The Effect of Agriculture Practices on Nutrient Transport in the Blackwood – Scott Catchment, Western Australia

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ABSTRACT

The Blackwood – Scott catchment is located in the south west of Western Australia and covers approximately 2.25 million hectares from Augusta on the west coast to Kukerin and Nyabing in the east. The vast size of the catchment leads to a wide variety of practiced land uses including intensive agriculture, broad acre cropping and plantation forestry. The land use trends are currently undergoing a major shift in some areas of the catchment towards more intensive agriculture such as dairying and intensive animal production, which export nutrients at a greater rate than conventional agriculture.

The trophic status of Hardy Inlet at the catchment outlet is dependent on the loading and ratio of total nitrogen and total phosphorus from the catchment. Recent observations of phytoplankton blooms in the Inlet and the lower reaches of the Scott River indicate that the nutrient levels are high enough to be of concern. The aim of this study is to determine the effects of the different land uses on the nutrient levels in the Blackwood and Scott rivers, and to determine the major sources of nutrients within the catchment.

Based on a review of the existing literature on the nutrient transport in the catchment, and observed nutrient loading, it is determined that the lower four subcatchments of the Blackwood River and all three Scott River subcatchments are the key sources of nutrients in the catchment. Hence future planning and management of the nutrient transport in the catchment should be focused on the subcatchments.
ACKNOWLEDGEMENTS

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This project would not have been possible without the support of friends and family, thank you for all your help and support.
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1.0 INTRODUCTION

Eutrophication is fast becoming a major problem for the waterways of Australia. Effects of eutrophication include increased algal blooms, anoxic events and fish kills. These effects can be detrimental to ecosystem integrity and biodiversity. The increased productivity associated with eutrophication can usually be attributed to an overabundance of nutrients in the system, particularly forms of nitrogen and phosphorus. These nutrients are transported to the water column via a number of pathways including overland flow, groundwater flow and sediment release. Of these pathways, the overland flow component from the surrounding catchment is often the easiest to control.

In most Australian catchments, the nutrients present in overland runoff are a by-product of the land uses present in the catchment. In primarily agricultural catchments, direct application of nitrogen and phosphorus in the form of fertiliser or soil conditioner leads to massive fluxes of nutrient – rich runoff entering the river systems. Different types and intensities of land use are known to contribute different quantities and forms of nutrients to the river system.

To protect our waterways for future generations, it is important to understand and quantify the processes by which the nutrients affect water quality. An important aspect of this is to understand the links between catchment land use and nutrient transport. The purpose of this thesis is to investigate the relationship between land use and nutrient transport in the Blackwood - Scott catchment, a primarily agricultural catchment in the south west of Western Australia.
2.0 BLACKWOOD – SCOTT CATCHMENT

2.1 Catchment Location

The study location is the Blackwood – Scott Catchment in the South-West of Western Australia, as shown in Figure 2-1. The catchment covers approximately 22,000 km² and stretches from the town of Augusta in the Southwest to Wickepin in the North and Dumbleyung in the East. It is bounded by latitudes 32°35’ and 34°25’S and by longitudes 115° and 118°25’E. The catchment encompasses 18 shires and several major towns including Narrogin, Wagin, Katanning and Dumbleyung in the northeast, Kojonup and Boyup Brook in the centre and Bridgetown, Nannup and Augusta in the Southwest. The major rivers in the Catchment are the Blackwood (including the Arthur, Beaufort and Balgarup tributaries) and the Scott Rivers, both of which drain into the Hardy Estuary near the town of Augusta (Hardcastle and Cousins, 2000) (WRC, 2002)
2.2 Monitoring Stations

The data used in this research comes from a number of monitoring stations spread throughout the catchment. The monitoring stations are used by the Department of Environment, and a detailed list of stations with their names, number and other information, is available in Appendix 1. There is also a number of BHP Billiton monitoring stations used in the region. Figures 2-2, 2-3 and 2-4 below show the locations of each monitoring station.

Figure 2-2: Lower Catchment Monitoring Stations
Figure 2-3: Middle Catchment Monitoring Stations

Figure 2-4: Upper Catchment Monitoring Stations
2.3 Hydrogeology

There are two major hydrogeological provinces in the Blackwood – Scott Catchment, namely the Yilgarn South West Province, and the Perth Basin. There are also two minor provinces, the Leeuwin Province and Boyup Basin. The Yilgarn South West Province is the entire catchment east of Nannup, with the exception of a small segment near Boyup Brook classified as Boyup Basin. The Perth Basin extends west of Nannup to Augusta. The thin strip of land west of Augusta is classified as the Leeuwin Province.

The Yilgarn South West Province consists mostly of weathered and fractured granitic rock aquifers, with area to the east and west of the province displaying weathered and fractured gneissic rock aquifers. Along the palaeochannels - which mostly follow the existing riverbeds, superficial aquifers are found. The groundwater in the Province is generally saline, with local fresh occurrences.

The northern Perth Basin is mostly sedimentary aquifer of the Warnbro, Yarragadee and Lesueur formations. The southern region of the Basin along the Scott Coastal Plain is surficial aquifer. There are several small isolated patches of basalt aquiclude in the Perth Basin. The groundwater in the Perth basin is mostly fresh, with some brackish areas.

The Leeuwin Province consists of weathered and fractured rock aquifers of gneissic rocks and granulites. Most of the groundwater is fresh, but the some coastal western areas may be contaminated by ocean influence. The Boyup Basin is a sedimentary aquifer, with generally brackish groundwater and some local fresh occurrences (De Silva et al., 2000).
2.4 Soils

Soil types vary greatly within the Blackwood – Scott catchment. Over 30 specific soil types are described in the Atlas of Australian Soils (Northcote et al., 1960) for the region. The local soil type depends on the underlying geology and as well as the local topography. A general description of geology and soil type for the catchment is given below.

The Lower Catchment has a base of sedimentary rock, overlain by laterite derived yellow – brown and grey sandy gravels and sands. The southern Scott Coastal Plain is poorly drained deep loose sand.

Both the Middle and Upper Catchments have bedrock of Archaean gneiss, granite, migmatite and granulite. The Middle catchment is mostly covered by a lateritic plateau, giving rise to gravelly soils and sand. The Upper Catchment soils are mostly of a sandy and loamy duplex nature (De Silva et al., 2000).
2.5 Climate

The climate in the Blackwood – Scott Catchment varies significantly from east to west. Generally, the area experiences a semi – arid to Mediterranean climate, with hot, dry summers and cool, wet winters (BOM, 2004) (Hardcastle and Cousins, 2000) (WRC, 2002). The average annual rainfall varies from 480mm in the east at Katanning to almost 1000mm in the west at Augusta (BOM, 2004). The average temperatures for Augusta range from a daily minimum of 14°C to a maximum of 19.7°C (Figure 2-6). The equivalent temperature range for Katanning is 9.3°C – 22.1°C (Figure 2-5).

![Figure 2-5: Climate: Katanning](image)

![Figure 2-6: Climate: Augusta](image)
2.6 Vegetation

The vegetation in the Blackwood–Scott Catchment changes significantly with the different climatic and soil conditions found across the catchment. The vegetation of the Lower Catchment varies from low scrub and peppermint woodlands near the coast, to jarrah–marri forest further inland. Some patches of karri forest exist on the Leeuwin–Naturaliste Ridge. Isolated pockets of flooded gum, blackbutt and bullich are also found in this region. The Lower Middle Catchment is mostly jarrah–marri forest tending to marri–wandoo further to the north–east. It also includes areas of salmon gum, yate, casuarina and paperbark (WRC, 2002).

The vegetation of the Upper Middle Catchment consists of mixed woodlands of marri and wandoo. Pockets of jarrah, yate, york gum and salmon gum also exist. Vegetation surrounding the salt lakes includes casuarina, melaleuca, teatree and samphire. The Upper Catchment is vegetated mostly by mallee scrub and black marlock (Hardcastle and Cousins, 2000) (Hodgkin, 1978).

Appendix 2 details the scientific names of the vegetation found in the catchment.
2.7 Land Use

There are a number of different land uses currently evident in the Blackwood – Scott Catchment. They vary significantly across the catchment, depending mainly on rainfall. It has been estimated that native vegetation as described above in Section 2.6 occupies only 21% of the catchment area, the rest being cleared (77%) or used for plantation forestry (2%) (WRC, 2002).

The low rainfall area of the catchment East of Darkan supports mostly cropping in the form of wheat and sheep farming, with very little remnant vegetation. In the medium rainfall area between Darkan and Boyup Brook there is more diverse land use, including cropping, grazing and plantation forestry. The higher rainfall areas west of Boyup Brook support a very wide range of land uses, including horticulture, dairying, cropping, grazing, animal production and plantation forestry. The Lower Catchment also includes greater proportions of remnant native vegetation. Table 2-1 outlines the specific proportion of each land use in the catchment according to WRC, 2002.

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Area (Ha)</th>
<th>%</th>
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<tr>
<td>Cropping</td>
<td>1592022</td>
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<tr>
<td>Natural Vegetation</td>
<td>477436</td>
<td>21.2</td>
</tr>
<tr>
<td>Pasture</td>
<td>108264</td>
<td>4.8</td>
</tr>
<tr>
<td>Plantation</td>
<td>46175</td>
<td>2.1</td>
</tr>
<tr>
<td>Horticulture</td>
<td>13723</td>
<td>0.6</td>
</tr>
<tr>
<td>Dairy</td>
<td>8234</td>
<td>0.4</td>
</tr>
<tr>
<td>Mining</td>
<td>1809</td>
<td>0.08</td>
</tr>
<tr>
<td>Res/Rural Residential</td>
<td>1074</td>
<td>0.04</td>
</tr>
<tr>
<td>Animal Prod (inc Pigs)</td>
<td>563</td>
<td>0.02</td>
</tr>
<tr>
<td>Other</td>
<td>1536</td>
<td>0.06</td>
</tr>
<tr>
<td>Total</td>
<td>2250836</td>
<td>100</td>
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Table 2-1: Land Use in the Blackwood - Scott
3.0 LITERATURE REVIEW

3.1 Catchment Land Use

3.1.1 Catchment Pollution

Nitrogen (N) and Phosphorus (P) are leading pollutants in lakes, rivers and estuaries (Arbuckle and Downing, 2001), and the excess amounts of these nutrients can be related to land use in the catchment. Other types of catchment pollution include siltation due to erosion, contamination by toxins, introduction of exotic species and loss of biodiversity (Carpenter et al., 1998). Catchment pollution can result from either a point source or a diffuse source in the catchment. The type of pollution caused by each source differs, as do the strategies that can be employed to reduce the effects of the pollution on the catchment (Carpenter et al., 1998).

Point Sources

Point sources include effluent of runoff from wastewater treatment plants, abattoirs, and rubbish tips (WRC, 2002). Point sources tend to have a continual, constant rate of discharge. Point sources of catchment pollution can be more easily targeted for control and management.

Diffuse Sources

Nonpoint or diffuse sources of catchment pollution are derived from subsurface, surface and atmospheric flows into receiving waters. Diffuse sources are regarded as the major sources of nitrogen and phosphorus pollution in developed countries. Typical diffuse sources of nitrogen and phosphorus to receiving waters include the following: runoff from agriculture, pasture and urban activities.
3.1.2 Effects of Land Use

Natural

For the Blackwood – Scott catchment, natural land uses are defined as the remnant native vegetation which covers more than 20% of the total catchment area (See Section 2.6 and Appendix 2 for more details). The runoff from native vegetation has been estimated for this catchment at 0.8 kg/ha/year for TN and 0.001 kg/ha/year for TP (WRC, 2002). Native vegetation often has the ability to take up nutrients in runoff, so it is useful as a riparian buffer zone along waterways. This form of nutrient reduction is currently supported by the department of Conservation and Land Management and the Department of Environment (Oates, 2000a) (Oates, 2000b).

Agricultural

Agricultural activities are responsible for an increase in nutrient fluxes to freshwater ecosystems worldwide (Arheimer and Liden, 1999) (Buck et al., 2003) (Carpenter et al., 1998) (Summers et al., 1999) (Weaver and Reed, 1997) (Young et al., 1995). Agricultural soils are often nutrient rich, drained, tilled and fertilised regularly. Apart from this, they are lacking in vegetation cover for large parts of the year. These characteristics lead to the occurrence of nutrient – rich runoff from agricultural landscapes. Nitrogen and phosphorus are the leading pollutants commonly found this agricultural runoff (Arheimer and Liden, 1999). The nutrients are generally added as s and soil conditioners.

The different types of agriculture present in the Blackwood – Scott contribute variable fluxes of nitrogen and phosphorus to the river, and in variable proportions. Animal agriculture and grazing generally has a low export rate per hectare of both nitrogen and phosphorus, with a low N:P ratio, whereas row cropping has a low export rate per hectare with a higher N:P ratio.
Horticulture and intensive animal production have higher exports per hectare and generally result in higher N:P ratios. The stoichiometry of nutrients in the water column is one of the limiting factors for algal growth, and hence is an important factor to note for improving water quality (Arbuckle and Downing, 2001).

The following table highlights the mean phosphorus application rate for different land uses on the South coast of Western Australia, (adapted from Weaver and Reed, 1997) (Table 3-1).

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Mean P Application Rate (kg P / ha)</th>
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<tr>
<td>Grazing – Sheep</td>
<td>12.5</td>
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<tr>
<td>Grazing – Beef Cattle</td>
<td>13.8</td>
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<tr>
<td>Grazing – Horses</td>
<td>15.3</td>
</tr>
<tr>
<td>Grazing – Dairy Cattle</td>
<td>14.6</td>
</tr>
<tr>
<td>Cropping – Meadow Hay</td>
<td>18.4</td>
</tr>
<tr>
<td>Cropping – Cereal Hay</td>
<td>18.4</td>
</tr>
<tr>
<td>Cropping – Cereal</td>
<td>14.4</td>
</tr>
<tr>
<td>Orchards / Vineyards</td>
<td>23.3</td>
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<tr>
<td>Horticulture – Potatoes</td>
<td>84.1</td>
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<tr>
<td>Horticulture - Vegetables</td>
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Table 3-1: P Application Rates for Various Land Uses

The application rate is not the only factor in the production of nutrient-rich agricultural runoff. The time of application also plays a major role. Farmers who fertilise late in the season (June / July) are risking a large proportion of the fertiliser be washed away with the first rains of winter. This produces both an economic loss for the farmer and also an environmental loss in terms of nutrient-rich runoff entering the water system (Weaver and Reed, 1997).

The phosphorus status of the soil which the fertiliser is added is also an important consideration. The phosphorus status of the soil refers to the response of a crop on the soil to the addition of phosphorus. A low
phosphorus status soil indicates that a significant crop response will be seen, following phosphorus application. A high phosphorus status soil indicates that there will be no significant difference to the crop after the addition of phosphorus (Yeates et al., 1991). Farmers need to be aware of the nutrient status of their soil, to provide the most efficient regime of fertilisation. It is still common on the south coast of WA for soils to receive phosphorus application independently of the soil phosphorus status (Weaver and Reed, 1997).

As an example of fertiliser use in the Blackwood – Scott catchment, potato farmers in the Scott catchment annually add between 75 and 250kg/ha of phosphorus to their crops, depending on the soil type. Potato crops in the area also require approximately 450kg/ha of nitrogen per year, of which only around 100kg is removed with the crop (Gerritse, 1996). These nutrients are then transported to the Scott River via surface and subsurface flows, and ultimately find their way to the Hardy Inlet (Arbuckle and Downing, 2001).

**Urban**

There are many urban sources of catchment pollution. Diffuse sources include runoff from construction sites, lawn fertilisers and inputs from unsewered developments (Carpenter et al., 1998). For this catchment in particular, the urban areas mostly consist of residential and rural – residential developments. The urban land use in the Blackwood – Scott consists of approximately 1074 ha, or 0.04% of the catchment in total. Urban runoff can be considered insignificant for nutrient transport in the Blackwood – Scott, due to the low export rates of both nitrogen and phosphorus and the small urban area.
3.2 Nutrients

3.2.1 Nitrogen and Phosphorus Processes

Nitrogen

Nitrogen is one of the most significant nutritional and structural components of biota. Along with phosphorus, nitrogen is essential to ecosystem function and has the potential to become the limiting nutrient for photosynthesis and phytoplankton productivity (Arbuckle and Downing, 2001). Nitrogen exists in fresh water in following forms:

- Dissolved molecular nitrogen, N₂
- Organic Compounds inc amino acids, amines, proteins
- Ammonia, NH₄⁺
- Nitrite, NO₂⁻
- Nitrate, NO₃⁻

Sources of nitrogen in rivers include precipitation onto water surface, nitrogen fixation and inputs from both groundwater and surface drainage. Nitrogen can be transformed whilst in the water column by nitrification and lost via effluent outflow, denitrification and permanent sedimentation (Figure 3-1) (Whitehead et al.).

![Nitrogen Processes Diagram](image-url)
Figure 3-2 shows the changes in oxidation number of nitrogen, during several pathways of biochemical transformation.

**Figure 3-2: Nitrogen Oxidation States**

**Nitrification**

The broad definition of nitrification is the biological conversion of organic and inorganic nitrogenous compounds to a more oxidized state under aerobic conditions (Wetzel, 1983). The actual reactions present are complex but generally consist of the oxidation of ammonia to nitrate, by the nitrifying bacteria *Nitrosomonas* and *Nitrobacter*.

Overall Nitrification Equation

\[
\text{NH}_4^+ + \frac{1}{2}\text{O}_2 \rightarrow \text{NO}_3^- + \text{H}_2\text{O} + 2\text{H}^+
\]

*Equation 3-1: Nitrification*

The actual reaction proceeds in a number of stages, as follows:

(i) Initial Nitrification

\[
\text{NH}_4^+ + \frac{1}{2}\text{O}_2 \leftrightharpoons 2\text{H}^+ + \text{NO}_2^- + \text{H}_2\text{O}
\]
Equation 3-2: Nitrification Step 1

The initial nitrification proceeds via a series of oxidation stages by bacteria, fungi and autotrophic organisms. The intermediate products include hydroxylamine, NH$_2$OH, pyruvic oxime, H$_2$N$_2$O$_2$, and nitrous acid, HNO$_2$. The initial nitrification to of ammonia to nitrite is undertaken by nitrifying bacteria *Nitrosomonas*.

(ii) Oxidation of Nitrite to Nitrate

$$\text{NO}_2^- + \frac{1}{2}\text{O}_2 \rightleftharpoons \text{NO}_3^-$$

Equation 3-3: Nitrification Step 2

The further oxidation of nitrite is facilitated by the nitrifying bacteria *Nitrobacter*, resulting in the formation of nitrate.

**Denitrification**

Denitrification is a biochemical reduction of oxidized nitrogen anions by bacteria (Wetzel, 1983). The end product of nitrification is generally N$_2$ which can be lost by the system. Under some temperature conditions, the end product can be nitrous oxide, N$_2$O, which is quickly reduced to N$_2$. Denitrification occurs in anaerobic conditions in the presence of oxidisable organic substances. The complex reactions can be generalized by the following succession from nitrate to nitrite to nitrous oxide to molecular nitrogen, as shown below. In most systems, nitrification and denitrification occur simultaneously.

$$\text{NO}_3^- \rightarrow \text{NO}_2^- \rightarrow \text{N}_2\text{O} \rightarrow \text{N}_2$$

Equation 3-4: Denitrification
Fixation

Nitrogen fixation occurs both from the water column and in the underlying sediments. It involves the transformation of molecular nitrogen $N_2$ into useable organic forms. It can be achieved by some blue-green algae and some bacteria. Species of blue-green algae capable of nitrogen fixation are generally limited to those which contain heterocysts; the specialized cells that are the site of nitrogen fixation. Nearly all photosynthetic bacteria are capable of nitrogen fixation. The most common species of heterotrophic nitrogen fixing bacteria include *Azotobacter* and *Clostridium pasteurianum*. Such species use nitrogen fixation as an alternative source of nitrogen when TN:TP is low in the water column, usually gaining a competitive advantage over other species which may be limited by the lack of usable nitrogen.

Sedimentation

Sedimentation can be defined as the decomposition of sedimenting organic matter (Wetzel, 1983). Soluble organic matter released by phytoplankton decomposes rapidly in the water column before it reaches the sediment interface. Particulate organic matter is slower to decompose and significant amounts can reach the sediment interface. Inorganic and organic compounds often contain both N and P; hence the sedimentation process can influence the quantity and form of nutrients present in the water column.
PHOSPHORUS

Like nitrogen, phosphorus is also found in a number of forms in the water column. It is a natural element found in rocks, soils and organic material. It is usually present in both dissolved and particulate forms (Wetzel, 1983). Some common forms of phosphorus are listed below

- Organic compounds
- Adsorbed phosphorus on sediments
- Phosphoric Acid $\text{H}_3\text{PO}_4$
- Dihydrogen Phosphate $\text{H}_2\text{PO}_4^-$
- Hydrogen Phosphate $\text{HPO}_4^{2-}$
- Phosphate $\text{PO}_4^{3-}$

Phosphorus occurs in natural water almost entirely in the form of phosphates. The major form of phosphorus used by plants is orthophosphate, the salts of phosphoric acid. Orthophosphate is also known as FRP or filterable reactive phosphorus (GeoscienceAustralia et al., 2004)

Phosphorus, like nitrogen, is exported from the water column by sedimentation. However, the internal loadings of phosphorus and nitrogen are not stable, and these nutrients can be resuspended into the water column by bacterial reactions under anoxic conditions. Resuspension is also possible by stream bed erosion. Once resuspended, the phosphorus (and nitrogen) can again be taken up by phytoplankton which can lead to problems such as eutrophication (see Section 3.3).
3.2.2 Limiting Nutrients

Nutrients have the potential to limit biological growth and production, when light and temperature are adequate, and loss rates are not excessive (Heckey and Kilham, 1988). In particular, algal growth is generally limited by the presence of nitrogen, phosphorus and occasionally silica.

3.2.3 Nutrient Stoichiometry

The relative proportions of nutrients in the water column also effect biological productivity and community structure (Arbuckle and Downing, 2001). VH Smith (1983) studied the N:P ratio of 17 lakes around the world, and found that there was a tendency for blue – green algal blooms to occur when the epilimnetic N:P ratio fell below 29:1 by weight. The occurrence of blue – green algae can be attributed to the nitrogen fixing capacity of the species. Other phytoplankton which cannot obtain nitrogen from the atmosphere cannot maintain high growth rates in nitrogen depleted environments, thus are out - competed by the blue – green species.

The atomic TN:TP ratio in agricultural catchments vary between 30:1 and 300:1 (Arbuckle and Downing, 2001). These correspond to mass ratios of approximately 13:1 to 135:1. When compared with the results from Smith, 1983, it is obvious that in at least some catchments, the potential for blooms of blue – green algae exists.
3.3 **Eutrophication**

3.3.1 Causes of Eutrophication

Eutrophication is a major ecological problem in lakes, rivers and estuaries worldwide (Carpenter et al., 1998). It can be defined as an increase in primary production due to excesses of available nutrients. It can also lead to changes in biological structure and turnover, and may increase the trophic state of the water body (Table 3-2) (Elser and Urabe, 1999). Eutrophication in freshwater systems is normally directly attributed to the presence of excessive concentrations of nitrogen and phosphorus in the water column, however, the stoichiometry of these nutrients is also a critical factor for blooms to occur (see Section 3.2.3).

<table>
<thead>
<tr>
<th>Water Quality Characteristic</th>
<th>Oligotrophic</th>
<th>Mesotrophic</th>
<th>Eutrophic</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP (mg/m³)</td>
<td>8.0</td>
<td>26.7</td>
<td>84.4</td>
</tr>
<tr>
<td>TN (mg/m³)</td>
<td>661</td>
<td>753</td>
<td>1875</td>
</tr>
<tr>
<td>Chlorophyll a (mg/m³)</td>
<td>1.7</td>
<td>4.7</td>
<td>14.3</td>
</tr>
<tr>
<td>Chlorophyll a Peak (mg/m³)</td>
<td>4.2</td>
<td>16.1</td>
<td>42.6</td>
</tr>
<tr>
<td>Secchi Transparency Depth (m)</td>
<td>9.9</td>
<td>4.2</td>
<td>2.45</td>
</tr>
</tbody>
</table>

Table 3-2: Characteristics of Trophic Levels
3.3.2 Local Effects of Eutrophication

The immediate effects of eutrophication are increased primary production, elevated biomass and chlorophyll a levels, and shifts in species composition. The algal blooms associated with eutrophication account for most of the increased production and biomass. When the populations become unsustainable, the mass death and decomposition of the phytoplankton causes an elevated flux of nutrients from the water column to the sediments (GeoscienceAustralia et al., 2004).

The long term effects include oxygen depletion (anoxia), increased incidence of fish kills, the loss of aquatic habitats and decreased aquatic biodiversity (Wetzel, 1983). There is also the possibility of future nutrient resuspension from the sediments back to the water column, which can cause recurring algal bloom and associated problems.

Eutrophication can also be detrimental to the aesthetics and perceived human value of the system. The presence of toxic species can influence the economic value of the system by effectively closing down commercial fishing and recreational activities on or near the river.
4.0 PAST WORK

There have been a number of past studies of the area which support and influence the direction of this current work. In particular, the following three studies provide useful insights into the system.

4.1 Environmental Studies of the Blackwood River Estuary

The first detailed study of the Blackwood River estuary was undertaken in the mid 1970’s for the Department of Conservation and Environment (Hodgkin, 1978). It was commissioned to research the impacts of a proposed dredging of mineral sands near the mouth of the Blackwood and upstream near Molloy Island. The study also had the long term objective of understanding the Blackwood river estuary ecosystem for future management.

It is divided into four sections, firstly the Blackwood Catchment; incorporating the climate, geomorphology, hydrogeology, vegetation and fauna of the catchment. The second section is devoted to the physical factors in the estuary and the third to the biological factors in the estuary. The fourth section attempts to gain a social perspective of the lower catchment and estuary.

This report provides an important historical context for new work in the catchment and specifically around the Hardy Inlet and estuary. Comparisons can be made between data collected in the 1970’s and current readings to understand changes in the catchment over time and hopefully to help predict future variations.
The comparisons between the 1978 data and current data in terms of rainfall and river flow are presented in Figures 4.1 to 4.6.

**Rainfall**

**Augusta**

![Figure 4-1: Rainfall at Augusta, 1975 and 2004](image1)

**Wagin**

![Figure 4-2: Rainfall at Wagin, 1975 and 2004](image2)
The rainfall to the Blackwood – Scott catchment has shown some variability since the 1978 study. The trends of the long term averages have been increased rainfall at Wagin, Boyup Brook and Nannup (Figures 4-2, 4-3, 4-4 respectively) and decreased rainfall at Augusta on the south – west tip of the catchment (Figure 4-1).
River Flow

The average monthly river flows are shown for Nannup in Figure 4-5 and Darradup in Figure 4-6.

Figure 4-5: River Flow at Nannup, 1955 and 2003

Figure 4-6: River Flow at Darradup, 1975 and 1999

The average monthly river flow appears to have decreased by a significant amount at both stations. Figure 4-5 shows the historic average at Nannup from 1940 – 1955 against the current average from 2001 – 2003. Figure 4-6 shows the historic average at Darradup for 1965 – 1975 against the current average from 1976 – 1999.
4.2 **Hardy Inlet Water Quality**

The second report of significance to this study is the first in a proposed series of reports on Water Quality Sampling in the Hardy Inlet, produced by the Water and Rivers Commission in 2000 (Hardcastle and Cousins, 2000). The report provides a summary of data collected in the Hardy Inlet and the lower Blackwood and Scott rivers in 1999. The report is divided into three main sections, chemical parameters, physical parameters and biological parameters.

The data used for the report is taken from some of the Department of Environment sampling sites that are used in this work, and some others. Twelve main sampling sites were used, mostly within the Hardy Inlet, and two continuous gauging stations were used to determine riverine flow data over the study period. These stations are situated at Hut Pool (609019): 45km upstream on the Blackwood River, and 8.5km up the Scott River at Brennans Ford (609002).

The physical parameters were obtained using a Hydrolab multiprobe to record temperature, salinity, specific conductivity, dissolved oxygen, pH and turbidity. Secchi dick readings were also used to determine light penetration.

Water samples were used to define the chemical parameters for this report. Total nitrogen and total phosphorus concentrations were obtained using unfiltered samples, and samples filtered through a 45µm cellulose nitrate filter paper were used to analysed for ammonia, nitrate and nitrite, soluble phosphorus, silica and dissolved organic carbon. Chlorophyll and phaeophytin content was analysed using a 4.7cm glass microfibre filter.
Integrated water samples taken through the water column were used to analyse the phytoplankton present in the Inlet. The major forms of phytoplankton in the Hardy Inlet were diatoms, cryptophytes and chlorophytes, with some occurrences of dinoflagellates and the often toxic cyanobacteria. It was found that the cell counts were generally below 5000 cells/mL, but a bloom of diatoms was recorded at West Bay in a sheltered arm of the Inlet, where cell numbers reached almost 130 000 cells/mL in September of 1999.
4.3 Aggregated Emissions of TN and TP to the Blackwood - Scott

This report was written in November 2002, by the then Water and Rivers Commission (now Department of Environment) for the National Pollutant Inventory (NPI). The NPI is a national database of information on the types and amounts of certain substances being emitted to the air, land and water (DEH, 2004).

The aim of the research is to report the annual aggregated emissions of total nitrogen and total phosphorus to the Blackwood – Scott catchment for the NPI. This paper also estimates the actual stream loading of nutrients, taking into account in – stream nutrient assimilation.

The aggregated emissions are estimated using the Catchment Management Support System (CMSS) model, as described in (Letcher et al., 1999). CMSS is a simple empirical catchment scale model, and will be described in more detail in Section 7. The assimilated loads are estimated in CMSS using an assimilation model based on the following equation (Equation 4-1)

\[ L_t = L_0 e^{-kt} \]

Equation 4-1: In – Stream Assimilation

Where:
L\(_t\) = load at time t
L\(_0\) = initial load at time t = 0
k = coefficient rate based on the water depth
t = time for decay

These estimated loadings are then compared to the available monitoring data for the catchment, taken from both Department of Environment and BHP Billiton monitoring stations. This report and its findings will be critically reviewed in Section 7.
5.0 DATA

The data available for this study was very limited. The only comprehensive data set available was obtained from the Department of Environment. Their monitoring of the south – west region of WA includes surface water, groundwater and meteorological stations. There are 500 surface water stations listed for the Blackwood – Scott catchment (Department of Environment, 2004)

A number of surface water characteristics are sampled, with some stations carrying out discrete monitoring, and others continuous monitoring. The most basic data necessary to get an understanding of nutrient transport through the catchment is as follows;

- Discrete Total Nitrogen Concentrations
- Discrete Total Phosphorus Concentration
- Continuous Flow Measurements

For realistic application the flow, total nitrogen (TN) and total phosphorus (TP) measurements must be taken for the same time periods. This is due to the fact that for large portions of the year, the upper Blackwood system generates little or no runoff. Hence, it follows that there is no large nutrient transport to the lower catchment from agricultural runoff for the periods of no flow.
Although there are such a large number of monitoring stations in the catchment, the selected stations are the most appropriate based on their available corresponding flow and nutrient data, as well as their position on the river and the length of time data has been collected at that particular point. The position of most monitoring stations corresponds with the outflow of a particular subcatchment. This is useful for attempting to determine a generated nutrient load for each subcatchment. Stations that have been in use for a longer time period are also preferred, as they provide an insight into annual variability of flow and nutrient concentration.

The quality of the data is another consideration. An issue noted with the nutrient concentration data from the Department of Environment is detection and laboratory reporting limits. Figure 5-1 provides an example of TP concentration data for Station 609012 on the Blackwood River at Winnejup.

This is typical discrete monitoring data for the catchment. The laboratory used to analyse this data has a reporting limit of 0.4mg/L. Generally, the TP concentrations in the river are below this limit, and so are unreportable. There are only approximately 10 useful data points for this station over the 10 year period, and it is impossible to predict seasonal trends or generate accurate phosphorus loadings for this station.

Figure 5-1: TP Concentrations at 609012
Figure 5-2 shows the same station (609012) for the year 2002. The sparse nature of the data is evident in this plot, with only 24 readings in the 12 month period, and only 5 of these above the detection limit.

Figure 5-2: Annual TP Concentrations at 609012

The majority of the data is of the same quality as the example of Station 609012. The data from the Department of Environment is of exceedingly limited usefulness for determining realistic nutrient loads from the subcatchments of the Blackwood – Scott.
6.0 METHODS

The aim of this research is to understand and quantify the relationship between land use and nutrient transport in the Blackwood – Scott catchment. It was envisaged that this could be achieved firstly by calculating approximate nutrient loadings for each of the 21 subcatchments. The resulting nutrient loadings could then be used to determine the key subcatchments that contributed the most nutrients to the system. Once the key subcatchments were identified, they could then be modelled in terms of land use and nutrient loading. The modelled land use in the key subcatchments could then be varied to match the current trends in land use planning for the region. Thus the probable effects of the current land use trends could be discovered, and appropriate recommendations could be made for the management of the Blackwood – Scott system.

However, the lack of appropriate data outlined in Section 5, necessitated that the research take a different direction. There was not enough corresponding nutrient and flow data to accurately estimate the nutrient loading for each subcatchment. Without an accurate description of the nutrient transport in the catchment, it was not feasible to try and model the situation with anything more sophisticated than a basic catchment scale empirical model. This type of modelling has already been undertaken in the Blackwood – Scott using CMSS (Catchment Management Support System) (Letcher et al., 1999).

The aims of the project were slightly revised to include a critical review of the CMSS modelling, and comparison with the existing data. From this, the key subcatchments were identified within the catchment, and the land uses in these subcatchments were compared, to determine which land uses could be considered detrimental to catchment health.
6.1 Critical Review of CMSS Modelling

The critical review of CMSS modelling was undertaken in 6 major sections, as follows:

- Observed Load Calculations
- Point Source Calculations
- Diffuse Source Calculations
- In – Stream Assimilation Calculations
- CMSS Results

6.2 Comparison with Existing Data

To be considered useful for describing the nutrient transport in the catchment, the CMSS modelling must be comparable to existing catchment data. The results obtained using CMSS are compared with physical data from the Department of Environment and BHP Billiton. The modelled assimilated cumulative loads are compared with some observed loadings of total nitrogen and total phosphorus in both the Blackwood and Scott Rivers.

6.3 Identification of Key Subcatchments

The verified results from CMSS modelling can then be used to identify key subcatchments in the Blackwood – Scott. These key subcatchments are identified using the variation of modelled and observed nutrient loads with distance upstream from the catchment outlet.
6.4 *Subcatchment Land Use*

The land uses in the key subcatchments are determined, using a land use map produced for the National Land and Water Resources Audit by the Department of Agriculture, Western Australia. The proportion of intensive land uses are noted, as are the major land uses in these subcatchments compared with other subcatchments in the Blackwood – Scott.

6.5 *Catchment Management*

The implications of the land uses present in the key subcatchments are then related to catchment management, in particular land use planning. Recommendations for future land use planning based on this type of approach are outlined, with emphasis on regulating intensive land uses on inappropriate soils.
7.0 CMSS MODELLING

7.1 Observed Load Calculations

A major part of the WRC, 2002 report is devoted to calculating the observed nutrient loads in streams and rivers in the Blackwood – Scott catchment. The data used for this assessment is the same Department of Environment data described in Section 5, along with data from six BHP Billiton monitoring stations in the lower catchment. The quality of the BHP Billiton data is undetermined, whilst most of the Department of Environment data is known to be of inferior quality.

TOTAL PHOSPHORUS

Total phosphorus loadings are calculated using data from one Department of Environment station: 609026 (Milyeannup on the Scott River), and the six BHP Billiton Stations.

Scott River Data

<table>
<thead>
<tr>
<th>Station Number</th>
<th>Dates</th>
<th>Number of Samples</th>
<th>Average # of Samples per Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>07/1990 – 12/2001</td>
<td>146</td>
<td>1</td>
</tr>
<tr>
<td>S2</td>
<td>07/1990 – 12/2001</td>
<td>147</td>
<td>1</td>
</tr>
<tr>
<td>S3</td>
<td>08/1990 – 12/2001</td>
<td>143</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 7-1: Scott River TP Data

The calculations of annual loads in the Scott River are based on an average of only one data point per month for 3 of the 4 stations used. The fourth station has a more appropriate number with more than 1 sample taken per week.
Blackwood River Data

<table>
<thead>
<tr>
<th>Station Number</th>
<th>Dates</th>
<th>Number of Samples</th>
<th>Average # of Samples per Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>B2</td>
<td>07/1990 – 12/2001</td>
<td>142</td>
<td>1</td>
</tr>
<tr>
<td>B3</td>
<td>07/1990 – 12/2001</td>
<td>146</td>
<td>1</td>
</tr>
<tr>
<td>B4</td>
<td>10/1996 – 12/2001</td>
<td>56</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 7-2: Blackwood River TP Data

The calculations for the annual phosphorus loads in the Blackwood River are based on samples taken once a month. This sparse sampling does not accurately capture the trends in nutrient concentration, and peak concentrations may be missed altogether by this method.

TOTAL NITROGEN

The total nitrogen loadings were calculated for 3 Department of Environment stations on the Scott River (609026, 609002 and 6091051) and 8 stations on the Blackwood River (see Table 7-3).

Scott River Data

<table>
<thead>
<tr>
<th>Station Number</th>
<th>Dates</th>
<th>Number of Samples</th>
<th>Average # of Samples per Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>609026</td>
<td>06/1996 – 11/2000</td>
<td>238</td>
<td>12</td>
</tr>
<tr>
<td>609002</td>
<td>06/1996 – 11/2000</td>
<td>167</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 7-3: Scott River TN Data

Most of the sampling for TN in the Scott River appears to have been on a 2-3 samples per week basis. This level of sampling could probably pick up the major trends in nitrogen concentration in the river, although for more accurate loadings, more intensive sampling routines should be considered.
The total nitrogen sampling on the Blackwood River has been carried out approximately once per month. This level of sampling effort is not enough to be able to estimate annual nutrient loadings with any accuracy.

The majority of the data used for calculating annual nutrient loads for the Blackwood – Scott catchment is too sparse for the purposes of accurate estimation. However, these two data sets are the only long – term monitoring data available for use in this research, so they are the best possible indication of the nutrient transport in the catchment.
7.2 **Point Source Calculations**

Point sources of nutrients in the Blackwood – Scott include several wastewater treatment plants, an abattoir and numerous landfill sites. The 6 major wastewater treatment plants and the abattoir are included in the modelling as point sources, and the annual export rates for these sites are available from the Department of Environmental Protection. The average annual TN and TP exports are given below in Table 7-5.

<table>
<thead>
<tr>
<th>Facility</th>
<th>TN Export (kg/source/year)</th>
<th>TP Export (kg/source/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nannup WWTP</td>
<td>600</td>
<td>50</td>
</tr>
<tr>
<td>Bridgetown WWTP</td>
<td>1500</td>
<td>290</td>
</tr>
<tr>
<td>Kojonup WWTP</td>
<td>900</td>
<td>50</td>
</tr>
<tr>
<td>Narrogin WWTP</td>
<td>9000</td>
<td>2100</td>
</tr>
<tr>
<td>Wagin WWTP</td>
<td>1200</td>
<td>525</td>
</tr>
<tr>
<td>Katanning WWTP</td>
<td>5400</td>
<td>1500</td>
</tr>
<tr>
<td>Katanning Abattoir</td>
<td>11000</td>
<td>1700</td>
</tr>
</tbody>
</table>

*Table 7-5: Exports from Point Sources*

The total export total nitrogen and total phosphorus by point sources are simply added to the totals modelled for diffuse sources in the catchment to give a total export for nitrogen and phosphorus. The only possible inaccuracy in this calculation is the omission of nutrient exports of the landfills. Landfills are known to contribute significant amounts of both nitrogen and Phosphorus to the catchment, but no data has been published to quantify their effect on the Blackwood – Scott catchment.
7.3 **Diffuse Source Calculations**

Nutrient exports from diffuse sources are estimated using assigned export rates for each land use in the catchment. The export rates for land uses in the Blackwood – Scott have been based on previous CMSS modelling of the Ellen Brook and Southern River catchments. These catchments have similar areas to the smallest subcatchments is the Blackwood – Scott, and are both located in Western Australia.

The actual export rates for particular land uses depend on a variety of parameters other than land use including catchment size, travel times, presence of riparian vegetation as well as local climate, physiography and soil type. No variability due to these parameters is captured by the CMSS model. Some alterations are made to the land use to account for this error, including breaking down land uses into two distinct annual rainfall regions and three soil categories. However, there are inherent errors in using export rates based on other catchments, and there are no considerations given to errors from catchment size, travel times, riparian vegetation and local physiography.

Export rates and associated errors for diffuse sources are tabulated in the report, and the estimated errors are as large as +/-50%, in the case of TN exports from horticulture.
7.4  *In – Stream Assimilation Calculations*

As mentioned in *Section 4.3*, the paper also estimates an assimilated nutrient load for each subcatchment. This load is estimated using the formula in *Equation 7-1* below.

\[ L_t = L_0 e^{-kt} \]

*Equation 7-1: In – Stream Assimilation*

Where:
- \( L_t \) = load at time \( t \)
- \( L_0 \) = initial load at time \( t = 0 \)
- \( k \) = coefficient rate (see *Equations 7-2 to 7-5*)
- \( t \) = time for decay

This relationship is based on simple exponential decay of nutrients in the water column. It does not directly take into account the changing flow rates in the river. Many of the subcatchments in the upper catchment do not experience year round flows, and the calculations are based on an estimate average stream depth.

It follows that the estimations for in – stream assimilation will be overestimating the actual assimilation of nutrients especially in the upper subcatchments.
In $k = -1.83 - 1.2\cdot \text{depth}$
Equation 7-2: Blackwood TN assimilation rate coefficient

In $k = 1.35 - 1.2\cdot \text{depth}$
Equation 7-3: Scott TN assimilation rate coefficient

In $k = 1.76 - 1.2\cdot \text{depth}$
Equation 7-4: Blackwood TP assimilation rate coefficient

In $k = 0.89 - 1.2\cdot \text{depth}$
Equation 7-5: Scott TP assimilation rate coefficient

The relationship of water depth and rate coefficient, $k$, is shown in Equations 7-2 to 7-5. The constants in these equations are derived empirically.
7.5 CMSS Results

The results of the CMSS modelling indicate that the Blackwood – Scott catchment produces an aggregated annual total nitrogen load of 1891 tonnes and aggregated annual total phosphorus load of 156 tonnes. The assimilated nutrient loads for nitrogen and phosphorus in the catchment are reported as 1540 tonnes and 43 tonnes respectively.

Both the cumulative assimilated loads and the subcatchment aggregated emission rates suggest that the three Scott subcatchments and the four lower Blackwood subcatchments (Bw1, Bw2, Bw3 and Bw4) are responsible for disproportionately large nutrient loads to the system.
8.0 CATCHMENT RESULTS

8.1 CMSS Vs Existing Data

The following four figures illustrate the comparison between observed nutrient loads at stations on the Blackwood and Scott Rivers and modelled assimilated loads at for subcatchments. The ratio of local TN/total TN at the output is shown against distance upstream from the catchment outlet. This approach shows the comparative trends of each data set, but ignores the differences magnitude between the two. An interesting point to note is that all but one plot shows an increase in nutrient concentration from the catchment outlet to the next monitoring station. This possibly indicates that the lower reaches of both the Scott and Blackwood Rivers are experiencing high assimilation rates, which are not captured by the CMSS modelling.

Figure 8-1 shows total nitrogen loadings for the Scott River. There are only three monitoring stations in this region with appropriate flow and total nitrogen data. The CMSS modelling seems to overestimate the nutrient load from the upstream catchments when compared with observed data.

![Assimilated Load TN Scott](image)

**Figure 8-1: Total Nitrogen Loadings for the Scott River**
The total nitrogen loadings for the Blackwood are shown in Figure 8-2. The modelled loadings do not reflect the elevated observed loadings near the catchment outlet.

![Assimilated Load TN BW](image1)

**Figure 8-2: Total Nitrogen Loadings for the Blackwood River**

**Figure 8-3** shows the total phosphorus loadings for the Scott catchment. The trends are similar to total nitrogen, and the observed loads indicate a modest increase in total phosphorus concentration over the lower 10km, where the modelled loadings do not.

![Assimilated Load TP Scott](image2)

**Figure 8-3: Total Phosphorus Loadings for the Scott River**
Figure 8-4 shows the total phosphorus loadings for the Blackwood River. There is not enough observed data for comparison, but the CMSS modelled data displays some interesting trends. The relative concentrations of phosphorus decrease over the first 50km from the catchment outlet, then rise over the next 150km upstream, before dropping decreasing until the end of the catchment. This trend indicated high assimilation of phosphorus between 50km and 200km upstream, or an underestimation of phosphorus loadings around 50 km upstream, coupled with an overestimation of loadings for the next 200km. Increased assimilation rates are possible in the lower subcatchment, because of the higher proportion of riparian vegetation and natural land uses.

Figure 8-4: Total Phosphorus Loadings for the Blackwood River
8.2 Key Subcatchments

The key subcatchments responsible for elevated nutrient loads can also be determined from Figures 8-1 to 8-4. If all subcatchments were contributing equivalent nutrient exports, the relationship between nutrient ratio and distance from source should be linear.

It is evident in the two Blackwood plats, Figure 8-2 and Figure 8-4, that the majority of the nutrients are sources from the lower portions of the catchment. In the case of total phosphorus, nearly 50% of the inputs are occurring within the first 50km from the output. This implicates the four lowermost subcatchments: Bw1, Bw2, Bw3 and Bw4.

The relative influence of the Scott catchments is not evident given only the nutrient ratios. The observed loads for both TN and TP indicate that the three Scott subcatchments Sc1, Sc2 and Sc3 are contributing elevated nutrient loads to the system.

The key subcatchments identified using observed data coincide with the subcatchments flagged by CMSS modelling of the catchment (see Section 7, in particular 7.5). From both observation and catchment modelling, it is shown that the main contributors of nutrients in the form of total nitrogen and total phosphorus are the three Scott River subcatchments and the lowest four Blackwood River subcatchments.
8.3 Subcatchment Land Use

Land uses in the key subcatchments are described in the following figures. The data for this land uses was obtained from the Department of Environment, which was modified from the National Land and Water Resources Audit by the Department of Agriculture, WA (NaturalHeritageTrust, 2004).

![Blackwood Subcatchment Land Uses](image)

**Figure 8-5: Blackwood Subcatchment Land Uses**

Figure 8-5 shows the proportional land uses in each of the four key subcatchments along the Blackwood River. Although pasture and natural environments make up the majority of the land use, there is a significant proportion of intensive agricultural land uses including horticulture (both perennial and seasonal), dairy farming and intensive animal production.

The areas for the intensive land uses are summarized in Table 8-1 below.

<table>
<thead>
<tr>
<th>Subcatchment</th>
<th>Area of Intensive Land Use (km²)</th>
<th>% Of Intensive Land Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bw1</td>
<td>2.16</td>
<td>2.49</td>
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<tr>
<td>Bw2</td>
<td>21.53</td>
<td>14.87</td>
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<tr>
<td>Bw3</td>
<td>12.6</td>
<td>11.39</td>
</tr>
<tr>
<td>Bw4</td>
<td>69.2</td>
<td>22.39</td>
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</table>
Table 8-1: Intensive Land Uses in the Blackwood Subcatchments

The intensive land uses take up over 105km² of land in the lower Blackwood key subcatchments. This represents over 15% of the land available in those regions. The corresponding land uses in the key Scott subcatchments are shown in Figure 8-6. Dairy farming and seasonal horticulture are the intensive agricultural land uses on the south coast. Table 8-2 shows the area taken up by these land uses.

![Scott Subcatchment Land Uses](image)

**Figure 8-6: Scott Subcatchment Land Uses**

<table>
<thead>
<tr>
<th>Subcatchment</th>
<th>Area of Intensive Land Use (km²)</th>
<th>% Of Intensive Land Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sc1</td>
<td>3.45</td>
<td>7.33</td>
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<tr>
<td>Sc2</td>
<td>18.43</td>
<td>8.83</td>
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<tr>
<td>Sc3</td>
<td>20.11</td>
<td>5.13</td>
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Table 8-2: Intensive Land Uses in the Scott Subcatchments

There are over 40 km² of land used for intensive agriculture in the Scott catchment. This represents approximately 6.5% of the land in the Scott catchment.
8.4 Catchment Management

The high proportions of intensive agriculture land use practices in the south–west of the catchment has been shown to lead to elevated loadings of total nitrogen and total phosphorus in the Blackwood–Scott. The disproportionately large export rates for intensive agricultural land uses make them potential targets for catchment management solutions to the nutrient problem in the catchment. Management options include limiting the amount of land allocated to such intensive land uses in future planning, changing the average export rate of nutrients from the catchment by reducing the volume of soil conditioners added, attempting to reduce the nutrient loads in runoff before it reaches the river with increased riparian vegetation, or a combination of all of these options.

All of these options listed above are economically viable when compared to the cost of directly treating the water quality issues in the Hardy Inlet. The management options and subsequent recommendations are listed in more detail in Section 10.
9.0 CONCLUSIONS

The lack of reliable and accurate data for the water quality of the Blackwood – Scott catchment makes it difficult to accurately quantify the nutrient transport throughout the catchment. Current estimates suggest that the majority of nutrients are entering the waterways via diffuse sources, and that the lower subcatchments (Bw1, Bw2, Bw3, Bw4, Sc1, Sc2 and Sc3) with higher proportions of intensive agricultural land practices are contributing a disproportionate loading to both total nitrogen and total phosphorus to the system.

Catchment management practices can be influenced with high quality nutrient models, which hopefully will lead to greater protection and enhancement of the water quality in the Blackwood – Scott system and in particular the Hardy Inlet. This research is useful as a critical review of nutrient transport process estimation in the catchment and also as an initial indication for future catchment management options.

Future monitoring should be carried out on a far more regular basis (daily rather than monthly), so that any catchment scale modelling can be fitted to actual catchment data. Any subsequent modelling will then be able to more accurately account for other effects on export rates, for example rainfall and soil type, which will provide a greater understanding of the nutrient transport processes in the catchment.
## 10.0 RECOMMENDATIONS

<table>
<thead>
<tr>
<th>Catchment Monitoring</th>
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<tbody>
<tr>
<td>Continuous flow data for more than 2 stations</td>
</tr>
<tr>
<td>At least weekly monitoring of TN concentrations at the same stations</td>
</tr>
<tr>
<td>At least weekly monitoring of TP concentrations at the same stations</td>
</tr>
<tr>
<td>Ensure the locations of monitoring stations are appropriate (outflow point of subcatchment is ideal)</td>
</tr>
<tr>
<td>Export data for catchment point sources (eg local landfills)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Land Use Planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit future land allocation to intensive agriculture</td>
</tr>
<tr>
<td>• Maintain current limits</td>
</tr>
<tr>
<td>• Decrease current limits</td>
</tr>
<tr>
<td>Reduce export rates from intensive land use areas</td>
</tr>
<tr>
<td>• Decrease annual addition of nutrients in fertiliser (Farming Practices)</td>
</tr>
<tr>
<td>• Limit excessive nutrient losses by runoff (Farming Practices)</td>
</tr>
<tr>
<td>Reduce nutrient transport to waterways</td>
</tr>
<tr>
<td>• No clearing of remnant vegetation</td>
</tr>
<tr>
<td>• Use of riparian buffer zones</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Regional Farming Practices</th>
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<tr>
<td>Free soil testing, with professional recommendations</td>
</tr>
<tr>
<td>Free fertiliser regime monitoring, with professional recommendations</td>
</tr>
<tr>
<td>Increased education to local farmers by landcare professionals</td>
</tr>
<tr>
<td>Accessible regional soil mapping</td>
</tr>
<tr>
<td>Accessible information regarding regional land use planning</td>
</tr>
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<table>
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<tr>
<th>Future Research</th>
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<tbody>
<tr>
<td>Nutrient transport modelling, including effects of climate and soil type</td>
</tr>
<tr>
<td>Research into internal (sediment) nutrient cycling</td>
</tr>
<tr>
<td>Research into in – stream assimilation of nutrients</td>
</tr>
<tr>
<td>Comparisons between Blackwood – Scott and other catchments</td>
</tr>
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</table>

*Table 10-1: Recommendations*
11.0 REFERENCES


Weaver, D. and Reed, A. (1997) "Patterns of Nutrient Status and Fertiliser Practice on Soils of the South Coast of Western Australia", *Agriculture, Ecosystems and Environment*, 67, 37 - 53.


WRC (2002) "Aggregated Emissions of Total Nitrogen and Total Phosphorus to the Blackwood and Scott River Catchments, Western Australia", Water and Rivers Commission,


# APPENDIX 1: Monitoring Stations

## Scott River Monitoring Stations

<table>
<thead>
<tr>
<th>Station Number</th>
<th>Organisation</th>
<th>Station Name</th>
<th>River</th>
<th>Latitude</th>
<th>Longitude</th>
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<td>WRC</td>
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## Lower Blackwood Monitoring Stations

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APPENDIX 2: Vegetation

Lower Catchment

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<th>Common Name</th>
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<tbody>
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<td>Eucalyptus marginata</td>
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<tr>
<td>Marri</td>
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<td>Peppermint</td>
<td>Agonis flexuosa</td>
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<td>Karri</td>
<td>Eucalyptus diverscolor</td>
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<td>Flooded Gum</td>
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<td>Blackbutt</td>
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<tr>
<td>Bullich</td>
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Lower Middle Catchment

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<tr>
<th>Common Name</th>
<th>Scientific Name</th>
</tr>
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<td>Marri</td>
<td>Eucalyptus calophylla</td>
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<td>Yate</td>
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</tr>
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<td>Allocasuarina spp</td>
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### Upper Middle Catchment

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</tr>
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<td>Eucalyptus wandoo</td>
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<td>Salmon Gum</td>
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<tr>
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<td>Allocasuarina spp</td>
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### Upper Catchment

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