivers in 1988 (when annual runoff approached 50 mm) suggests that, when they are in flood, the inland catchments rise to phosphorus concentration and export regimes more typical of the higher rainfall catchments. In short, catchments which are highly cleared and developed for conventional broadscale agriculture (>70%) will export large amounts of phosphorus if there is sufficient runoff. It is the recurrence interval between these floods which must be taken into account when considering estuarine water quality management in the South-West - where many estuaries are poorly flushed and retain a large fraction of the inflowing phosphorus load.

The inter-relationships between agriculture, runoff and phosphorus export are complex but can be considered as a three-dimensional plot (Figure 13). Alternatively, plotting runoff-weighted phosphorus export against the extent of agriculture in a catchment also demonstrates the non-linear relationship of phosphorus export to agricultural development of a catchment and the wide variation in phosphorus export between dry and wet years (Figure 14).

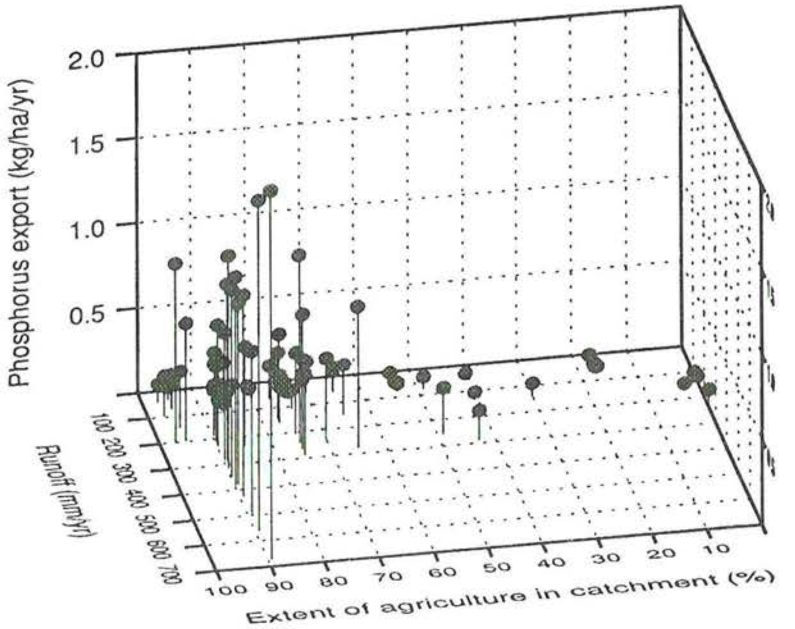



*Figure 13: The catchments of the South-West of Western Australia show accelerated phosphorus export when broadscale agricultural exceeds 70% of the catchment and the catchment is wet.*

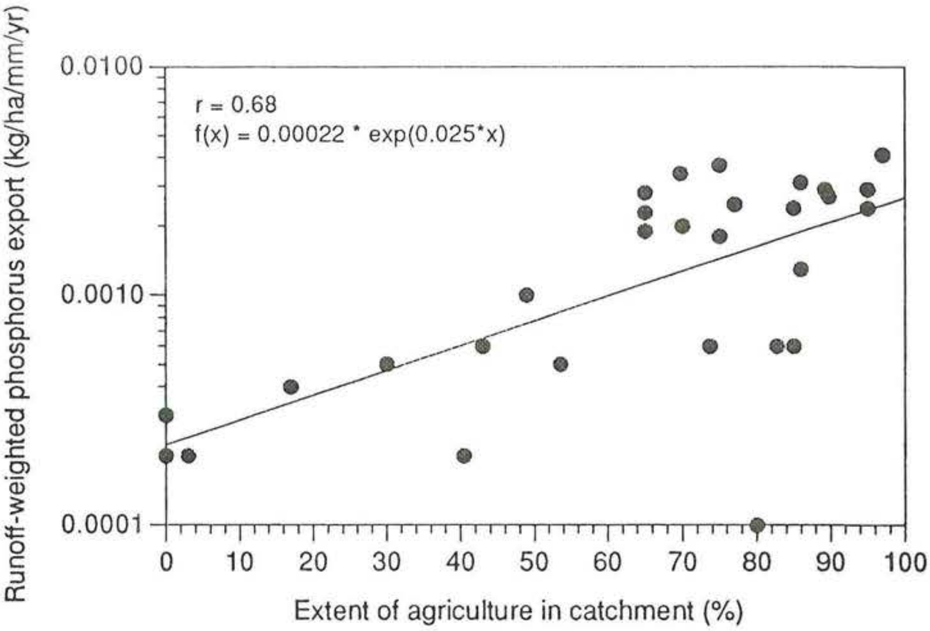



*Figure 14: The catchments of the South-West of Western Australia show a strong log-linear relationship between runoff-weighted phosphorus export and the extent of conventional broadscale agriculture in the catchment. (Note: r = 0.80 if the Blackwood River data are omitted. They are considered an outlier because of the lack of information regarding the behaviour of this catchment under high runoff.*

## 8. Catchment clearing and the hydrological balance

Interestingly, the relationship between agriculture and catchment phosphorus export is non-linear. It is well documented that catchment clearing causes groundwater levels to rise and runoff to increase (Loh and Stokes, 1981; Sharma et al. 1982; Stokes and Loh, 1982; Tyskin et al., 1982; Ruprecht et al., 1985; Western Australian Water Resources Council, 1986; Water Authority, 1987b; Schofield et al., 1988; Stokes, 1988; Schofield, 1990), so much so, that the Steering Committee for Research on Land Use and Water Supply investigated the prospects of forest thinning to increase surface runoff into metropolitan dams in response to climate change (Water Authority, 1987). Similarly, it is increased runoff resulting from the conversion of forests to agricultural land which is 'creamed-off' by agricultural drains (constructed to alleviate waterlogging), and which inadvertently transport phosphorus and other solutes from the farms to the rivers in the region.

Supporting this view, it has been estimated that streamflows from the coastal plain portion of the Peel-Harvey Estuary catchment have doubled as a consequence of agricultural development (Water Authority, 1986). In addition, computer modelling undertaken in the South-West by Ruprecht et al. (1985) demonstrates that winter runoff increases dramatically when a forested catchment is cleared for agriculture, irrespective of rainfall regime.

The non-linear nature of the effects of the extent of agriculture in catchments on phosphorus export is undoubtedly due to the disruption of catchment hydrological processes following the replacement of deep-rooted native vegetation with agricultural pastures. The change in vegetation, or more precisely the reduction in catchment evapotranspiration, causes surface runoff to increase and groundwater levels to rise, further exacerbating waterlogging of the agricultural areas. This in turn stimulates farmers to construct drains, inadvertently enhancing the movement of phosphorus-laden runoff to streams in the region. Processes similar to these have long been identified as a major cause of increasing stream and land salinity problems in the South-West.

Recent studies conducted in Albany have shown that native vegetation intercepts and transpires 754 mm of a total of 812 mm rainfall. No surface runoff occurs under native vegetation, with 58 mm being lost to groundwater. Upon conversion of native vegetation to pasture, rainfall interception and transpiration falls to 588 mm (down 11%), groundwater inputs rise to 171 mm (up 14%) with surface runoff now amounting to 52 mm, or 6% of annual rainfall (Water Authority, 1992; Figure 15). It is this combination of increased groundwater recharge and surface runoff which has exacerbated waterlogging and necessitated the construction of agricultural drains in the region.

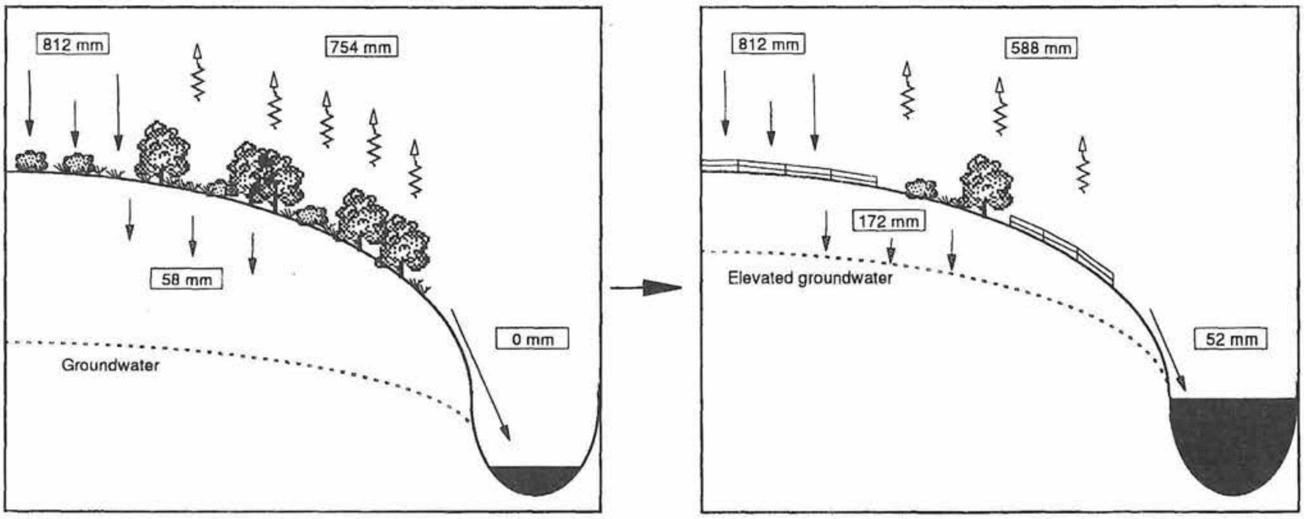



*Figure 15: Catchment evapotranspiration, groundwater recharge and surface runoff are dramatically altered with the conversion of deep-rooted perennial forests to agricultural pastures (after Water Authority of Western Australia, 1992a).*

# 9. Implications for management

If the incidence of algal blooms in streams and estuaries in the South-West is to be managed, further land clearing to accommodate the expansion of broadscale agriculture is imprudent, particularly in the catchments of estuaries which are already marginal or eutrophic - at least until the management of existing diffuse sources of phosphorus is greatly improved. In these catchments the full effects of past clearing and fertilizer applications may not yet be obvious. Even if the replacement of native vegetation with conventional agriculture is halted immediately, soil phosphorus levels and catchment phosphorus export are destined to continue to rise as a consequence of the continued application of phosphatic fertilizers to farmlands in these catchments. These increases could be substantially reduced by expanding fertilizer management activities from catchments of estuaries with documented eutrophication problems to those catchments in which broadscale agriculture comprises more than 60-70% of the catchment area and which are prone to frequent waterlogging.

In addition to managing the application of fertilizers, rehabilitation of the hydrological processes of these catchments may well be required in the long-term if eutrophication is to be managed (eg Kalgan River). Any such strategies are likely to necessitate a reduction in the incidence of waterlogging and surface runoff and are thereby likely to complement strategies to reduce groundwater levels and salt problems, and would require integration with them.

Scope exists to reduce phosphorus export from catchments in the South-West by managing evapotranspiration on a catchment scale. More work in this area is required, but it would appear that a deficit in catchment evapotranspiration, associated with conversion of native vegetation to annual pastures, could be substantially offset by:

- planting a smaller, but evapotranspirationally equivalent, area of high-water-using trees;
- the introduction of deep-rooted perennial pasture species; or
- by conducting water harvesting on farms.

Some trees suitable for farm planting in the higher rainfall areas, such as *Eucalyptus globulus* (Tasmanian Blue Gum), exhibit prodigious rates of growth and evapotranspiration (1400 mm/yr from plantations under irrigation) and are economically viable alternatives to traditional forms of farming. Trees also have the added advantages of:

- providing shelter for stock;
- improving soil moisture retention;
- providing associated conservation benefits;
- enhancing landscape and aesthetic values; and
- providing diversification in farm income.

On other fronts, economic incentives should be considered to encourage farmers to either retain appropriate portions of bushland or plant trees on farms in priority catchments (eg Peel-Harvey, Oyster Harbour, etc). This may not be as difficult as it first appears as the proportion of farms with significant stands of vegetation (native or plantation) are likely to be small in relation to the total number of farms. This inequity could actually facilitate change. For example, with a minor change in the way farm drainage rates are calculated a rebate could be offered to farmers to retain bushland or conduct tree plantings, while ameliorating the need for the state to expand expensive drainage networks. Importantly, the addition of trees in the catchment landscape would reduce runoff, stream phosphorus concentrations and phosphorus export. Clearly, close farmer consultation would be needed in the formulation of this, or indeed any, strategy designed to address equity issues amongst farmers.

Priority should now be given to estimating the eutrophication susceptibility of the estuaries of the South-West. Such estimates would undoubtedly prove to be useful tools for regional resource managers and planners, particularly in the absence of long term measures of nutrient enrichment in these estuaries. In addition, this would provide a priority listing of catchments which should be considered for the extension of fertilizer management services.

## 10. Acknowledgments

Special thanks to Charles Maling and Kevin McAlpine (Environmental Protection Authority), Bruce Gallash (Shire of Denmark), Terry Goodlich and Bruce Bond (Department of Conservation and Land Management, Walpole), Peter Helsby (Water Authority, Albany) and Anne Green (Albany) for their assistance with the collection of field data; Brendon Hewson, Peter Kiss (Environmental Protection Authority) and Roger Schultz (Chemistry Centre of Western Australia) for the analysis of water samples; Robert Humphries (Water Resources Council) for providing encouragement and editorial comment; Water Authority of Western Australia (Perth) for the provision of streamflow records; South Coast Estuaries Project Group (Albany) for the provision of catchment monitoring data; and Sally Robinson (Office of Catchment Management) for providing me with the opportunity to write this report.

## 11. References

Birch, P B, Forbes, G G and Schofield, N J (1986). Monitoring effects of catchment management practices on phosphorus loads into the eutrophic Peel-Harvey Estuary, Western Australia. Water Science & Technology 18, 53-61.

Cosser, P R (1989). Nutrient concentration-flow relationships and loads in the South Pine River, south-Eastern Queensland. Aust Journal of Marine and Freshwater Research 40, 613-630.

Environmental Protection Authority of Western Australia (1988). Environmental guidance for land use in southern Western Australia. EPA Bulletin 319 (1).

Finlayson, B L and McMahon, T A (1988). Australia vs the World, a comparative analysis of streamflow characteristics. In 'Fluvial Geomorphology of Australia', ed. R F Warner, pp. 17-40. (Academic Press)

Government of Western Australia (1992). State of the Environment Report. ISBN 07309 54226.

Hakanson, L (1990). Environmental hazard analysis - contamination of nutrients, mercury and cesium-137 in natural waters. Limnologica 20, 339-346.

Hodgkin, E P and Clark, R (1988-1990). Estuaries and coastal lagoons of south western Australia. Environmental Protection Authority of Western Australia, Estuarine Studies Series Nos 1-8.

Kinhill Engineers Pty Ltd (1988). Peel Inlet and Harvey Estuary management strategy, Environmental Review and Management Programme - Stage 2. (State Printing Division)

Loh I C, Gilbert C J and Browne K P (1981). Nutrient concentrations of streamflow in the Murray River Basin, Western Australia. Water Resources Branch, Public Works Department of Western Australia, Report WRB17.

Loh, I C and Stokes, R A (1981). Predicting stream salinity changes in south-western Australia. In 'Land and Stream Salinity', ed. J W Holmes and T Talsma, pp.227-260. (Elsevier)

Lukatelich, R J, Schofield, N J and Mc Comb, A J (1984). The nutrient status of Wilson Inlet, Western Australia (1982-1983). Department of Conservation and Environment , Western Australia, Bulletin 159.

McAlpine, K W, Spice, J F and Humphries, R (1989). The environmental condition of the Vasse Wonnerup Wetland System and a discussion of management options. Environmental Protection Authority of Western Australia, Technical Series 31.

McComb A J (1983). The effect of land use in catchments on aquatic systems: a case study from Western Australia. Centre for Water Reseach, University of Western Australia, Report ED-83-064.

Omernik J M (1976). The influence of land use on stream nutrient levels. Ecological Research Series, Environmental Research Laboratory, Office of Research and Development, USEPA, Corvallis, Oregon. EPA-600/3-76-014.

Omernik J M (1977). Nonpoint source - stream nutrient relationships: a nationwide study. Ecological Research Series, Environmental Research Laboratory, Office of Research and Development, USEPA, Corvallis, Oregon. EPA-600/3-77-105.

Public Works Department of Western Australia (1982). Streamflow records of Western Australia to 1982 - Volume 1.

Ruprecht, J K, Stokes, R A and Pickett, R B (1985). Denmark River yield and salinity study. Water Authority of Western Australia, Report WH 8.

Schofield, N J (1990). Water interactions with land use and climate in south western Australia. Water Authority of Western Australia, Report WS 60.

Schofield, N J, Birch, P B, Forbes, G G, McAlpine, K W and Bott, G M (1984). Determining phosphorus losses from currently applied superphosphate and coastal superphosphate fertilizers and from soil storage for different soil types in the Peel-Harvey catchment. In 'Potential for Management of the Peel-Harvey Estuary'. Department of Conservation and Environment, Bulletin 160.

Schofield, N J, Ruprecht, J K and Loh, I C (1988). The impact of agricultural development on the salinity of surface water resources of South-West Western Australia. Water Authority of Western Australia, Report WS 27.

Sharma, M L, Johnston, C D and Barron, R J (1982). Soil water and groundwater responses to clearing in a paired catchment study in south-western Australia. In 'First National Symposium on Forest Hydrology', ed. E.M. O'Loughlin and L.J. Bren, Australian Institute of Engineers.

South Coast Estuaries Project Group (1992). Reducing the nutrient load from rural sources to Albany's Harbours - draft. Western Australian Department of Agriculture.

Stokes, R A (1988). Manjimup district water resource model. Water Authority of Western Australia. Report WS 17.

Stokes, R A and Loh, I C (1982). Streamflow and solute characteristics of a forested and deforested catchment pair in south-western Australia. In 'First National Symposium on Forest Hydrology', ed. E.M. O'Loughlin and L.J. Bren, Australian Institute of Engineers.

Tyskin, E, Laurenson, E M and Wu, A Y (1982). Hydrologic effects of replacement of eucalypt forest by pasture and pines. In 'First National Symposium on Forest Hydrology', ed. E.M. O'Loughlin and L.J. Bren, Australian Institute of Engineers.

Vaithiyanathan, P and Correll, D L (1992). The Rhode River Watershed: phosphorus distribution and export in forest and agricultural soils. Journal of Environmental Quality 21, 280-288.

Water Authority of Western Australia (1986). Streamflows to the Peel-Harvey Estuary. Water Authority of Western Australia, Report WP 18.

Water Authority of Western Australia (1987a). Forest management to increase water yield from the Northern Jarrah Forest. A report by the Steering Committee for Research on Land Use and Water Supply. Water Authority of Western Australia, Report WS 3.

Water Authority of Western Australia (1987b). Stream salinity and its reclamation in South-West Western Australia. A report by the Steering Committee for Research on Land Use and Water Supply. Water Authority of Western Australia, Report WS 52.

Water Authority of Western Australia (1992a). Albany sewerage, treatment and disposal of wastewater - Public Environmental Review. Water Authority of Western Australia, ISBN 0 949397 57 1.

Water Authority of Western Australia (1992b).The South-West irrigation strategy study - phase 2 technical report. Water Authority of Western Australia, Report WP 171.

Western Australian Water Resources Council (1986). Surface water resources assessment in Western Australia. A background report by the Working Party. WAWRC Publication WRC 1/86.

Yeates, J S, Arkell, P T, Russell, W K, Deeley, D M and Peek, C (1985). Management of agricultural phosphorus losses from the soils of the Peel-Harvey catchment. In 'Peel-Harvey Estuarine System Study: Management of the Estuary'. Department of Conservation and Environment Bulletin 195.

Office of Catchment Management
2nd Floor
25 Irwin Street
Perth WA
6000

ISBN 0-7309-5477-3