GOULBURN BROKEN WATER QUALITY WORKING GROUP

DRYLAND DIFFUSE SOURCE NUTRIENTS FOR GOULBURN BROKEN CATCHMENT

MARCH, 1995

Issues Paper 2

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1. INTRODUCTION

1.1 Background to Study

The Goulburn-Broken catchment lies within the southeast corner of the larger Murray Darling Basin and is a tributary to the Murray River. The Goulburn-Broken catchment covers 2.4 million ha in Northern Victoria. Land use within the catchment includes dryland agriculture forestry, national parks, irrigated agriculture, intensive animal industries, horticulture, and urban and industrial development. The impact of these activities impacts not only on the Goulburn-Broken catchment but also the downstream Murray system.

Algal blooms have been occurring within the catchment which impose a cost on local and regional communities in terms of loss of water quality and contributes to the declining water quality of the Murray River. Research has indicated that nutrients such as nitrogen and phosphorus combine with other conditions to influence the growth of blue green algae. Nutrient management within the catchment is considered to be a means of controlling the occurrence of algal blooms.

A nutrient management strategy is currently being prepared the Goulburn-Broken Water Quality Working Group (WQWG).

The following goals to be achieved by the strategy development process have been set up as follows:

- minimise blue green algae outbreaks;
- minimise/optimise water treatment costs;
- minimise nutrient contributions to the Murray;
- foster regional development by ensuring supplies of good quality water; and
- enhance the riverine environment.

The WQWG has prepared a nutrient management strategy inception report. This report collated the results of a number of workshops, the AEAM process and existing technical information.

The Adaptive Environmental Assessment and Management (AEAM) process was used in the WQWG workshops to identify the water quality and catchment management issues and possible remedial management options. The result of the workshops suggested that the major nutrient sources having regional inputs on the surface waters are irrigation drainage, dryland areas, and sewage discharge points in the Lower Goulburn. Other possible sources with local significant inputs include septic tanks, urban runoff and discharge from intensive agricultural industries.

CMPS&F Pty Limited has been engaged by Goulburn Murray Water (GMW) on behalf of the WQWG to undertake three independent studies on:

- Dryland diffuse sources (in conjunction with Rendell and McGuckian);
- Sewerage treatment plants; and
- Urban areas and local issues.

Two other studies of irrigation drainage and intensive animal industries are also currently being undertaken making a total of five studies which will be integrated into a catchment water quality management strategy.

2. STUDY OUTLINE

To accomplish the aims of the study, the WQWG set the following objectives for the dryland study:

> "…prepare a report identifying the water quality problems due to diffuse sources of nutrients originating in the non-irrigated (dryland) area, and review the relationships between landuse and nutrient production, and suggest strategies to deal with these problems having due regard to environmental, social and economic values."

Key areas of the study have focussed on:

- identifying and where possible, quantifying the sources of nutrients originating from the dryland areas of the catchment;
- review and recommend best management practices (BMPs) to reduce nutrient impacts and production from dryland areas;
- identify knowledge gaps with regard to determining the source and/or management of diffuse source nutrients.

Stream data from the Victorian Water Quality Monitoring Network (VWQMN) was collated and used to identify the levels of nutrients in streamflows for a variety of sub-catchments. Data on land management systems and land use was combined to provide indications of nutrient loads being generated from the dryland sources on a sub-catchment basis.

A literature review was also undertaken to identify the critical components of the nutrient cycle and corresponding sources of nutrients from dryland (i.e. non-irrigated, non-urban) areas. This literature review also focussed on management practices that have been developed to manage nutrient losses to surface waters.

The results of the catchment appraisal and literature search have been drawn together to define the sources of nutrients in the dryland areas and propose best management practices to minimise these sources.

Throughout the study, CMPS&F and Rendell McGuckian have co-ordinated their activities, provided progress reports and discussed arising issues with a steering committee from the WQWG. Members of the steering committee included landholder, government (technical) and other interest group representatives. Their input and co-ordination has ensured that clear direction to the study has been maintained.

The development and implementation of the nutrient strategy will involve all of the catchment community. In order to provide a forum for the community to input to this process, the study team has presented the results of this study to a community workshop prior to final preparation of the consultant's report.

3. LITERATURE REVIEW

3.1 Introduction

The occurrence of algal blooms in Victorian inland waters has been attributed to increasing levels of nutrients. Of particular concern is the outbreaks of toxic blue-green algae (Cyanobacteria). These outbreaks are attributed in the main to unnaturally high levels of phosphorus, although other contributing factors including the nitrogen: phosphorus ratio, weather conditions and water flow conditions also come into play in initiating an algal bloom.

The problem of algal blooms in inland Australian waters has been recognised by water resource mangers since early this century. Early reports and committees, such as the AWRC 1974 have collated a variety of instances of algal blooms. Recently the problem has received more prominent attention due to unusually large outbreaks of toxic blue-green algae in the Gippsland Lakes and in the Murray-Darling Basin.

Despite the early recognition by Australian authorities of the problem, little work has been completed to date on defining actual nutrient management, seen as the key to controlling algal outbreaks.

In undertaking this study of dryland diffuse nutrient sources in the Goulburn-Broken catchment, it was considered appropriate to draw as much as possible from what work has been completed in Australia, but also from comparable situations from overseas. This review of literature has by necessity been narrowed to:

- quantification of nutrients from diffuse sources in dryland catchments;
- define the processes of nutrient generation and delivery to waterways in dryland catchments;
- review the design and implementation of best management practices for controlling diffuse nutrient sources.

Each of those items is discussed in detail in the following sections.

The value of the literature review lies in defining where the study of diffuse nutrient sources in the Goulburn-Broken catchment should focus.

3.2 Nitrogen and Phosphorus Transport Processes

Nitrogen and phosphorus can reach watercourses through runoff, erosion and leaching into groundwater. The process of transporting nitrogen and phosphorus can differ and will be dealt with separately.

3.2.1 Phosphorus

Phosphorus is the major nutrient that is attributed to the growth of blue-green algae (Garman and Sutherland, 1983). Phosphorus is present in the soil as soluble orthophosphate and inorganic phosphate. Both forms have the potential to affect algal growth as insoluble forms of phosphate are able to be released under certain conditions. Because of this, it is important to consider total phosphate when investigating the effect of phosphorus on algal growth (Cahill,1977). Most of the total phosphate in transport during storm flow conditions occurs in association with particulate matter, as measured by suspended solids (Cahill,1977).

Phosphorus adheres to soil particles and organic matter by a process known as adsorption. Because of its association with soil particles, phosphorus is found in surface runoff rather than in groundwater (Wood, 1975). If leached in a soluble form it is adsorbed onto particles deeper down the soil profile where the soil is phosphorus deficient (Wood, 1975). Because phosphorus is commonly associated with soil particles it can enter waterways through the process of erosion and overland transport (Woods, 1983).

Erosion occurs as a natural process which, due to a variety of activities, can be accelerated. Clearing vegetation from the land surface allows water and wind to increase the transported load of soil particles. Erosion processes are dealt with in more detail in Section 3.4.

Nutrient loss depends upon the duration and intensity of rainfall, angles and length of slope of land, area of land, soil type, nutrient content, vegetative cover and agricultural practices (Wood, 1975). Additionally, wind can carry fine particles over distances though this is a function of the velocity of the wind, area of land, soil type and the amount of vegetative cover available. Wood, (1975) gives a range of 0.01 to 45 kg/ha/yr for total phosphorus lost by runoff and erosion from American sites. The wide range indicates the variation that can be found between catchments.

3.2.2 Nitrogen

Nitrogen undergoes several chemical processes collectively known as the nitrogen cycle. This cycle determines the quantity of nitrogen available for transport into waterways. In the soil, nitrogen occurs as organic nitrogen from the breakdown of organic matter or as inorganic nitrogen in the form on ammonia or nitrate.

Organic nitrogen is the primary form of nitrogen found in soils. However, plants can only take up and use ammonia or nitrate. Organic nitrogen is converted to ammonia and nitrate by microorganisms. The organic nitrogen is initially converted to ammonia which is then nitrified to nitrate when the soil is well oxygenated. The rate of nitrate formation depends on the nature of the organic matter, the soil temperature, carbon and oxygen availability and moisture level (OECD, 1986). The amount of nitrate and ammonia available for transport into water systems is also dependent upon the amount taken up by crops, plants and grasses. Hall and Risser (1992) suggest around 38% of available ammonia and nitrate is taken up by crops.

The amount of organic nitrogen available for transport into water systems is dependent upon the amount converted to ammonia and nitrate but this is a small proportion of the total amount of organic nitrogen. This suggests that organic nitrogen is the form of nitrogen that has the highest potential of being transported to water systems.

Blue green algae can utilise all forms of nitrogen (Fitzgerald, 1972). Blue green algae will take up ammonia and nitrate when available and will also convert organic nitrogen to ammonia and nitrate if required. Algae grown in an environment containing ammonia and/or nitrate do not convert nitrogen without a preliminary starvation period during which the nitrogenase enzymes can develop (Fitzgerald, 1972). Thus any form of nitrogen present in water systems can potentially result in algal growth.

Nitrogen is transported to water systems dissolved in water or attached to eroded soil particles. Nitrate is highly soluble in water and can be exported in overland runoff or leached through the soil into the groundwater. A study by Hall and Risser (1992) found that 38% of the nitrogen in the soil of agricultural land in Pennsylvania was lost via groundwater and less than 1% was lost through surface runoff. The dry conditions in Australia would indicate that a greater percentage of nitrogen would be lost through surface runoff however loss to groundwater is an important consideration as nitrate is prone to vertical leaching (OECD, 1986). Groundwater can discharge into the surface water systems and hence, can be a source of nitrogen into surface waterways. Groundwater is often the major contributing source to stream base flows in the upper reaches of the catchment.

Soil particles suspended in runoff or blown into water systems are able to carry organic nitrogen into waterways. During significant erosion, the organic soil nitrogen contribution is greater than the soluble nitrogen contribution (Armstrong et al, 1974 cited in Logan,1977). This is due to organic nitrogen present in surface soil, crop residue and other organic debris being carried by water from rainfall events. Additionally, runoff sediment is enriched with nitrogen, i.e. the total nitrogen content of the sediment is higher than the soil from which it originated (Logan, 1977). This is due to selective clay transport where particles at the soil surface, which are most likely to bear nitrogen, are more readily transported (Logan,1977). The density of some nitrogen bearing organic matter is lower which enables it to be carried more readily by water (Logan,1977), also contributing to higher nitrogen loads.

3.2.3 Land Use and Water Quality

Nutrient adsorption onto soil particles entering water systems through the process of erosion plus the increased concentrations of nutrients exported from fertilised land suggests that there is a relationship between land use and water quality. However, there is no data to substantiate this assumption (Woods, 1983).

Dickinson and Wall (1977) have indicated the sediment yield to be expected from different land uses. These are presented in table 3.1 below:

Table 3.1
Sediment Yield for Different Landuse

Land Use	Sediment Yield
Natural forest or grassland	Low
Heavily grazed area	Low to Moderate
Cropping	Moderate to Heavy

(adapted from Dickinson and Wall, 1977)

Table 3.1 indicates that as the disturbance of the land increases, sediment yield increases. As nutrients are exported on sediments it follows that as disturbance increases, nutrient export increases but there is no actual data to support this.

Recent studies completed by CSIRO (Murray et al 1993) in the Murrumbidgee catchment have identified that in high flow events (i.e. flooding) a large fraction of sediment in the stream flow was actually derived from the upland areas of the basin. Daily turbidity data also confirmed that sediment loads were derived from upland sources. It was also found that in the lower reaches of the Murrumbidgee River, suspended sediments were in part derived from reworked bank material derived from flood plain channel re-alignment.

A study of the Snowy River Catchment by Caitcheon et al (1991) has similarly indicated that of six major tributaries to the Snowy, three upper catchments contribute most of the sediment.

3.3 Quantification of Nutrients Sources and Land Management Practices

Cahill, (1977) suggests that an estimate of load contributed per unit area of watershed (kg/ha) depends entirely upon the period sampled and that a rigorous analysis of individual events in a watershed is necessary to understand the generation of diffuse pollutants, ie. diffuse pollutant transport is a function of the hydrologic response of the basin. Hence documented values for pollutant transport can vary considerably between catchments, and values presented below are indicative only.

3.3.1 Agriculture

Pasture and Cropping

To improve pastures and to achieve greater crop yields, fertilisers containing nitrogen and phosphorous are applied to agricultural land. In Australia in 1972/73, 0.3 kg/ha of nitrogenous fertilisers was applied compared with 17.4 kg/ha and 46.2 kg/ha in U.S.A. and Europe respectively. The lower level of nitrogenous fertiliser application is due to Australian agriculture relying primarily on nitrogen fixation by pasture.

Superphosphate is the dominant fertiliser applied in support of agriculture and activities due to the generally low phosphorus status of Australian soils. Use of fertilisers within the catchment is discussed in Section 4.4.

The amount of fertiliser applied will differ with the type of agriculture. Some types of agriculture require large amounts of fertilisers such as dairy farming where lush green grass produces a higher yield of milk.

Nutrients contained in fertilisers can be leached through the soil and into the groundwater. The groundwater may then discharge into surface water. Clearing the land results in greater runoff after a rainfall event and erosion of the soil. As discussed in section 3.2, runoff and erosion of soil from agricultural land can carry nutrient particles and dissolved nutrients.

Clearing the land has also increased the concentration of nitrogen in the soil regardless of fertiliser application (Lawrence, 1983). This is due to grasses producing more organic matter as the life cycle of grasses is much shorter than trees. Clearing also increases the recharge rate as evapotranspiration is reduced. This results in nitrogen being leached in greater quantities into groundwater and has lead to increased nitrogen levels in groundwater (Lawrence, 1983). Hence, the application of fertiliser coupled with the cleared nature of the land, potentially makes agriculture a significant source of nutrients to water systems.

Amount of nutrients exported from agricultural land is given in table 3.2 below:

Table 3.2
Quantity of Nitrogen and Phosphorus
Exported From Agricultural Land

Nutrient Source	Nitrogen Exported kg/ha/yr	Phosphorus Exported kg/ha/yr
Unfertilised arable land	5-45	*
Fertilised arable land	145	*
Fallow land	185	*
Cultivated land	*	0.01-0.72
Grassland	8	0.2-0.3
Pasture#	0.057-1.19	0.04-0.207

Notes: * figures unavailable
New Zealand data based on the application of 380 kg/ha/yr of superphosphate over varying rainfall conditions.
(McColl et al, 1977; Wood, 1975; Loehr,1974)

This data is primarily based on American and European studies where larger amounts of fertiliser is applied compared with Australia. Actual catchment rates of fertiliser application are discussed in Section 4.

The export of nitrogen from a New Zealand pasture with the application of phosphate based fertiliser is much smaller that the export from unfertilised and fertilised arable land in America and Europe. The amount of nitrogen exported from Australian fertilised and unfertilised arable land would be much smaller than these overseas figures as less fertiliser is applied in Australia.

Martens, (1993, cited in Erskine and Saynor, 1994) quotes Australian figures of 0.24 kg/ha/yr of phosphorus export from pastures and orchards and 1.13 kg/ha/yr of phosphorus export for grazed, cropped and pasture areas. For pastures, the Australian figure is very close to the New Zealand figure for phosphorus. However, Australia does not apply as much superphosphate as New Zealand and therefore a greater difference between the two export rates would be expected. The relative closeness of the export rates may be explained by different climate and soil conditions. This highlights the problem of applying overseas data to Australian conditions.

Significant amounts of nitrogen are exported from fallowed land. This may be a function of the amount of fertiliser applied, though again it is difficult to relate this figure to Australia as the climate and geographical conditions vary considerably in America and Europe.

From the overseas figures for unfertilised and fertilised arable land, it can be concluded that land uses which involve the application of fertiliser greatly increase nitrogen export and that agricultural landuses which involve the application of different amounts of fertiliser may also affect the export of nitrogen. This is supported by data given by Loehr which is presented in Table 3.3.

Table 3.3
Nutrient Values for Fertilised and Unfertilised Cropland

Cropland	Unfertilised kg/ha/yr		Fertilised kg/ha/yr	
Landuse	Total P	Total N	Total P	Total N
Corn	0.12	5.0	0.21	13.5
Oats-alfalfa	0.12	3.8	0.12	5.1
Alfalfa, 1st yr	0.12	4.3	0.13	3.5
Alfalfa, 2nd yr	0.07	4.2	0.20	7.7
Continuous corn	0.23	5.9	0.26	12.5
Bluegrass sod	0.01	0.3	0.11	0.6

(adapted from Loehr, 1974)

According to Table 3.2 there is a general increase in both Phosphorus and Nitrogen export after fertiliser application. For a non continuous corn crop there is a significant increase in both nitrogen and phosphorus export after the application of fertiliser. This large increase also occurred for a continuous crop of corn for nitrogen but the level of phosphorus export remained fairly constant.

The large difference in nutrient export between corn and continuous corn for unfertilised land suggests that cropping regimes affects nutrient export when fertiliser is not applied. The lack of difference between the two corn regimes for fertilised land suggests that the affect of a cropping regime is blanketed by the affect of fertiliser application. This is also the case between alfalfa planted every 1 year and alfalfa planted every 2 years. It is concluded that for unfertilised land, the difference in nutrient export between landuse is very large. For fertilised land the difference is relatively small.

In both Table 3.2 and 3.3, the type of fertiliser applied is not specified. The literature did not indicate if the land had been fertilised with nitrogen or phosphate based fertiliser. Depending upon the vegetation, applying phosphate may also increase the levels of nitrogen in the soil and hence the nitrogen export. This occurs where phosphate stimulates the growth of nitrogen fixing plants.

The phosphorus loadings given in Table 3.2 for cultivated land is wide, ranging from 0.01 to 0.72 kg/ha/yr. This range can be accounted for by different climates and geographical conditions. For grassland the range is much less: 0.2-0.3 by kg/ha/yr. This range is less than the midpoint for cultivated land and this is consistent with findings that phosphorus concentration is a function of grass length (Cullen, 1983).

Phosphorus becomes more concentrated on pasture with grass length of 10 cm compared to a grass length of 2.6 cm particularly after fertiliser application (Cullen, 1983). Grasslands may be comparable to rangelands in Australia where grazing occurs on uncleared native vegetation.

Livestock

Livestock manure is another source of nutrients. Overseas, the contribution of manure is significant as it is used as fertiliser. In Australia, it is of comparative insignificance in paddocks in normal circumstances as grazing animals are stocked at lower rates. However, stock able to directly access streams and creeks may potentially contribute to nutrient levels.

In periods of drought where ground cover is reduced and the top soil becomes hard, manure may be cause for concern as during a rainfall event, water does not permeate the dry soil and runs off with a velocity that can carry manure directly into watercourses. Additionally, in dry conditions, manure and urine persist on the pastures making it susceptible to transport during a storm event. McColl (1979, cited in Cullen, 1983) found that the highest nutrient concentrations occurred in summer when there were few runoff events, pasture dies back and manure and urine persisted on the pasture surface. Hence nutrients may be built up over dry summer months and are washed away with the beginning of winter.

Nutrient loads in manure for different livestock is given in Table 3.4.

Table 3.4
Nutrient loadings in Livestock Manure[1]

Animal	Nitrogen kg/yr	Phosphorus kg/yr
Horse	75[(2)]	≈12
Cow	70[(2)]	≈9
Pig	20	6
Goat	10	1.5
Sheep	10	1.5

(adapted from Wood, 1975)

Horses and cattle contribute the largest quantity of nitrogen and phosphorus. The concentration of manure at dairy farms can be quite significant as a large number of cows are concentrated in a small area twice a day. The South Coast Estuaries Project Group Catchment Land Care Centre (1991) has estimated that 4 dairies in the catchment of Oyster Harbour in Western Australia export 1500 kg of nitrogen and 500 kg of phosphorus.

Dairy farmers also irrigate their land. Irrigation affects the load of nutrients exported. Irrigation produces more runoff than would otherwise occur (Small, 1985). Runoff carries soluble surface nutrients and nutrient bearing sediment. Coupled with fertilising, irrigation can increase the potential for nutrient export.

3.3.2 Forested land

The upper part of the Goulburn catchment is heavily forested. Other forested areas are scattered through the mid and lower regions (refer to Figure 4a). Therefore it is appropriate to consider the quantities of nutrients generated by forested land management and other associated activities. Native forests can be a source of nutrients to watercourses (Cornish, 1983). The break down of organic matter results in nitrogen and phosphorous which can be carried by runoff into watercourses or leached through the soil into the groundwater (Cornish, 1983). Organic matter can fall directly into watercourses and break down in the water. Mackenthun (1965, cited in Wood, 1975) quotes that 26.4 kg/ha/yr of nitrogen and 1.0 kg/ha/yr of phosphorus is returned to the forest floor as leaf litter from conifers and that 18.6 kg/ha/yr of nitrogen and 3.7 kg/ha/yr of phosphorus is returned from hardwoods. In a forest ecosystem this amount would increase as a function of forest density and type.

Levels of nitrogen and phosphorus found in undisturbed forest floor litter for three forest types are given in table 3.5.

[1] Actual loadings dependant on animal age. Figures quoted are for mature animals.

Table 3.5
Nutrient levels found in Forest Floor litter

Forest Type	Nitrogen kg/ha/yr	Phosphorus kg/ha/yr
Grassy forest	28.8	2.68
Layered forest	78.8	7.73
Beech forest	51.8	2.90

(adapted from Wood, 1983)

In table 3.5, grassy forest refers to an open community with snow grass floor dominated by Eucalyptus fastigata. Layered forest refers to a wet sclerophyll forest dominated by Eucalyptus saligna. The beech forest refers to a dense forest of Antarctic Beech. Different forest types export significantly different amounts of nitrogen. A layered forest contributes the most nitrogen and phosphorus.

The data in Table 3.4 is an indication of the levels of nutrients which can potentially migrate into watercourses. The levels of nutrients actually exported from undisturbed forest are much less. Loehr (1976) has reported values for nitrogen and phosphorus exported from forest area as 3 - 13 kg/yr/ha and 0.03 - 0.9 kg/yr/ha respectively. McColl (1977, cited in Cullen, 1983) has reported a range of 0.124 - 0.293 kg/yr/ha of phosphorus for native forests in New Zealand. Uttormark (1974, cited in Wood, 1975) reports a total nitrogen range of 1.3 - 5.1 kg/ha/yr and 0.01-0.86 kg/ha/yr for total phosphorous from undisturbed forests overseas.

Logging in forests can increase runoff and erosion (Wood, 1975). According to Wood (1975), there is no quantitative evidence for nutrients being transported to waterways through erosion processes. Review of various work completed in Victoria found that nutrient monitoring was not undertaken because dissolved concentrations were found to be so low. No account had been taken of nutrients attached to suspended sediments.

Studies indicate that runoff and erosion levels for logged areas increase and then decrease back to pretreatment levels after a period of time (Kriek and O'Shaughnessy 1974 cited in Wood, 1975). Clinnick (1984) suggests that sediment production increases between two and four times following logging returning to normal levels 2-3 years after harvesting is completed.

Disturbance of the ground from vegetation removal and vehicle movement and the use of equipment has been suggested is the main cause of erosion (Cornish, 1983). Roads within forests have been identified as the major source of stream sedimentation in forested areas by several studies outlined in Clinnick, (1984). These roads are associated with logging, but also are used for visitor access or forest management (fire trails).

A study of a small catchment by Western (1982 pers comm) at Gembrook indicated that at a high proportion of sediment in the waterways was due to erosion from forest tracks and recreational reserves on the stream banks. Further, it was found that sediment transport on adjoining farm land was largely a matter of soil redistribution within the paddocks. Little sediment was observed to enter the stream from the farmland.

Weston (pers comm) also observed that although the nutrient status of the forest soils was low, due to the high sediment loss rates, a high proportion of the phosphorus and nitrogen in the waterway was due to the erosion being experienced in the forested area.

Fire occurring naturally, through accident, or as a management tool may also affect nutrient export. Apart from clearing vegetation, fire can alter the structure of the soil and render it more prone to erosion (Clinnick, 1984). Coarse textured soils become less cohesive, have lowered infiltration rates and increased susceptibility to leaching when organic matter is lost through fire (Clinnick, 1984). Midgley, (1973 cited in Wood, 1975) compares water quality from two neighbouring catchments in the A.C.T. one of which had been burnt. Midgley quotes a range of 0.19-0.26 mg/l of soluble phosphorus for the unburnt catchment and 0.20-0.32 mg/l of soluble phosphorus for a burnt catchment. Wood (1975) suggests that a fire followed by a heavy rain event may result in significant nutrient loss, although this has not been quantified.

3.3.3 Landfill

Landfills are potential diffuse source of nutrients. Decomposing organic matter produces nitrogen, nitrate, ammonia and phosphate that can be leached through the soil. In sanitary and large municipal landfills this leachate is collected and disposed of. However, in rural areas landfills generally do not have the controls that these landfills have. As a result, leachate can contaminate groundwater which may then discharge into streams, creeks or rivers.

Concentrations of nutrients in leachate varies considerably. Leachate characteristics are influenced not only by the materials placed in the fill but also by the stage of decomposition and the physical characteristics of the percolating water and the soil adjacent to the fill or used for cover (Pohland, 1975). Additionally, the physical, chemical and biological activities within the fill influence the composition of the leachate (Brunner and Keller, 1972). Hence the concentration of nitrogen and phosphorus in leachate can vary significantly. Pohland (1975) reports a large range of concentration for ammonia: 0.2 to 106 mg/l, and nitrate: 5 to 196 mg/l. Brunner and Keller (1972) report ranges of 2.4 to 482 mg/l for organic nitrogen, 0.22 to 480 mg/l for ammonia and 0.3 to 130 mg/l nitrate for the first 1.3 litres of leachate per cubic foot of a compacted, representative municipal solid waste.

3.3.4 Rainfall

Nutrients occur naturally in rainfall. Table 3.6 presents the levels of nutrients typically found in American precipitation. Nitrogen occurs naturally in the atmosphere and is precipitated as part of the nitrogen cycle. In Table 3.6 the levels of nitrogen in urban and rural precipitation are fairly similar. This was also found by Thomas and Greene (1993) who quotes figures of 0.23 mg/l of nitrates for a rural site and 0.21 mg/l of nitrates for an urban site in Australia.

In contrast, the PO_4 levels differ substantially between rural and urban. This indicates that human activities (vehicles, industry) have increased the concentrations of phosphates in rainfall. Loehr, (1974) suggests that precipitation characteristics are influenced by man-made events such as fuel burning, automobiles, and manufacturing operations.

Table 3.6

Nutrient Concentrations in Rainfall

Nutrient	Urban Land mg/l	Rural Land mg/l	Forested Land mg/l
NH_4-N	*	*	0.16
NO_3-N	*	*	0.30
Inorganic N	0.7	0.9	*
Total N	1.27	1.17	*
Hydrolysable PO_4-P	0.24	0.08	*
Total PO_4	*	*	0.008

(adapted from Loehr, 1974)

Note: * figures unavailable

Some Australian figures have been summarised in Wood (1975) and these are presented in Table 3.7.

Table 3.7
Australian Figures for Nutrient Levels in Precipitation

Nutrient	kg/ha/yr
Nitrate	0.5
Ammonia	0.7
Total N	3.69
Total P	0.137

(adapted from Wood, 1975)

The landuse associated with these values is not specified in the literature. Therefore it is difficult to relate nutrient levels in precipitation with land use. The difference in units between the two data sets presented makes it impossible to prepare a meaningful comparison.

3.3.5 Geology

Phosphorus is a relatively immobile element in the landscape and in most cases the phosphorus content of a soil is inherited from the soil parent material, i.e. the amount of phosphorus derived from fertilisers or organic litter is relatively small. In the native state, i.e. unfertilised soils, the phosphorus status of a soil is purely determined by the parent material of the soil and from contributions of upland erosion. Soils associated with basalts, or its alluvial derivatives, provide phosphorous rich parent material, thus these basalt derived soils contain relatively high levels of native phosphorus (Table 3.8). Whereas phosphate low parent material (sedimentary rocks or unconsolidated material of similar origin) produces soil with low phosphorus content (Table 3.8).

Table 3.8
Average Soil Phosphorus Content % P_2O_5) of some Australian Soils (based on their parent material) (derived from Stace *et al* 1968)

Soil Type based on Parent Material	Percentage P_2O_5
Siliceous sands	0.005 - 0.02
Calcareous sands and limestones	0.03
Sedimentary soils (shales, slates, mudstones)	0.01 - 0.05
Metamorphic and granite derived soils	0.01 - 0.05
Soils derived from basaltic rocks	0.1

3.4 Erosion Processes

Overland flow occurs when rainfall intensity is greater than the permeability (infiltration rate) of the soil. Conditions of high rainfall intensity are not unusual in southern Australia but occur only for a short duration, and in most cases cause very little soil movement. However, when the rainfall event which results in overland flow persists and if it occurs at the time of the year when there is very little protective vegetative cover, soil movement in overland flow can be very high. Soil movement during intense rainfall, on a sloping (5% slope) red-brown earth near Charlton in north-central Victoria varied from zero to 10 t/ha (van Rees unpublished data). In southern New South Wales soil erosion has been studied in much greater detail than in Victoria and values in the order of 15 t/ha from a single rainfall event have been recorded (Edwards 1987).

On gently sloping cropping land most movement of soil during intense rainfall events should be seen as redistribution from the upper slopes to the lower slopes, contributions to sediment loads in waterways from overland flow are unknown and in most cases are likely to be very low because of the distance from paddock to waterway. Erskine *et al* (1993) note that much of the material sourced from sheet and gully erosion is stored in alluvial fans or in abandoned stream courses, and that only a small proportion reaches the Goulburn River. Eventual transport into the Goulburn generally coincides with large overland flow event.

If the overland flow is intense the flow becomes concentrated into rills and eventually into gullies, the amount of water and soil movement becomes very rapid and can travel large distances. Berg and van Rees (1989) reported over 1000 tonnes of soil being moved in a single gully following an intense rainfall event in the Kaniva district in western Victoria. Rainfall events which cause massive overland flow and initiation of gully flow are relatively rare in southern Australia. These events are episodic and make average annual soil loss figures difficult to interpret.

It is highly likely that the sediments moved in overland flow are nutrient rich because the top layer of soil (top few millimetres) is moved during intense rainfall events. Very little is known about the actual nutrient concentration in overland flow. The sediment collected in the soil loss studies near Charlton contained 5 times the basal rate of organic matter and total nitrogen. Unfortunately phosphorus levels were not recorded in the runoff (van Rees unpublished data).

Erosion caused by tunnels and gullies is mass movement of soil which on a nutrient:soil ratio of movement, is not as nutrient rich as sheet or rill erosion (Berg and van Rees 1989). Nevertheless, the mass movement of soil can contribute greatly to turbidity in waterways, and will still transport the nutrient rich surface layers into the stream systems.

The amount of soil moved in overland flow is a function of the intensity of rainfall, the permeability of the soil, the length and steepness of slope, and the amount of vegetative protection. Land management practices aimed at reducing the amount of soil movement within a catchment has to deal with each of these factors. Rainfall intensity cannot be managed but the other factors contributing to erosion susceptibility can be. Water management in a catchment must take into account soil conservation practices which deal with increasing the permeability of the soil, providing greater vegetative cover and reducing the length of slope. In some cases, buffer strips which catch suspended solids in overland flow, adjacent to waterways, may also be useful in reducing the amount of sediment which reaches a stream.

Since agricultural settlement in Victoria commenced inland of the Great Dividing Range in the mid 1800s, clearing of the native vegetation resulted in an increased susceptibility of the soil to erosion. Burch (1987) has reported that conversion of forest to grassland at Puckapunyal greatly increased the severity and frequency of storm runoff and erosion risk.

The native phosphorus and nitrogen pools were mined by early agricultural practices and production from agricultural land decreased until superphosphate was introduced earlier this century. However, inappropriate land management practices kept resulting in large scale erosion, it was not until the late 1940s with the establishment of the then Soil Conservation Board that erosion control methods were developed and implemented. Much of Victoria's landscapes are now less susceptible to erosion than they were.

Large volumes of soil were lost pre 1950s, and ended up as sediment loads. A study of the Goulburn basin by Erskine *et al* (1993) reports that sediment lost due to original European settlement was mostly deposited on the flood plains and not lost to the river system. From 1900 to 1950 some of this material was reworked by extensive erosion and deposited in the Goulburn and tributaries. Since the 1950's much of these river and stream deposits have been moving slowly downstream, although much of the material remains in the Goulburn basin. These sediment loads may still be contributing phosphorus and nitrogen to our waterways.

3.5 Best Management Practices

Best management practice (BMP) is promoted as a management tool to control the amount of nutrients entering water systems.

Studies indicate that BMP does not necessarily result in reduced nutrient levels. Goodman, Collins and Rapp (1992) found that it was difficult to establish a relationship between BMP and water quality. Koerkle (1992) found that no statistically significant changed occurred in nutrient concentrations after BMP had been implemented for 3.5 years. Clausen and Cassell suggest that the effect upon nutrient concentration of BMP may take many years to occur depending upon the amount of input reduction and initial field nutrient concentrations. Gunsalus (1992) found that total phosphorus concentrations decreased after the initiation of BMP over a period of 20 yrs.

This lag time can be explained by the relationship between nutrients and soil particles. Phosphorus and, to a lesser extend, nitrogen can adsorb onto soil particles. Particles carrying adsorbed nutrients may lie on the bottom of dams and lakes or in deep holes within streams. The nutrients may then be released at a later time. In this situation, the water system becomes a source of nutrients.

Additionally if nutrients are leached down through the soil they may be adsorbed deeper down in the soil profile. This acts as a store of nutrients which can then be released into the groundwater at a later time. The groundwater may then discharge into a surface water system. Hence the arrival of leached nutrients to the water system is delayed.

3.6 Summary and Conclusions

3.6.1 Nutrient Transport and Cycles

Emphasis in many of the overseas nutrient studies has been on nitrogen, as this is a major source of pollution for other than algae problems. However in Australia the presence of nitrogen (particularly nitrate) does not attract the same emphasis. Phosphorous has been identified as a key agent in the generation of algal blooms, although other factors such as the nitrogen:phosphorous ratio, stream flow conditions and temperature also come into play.

The main mode of transport of phosphorous in the environment appears to be by sediment transport. This is due to the high rate of adsorption of phosphorus by most Australian soils. Therefore studies of phosphorous transport require that total phosphorous be considered and not just dissolved/soluble forms.

It has also been noted by some workers that careful interpretation needs to be made when extrapolating data between different catchments. This is due to the variability in controlling factors such as soil type, micro climatic conditions, slope length and angle, runoff characteristics etc.

Nitrogen can be present as ammonia (NH_4), organic nitrogen (often expressed as TKN) and oxides of nitrogen (NO_3 and NO_2, or NOX). Organic nitrogen and NH_4 are readily converted to oxide forms, chiefly nitrate (NO_3). Nitrate is highly stable and soluble.

Because of its solubility NO_3 tends to be transported mostly by solution in runoff and groundwater. Organic nitrogen is generally adsorbed onto soil particles and is mostly transported by soil movement (erosion).

It is noted that groundwater seepage and soil interflow are the major source of stream baseflow in the upper reaches of the mountain streams and rivers. At these localities, the inflow of groundwater will be a major source of nitrogen. Other areas where water tables are high, notably in areas of dryland salinity, irrigation areas and in valleys, river flats may be contributing significant nitrate loads due to groundwater discharge.

3.6.2 Nutrient Sources and Relative Impacts

The identified sources of both phosphorous and nitrogen in the nutrient cycle can be classed as:

Natural - native elements derived from weathering of geological material (phosphorous)

- decay of vegetation (phosphorous and nitrogen)
- fixation by vegetation (nitrogen)
- input from rainfall

Man induced

- fertilisers (agricultural and forestry areas)
- waste water from industry and irrigated agriculture
- sewage effluent, including septic tanks
- wastes from intensive animal husbandry
- wastes from broad acre animal husbandry
- landfills and other waste disposal

A variety of loads and concentrations for nitrogen and phosphorous from overseas studies has been identified. The usefulness of this data is questionable, however as it has been noted that many of the inputs identified above are significantly different.

Some Australian data is available, and is summarised in Table 3.9 below.

Table 3.9
Nutrient Generation and Export Rates for
a Variety of Catchment Sources

Activity Source	Nutrient	
	Nitrogen	Phosphorous
Pasture and Orchards	-	0.24 kg/ha/yr
Grazing, cropping and pasture areas	-	1.13 kg/ha/yr
Cattle Sheep Horse	70 kg/yr 10 kg/yr 75 kg/yr	9 kg/yr 1-5 kg/yr 12 kg/yr
Forest floor litter - wet sclerophyll forest (generated but not exported) Undisturbed forest export rates	79 kg/yr 3-13 kg/ha/yr	8 kg/ha/yr 0.03-0.9 kg/ha/yr
Landfill generation rates	0.2-500 mg/L	-
Rainfall	3.7 kg/ha/yr	0.14 kg/ha/yr
Geology - sandy alluviate - sedimentary/granitic - basaltic	- - -	0.005-0.02% 0.01-0.05% 0.1%

The literature review indicates that there is a lack of data available for nutrient export rates from dryland agriculture and forested areas.

Available data does indicate however that nutrients in the streams can be from a variety of sources including:

- native soil phosphorous;
- nitrogen and phosphorous from decaying vegetation;
- rainfall;
- agricultural activities including fertilisers and animal husbandry; and
- industrial or urban activities.

The impact of the various sources depends on the interplay between land use, land systems and climatic conditions.

Agriculture

The application of fertilisers is seen to dominate nutrient export rates for all forms of agriculture. In an unfertilised state, cultivation and other soil disturbance activities significantly impact on nutrient export rates.

The impact of livestock exports can be through indirect or direct transport. Access to streams will result in direct input of nutrients. Similarly the collection of faecal material over dry periods with subsequent overland flow during rainstorm events can shift significant loads of nutrient material. Leaching of nutrients from animal excrement while significant overseas, is not likely to have a significant regional impact in the dryland catchment due to lower stocking rates. However, direct import of animal excretement may have a significant local affect.

Dairies known to occur along the river flats in the dryland catchments are noted as possible significant sources due to use of both irrigation and higher animal stocking rates.

Irrigated agriculture, including horticulture, occurs in the dryland catchment mostly along river flat areas. The subject of a separate consultancy, irrigated agriculture has been noted as a significant source of nutrients.

Forestry/Public Land/Native Forests/Recreational Areas

Nutrient export from forested areas can occur under undisturbed and disturbed conditions. The sources of nutrients are from native levels in the soil, forest litter, and rainfall inputs. Mechanism for transport of nutrients to the waterways include overland transport of sediment and forest litter, overland transport of dissolved nutrients (mostly nitrogen) and groundwater transport of dissolved nutrients (again mostly nitrogen).

The level of disturbance appears to be the controlling factor in actual export rates of nutrients. High levels of disturbance that expose the soil surface to erosion processes generate the higher nutrient export rates. Logging has been cited as increasing soil loss by a factor of two to four times unlogged rates, with rates dropping to `normal' levels after 2-3 years from cessation of activities.

Forest fires, of all forms, are also cited as increasing nutrient exports. Again, mainly due to exposure of soils, high intensity wildfires are quoted as creating higher export rates than low level cold burns or fuel reduction burns.

Some specific studies cited also indicate that unmade roads and tracks are also a major source of sediment, where they cross over streams. In one case (ie. Gembrook) it was noted that the major source was the section of road that slopes into the creek crossings.

Sediment from recreational reserves on stream banks have also been observed to be a major contributor to stream loads, due to surface disturbance by foot and vehicle traffic, and bank erosion.

Thus disturbed forest catchments have been observed to generate higher than normal sediment loads. These events are associated with high intensity rainfall, and are therefore episodic (ie. sporadic) by nature. Because nutrient transport is dominated by the erosion/transport of soil particles with adsorbed phosphorous (and nitrogen), these soil loss events are also associated with nutrient loss.

Landfills

The generation of nutrients, notably nitrogen, by landfills has been cited as sometimes being a significant local source, mostly to groundwater which subsequently discharges to surface water bodies.

Rainfall

Literature data has been obtained indicating nutrient import levels by rainfall. The actual concentrations of nutrients in rainfall varies with land use. Typically industrial/urban areas have higher levels due presumably to airborne pollution.

Nutrients imported into the catchment can be exported immediately if rain falls directly into water bodies such as Lake Eildon, or fall onto land and follow the same path as discussed already (ie. adsorption, overland transport and/or leaching).

Soil Formation

The formation of soils from parent geological material is also a source of nutrients, chiefly phosphorous. This `native' phosphorous in undisturbed areas would be the chief component of `natural' or baseline nutrient levels.

For some soils derived from basaltic materials, natural soil loss could generate high nutrient loads into nearby waterways due to the high native phosphorous levels.

Accelerated erosion due to soil disturbance is likely to increase loss of native nutrient levels.

3.6.3 Erosion Processes

Erosion is obviously an important chain in the nutrient export process due to the potential to move nutrient materials into streams.

Erosion occurs predominantly on sloping ground where slopes exceed 5%. In most areas (agricultural and forestry) erosion is merely a redistribution of soil from one area to another. Thus the further the distance from waterways the less likely any impact from erosion. Studies of the Goulburn basin indicate that only a small percentage of eroded material reaches waterways during any one erosion episode.

It is noted however that some forms of erosion, ie. gully erosion, can transport a lot of sediment over greater distances due to the higher volume of flows. Gully erosion can therefore have a greater impact on streams than sheet or rill erosion.

Actual erosion events are sporadic and depend on a number of factors including erosivity of the rainfall event, lands system characteristics and soil surface condition. Therefore nutrient export dependant on soil erosion will also be sporadic.

Recent studies completed by CSIRO for the Snowy River and Murrumbidgee River catchments have indicated that a substantial level (> 75%) of sediment load during high flow events is due to soil loss in the uppermost parts of the catchment. This new evidence highlights the importance of managing the steeper, more erosion prone mountain and hills at the headwaters of the stream.

Studies of the Goulburn basin suggest that much of the current bed load moving down the Goulburn and its tributaries is material eroded from cleared land after early European settlement.

3.6.4 Impact of Best Management Practice

Studies completed in the USA indicate that the implementation of best management practices to control nutrient export will not have immediate effects. It has been concluded that the delay is due to the presence of nutrients held in storage within the stream systems.

In at least one case beneficial impacts were noted after 20 years of implementing BMP's.

3.7 Implications for the Goulburn Broken Catchments.

The results of the literature highlight the need to understand the erosion processes, land systems and land uses within the catchment, and the processes of sediment movement within the stream and river network.

Particular consideration needs to be paid to:

- the forms of agricultural land use, and where it occurs;
- the management of the upland areas of the catchment;
- the nutrient status of the soil types in the catchment and their erodability;
- nutrient imports from rainfall and consideration of what is baseline (natural) levels of nutrients in the stream system; and
- control options focussing on prevention of erosion.

The fate of sediment and associated nutrient loads also requires attention. In particular, the presence of water storages such as Eildon, Nillahcootie and Goulburn Weir acting as sediment traps are also likely to be acting as nutrient sinks. Data from the U.S.A. indicates that in turn, these sinks may also act as low level sources, particularly for the release of phosphorus, under certain conditions. These aspects of in stream nutrient dynamics were highlighted as important in understanding the complete nutrient cycle, however this area of study falls outside the study brief and will not be considered further.

The focus on erosion processes and nutrient loss also needs to be considered in an historical content as well as the current situation. It has been highlighted that much of the sediment in the streams network is the result of erosion events immediately following European settlement, and the period between the 1940s and 1950s. It is therefore likely that transport of adsorbed nutrients is associated with these events, and at least part of the source of phosphorus may be due to release from these sediments.

In contrast, the better condition of the catchment in more recent times, and the reduced erosion indicates that the focus on modern nutrient sources should be on:

- naturally high sediment sources area; and
- areas of erosion close to streams and rivers.

The transportation of nitrogen by groundwater may also be a concern for local hotspots where landfills, intensive agriculture or high water tables occur close to streams. On a regional scale however imports from groundwater are not considered to be of significance in the dryland catchment.

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4. CATCHMENT DESCRIPTION

4.1 Goulburn Broken Catchment Definition

The study area covers a significant area of the Northern Victorian river catchments which belongs to the Murray Darling Basin. The study area consists of both the Broken River catchment and the Goulburn catchment. It covers an area of some 2.4 million hectares of which approximately 400,000 hectares belongs to the Broken River catchment area and 2.0 million hectares belongs to the Goulburn.

The boundaries of the study area are the watersheds of the Goulburn and Broken Rivers to a line where the Goulburn Irrigation Districts commence but does not includes the dryland areas adjacent to the Goulburn and Murray Rivers in the Goulburn Murray Irrigation regions (refer Figure 1). This area covers some 1.8 million hectares of the catchment.

4.1.1 The Goulburn River Catchment

The Goulburn catchment is generally divided into the upper Goulburn, the mid-Goulburn and the lower Goulburn.

The upper Goulburn catchment includes the sub-catchment of Lake Eildon and the sub-catchment of the Goulburn River above the Strathbogie Ranges.

The upper Goulburn is characterised by:

- Mountain areas with shallow stony soils, steep slopes with high rainfall;
- Foothill areas with shallow soils on the lower hillside and deeper more fertile soils in the valleys;
- Highland areas characterised by flat or undulating landscapes with solodic soils.

The geology of this area is predominantly mudstones or sandstones.

The mid-Goulburn catchment comprises the sub-catchments of the Goulburn River between Eildon Weir and the Goulburn Weir at Nagambie. It includes the major tributaries to the Goulburn River from the catchments of the Strathbogie Ranges, and other foothill systems.

The mid Goulburn is characterised by;

- Mountain areas with shallow, stony soils, steep slopes and high rainfall;
- Foothill areas typified by rolling landscapes with shallow, stony soils on the hill tops and upper hillsides, and broad valleys with deeper and more fertile soils; and

- Alluvial plains characterised by river flats and gentle hills with deep fertile soils.

The geology of this area is predominantly sedimentary rock with granite in the area of the Strathbogie ranges

The lower Goulburn catchment encompasses the area below the mid-Goulburn catchment, extending north to the Murray River. It is characterised by:

- Riverine plains typified by flat and low hill landscapes with shallow to deep alluvial soils.

The geology of this area is predominantly alluvial clay and sand sediments.

4.1.2 The Broken River Catchment

The Broken River is a major tributary of the Goulburn River. An anabranch of the Broken River, the Broken Creek, splits from the river north of Benalla and discharges directly to the Murray River.

The catchment can be broken into the upper and lower Broken catchment. The upper catchment covers the upper reaches of the Broken River to Casey's Weir. It is characterised by northern mountainous igneous rocks with shallow soils and southern mountainous sedimentary rocks with shallow stony soil. The catchment also encompasses the northern edge of the Mansfield plain.

The lower catchment refers to the land north of Casey's Weir and stretching north and west. This part of the catchment is predominantly composed of deep riverine plain soils with scattered low hills of sedimentary rock.

4.1.3 Subcatchment Study Locations

In order to develop an understanding of the nutrient loads being generated and to assist in defining "hot spot" sources, a review of data from the VWQMN (1994) was undertaken.

Thirty nine gauging stations are located in the Goulburn Basin (refer Figure 2) as part of the VWQMN, of which fifteen are currently being monitored. Similarly nine stations are located in the Broken Basin (refer Figure 3) with only five being currently monitored for nutrients.

Historical data was collated for sixteen stations in the Goulburn Basin and eight from the Broken Basin to provide an overview of the nutrient loads in the surface waters. These stations were then refined down to thirteen stations and two stations for the Goulburn and Broken Basins respectively to estimate nutrient local generation for a cross-section of land use and land management systems.

The location of these stations and their catchment areas are shown in Figure 4B. A list of the stations and associated land use and land management systems is presented in Table 4.1. The results from this data review and their implications are presented in Sections 4.5 and 4.6 respectively.

Table 4.1
Subcatchment Landuse/LMU's/Catchment Areas

Table 4.1 (Cont'd)
Subcatchment Landuse/LMU's/Catchment Areas

4.2 Catchment Characterisation

In order to understand the nature of any dryland nutrient sources it is first necessary to define the catchment with respect to land management systems (units), land use, rainfall and other physical characteristics that potentially impact on the generation of nutrients as outlined in the literature review.

4.2.1 Land Management Units

A summary of the land management units (LMU) of the catchment is presented below. These summaries are based on the LMU's reported in the Draft Goulburn Dryland Salinity Management Plan, 1989 (refer Figure 5). Additional information regarding susceptibility to erosion and water shedding characteristics are also included.

The LMU's in the catchment are:

Cambrian Volcanics - LMU 1

This landform is located in the province of Dookie and Colbinabbin. It is characterised by undulating to steep hills and rocky ridge tops. Friable red soils are located on slopes and black soils are located on lower areas. The land is currently used for cropping and grazing. It is a minor source of water and is prone to sheeting and gully erosion.

Devonian Volcanics - LMU 2

This landform is located in the Warrenbayne, Balmattum, Boho, Sheans Creek and Euroa province. It is characterised by moderate to steep hills facing north-west along the fringe of central highlands. The top soil on the ridges is shallow and sandy. Soils on slopes are reddish duplex with high acid and aluminium levels. Land use is grazing and cropping and mostly woodland areas. Water supply from this area is minor. Some sheet erosion occurs.

Siluro-Devonian Sediments - LMU 3

This landform is located in the province of Caniambo, Earlston and Koonda. It is characterised by undulating hills developed on deeply weathered sediments. Ridge top soils are skeletal with duplex soils on the slopes. The land is used for grazing and some cropping. Runoff is low, and is prone to sheet and gully erosion.

Devonian Granites - LMU 4, LMU 9 and LMU 12

This landform in the Strathbogie, Longwood and Hughes Creek province, it is characterised by moderate to steep rounded hills. Soils on ridge tops are sandy with reddish duplex soils on slopes. Land use is mostly grazing but includes some cropping and forested areas. Runoff from this area is high. The erosion hazard is low with some sheet erosion occurring on slopes.

This landform in the Pyalong province, is characterised by moderate to steep rounded hills and broad colluvial slopes. This area is mostly cleared for grazing with some minor areas of native forests remaining. Runoff is fairly high. Sheet and gully erosion may occur in cleared areas.

This landform in the Thoona and Wilby Boweya province, is characterised by moderate to steep rounded hills. The area is woodlands with some grazing. Runoff is low. The erosion hazard is low except on slopes where cleared areas are prone to sheet erosion.

Siluro Devonian Volcanics, Metamorphics and Sediments - LMU 5

This landform is located in the Molyullah, Tatong and Lurg province. It is characterised by moderate to steep dissected hills at Lurg and Tatong, and undulating hills at Molyullah. Rocky ridges are common with deep alluvium along Hollands Creek Valley. Land use ranges from grazing and some cropping in undulating areas to closed forest in steep areas. The area is a major water source for the Broken River. There is the potential for sheet erosion to occur in cleared steep areas.

Siluro-Devonian Sediments (deeply weathered) - LMU 6

This landform is located in the Glenauroua Puckapunyal and Rushworth province. It is characterised by moderate rounded hills with rocky ridges and reddish duplex soils on lower slopes. The land is mostly forested with some grazing. Runoff is high. Sheet and gully erosion may occur in cleared areas.

Siluro-Devonian Sediments (steep) - LMU 7

This landform is located in the province of Strath Creek, Yea, Alexandra and Whiteheads Creek.

It is characterised by moderate to steep dissected terrain, and rocky ridges are common. Land uses include some grazing and mostly forest and alpine. It provides a major source of water for the Goulburn River downstream of Eildon. Cleared areas are prone to sheet and gully erosion on upper and lower slopes respectively.

Carboniferous Sediments - LMU 8

This landform is located in the Mansfield province. It is characterised by undulating hills and broad valleys. Some grazing occurs and areas of woodland exist. Runoff is variable with some land systems being a major source of water and/or sediments. Mild sheet erosion occurs and serious gully erosion exists around streams.

Quaternary Riverine Plain Sediments - LMU 10

This landform is located in the province of Miepoll, Kialla East, Yabba North, Youanmite, Kotupna, Wanalta and Cornella. It is characterised by broad valleys, outwash plains and depositional terraces. The main landuse is cropping and grazing. Runoff from this area is low, and the erosion hazard is low.

Ordovician Sediments - LMU 11

This landform is located in the province of Goorambat, Devenish and Boweya. It is characterised by moderate sloping, low hills. The area is cleared and is currently used for grazing. Runoff from this area is low. Minor sheet erosion may occur on slopes.

Quaternary Basalt - LMU 13

This landform is located in the Broadford, Sunday Creek and Kilmore province. It is characterised by low broad plateaus or basalt flows along valleys. Grazing occurs in the area. The runoff is low and there is little erosion hazard.

4.2.2 Land Systems, Runoff and Sediment Production

Because these LMU's were developed for the salinity management plan, they have been based on a compilation of geology, land systems and similar hydrogeological characteristics. There is need to understand some of the underlying characteristics of each LMU. Of particular importance for this study is the association of:

- soil chemistry (in particular nitrogen and phosphorus);
- soil erosion susceptibility; and
- runoff and sediment contribution to stream flows,

for each LMU, as the literature review has detailed that each of these factors plays a key role in determining the sources of nutrients for the catchment waterways.

Tabulated summaries of three land studies completed for the catchment covering the Broken River, Eildon (Upper Goulburn) and Mid Goulburn River (Soil Conservation Authority 1974, 1977 and Department Conservation and Environment 1990, respectively), are presented below (refer Table 4.2).

This data indicates that the major watershed areas and land management units are the:

- Carboniferous (LMU8), in particular the Archerton, Cambatong and Tolmie land systems in the Broken Catchment;

- Steep Siluro-Devonian Sediments (LMU7), in particular the Jamieson, Howqua Bindaree, Taponga and Buller land systems in the Goulburn catchment;

- LMU5 (Silurian-Devonian Sediments, Volcanics and Metamorphics), in particular, the Moorngag Archerton, Loombah and Tiger Hill land systems;

- Devonian Granites (LMU4), in particular the Strathbogie, Moonee Moonee and Swanpool land systems; and

- Devonian Volcanics (LMU2), in particular the Loombah and Tiger Hill land systems.

Major areas of sediment generation in the Goulburn and Broken river catchment studies have been noted by previous workers (Rundle 1977, and Rundle & Rowe 1974 respectively) to be from the following land systems:

- Mansfield (Carboniferous sediments);
- Table Top (Carboniferous sediments);
- Benalla - Benalla and Mokoan land sub-systems of the Quaternary Riverine Plan sediments;
- Eildon (Steep Siluro-Devonian sediments); and
- Maintongoon (steep Siluro-Devonian and Ordovician Sediments).

Rundle (1974) noted that the major hydrological difference between the useful water yielding land systems and the sediment yielding systems was the propensity of the latter to rapidly develop large volumes of overland flow in late winter and summer thunderstorms. In contrast, the land system developing useful water yields do so with little overland flow with water delivery being predominantly by storage and stream seepage on a year round basis.

Table 4.2
Land Systems, Land Management Units and Sediment Generating Characteristics

LMU (LMU Number)	Land System (as related to Broken River Catchment systems)	Soil Types	Erosion Susceptibility and Status	Runoff/Sediment Generation Characterisation	Catchment
Carboniferous (LMU8)	Mansfield (Sedimentary)	Gilgaie, Duplex Gradational and Clay Soils	Low hazard but drainage lines gullied. Minor sheet erosion	Peak runoff in summer thunderstorms. Minor water source - high sediment source	Broken River
	Table Top (Sedimentary)	Duplex, Gradational Stoney Loams	High hazard of gully, sheet tunnel	Flash floods and high sediment. Low annual water yield. Storm runoff	Broken River
	Tolmie	Duplex, Gradational	Moderate hazard. Some current erosion limited to steeper ridge tops.	Significant supply with peak water falls	Broken River
	Cambatong (Sedimentary)	Clay loam, gradational	High sleet hazard. Current low occurrences.	Significant water source all year	Broken River
	Archerton (Basalt)	Gradational	Low; rilling of tracks road drains and when cultivation crossed drainage lines	High water yield. Significant supply area to Benalla W.S.	Ryan's Creek (Loombah Reservoir)
Siluro-Devonian Sediments (LMUs 3,6 & 7)	Lurg	Strong loams Duplex Gradational	Hazard high to moderate. Some sheet and gully erosion.	Low yield, low steady runoff in winter. Some summer storm runoff.	Broken River and Mokoan Basin
	Moorngag	Refer to LMU 5			Broken River and Goulburn River

Table 4.2 (Cont'd)
Land Systems, Land Management Units and Sediment Generating Characteristics

LMU (LMU Number)	Land System (as related to Broken River Catchment systems)	Soil Types	Erosion Susceptibility and Status	Runoff/Sediment Generation Characterisation	Catchment
Ordovician Sediments (LMU11)	Lurg	Refer to Siluro-Devonian Sediments (LMUs 3, 6 & 7)			Broken River
	Moorngag	Refer to LMU5			Broken River
Siluro-Devonian Sediments (LMU5)	Loombah	Refer to Devonian Volcanics (LMU2)			Broken River
Volcanics	Tiger Hill	Refer to Devonian Volcanics (LMU2)			Broken River
Metamorphics	Archerton	Refer to Carboniferous (LMU8)			Broken River
	Lurg	Refer to Siluro-Devonian Sediments (LMUs 3, 6 & 7)			Broken River
	Moorngag	Gradational	Moderate - high hazard	Contribution from high rainfall areas	Broken River and Goulburn River
	Wrightly (Metamorphics and Cambrian Volcanics)	Gradational Stony loams	Moderate - high hazard Some mass movement and sheet on steeper slopes	Low yielding	Broken River (Downstream Nillahcootie and Hollands Creek)
Devonian Granites (LMU4)	Strathbogie (Granite)	Duplex Gradational	Moderate hazards on steeper slopes. Little occurring.	Substantial water supply source.	Broken River
	Moonee Moonee (Granite)	Duplex Gradational	Low - moderate hazard. Steep slopes high if cleared. Little erosion. Sheet after fire and in logging areas.	Major water source, significant summer flows	Broken River (Downstream Nillahcootie)
	Swanpool	Duplex	Hazard is low. Moderate -	Significant source for winter	Broken River

Table 4.2 (Cont'd)
Land Systems, Land Management Units and
Sediment Generating Characteristics

LMU (LMU Number)	Land System (as related to Broken River Catchment systems)	Soil Types	Erosion Susceptibility and Status	Runoff/Sediment Generation Characterisation	Catchment
	(Also consists of Riv. Plan alluvium derived from granite sources)	Gradational Loams	high on steel slopes. Minor gully and stream erosion	and spring flow.	
Devonian Granite (LMU12)	Warby	Sandy loams Gradational Duplex	Hazard is high to moderate on slopes. Lower on plateau. Some sheet, rill and stream channel.	Low yield. Summer storm runoff from bare soils. High soil permeability. Some springs.	Holland Creek (Broken River)
Devonian Granites (LMU9)	Cobaw Plateau/ Mt Disappointment	Gradational Uniform	Moderate hazard of sheet and rill erosion. High on steeper slopes.	Low yielding. Susceptible to high intensity summer storms.	Tributaries to Goulburn River
Cambrian Volcanics (LMU1)	Wrightly	Refer to LMU5			Broken River
Devonian Volcanics (LMU2)	Loombah	Duplex Gradational	Moderate to high susceptibility to sheet erosion gully and slumping on steeper slopes. Low to moderate elsewhere. Sheet and gully erosion on cleared areas and roads/tracks. Some gully erosion in drainage lines.	Significant water source	Broken River
Devonian Volcanics (LMU2)	Tiger Hill	Gradational Clay loams	Generally low hazard due to high material permeability Compacted and cleared surfaces (logging and tracks)	Significant water source	Broken River Tributaries (Benalla Water Supply)

**Table 4.2 (Cont'd)
Land Systems, Land Management Units and
Sediment Generating Characteristics**

LMU (LMU Number)	Land System (as related to Broken River Catchment systems)	Soil Types	Erosion Susceptibility and Status	Runoff/Sediment Generation Characterisation	Catchment
			increase in erosion hazard. Localised erosion recorded		
Quaternary Sediment (LMU10)	Benalla-Benalla	Duplex Gradational (Gilgari Gradational) Loams	Generally low. Moderate near hills. High stream back erosion. Some gullying due to nearby hill runoff.	Low areas prior to flood with high sediment loads	Broken River and Goulburn River
	Benalla-Mokoan	Gradational Minor Duplex Calcerous (saline) gilgaid clays (swampy areas)	Low-moderate near hills. Low - nil in plans and swamp. Some minor gully erosion, and stream bank erosion.	Low yield with high sediment	Mokoan Basin and Broken River
	Benalla-Samiria	Duplex Gradational	Moderate - high rill, sheet and gully erosion. Some stream back erosion.	Winter runoff	Broken River
Quaternary Sediment (Cont'd) (LMU10)	Benalla-Warranbayne-Tatong (foothills of ranges and valleys)	Gradational Duplex	Moderate - low erosion hazard. Some stream erosion.	High yielding with rapid delivery (flood prone)	Broken and Goulburn Tributaries
Quaternary Basalt Association (13)	Kilmore Basalts (Soil Association 7)[1]	Uniform	High gully erosion hazard. (Salinity)	Unknown	Goulburn Tributaries (Sugarloaf and Sunday Creeks)

Note: (1) Reconnaissance Survey of the Middle Reaches of the Goulburn River Catchment, 1990.

4.2.3 Land Systems, Land Units and Nutrient Levels

Phosphorus is a relatively immobile element in the landscape and in most cases the phosphorus content of a soil is inherited from the soil parent material, i.e. the amount of phosphorus derived from fertilisers is relatively small. In the native state, i.e. unfertilised soils, the phosphorus status of a soil is purely determined by the parent material of the soil and from contributions of upland erosion. Soils associated with basalts, or its alluvial derivatives, provide phosphorus rich parent material, thus these basalt derived soils contain relatively high levels of native phosphorus (Table 4.3). Whereas phosphorus low parent material (sedimentary rocks or unconsolidated material of similar origin) produces soil with low phosphorus content (Table 4.3).

Table 4.3
Average Soil Phosphorus Content (% P_2O_5) of some Australian Soils based on their parent material (derived from Stace *et al* 1968)

Soil Type based on Parent Material	Percentage P_2O_5
Siliceous sands	0.005 - 0.02
Calcareous sands and limestones	0.03
Sedimentary soils (shales, slates, mudstones)	0.01 - 0.05
Metamorphic and granite derived soils	0.01 - 0.05
Soils derived from basaltic rocks	0.1

Table 4.4 presents a compilation of phosphorus levels for soils associated with the land units/systems and geology of the catchment. Based on the available data the highest levels of native phosphorus (0.05 - 0.1%) are associated with soils from the following land systems:

- Mansfield : (Carboniferous sediments)
- Archerton : (Older volcanics Basalts)
- Tiger Hill : (Devonian volcanics)
- Wrightly : (Cambrian Volcanics)
- Benalla-Benalla Alluvials : (Duplex soils were found to have high phosphorus levels in the top layer of stream bank alluvials)
- Buller : (Cambrian Volcanics, Basalt and Devonian Granites have high phosphorus levels).

Moderate levels (0.01 - 0.05%) were found in soils derived from sedimentary rocks of Siluro-Devonian age, and some soils developed from igneous and volcanics of Devonian age. Lowest levels of phosphorus were found in soils derived from alluvial material, and granites and acid volcanics.

These findings are consistent with the general trend described earlier, highlighting the dominance of the underlying geological material in controlling native phosphorus levels.

Table 4.4
Native Nutrient Levels for Soils in the Goulburn and Broken River Catchments

Land System	Base Geology	LMU's	Soil Types	Nutrient Status[1]	
				(% P)	(% N)
Strathbogie (equivalent to Taponga and Bindaree)	Granite	Devonian Granite (4)	Duplex Gradational	Moderate (0.01 - 0.02)	-
Moonee Moonee	Granite	Devonian Granite (4)	Duplex Gradational	Moderate (0.018 - 0.025)	(0.071 - 0.22)
Swanpool	Granite Granite Alluvium	Devonian Granite (4) Quaternary (10)	Duplex	Alluvial - Low-Mod (0.013 - 0.017) Granite - Moderate (0.01 - 0.024)	(0.079 - 0. - 0.032 (0.032 - 0.088)
			Gradational	-	-
			Loams	-	-
Mansfield	Carboniferous Sediments	Carboniferous (8)	Duplex	Moderate (0.011 - 0.024)	-
			Gradational	High	-
			Clays	Mod-High (0.017 - 0.05)	-
Table Top	Carboniferous Sediments	Carboniferous (8)	Duplex	Low - Mod (0.011 - 0.021)	(0.05 - 0.19)
			Gradational	Low - Mod (0.004 - 0.018)	(0.06 - 0.18)
			Stony loams	Not known	-
Tolmie	Carboniferous Sediments	Carboniferous (8)	Duplex	-	-
			Gradational	Low (0.004 - 0.018)	(0.13 - 0.99)
Cambatong	Carboniferous Sediments	Carboniferous (8)	Clay loams	Moderate (0.024 - 0.039)	(0.1 - 0.5)
			Gradational	Moderate (0.051)	(0.14 - 0.46)
Archerton	Other Volcanic Basalts	Carboniferous (8)	Gradational	Mod-High (0.051 - 0.087)	(0.076 - 0.26)

Table 4.4 (Cont'd)
Native Nutrient Levels for Soils in the Goulburn and Broken River Catchments

Land System	Base Geology	LMU's	Soil Types	Nutrient Status[1] (% P)	Nutrient Status[1] (% N)
		Siluro-Devonian (5)			
Loombah (equivalent to Taponga, Jamieson)	Devonian Volcanic Rhyodacites & Rhyolite	Siluro-Devonian (5) Devonian Volcanics (2)	Duplex Gradational	- Moderate (0.012 - 0.025)	- (0.65 - 0.18)
Tiger Hill	Devonian Volcanic Rhyodacites & Physilites	Siluro-Devonian (5) Devonian Volcanics (2)	Gradational Clay Loams	High (0.051 - 0.087)	(0.027 - 0.25)
Lurg	Siluro-Devonian Sedimentary Sandstones and Mudstones	Siluro-Devonian 3, 5, 6, and 7	Stoney loams Duplex Gradational	Low-Mod (0.011 - 0.052) Low (0.009 - 0.013) Moderate (?) (0.04)	(0.1 - 0.51) (0.025 - 0.094) (0.057 - 0.32)
Warby	Devonian Granite	Devonian Granite (12)	Sandy loam Gradational Duplex	Low (0.06 - 0.022) Moderate (0.012 - 0.027) Low (0.006 - 0.011)	(0.024 - 0.13) (0.054 - 0.21) (0.042 - 0.14)
Coban Plateau/ Mt Disappointment	Devonian Granites	Devonian Granite (9)	Gradational Uniform (loams)	Low -	- -
Moorngag (equivalent to Eildon, Maintangon, Jamieson, Mongque, Binderee and Tapoga)	Ordovician and Silurian Sediments of Sandstone, Mudstone, Siltstones, Shales	Siluro-Devonian (5&7)	Gradational Duplex Uniform	Low (0.014 - 0.- 017) Low-Mod (0.14 - 0.025) Moderate (0.026 - 0.054)	(0.053 - 0.49) (0.091 - 0.22) -
Wrightly (equivalent to Bindaree)	Cambrian Volcanics and Metamorphics	Cambrian Volcanics (1)	Gradational	High (0.035 - 0.089)	(0.071 - 0.30)

Table 4.4 (Cont'd)
Native Nutrient Levels for Soils in the Goulburn and Broken River Catchments

Land System	Base Geology	LMU's	Soil Types	Nutrient Status[1]	
				(% P)	(% N)
		Siluro Devonian (5)	Stoney Loams	-	-
Benalla - Warrenbayne - Tatong	Quaternary Alluvials from Acid Volcanics	Quaternary Alluvials (10)	Gradational Duplex	- -	- -
Benalla - Benalla	Quaternary Alluvials	Quaternary Alluvials (10)	Duplex Gradational Loams	Low-High (0.008 - 0.16) Low-Mod (0.002 - 0.044) Moderate (0.021 - 0.03)	(0.039 - 0.021) (0.039 - 0.19) (0.074 - 0.28)
Benalla Mokoan	Quaternary Alluvials (Swamps)	Quaternary Alluvials (10)	Gradational Clays Duplex	- Low-Mod (0.008 - 0.03) -	- (0.031 - 0.39) -
Benalla - Samaria	Quaternary Alluvials most from sedimentary rocks	Quaternary Alluvials (10)	Duplex Gradational	- -	- -
Quaternary Basalt Association (Soil Association 7)[2]	Newer Volcanic Basalts	Quaternary Basalt (13)	Uniform	-	-

Table 4.4 (Cont'd)
Native Nutrient Levels for Soils in the Goulburn and Broken River Catchments

Buller[3] (Alpine Areas)	Variety of Cambrian Volcanics	Cambrian Volcanics (1)	Gradational	Mod-High (0.044 - 0-.089)	-
	Devonian Granite	Siluro-Devonian (Steep)	(Alpine Hummus) Uniform Gradational	High (0.065 - 0.086) -	(0.058 - 0.72) -
	Silurian Mudstone		(Alpine Hummus transitional)	Mod (0.039 - 0.045)	(0.043 - 0.36)
	Basalt		Uniform	High (0.078 - 0.16)	(0.16 - 1.28)

Notes: (1) Data compiled from A. Rundell 1974, Rundell & Rowe 1977 unless otherwise noted
(2) Reconnaissance Survey
(3) Eildon Catchment Land Study 1977

Much of the native phosphorus in a soil is bound to a variety of soil complexes and is not in a form available to plants. Phosphate added as fertiliser is also, depending on soil type, rapidly `fixed' to a form not readily available for plant uptake. The major factors influencing the `fixing' of phosphorus in a soil deal with the mineral composition of the soil. Soils high in iron content (free iron oxides) and soils high in hydroxy-aluminium polymers attached to clay or organic matter `fix' high proportions of phosphorus. The latter is especially true for soils with an acidic profile.

A review of soil analytical data from land studies in the Eildon and Broken catchments (Rundle 1974 and Rundle & Rowe 1977) confirms that the soils with the highest levels of phosphorus also had the highest levels of iron (free iron oxides) and were consistently acidic (pH of between 5 and 6).

Many of the soils with lower phosphorus levels were found to also be acidic (pH between 4 and 6) but had low free iron contents.

In the lower reaches of the catchment, where broadacre production of sheep and cereals is a major landuse, the application of superphosphate fertiliser is a common practice. Much of the phosphate added in the fertiliser is rapidly bound to the soil and is not available to plants. The extent with which phosphates are bound or 'fixed' has a bearing on the effectiveness of phosphate fertilisers for improving plant growth, as well as influencing the amount of phosphate lost to waterways. Phosphorous in phosphate solution is reasonably mobile, but phosphorus bound to clay complexes, iron oxides, aluminium hydroxides and organic matter is relatively immobile.

Much of the landuse of the undulating hills in the lower reaches of the Goulburn-Broken is for pasture production. Under pasture, superphosphate fertiliser is broadcast on to the surface soil, where it accumulates because phosphate is relatively immobile in the soil. As a result, the top layer (top 10 mm) of the surface soil becomes phosphate rich. However, this same top layer of soil, as it is fertilised, gains in organic matter, and this binds or 'fixes' free phosphate to organic phosphorus. This layer can contribute significantly to phosphorus in waterways, either as fixed phosphorus in organic matter or as a phosphate, if erosion transports this nutrient rich layer to waterways.

In a cropping situation the process is quite different. During cultivation, carried out for weed control and preparation of a seed bed, the soil and superphosphate is mixed in the top 100 mm of soil. This exposes the phosphate to chemical reaction (sorption) with a large volume of soil. Thus on cropping soils much larger volumes of soil need to be transported to waterways during erosion events to contribute similar rates of phosphorus as occurs on soils primarily used for pasture production.

As with phosphorus, the nitrogen cycle in soils is very complex. The major difference between the two nutrients is that nitrogen is generally not added, or only in very small quantities, as fertiliser under broad-acre cropping and pasture enterprises. The major forms of nitrogen in our soils are part of organic complexes, and total nitrogen contents of the topsoil (top 100 mm) are generally less than 0.1% (range 0.05% to 0.15%). The organic forms of nitrogen are not labile and little movement occurs within the soil profile.

The plant available forms of nitrogen, mainly nitrate and ammonium, are usually in a very low concentration (less than 20 ppm in the topsoil). The available forms of nitrogen are readily leached and can potentially, contribute a nitrogen source to waterways via groundwater. However, the current available nitrogen status of soil in the Goulburn-Broken is very low and leaching is unlikely to contribute any significant amounts of nitrogen to waterways.

Table 4.4 also presents a compilation of analytical results for total nitrogen in soils in the catchment (derived from Rundle 1974, Rundle & Rowan 1977). No data is available for "available nitrogen", however the levels of total nitrogen provide an indication of likely available nitrogen levels.

A number of soils exceed the upper range level of 0.15% total nitrogen. These soils are associated with the following land systems/geology:

- Moonee Moonee - Granite (up to 0.27%)
- Mansfield, Table Top, Tolmie and Cambatong - Carboniferous sediments (e.g. maximum levels range from 0.14% up to 0.5%).
- Archerton - Basalts (up to 0.26%)
- Tiger Hill - Acid volcanics (up to 0.25%)
- Lurg - Siluro-Devonian sediments, stony loams only (up to 0.51%, possibly associated with sheep camps on ridge tops).
- Warby - Granite (up to 0.21%)
- Moorngag - Ordovician sediments (minimum ranges 0.22% - 0.49%)
- Wrightly - Cambrian Volcanics (up to 0.3%)
- Benalla - Mokoan and Benalla subsystem alluvial deposits (up to 0.39 % and 0.28% respectively)
- Buller - Granites (0.72%) Silurian sediments (0.36%) and Basalts (0.10 - 1.28%).

With the exception of the Buller basalt soils, the highest levels of total nitrogen were recorded in the topsoil. Levels of total nitrogen decreased rapidly below 0.1% with depth.

For the Benalla-Benalla total nitrogen levels, the high topsoil levels were associated with river terrace alluvial.

The Buller basalt derived soils are reported as being generally thin (30 cm or so) with high total nitrogen levels throughout the profile reflecting their peaty nature.

The most likely source of nitrogen in waterways for the Goulburn Broken Catchment is from eroded nutrient rich layers of soil. The contribution in this case would be mainly as organic forms of nitrogen which would need to breakdown to nitrate and ammonium before it become available to algae.

4.2.4 Rainfall and Erosion

The pattern of rainfall, combining with physical characteristics of the receiving land determine the generation of overland flow, soil interflow, stream flow and sediment generation patterns.

Low intensity rainfall over long periods, e.g. drizzle, usually results in very little surface runoff and sediment generation on most soil types, even low permeability soils that have been cleared. The exception to this is where soils are already wet and have little capacity to store extra rainfall.

High intensity rainfall even over short periods, e.g. thunderstorms, can generate high levels of surface runoff and sediment. Overland flow will be generated when the rainfall intensity is so great that water accumulates at the surface faster than it can infiltrate into the soil. Soils prone to water erosion due to natural physical properties or man induced states (e.g. clearing or cultivating) can generate high sediment loads in the resulting overland flow.

Because of the vast size of the Goulburn-Broken catchment and topographical differences, the level of rainfall varies widely. On the north and north-western plains rainfall is typically around 600 mm/year. This steadily increases to the south and south-east, with the highest levels of 1700 mm/year recorded for the Marysville district.

The increase in rainfall is due to the orographic uplift effects of the ranges, resulting in more rain days and snowfalls in the range areas.

The pattern of intensity over the catchment is reasonably consistent. Rainfall is predominantly of low intensity long duration in the winter early spring period (i.e. May to September). Summer and autumn rainfall is dominated by shorter duration higher intensity rainfall as typified by the summer thunderstorms. Local variations often occur due to local climatic variations and topographic effects.

Also some late winter high intensity falls of long duration occur due to strong southerly airstreams directing cold moist air from the southern ocean. These events often result in flooding of the lower lying northern plains and valleys.

Erosion events are closely linked to the timing of the high intensity rainfalls. The greatest erosion risk is where high intensity rainfall coincides with landuse activities that expose soil surfaces to the erosion processes.

Activities such as fallow over summer, and cultivation prior to autumn breaks can expose soil to erosive rainfall. Other events, such as forest wild fires, fuel reduction burning, road building activities and land clearing/logging can also expose soil surfaces at critical climatic periods.

Rainfall intensity data provided by White (1990) in the study of the mid-Goulburn is presented below in Figure 6.

This data shows that even short duration (6 minute) rainfall bursts have rainfall intensities of 50 mm/hr or more, in excess of all but the most permeable soils. Short storms with return periods of 1 - 10 years or more, exceed intensities of 100 mm/hr.

This data, typical for the upper and mid catchment area indicates that the short duration (30 minutes or less) storms can generate high levels of ponded or surface water of up to 20-30 mm. The combination of intensity and surface water available for overland flow make such events the most likely to generate high levels of erosion.

Susceptibility to erosion for the various land management units/land systems was provided in Table 4.2. Defining actual erosion hazards is difficult as all soils will have changing degrees of hazard with changes in soils surface conditions and management. As a general rule, the susceptibility to erosion will increase with removal of surface cover, increases in slope length and/or steepness and activities which will concentrate flow, i.e. roads, earthen drains, cultivation up and down hill slopes.

The LMU's and associated and systems with the highest soil erosion hazards are:

- Carboniferous - Table Top and Combatong land systems
- Siluro - Devonian Sediments - Lurg, Moorngag and Wrightly Land systems
- Devonian Granites - All systems have high hazard where steep slopes occur.
- Devonian Volcanics - Loombah land system
- Quaternary Alluvial - Benalla - Samaria land sub-system
- Basalt Association - Kilmore Basaltic soils.

It is stressed again that other land units/systems will have varying degrees of hazard depending on management, and therefore should not be forgotten in developing overall management strategies for controlling nutrient movement in soil erosion processes.

4.3 Land Use

4.3.1 Agricultural Data

The analysis of agricultural land use in the dryland component of the Goulburn Broken Catchment has been based upon Australia Bureau of Statistics (ABS) data. The data has been collected at Shire and Parish level. The dryland catchment boundaries do not coincide exactly with the Shire and Parish boundaries,however, the general trends are considered representative.

ABS data is only collected from those properties which have an "estimated agricultural value of output" (i.e. gross farm income) of more than $25,000. Therefore the data excludes lower income farms, "hobby and small, part-time farmers." Because of this, the ABS figures provide only an indication of general trends in land use and management practices, and not hard figures.

Shire data has been collated for several years (1986, 87, 89, 90) to examine seasonal variability. A summary of this data is given in Appendix A. Note that this data was provided for shires prior to the 1995 changes in boundaries as shown in Figure 7.

Parish data was supplied by Department of Agriculture Benalla, from ARCVIEW system for 1 year 1991/92 and the relevant data is given in Appendix B.

Table 4.5
Area of Farmland

Shire	Total Land Area ha x 1000	Farmland (ABS data) ha x 1000	%
Upper-Mid Catchment			
Mansfield	390	84	22
Alexandra	224	56	25
Broadford	56	15	26
Yea	142	70	49
Kilmore	51	26	51
Subtotal	*862*	*251*	*29*
Mid-Lower Catchment			
Benalla City	2	1	47
Benalla Shire	231	133	58
Waranga	160	102	64
Seymour	97	63	66
Violet Town	93	65	70
Euroa	140	105	75
Goulburn	103	81	78
Tungamah	113	95	84
Sub-total	*939*	*645*	*69*
Total	**1,801**	**896**	**50%**

From the above table it can be seen that:

- the shires in the upper-mid catchment have about 30% farmland
- the shires in the mid-lower catchment have about 70% farmland

Table 4.6
Number of Farms

Shire	Farmland (ABS data) ha x 1000	No. of Farms
Upper-Mid Catchment		
Mansfield	84	183
Alexandra	56	161
Broadford	15	36
Yea	70	207
Kilmore	26	83
Sub-total	*251*	*670*
Mid-Lower Catchment		
Benalla City	1	5
Benalla Shire	133	404
Waranga	102	310
Seymour	63	122
Violet Town	65	164
Euroa	105	286
Goulburn	81	145
Tungamah	95	395
Sub-total	*645*	*1,831*
Total	**896**	**2,501**

From Table 4.6 it can be seen that ¾ of the farms are located in the mid-lower catchment.

Land Use

The land use for the catchment is mainly pasture for beef cattle and sheep. It is difficult to obtain an exact area for each land use because Shire and Parish boundaries overlap the irrigation areas.

It is estimated that the land use within the "dryland" portion of the catchment as shown below in Table 4.7.

Table 4.7
Estimated Land Use For "Dryland" Catchment

		Total	Upper-Mid	Mid-Lower
Total land area	- ha	1,800,000	862,000	939,000
Farmland	- ha	986,000	251,000	645,000
Pasture		645,000	195,000	450,000
Crops	- Cereal	30,000	1,000	29,000
	- Legume	10,000	200	10,000
	- Lucerne	1,500	300	1,200
Horticulture			500	700
Irrigated area within dryland (i.e.		1,200	1,500	6,800
along rivers)		8,300		

Table 4.8
Landuse by Shire

Shire	Total Area of Properties (ha)	Total Number of Properties	Native Pastures (ha)	Props.	Sown Pasture (ha)	Props.	Total Crops (inc. hort) (ha)	Props.	Total Hort. Crops (ha)	Props.
Upper-Mid Catchment										
Mansfield	76,570	154	31,976	95	32,175	107	370	18	33	8
Alexandra	47,137	139	18,528	91	23,513	96	317	18	103	8
Broadford	13,818	27	3,857	16	6,810	19	105	4	2	1
Yea	63,979	186	21,142	101	34,410	133	433	36	322	30
Kilmore	23,535	73	8,050	42	11,816	49	353	16	16	3
Sub-total	*255,039*	*579*	*83,553*	*345*	*108,724*	*404*	*1,578*	*92*	*476*	*50*
Mid-Lower Catchment										
Benalla City	1,573	7	1,079	4	465	4	83	2		
Benalla Shire	123,064	350	26,852	155	62,987	264	12,741	154	311	20
Waranga	96,899	277	12,598	100	49,397	240	16,825	168	416	16
Seymour	62,312	108	26,649	74	30,075	80	667	27	113	10
Violet Town	58,518	135	11,609	63	33,788	109	4,360	68	5	3
Euroa	96,175	245	23,468	123	59,390	201	5,938	96	31	6
Goulburn	71,895	133	16,620	64	43,096	109	5,775	69	315	9
Tungamah	89,793	367	12,236	114	42,901	299	23,296	213	415	21
Sub-total	*600,230*	*1,622*	*131,111*	*697*	*322,099*	*1,306*	*69,685*	*797*	*1,606*	*85*
Total	**825,269**	**2,201**	**214,664**	**1,042**	**430,823**	**1,710**	**71,263**	**889**	**2,082**	**135**

Table 4.9
Livestock By Shire

Shire	Total Area of Pastures (ha)	Total Number of Properties	Total Meat Cattle (ha)	Total Meat Cattle Props.	Total Sheep & Lambs (ha)	Total Sheep & Lambs Props.	Total Dse's#	Total Dse/ha
Upper-Mid Catchment								
Mansfield	64,151	154	28,449	136	145,718	105	466,638	7.3
Alexandra	42,041	139	23,030	119	56,219	55	300,574	7.1
Broadford	10,667	27	2,921	21	27,553	18	63,651	6.0
Yea	55,552	186	28,091	149	114,885	95	424,516	7.6
Kilmore	19,866	73	8,335	55	52,323	42	148,754	7.5
Sub-total	*192,277*	*579*	*90,826*	*480*	*396,698*	*315*	*1,404,133*	*7.3*
Mid-Lower Catchment								
Benalla City	1,544	7	87	3	5,231	4	7,409	4.8
Benalla Shire	89,839	350	33,773	247	265,890	236	670,093	7.5
Waranga	61,995	277	8,947	141	200,113	151	339,611	5.5
Seymour	56,724	108	12,248	68	191,592	75	361,970	6.4
Violet Town	45,397	135	8,804	68	156,529	109	283,701	6.2
Euroa	82,858	245	17,849	165	250,186	193	491,223	5.9
Goulburn	59,716	133	10,774	77	164,564	110	313,445	5.2
Tungamah*	55,137	367	7,317	156	138,467	146	246,254	4.5
Sub-total	*453,210*	*1,622*	*99,799*	*925*	*1,372,572*	*1,024*	*2,713,705*	*6.0*
Total	**645,487**	**2,201**	**190,625**	**1,405**	**1,769,270**	**1,339**	**4,117,838**	**6.4**

Notes: * These shires have significant dairy cattle that are not included
Dse rating for sheep and lamb numbers is 1.25 and for meat cattle is 10

Livestock

The predominant livestock is beef and sheep.

The estimated livestock for each shire is shown. Stocking rates are calculated in DSE units (dry sheep equivalents). From Table 4.9 it can be seen that:

- The average stocking rate is 6.0 DSE per Ha of pastures
- The stocking rate does not vary much throughout the catchment
- The lower catchment has a slightly lower stocking rate.

In addition to the above sheep and beef cattle, there are some 100 dairy farms with 10,000 cows scattered throughout the "dryland" area. These dairy farms are on irrigated pastures beside rivers.

Cropping

A review of ABS data from 1985 to 1992 (refer Appendix B) shows that the major crop within the area is cereals. The average area of cropping is approximately 35,000 ha, of which 20,000 is wheat. Legumes make up a further 10,000 ha, and other crops make up approximately 5,000 ha.

The actual area of cropping will vary in any one year, and appears to largely vary with the relative income of other enterprises. For example, over the period 1985 to 1990, when wool prices were peaking, the proportion of wheat to other crops declined from 63% to 37%. The proportion of wheat to other crops has declined from 63%, in 85/86 to 37% in 89/90.

An average value of 35,000 ha for cereal cropping, with wheat making up some 57% of the crop, has been adopted for this study.

Irrigation

Irrigation by private river diversion and groundwater pumping is found scattered throughout the dryland catchment and totals about 8,300 ha of which 7,400 is pasture and 900 ha horticulture. Irrigation data is presented in Tables 4.10 and 4.11.

Table 4.10
Irrigated Area by Shire

Area (ha)	Pasture	Cereal Crops	Vegetables	Fruits	Grapevines	Other Crops	Total Irrigated
Upper-Mid Catchment							
Mansfield			1	5	20		27
Alexandra	741		49	27		1	808
Broadford	173		2				175
Yea	257		97	34	21	20	428
Kilmore	5			5	4		14
Sub-total	*1,176*	*0*	*140*	*71*	*45*	*21*	*1,452*
Mid-Lower Catchment							
Benalla City							
Benalla Shire	2,160		1	63	94	0	2,318
Waranga	11,091	351	307	12	9	131	11,901
Seymour	892		2	5	36	58	993
Violet Town	577					15	592
Euroa	1,897			9			1,906
goulburn	668				306		974
Tungamah	11,495	92	4	354	16	182	12,144
Sub-Total	*28,780*	*443*	*314*	*443*	*461*	*386*	30,828
Total	**29,956**	**443**	**454**	**514**	**506**	**407**	**32,280**

* Most of the irrigated areas in these two shires belong in the "irrigated" section of the catchment.

Table 4.11
Types of Irrigation Properties (No's) by Shire

Area (ha)	Pasture	Cereal Crops	Vegetables	Fruits	Grapevines	Other Crops	Total Irrigated
Upper-Mid Catchment							
Mansfield			1	2	1		4
Alexandra	18		2	4		1	24
Broadford	2		1				3
Yea	14		9	6	4	5	37
Kilmore	1			1	1		3
Sub-total	*35*	*0*	*13*	*13*	*6*	*6*	*71*
Mid-Lower Catchment							
Benalla City			1				
Benalla Shire	45	8	10	8	5	1	56
Waranga	152		1	2	2	4	163
Seymour	17			1	2	2	23
Violet Town	13					1	13
Euroa	17			2			20
Goulburn	23				6		28
Tungamah	188	4	1	17	1	3	202
Sub-Total	*457*	*12*	*13*	*30*	*16*	*11*	*505*
Total	**492**	**12**	**26**	**43**	**22**	**17**	**576**

Irrigation particularly occurs along the highly productive river flats throughout the catchment. In the upper catchment where rainfall is greater, the amount of irrigation needed is reduced.

Horticulture

Scattered throughout the dryland catchment is about 100 properties with about 1,200 hectares. This does not include small properties with gross income less than $25,000 such as small vineyards. (< 5ha).

The horticulture is generally irrigated and comprises:

Irrigated	Vegetables	150 ha
Irrigated	Fruit	150 ha
Irrigated	Grapevines	500 ha
Irrigated	Other	100 ha
Dry	Horticulture	300 ha

Pigs

The ABS (Census 1993) shire data indicates that there are 44 properties with piggeries of gross income greater than $25,000 and a total number of pigs of 16,670. About half of these properties are located in the Waranga and Tungamah Shires which include part of the irrigated catchment. Table 4.16, however, presents results of the study of intensive animal industries in the catchment which indicate a total number of 37,200 pigs in the catchment.

Table 4.12
Number of Pigs by Shire

Shire	Total Pigs Number	Properties (ABS data)
Alexandra (S)	400	-
Benalla (S and C)	2,100	6
Broadford (S)	0	0
Euroa (S)	800	2
Goulburn (S)	2,600	2
Kilmore (S)	1,100	-
Mansfield (S)	700	4
Pyalong (S)	400	-
Seymour (S)	400	-
Tungamah (S)	8,000	16
Violet Town (S)	1,000	2
Waranga (S)	19,500	10
Yea (S)	200	2
Total	**37,200**	**44**

4.3.2 Public Land

Approximately 50% has of the catchment is classed as public land, i.e. owned and managed by the State. Major uses of land in the catchment are considered to be:

- Timber and other forestry production
- Water supply
- Tourism and recreation
- Mining and quarrying
- Conservation
- Military training

Each of these landuses and their potential nutrient impacts on water bodies is considered below.

Forestry

Forestry activities have been and will continue to occur in the Goulburn-Broken Catchment. Both softwood and hardwood timber production occur. Activities include production of round and split timbers, pulpwood/woodchip production and firewood.

The main impacts from forestry related activities are those which create areas of exposed soils. This obviously includes logging, however other activities including snigging, road/track building, back burning and fuel reduction burning can all result in the removal of surface debris material and expose surface and subsoils to erosive rainfall.

Water supply

Harvesting of water occurs in the upper parts of the catchment for the provision of both potable town water supplies and irrigation supplies to the northern plains.

Proclaimed Water Supply Catchments in the study area are shown in the Table 4.13 below.

Table 4.13
Proclaimed Water Supply Catchment

Catchment Name	Town	Area (sq.km)	Use
Upper Goulburn	-	3,535	Irrigation
Honeysuckle Creek	Violet Town	25	Town supply
Seven Creek and Mountain Hut Creek	Euroa	191	Town supply
Nine Mile Creek	Longwood	4	Town supply
Sunday Creek	Broadford-Kilmore	20	Town supply
Mollison Creek	Pyalong	166	Town supply
Lake Nillahcootie	-	413	Irrigation/Stock/Domestic
Ryan's Creek	Benalla	78	Town supply
Kilmore (Hazel and Harpers Creeks)	Kilmore, Wandong	5	Town supply

Former water supply catchments covered by land use determinations under the former Soil Conservation and Utilisation Act (1958) were:

- Upper Delatite (240 sq.km) for town supply to Mansfield

- The Lake Eildon environs (868 sq.km) for irrigation supplies being harvested at Lake Eildon.

Lake Mokoan, a former swamp, is used as a diversion basin for irrigation supplies from the Broken River.

Mean annual flow from the combined catchment is in the order of 3,365,000 ML (Department Water Resources 1989), representing approximately 20% of average annual rainfall. Of the total volume of water flowing from the catchment, approximately 1,880,000 ML is currently developed (i.e. harvested) for urban, agricultural or other use. Over 90% of this is used for irrigated agriculture.

The harvesting of water in the catchment has altered the flow regimes of the Broken and Goulburn Rivers, particularly below Nillahcootie, Eildon and Goulburn weirs. DWR (1989) reported a total of diverted flow of approximately 2,110,000 ML or 63% of the mean annual flow.

Landuses, in particular those affecting the quality of overland flow, within these water supply catchments impact on the quality of town and irrigation supplies.

Tourism and Recreation

Tourism and recreational pursuits is an expanding landuse in the catchment, particularly in the upper parts, i.e. the ranges. Activities include:

- sightseeing and picnicking;
- 4WD's, bushwalking and camping;
- fishing and hunting;
- water skiing, canoeing and other water sports;
- fossicking; and
- snow skiing.

A number of these activities incorporate large scale modifications to the landscape, e.g. snow skiing areas require clearing and grooming. Others require less changes either in terms of less area or more subtle changes, such as clearing tracks for 4WD's, making clearings for picnic spots or providing river access for water sports.

Recreational and tourist activities can expose soil surfaces to erosive rainfall, provide pathways for concentrated surface flows (i.e. tracks and roads) and change surface hydrology. In particular the findings of Weston in 1989 (pers comm) indicates that bare soil tracks and riverside recreational reserves can be a major source of sediment (and nutrient) during overland flow.

Mining and Quarrying

The study area is noted for a number of gold and other mineral provinces, e.g. Woods Point and Gaffneys Creek. Quarrying activities including river gravel extraction have been undertaken in the past to provide road making and other building uses.

Extractive industries, particularly open cut (quarries), river gravel extraction and river dredging can have obvious and immediate impacts on water quality. Such activities are generally strictly controlled to obviate the impact. However, associated infrastructure such as access roads, and historical clearing for timber supplies can also impact on stream quality.

Again those activities either directly or indirectly related to extractive activities that expose surface soils are considered to have the potential to contribute to nutrient losses.

Conservation and Public Land Management

The study catchment encompasses a number of state and national park areas, e.g. Fraser National Park. The management of these areas often overlaps with the recreational activities outlined previously. The impacts of such activities is also relevant to these areas.

In the forested areas of the catchment (predominantly the ranges) management activities such as fuel reduction burning may also have limited short-term inputs. Balanced against this, however is the major impacts of large scale bushfires (cited by Clinnick 1984) where large areas of ground protecting tree cover are removed.

Thus, while some management activities such as fuel reduction burns and construction of fire access tracks may have limited affects, a balance must be struck to prevent larger, more serous affects of major bushfires.

Military Training

Due to the nature of military training activities, soils can often be exposed or subjected to activities that increase the erosion hazard (e.g. through loss of soil structure). The main area of military activity is Puckapunyal. This area is, however, subject to extensive soil erosion control works. Studies undertaken by CSIRO are believed to indicate that actual sediment loads now leaving the Puckapunyal catchment are considerably reduced since erosion control works began.

It is noted that some limited activities are also undertaken in forested areas of the catchment (White 1990). Such activities present the same form of impact as other activities in these areas (i.e. vehicle traffic, changes to soil structure, removal of protective vegetative cover), such as logging or 4WD use may have.

4.3.3 Other Rural Activities

The point source impacts of nutrients from urban centres is the subject of another consultancy, and no consideration of these sources will be made here. However, there are a number of other activities in the rural areas of the catchment that through the mechanism of nutrient transport, can be considered as diffuse sources. These activities include:

- land irrigation of effluent/wastewater
- landfills
- septic tank systems
- disposal of industry/processing wastes.

Nearly all of these activities can generate diffuse nutrient loads by the same mechanism, leaching of nitrogen into groundwater and eventual discharge to streams.

Other activities, such as rural residential developments and hobby farms can also be diffuse sources of nutrient due to the impact with respect to changes in landuse, vegetation cover, surface drainage and effluent generation.

In assessing the catchment for diffuse sources of nutrients, the activities outlined above have been found to be mostly related to:

- Sewerage/septic systems associated with caravan parks along the mid-upper reaches of the Goulburn;
- Housing/rural development close to streams, with septic systems;
- Intensive animal industries located close to waterways which irrigate land with liquid wastes;
- Sewage plants located close to waterways or have shallow water tables;
- Industries not connected to town sewage systems, e.g. wineries; and
- Landfills located within the vicinity of waterways.

It was also considered that a range of activities at alpine resorts (such as water supply, landfilling and sewerage treatment) could also be generating diffuse sources. However, as the resorts could be targeted as a whole, treatment of this issue as an urban point source would be more appropriate.

The location of sewage land disposal sites and landfills obtained from a questionnaire circulated to shires in the catchment during the course of the urban drainage study are shown in Figure 8.

The data obtained highlights the presence of land disposal that is occurring in the upper part of the catchment, where generally the best land for disposal by irrigation is located close to streams. However, the data obtained shows that the level of effluent being applied to ground or into soakage pits is not great, ranging from 5,000 L/yr up to 56,000 L/yr for individual sites. While a potential local nutrient problem, seepage of nutrient loaded groundwater from these sites is not considered to be significant at a regional scale.

Little data was received from shires regarding the location of landfills. The sketchy information gathered to date suggests that landfills in this catchment are generally not located close to streams. On a regional scale, therefore, landfills are not considered to be a major source of diffuse nutrients.

The investigation of intensive animal industries is the subject of a separate consultancy, and shall not be addressed further. It is noted, however, that the highest risk of low levels of diffuse nitrogenous nutrients can be expected from sites located close to waterways (i.e. within 100 m to 200 m of the stream banks).

No secondary industry sites were identified from the shire surveys to have independent wastewater disposal, although it is noted that the response rate to the questionnaire was low. One area which was focussed on during the study is the disposal of waste, including grape pulps, etc. from wineries located within the catchment. Many of the wineries in the catchment are located close to streams. The potential exists for loss of organic matter containing nutrient material to the streams to create local nutrient hotspots.

4.4 Agricultural Nutrient Inputs

In 1989/90 an average 64% of farm properties applied some fertiliser (based on ABS data). After allowing for the Shires partly within the more intensive irrigation areas it appears that there is little difference in the numbers of farms applying some fertiliser between the upper-mid and mid-lower catchment. The main fertiliser applied was superphosphate.

Table 4.14
Number of Farms Applying Fertiliser in a Year (1989/90)

Shire	No. of Farms	No. Applying Fertiliser		Super	Nitrogen	Mixtures
		Total No.	%			
Upper-Mid Catchment						
Mansfield	183	102	56	96	7	13
Alexandra	161	90	56	73	7	32
Broadford	36	14	39	12	1	4
Yea	207	118	57	91	6	38
Kilmore	83	43	52	35	1	10
Sub-total	*670*	*367*		*307*	*22*	*97*
	%	*55%*		*46%*	*3%*	*14%*
Mid-Lower Catchment						
Benalla City	5	3	60	3	0	0
Benalla Shire	404	259	64	241	12	33
Waranga	310	228	74	212	34	28
Seymour	122	72	59	67	4	14
Violet Town	164	98	60	93	3	7
Euroa	286	161	56	151	6	21
Goulburn	145	105	72	97	3	14
Tungamah	395	306	77	278	86	41
Sub-total	*1,831*	*1,232*		*1,142*	*148*	*158*
	%	*67%*		*62%*	*8%*	*9%*
Total	**2,501**	**1,599**	**64%**	**1,449**	**170**	**255**

4.4.1 Current Application Rate

In any one year, landholders generally don't apply fertiliser to the whole farm area although most of the cropping area is likely to receive fertiliser.

From the Parish data (ABS 1991/92) it was found that in the dryland area:

Fertiliser Applied	-	19,414 tonnes of "Super" (equivalent to 1,670 t of phosphorus)
Area Fertilised	-	141,517 ha
% Farmland	-	17%

Application Rate	-	0.14 t/ha "Super" (equivalent to 12.2 kg phosphorus/ha)
Average Rate for Farmland	-	0.024 t/ha (2 kg phosphorus/ha)
Average Rate for Parish	-	0.011 t/ha (1 kg phosphorus/ha)

Within parishes fertiliser application rate varied from 0.05 t/ha to 0.42 t/ha but the majority of parishes were within the range of 0.1 - 0.2 t/ha (or 9-18 kg P/ha).

It was not possible to determine the average application rate for the farmland within a parish.

The overall parish application rate varied from zero in forested parishes to 0.04 t/ha in the parish of Dookie (3.5 kg phosphorus/ha).

The fertiliser application rates varied from year to year although the variation has not been as much was expected since the wool slump in 1989/90. It appears that the application has varied from about 20,000 to 30,000 tonnes of Super in recent years.

The variation in total Shire total fertiliser applications from year to year are shown below.

Year	**1986**	**1987**	**1989**	**1990**	**1992**
Fertiliser tonnes	35,430	30,521	39,284	33,918	est 27,000

Note, the above figures include about 10,000 tonnes which are applied to the irrigation section of the Shires.

It would appear that the irrigation properties apply about 5-10 times the fertiliser application compared to a dry farm.

4.4.2 Fertiliser Since European Settlement

Soil phosphorous levels have changed dramatically several times since European settlement and the key periods are:

- pre-European state - soil with naturally low available phosphorus levels (Total phosphorus in forest typically average 0.06%) but relatively high phosphorus in the vegetation biomass.

- clearing and burning which released vegetation biomass nutrients into soils and waterways.

- exploitation of nutrients following clearing which resulted in good yields (note average what yields at clearing were 0.2 tonne/ha lower than what they are now although more marginal country is presently under cultivation).

- low fertility and low yields around the turn of the century (1880 - 1910) (total phosphorus in native pasture 0.025%).

- application of "super" with rapid increase to 1 million tonnes of "super" Australia wide in the 1930's.
- super applications peaked Australia wide at 4 million tonnes in 1970.
- with removal of super bounty and rapid price increase, fertiliser has now declined to 2 million tonnes.

It is not known, however, what proportion of the increase super use in the 1950 - 1970's occurred in intensive agriculture (cropping/irrigation) compared to the grazing areas. However, it is possible that in the 60's the rates in the catchment were up to double (i.e. 4 kg/ha farmland) what they currently are.

4.4.3 Crop versus Pasture

The relative application rates for Pasture and Crops are shown in Table 4.15 below:

Table 4.15
Fertiliser Application

Land Use	1985/85	1989/90
Crop:		
Area ha	82,000	40,000
Tonnes	11,300	4,400
Rate t/ha	.14	.11
Pasture:		
Area ha	185,000	220,000
Tonnes	24,100	28,530
Rate t/ha	.13	.13

From this data it would appear that:

- application rates are similar for pasture and crop although the shires that have little crop and no irrigation apply slightly less fertiliser per hectare, i.e. about .11 t/ha;
- about 30% of the pasture area is fertilised in any year; and
- almost all of the crop land is fertilised.

4.4.4 Type of Fertiliser

The major fertiliser applied is Phosphate (P) either "single" or "double strength super".

There is only a small amount of alternative fertilisers and even then the major component is still phosphate.

For the shires concerned (including the irrigation parts of Waranga and Tungamah) the relative uses as tonnes of fertiliser are:

Year	Phosphorous	Nitrogenous	Mixture
86/87	30,521	1,365	2,569
88/89	39,284	1,683	5,021

4.4.5 Nutrients Removed by Agricultural Products

Nutrients are removed by agricultural products at rates as shown in Table 4.1.6. (Ref. Pivot Fertiliser).

Table 4.16
Rates of Nutrient Removal - kg

Agricultural Product	Unit Production Rate	Nutrient Removal Rate (kg/unit production)	
		Nitrogen	Phosphorus
Meat	50 kg live	3	0.40
Wool	5 kg greasy	1	0.02
Cereal	1 tonne	20	2.7
Legumes	1 tonne	40	4.5
Lucerne	1 tonne	27	3.0
Grapes	1 tonne	8	1.3
Hay	1 tonne	30	3.0
Milk	1,000 litres	6	1.3
Stone Fruit	per ha	70	11.0

The estimated removal of phosphorus within the dryland catchment is shown in Table 4.1.7 below.

Table 4.17
Catchment Phosphorus Removed by Agricultural Production

Product	Quantity in Catchment	Agricultural Units exported from Catchment	Production Rates (av)	Total Production	Rate of P (kg) Removed	Total P (kg) Removed
Beef	166,000 hd	90,000 hd	400 kg/hd	36,000,000/kg	0.40 kg/50kg	288,000
Sheep - meat	1,900,000 hd	800,000 hd	40 kg/hd	32,000,000/kg	0.240 kg/50kg	256,000
- wool	1,900,000 hd	2,185,000 hd	5 kg/hd	9,832,500/kg	0.02 kg/5kg	39,330
Dairy	10,000 hd	4,000 L/hd	4000 L/hd	40,000,000L	1.00 kg/1000L	40,000
Cereal	30,000 ha		2 t/ha	60,000	2.70 kg/5	162,000
Legumes	10,000 ha		2 t/ha	18,000	4.50 kg/5	81,000
Horticulture	1,200 ha				11.00 kg/ha	13,200
Lucerne	1,500 ha		4 t/ha	6,000	3.00 kg/5	18,000

Product	Quantity in Catchment	Agricultural Units exported from Catchment	Production Rates (av)	Total Production	Rate of P (kg) Removed	Total P (kg) Removed
					Total P (kg)	**897,530**

It appears that about 900 tonnes of phosphorus is removed by agricultural products each year. This represents about 1 kg of phosphorus per ha of farmland or 0.5 kg of phosphorus per total catchment area.

In other words of the annual fertiliser application of 2-3 kg of phosphorus per ha of farmland about 1 kg of phosphorus per ha is removed by the agricultural products. This suggests that total phosphorus levels could be still be building up in the soils.

Other research (ref. Robert White "Is a decline in Soil Fertility Contributing to Land Degradation in Australia?", Agricultural Science July 1993) suggests that livestock removal is 0.7 kg of phosphorus per DSE. For this catchment the stocking rate is about 4.50 DSE per ha of farmland. This suggests that livestock removal could be nearer 3 kg of phosphorus per ha. It is understood that this livestock removal estimate includes an allowance for "transfer of nutrients away from pasture to "livestock camps" yards, laneways, etc. but not necessarily out of the catchment.

Of course, the simple equation of nutrients in and out is complicated by the chemical processes involved. Phosphorus, either native or applied through fertiliser, is not always available and is often locked up in the soil.

4.4.6 Fertiliser Removed in the Catchment Waterways

It has been previously estimated (AEAMS model) that the annual contribution of phosphorus from the dryland areas is around 100 tonnes. This is equivalent to 0.04 kg/ha over the whole catchment. If it was assumed that the phosphorus all came from the farmland (which it does not) then the annual loss to the waterway is 0.11 kg/ha.

This maximum loss of phosphorus to the waterways represents about 3-5% of the annual input of phosphorous from fertiliser application.

These figures indicate that the loss of phosphorus from fertilisers is minimal, and is in reality likely to range below 3% of annual use.

4.5 Groundwater Inputs

A search of the State Groundwater Data Base was completed to obtain nutrient data for groundwater in the Goulburn Broken dryland catchment.

Approximately 1000 bores were identified as having been analysed for nutrients, predominantly nitrate and nitrite as NOx (i.e. total oxides of nitrogen). Some phosphorus levels were also available for a limited number of bores. This data is enclosed as Appendix C.

Catchment Assessment

At a regional catchment level, the groundwater concentrations of nitrogen varies widely (refer Table 4.18) from < 0.15 mg/L to in excess of 40 mg/L at some locations.

Average total NOx was found to be 2.0 mg/L across the dryland catchment. Average values for ortho-phosphate and total phosphate were found to be 0.01 mg/L and 0.26 mg/L respectively.

Table 4.18
Gauging Station Sub-catchment Nitrous Oxides in Groundwater

Table 4.18 (Cont'd)
Gauging Station Sub-catchment Nitrous Oxides in Groundwater

The level for phosphorus is expected to be low as leaching of phosphorus is limited due to rapid fixing in soil.

The predominant oxide of nitrogen found in groundwater is nitrate (NO_3). Nitrate is highly soluble and chemically inert, making it unlikely to be lost from the groundwater system.

Relationship to LMU's

Table 4.18 shows the levels of nitrogen found in groundwaters sampled from a variety of bores within individual LMU's. It is evident that the highest levels of nitrate (as NOx) are associated with LMU's associated with granitic and acid volcanic geology. The sandier soils, and associated higher leaching rates would suggest that high NOx levels would occur if suitable surface sources were made available.

Mixed levels of NOx were found for LMU's that cover a mixed variety of geology. Again higher levels of NOx are found to be associated with the sandier soils. High levels were also found to be associated with the Carboniferous sediments of LMU's.

Low to moderate levels of NOx were found to be associated with the Silurian-Devonian and Ordivian sediments of LMU 7 and LMU 3.

Groundwater Nitrogen Levels in Gauging Catchments

Comparison of groundwater NOx levels with the base flow (minimum) loads for the monitoring sub-catchments indicates that there is no discernible pattern, (refer to Table 4.18).

The highest NOx loads in the streams are for the Murrindindi and Sevens Creek stations. These have variable groundwater NOx levels with Murrindindi levels indicated to be reasonably low, i.e. below 2 mg/L. Conversely some of the sub-catchments with higher NOx groundwater levels have extremely low surface loads.

The conclusion is reached therefore that:

(a) with respect to nitrate levels in groundwater, soil type and geology have a controlling influence; but

(b) processes other than groundwater seepage dominate the level of NOx in the stream flows.

4.6 Sub-Catchment Water Quality Data

Analysis of Water Quality Data

As described previously fourteen sub-catchments were selected to assess nutrient load generation from various land system and land use areas. The location of these sub-catchments are shown in Figure 4.

A summary of the water quality data is presented in Table 4.19 below. The highest average phosphorous generation loads (kg/ha/yr) are clearly seen to be sourced from the:

- Delatite River;
- Big River;
- Broken River (at and upstream of Nillahcootie);
- Hollands Creek (possibly both Hollands and Ryans Creek);
- the upper catchment of the Murrindindi River; and
- Acheron River.

Comparison of those results indicates that:

- Grazing and intensive agricultural activities on the Delatite and Hollands Creek catchments are possibly contributing high phosphorous loads.

- Activities in the forested catchments and upper catchments are generating phosphorous loads that are greater than for downstream and lower catchment areas.

- The Murrindindi and Delatite Rivers produce the highest phosphorous loads on a per kg/ha/yr basis.

- The only gauged catchment on the plains, Castle Creek is amongst the lowest phosphorous load generating sub-catchments.

- Nitrogen load generation follows a similar trend, with upper catchments generating the highest loads.

- The catchments with the highest load generation do not necessarily have the most degraded systems or highest levels of dissolved concentrations of phosphorous and nitrogen.

Table 4.20 presents a summary of the agricultural landuse information for selected sub-catchments with the highest phosphorous export rates. This comparison of agricultural landuse and fertiliser inputs indicates no significant variations from more regional data (refer Appendix B). It is therefore concluded that agriculture is not the major source of these nutrients and that other processes are operating within these catchments to generate these export loads.

Table 4.19
Gauging Catchment Water Quality Data

Table 4.19 (Cont'd)
Gauging Catchment Water Quality Data

Table 4.19 (Cont'd)
Gauging Catchment Water Quality Data

Table 4.20
Gauging Catchment Nutrient Export Rates

Table 4.20 (Cont'd)
Gauging Catchment Nutrient Export Rates

Table 4.20 (Cont'd)
Gauging Catchment Nutrient Export Rates

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NUTRIENT GENERATION AND EXPORT

Summary of Catchment Characterisation

The presentation of the water quality flow data clearly indicates that the major sources of nutrients in the stream network are in the upper reaches of the Goulburn-Broken catchments.

This correlates with the reports of high sediment export being noted for a number of the upper catchment land systems. It also correlates well with the recent CSIRO findings for the Snowy and Murrumbidgee Rivers.

The source of phosphorous would appear to be closely aligned with soil erosion processes operating in these locations. The dominant landuse in these catchments, particularly the

Murrindindi River and Big River catchments is forested catchments which are utilised for recreational and other activities. It has been noted in particular that logging operations have not occurred in these two particular catchments for some time.

Drawing on the results of Weston (pers comm) and others (as presented in the literature review) the likely sources of nutrient are the forest tracks and riverside reserves from these particular catchments.

The situation with the Delatite River is likely to be a combination of both upland erosion and agriculture. It has been noted that intensive seed growing operations are undertaken within this catchment. Similar activities for the Broken River have also been noted in the Mansfield district.

It should also be noted that for both the Broken River and Delatite River, the headwaters lie in Carboniferous sediments. These have been noted in earlier land studies as being major sources of sediment during high winter flows. These particular sedimentary rocks also develop soils with relatively high native phosphorous levels.

The headwaters of Hollands Creek and its tributary, Ryans Creek, also lie in the upland areas associated with Carboniferous sediments and some basaltic materials. The latter are also noted for naturally high phosphorous levels.

It is concluded, therefore that the major diffuse source of nutrients (phosphorous) from the dryland catchment is from upland areas where erosion rates are higher and adsorbed phosphorous (either natural or from fertiliser) is transported by soil erosion.

Comparison of Catchment Nutrient Generation Rates and AEAMS Assumptions

Table 5.1 below presents the range of nutrient generation rates for a variety of landuses developed during the AEAM workshops. Based on the findings of this study it would appear that the values assumed for native forest areas underestimate the loads that can be generated from these areas.

Ranges for phosphorous loads in particular were found to range from 0.02 up to 0.4 kg/ha/yr. This is compared to the range of 0.01-0.04 kg/ha/yr phosphorous for the AEAM model.

Table 5.1
AEAMS Assumed Generation Rates for Land Uses

	Generation Rate (kg/ha/yr)

Land Use Type		
	Total Phosphorous	Total Nitrogen
Native forest - undisturbed	0.01 - 0.02	0.06 - 0.2
- disturbed	0.02 - 0.04	0.12 - 0.4
Pasture	0.03 - 0.4	0.1 - 4.6
Crop land	0.04 - 0.4	0.3 - 4.5
Irrigated land	0.3 - 3.5	0.9 - 1.4
Urban land	0.1 - 5.0	3 - 13
Stormwater runoff	0.2 - 2.0	2 - 8
Construction site runoff	8.4 - 22.5	315.3 - 62.2

Conversely export loads for phosphorous from agricultural land (0.02-0.1 kg/ha/yr) were found to be in the lower order of ranges for the assumed AEAM inputs of 0.03 - 0.4 kg/ha/yr.

Similar trends are also the case for nitrogen export loads for both forested and agricultural land uses.

Nutrient Generation and Catchment Balance Calculations

Generation Rates

By allocating average nutrient generation rates from the selected sub-catchments to the various land management units, nutrient generation rates to the catchment stream systems have been estimated for phosphorus and nitrogen (refer Figure 9).

Annual catchment generation rates ranging between 126 to 154 tonnes per year and 1980 - 2340 tonnes per year for total phosphorous and total nitrogen respectively have been estimated. In comparison the AEAM model indicated rates of 110 tonnes and 1550 tonnes per year of total phosphorous and total nitrogen from the dryland areas.

The figures for total phosphorous are in reasonable agreement, while the calculation of nitrogen is some 30-50% higher than the AEAM model.

It is noted however that based on a catchment outflow of stream water of 3,365,000 ML (Dept Water Resources 1989) sourced from rainfall (with an average NOx concentration of 0.2 mg/L) a natural base flow of the order and 670 tonnes of NOx can be expected. The generation of total nitrogen from dryland diffuse sources in the catchment due to sources other than rainfall is therefore estimated to be around 1300-1670 tonnes per annum.

Catchment Balance Calculations

In Section 4 a variety of diffuse nutrient sources were identified as potential inputs to the catchment. These included:

- Natural nutrients derived from weathering of parent geological material, decaying vegetation, nitrogen fixation by plants and rainfall;

- Human induced sources from fertiliser use, disposal of wastewater, septic tanks, landfills and other waste disposal.

Mechanisms of transport of these nutrients to the streams have been identified as being either by overland flow, eroding soil or by groundwater discharge.

The catchment characterisation presented in Section 4, however, has identified that overland flow and erosion of soils and subsequent deposition into streams is likely to be the predominant mechanism of diffuse source nutrients entering the catchment waterways. Other mechanisms such as groundwater discharge have a much smaller input.

Consequently the major sources of the diffuse nutrients will be those associated with overland flow and erosion processes, namely:

- Natural nutrients including native phosphorus and rainfall
- Fertiliser inputs.

Based on mean annual rainfalls and the average concentrations of nitrogen in rainfall (Section 4), annual loads into the catchment have been estimated as:

Annual Rainfall	Nutrient Concentration	Annual Input
15,075,000 ML	0.2mg/L	3015 tonnes

A figure of 0.14 kg/ha/yr of total phosphorus was also cited (refer Section 4). For the dryland catchment, an input from rainfall in the order of 240 tonnes/yr on average would be expected. However, much of this phosphorous would become bound to soil and not enter the water system directly.

The levels of native phosphorus and nitrogen in the catchment soils has been described in Section 4. To summarise, many of the soils in the headwaters of the catchment were found to have high native phosphorus and nitrogen levels as were some of the soils associated with stream bank alluvials.

The actual contribution of the native nutrients to the catchment waterways is unknown. Calculation of these figures would require detailed knowledge of site-specific erosion rates which are not available. It is considered that compared to other inputs the overall contribution will only have significant impact where other inputs such as fertilisers are absent, e.g. native forest areas.

Fertiliser inputs to the catchment have previously been considered to be the other significant source of diffuse nutrients to stream systems. Data on fertiliser use rates have been presented in Section 4. Based on ABS data an average input rate of 2 kg/ha of phosphorus was estimated for farmland across the catchment. Estimated farmland areas for the Upper-Mid Catchment is 250,000 ha and for the Mid-Lower Catchment, 600,000 ha.

The loss of nutrients from the catchment from diffuse sources can be estimated by the use of annual load figures for the various sub-catchments selected for this study (see Section 4).

Table 5.2 summarises the findings for the catchment.

Table 5.2
Nutrient Loads in Streams from Various Catchment Areas

Catchment Section	LMU	Catchment Area (ha)	Average Nutrient Load (kg/ha/yr)	
			Phosphorus	Nitrogen
Upper Catchment	Basalts and Carboniferous	180,000	0.2	3.5
	Steep Sedimentary	540,000	0.1	1.5
Mid Catchment	Mixed (sedimentary igneous and metamorphics)	360,000	0.1	1.7
Lower Catchment	Alluvials	720,000	0.02	0.11

Ranges for estimated stream load contributions for the catchment are presented pictorially in Figure 9.

Table 5.3 presents a balance between the nutrient inputs to the catchment from fertiliser and rainfall and nutrient outputs to the Goulburn and Broken Rivers, based on the sub-catchment load.

Table 5.3
Dryland Catchment Nutrient Balance

Source	Upper-Mid Catchment (Uplands + 62% of foothills)	Mid-Lower Catchment (Plains + 38% of foothills)	Total Catchment
Fertiliser Phosphorus	500 tonnes	1200 tonnes	1790 tonnes
Rainfall Phosphorus NOx	120 tonnes 1760 tonnes	130 tonnes 1250 tonnes	250 tonnes 3010 tonnes
Total Inputs Phosphorus NOx	620 tonnes 1760 tonnes	1330 tonnes 1250 tonnes	2040 tonnes 3010 tonnes
Outputs via Waterways -Phosphorus -NOx	113 - 139 tonnes 1040 - 1230 tonnes	13 - 15 tonnes 940 - 1110 tonnes	126 - 154 tonnes 1980 - 2340 tonnes
% of inputs -Phosphorus -NOx	18 - 22% 60 - 70%	approximately 1% 75 - 90%	6% - 8% 66% - 78%

The major sources of phosphorous load are indicated to be from the upper catchment areas. Nitrogen loads to the waterways is slightly higher from the lower catchment.

Ranking of Nutrient Source Areas and Activities

The results of the sub-catchment nutrient load analysis combined with the results of the catchment characterisation and catchment land use indicate that the major sources of phosphorus nutrients is from upland areas of the catchment.

In particular the highly erodable Carboniferous sediments, as well as the steeper sedimentary, volcanic and granitic soils in the highlands are implicated as a major source of sediment to the stream systems.

Because of the preferential adsorption of phosphorous to soil particles it is concluded that these areas of sediment source are also likely to be major sources of phosphorous to the stream systems. The phosphorus is likely to be derived from both fertiliser use and for the Carboniferous and Volcanic soils from high native phosphorus levels.

Identification of Key Activities

By combining the data from Section 4 on landuse and nutrient generation rates (refer Tables 4.18 and 4.19) with ABS data on areas of landuse activities, it is also possible to identify the nutrient loads being generated as landuse activities.

Table 5.4 presents the results of these calculations. The reasonable agreement between the estimates of phosphorus loads for land management units and land activities provides a reasonable degree of confidence to these estimates. Nevertheless the estimates have been based on scant data and more work is recommended to further refine the understanding of diffuse nutrient sources.

The calculations indicate that for the mid-lower catchment areas the key activities generating diffuse phosphorus (nutrient) loads are:

- Pastures (contributing 70%) with native or unimproved pastures contributing up to 50% of long term annual loads.
- Forestry contributing some 20% of diffuse phosphorus loads.

In the upper-mid catchment key activities identified are:

- Forestry, contributing some 90% of phosphorus loads.
- Pasture, contributing approximately 10% of phosphorus loads.

Table 5.4
Dryland Catchment Phosphorus Generation Loads
Based on Landuse Activities

Landuse	Mid-Lower Catchment			Upper-Mid Catchment		
	Area (ha)	Nutrient(1) Generation Rate (kg/ha/yr)	Loads/yr (tonnes)	Area (ha)	Nutrient(1) Generation Rate (kg/ha/yr)	Loads/yr (tonnes)
Pasture - Native	130,000	0.1	13	83,000	0.1	8.3
- Improved	320,000	0.02	6.4	109,000	0.02	2.2
Cropping	40,200	0.02	0.8	1,500	0.1	0.2
Horticulture	700	0.2	0.1	500	0.4	0.2

Irrigation	6,800	0.2	1.4	1,500	0.2	0.3
Forestry	294,000	0.02	5.9	611,000	0.15	91.7
Total	937,000	-	27.6	862,000	-	102.9

Note: (1) Adopted from catchment landuse\values in Table 4.18 _ published values.

The conclusion is drawn that forestry activities in the upper to mid catchment and pasture based activities, in particular unimproved pastures, over the whole catchment are key activities that can be targetted for nutrient reduction.

Specific land uses that increase the erosion hazard of the soils are considered to be the main areas that will provide the sources of sediment/phosphorous to the Goulburn-Broken system. Particular land uses highlighted in this study are:

- forestry tracks that cross waterways.
- riverside forest reserves used for recreational purposes.
- agricultural activities (including cultivated and pastoral activities) along waterways and/or in erosion prone land systems.

Other activities in both the mid and lower parts of the catchment that have been identified as more in line with point sources, and may be causing local water quality issues are:

- dairy and other irrigated agriculture activities along waterways (indicated to contribute some 5% of phosphorus loads in the mid-lower catchment);
- caravan parks with soakage pits/land disposal of waste water along the Goulburn River;
- wineries located adjacent to waterways;
- site of land disposal of waste water (either industrial and/or domestic) in proximity to waterways.

Other activities such as landfills and septic tanks appear to have a lower level of impact than has been reported overseas.

Ranking of Areas

In terms of producing loads the ranking of regional significance are:

Upland ranges - producing some 65% of phosphorous and nitrogen loads.

Foothills - producing some 25-30% of phosphorous and nitrogen loads.

Plains - producing some 5-10% of phosphorous and nitrogen loads.

Of the fourteen sub-catchments evaluated the ranking of the 12 upper catchments are shown in Table 5.4.

Table 5.5
Goulburn Broken Catchment Dryland Nutrient Study
Analysis of Dryland Nutrient Source Areas
Ranked from Highest to Lowest

Sub-catchment	Catchment Area (ha)	Average Generated Loads kg/ha/yr		Annual Nutrient Load (tonnes/yr)		% Range of Annual Catchment Load			
						Tot P		Tot N	
		Tot P	Tot N	Tot P	Tot N	Upper	Lower	Upper	Lower
Delatite Rv	34375	0.5	0.7	17.2	24.1	13.6%	11.2%	1.2%	1.0%
Big Rv	61875	0.2	1.5	12.4	92.8	9.8%	8.0%	4.7%	4.0%
Hollands Ck	41875	0.2	2.1	8.4	87.9	6.6%	5.4%	4.4%	3.8%
Acheron Rv	61875	0.1	2.3	6.2	142.3	4.9%	4.0%	7.2%	6.1%
Broken Rv (u/s Moorngag)	49690	0.1	3.2	5.0	159.0	3.9%	3.2%	8.0%	6.8%
Goulburn Rv (u/s Jamieson)	73750	0.02	0.2	1.5	14.8	1.2%	1.0%	0.7%	0.6%
Sevens Ck (u/s Polly McQuinns)	14375	0.1	3.3	1.4	47.4	1.1%	0.9%	2.4%	2.0%
Murrindindi Rv	5624	0.2	4.9	1.1	27.6	0.9%	0.7%	1.4%	1.2%
King Parrot Ck	11875	0.06	1.9	0.7	22.6	0.6%	0.5%	1.1%	1.0%
Sunday Ck	21875	0.02	0.3	0.4	6.6	0.3%	0.3%	0.3%	0.3%
Brankeet Ck	13750	0.03	0.4	0.4	5.5	0.3%	0.3%	0.3%	0.2%
Sugarloaf Ck	48750	0.006	0.2	0.3	9.8	0.2%	0.2%	0.5%	0.4%
TOTALS	439689			54.99	640.25	43.6%	35.7%	32.3%	27.4%

Of the currently monitored catchments, seven contribute between 34% and 41% of the total dryland catchment phosphorous load, while only making up 16% of the total dryland catchment.

Eight sub-catchments currently monitored contribute between 26% and 30% of the total nitrogen load, while also only making up 16% of the area of the total dryland catchment.

The highest contributing catchments of diffuse dryland nutrients are:

- The Delatite River;
- Big River;
- Hollands Creek;
- Acheron River;
- Broken River upstream of Moorngag; and
- Sevens Creek upstream of Polly McQuinns Weir.

The Murrindindi River, while noted for a high generation rate for total phosphorus and total nitrogen contributes around 1% of the total catchment diffuse source nutrients. Similarly the King Parrot Creek, which has a high generation rate for total nitrogen, contributes only around 1% of total nitrogen and less for total phosphorus.

Catchment Management Implications

Eildon Catchment

The three gauged sub-catchments upstream of Eildon weir are indicated to generate some 20 - 25% of the catchment's total diffuse phosphorus and between 6 - 7% of the catchment's total diffuse source nitrogen; 32 tonnes and 137 tonnes respectively.

The actual nutrients exported from the Eildon catchment based on weir gauging data from August 1990 to August 1994 is:

- Annual Load of Total Phosphorus = 14 tonnes
- Annual Load of NOx = 240 tonnes

As expected, the Eildon Weir is acting as a sink, although only for phosphorus. The available figures indicate that some 50% of phosphorus is being stored within Eildon Weir.

In contrast, nitrogen appears to be added in the immediate weir environs, with only some 55% of outgoing nitrogen being accounted for by the three gauged upgradient catchments.

It is concluded from these figures that Eildon Weir is currently acting a sink for phosphorus from the surrounding Eildon catchment. This stored phosphorus may be released under various flow or climatic conditions and be exported downstream or impact on the lake environment.

Targetted management of diffuse source nutrients for the upper Goulburn catchment will therefore have a long term benefit in reducing phosphorus storage at the weir. Immediate benefits to the whole catchment may not be so apparent.

Remaining Dryland Catchments

The data from the sub-catchment gauging stations indicates that after allowing for the storage at Eildon some 10-12% of the catchment's total annual diffuse source dryland phosphorus is generated in the Upper Goulburn catchment. Another 6-8% of the catchment diffuse phosphorus and 11-13% of the catchment diffuse nitrogen is generated from the mid-Goulburn catchment. Most of this is indicated to be generated from the headwaters of the streams in the Mid-Goulburn area.

The scant data for the Broken catchment indicates that some 9-11% of the catchment diffuse phosphorus and 11-12% of the diffuse nitrogen is generated in the upper (range) areas of the Broken River and Holland Creeks systems.

The data indicates that action to reduce diffuse nutrients should be targetted to the upper catchments of key stream systems such as those identified in Table 5.4.

CURRENT CODES OF PRACTICE

A review of current legislation and codes of practice that may be applicable to the control of nutrients in waterways indicates that the following are applicable for instigating or developing management of landuse or other activities that potentially generate diffuse sources of nutrients in the dryland catchment.

Parliamentary Acts/Legislation:

- State Environment Protection Policy (SEPP) Victorian Inland Waters (note that no catchment specific SEPP applies to the Goulburn Broken catchment or sub-catchments);
- State Environment Protection Policy - Municipal Landfills;
- (Draft) State Environment Protection Policy - Groundwaters of Victoria;
- Planning and Environment Act 1987, notably (through municipal) planning schemes (Section 6 of the Act) and statewide amendments to municipal planning schemes.
- Land Conservation (Vehicle Control) Act 1972;
- Catchment and Land Protection Act 1994, via the declaration of special areas, landuse conditions and issuing of land management notices (Parts 4 and 5 of the Act);
- Conservation, Forests and Lands Act 1987, under its general objectives (as outlined in Section 4 of the Act) and the development of codes of practice (under Section 5 of the Act);
- Water Act 1989 as per Sections 1(b), 1(d), 1(j) and 1(k) of the Act and via Sections 67 and 68 (Licensing Works), Section 107 (Environmental and Recreational Areas) and Part 10 (Waterway Management).

Codes of Practice/Guidelines

- Code of Forest Practices for Timber Production (DCNR)
- Construction Techniques for Sediment Pollution Control (EPA)
- Guidelines for Minimising Soil Erosion and Sedimentation from Construction Sites in Victoria (DCNR, formerly SCA). This text includes guidelines for minimising impacts from bare tracks.
- Septic Tanks Code of Practice.

It is the consultants belief that of these acts, codes and guidelines the most applicable to the minimisation of diffuse nutrient sources in the Goulburn-Broken Catchment are:

- Code of Forests Practice for Timber Production;
- Declaration of special areas under the Catchment and Land Protection Act; and
- Guidelines for minimising soil erosion and sedimentation.

Current landcare programmes by DCNR and DAV to improve farm management, and reduce soil erosion are also highly relevant, although the results of this study suggest that targeting upper catchment agricultural areas will bring about more nutrient benefits.

It is noted also that the Code of Forest Practice, while attending to such issues as minimising soil erosion and degradation of water quality lacks the necessary detail to assist in achieving these aims. While it is understood that prescriptions are often appended to this code for different areas, these prescriptions may not be consistent across the catchment or may rely on minimal data or understanding of actual nutrient transport processes in the relevant catchment areas.

There is a need therefore to strengthen the technical aspects of erosion control within this code.

The siting of recreational reserves appears to be subject to considerations other than control of sediment loss and nutrient impacts. However it is recommended that the results of this study be drawn to the attention of the departmental planners involved so that consideration be given to controlling riverside activities in key catchment areas (eg. Big River and Murrindindi River).

It is also considered that the use of guidelines for minimising erosion from bare soil tracks in upper catchment areas be emphasised to a greater degree than is currently done to local shires, machinery/plant operators and forest managers.

In summary therefore, relevant guidelines and acts appear to be available to reduce impacts of sediment transported nutrients from both private and public land. Other minor diffuse sources and dryland point sources identified earlier (such as landfill, septic wastes etc.) are also covered.

It is the consultants belief however, that the level of understanding of detrimental impacts created by erosion and the remedial activities needed to prevent such impacts required is not well understood by those on the ground.

BEST MANAGEMENT PRACTICES

Agricultural Practices

The major mechanism for diffuse nutrients entering the waterways in this catchment has been identified as erosion. The main agricultural landuse identified as generating phosphorus loads is pastoral activities, in particular unimproved (i.e. native) pastures. Therefore, any management practices to reduce nutrients entering must incorporate erosion control techniques throughout the general catchment. To have the most beneficial impact, BMPs need to be directed toward pasture based activities as a first priority.

Those techniques must be robust enough to reduce the erosion risk in extreme events eg. 1973/74. In those years large quantities of soil moved to waterways which have acted as a sink for phosphorus release from sediments in later years.

The erosion control techniques need to be especially concentrated on the steeper areas (> 5% slope) of the catchment. These techniques include:

- Farm planning on the basis of land systems and land erosion classes;
- Maintenance of good soil cover, especially in periods of erosive rainfall (summer and autumn);
- Use of perennial pastures that can act as filters to trap sediment and adsorb overland flow, eg. phalaris, tall wheat grass;
- Maintain appropriate stocking rates on pasture areas;
- Remediation of existing erosion, especially gullied areas, that act as conduits for overland flow;
- Revegetation of marginal steeper slopes and hill tops.

Applicable erosion control techniques to reduce nutrient contributions from cropping areas are:

- Adoption of conservation tillage, including stubble retention; and
- Adoption of contour ploughing and/or cessation of cultivation practices in steeper slopes.

As detailed in Section 4.4, agricultural use of fertilisers is contributing only a very small percentage of diffuse nutrients. Broad scale modification of fertiliser management is therefore unlikely to have any significant benefit in reducing nutrient loads in the catchment waterways.

The majority of the erosion which directly impacts on the waterway systems is that which occurs close to the waterway itself. Pastoral management practices need to concentrate on these areas close to the streams with practices such as keeping stock away from streams in order to reduce:

- stream bank erosion and water overland flow inputs (ie. preferred pathways); and
- transfer of excrement nutrients directly into streams.

Another important practice that can be implemented is the creation of buffer strips (i.e. areas of no cultivation and minimum grazing), on both public and private land along stream courses. Buffer strips filter overland flow of sediment and adsorbed nutrients. They also serve to reduce direct agricultural impacts as described above.

Research completed by a number of workers (including those cited in the literature review, eg. Clinnick and Weston), have found that a width of 10 metres for buffer strips has proven to be effective in filtering sediment from overland flow. Up to an 80% reduction for a 1 in 10 year storm event was reported by Greenhill (1984). For potato cropping areas studied by Greenhill and Weston (1984) a reduction in phosphorous levels of about 70% was reported for a one in two year storm event of 52 mm in 12 hours. The effectiveness of buffer strips in higher intensity storm events that are considered to be the major sources of sediment and nutrients have not been reported.

For the pasture irrigation areas the best management practices would be as determined by the "irrigation study findings" that are being undertaken concurrently with this study by a separate consulting group.

For the horticulture (irrigated and non-irrigated) areas which are often on steep and very erodable soil adjacent to streams the "practical" practices include:

a) avoiding where possible row cultivation "up and down" the slope

b) using buffer strips at the bottom of the slope

c) collection and re-use of irrigation run-off

For the 100 dairies scattered throughout the "dryland" catchment it is also important that dairy wastes don't enter the streams. Similarly waste from wineries, piggeries, lawn farms and small scale intensive industries must not be allowed to enter the streams.

Forests and Public Land Management

Logging

As listed earlier, logging operations are carried out under the Code of Forest Practice. The practices listed in this code for minimising soil erosion and impact on the streams are consistent with worldwide practices for minimising soil erosion in any site involving soil disturbance, movement of machinery and construction of tracks.

It is considered therefore the most appropriate course of action to minimise the impacts of logging operations is to ensure compliance with the code. Additional education of both forest managers and logging contractors should be encouraged to ensure the importance of such practices is understood and complied with.

Recreational Access Tracks and Reserves

It is considered that the siting of recreational river reserves needs to take into account the following issues:

- prevention of stream bank erosion;
- maintenance of good ground cover;
- inclusion of buffer strips between reserves (especially camping areas) and waterways;
- possible restriction of numbers gaining access to riverside camp sites;
- installation of appropriate levels of toilet facilities on permanent camping reserves, with such facilities sited to prevent or minimise nutrient losses; and
- minimise vehicle access to stream banks.

While the need for access tracks for recreational/fire fighting is recognised, consideration needs to be made of the siting of tracks. It may be that restricted access should be maintained in critical catchment areas.

Similarly, it should be ensured that tracks are constructed to a suitable standard, with minimisation of erosion being a prime consideration.

Where tracks cross or approach waterways, side cut diversions should be directed into well vegetated areas to reduce sediment loads into the streams. Consideration should also be given to including more side cuts and diversions in the last 10 metres of any track approaching a waterway. It is also suggested that tracks should not approach waterways/drainage lines at right angles. This will avoid overland flow gaining direct, high velocity entry into the stream preventing bank erosion, and deposition of eroded material into the stream bed.

Fire Control

The use of fuel reduction burns has been noted as contributing to nutrient loads/erosion because of the removal of ground cover. It is noted however that far more serious erosion and nutrient export will occur following wildfire where all vegetative cover (both ground and canopy) is removed.

The trade off of small scale nutrient export events is considered acceptable when compared to the catastrophic nature of wildfire impacts. Control of nutrient exports is therefore seen to benefit from fuel reduction burns.

Water Supply Catchments

It has been noted that for at least two town water supply catchments (ie. Euroa and Violet Town) agricultural activities occur within the upgradient location of storages.

Based on the results of this study such land use is considered to be inappropriate. In particular, the overland transport of animal excreta into the storages after extended dry periods is considered to be a major contributor to poor water quality and nutrient loading.

It is recommended that for such water supply catchments, consideration be given to changes in upgradient land management including:

- maintenance of good ground cover at all times;
- maintenance of buffer strips immediately upgradient of storage areas;
- possible revegetation of upper catchment areas and removal of stock.

Benefits and Barriers

Nutrient Benefits

Quantification of actual nutrient benefits by implementation of the best management practices is considered to premature at this time, given the lack of available data. In particular data is lacking in the following key areas:

- lack of data regarding the reduction in nutrients by use of buffer strips under different land use scenarios;
- lack of relevant catchment data on actual nutrient loads emanating from a wider variety of sub-catchments and land use/land system area, including forestry tracks;
- an inability to predict adoption rates of best management practices;
- expected time lags of up to 20 years between implementation of BMPs and actual benefits; and
- in-stream dynamics of nutrient behaviour.

Despite the lack of solid data, this study has indicated with some confidence that the **average** annual level of nutrient contributions are in the order of 100 - 150 tonnes per annum of total phosphorus and 1600 - 2000 tonnes of total nitrogen.

It should be noted that actual nutrient contributions loads are in fact episodic, depending for the most part on rainfall and erosion events, particularly for phosphorus.

As a possible indicator of the order of magnitude of benefits from use of BMPs to reduce the nutrient loads it is suggested that over any one ten year period the majority, say 75%, of nutrients is due to a 1:10 year or greater storm event. Between such events, it is suggested that 1:5 year and 1:2 year storm events provide in the order of 15% and 10% of the long term nutrient loads, respectively.

Based on these assumed contribution rates, annual nutrient contributions could be derived from :

- 7 x 1:2 yr events producing the equivalent of 10% of long term average load, (10 - 13 tonnes for total phosphorus per event);

- 2 x 1:5 yr events producing the equivalent of 15% of long term average load, (21 - 25 tonnes of total phosphorus per event); and

- 1 x 1:10 yr or greater event of 75% long term average load, (95 - 116 tonne for total phosphorus per event).

Results from some field studies have suggested that buffer strips can reduce phosphorus loads by some 70% for 1:2 year events. Other erosion control methods may reduce losses by even more.

Adopting a range of reduction in loads for BMPs of 75% and 50% for both 1:2 yr and 1:5 yr events, it is estimated that the long term average loads can be reduced by 15 - 20%, i.e. a reduction of the ten year (annual) average to 100 - 120 tonnes per year.

These estimates also highlight the predominate role of episodic, high intensity rainfall events and the need to consider what management programs can be undertaken to manage these events, if at all.

It must also be kept in mind that the high intensity rainfall events and subsequent erosion will also induce greater levels of natural erosion. Consideration must also be given to determining what is the baseline, or "natural" nutrient inputs from the catchment which will remain outside the influence of BMPs.

In summary, the implementation of BMPs for dryland areas is difficult to quantify in actual terms of nutrient reduction/benefits. Possible long term reductions of between 10% to 20% may be achieved for BMPs that control the relatively lower levels of nutrient transport from more frequent, lower intensity storm events.

It should also be noted that reductions in nutrients will be in terms of future loads. Pre-existing stream nutrient loads, especially phosphorus held in sediment storage will continue to affect the stream quality for extended period, possibly up to 20 years.

The benefits of implementing BMPs for nutrient reduction should also be viewed in the context of :

- assisting in total catchment management with improvements in both land and water quality;
- reduction in current nutrient exports to catchment waterways and storages;
- long term reduction in nutrient loads to the catchment streams with resultant benefits in controlling algae blooms.

Barriers to Adoption

Past experience with a variety of land management programmes tell us all that the single greatest barrier to achieving management of diffuse source nutrients will be in changing the culture of <u>all</u> land managers.

Generally barriers to adoption are:

- failure to understand the processes;
- failure to understand a land manager's role;
- inability to grasp the importance of adopting new practices; and
- failure to develop an empathy and ownership of the problem.

It is therefore considered appropriate that the single most important task that can be undertaken to implement adoption of BMPs is a concentrated education programme aimed at tackling these educational issues.

At an estimated cost of $100,000 over two years, the appointment of a catchment education officer, and implementation of an education programme targeting key catchment areas previously defined is considered to be crucial to successful control of diffuse source, sediment derived nutrients.

KNOWLEDGE GAPS

During the completion of this study a lack of vital data was identified. Specific data gaps identified are:

(1) Insufficient gauging data for a broader range of catchment and land use areas. In particular more gauging data needs to be gathered for sub-catchments on the alluvial plains and in actively forested sub-catchment. Gauging data needs to include monitoring of phosphorus and nitrogen levels.

(2) A lack of long term stream flow data which covers high flow periods when it is suspected that the major erosion events occur.

(3) A lack of high frequency gauging data, (most data being only weekly or monthly).

(4) A lack of data on the impact of what have been termed dryland point sources, such as dairy farms, horticultural farms, irrigated farms and wineries that are sited adjacent to waterways.

(5) The influence of proposed best management practices, in particular the nutrient reductions from use of buffer strips. The effectiveness of the BMPs needs to be evaluated for a wide range of scenarios of landuse, land classes, rainfall events, and overland flow conditions.

(6) A lack of data regarding the pre-existing waterway conditions in relation to sediment loads and stored nutrients.

(7) An understanding of the in-stream nutrient dynamics, in particular, the large storages acting as major nutrient sinks and possible low level sources is not well understood.

With respect to the implementation of a nutrient strategy it is considered that the most critical areas requiring attention are points (1), (5) (6) and (7) above.

There is a real need to adopt activities aimed at addressing these gaps and understand the complex factors involved.

Costs of implementing programmes to evaluate these areas are difficult to estimate, but are likely to be in the order of:

- $100,000 - $150,000 over three years to evaluate BMPs.
- $100,000 - $200,000 over five years to evaluate current stream conditions, and evaluate in-stream nutrient dynamics.

These programs should involve:

- the establishment of gauging stations in targetted sub-catchments on the alluvial plains and other forested areas.

- the establishment of a field monitoring program to ascertain the site-specific sources of nutrients from the upper-mid catchment. Particular areas requiring attention are forestry roads, forestry roadside recreational reserves and logging areas, dryland dairy farms, and intensive agriculture and horticultural areas.

- the trialling of best management practices in a pilot sub-catchment area. Extensive monitoring will be required to ascertain the direct benefits in terms of nutrient reductions.

- stream and sediment sampling during a variety of flow conditions to ascertain current nutrient characteristics of the major waterways.

The completion of CSIRO studies similar to those completed for the Murrumbidgee, and Snowy River catchments are recommended in order to characterise the source of sediments in the streams. Firmer quantitative relationships between in-stream sediment loads and nutrient loads need to be determined.

Implementation of these programs will assist in developing better directed diffuse nutrient reduction strategies, in particular in assessing what BMPs should be encouraged, where the most strategic areas for implementing nutrient reduction strategies, enabling better quantification of nutrient benefits and, importantly, the expected costs and benefits from reducing nutrient loads.

ECONOMIC EVALUATION OF BMPs

Identification of Costs and Benefits

The study team note the following points when considering the economic cost/benefits of implementing BMPs:

- The basis for developing benefits in reduced nutrient exports to the waterways are at best tentative. A greater level of long term data across a wider range of sub-catchments is required to refine the estimates of nutrient export and target areas of major dryland (diffuse) sources.

- Costs for implementing the BMP program include -

    - $100,000 over two years for a catchment education program;
    - $100,000 - $ 150,000 over three years to evaluate BMPs;
    - $100,000 - $ 200,000 over five years to evaluate current stream conditions and in-stream nutrient dynamics.
    - monetary or in-kind provisions to land managers for implementing erosion control measures.

- Reduction in nutrient loads (based on total phosphorus) are likely to be only of the order of 10% to 20% for true diffuse sources, due to reduction of sediment transported nutrients. These reductions are estimated to be in the order of 10 to 30 tonnes per year.

  The most significant loads into the system for diffuse sources are likely to be due to sporadic periods of high rainfall and erosion and are unlikely to be controlled by proposed land management practices.

- Benefits for reductions in erosion (i.e. sediment transported nutrients) will have benefits to landholders and land managers, including:

    - reduced cost for repair of damaged land;
    - reduced maintenance costs (for tracks/roads);
    - improved soil and crop conditions.

- Costs to land managers can include:
  - loss of productive land for buffer strips;
  - increased cost for re-alignment of tracks and installation of silt traps and buffer strips;
  - loss of income from reduced forestry areas;
  - capital cost for fencing of river frontage and installation of stock watering systems;
- Estimating actual costs and benefits to the land managers for implementing BMPs is considered to be too site specific for the purposes of this study. Consideration to such an evaluation may be achievable on a sub-catchment basis, once specific areas can be targeted for nutrient reduction programs.

Potential costs and nutrient benefits for implementing BMPs have been prepared as a basic guide to assist in future decisions regarding the nutrient strategy. Details of costs and benefits are outlined in Tables 9.1 and 9.2 (agriculture and forestry respectively). The costs for implementing the BMPs have been derived from a recent literature review completed on behalf of the NSW EPA for control of phosphorus discharges.

Reduced nutrient load generation rates have been based on a possible reduction range of a maximum of 80% for short term, low intensity rainfall/erosion events and 20% for long term average loads which take into account periodic high intensity rainfall events (refer Section 7.3.1).

Table 9.1
Costs and Benefits of Implementing BMPs - Agriculture

Landuse	BMP Activity	Expected Reduced Nutrient (Phosphorus) Generation Rate (kg/ha/yr)	Costs ($'s)		Estimated Catchment Phosphorus Land Reductions (tonnes/yr)
			Establishment	Annual Operating	
Unimproved Pasture	Pasture improvement[1]	0.02	$120/ha	$20/ha	2 - 10
	Buffer Strips	0.08 - 0.03	$1460 - $2700/ha	$230/ha	2 - 10
Improved Pasture	Buffer Strips	0.016 - 0.006	$1460 - $2700/ha	$230/ha	1 - 4
Cropping	Conservation tillage	0.016 - 0.006 for mid to lower catchments	$28/ha	N/A	0.2 - 0.6
	Diversion banks		$120/ha	$35/ha	
	Grassed waterways	0.08 - 0.03 for upper to mid catchment	$50 - $100/ha	$35/ha	
	Simple buffer strips		$130 - 1000/ha	$250/ha	
	Complex buffer strips[2]		$1560/ha	$240/ha	

Notes: (1) Cost figures based on planting of perennial pasture, and excludes fencing and/or extra livestock requirements. (Derived from Goulburn Broken Dryland Salinity Management Plan)

(2) Includes use of trees in buffer strip.

Table 9.2

Costs and Benefits of Implementing BMPs - Forested Areas

Landuse	BMP Activity	Expected Reduced Nutrient (Phosphorus) Generation Rate (kg/ha/yr)	Costs ($'s)		Estimated Catchment Phosphorus Land Reductions (tonnes/yr)
			Establishment	Annual Operating	
Native Forests	Buffer Strips[1]	0.016 - 0.006 for mid-lower catchment	$5 - $10/ha	$30/ha	Between 1-4 tonnes/yr for mid-lower catchment
Plantation Forests	Buffer Strips	0.03 - 0.12 for upper-mid catchment	Nil	$990/ha	
All Forests	Relocate Roads		$2600/ha	N/A	Between 19-64 tones/yr for upper-mid catchment

Notes: (1) Based on 40 m wide strips.

Economic Analyses

Unit costs for reduction of phosphorus have been developed to provide an indication of the most cost effective measures.

The unit costs have been developed on the following assumptions:

- net present values have been calculated on the basis of a 30 year planning life;
- implementation programs begin and end in the first year;
- a base discount rate of 8% applies over the 30 year life (sensitivity testing at 4% and 10% were also applied);
- the costs of completing nutrient load reduction works can be accurately estimated on the basis of available data;
- the costs as presented are net costs after costs and benefits to the land manager have already been accounted for; and
- reductions in nutrient loads will begin immediately after implementation.

Clearly some of these assumptions are difficult to validate and comparison of unit cost reductions must be tempered with professional judgement.

In particular it should be noted that not all programs can begin and end in year one, and that nutrient reductions will not begin immediately after implementation. Current data indicates reduction in diffuse source nutrients may take up to ten years or more.

Table 9.3 presents the results of the unit cost reduction analysis. More details are provided in Appendix D.

Table 9.3
Estimated Annual Cost of Unit Nutrient Reduction

NPV per Kg P Removed	Unimproved Pasture		Improved Pasture			Cropping			Forests
	Pasture Improve-ment	Buffer Strips	Buffer Strips	Conservation Tillage	Diversion Banks	Grassed Waterways	Simple Buffer Strips	Complex Buffer Strips	Buffer Strips
@ 8%	$6,768	$3,490	$4,141	$1,201	$236	$1,514	$5,091	$5,867	$99
@ 4%	$9,414	$4,830	$5,731	$1,247	$342	$2,226	$7,297	$8,102	$155
@ 10%	$5,952	$3,076	$3,650	$1,179	$203	$1,297	$4,415	$5,176	$82

These results indicate the cost effectiveness of targeting nutrient management strategies at the forested catchments, where for low capital and operating costs, effective impact on a large proportion of the diffuse phosphorus loads may be controlled.

Application of the Economic Analysis

The development of the unit costs for reduction of phosphorus was, by necessity, completed on a regional scale basis. A number of gross assumptions, as outlined, were required in order to accommodate the style of economic analysis required.

In particular it is noted that in order to develop costs of implementing nutrient reducing programs, gross assumptions were required to be applied to the extent of works to be completed. For some programs, such as realignment of forests tracks, the detail required for this analysis is clearly beyond the current study brief. Developed costs of programs may be in error by a factor of up to 100%.

It is stressed therefore that the unit cost reductions are applicable only for a regional comparison of other nutrient reduction programs.

Refined economic analysis for more localised programs could only be completed after a number of assumptions can be verified. In particular data is required on:

- actual nutrient load reductions, in particular for nitrogen as well as phosphorus;
- net costs can be verified; and
- more detailed analysis of program costs can be completed.

REFERENCES

NSW EPA (1994) "Point/Non Point Source Trading to Reduce Phosphorus Discharges: Literature Review" Environmental Economic Series.