Government of **Western Australia**
Department of **Water**

Hardy Inlet water quality improvement plan

Stage one – the Scott River catchment

Looking after all our water needs

August 2012

Hardy Inlet water quality improvement plan

Stage one – the Scott River catchment

Looking after all our water needs

Department of Water

August 2012

Department of Water
168 St Georges Terrace
Perth Western Australia 6000
Telephone   +61 8 6364 7600
Facsimile   +61 8 6364 7601
National Relay Service 13 36 77
www.water.wa.gov.au

August 2012

ISBN 978-1-921907-24-1 (print)
ISBN 978-1-92-1907-25-8 (online)

Acknowledgements

The Department of Water would like to thank Kirrily White compiling and writing the document and the following people for their contribution to this publication: Joel Hall, Vanessa Forbes, Joanna Hugues-Dit Ciles, Kath Lynch, Breanne Brown, Don Bennett, Martin Staines, David Weaver, Rob Summers, Karen Rebuck and Merryn Delaney.

Reference details

The recommended reference for this publication is: White, KS 2012, *Hardy Inlet water quality improvement plan: Stage one – the Scott River catchment;* Department of Water, Western Australia.

For more information about this report, contact Kath Lynch, Busselton District Manager.

Cover photograph: Hardy Inlet and Augusta from the air (Simon Neville, 2010).

Disclaimer

Contents

Figures

Tables

Summary

This water quality improvement plan is essentially an investment plan to provide for the long-term improvement and protection of water quality in the Hardy Inlet. The inlet is a highly valued estuary, both socially and ecologically. It provides important habitat for migratory and resident waterbirds and is extensively used for recreational fishing, boating and ecotourism. As land use in the estuary's lower catchments has intensified during the past decade, symptoms of nutrient enrichment have emerged in the inlet. Algal blooms and fish kills have occurred more regularly and community concern about the inlet's health has been growing.

The estuary receives flow from the Blackwood and Scott rivers, the smaller Westbay and Turnwood creeks and the local drains of the Augusta townsite. The first stage of this plan is focused on managing the largest source of phosphorus load to the inlet: the Scott River catchment. Subsequent stages will address other key sources of nutrients to the inlet, including those delivered by the Lower Blackwood catchment and the Augusta townsite.

This plan brings together current scientific knowledge of the Hardy Inlet's water quality status for the purposes of nutrient management planning. Water quality monitoring and modelling by the Department of Water have been used to provide information on the sources of nitrogen and phosphorus from the Scott River catchment. The nutrient reductions required to alleviate the current water quality problems in the Hardy Inlet (particularly in the upper inlet near Molloy Island) have been identified and nitrogen and phosphorus concentrations and load targets for the discharge point of the Scott River into the Hardy Inlet established (presented below). These targets equate to a 28 per cent reduction in phosphorus load and no further increase in nitrogen load.

Nutrient	Winter median concentration (mg/L)		Average annual load (t/yr)	
	Current status	Target	Current status	Target
Total phosphorus	0.15	0.10	11.2	8.1
Total nitrogen	1.0	1.0	78.1	78.1

Water quality monitoring and modelling have identified that most of the current phosphorus load from the Scott River catchment is derived from diffuse agricultural sources. Nutrient sources on Molloy Island, such as septic tanks, are minor and unlikely to be substantially contributing to the existing water quality problems.

Improving fertiliser management through soil and tissue testing and modifying current fertiliser applications is predicted to substantially reduce phosphorus loads from the Scott River catchment. Combined with other options including riparian management and upgrading of dairy effluent systems, it is estimated that water quality targets can be met.

Meeting the phosphorus-load reduction target will require a comprehensive approach involving a range of management actions. The plan outlines 12 recommended management measures (presented below). The first three are identified as being of critical importance; that is, they require immediate implementation.

Critical management measures

1 Implement best-practice fertiliser management across the catchment

2 Investigate and mitigate farm-scale nutrient hotspots in the catchment

3 Carefully evaluate proposals for further intensification of land uses in the catchment to ensure that achieving the water quality improvement plan targets is not jeopardised

Other management measures

4 Develop and implement a rural drainage management plan for the Scott River

5 Develop and implement a river action plan for the Scott River

6 Assess and upgrade effluent management at dairies in the catchment

7 Undertake paddock-scale trials of soil amendment

Further research requirements

8 Undertake priority research projects to improve knowledge about the Hardy Inlet system and how best to manage nutrients in the catchment

Planning

9 Develop stage two of the *Hardy Inlet water quality improvement plan*

Monitoring and review

10 Undertake ongoing water quality monitoring in the catchment

11 Review progress towards implementation of management actions and water quality targets after five years

Implementing the water quality improvement plan

12 Establish a governance structure, led by the Department of Water, to implement the water quality improvement plan across various state government agencies, local government, industry bodies, natural resource management organisations and the community

The above management measures are integrated within specific recommendations for each agricultural industry. The plan's implementation strategy details the actions required under each management measure, which organisation is responsible for implementing the management measure and, where possible, the estimated associated capital costs. Specific information about individual management measures is also provided to guide implementation.

The Hardy Inlet is a highly valued south-west estuary and substantial natural values remain in the Scott River despite the intensification of agriculture and increased water use. It is anticipated that implementation of this plan will lead to an improvement in the ecological condition of the river and inlet, contribute to the inlet's long-term protection and improve water quality and water use efficiency in the Scott River catchment, while also facilitating sustainable agricultural production in the catchment.

The recommendations in the investment plan will be implemented as funding becomes available, through a variety of funding programs including the State NRM program (especially for the Fertiliser Partnership components), as well as through individual and agency actions not dependent on funding.

1 Introduction

1.1 The need for a water quality improvement plan

The Hardy Inlet is an iconic estuary valued by many for its exceptional beauty, ecological values and recreational opportunities. The inlet is one of only two large permanently open estuaries on Western Australia's south coast, and is an important nursery for marine finfish. Resident and migratory waterbirds feed and seek refuge around the inlet, and a wide variety of aquatic fauna and plants are also supported (DEC 2006). Over the years a growing number of families have enjoyed the shelter of and easy access to the inlet, leading to its popularity for recreational fishing. Ecotourism ventures such as river cruises, as well as houseboats and waterfront holiday accommodation, have also thrived on and around the inlet. The inlet's health is intrinsic to the lifestyles of many residents from the communities of Augusta and Molloy Island and supports very high economic, social and environmental values. The long-term protection of the estuary's water quality is vital if such values are to be preserved for future generations.

During the past decade the Hardy Inlet has started to show signs of nutrient enrichment (Forbes, in press). Intensification of land use in the lower catchments during the past 20 years has led to a higher load of nutrients from agricultural sources, such as fertilisers and animal waste, in addition to urban runoff. To retain economically viable industries, farmers in the catchment have needed to respond to market-driven changes. Where water has been available, these changes have seen many low-intensity dryland grazing properties move to higher-intensity irrigated agriculture, originally for horticulture (mainly potatoes) and more recently for irrigated dairy. A substantial increase in the number of blue gum plantations has occurred in the catchment, as well as growth of the Augusta townsite. While these changes to the rural and urban landscape have brought important economic growth to the area, they have contributed to the declining water quality. Potentially toxic cyanobacteria blooms (*Lyngbya*) have been reported in the inlet since January 2005 and are now a regular summer occurrence (Forbes, in press). Low oxygen concentrations within the water column have contributed to fish kills in the inlet (Kitsios 2007) and the local community has expressed concern about the decline in water quality, particularly in the lower inlet where increased blooms of the filamentous green algae *Cladophora* and *Enteromorpha* have occurred (Forbes 2010). Without management these issues may become widespread and regular incidences. Future plans for further intensification of agricultural land uses in the Hardy Inlet catchment need to be carefully evaluated since these water quality issues have the potential to be exacerbated.

1.2 Catchments of the Hardy Inlet

The Hardy Inlet drains nearly 23 000 km^2 of land. A large proportion of the flow and nutrient load delivered to the estuary is derived from the high-rainfall areas of the Scott River and Lower Blackwood catchments (Figure 1.1). For the purposes of this plan, the area referred to as the Lower Blackwood catchment also includes the catchments of Westbay and Turnwood creeks and the Augusta townsite.

While the Upper Blackwood catchment comprises a very large area of land, much of it is located in the low-rainfall areas of the Western Australian wheatbelt where little flow is generated. High-rainfall components of the catchment, such as the areas downstream of Bridgetown and Nannup, are associated with large areas of native vegetation such as state forest. The high proportion of native vegetation in these areas has further minimised the proportion of nutrient load delivered to the Hardy Inlet from this area of the catchment.

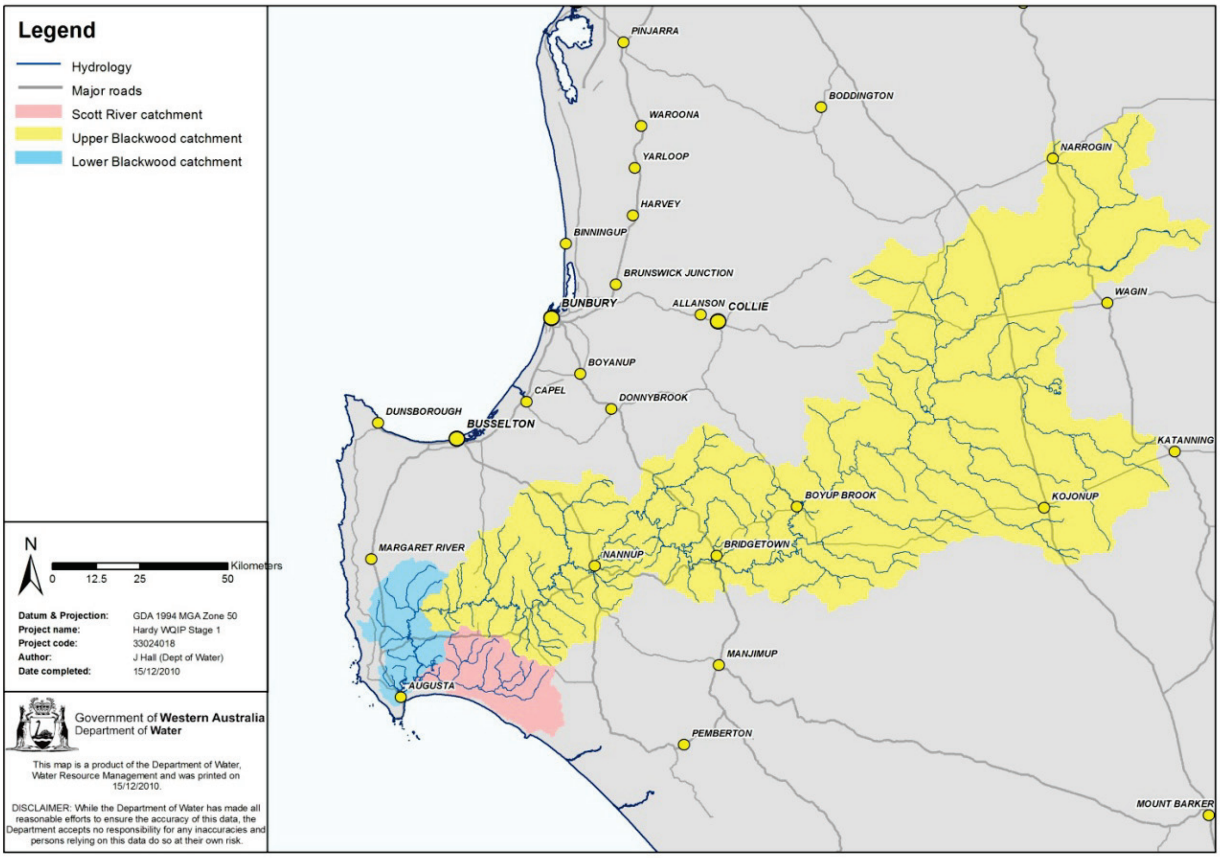


Figure 1.1 The catchment of the Hardy Inlet

1.3 A staged approach

In recognition of the Hardy Inlet's important values and recent decline in water quality, the Government of Western Australia has funded the development of this stage-one water quality improvement plan for the Hardy Inlet, with a focus on the Scott River catchment. It is envisaged that water quality planning for the Lower Blackwood catchment will follow as the second stage of this plan, encompassing the catchments of the Lower Blackwood River, Westbay and Turnwood creeks and the Augusta townsite.

The following factors have led to the selection of the Scott River catchment as the focus of this stage-one plan:

- The Scott River catchment contributes a disproportionate share (based on monitoring data) of the phosphorus load to the Hardy Inlet when compared with the rest of the catchment. Phosphorus contribution from the Scott River catchment accounts for 60 per cent of the load to the Hardy Inlet, while comprising only three per cent of the catchment area (Forbes 2010).

- Water quality monitoring has been undertaken in the Scott River catchment fortnightly for 10 years and land use data have recently been updated. In contrast, a significant data collection and collation task is required to enable planning for other areas of the Hardy Inlet catchment.
- There are a small number of land uses and landholders in the Scott River catchment. This is likely to lead to efficiencies in achieving nutrient management action on the ground.
- A good working relationship has already been established with key industry and natural resource management groups in the Scott River catchment.
- The Scott River catchment supports important economic and social values, thus the long-term sustainable development of agriculture in the catchment is a key priority.

This staged approach has enabled the water quality planning process for the Scott River catchment to start immediately, using currently available resources and data. Figure 1.1 displays the catchment of the Hardy Inlet, including the wider Blackwood catchment, Scott River catchment (stage-one area) and Lower Blackwood catchment (stage-two area).

1.4 Overview and aims

This plan provides a strategic approach to reducing nutrients delivered to the Hardy Inlet from the Scott River catchment. The management practices described here have been selected for the local area using empirical models based on current knowledge and data verified by field measurements. The plan's aim is to provide clear and achievable advice about the best-possible mix of management tools to meet load reduction targets for nitrogen and phosphorus from the catchment for the next decade and beyond. Many of these tools (best-management practices) have previously been described in the water quality improvement plan for the Vasse-Geographe catchment (DoW 2009) and have been updated or refined for application in the Scott River catchment.

It is anticipated the plan's recommendations will help governments and the community to achieve the long-term protection of water quality in the Hardy Inlet, while maintaining sustainable use of the wider Scott River catchment.

1.5 Stakeholder engagement process

Engagement with stakeholders likely to be involved with nutrient management initiatives in the catchment began early in the plan's development phase. An advisory committee comprising community, government and industry representatives was formed to oversee the plan's development. The advisory committee included representatives from the:

- Department of Water
- Department of Agriculture and Food (DAFWA)
- Shire of Augusta–Margaret River

- Lower Blackwood Land Conservation District Committee (LCDC)
- Scott River Growers Group
- Blackwood Basin Group
- the local community
- industry representatives for dairy and blue gum plantations.

1.6 Guiding principles

Three guiding principles underpin the recommendations presented in this plan. These are:

1. **Sustainability of industries**

   Management measures should aim to enhance the sustainable development of both the agricultural and ecotourism industries in the catchment. To this effect management measures should be both economically viable and effective at reducing nutrient export from the catchment. Every effort should be made to develop new methods to continually improve the sustainability of industries in the catchment.

2. **Management of nutrients at source**

   Nutrients will be managed on-site (‘on-paddock’ or ‘on-farm’) as a first priority, in recognition of the efficiency of this approach and the principles of the treatment train (work from farm outwards).

3. **Restoration and preservation of biological function**

   Management measures will provide for integrated management of the Hardy Inlet and Scott River systems to preserve their natural integrity, in acknowledgement of this plan’s wider aims. To this end – in the restoration of viable biological function within the river and inlet systems – the management of sediment, pesticides and herbicides will be also considered when choosing and prioritising recommendations.

2 The Hardy Inlet

2.1 Location and features

The Hardy Inlet is a relatively small estuary of approximately 9 km^2 area located at Augusta on Western Australia's south coast. The inlet drains nearly 23 000 km^2 of land from the combined catchments of the Blackwood and Scott rivers, and the smaller Westbay and Turnwood creeks. The inlet discharges to Flinders Bay via a long entrance channel (DEC 2006).

An aerial view of the inlet is shown in Figure 2.1 and its key features illustrated in Figure 2.2. Molloy Island is located near the mouths of the Scott and Blackwood rivers. The island has been developed for lifestyle housing but retains a significant proportion of native vegetation. To the east and south of Molloy Island are the Molloy-Scott basins. These basins are connected to the main body of the inlet via narrow channels running either side of Molloy Island. Thomas Island is smaller, undeveloped and located further downstream in the centre of the widest part of the inlet. A fluvial delta runs between the two islands. Further downstream the inlet narrows to a channel as it flows past Augusta and then the entrance channel narrows further as it reaches the mouth at Flinders Bay. To the north-east of the entrance channel is Swan Lake. Before the 1920s this lake was fresh, but it became brackish after the channel failed to develop a sandbar and salt water entered the lake. Another lagoon known as the Deadwater was once located between Swan Lake and the entrance channel, but this disappeared as the channel migrated eastwards over time (Brearley 2005).

Figure 2.1 Aerial view of the Hardy Inlet and Augusta (photo: Simon Neville)

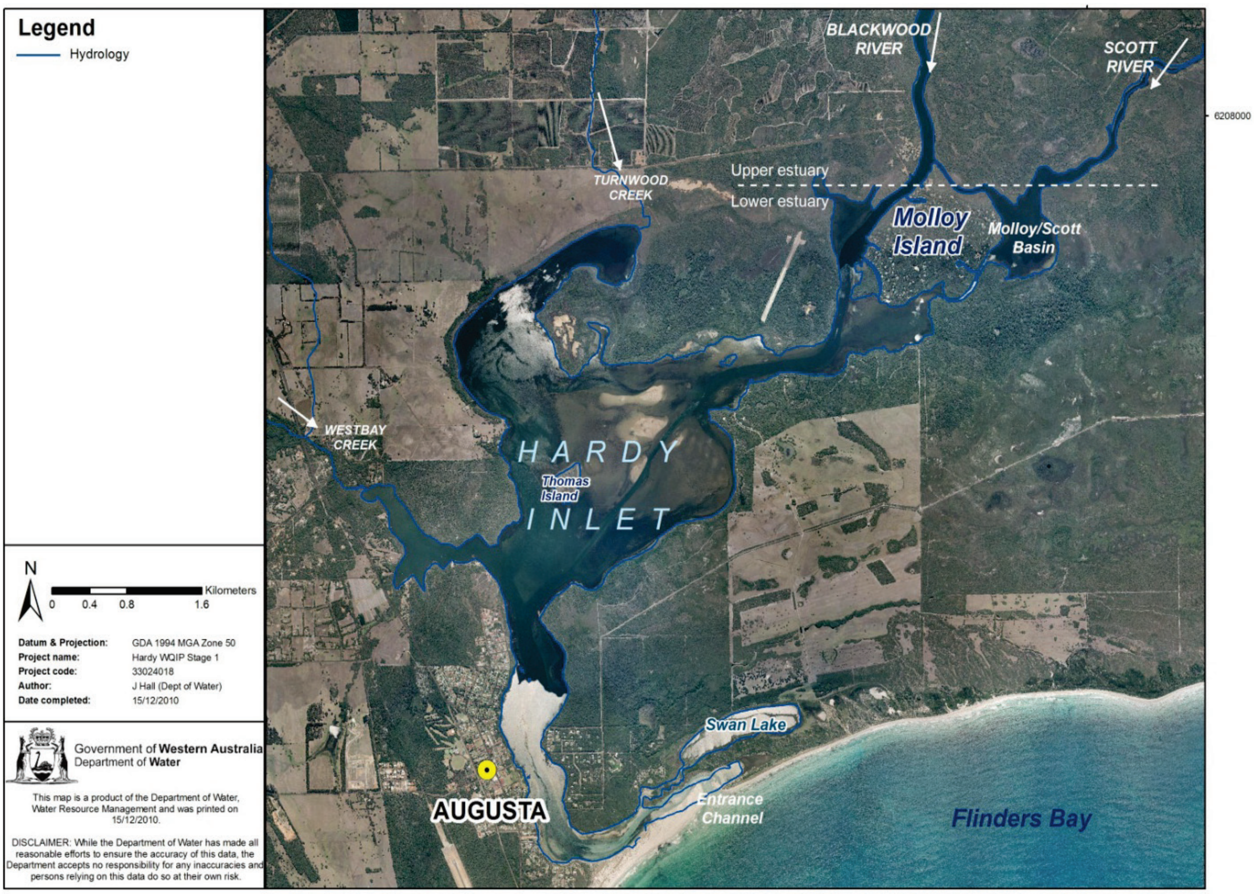


Figure 2.2 Key features of the Hardy Inlet

2.2 Landscape and geomorphology

Most of the Blackwood catchment, referred to as the middle to upper catchment, is located east of the Darling Scarp (Figure 2.3). The upper catchment lies in the low-rainfall wheatbelt area, with the boundary some 300 km inland from the coast, east of Kukerin and Nyabing. This area is characteristically flat, occupying broad floored valleys and salt lake systems. This area drains internally to the lakes and only contributes to the Blackwood River when Lake Dumbleyung overflows. Such an event is very rare and is believed to have occurred only three times in the past 100 years (Kelsey 2002). The middle catchment crosses the Darling Scarp where the topography is higher and the depth of the river valley increases to the west. Geologically the middle to upper catchment is underlain by a broad and ancient plateau known as the Yilgarn Craton. This plateau is mainly comprised of highly weathered granite and gneiss with numerous dolerite dykes and faults (SWCC 2005).

West of the Darling Scarp, most of the Lower Blackwood catchment and the Scott River catchment lie on the Perth Basin. The Perth Basin consists predominantly of sedimentary rock such as sandstone, siltstone, mudstone, claystone and, in places, coal (SWCC 2005). Within this region the Lower Blackwood River and its tributaries drain the Blackwood plateau while the Scott River drains the Scott Coastal Plain (Kelsey 2002).

The smaller Westbay and Turnwood creeks and a portion of the Lower Blackwood River also drain the Leeuwin Complex, which bounds the south-west margin of the Perth Basin. The

Leeuwin Complex occupies the Leeuwin-Naturaliste Ridge and consists of metamorphic rock beneath a laterite plateau (SWCC 2005).

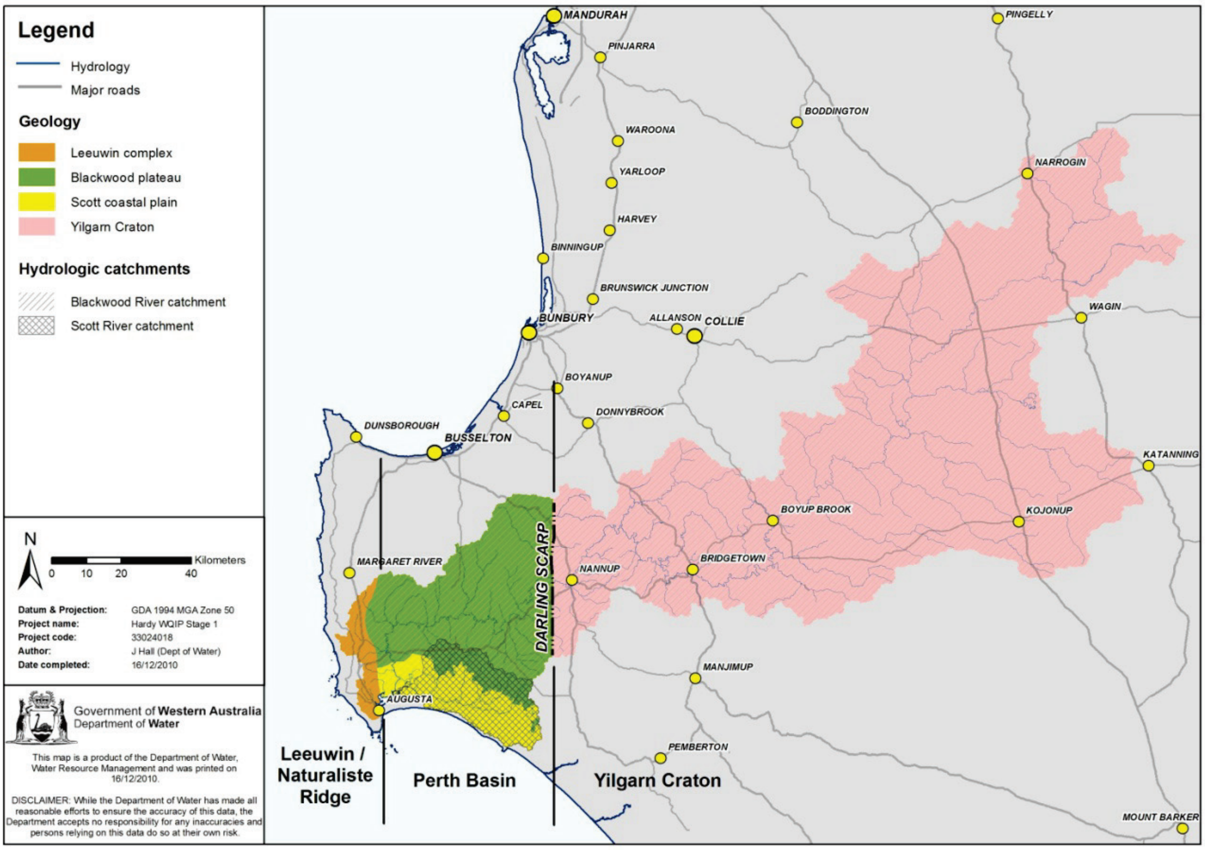


Figure 2.3 Geology of the Blackwood and Scott river catchments

2.3 Ecological values

Waterbirds

The Hardy Inlet provides rich and varied habitats for waterbirds and is among a number of important summer refuge areas in the state's south-west. Fifty-seven resident and migratory waterbird species have been recorded on the estuary, including 18 species that migrate from the northern hemisphere each year to feed during spring and summer (Brearley 2005). Pelicans live in the estuary for much of the year except during their nesting season from March to August when they migrate north. The balance comprises local migrant species that arrive as inland waters recede (e.g. black duck, black swan), winter visitors (e.g. white egret) and residents of the estuary (e.g. cormorants, gulls).

The various waterbird species favour different areas of the estuary depending on the availability of their food preferences. The tidal flats covering large areas of the inlet, Molloy basin and Swan Lake (and previously the Deadwater) are important feeding grounds for migratory waders (Brearley 2005). These birds feed on invertebrates from within the shallow sediments. Seagrasses growing in slightly deeper areas that are permanently inundated are important for the black duck, musk duck and grey teal. Black swans feed on even deeper seagrass meadows (about one metre), consuming huge quantities of *Ruppia* each day and congregating where the seagrass is most dense, such as at Swan Lake (Brearley 2005). Cormorants and gulls feed on fish and therefore use the deeper and open water zones of the estuary. Rush beds provide cover for little grass birds, swamp hens and white egrets while white ibis and white-faced heron feed among the samphire (Brearley 2005). The availability of each of these habitats and food resources depends on the maintenance of a healthy ecosystem within the estuary.

Aquatic fauna

The diversity of fish species found in the Hardy Inlet matches that of the waterbirds, with 57 species recorded in one survey during 1974–75 and 49 in a less extensive study in 1994 (Brearley 2005). The composition of species found varies with the seasonal changes in hydrology, with some species preferring fresh and others marine conditions. Common resident species that live their entire lifecycle in the estuary or associated river reaches include the black bream, south west goby, long-finned goby, hardy head and cobbler. Some non-resident species such as sea mullet and sand whiting are also present throughout the year, though in lower numbers during the winter when fresh water prevails due to high river flows. Others such as the southern garfish, old wife and flathead move out of the estuary entirely during this fresh phase (Brearley 2005). Most of the species found are predatory, feeding on a range of invertebrates in the estuary.

The inlet provides an important nursery habitat for marine finfish such as sea mullet, King George whiting and silver bream. These juveniles seek the shelter afforded by seagrass meadows such as those found in Swan Lake. Juvenile blue swimmer crab also shelter in the lower estuary during its marine phase (Brearley 2005).

Recreational fishing has long been a popular pursuit on the Hardy Inlet. Recreational anglers target black bream, western sand whiting and Australian herring (Prior & Beckley 2006). The single professional fishery operating in the estuary mainly takes whiting, mullet and small numbers of black bream and Australian herring.

The Hardy Inlet’s diverse invertebrate community is a vital component of the ecosystem, with most fish and waterbirds relying on these as their direct food source. Fifty-five species of invertebrates have been recorded in the estuary. The most common are species of worms, bivalves and snails (Brearley 2005). Others include polychaetes, amphipods, shrimps, crabs, echinoderms and nematodes (DEC 2006). As for other fauna, the invertebrate species each have clear habitat preferences with individual species preferring sand shoals, silts, aquatic plants, rocks or logs. Loss of these habitats would therefore have potentially widespread consequences on the estuary ecosystem.

A range of other fauna species also makes opportunistic use of the estuary and its shores. Bottlenose dolphins frequent deeper portions of the estuary, while frogs, lizards, snakes and small mammals such as the western ringtail possum can be found among the rushes and peppermint thickets that line the shore of the inlet.

Submerged aquatic vegetation and macroalgae

Five aquatic plants grow within the waters of the Hardy Inlet. These include the three seagrass species – eelgrass *Zoestera mucronata*, narrow paddleweed *Halophyla decipiens* and swan grass *Ruppia megacarpa* – which dominate the lower estuary. The freshwater ribbon weed *Potamogeton pectinatus* grows in the upper reaches around Molloy Island while *Lepilaena cylindocarpa* also grows sparsely throughout the estuary (Brearley 2005). Narrow paddleweed is found in very few estuaries, tending to favour deeper offshore locations.

The meadows of *Ruppia* and *Potamogeton* are a particularly important food source for black swans. There has been little change in *Ruppia* distribution except for the appearance of new areas of the species in the estuary channel (southern natural exit), which may have been established as a result of the calmer conditions created by low flows (Forbes 2006). *Ruppia* also plays an important nutrient buffering role in the inlet. It takes up inorganic nitrogen (such as nitrite/nitrate) via its leaves and roots, thereby reducing the availability of nitrogen for nuisance species of macroalgae and phytoplankton (Forbes 2010).

Macroalgae are a natural feature of the Hardy Inlet and provide important habitat and food for invertebrates and juvenile fish. Macroalgae are grouped according to their pigments into reds (rhodophyta), greens (chlorophyta), browns (phaeophyta) and blue-greens (cyanobacteria/cyanophyta). Some species of macroalgae grow attached to substrate such as rocks, woody debris or on the blades of seagrass. Others are free-floating and tend to accumulate in shallow areas where the actions of water movement and wind may transport them (Forbes 2010).

A range of marine species of macroalgae occur in the southern lower estuary where they are primarily attached to rocks in the shallows. Free-floating algae (*Chaetomorpha linum* and *Polysiphonia*) also occur in the channel that was the former Deadwater lagoon. The brown alga *Cystoseira trinodis* is found throughout a large area of the inlet (Forbes 2006).

Fringing vegetation

The Hardy Inlet's fringing vegetation is largely intact and in excellent condition. Various zones of riparian plants are present in many areas, with rushes such as juncus giving way to salt then freshwater melaleucas and flooded gums (*Eucalyptus rudis*), with jarrah (*Eucalyptus marginata*) and marri (*Corymbia calophylla*) occupying rises further up the bank (Brearley 2005). Many other south-west estuaries have lost components of these zones to land clearing. Fringing vegetation along the main Scott River channel is also largely intact. Notably, the preservation of large areas of riparian vegetation was made possible by the creation of a foreshore reserve when titles along the main river channel were created. This high-quality riparian vegetation plays an important role in maintaining river health and its ability to process nutrients. With the exception of the foreshore of Augusta and to some degree Molloy Island, the dense fringing vegetation gives the impression of an undeveloped catchment belied by aerial photographs that reveal the true extent of the clearing beyond these foreshore reserves.

2.4 Economic and social values

Aboriginal use of the Cape Leeuwin area dates back more than 50 000 years. Caves in the limestone ridge running between Cape Leeuwin and Cape Naturaliste (in particular Devil's Lair) show some of the earliest-recorded archaeological evidence of these early civilisations in Australia (Rigby 1995). Before European settlement the Aboriginal people of the south-west formed a socio-cultural group collectively known as the Nyungar (O'Connell et al. 1995). The group of Nyungar people that traditionally occupied the area of land between Cape Leeuwin and Bunbury were known as the Wardandi people 'the people that lived by the ocean and followed the forest paths' ('Wardan' meaning ocean) (Collard 1994). The Blackwood River, Yarragadee Aquifer and Milyeannup area are registered as sites under the *Aboriginal Heritage Act 1972* (WA). As for other wetlands and estuaries in the area, it is likely the Hardy Inlet and its shores provided an important summer source of food. Waterways in general also have particular spiritual importance to Aboriginal people.

Today the Hardy Inlet supports very high social and economic values. The inlet provides a combination of safe boating conditions, good recreational fishing and outstanding natural scenery. It also provides opportunities to experience sailing, canoeing, bird watching and wildflowers. Many visitors to Augusta and Molloy Island come to enjoy these activities, and accordingly the inlet is an important tourism drawcard. Ecotourism opportunities are popular and there are now two businesses operating river cruises on the inlet and one that provides houseboats for hire. The area's permanent residents also place a high value on the inlet: for many it is enmeshed in their everyday lives. Poor water quality in the inlet has the potential to adversely affect these economic and social values.

2.5 Hydrology

The Hardy Inlet has the highest discharge to the ocean of all south-west estuaries, with over double the discharge of the Swan-Avon system which has a catchment five times the size (Kelsey 2006). The Blackwood River accounts for 88 per cent of this flow, with most originating in the Lower Blackwood catchment where rainfall is greatest and groundwater flow is also contributed from the Yarragadee Aquifer. The Scott River contributes seven per cent to the total annual flow of the Hardy Inlet (Forbes 2010).

The shape of the Hardy Inlet near the mouths of the Blackwood and Scott rivers has an influence on the mixing of nutrients from these rivers with the wider estuary waterbody. Flow from the Blackwood River drains directly into the main body of the inlet where mixing and dilution of nutrients occurs rapidly. However, flow from the Scott River does not pass directly into the inlet's main basin. Water must first travel through a wider neck at the top of the inlet known as the Scott basin, where flow slows down and then makes its way through two narrow channels either side of Molloy Island. The position of Molloy Island and the slowing of water as it passes through the Scott basin both act to reduce the mixing of nutrient-rich water from the Scott River with the larger waterbody of the estuary (Forbes 2010). Hence there is less opportunity for dilution of nutrients from the Scott River with the waters of the estuary – due to a higher residence time in the Scott basin and around Molloy Island and increased deposition of sediment and organic matter in the restricted waters around the island.

The mouth of the Hardy Inlet is permanently open to the ocean, allowing tidal exchange of fresh water and salt water from the ocean. When salt water enters the estuary it forms a layer of salty water along the estuary floor (as salt water is denser than fresh water). This layering is referred to as 'stratification' and the salty bottom layer is called a 'salt wedge'. In the shallows the two layers are often mixed by the actions of wind and current, yet they remain separate in the deep zones of the estuary. The salt wedge prevails for much of the year in the deepest areas of the estuary, such as in the Blackwood estuary. Only very large river flows are capable of flushing and mixing water from these deepest pools. Oxygen levels can fall to critical levels at the bottom of these pools, leading to fish kills and foul odours.

2.6 Water quality issues

Serious water quality issues in the Hardy Inlet have emerged relatively recently. In particular, blooms of macroalgae have become more regular during the past decade. Blooms of the potentially toxic cyanobacteria (blue-green) species *Lyngbya aestuarii* have occurred upstream of Molloy Island every summer since 2005. In the lower estuary, increases in blooms of filamentous macroalgae such as *Cladophora* and *Enteromorpha* have been recorded close to the Augusta urban area. Further upstream, thousands of black bream died near the mouth of the Blackwood River in 2006 when decaying phytoplankton (microscopic algae) reduced oxygen levels in the water column (Forbes 2010). Bacterial activity within accumulated organic sediments in the deep pools of the Blackwood estuary, Westbay Creek and Scott basin contribute to low oxygen levels and the release of nutrients from sediments under anoxic conditions. The emergence and persistence of these issues demonstrate that water quality in the inlet is now in decline and requires urgent management.

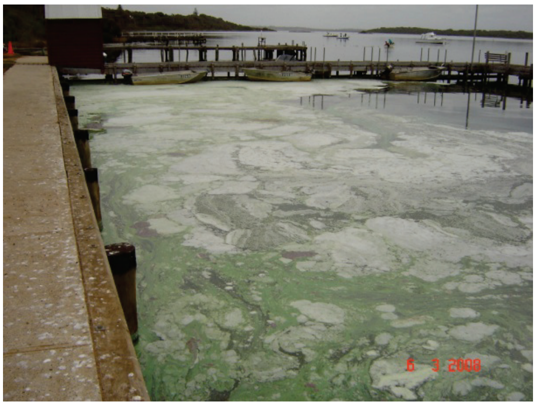
Various sources of nutrients are believed to be responsible for the different water quality issues, depending on their location. For example, filamentous green algae *Cladophora* and *Enteromorpha*, attached green algae *Ulva flexuosa* subspecies *paradoxa* and the red algae *Hinksia michelliae* have all been recorded in high abundance along the shallows near Augusta, where runoff is received from urban drainage. Given their location, it is likely that these species are responding to urban sources of nutrients such as urban fertilisers and leaking septic tanks (Forbes 2010). In contrast, the blooms of *Lyngbya* near Molloy Island are likely to be receiving direct nutrient contributions from the phosphorus-rich waters of the Scott River (Forbes 2010). Flow dynamics around Molloy Island are also believed to exacerbate this problem by reducing mixing and dilution of nutrients from the Scott River with the water from the main inlet basin. Algae respond directly to ambient nutrient concentrations in the water, so limitations to dilution via mixing can have a direct effect on algal growth in problem areas.

Phytoplankton (microscopic algae) are also natural components of aquatic ecosystems and many species are a food source for aquatic animals. Some species of phytoplankton are considered harmful and indicate deteriorating water quality conditions. Some of these species have been recorded in the Hardy Inlet, including dinoflagellates *Dinophysis acuminata*, *Gymnodinium complex* and *Prorocentrum minimum/Katodinium* sp., as well as cyanobacteria *Trichodesmium* and *Anabaenopsis* sp. (Forbes 2010). These species often respond to nutrient-rich water resulting from summer rainfall events. The presence of the marine dinoflagellate species *Dinophysis acuminata* is of particular concern, given it has been associated with diarrhetic shellfish poisoning (Forbes 2010).

In August 2010, concerns about water quality issues in the lower Hardy Inlet culminated in a controversial decision by the Shire of Augusta–Margaret River to artificially open the mouth of the Hardy Inlet in an attempt to increase flushing of the inlet. This issue is discussed further in Section 2.9. The Hardy Inlet's present water quality issues are summarised in Table 2.1.

Table 2.1 Summary of water quality issues recorded in the Hardy Inlet

Location	Issue	Example
Upstream of Molloy Island	*Macroalgal blooms* Growth of the potentially toxic cyanobacteria (blue-green algae) *Lyngbya aestuarii* near the top end of Molloy Island has been a regular occurrence since 2006. Such species are known to respond to elevated phosphorus. It is likely that phosphorus-rich water from the Scott River contributes to these blooms.	 Sampling a dense bloom of *Lyngbya aestearii* near Molloy Island
Lower estuary near the Augusta town site	Blooms of the filamentous green macroalgae *Cladophora* and *Enteromorpha* have occurred in the shallows of the lower estuary near boat ramps and drain outlets close to Augusta. These blooms are likely to be responding to elevated nutrients from urban fertilisers and septic tanks.	 Attached macroalgae growing in front of the caravan park at Colour Patch near the August townsite (photo: Merryn Delaney, Shire of Augusta–Margaret River)

Location	Issue	Example
West Bay and wider Hardy Inlet	*Phytoplankton blooms* Blooms of potentially harmful phytoplankton (microscopic algae) have been recorded in the inlet, but are infrequent. The presence of phytoplankton species in large numbers indicates a deteriorating system.	 Phytoplankton bloom at the Augusta jetty in 2008 (photo: Katie Biggs)
West Bay, Scott basin and the Blackwood estuary	*Low oxygen levels and nutrient release from sediments* Organic-rich sediments have accumulated in deep zones of the estuary at West Bay, Scott basin and the Blackwood estuary. Low oxygen conditions in these deep areas are caused by stratification combined with the activities of bacteria breaking down organic matter. Nutrients in the sediments are released under low oxygen conditions and made available for further algal growth.	 Sediment core collected in West Bay in 2008 (photo: Geoscience Australia)
Upper Blackwood estuary	*Fish kills* Thousands of black bream died in the upper estuary in 2006 when decaying phytoplankton reduced oxygen levels in the water column. In 2009 black bream were caught with lesions consistent with those caused by the pathogenic fungus *Aphanomyces*. It is not clear whether poor water quality has contributed to the presence of the fungus.	 Lesion on a black bream caught at the Augusta Jetty in 2009 (photo: Robb Gibbs)

Location	Issue	Example
Colour Patch	*Shellfish kills* In August 2010 an estimated 60 000 dead bubble shells (*Bulla quoyi*) washed up on the foreshore of the inlet with large numbers around Colour Patch, the East Augusta foreshore and along the mouth of the Hardy Inlet. Water quality and phytoplankton monitoring detected no potentially harmful algae species that may have contributed to the death of the shellfish. No definite conclusion as to why the deaths occurred was reached, however mass deaths of this species have been reported in the literature, associated with reproductive events or rapid changes in salinity (e.g. from a rainfall event).	 Bubble shells washed up on the foreshore near Augusta (photo: provided to Shire of Augusta–Margaret River by anonymous photographer)

2.7 Current water quality status

The Hardy Inlet's nutrient status varies considerably depending on the sampling location. Figure 2.4 illustrates the location of water quality sampling sites in the Hardy Inlet. Figure 2.5 illustrates the high concentrations of total phosphorus and total nitrogen measured at the mouth of the Scott River (SRFO1), in the Scott River basin (MIFO4) and in the channel next to Molloy Island,(MIFO3). The blooms of *Lyngbya* that have occurred in the Scott River basin (MIFO4) are likely to have responded directly to these high levels of phosphorus, given this species is known to respond to high phosphorus concentrations and organic loading. At the mouth of the Blackwood River (BRFO1), only total nitrogen is higher than guideline values. The concentrations of both nitrogen and phosphorus decrease markedly in the lower reaches of the estuary where tidal influences also contribute to further dilution of nutrients in the water column.

The red line on the graphs indicates the *Australian and New Zealand guidelines for fresh and marine water quality* (ANZECC guidelines) (ANZECC & ARMCANZ 2000). These guidelines were established to help identify the water quality objectives for maintaining current and future environmental values. Different guidelines have been developed for a range of water quality parameters – for various categories of rivers and estuaries – in different areas of the country. They are one of several tools to assess the ambient water quality of natural waterways.

During winter (high flow), nitrogen concentrations are above these guidelines at all sites except one located near the mouth of the inlet (site HIF01), but meet the guidelines during summer (low flow) throughout the inlet. The phosphorus concentrations in winter are well above guidelines at the mouth of the Scott River and around its basin, and to the west and south-west of Molloy Island (sites MIF101, MIF102, MIF103, MIF104, SRF101).

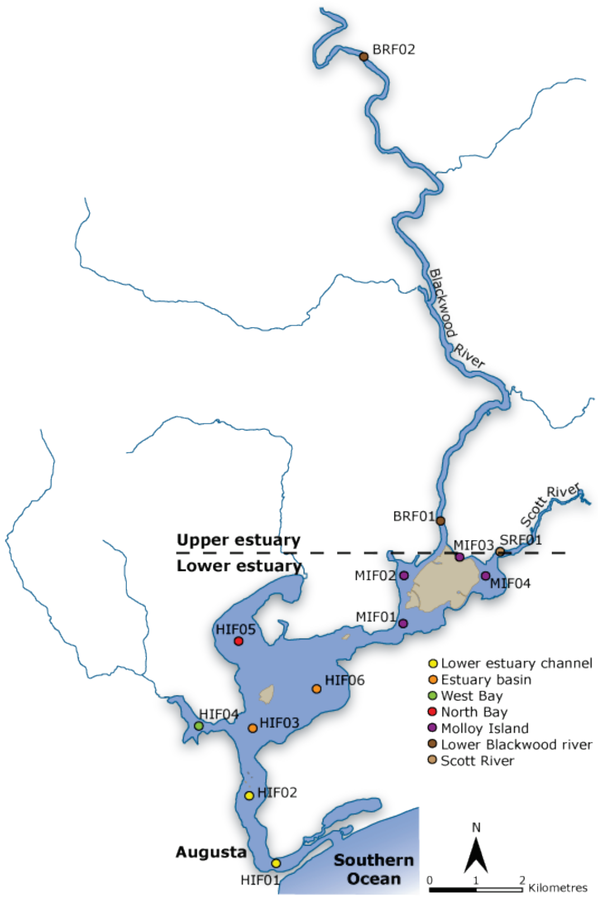


Figure 2.4 Water quality sampling sites in the Hardy Inlet (Forbes, in press)

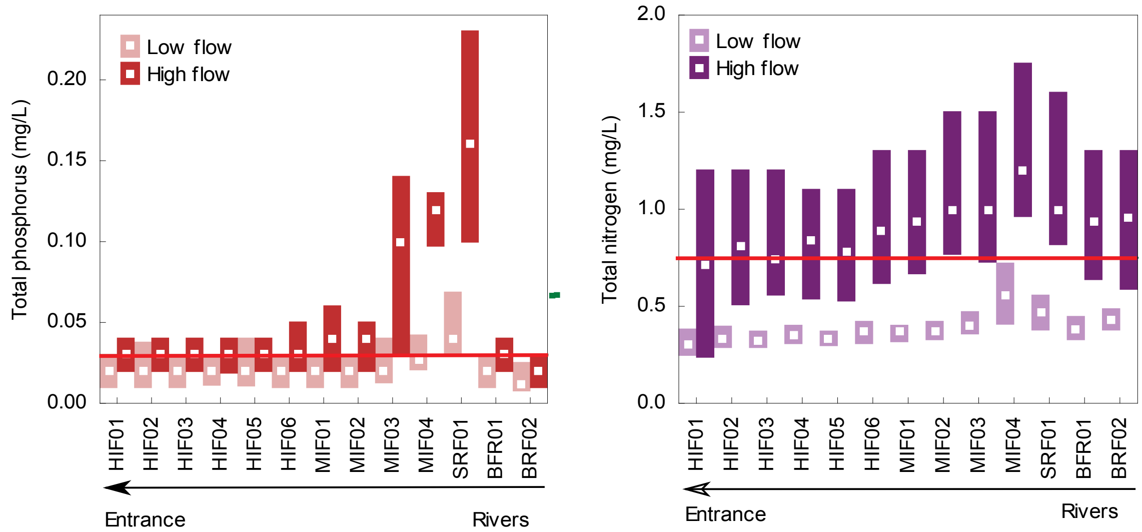


Figure 2.5 Surface water total phosphorus and total nitrogen concentrations during high (Jul-Sep) and low (Dec-Feb) flow periods in the Hardy Inlet between 2003 and 2009 (Forbes 2010). The coloured box plot shows the 80th to 20th percentile data range with the median shown by the small white box.

The mouth of the Scott River is the only site that exceeds the ANZECC guidelines for phosphorus during summer. Dissolved phosphorus measured as soluble reactive phosphorus (SRP) as a proportion of the total varies seasonally from a median of 23 per cent during summer to 65 per cent during winter.

The total load of a given nutrient is a function of flow and the nutrient concentration at the base of a particular catchment. Catchments with high concentrations of nutrients and high flows will generally contribute the largest overall load of nutrients. In contrast, high concentrations of nutrients and low flows (or vice versa) can lead to low to moderate loads of nutrients.

Water quality monitoring of the Hardy Inlet and Blackwood and Scott rivers has enabled nitrogen and phosphorus loads and flows from both river systems to be calculated. The Blackwood River contributes far more nitrogen than the Scott during summer (low flow) and winter (high flow) (Table 2.2). The situation is quite different for phosphorus. During winter the Scott River contributes the greatest share of phosphorus load, but during summer the Blackwood River contributes slightly more phosphorus than the Scott. The summer contribution of both nitrogen and phosphorus from the Scott River is very small since there is little to no flow at this time of year.

The concentrations of total nitrogen in the Scott River basin are comparable with those at the mouth of the Blackwood River. While the load of total nitrogen from the Blackwood is very large, the overall concentration is diluted by the large flows. Further dilution also occurs via mixing of water from the river and the wider inlet, a process obstructed in the Scott River basin by the presence of Molloy Island. The phosphorus load from the Scott is disproportionally large compared with the flow.

Table 2.2 Total nitrogen and phosphorus loads for the Scott and Blackwood rivers (note the relatively low flow of the Scott compared with the Blackwood)

Waterway	**Nitrogen (tonnes)**	**Phosphorus (tonnes)**	**Flow (GL, % total)**
Blackwood (June- Oct)	339	6.1	528 (87%)
Blackwood (Nov - May)	5.5	0.13	16 (97%)
Scott (June - Oct)	78	12.4	78 (13%)
Scott (Nov - May)	0.5	0.08	0.5 (3%)

2.8 Sediments and nutrients

Under healthy estuarine conditions phosphorus remains bound to sediment particles in the estuary, while nitrogen is converted to oxide forms by nitrification and lost from the system as N_2 gas via a process known as denitrification. When excessive build-up of organic matter occurs in deep pools, further reductions in oxygen concentrations can occur because of the bacterial activity working to break down the organic matter. Under prolonged and extreme low oxygen conditions (anoxic or hypoxic conditions) the nitrification process is prevented, leading to a build-up of ammonium in the pore water of the sediments (Forbes 2010). Anoxic conditions also cause phosphorus to be released from the sediment as a result of sulfate reduction, which also creates unpleasant hydrogen sulfide odours (Forbes 2010).

A recent study of the Hardy Inlet’s sediments found nutrients were being released from an accumulation of organic-rich sediments in the deeper waters of West Bay, the channel around Molloy Island and the Blackwood estuary (Forbes 2010). The study also showed the estuary had the capacity to bind phosphorus in the sediment over much of its area, thus reducing the availability of phosphorus for algal growth. In other words there is some capacity to accommodate phosphorus loading from the catchment. Ammonia release was common to all three areas but the high release of phosphate was more localised to West Bay, indicating a high organic loading of phosphorus in this area or possibly the phosphorus-binding capacity of these sediments being low (Forbes 2010). Further details about this process are provided in Forbes (2010).

2.9 The mouth of the inlet

The Hardy Inlet is one of only a few permanently open bar-built estuaries in south-west Western Australia. The location of the mouth of the estuary has been highly dynamic since it was first described at the time of European settlement in 1830. A detailed account of these changes is provided by Brearley (2005). Throughout a period of 175 years the mouth has migrated a number of times from a location close to Dukes Head and an eastward location some 2 km along the Flinders Bay shoreline. Changes to the Deadwater and Swan Lake have also occurred, as sand spits have been formed and breached by river flows and floodwaters.

Since many of the changes to the mouth of the inlet occurred before clearing of the catchment and artificial channel works, it seems likely there is no ‘natural’ or ‘original’ channel position (Brearley 2005). In the early days the combination of dynamic river flows, ocean currents and longshore drift combined to form a western spit near Dukes Head, which caused the migration of the inlet mouth eastward. High-flow events would have naturally breached the spit near Dukes Head, as may have occurred before the first records of the mouth location in 1930 (Brearley 2005). Subsequent low-flow years combined with changes brought about by grazing and drainage practices then led to the re-creation of the sand bar. The west–east migration of the mouth seems to have followed this pattern between 1925 to 1945 and 1983 to 2005 (Brearley 2005).

In more recent times river flows have been reduced as winter rainfall has declined in the Blackwood catchment. The reduction in flow has resulted in sediment deposition at the entrance, causing further eastward migration and narrowing of the mouth (Forbes 2010). Figure 2.6 illustrates the eastern location of the mouth in 2010. To the left of the entrance channel in this photo is Swan Lake.

In August 2010, community concerns about the lower Hardy Inlet’s water quality near the Augusta townsite culminated in the Shire of Augusta–Margaret River excavating an artificial entrance near Dukes Head. This attempt to improve flushing of the inlet was unsuccessful since flows from the inlet were insufficient to counteract the effect of the incoming tide, which caused the ocean end of the channel to fill with sand. The dredged entrance was re-established in 2011 but the main flow passed through the natural opening.

Further attempts to improve flushing of the inlet by similar means are unlikely to be successful, since strong river flows resulting from increased rainfall is the primary mechanism for flushing of the inlet.

Figure 2.6 The mouth of the Hardy Inlet in 2010 (photo: Brian Combley)

3 The Scott River catchment

3.1 Location and subcatchments

The Scott River catchment has an area of 691 km^2 or approximately three per cent of the total estuary catchment. It is divided between the Shire of Augusta–Margaret River in the west and the Shire of Nannup in the east. The catchment area referred to in this plan includes land draining to the Scott River and Molloy Island, which is located downstream from the mouth of the river (Figure 3.1).

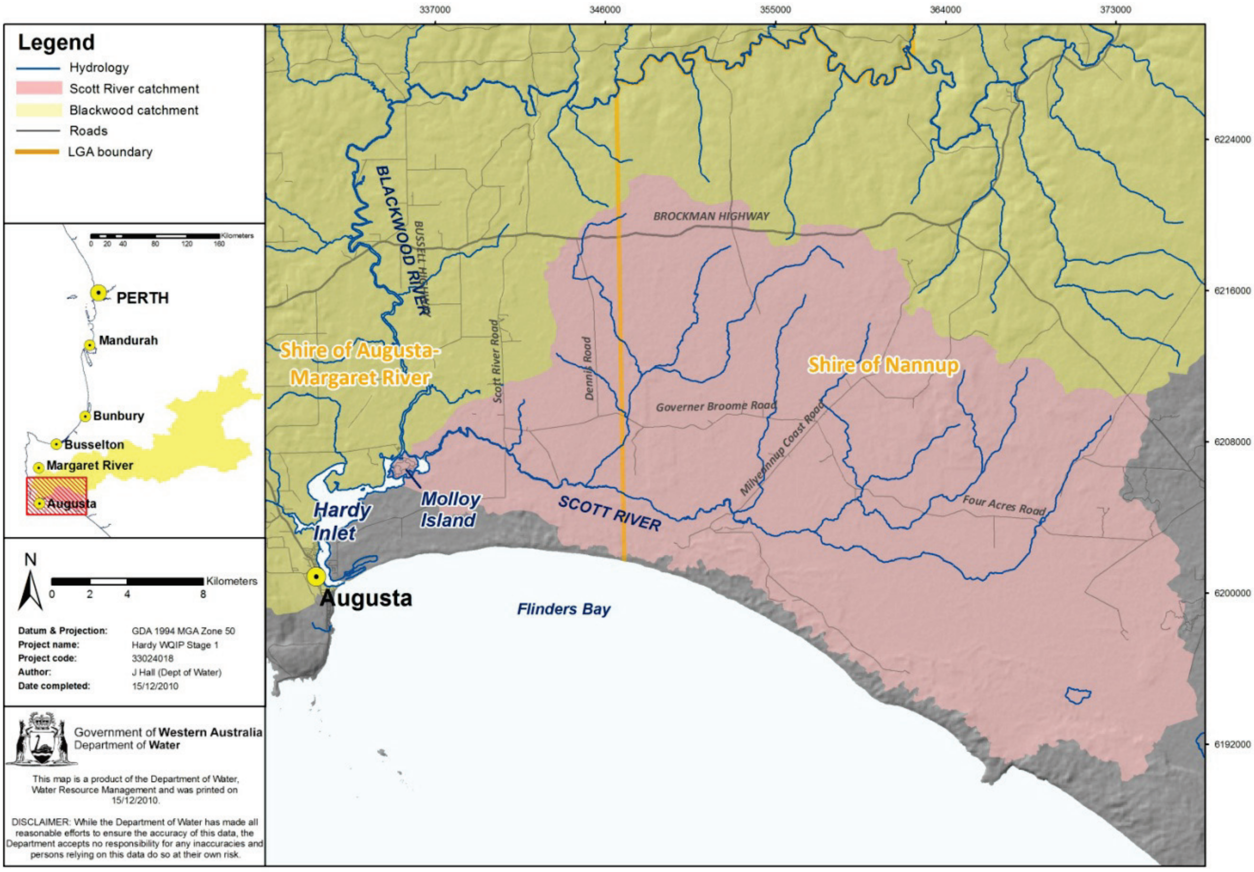


Figure 3.1 Hydrological catchment of the Scott River

3.2 Geomorphology and soils

The Scott River hydrologic catchment comprises a large part of the Scott Coastal Plain. The plain and the catchment are separated from the Southern Ocean by a narrow strip of coastal dunes. The centre of the catchment is flat, low lying and prone to waterlogging during the winter. In the north of the catchment land is gently undulating as it rises towards the Barlee Scarp, which forms the northern boundary of the Scott Coastal Plain. The areas of the Scott Coastal Plain that drain to the Blackwood and Donnelly rivers have been excluded from this study as these are outside the hydrologic catchment of the Scott River.

Surface soils in the Scott River catchment vary from fine white, brown and grey sands to coffee rock and clay. At depths below a metre, a range of fine and course sands are found as well as rock, clay, sandstone, coffee rock, shale, quartz, gravel and basalt (Hall 2010). In contrast, Molloy Island has mainly duplex soils. These include areas with yellow to loamy sand that have increasing clay content with depth, and areas with bleached sand over coffee rock, some with gravel or gravelly clay underlying the coffee rock (Jeffery 2010). Molloy Island shares the same soil landscape mapping unit as much of the land draining the Blackwood River's lower reaches (flats on floodplains and river terraces) (Tille & Lantzke 1990). While widespread in the Lower Blackwood area, this unit only occurs in a very small part of the Scott River lower catchment, near the shores of the lower Scott River estuary.

Many of the soils in the Scott River catchment have a low ability to retain phosphorus within the soil profile and therefore pose a high risk for the transport of phosphorus from the catchment to the Hardy Inlet (Kitsios 2007). Figure 3.2 shows a map of the catchment's soil phosphorus retention index (PRI) and an associated risk for phosphorus leaching if high levels of phosphorus fertiliser are or have been applied (from DAFWA). Those soils with a low PRI are predominantly located along the catchment's southern margin, although smaller pockets and veins of low-PRI areas are also dispersed throughout.

A recent study of Molloy Island's soils concluded they had a low risk of phosphorus transport, since testing at most sites identified moderate to very high PRIs (Jeffery 2010). Results from soil tests at a variety of locations on the island indicated it was likely that septic tank nutrients were being retained by the duplex soils around the leach drains. The processes ensuring this nutrient retention include phosphorus adsorption (very high PRI values), uptake by vegetation and possibly denitrification (Jeffery 2010). As part of the study, water quality samples were planned to be collected in winter, but low winter rainfall resulted in the drains remaining dry.

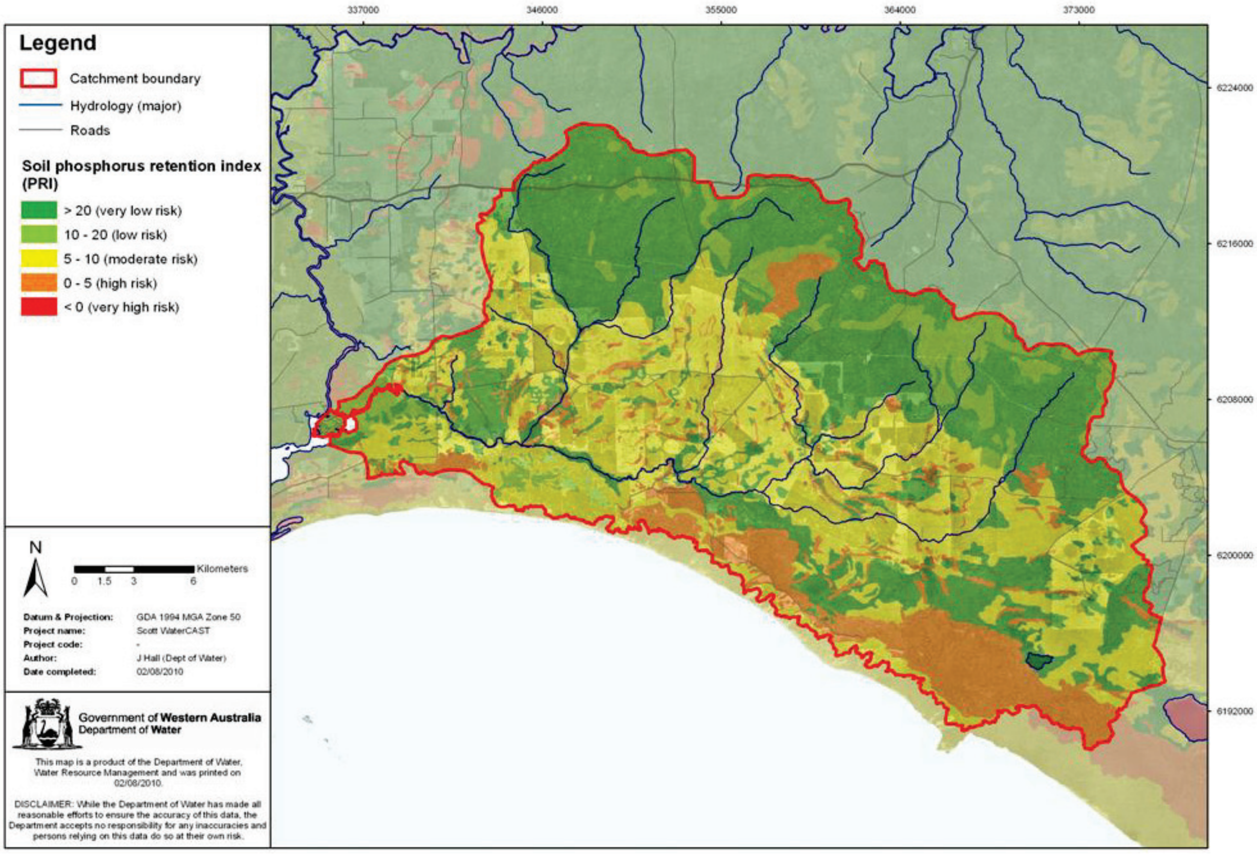


Figure 3.2 Soil phosphorus retention index map for the Scott River catchment

3.3 Acid sulfate soils

Thirty four per cent of the Scott River catchment contains potential acid sulfate soils (Kelsey 2006). These soils occur naturally. They contain iron sulfides, mainly in the form of pyrite, and are often associated with low-lying coastal and seasonally inundated areas (DEC 2009). The Scott Coastal Plain has been identified as one of five key areas of concern in Western Australia for potential acid sulfate soils (DEC 2009). Figure 3.3 illustrates potential risk areas in the Scott River catchment where potential acid sulfate soils may be located in the shallow soil profile (after Degens & Wallace-Bell 2009)

Potential acid sulfate soils do not pose a problem when they are undisturbed, but can form sulfuric acid when exposed to air due to a reaction between oxygen and the iron sulfides in the soil. This can occur when oxygen enters the soil profile as a result of excavation, drainage or lowering of the watertable. Changes to watertables may result from abstraction activities, reduced rainfall arising from climate change, or increases in plantation trees with transpiration rates that exceed native vegetation (Degens & Wallace-Bell 2009). Potential acid sulfate soils are known as actual acid sulfate soils once they have been disturbed and are oxidising, thereby releasing sulfuric acid within the soil (Degens & Wallace-Bell 2009).

The oxidisation process that occurs when potential acid sulfate soils are disturbed results in the formation of minerals that store acid (such as jarosite). This process can break down the soil structure, chemically dissolve clays and release high concentrations of metals such as aluminium and iron as well as nutrients to the shallow groundwater. These contaminants can then be leached and transported into nearby aquifers and surface water systems (DEC 2009). Aluminium is particularly toxic to aquatic life and this toxicity can be exacerbated during neutralisation, for example when acid waters mix with alkaline waters. Low soil pH also limits the capability of plants to use nutrients, and can therefore further increase the amount of nutrients that are leached from the soil and eventually lost to waterways. An extensive review and explanation of the potential impacts from disturbance of acid sulfate soils on the Scott Coastal Plain is provided by Degens and Wallace-Bell (2009). The actual impacts depend on the nature of the acid release and include the following potential issues:

- localised soil scalding, plant death and poor plant recruitment
- nutrient and toxic-iron stressed plants
- lesions to animals occupying affected areas
- poor subsoil root growth, water stress and reduced nutrient uptake (leading to increased nutrient leaching from the soil)
- death of irrigated plants; poor stock water quality
- localised accumulation of iron precipitates causing the death of aquatic invertebrates and blockages in irrigation equipment
- increased colouration and eutrophication of waterways as a result of increased leaching of organic matter from soils and riparian zones by acid-rich water
- risk of metal bioaccumulation in wildlife and livestock.

The BHP Beenup mineral sands mine that operated on the catchment's border for a short time was plagued by problems resulting from exposure of deep acid sulfate soils. Extensive lime management of the acid sulfate soils was undertaken and monitoring of the rehabilitated mine site continues to this day.

A recent study of acid sulfate soils on the Scott Coastal Plain confirmed that extensive areas of the plain (530 ha) pose a potential acid sulfate soil hazard (Degens & Wallace-Bell 2009). Of the sites investigated in that study, 20 per cent were also found to have actual acid sulfate soils (i.e. the soils were oxidising and producing acid). Possible causes of disturbance to the potential acid sulfate soils differ according to the site location, but they include localised drawdown of groundwater by abstraction and blue gum plantations, in addition to disturbance caused by artificial drainage works in the catchment (Degens & Wallace-Bell 2009).

The possible risks to the Hardy Inlet from acid sulfate soils in the Scott River catchment require important management consideration. Given the low-lying nature of the landscape and the associated slow subsurface flows, acid from actual (disturbed) acid sulfate soils may accumulate substantially within the soil profile before the problem becomes apparent within local waterways (Degens & Wallace-Bell 2009). If this occurs it may not be possible to apply land-based remediation options if the extent of the acidification is too great. It is possible that early warning signs are already emerging in at least two waterways in the catchment (tributaries flowing south from the Barlee Scarp across Four Acres Road and Dennis Road). The long-term water quality monitoring program has shown a clear declining trend in pH in the Four Acres Road tributary and is starting to decline in the Dennis Road tributary (Robb

Donohue pers. comm. 2006, cited in Degens & Wallace-Bell 2009). Further investigations into the causes of these changes are an important management priority.

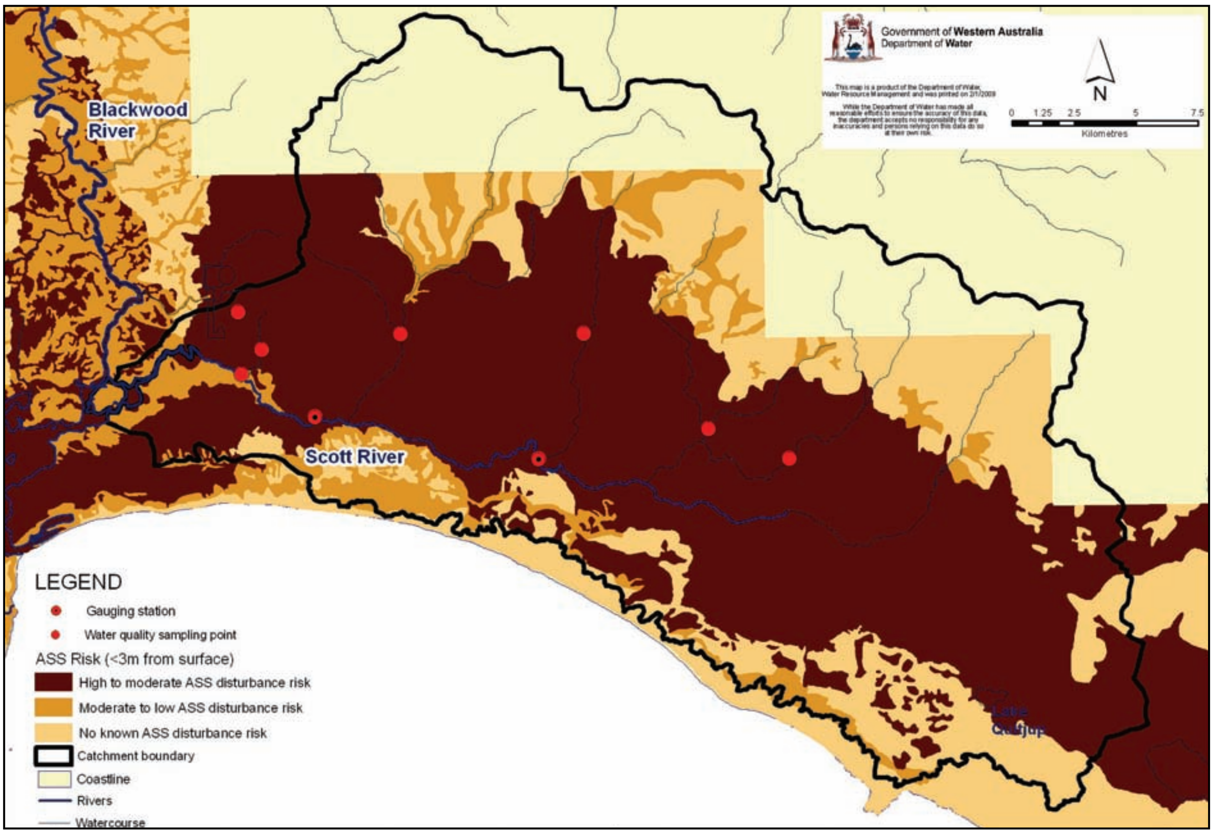


Figure 3.3 Potential acid sulfate soil hazard risk in the Scott River catchment

3.4 Climate and hydrology

The Scott River catchment experiences a Mediterranean climate with hot dry summers and cool wet winters. The average annual rainfall in the catchment is 970 mm (for the years 1970 to 2009), predominantly falling between May and October each year. Interestingly, the catchment has not seen the significant decline in rainfall between 1970 and the present that regions north of Perth have experienced (Hall 2010). Elsewhere in the south-west (e.g. the Blackwood catchment) there is an apparent long-term shift towards lower rainfall and reduced river flows in addition to the reduced seasonality of rainfall (reduced winter rainfall and increased summer rainfall).

The aquifers below the Scott River catchment include the superficial, Leederville, Yarragadee, Parmelia and Lesueur (Baddock 1995). Extensive waterlogging of the catchment occurs during winter. The Scott River's flows usually cease in November to December as the groundwater recedes and runoff falls away with the seasonally dry conditions. Flows generally start again in May to June each year.

The hydrology of the Scott River catchment has been modified extensively via the construction of artificial drains. Drains increase the hydraulic head between groundwater and surface water and therefore have the capacity to transport more water and more dissolved and particulate nutrients to the Scott River compared with an undrained catchment. Although they have enabled a wider area of the catchment to be developed for agriculture, they are also likely to have contributed to larger nutrient loads from the catchment.

Other important hydrological features include the Gingilup Swamps and Lake Quitjup in the catchment's south-east. These are part of a chain of wetlands known as the Gingilup – Jasper Wetland System which stretch eastwards and beyond the catchment boundary to Lake Jasper. This system is recognised as having national significance (Hearn et al. 2002) and is listed on the Register of the National Estate.

3.5 Environmental flows

As for many other south-west waterways, the Scott River has experienced a gradual reduction in flow during the past 40 years. This decline is illustrated by Figure 3.4, which shows annual flow for this period at the lower reaches of the Scott River (Brennan's Ford). A decreasing trend in flow (illustrated by the red line) has emerged, with average flow over the past decade being 35 per cent lower than the average from 1970 to 2000. Baseflow has also decreased during this time yet only marginal decreases in rainfall have occurred (Figure 3.5). It is difficult to assign an exact cause for the reduction in flow in the Scott River. An investigation into the surface water/groundwater interactions is needed to clarify the likely causes.

A change in the average runoff coefficient measured at Brennan's Ford from 16 per cent (1975–99) down to 10 per cent during the past decade indicates a clear change in the catchment's water balance (Figure 3.6). In an average year pasture on the Swan Coastal Plain generally has a coefficient of runoff of 20 to 25 per cent, whereas deep-rooted vegetation (native vegetation or plantation) has a coefficient of runoff of 5 to 15 per cent. The impact of these changes on the ecology of the Scott River and the Hardy Inlet is currently unknown.

There are now significant additional pressures on these systems compared with their pre-clearing state, as well as a risk that reduced flows may have a direct influence on their ability to assimilate higher concentrations of nutrients. For example, the accumulation of nutrients and organic material in the Scott basin north and east of Molloy Island is influenced by the reduced movement of water as flow dissipates in the basin, which is then restricted further by the narrow channels around the island (Forbes, pers. comm., DoW). Further reductions in flow from the Scott River have the potential to lead to higher concentrations of nutrients in this area, as lower flows reduce dilution in addition to further slowing water movement. Furthermore, more sediment has accumulated in the Scott basin and this has further changed the flow characteristics (Richard Pickett, pers. comm., DoW). Low flows that occur in the area now also appear to have much lower tannins than previously – increasing the risk of algal blooms since light penetration is improved with lower water colouration (Richard Pickett, pers. comm., DoW). The lower tannins during the low-flow period may be caused by the reduced area of shallow groundwater in the catchment interacting with surface waters. Much of the tannin in the Scott is likely to come from shallow groundwater discharge from the catchment's upper reaches. There, groundwater interactions with peat-rich wetlands contribute tannins and humic acids to the surface water, but with increasing episodes of low flows there has been reduced mobilisation of these colour-rich waters downstream. The combined effect of high nutrient concentrations and reduced tannin staining of low flows from the Scott River may be a driver of algal blooms in the Scott basin (Richard Pickett, pers. comm., DoW). Further studies are needed on the role of tannins in controlling algal blooms and the potential causes of reduced tannins in low flows from the Scott River.

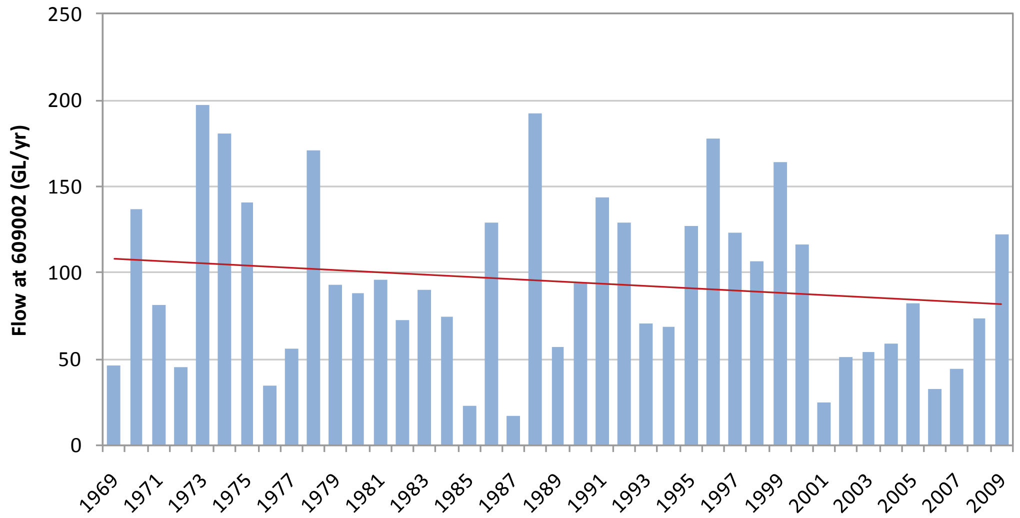


Figure 3.4 Annual flow at Brennan's Ford between 1969 and 2009

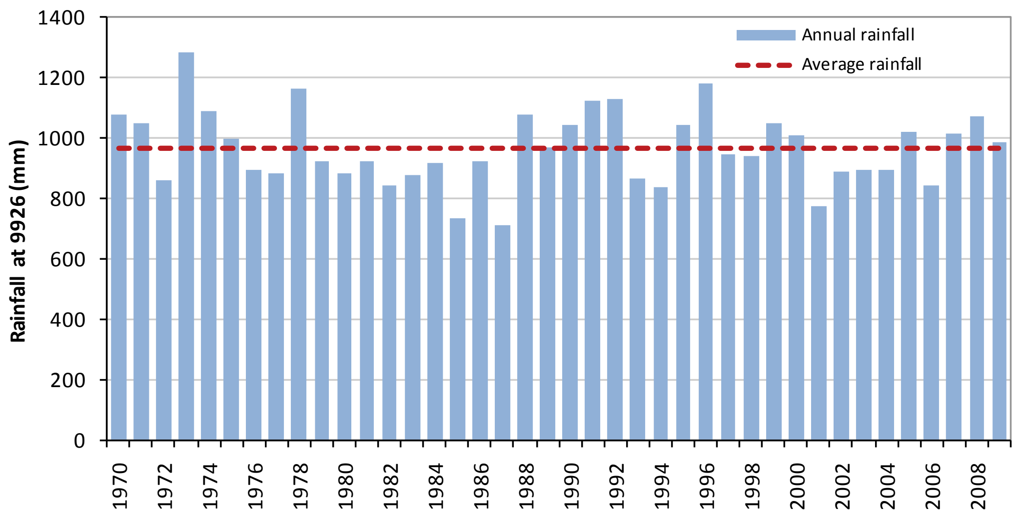


Figure 3.5 Average annual rainfall for the Scott River catchment

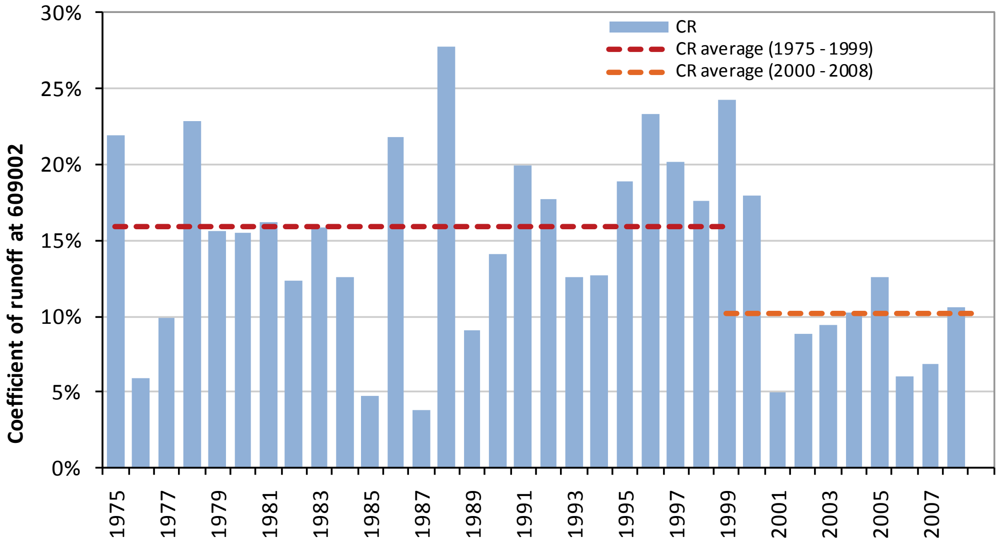


Figure 3.6 Coefficient of runoff for the Scott River catchment

3.6 Ecological values

The Scott River catchment retains outstanding ecological values. Sixty-seven per cent of the catchment remains under native vegetation cover. These areas of vegetation are highly diverse, comprising 31 different vegetation complexes of which 10 are identified as being poorly represented in secure reserve systems (DAFWA 2001). The ironstone soils of the catchment support a unique range of vegetation assemblages including many rare and priority flora species. The Scott River ironstone ecological community is confined to the Scott Coastal Plain and is listed as a threatened ecological community (TEC) (DEC 2006). It consists of winter-wet shrubland on ironstone, typically dominated by *Melaleuca preissiana*, *Hakea tuberculata*, *Kunzea micrantha* or *Melaleuca incana* subsp. Key threats to the TEC include dieback disease, altered hydrology, grazing and clearing.

The main Scott River channel retains substantial and excellent quality riparian vegetation, principally as a result of an established foreshore reserve. While detailed surveys of the riparian vegetation and aquatic values have not been undertaken, the riparian zone is likely to provide important habitat for a range of aquatic and terrestrial fauna species given that such a wide zone of riparian vegetation remains largely undisturbed.

3.7 Land use and economic values

European people first sighted and named Cape Leeuwin in 1622 from the Dutch merchant ship 'The Leeuwin' while on voyage to Batavia (now known as Jakarta in Indonesia). French ships and American whalers frequented the coast over the following century, but it was not until the 1830s that the first British settlement in the south-west was established on the shores of the Hardy Inlet at Augusta (Rigby 1995). These early settlers experienced great hardship and many moved to the Vasse region (WAPC 1998). After 1850 the expansion of the timber and pastoral industry saw Augusta grow again.

In the Scott River catchment agricultural development began in the 1860s when cattle runs were developed by the Bussell, Brockman and Longbottom families (DAFWA 2001). Significant clearing of the catchment occurred during the early 1900s and fertiliser trials were underway in the catchment as early 1919 (Kitsios 2007). Further development of the western catchment began in the 1920s and 1930s when the British and Western Australian governments jointly formed the Group Settlement Scheme (WAPC 1998). At about the same time land around Milyeannup was also opened up for agriculture (DAFWA 2001).

Clearing of additional lots occurred in the 1960s as part of the conditional purchase scheme. By this time land in the catchment's west was primarily used for dairy, with grazing in the east (DAFWA 2001). Further clearing also occurred during the 1970s and 1980s to enable the expansion of pastoral areas. In 1974 Molloy Island was purchased for subdivision and development of large residential bush lots. The barge to transport vehicles to the island began operating in 1977.

When returns from grazing plummeted during the 1990s many farmers in the area intensified their land use. Dairy farms spread eastward and large areas were planted with blue gums. The availability of high-quality Yarragadee groundwater enabled irrigation of potatoes under 40 ha centre-pivot systems using bores capable of drawing 1 000 000 m^3 of water each year (DAFWA 2001). The potatoes were grown under a three-year rotation primarily with grazing.

The late 1990s also saw a brief period of mineral sands mining on the catchment's border. Extraction of ilmenite, zircon, leucoxene and rutile at the BHP Beenup mine site began in 1997 with an expected mine life of 20 years. But the mine closed in April 1999 after running for only two years, due to maintenance problems caused by high levels of clay in the ore body, the abrasiveness of the sand and the exposure of acid sulfate soils (see Section 3.3).

Further changes in the catchment occurred after the closure of Simplot's potato factory in Manjimup in 1999. Farmers that had diversified into potatoes now found they no longer had a viable local market for their produce and this led to the gradual replacement of potatoes with irrigated dairy and smaller areas of broccoli and lucerne. Many beef farmers also made the change to dairy. The new dairy farms include four large share-milking farms that are part of the New Zealand-based Lactanz company. Share-milkers are responsible for the costs of management, labour, stock and machinery while the company pays for the land and development costs.

Unlike many other catchments in the south-west, native vegetation still covers most of the Scott River catchment (figures 3.7, 3.8, 3.9; Table 3.1). Tree farming has increased during the past decade and many properties are now partly or entirely devoted to farming blue gums (14 per cent of the catchment). Dryland grazing, mainly for beef but also including some sheep, forms 11 per cent of the catchment area. Dairy farms now occupy four per cent of the catchment with just over half of this area as irrigated dairy. Molloy Island now has 273 residential lots of which 204 have been developed. With the exception of clearing required for roads, residential buildings and water tanks, most native vegetation on the island is still intact (Figure 3.10).

Agricultural production in the Scott River catchment has substantial economic value. Many of its farms have productive capacity many times the state or national average for their industry. For example, some of the larger dairy farms in the catchment milk 1500 to 2000 cows, while the state average herd size is only 330 cows (Western Dairy 2010). The availability of high-quality groundwater, together with land capability suitable for irrigated agriculture, has heightened opportunities to maximise the potential return from these industries.

The land use changes that have occurred in the Scott River catchment during the past few decades have also resulted in changes to nutrient inputs to the catchment. Potatoes required large amounts of annual phosphorus fertilisation, and these have largely been replaced by dairies that have high annual nitrogen inputs from fertilisation and/or fixation from clover. Blue gums are also fertilised, though only at planting and then either once or twice during the next four years (during their first five years of growth).

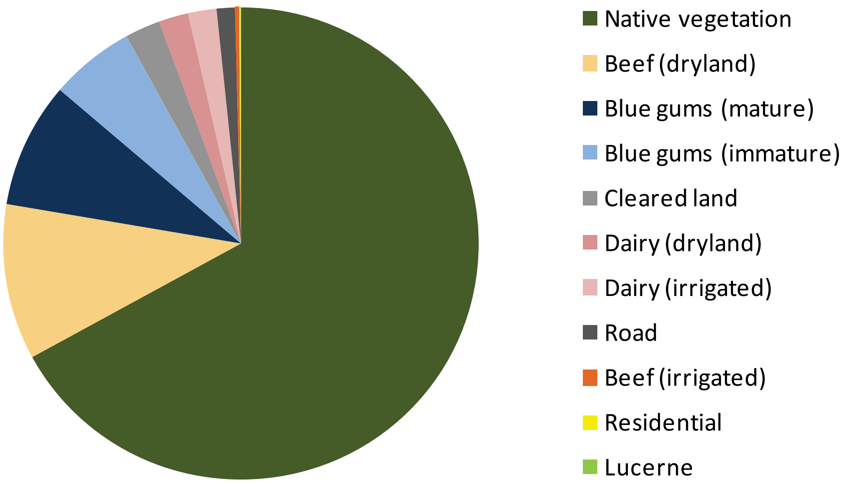


Figure 3.7 Proportions of land uses in the Scott River catchment

Table 3.1 Area occupied by each land use in the Scott River catchment

Land use	Area (km^2)	Proportion of total area (%)	Proportion of cleared catchment (%)
Native vegetation	462.3	66.9	–
Dryland grazing	66.4	9.6	29.0
Blue gums (mature)	58.9	8.5	25.8
Blue gums (immature)	39.7	5.7	17.4
Cleared land	16.7	2.4	7.3
Dairy (irrigated)	14.6	2.1	6.4
Dairy (dryland)	12.6	1.8	5.5
Beef (dryland)	6.8	1.0	3.0
Beef (irrigated)	2.0	0.3	0.9
Residential	0.6	0.1	0.3
Total	689.5		

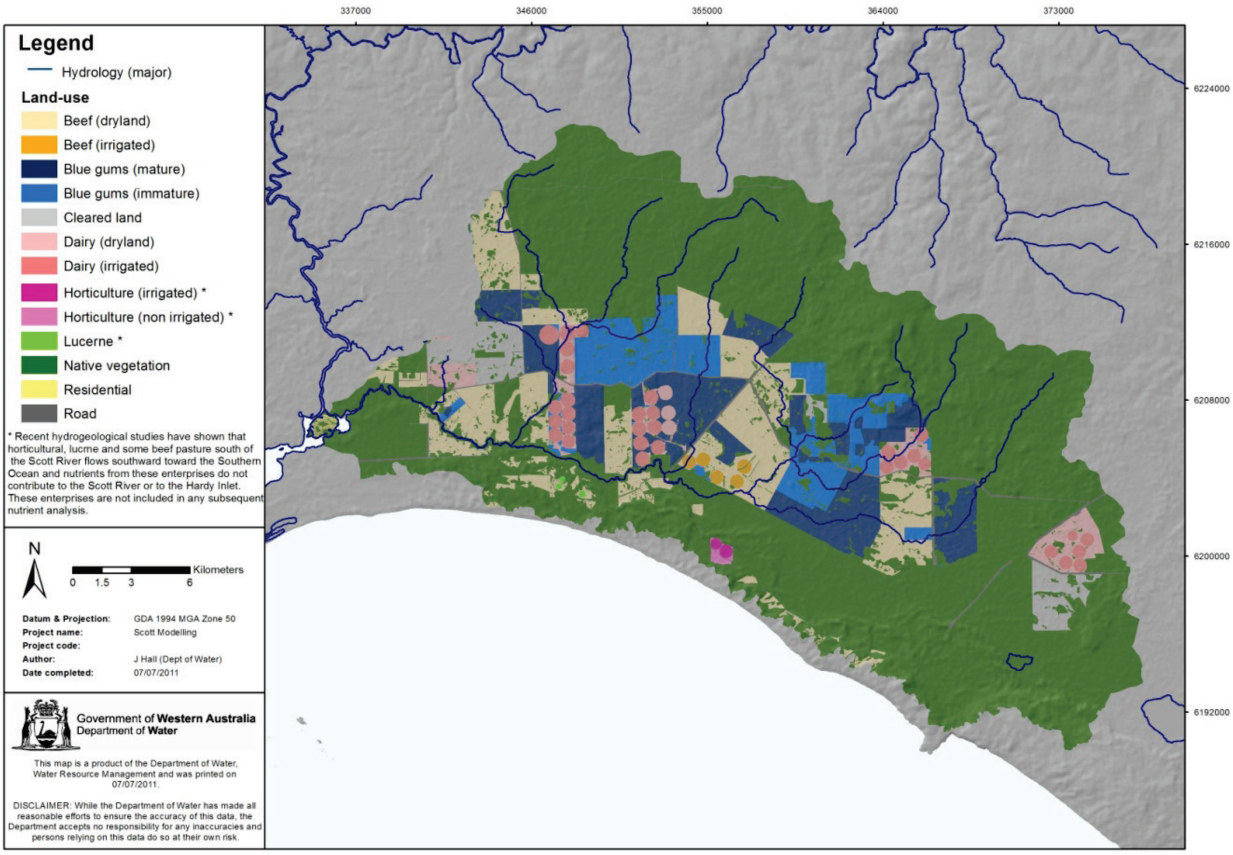


Figure 3.8 Land use map for the Scott River catchment

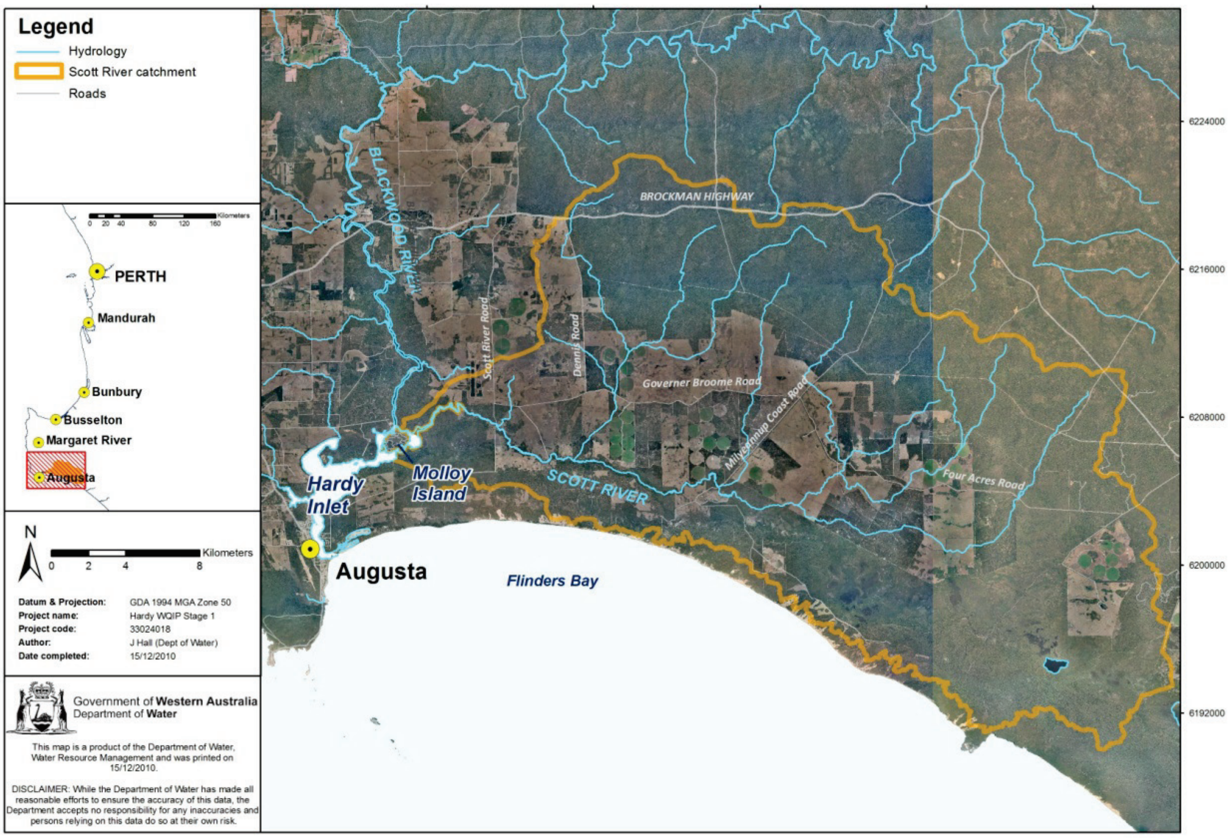


Figure 3.9 Aerial view of the Scott River catchment

Figure 3.10 Aerial view of Molloy Island

4 Scott River water quality

4.1 Water quality status

Water quality sampling of the Scott River catchment has been undertaken every fortnight for the past 10 years at multiple locations in the catchment (Figure 4.1). This figure shows the location of water quality sampling sites and seven identified subcatchments within the Scott River catchment. Sampling sites are not located in all subcatchments.

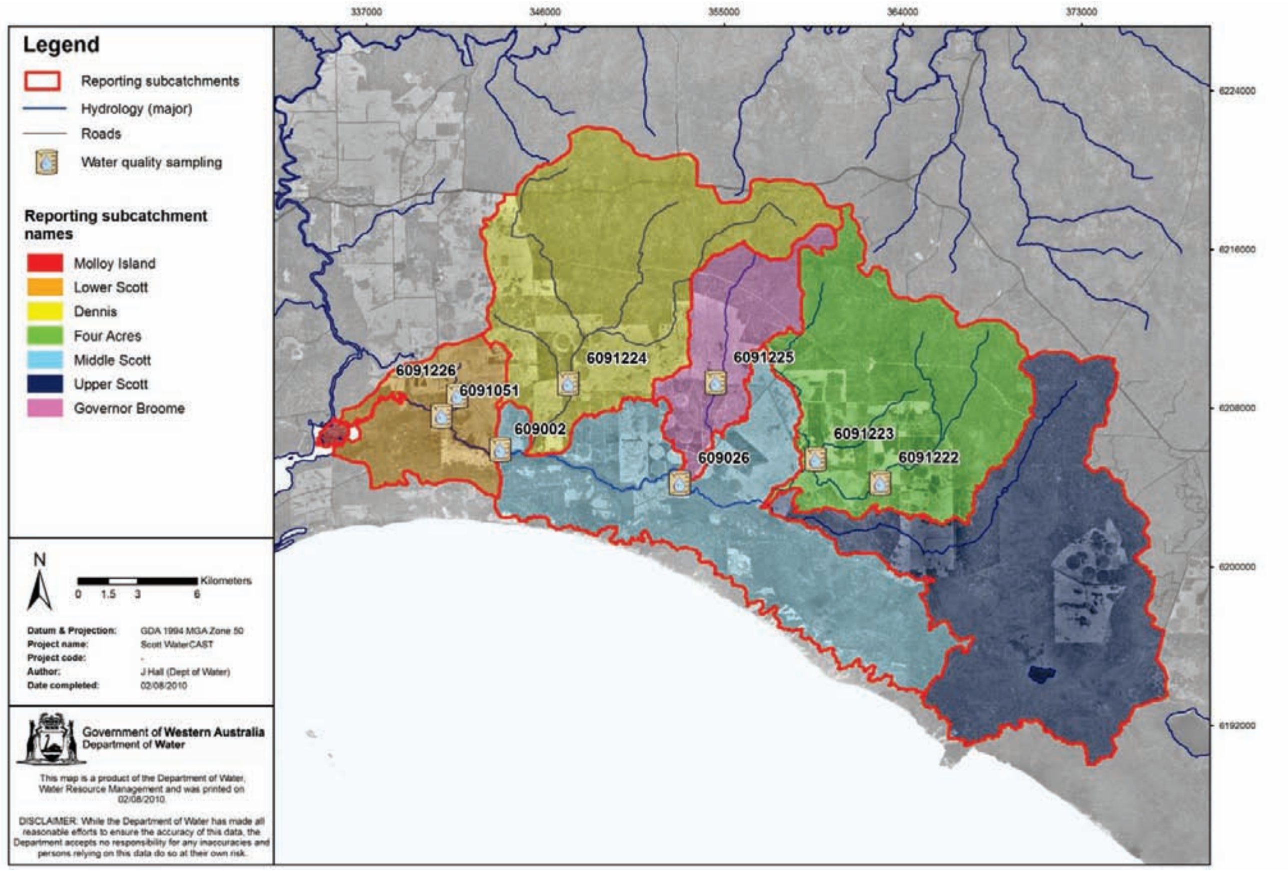


Figure 4.1 Scott River subcatchments and water quality sampling sites

A much longer data record exists for the Brennan's Ford sampling site (609002) located in the Lower Scott subcatchment, where regular samples were also collected during the mid-1980s and early 1990s. Data from this longer-term monitoring shows a clear story of nutrient enrichment as agricultural uses in the catchment have expanded and intensified. Figures 4.2 and 4.3 show the winter median concentrations of total phosphorus (TP) and total nitrogen (TN) at Brennan's Ford between 1984 and 2009. The red line on these graphs shows the ANZECC guidelines for TP and TN in the lowland rivers of south-west Western Australia. Although the sampling record is not continuous over this period, there has been a noticeable increase in the median TP concentrations. During the mid-1980s TP and TN concentrations were well below the ANZECC guidelines. Less frequent sampling occurred over the following 10 years, but a small number of samples collected in the early 1990s showed TP concentrations approaching or just over the ANZECC guideline. By 2002–04 TP concentrations were over double the ANZECC guideline. Although the median TN concentrations also increased slightly they have remained below the ANZECC guideline. Large variations in the data indicated by the 10th and 90th percentiles (error bars) are typical of a catchment that releases pulses of nutrients following periodic fertiliser application, or when heavy rain events flush nutrients from paddocks and drains. The changes in water quality occurred during the same period that land use intensified in the catchment.

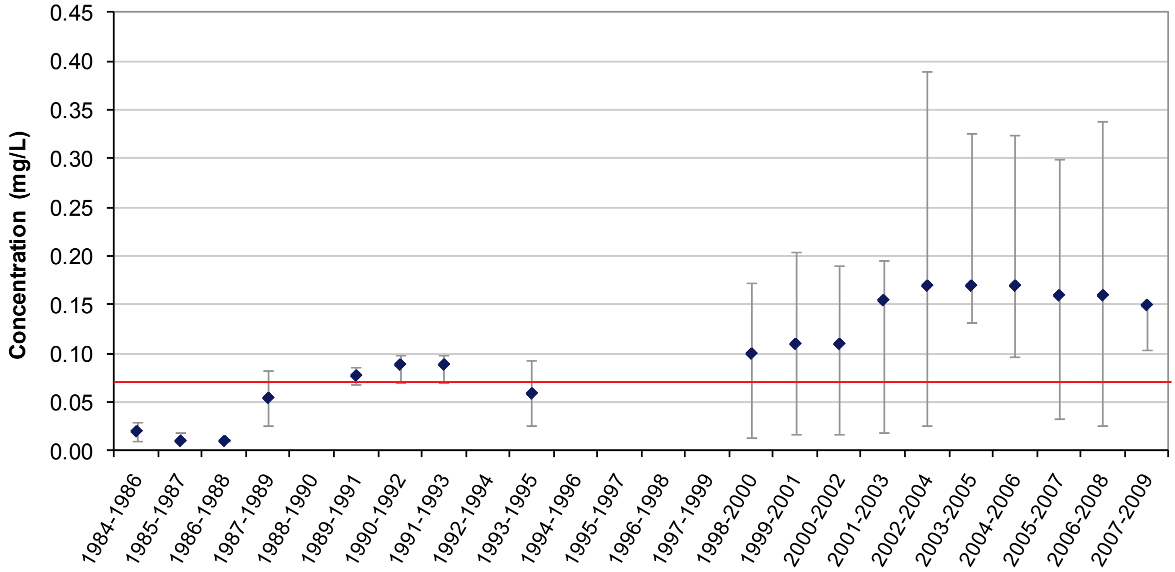


Figure 4.2 Winter median TP concentrations from Brennan's Ford (609002)

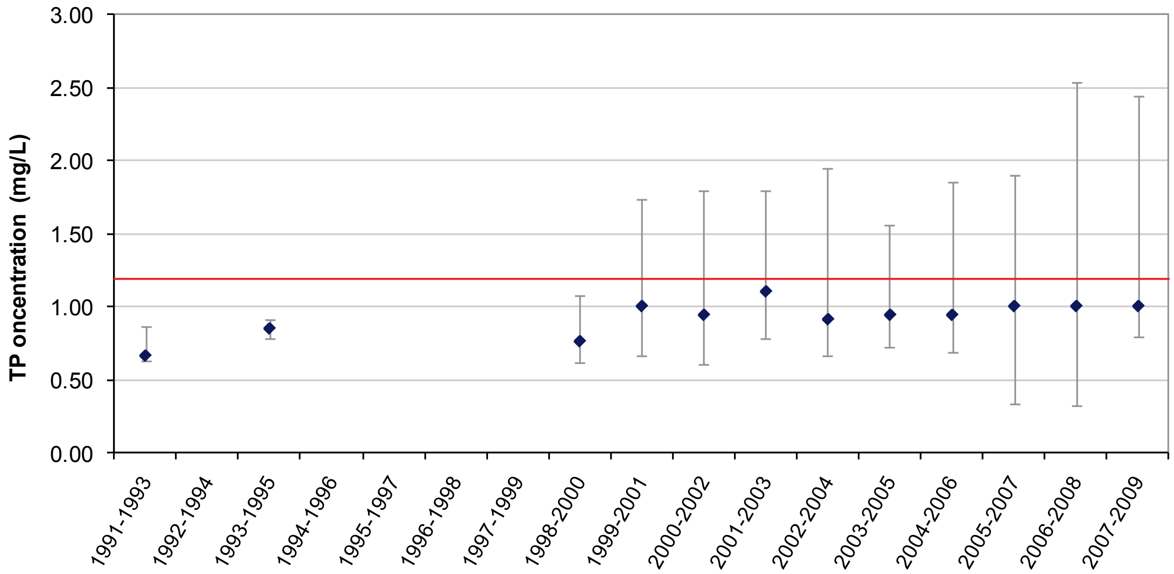


Figure 4.3 Winter median TN concentrations from Brennan's Ford (609002)

Water quality data from tributaries of the Scott River is highly varied depending on the location of sampling (figures 4.4 to 4.5). Sampling data from site 6091222 located in the middle of the Four Acres subcatchment has consistently shown the highest concentration of TP. TN was also elevated at this site. The lowest concentration of TP was recorded at site

6091224, located on a minor tributary immediately below an established mature blue gum plantation in the Dennis subcatchment. The sampling point is not located on the main tributary and therefore does not sample flow from adjoining land uses. It should be noted that sampling points located in each subcatchment do not reflect the entire subcatchment's water quality status because they are not located at the base of the subcatchment. Sampling points are also not located in the Upper Scott or Molloy Island subcatchments.

TN concentrations decrease markedly and TP concentrations decrease slightly in the main river channel from the upstream site 609026 to the downstream sites 609002 and 6091051. It is thought that these observed reductions are in part due to the dense and wide riparian zone along the main Scott River channel (Hall, pers. comm., DoW; Water and Rivers Commission 2002).

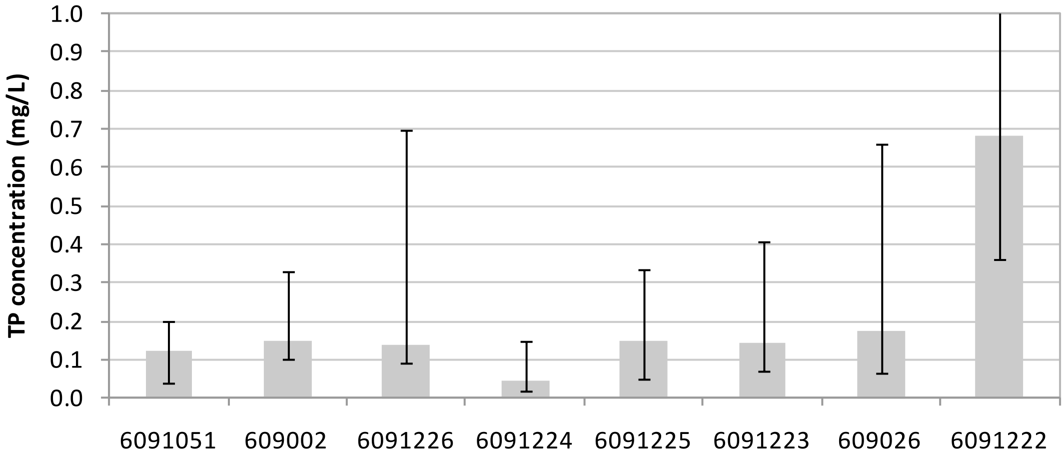


Figure 4.4 Winter median total phosphorus concentrations (2007-09) for water quality sampling sites in the Scott River catchment (bars indicate 10th and 90th percentiles)

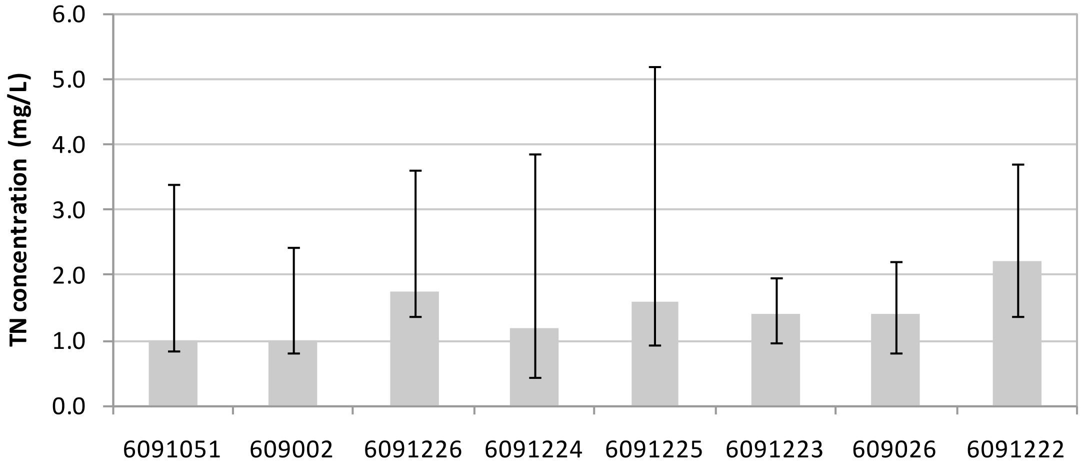


Figure 4.5 Winter median total nitrogen concentrations (2007–09) for sampling sites in the Scott River catchment (bars indicate 10th and 90th percentiles)

4.2 Water quality issues

To date the elevated nutrient concentrations in the Scott River have not resulted in excessive algal growth within the river itself. Water movement in the river combined with heavy tannin staining of the river water (which limits the light penetration required for algal growth) have limited excessive growth of algae. Tannin colouration of the river water is largely derived from the formation of humic substances that occurs when groundwater flows through the catchment soil profile (Richard Pickett, pers. comm., DoW). These tannins are also combined with those formed by fulvic acid derived from the breakdown of native vegetation in the catchment. The main impact of nutrient enrichment in the Scott River has therefore occurred within the estuary, near the river's drainage point (discussed in Section 2.6).

There is some emerging evidence of acid drainage in the Scott River catchment resulting from disturbance of potential acid sulfate soils. This issue is discussed in more detail in Section 3.3. Disturbance can result from excavation activities such as drainage works, lowering of the watertable from water abstraction (pumping), or from increased water uptake by blue gum plantations (Degans et al. 2009).

Table 4.1 Summary of water quality issues for the Scott River

Location	Issue	Example
Scott River	*Elevated nutrients* Regular water quality monitoring indicates the Scott River and its tributaries have elevated nutrient concentrations. Brennan's Ford (10 km upstream from the catchment outlet) has moderate TN and high TP status. Naturally high levels of tannin in the Scott River restrict light penetration in the water column and prevent proliferations of algal growth in the river.	 Water quality sampling site at Brennan's Ford on the Scott River.
Scott River tributaries	*Acid drainage* Thirty-four per cent of the Scott Coastal Plain is at risk of acid drainage that may result from the disturbance of potential acid sulfate soils.	Low pH levels have been recorded in tributaries near Four Acres Road and Dennis Road (Degans et al. 2009).

4.3 Water quality targets

Background to water quality targets

An important stage in this plan's development has been the establishment of water quality targets for the Scott River. Nutrient targets are typically used as numerical 'management goals' to reflect the nutrient concentration or loads that management actions aspire to achieve. Such targets have been in place for many years in the Swan-Canning and Peel-Harvey catchments, but have not previously been established for the Scott River.

In setting water quality targets, it is important to consider the role of both nutrient concentrations and loads as assessment tools. The former measures the concentration of a particular nutrient in the waterway at any one time, while the latter measures the total weight (load) of a particular nutrient delivered to or by a waterway over a given time period (usually an annual average over a number of years) and is a function of both concentration and flow. Both have particular advantages and applications.

The total load of nutrients is important when dealing with closed estuarine systems that have the potential to accumulate nutrients attached to sediment particles and then release nutrients back into the water column. This is particularly the case for phosphorus which readily attaches to sediment, but less so for nitrogen which is generally delivered in a soluble form and can be lost from the system via denitrification. Some release of nutrients may be occurring from sediment in the deep pools of the Hardy Inlet. Nutrient loads are difficult to measure because they require installation of expensive flow-gauging stations and are associated with a high degree of imprecision, particularly under high-flow conditions. Nutrient loads are also less relevant to the management of marine systems, which tend to flush such loads on a regular basis.

Where control of algal growth is the management goal, the concentration of nutrients is very important since algae responds to ambient water quality conditions. Nutrient concentrations are simpler to measure than loads and are also associated with more precision. It is for these reasons that the Department of Water uses water quality targets that are primarily based on the concentration of particular nutrients. This plan also presents those targets in terms of the calculated load of nutrients that the river would deliver to the inlet if it were to meet the defined concentrations. This latter approach enables the management options to be evaluated in terms of their likely reduction in nutrient loads if implemented in the catchment. Such evaluations (referred to as a cost-benefit study) are discussed in Section 5.2.

Targets for the Scott River

For the purposes of this plan, water quality targets for the Scott River were identified with the aim of preventing *Lyngbya* algal blooms in the upper Hardy Inlet. Algal blooms (*Lyngbya*) have emerged as a regular issue in the upper Hardy Inlet from 2005 onwards. This species is known to respond to elevated phosphorus and high organic loading. The phosphorus target was therefore based on the median concentrations measured at Brennan's Ford in the year 2000, five years before the *Lyngbya* blooms emerged. This approach is consistent with that proposed in the *Sustainability strategy for the Scott Coastal Plain* (2000) and equates to a TP concentration target of 0.1 mg/L. For nitrogen the target reflects the current nitrogen status of the river: a median winter concentration of 1.0 mg/L. The median TN concentration has not dramatically changed since 2000 and *Lyngbya* can fix nitrogen. Both targets are the same as those adopted for waterways in the Vasse-Geographe, Peel-Harvey and Swan River catchments. A summary is presented in Table 4.2 below. The concentration targets equate to a 28 per cent reduction in current phosphorus load and no further increase in the nitrogen load from the Scott River.

Targets for individual reporting catchments have not been established because some assimilation of both nutrients occurs as water flows down the main Scott River channel (see Section 4.1). In addition, it is likely that nutrient management measures will be needed in all subcatchments to improve the quality of water discharged by the Scott River.

Table 4.2 Target phosphorus and nitrogen concentrations and loads

Nutrient	Winter median concentration (mg/L)		Average annual load (t/yr)	
	Current	Target	Current	Target
Total phosphorus	0.15	0.10	11.2	8.1
Total nitrogen	1.0	1.0	78.1	78.1

4.4 Sources of nitrogen and phosphorus in the catchment

Understanding the nutrient sources attributed to particular land uses is critical to prioritising the necessary management actions to reduce nutrient loading. As for other Western Australian river systems, the Scott River had very low concentrations of phosphorus and nitrogen before agricultural development of the catchment. The sandy soils of the catchment are naturally nutrient poor and the native plants have adapted to these conditions. Some species of native plants, particularly acacias, are able to ‘fix’ nitrogen in the same manner as legumes and clover. A proportion of the nitrogen recorded in the river is therefore derived from native vegetation in the catchment.

Most other sources of nutrients in the river are derived from agricultural sources. These include phosphorus and nitrogen built up in soils from fertilisation and animal excreta, nitrogen fixed by pasture clover and effluent derived from dairy sheds and feedlots. Of these sources, nutrients either directly or indirectly from fertilisers are a significant component of both phosphorus and nitrogen – though the amount, type and frequency of fertiliser applications varies according to the different land uses. Imported feed along with fertilisation and pasture fixation are the nutrient sources in animal excreta.

Nutrient budget surveys undertaken by DAFWA together with industry consultation have provided data for the typical application rates of fertilisers for each agricultural land use in the Scott River catchment. A summary of these data is presented in Table 4.4. Of particular note in this table is the ratio of nitrogen to phosphorus that irrigated dairies are applying in the catchment at present. A high nitrogen rate is required for viable production yet the phosphorus rate of 76.5 kg/ha is likely to be much larger than what the pasture requires (Don Bennett & Martin Staines pers. comm., DAFWA). These figures indicate the potential for irrigated dairies in the catchment to reduce their annual fertiliser costs, while also maintaining production and reducing the phosphorus load exported from their farms.

The overall input load of phosphorus and nitrogen delivered by each land use is a function of both the input rate and the land area occupied by each land use. Table 4.5 summarises the input rates and input loads for each land use.

The resulting phosphorus and nitrogen input loads from all diffuse sources are also compared with the total loads from point sources (effluent from six dairy sheds and one feedlot) (Table 4.5). While point sources such as dairy effluent contribute to the overall nutrient loads, those from the combined diffuse sources are a much larger contributor of both nutrients.

Table 4.3 Fertiliser practices in the Scott River catchment (data from nutrient surveys)

Land use	**Typical product and description**	**Typical application rate / frequency**
Irrigated dairies	Grazeburst™ 25.3% N and 3.9% P	12 to 15 applications per year 160 kg/ha/application
Dryland dairies	Hayburst™ 18% N and 2.5% P or Springburst™ 13.7% N and 2.6% P	200 to 300 kg/ha per year
Irrigated beef	Grazeburst™ 25.3% N and 3.9% P	8 to 9 applications per year 120 kg/ha/application
Dryland beef	Highly varied. Includes Springburst™ 13.7% N and 2.6% P; Hayburst™ 18% N and 2.5% P; urea and other NPK mixes	Varies significantly with individual properties.
Blue gum plantations	Agras™ 16.1% N and 9.1 % P	200 kg/ha at establishment then 1 to 2 times over next the 5 years at 200 to 300 kg/ha

Table 4.4 Average annual fertiliser application rates and total nitrogen and phosphorus input loads for Scott River land uses (Hall 2010).

Land use	Input rate		Area	Total input load	
	Phosphorus (kg/ha/yr)	Nitrogen (kg/ha/yr)	(km^2)	Phosphorus (t/yr)	Nitrogen (t/yr)
Dryland beef	19.8	189.9	73.2	144.9	1390.1
Dryland dairy	21.5	241.5	12.6	27.1	304.3
Blue gums (<5 years old)	19.0	43.8	39.7	75.4	173.7
Irrigated beef	31.0	258.4	2.0	6.2	51.7
Irrigated dairy	76.5	604.5	14.6	111.7	882.6
Residential	6.6	27.4	0.6	0.4	1.6
Blue gums (>5 years old)	0.2	5.0	58.9	1.4	29.5
Cleared land	0.5	0.0	16.7	0.9	0.0
Roads	1.6	25.0	8.6	1.4	21.5
Native vegetation	0.7	21.3	462.3	34.0	984.7
Subtotal: diffuse sources				**403.4**	**3840**
Point sources (dairy sheds and feedlot)				1.3	6.4
Septic systems				0.2	1.1
Total				**404.9**	**3847.2**

Water quality modelling

The software package ‘Source Catchments’ (eWater 2010) was used for the water quality modelling process. Source Catchments is specifically designed for hydrologic and constituent modelling at whole-of-catchment scale and has been used for similar projects in many other Australian water catchments. A detailed explanation of the water quality modelling process is presented in Appendix A and documented in the report (Hall 2010).

The water quality modelling has enabled a breakdown of nutrient sources by land use and subcatchment to be estimated for the Scott River catchment. The model was calibrated with measured data from the water sampling program and the land use data was rigorously ground-truthed with help from DAFWA and Scott River farmers. This modelling information was based on the fertiliser input rates identified in Table 4.4, land use data, soils information, and water quality monitoring data that has been collected fortnightly in the catchment during the past 10 years. A breakdown of the source by land use has been provided for each of the seven subcatchments of the Scott River catchment (see Section 4.1). This approach has enabled hotspots of nutrient sources to be identified in the catchment both in terms of geographic location and specific land uses that may be contributing a disproportionate share of the overall nutrient load. This information was used to prioritise the management actions presented in this plan.

Nutrient sources by land use

Whole-of-catchment sources

Tables 4-5 and 4-6 present the modelled phosphorus and nitrogen load for each land use, the load per unit area generated by these land uses and the area they occupy in the catchment. Land uses in each table have been listed in order of highest to lowest phosphorus or nitrogen load. Some land uses in the catchment clearly contribute a disproportionate share of the nutrient load, given the area of land they occupy. Using pie charts, figures 4.6 and 4.7 illustrate the proportions of phosphorus and nitrogen loads generated by each land use.

Irrigated dairy paddocks are estimated to contribute the largest overall load of phosphorus from the catchment and the second-highest phosphorus load per unit area. They occupy only two per cent of the catchment area. In contrast, dryland beef (including mixed beef/sheep paddocks) are estimated to contribute slightly less phosphorus but with a much lower phosphorus load per unit area. They occupy more than 10 per cent of the catchment area.

Establishing blue gums (under five-year-old) are also estimated to be a significant source of phosphorus and while they have a similar load per unit area to dryland beef, they occupy a smaller area of the catchment.

Dairy sheds, native vegetation and irrigated beef are each estimated to contribute a smaller proportion of the overall phosphorus load compared with other land uses, though dairy sheds are estimated to contribute the third-highest phosphorus load per unit area. The lowest load of phosphorus was estimated to be delivered by the combined residential areas of Molloy Island and roads, while the lowest load per unit area of phosphorus was likely to be generated by native vegetation and established (more than five-year-old) blue gums. Despite the low load per unit area generated by native vegetation, the total load of phosphorus delivered was still estimated to be higher than five other land uses. This is because native vegetation occupies the largest overall area of the Scott River catchment. While a natural source, very small amounts of phosphorus are generated as a result of the breakdown of leaf litter and other organic matter in remnant bushland areas.

The dominant sources of nitrogen in the catchment differ from the phosphorus sources. The contributions from nitrogen-fixing plants (e.g. clover) and native plants that also fix nitrogen (e.g. acacia species) have also been included. Dryland beef is predicted to be the largest source of nitrogen from the catchment but generates the second-largest load of nitrogen per unit area. Irrigated dairy is predicted to deliver the next-largest overall load of nitrogen and the largest load per unit area. Native vegetation is estimated to contribute the third-largest overall load of nitrogen but by far the smallest load per unit area, noting that it occupies the greatest proportion of the catchment (66.7 per cent). Non-established blue gums are estimated to contribute a slightly smaller load of nitrogen than native vegetation. Dryland dairy paddocks are also estimated to be important contributors of the nitrogen load. The balance of the nitrogen load is estimated to be contributed by the combined smaller contributions of the remaining land uses in the catchment.

Table 4.5 Modelled annual phosphorus load, annual load per unit area and land use area for Scott River land uses

Land use **(listed in order of highest to lowest phosphorus load)**	**Phosphorus load (tonnes)**	**Load per unit area (kg/ha P)**	**Area (km^2)**
Irrigated dairy paddocks	3.99	2.73	14.6
Dryland beef/mixed grazing	3.53	0.48	73.2
Blue gums (immature)	2.08	0.52	39.7
Dryland dairy paddocks	0.84	0.67	12.6
Native vegetation	0.34	<0.01	462.3
Dairy sheds	0.19	0.95	2.0
Irrigated beef	0.14	0.70	2.0
Blue gums (mature)	0.04	0.01	58.9
Feedlot	0.03	0.31	<1.0
Roads and residential	0.02	0.02	9.2
Total	**11.21**		

Table 4.6 Modelled annual nitrogen load, annual load per unit area and land use area for Scott River land uses

Land use (listed in order of highest to lowest nitrogen load)	**Nitrogen (tonnes)**	**Load per unit area (kg/ha N)**	**Area (km^2)**
Dryland beef/mixed grazing	31.8	4.34	73.2
Irrigated dairy paddocks	13.9	9.52	14.6
Native vegetation	12.3	0.27	462.3
Blue gums (immature)	11.0	2.77	39.7
Dryland dairy paddocks	5.0	3.97	12.6
Blue gums (mature)	2.6	0.44	58.9
Dairy sheds	0.8	4.00	2.0
Irrigated beef	0.4	2.00	2.0
Roads and residential	0.4	0.43	9.2
Feedlot	0.1	0.67	<0.1

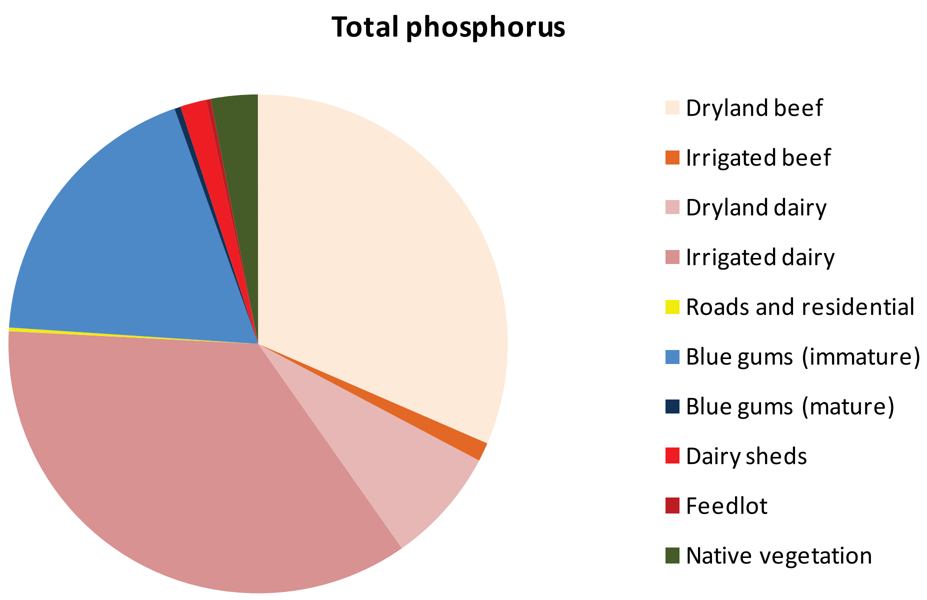


Figure 4.6 Sources of phosphorus by land use for the Scott River catchment

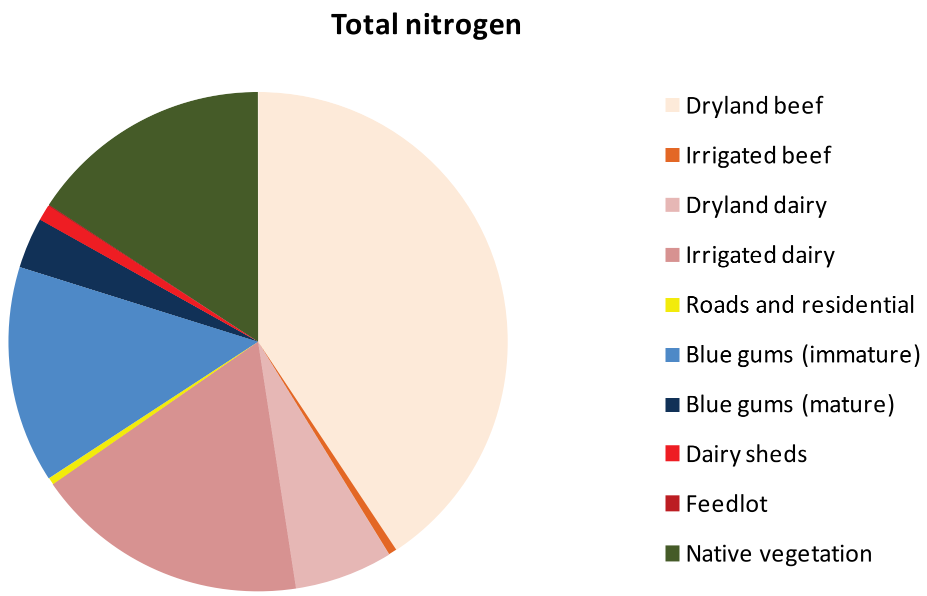


Figure 4.7 Sources of nitrogen by land use for the Scott River catchment

Nutrient hotspots

A subcatchment analysis of the phosphorus and nitrogen loads provides valuable information about nutrient hotspots in the catchment. Since water quality sampling points are not located at the base of each subcatchment, modelled data has been generated to enable the comparison of these loads from each subcatchment. Figure 4.8 presents the locations of each subcatchment. Figures 4.9 and 4.10 present the results of modelled loads of phosphorus and nitrogen for each subcatchment, taking account of concentration and flow information.

The Four Acres subcatchment contributes the largest load of phosphorus, followed by Middle Scott then Dennis. The Upper Scott, Governor Broome and Lower Scott subcatchments all contribute smaller and roughly equivalent phosphorus loads. The Middle Scott subcatchment contributes the largest load of nitrogen followed by the Dennis, Four Acres and Upper Scott subcatchments. The Lower Scott and Governor Broome subcatchments are much smaller, though still-important contributors of nitrogen. In contrast, the loads of both nitrogen and phosphorus from Molloy Island are negligible and are therefore barely visible on these graphs.

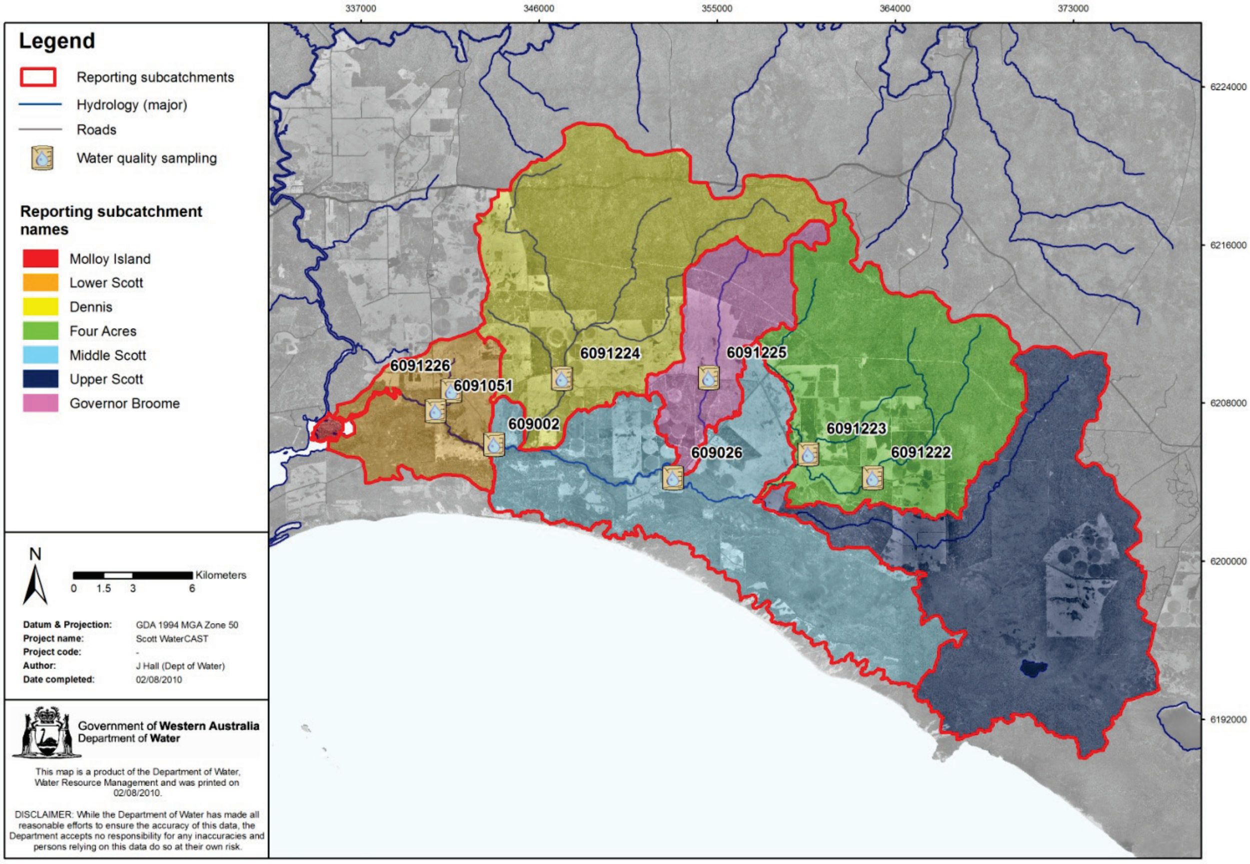


Figure 4.8 Locations of Scott River subcatchments

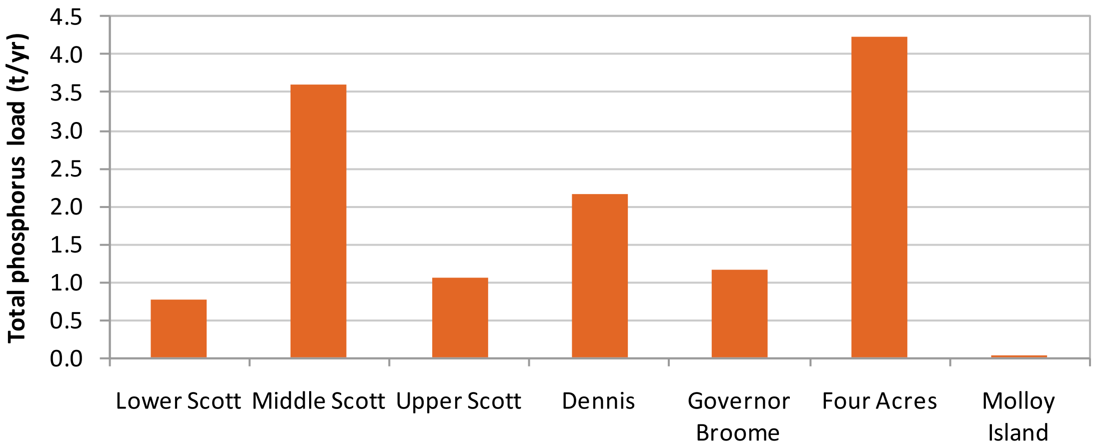


Figure 4.9 Modelled phosphorus load from Scott River subcatchments

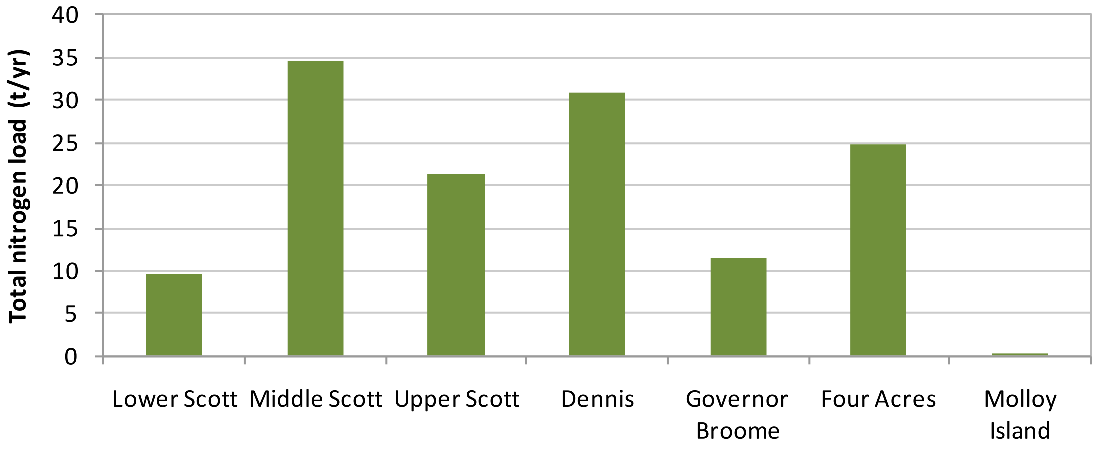


Figure 4.10 Modelled nitrogen load from Scott River subcatchments

Nutrient sources in each subcatchment

Water quality modelling tools have been used to identify the sources of phosphorus and nitrogen derived from each subcatchment. Proportions of nutrients assigned to different land uses are quite different across the subcatchments. The nutrient sources from each subcatchment are briefly summarised below. This information is presented in order of highest to lowest total subcatchment phosphorus load contribution and summarised in Table 4.7.

Four Acres

The Four Acres subcatchment is the most significant hotspot for phosphorus in the Scott River catchment and also contributes a large nitrogen load. More than half the phosphorus load in this subcatchment is derived from irrigated dairy paddocks (Figure 4.11). Further investigations are needed to identify the reasons for the high contribution of phosphorus from these dairy paddocks, though it is possible that deep drains have contributed to an increased rate of nutrient export. Immature blue gums, a dominant land use in this subcatchment, are also a major source of phosphorus. Dryland beef and dairy contribute smaller but still-important phosphorus loads while those contributed by native vegetation and dairy sheds are small. Key sources of nitrogen in this subcatchment are immature blue gums, irrigated dairy, dryland beef and native vegetation.

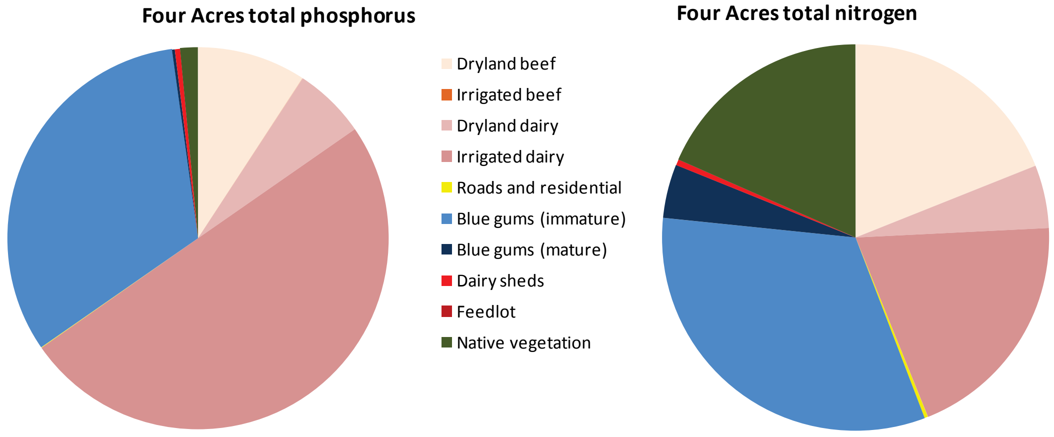


Figure 4.11 Sources of phosphorus and nitrogen from the Four Acres subcatchment

Middle Scott

The Middle Scott subcatchment contains a large extent of the main Scott River channel. This subcatchment contributes the second-greatest phosphorus load in the Scott River catchment and the greatest nitrogen load. Dryland beef and irrigated diary are by far the largest contributors to the phosphorus load, with a smaller but significant fraction also derived from irrigated beef. More than half the nitrogen load from Middle Scott is derived from dryland beef, though other significant sources are irrigated dairy and native vegetation. Irrigated beef also makes an important contribution to both the nitrogen and phosphorus loads in this catchment.

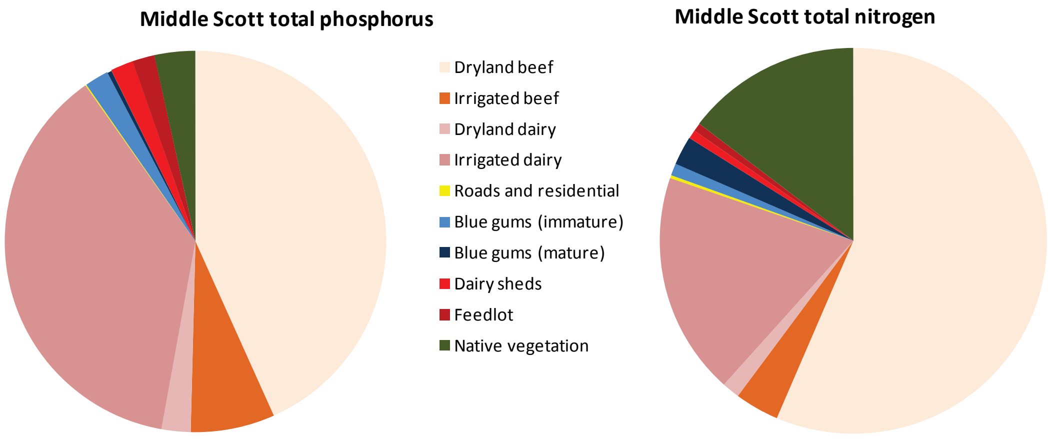


Figure 4.12 Sources of phosphorus and nitrogen from the Middle Scott subcatchment

Dennis

The Dennis subcatchment contributes the third-largest phosphorus load and the second-largest nitrogen load to the Scott River system. Dryland beef and irrigated dairy are the two most important sources of both nutrients in this subcatchment, followed by immature blue gums. Native vegetation is also a significant source of nitrogen, owing to the large amount of remnant bushland.

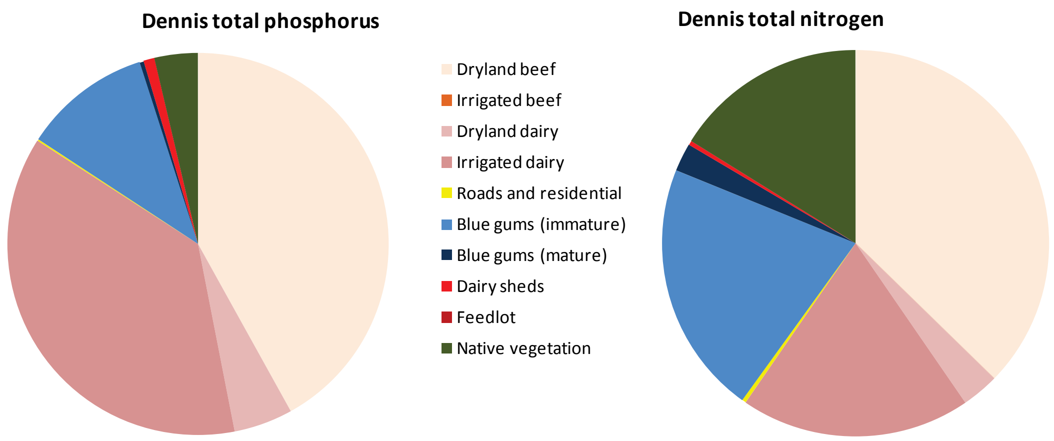


Figure 4.13 Sources of phosphorus and nitrogen from the Dennis subcatchment

Governor Broome

The Governor Broome subcatchment is small in size and located in the centre of the Scott River catchment. Owing primarily to its small size, the phosphorus and nitrogen loads from this subcatchment are moderate. The key sources of both phosphorus and nitrogen are dryland beef and immature blue gums, with dryland and irrigated dairy also making important contributions to both nutrient loads. Notably, the proportion of phosphorus and nitrogen loads contributed by dairy sheds is much higher in this subcatchment than other subcatchments. This is likely to be due to a smaller overall area of cleared agricultural land in this subcatchment, thereby reducing the proportion of diffuse sources of nutrients in comparison with other larger subcatchments.

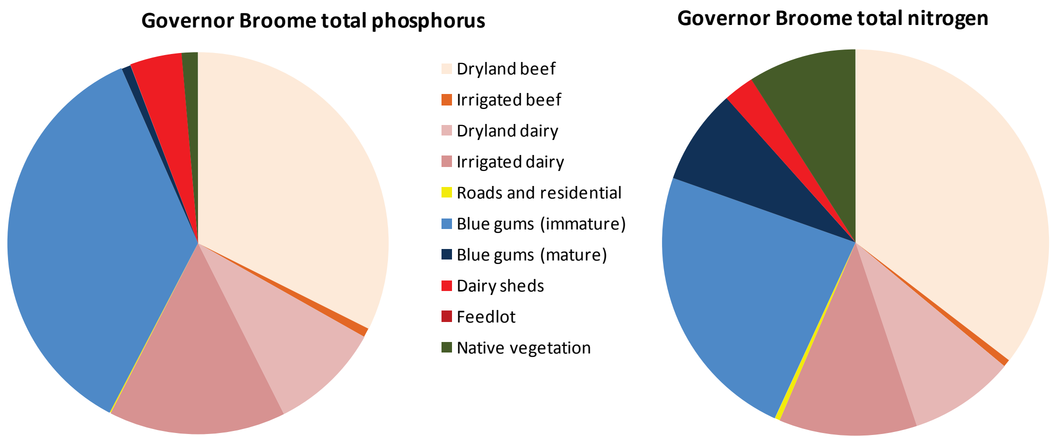


Figure 4.14 Sources of phosphorus and nitrogen from the Governor Broome subcatchment

Upper Scott

The Upper Scott subcatchment retains a large proportion of remnant vegetation and contains the upper reaches of the main Scott River channel. Key sources of both phosphorus and nitrogen are dryland beef, dryland dairy and irrigated dairy. Immature blue gums and dairy sheds are also important sources of phosphorus in this subcatchment. Native vegetation contributes a large proportion of the nitrogen load, owing to the high proportion of remnant vegetation retained.

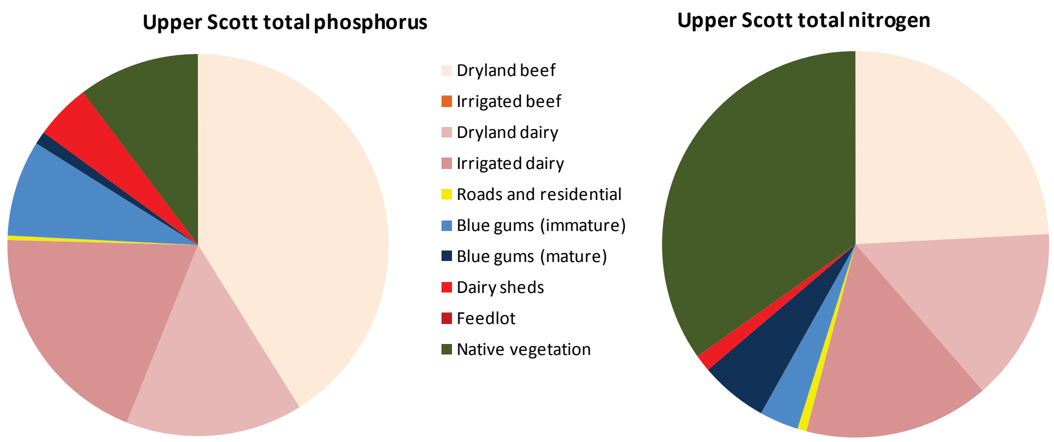


Figure 4.15 Sources of phosphorus and nitrogen from the Upper Scott subcatchment

Lower Scott

The Lower Scott subcatchment occupies a small area at the base of the Scott River catchment. It contains the lowest reaches of the main Scott River channel. A large proportion of the land to the south of the river is native vegetation. Lower Scott contributes the second-lowest load of both phosphorus and nitrogen (the lowest is from Molloy Island). The majority of phosphorus and nitrogen from Lower Scott is derived from dryland beef, though dryland dairy is also an important source of both nutrients.

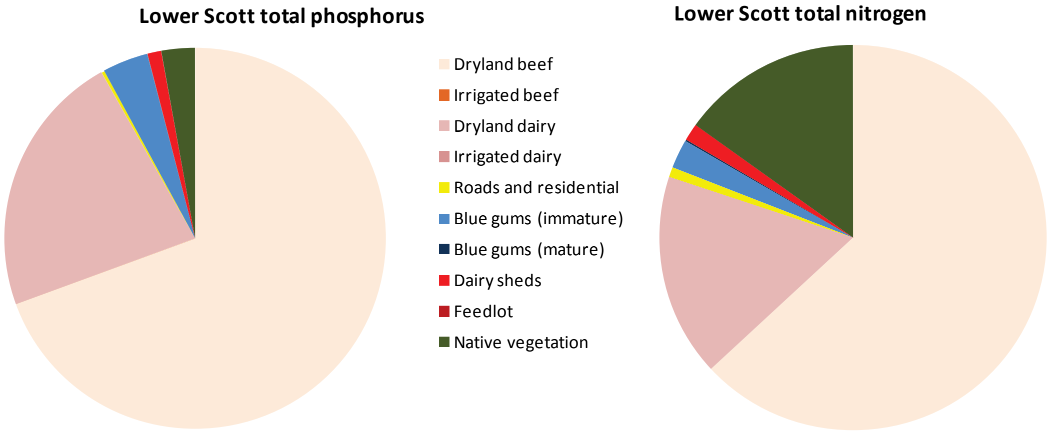


Figure 4.16 Sources of phosphorus and nitrogen from the Lower Scott subcatchment

Molloy Island

Molloy Island occupies a very small proportion of the Scott River catchment area and retains a large proportion of native vegetation. The total load of both phosphorus and nitrogen from this subcatchment is negligible compared with other subcatchments. The only land use on the island other than native vegetation is roads and residential (lifestyle housing). This land use delivers the vast majority of phosphorus load from the island and more than half the nitrogen load. Native vegetation is also an important source of nitrogen.

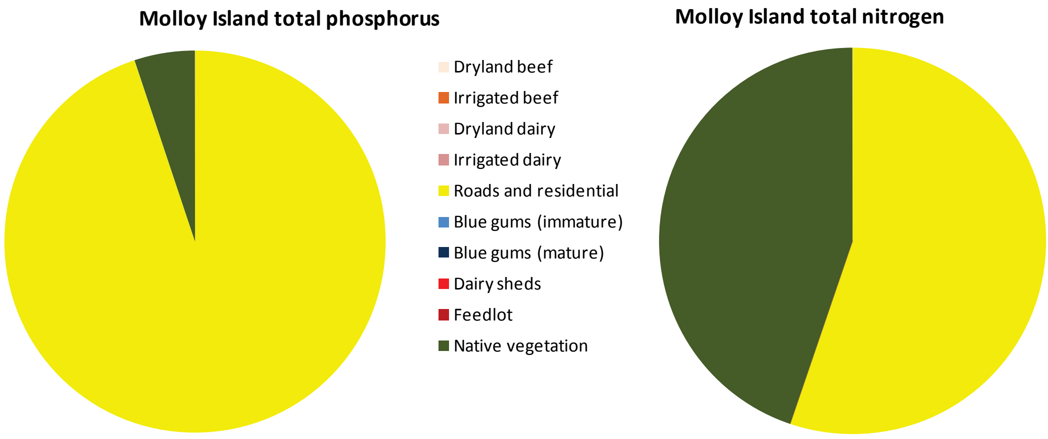


Figure 4.17 Sources of phosphorus and nitrogen from the Molloy Island subcatchment

Table 4.7 Land use nutrient-load contributions for reporting subcatchments and for the outlet of the Scott River catchment

Land use	Lower Scott	Middle Scott	Upper Scott	Dennis	Governor Broome	Four Acres	Molloy Island	Total	Outlet
Average annual total phosphorus load (tonnes)									
Dryland beef	0.54	1.56	0.43	0.91	0.38	0.39	0.00	4.21	3.53
Irrigated beef	0.00	0.26	0.00	0.00	0.01	0.00	0.00	0.27	0.14
Dryland dairy	0.18	0.09	0.16	0.11	0.11	0.26	0.00	0.90	0.84
Irrigated dairy	0.00	1.35	0.20	0.81	0.17	2.11	0.00	4.64	3.99
Roads and residential	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.02
Blue gums (immature)	0.03	0.07	0.09	0.24	0.42	1.37	0.00	2.21	2.08
Blue gums (mature)	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.05	0.04
Dairy sheds	0.01	0.07	0.05	0.02	0.05	0.02	0.00	0.22	0.19
Feedlot	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.07	0.03
Native vegetation	0.02	0.12	0.11	0.08	0.02	0.06	0.00	0.41	0.34
Total	0.78	3.61	1.05	2.17	1.17	4.22	0.01	13.01	11.21
Average annual total nitrogen load (tonnes)									
Dryland beef	6.1	19.5	5.1	11.5	4.1	4.7	0.0	51.1	31.8
Irrigated beef	0.0	1.3	0.0	0.0	0.1	0.0	0.0	1.3	0.4
Dryland dairy	1.6	0.5	3.1	1.0	1.0	1.3	0.0	8.5	5.0
Irrigated dairy	0.0	6.4	3.3	5.9	1.3	4.9	0.0	21.9	13.9
Roads and residential	0.1	0.1	0.2	0.1	0.0	0.1	0.0	0.6	0.4
Blue gums (immature)	0.2	0.3	0.7	6.5	2.7	8.1	0.0	18.6	11.0
Blue gums (mature)	0.0	0.8	1.2	0.7	0.9	1.1	0.0	4.8	2.6
Dairy sheds	0.1	0.3	0.3	0.1	0.3	0.1	0.0	1.2	0.8
Feedlot	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.1
Native vegetation	1.5	5.1	7.4	5.0	1.0	4.6	0.0	24.6	12.3
Total	9.6	34.5	21.3	30.8	11.6	24.9	0.1	132.9	78.1

5 Comparing management options

5.1 Nutrient management practices: definitions, limitations and benefits

Available management tools

A review of the potential on-ground management tools appropriate for the Scott River catchment identified five key options:

- fertiliser management
- riparian management
- effluent management
- soil amendment
- retrofitting rural drains.

A detailed discussion of each of these management tools follows.

Improve fertiliser management throughout the catchment

Definition

Best-management practices for fertiliser management include:

- conducting regular (annual) soil testing to determine the required nutrients and soil pH to meet crop, pasture or animal needs, and to ensure that soil-nutrient test levels do not exceed specified thresholds (i.e. no more than 10 per cent above the critical level for that soil)
- conducting regular plant-tissue testing during the growing season to detect and correct nutrient deficiencies – this will ensure that nitrogen and phosphorus have the best-possible uptake
- for dryland grazing: applying fertiliser after the break-of-season, preferably in split applications
- applying fertilisers at the times of year that nutrient requirements are greatest
- having unfertilised buffers between fertilised areas and watercourses
- using a calibrated fertiliser spreader to ensure even and accurate application rates
- avoiding fertilising when intense rainfall is forecast within the next two days
- avoiding fertilising firebreaks
- applying nutrients according to the recommendations of soil or tissue testing
- providing covered areas for stored fertiliser
- using a low-water-soluble phosphorus fertiliser on sandy soils when available on the market

- applying sufficient lime to ensure that pH levels are above 5.5 in the top 10 cm of soil
- using nutrient budgeting to help make fertiliser decisions.

Benefits

Achieving best-practice fertiliser management enables farmers across a broad range of land uses to maximise productivity while minimising losses of nutrients to local waterways. Best-practice fertiliser management is likely to deliver a net financial benefit to farmers across all Scott River subcatchments with a very low capital cost for implementation.

Current uptake

A recent survey of soil nutrient status from 31 farms between Scott River and Peel Harvey identified that between 61 and 91 per cent of the sampled paddocks did not require phosphorus fertiliser, but rather needed either potassium or lime or both (Richards 2010). These figures suggest there is potential for substantial improvements in fertiliser management in the Scott River catchment, as well as other areas of the south-west.

Barriers to adoption

- Lack of nutrient-budgeting tools and consistent advice from the fertiliser industry.
- Limited knowledge about appropriate rates of fertilisation for blue gums.
- Limited ongoing technical advice regarding nutrient management.

Limitations

Fertilisers account for only a proportion of the diffuse nutrient sources on farms. Other major sources include imported feed and manure and fixation for nitrogen. In addition, the amount of fertiliser required to maintain production levels on most farming systems is still likely to result in nutrient export well above that which would occur under natural (pre-clearing) conditions.

Advice for implementation

- Provide farmers with regular educational opportunities to build their understanding of how to interpret soil-test results.
- Support the development of nutrient-accounting packages and other tools that allow farmers to independently assess their fertiliser and nutritional requirements.
- Undertake demonstrations and case studies associated with best-management practices.
- Undertake fertilisation trials on blue gum plantations to increase knowledge about efficient use of fertiliser in this industry.

Implications for investment

Implementation would involve a very low capital cost. Costs of implementation would be balanced by net financial gains by farmers, though up-front funding would be needed for:

- research and development to assess appropriate rates of fertilisation for blue gum plantations across a variety of soil types
- coordination of extension programs
- cost of redevelopment of soil phosphorus assessment tools
- development of farm fertiliser management plans
- workshops and other educational opportunities
- management, monitoring and reporting of demonstration projects and case studies.

Specific catchments for implementation

All Scott River subcatchments (apart from Molloy Island).

Implementing riparian management and stock control

Definition

Best-practice riparian management includes:

- the fencing of streams and drains (a 15 m buffer either side of a stream is recommended as a minimum)
- rehabilitation and revegetation
- stock exclusion (where stock are present)
- construction of stock and vehicle crossings
- the provision of off-stream watering points.

Benefits

Riparian management prevents stock access to streams and drains, thereby preventing direct fouling and erosion. Grass-based vegetation strips alongside streams and rivers act as sediment traps, helping to filter a proportion of the nutrient-rich soil particles washed off paddocks (Keipert 2007).

Fringing native vegetation in the riparian zone provides shade throughout the year, which helps to keep water temperature low, and contributes hard tannin-rich leaves to fuel the food web. Tannins also play a role in limiting light penetration, thereby building resilience against algal blooms. They are particularly important in the Scott River, since it is believed that high tannin concentrations have prevented algal blooms in the river where they might otherwise have flourished – given the high measured concentrations of phosphorus and nitrogen. Riparian vegetation also helps to stabilise the banks of waterways, thereby reducing erosion, and is a source of woody debris and leaf litter that both provide important habitat for aquatic fauna. An extensive discussion of the benefits of riparian vegetation can be found in Pen (1999).

This management practice is not limited to particular land uses and has substantial ecological spin-offs with regard to habitat restoration. These are important considerations in the Scott River catchment where the main river channel retains important ecological values.

Although this plan's focus is necessarily on the reduction of nutrients, the intent is to improve water quality overall, which includes the protection of river aquatic habitat and restoration of degraded streams. Riparian vegetation establishment and management are essential to achieving these outcomes.

Current uptake

Funding and technical assistance for riparian management has previously been available to farmers in the Scott River catchment, yet the uptake has been low.

Barriers to adoption

- Very high capital cost for implementation.
- A need for improved data to determine the accuracy of the modelled nutrient-removal efficiency.
- Long-term maintenance costs and additional management requirements such as feral animal control, weed management, drain maintenance and fire management in excluded areas.
- May require farm-plan redesign on smaller streams.

Limitations

Although riparian management has previously been widely implemented in the south-west, research by DAFWA indicates that its best application is for reducing sediment-bound phosphorus from hills catchments with heavy soils (McKergow et.al. 2003; Steel et. al. 2009). In sandy catchments such as the Peel Harvey, most nutrients are transported in a dissolved form, usually in the subsurface groundwater layer that may bypass the riparian zone. The Scott is a wetter catchment and in waterlogged areas, recharge rejection or saturation by excess flow is the primary mechanism of runoff generation. Therefore, surface transport of both dissolved and particulate phosphorus may be a significant pathway − in which case riparian zones may have a greater effect than in the Peel Harvey.

It is likely that restoration of riparian zones on minor tributaries and paddocks in the Scott River catchment will have only a limited impact on overall nutrient export; however, carefully targeted riparian zone establishment (especially in waterlogged areas) may have nutrient-reduction benefits. It would also be effective at reducing sediment and associated nutrient loads from plantations during harvesting when large-scale soil disturbance occurs. Riparian management also restores important biological functions in waterways, a key aim of this plan. The apparent effectiveness of the main Scott River channel's riparian zone at reducing nitrogen and phosphorus concentrations lends weight to the potential benefit of restoring vegetation along creek lines. The key reason for inclusion of riparian management as a recommendation in this plan is for the improvement of biological function within the wider Scott River system.

Advice for implementation

- Undertake a survey of the Scott River's foreshore vegetation and its tributaries. Use the survey information to:

  - identify priority areas that are viable for restoration, focusing on linking gaps in riparian vegetation on the main river channel and lower sections of the adjoining tributaries
  - develop appropriate species lists for revegetation of the foreshore
  - engage with landholders of priority areas identified for restoration.
- Implement a high-level cost-sharing arrangement for riparian management which should include contributions to farm re-fencing and infrastructure redesign.
- Widely promote the benefits of riparian management to farmers through awareness programs and demonstration sites on minor streams.
- Maintain existing riparian zone vegetation in all the catchment's waterways.

Implications for investment

Implementing riparian management requires very high up-front capital costs. It requires landholders to take land around streams out of production and also has ongoing maintenance and management costs.

The impact of riparian management on nutrient transport for pastures in the Scott River catchment has not yet been established, as few comprehensive studies have been undertaken in Western Australia. Two published studies, one looking at the state's south coast and another the Peel-Harvey catchment, show widely varying water quality responses to the practice. Local data collected within the Scott River catchment would help to clarify the water quality response and reduce the risk associated with investment in riparian management. The link between the extent and condition of riparian vegetation and river function is well-established nationally.

Despite these costs and uncertainties, riparian management has other significant ecological benefits and is therefore still an important action for implementation. Given the high cost of implementation, a prioritised approach is likely to be required.

Specific catchments for implementation

An on-ground survey is required to identify priority sites for restoration.

Improving effluent management from dairy sheds and feedlots

Definition

Effluent management includes the collection, conveyance, storage, treatment and re-use of solid and liquid wastes. Best-practice dairy and feedlot effluent management should include the following elements as a minimum:

- containment and storage of effluent for application onto actively growing pasture during spring and summer
- settlement of solids from effluent in a pond (preferably lined or ideally in a concrete basin) or sump
- irrigation of effluent onto pasture or wood lots during spring or summer

- replacement of fertiliser with the irrigated effluent.

Please note: if ponds or sumps for removing solids from the waste stream are absent, then pump and sprinkler failure can occur. Such systems are not sustainable and are therefore not recommended as best practice.

Benefits

Approximately 10 to 15 per cent of nutrient problems arising from dairies are located in and around the dairy shed, with the remaining 85 to 90 per cent derived from diffuse nutrient transport from the farm (Keipert 2007). Therefore the maximum nutrient reduction from effluent management at the dairy shed is about 10 per cent of that produced on the whole farm. For fully shedded industries such as feedlots, as much as 100 per cent of effluent-produced nutrients could be managed.

For the Scott River catchment, effluent management is estimated to reduce phosphorus exports to the estuary by 0.11 t/yr. Although this is a relatively small quantity, the discharge has an extremely high concentration and is thus likely to affect local waterways. In addition, coliforms and other faecal contaminants are exported with dairy effluent, which can pose a threat to the environment and human health.

Current uptake

There are six dairies and one feedlot in the Scott River hydrological catchment. While none of these meet best-practice standards, one dairy does have a large settlement pond system. Effluent from these ponds is not completely irrigated to pasture and it is not clear whether leakage of these ponds to the superficial aquifer is a problem.

Barriers to implementation

- High up-front capital cost required to ensure implementation of low-maintenance systems.
- Limitations posed by the sandy, waterlogged soils characteristic of the Scott River catchment may complicate the effective design of effluent systems and increase costs in comparison with other areas.
- Most systems require some form of ongoing maintenance to ensure effective operation.

Limitations

Effluent management at dairies and feedlots addresses about 10 per cent of the total farm effluent. The balance accumulates in paddocks (where cattle spend most of their time) and is subsequently then washed or leached to drainage systems. Winter waterlogged conditions such as those experienced across much of the Scott River catchment have the potential to complicate effective effluent management. Direct irrigation of effluent to waterlogged areas is inappropriate and thus storage of winter effluent is required. Many of the dairies in the Scott River catchment are also very large and need to store large volumes of effluent. Storage of effluent throughout the winter is also very difficult in waterlogged conditions since leakage from holding ponds can occur. The cost of effluent management is therefore likely to be higher in the Scott River catchment than in other areas. On-site investigations would be needed for individual farms to assess viable design options.

Large capital costs and the requirement for ongoing maintenance to ensure effective operation of effluent systems has been a barrier to the installation and effectiveness of these systems in the past. It has been proposed that cost-sharing arrangements be undertaken to implement these systems, and industry-based approaches be used to promote these practices.

Advice for implementation

- Undertake an initial feasibility assessment of all effluent systems in the catchment to ascertain limitations and the likely costs associated with implementation.
- Provide cost-sharing arrangements to implement or upgrade to best-practice dairy effluent management.
- Widely promote the benefits of effluent management to farmers through awareness programs and demonstration projects.
- Adopt an industry-based approach to promote the implementation of best-management practices.
- Review and revise the dairy industry's codes of practice.

It should be noted that future programs involving cost-sharing arrangements for dairy effluent management should ensure maximum value is achieved – by only funding systems that meet best-practice effluent management standards. Lower-grade systems that exclude solids removal should not be funded.

Implications for investment

The cost/benefit analysis (Hall 2010) identified that effluent management upgrades were associated with the largest capital costs of all of the evaluated best-management practices and would deliver only a small reduction in phosphorus load (three per cent of the required target). Given the hydrological limitations of the Scott River catchment, an initial feasibility assessment is recommended. This would potentially also include geotechnical assessments at each site.

Implementation costs will involve:

- An initial assessment of the feasibility of best-practice effluent management at each dairy in the catchment.
- Cost-sharing arrangements to help with the capital costs of implementation (including geotechnical investigations, upgrading/modifying systems without ponds and sumps and developing appropriate designs for individual systems).
- Technical advice and extension to encourage uptake.
- Case study monitoring.

Specific catchments for implementation

One dairy is located in each of the agricultural reporting catchments; none currently meet best-practice standards. All catchments that contain dairy sheds should be targeted for implementation, subject to the outcomes of a feasibility study (Lower Scott, Middle Scott, Dennis, Four Acres and Upper Scott).

Using approved soil amendments on sandy soils

Definition

This practice generally involves applying high-phosphorus-fixing materials to sandy soils to improve their phosphorus-retention capacity and thereby reduce phosphorus leaching. Some amendments also have the potential to mitigate nitrogen leaching. Soil amendments include:

- loams and clayey soils with high iron and aluminium content (high PRIs)
- lime (increases pH of soils and availability of major nutrients – nitrogen, phosphate and potassium)
- gypsum (good sources of sulfur, mainly used on clayey soils)
- industrial by-products that have very high PRIs and no adverse environmental impacts.

Potential soil amendment options in the Scott River catchment include the use of Iron Man Gypsum (or neutralised used acid – NUA). Iron Man Gypsum is a by-product of the production of synthetic rutile by the mineral sands mining company Iluka Resources Pty Ltd. Depending on both the application and fertilisation rates the product would need to be reapplied within 10 years (Wendling & Douglas 2010). Iron Man Gypsum has been extensively tested by CSIRO for nutrient reduction, water retention, soil properties, potential leachates and potential toxicity and found to be environmentally benign. An extensive review of a range of mining by-products, such as Iron Man Gypsum and red mud, have been tested and reviewed by Wendling et al. (2010).

Alkaloam (also known as bauxite residue or red mud) is effective at reducing phosphorus leaching by 20 to 50 per cent (Rob Summers, pers. comm., April 2010) but is not yet available within an economically-viable distance from the Scott River catchment.

Initial investigations into soil amelioration using subsoil delving – mixing the higher-PRI subsoils into phosphorus-saturated topsoil (through soil tillage) – have been undertaken. Significant further research is needed to assess the benefits and impacts of this method.

Benefits

Improvements in pasture condition on sandy, less-productive land have been found as a result of bauxite-residue soil amendments, with commensurate increases in production levels and income.

Soil amendments can achieve a very high phosphorus-load reduction in catchments with a high proportion of sandy soils.

Recent studies have found NUA to be the most efficient mining by-product for the removal of phosphorus and nitrogen, in addition to having low ecotoxicity (Wendling & Douglas 2010). Iron Man Gypsum has been extensively tested on turf farms with high phosphorus fertilisation rates. It has yet to be tested for the effect on plant productivity at agricultural-scale application rates.

Current uptake

Trials using Iron Man Gypsum will be conducted by DAFWA, CSIRO and Iluka. The use of Iron Man Gypsum is encouraged on a trial basis for agricultural enterprises so that appropriate application methods and rates can be determined.

Barriers to adoption

- There is a general lack of commercially-available soil amendment products.
- There is no formal approval process for using mining by-products as soil amendments, although the Soil Amendment Working Group established under the *Fertiliser action plan* is working with the Department of Environment and Conservation (DEC) to develop an approval mechanism. However, since applications of less than 1000 tonnes per premises do not trigger a regulatory requirement, in effect, there is no regulatory restriction to applying Iron Man Gypsum or Alkaloam at agricultural-scale application rates.
- Alkaloam and Iron Man Gypsum products are not yet commercially available and the benefits in an agricultural setting are still being trialled. There is not yet a complete understanding of the productivity and paddock-scale phosphorus-reduction benefits or potential risks.
- The cost of transporting soil amendments over long distances can be prohibitive; for example, Alkaloam is not financially viable for use in the Scott River catchment due to the cost of transportation from the production location (Wagerup).

Limitations

- Iron Man Gypsum and Alkaloam need to be applied on a site-by-site basis and performance depends on a number of factors; for example, it is best applied where soil PRI is low throughout the soil profile and where subsurface leaching is the main pathway for transport.
- Iron Man Gypsum is considered most effective when it can be tilled into the top 10 cm of the soil profile. Non-tilling application methods are yet to be tested.
- Iron Man Gypsum, or indeed most soil amendments, will only reduce phosphorus export on soils with a low PRI, so will have a low impact on loads from some locations in the Scott River catchment and a limited impact on nitrogen loads overall.

Advice for implementation

- Continue trials of NUA to confirm phosphorus export and pasture productivity benefits and long-term animal health effects, establish feasibility, and identify potential limitations and risks in a range of agricultural settings.

- Encourage and assist Iluka to seek formal approval for targeted use of NUA in the Scott River catchment once the outcomes of trialling and testing have been confirmed.
- Undertake promotion, education and demonstration of approved products and techniques where clear benefits can be demonstrated and risks have been evaluated.
- Encourage the use of NUA at establishing blue gum plantations, especially when the soils are ripped and mounded; as well as turf farms or public open space in urban areas.

Implications for investment

Soil amendments can deliver significant phosphorus-load reductions on sandy soils – with a low capital cost and strong economic returns for farmers over time. Further experimental work is needed to establish acceptance for the widespread use of NUA in the Scott River catchment. Costs for implementation are therefore associated with:

- experimental trials and monitoring
- on-site assessments on a paddock basis to determine suitability of application
- promotion, education and demonstration of approved products to farmers
- cost-sharing arrangements.

Specific catchments for implementation

Subject to the availability of approved products, the focus for implementation would be sandy soils with a low PRI. The cost/benefit analysis presented in this plan has identified priorities for implementation of soil amendments in the following catchments:

- Dennis
- Governor Broome
- Four Acres.

Retrofitting rural drains

Definition

Some rural drains in the Scott River catchment have been constructed in a way that maximises opportunities for nutrient export to the main river system. In particular, deep drains encourage subsurface flow and can result in increased transport of leached nutrients from the soil profile. Re-profiling drains to a shallow swale may have some water quality benefits. Yet such works need to be carefully assessed and designed, and should not be undertaken on larger arterial drains.

Benefits

Wide, shallow drains have less opportunity to intercept subsurface flows than deeper drains and are therefore less likely to accelerate transport of dissolved nutrients from paddocks to the river system. Shallow drains also have less risk of disturbing acid sulfate soils.

Current uptake

A limited amount of drain restoration has previously been undertaken in the Scott River catchment. These works have focused on the re-contouring and revegetation of drains.

Barriers to adoption

- High capital cost of earthworks.
- Wide, shallow drains require more land area than narrow, deeper drains.
- Limited monitoring information is available to demonstrate the effectiveness of drain retrofitting projects.

Limitations

Retrofitting projects should not be undertaken on large arterial drains where earthworks are likely to be very costly and/or where previous evaluations indicate that the water quality benefits may be limited.

Advice for implementation

- Assess the rural drains in the Scott River catchment to identify opportunities where water quality benefits are likely to result from changes to the drain profile. Use this information to develop a rural drainage plan for the Scott River catchment.
- Provide cost-sharing arrangements to implement the recommendations of the rural drainage plan.
- Undertake educational and promotional activities in the catchment to increase awareness of the water quality benefits of maintaining shallow-profile drains.

Implications for investment

Retrofitting of rural drains requires high up-front capital costs, primarily for initial earthworks and then stabilisation works such as re-planting to reduce erosion risks. A prioritised approach (using a drainage management plan) is likely to be required, though this will also need an initial investment using staff or consultants with the necessary technical skills.

Specific catchments for implementation

An on-ground assessment is required to identify priority sites for drain retrofitting.

5.2 Cost/benefit analysis

To support this plan, the Department of Water undertook a cost/benefit analysis of four different management scenarios. The analysis enabled a comparison of the likely reduction in phosphorus and nitrogen loads and the financial costs and returns associated with different combinations of management practices. A detailed explanation of the cost/benefit analysis process is provided in Appendix A.

Only those management practices with sufficient data on the nutrient-reduction benefits, costs and financial returns could be analysed. Such data was not available for retrofitting of rural drains and accordingly this management option was not evaluated. The analysis provided only a broad indication of the likely capital costs, annual financial returns and nutrient-reduction benefits associated with implementation. The results should therefore be used only to support further investigations into individual best-management practices on a farm-scale, since the costs and benefits of each management option will vary on a site-by-site basis.

The four scenarios compared were:

- **Scenario 1: Fertiliser management**: implementation of best-practice fertiliser management at all dairy and beef/mixed grazing farms. Note: blue gum plantations were not included in this scenario due to a lack of data on the specific fertiliser regimes suitable for blue gums across varied soil types. Recommendations for further research to enable the provision of high-level fertiliser management advice to this industry have been included in this plan.
- **Scenario 2: Fertiliser and effluent management**: fertiliser management as for scenario 1, in addition to five of the six dairies being upgraded to include best-management effluent systems. A sixth dairy (in the Four Acres subcatchment) has a settlement pond system in place, but on-site investigations are recommended to determine whether leakage of these ponds to the superficial aquifer is a problem.
- **Scenario 3: Fertiliser, effluent and riparian management**: fertiliser and effluent management equivalent to scenario 2, in addition to targeted riparian management. Targeted areas were selected on the basis of restoring gaps in existing riparian vegetation in the lower catchment, where restored areas would adjoin larger and continuous sections of vegetetated riparian zones with viable biological function. Estimates of these areas would need to be confirmed via an on-ground survey.
- **Scenario 4: Fertiliser, effluent, riparian management and soil amendment**: Fertiliser, effluent and riparian management as for Scenario 3, in addition to the application of soil amendment to targeted blue gum enterprises on low-PRI soils.

The cost/benefit analysis clearly demonstrated that scenario 1 (fertiliser management on all grazing pasture) is likely to achieve the largest overall reduction in phosphorus load with the lowest capital cost (Table 5.1, figures 5.1, 5.2). Implementation of this scenario alone is predicted to achieve nearly all (93 per cent) of the required total reduction in phosphorus load from the Scott River while also delivering a net financial benefit. Capital costs for implementation (the cost of fertiliser testing and technical advice) are more than offset by the savings in applied fertilisers. It is likely the large reduction in phosphorus export would reach 100 per cent of the required target if this management tool was also implemented on other land uses in the catchment, such as blue gum plantations. Fertiliser management is likely to make the greatest impact in the Four Acres, Middle Scott and Dennis subcatchments, where contributions from irrigated dairy pasture are significant (Figure 5.1).

Scenario 2 (fertiliser management and effluent management) only improved progress towards the phosphorus-load reduction target by three per cent, but cost an additional $900 000. The high cost of implementing effluent management is associated with the Scott River catchment's large dairies and the limitations of its hydrological features. Despite this, the implementation of effluent management is likely to benefit water quality in the minor creek lines of the catchment since effluent released from dairies is typically highly concentrated in both phosphorus and nitrogen and also contains faecal coliforms. A small economic return of about $50 000/yr (for all five dairies combined) was also predicted for the inclusion of dairy effluent management, largely due to replacement of fertilisers on paddocks that received irrigated effluent. The implementation of dairy effluent management on its own would make only a small reduction in phosphorus and nitrogen loads in each catchment compared with those removed by fertiliser management alone (Table 5.2).

Scenario 3 (fertiliser management, effluent management and targeted riparian management) also made only a small increase in the the proportion of phosphorus load removed, and cost an additional $430 000 with no annual return to farmers (Table 5.1). Decisions about riparian management in this catchment are best made on the basis of the need to improve the biological function of streams rather than the nutrient-stripping benefits. Riparian vegetation stabilises stream banks, reduces sedimentation, provides important habitat for aquatic and terrestrial fauna, contributes to the detrital food chain, and provides shade for waterways thereby keeping water temperatures low. It should be noted that the individual phosphorus-load reduction was only slightly lower for riparian management compared with effluent management, but cost less than half that of effluent management (Table 5.2).

Scenario 4 (fertiliser management, effluent management, targeted riparian management and targeted soil amendment) substantially increased the proportion of phosphorus load removed and cost an additional $470 000 (Table 5.1). On its own it is estimated that soil amendment would achieve 31 per cent of the required phosphorus-load reduction target and deliver an annual catchment-wide return to farmers of more than $700 000 (Table 5.2). Despite the apparent benefits, this scenario has been included primarily for speculation since local soil amendment products are not commercially available at present.

Table 5.1 Estimated costs and removal of phosphorus for each management scenario (figures in red indicate a cost while black text indicates a return).

Scenario	Description	Total capital cost	Annual benefit	Phosphorus load removed (t/yr)	% of phosphorus target achieved	Nitrogen removed (t/yr)
1	Fertiliser management for all beef/mixed grazing and dairy pasture	$113 000	$573 000	3.31	93%	3.50
2	Scenario 1 plus best-practice dairy effluent mgt	$1 013 000	$623 000	3.42	96%	4.20
3	Scenario 2 plus targeted riparian mgt	$1 442 000	$623 000	3.49	98%	7.30
4	Scenario 3 plus targeted soil amendment on blue gums on low-PRI soil	$1 912 000	$704 000	4.57	128%	7.80

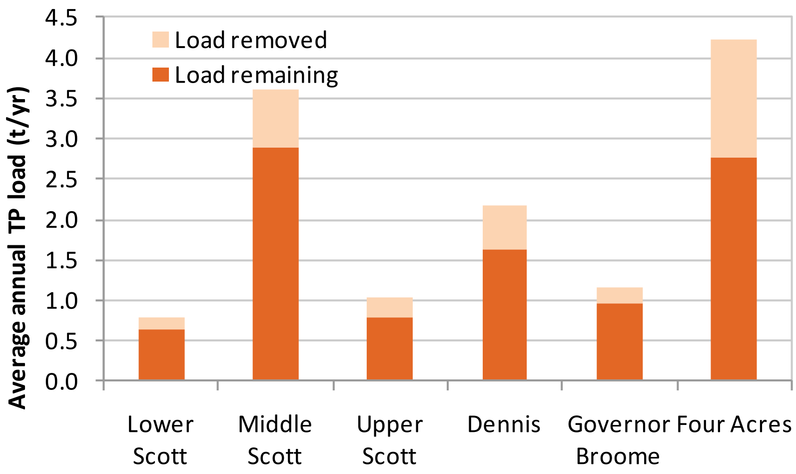


Figure 5.1 The estimated phosphorus load removed and remaining for scenario 1: fertiliser management on beef and dairy pasture for each subcatchment

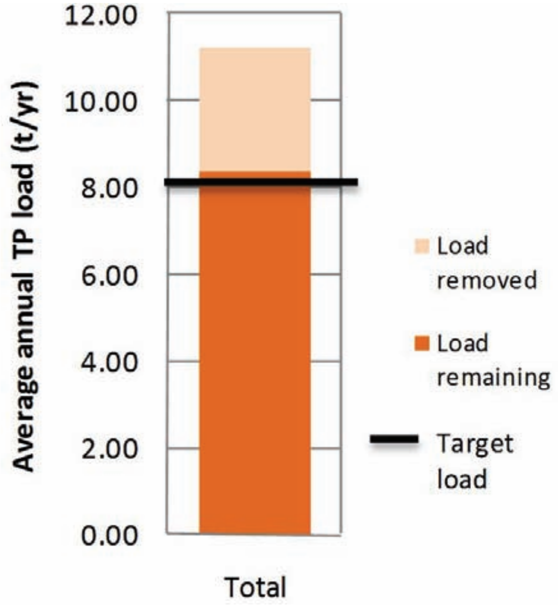


Figure 5.2 The estimated phosphorus load removed and remaining for scenario 1: fertiliser management on beef and dairy pasture for the Scott River catchment

Table 5.2 Estimated total costs and removal of phosphorus by individual best-management practices from each Scott River subcatchment

BMP	Phosphorus load removed (t/yr)	% of phosphorus target	Capital cost
Fertiliser management	3.31	93%	$113 000
Targeted soil amendment	1.09	31%	$470 000
Dairy effluent management	0.11	3%	$900 000
Targeted riparian management	0.10	2.8%	$430 000

6 Recommendations for nutrient management

6.1 Management messages arising from water quality modelling and cost/benefit analysis

The Department of Water's monitoring and modelling of land use sources of nutrients in the Scott River catchment have generated the following key messages with implications for water quality management:

1. Irrigated dairy currently contributes a disproportionate share of the phosphorus load to the Scott River (estimated 33 per cent) and comprises only two per cent of the catchment area. Most of this load is derived from surplus phosphorus in fertiliser applied in mixes with a nitrogen:phosphorus ratio that results in excess phosphorus being applied while meeting nitrogen requirements.
2. Dryland beef and mixed grazing is estimated to contribute 30 per cent of the phosphorus load, yet this contribution is more aligned with the overall area taken up by this land use in the catchment (10 per cent).
3. Blue gums are also a significant source of phosphorus, contributing an estimated 17 per cent of the total load and comprising a large area of the catchment at 14 per cent of the land area. About half of this area is immature blue gums (less than five years old), which provide more than 99 per cent of the phosphorus load from this land use.
4. Contributions of both nitrogen and phosphorus from Molloy Island are negligible.
5. The nutrient contributions from point sources (dairy and feedlot effluent) are a small fraction of those delivered by diffuse agricultural sources.
6. The Four Acres, Middle Scott and Governor Broome subcatchments are hotspots for phosphorus export.
7. Implementing fertiliser management alone on all pasture in the catchment has the potential to deliver up to 93 per cent of the required reduction in phosphorus at a low capital cost.

6.2 Catchment-wide recommendations

The recommended catchment-wide management measures to address sources of nutrients in Scott River catchment are outlined below. These are presented in order of importance, with the first three identified as being of critical importance and needing immediate implementation.

These catchment-wide management measures are complemented by and integrated with recommendations specific to each industry, as presented in Section 6.3; while advice for implementation of each management practice is provided in Section 5.2. The implementation strategy (Section 7.2) outlines more detailed actions to aid implementation of these management measures.

Critical management measures

1. *Implement best-practice fertiliser management across the catchment:* aim to achieve a 100 per cent adoption rate in the catchment.
2. *Investigate farm-scale nutrient hotspots in the catchment:* to further identify opportunities for on-site management of these nutrient sources.
3. *Carefully evaluate proposals for further intensification of land uses in the catchment:* ensure that nitrogen loads are not increased and that actions in this plan to reduce existing phosphorus loads are not offset by additional loads from new intensive enterprises.

Other management measures

4. *Develop and implement a rural drainage management plan for the Scott River*: assess the catchment's rural drains to identify opportunities and priorities for rural drainage works, with the aim to reduce nutrient exports to the Scott River while maintaining essential drainage functions. Implement priority drainage projects identified in the plan.
5. *Develop and implement a river action plan for the Scott River*: identify and implement priority areas for riparian management and restoration for the purposes of improving the wider Scott waterway system's biological function. Focus on areas with a high risk of sediment transport (e.g. heavy soils or adjacent to establishing blue gum plantations) and areas that link up existing high-quality riparian vegetation in the lower catchment.
6. *Assess and upgrade effluent management at dairies in the catchment*: undertake a feasibility assessment of all point sources of effluent in the catchment (currently six dairies and one feedlot) to identify opportunities, limitations and the likely costs of upgrading these systems to meet best-practice standards. Based on outcomes from the feasibility assessment, upgrade identified effluent management systems.
7. *Undertake paddock-scale trials of soil amendment*: when approved products are available, include advice about potential soil amendment options within fertiliser management programs.

6.3 Industry analysis and recommendations

Dairy farms

Summary of status and trends

At present there are six dairies in the Scott River catchment, including one dryland and five irrigated dairy farms. Some irrigated dairies also have dryland paddocks. Together they occupy approximately 2720 ha, or just below four per cent of the total catchment area.

Since the dairy industry was deregulated in 2000, the number of dairy farmers in Western Australia has decreased from 400 to 170. During this time the average dairy-farm size has doubled and is now the second-largest in Australia (after South Australia) at 256 ha (DAFWA 2009). These increases have been magnified in the Scott River catchment where the expansion of irrigated dairy farming has been enabled by the availability of high-quality Yarragadee groundwater. The deregulation of the dairy industry coincided with a time when irrigated potato growers in the catchment were leaving the industry due to the closure of the potato processing plant in Manjimup. These factors have combined to see some very large dairy farms develop in the Scott River catchment, some milking more than 1500 cows each. At least one dairy farm milks more than 2000 cows. This compares with the state average herd size of 330 (Western Dairy 2010). The large irrigated dairies include three Lactanz share farms (a fourth is located on the Scott Coastal Plain but is outside the hydrological catchment of the Scott River).

Dairy farms in the Scott River catchment make an important contribution to the state's milk supplies, but the size and intensity of these farms raises the risk of significant nutrient export. There is pressure to increase the number of irrigated dairies in the catchment, though this is limited by the availability of groundwater.

Nutrient loads

Dryland and irrigated dairy paddocks and dairy sheds in the catchment are predicted to contribute 5.0 tonnes of phosphorus and 19.7 tonnes of nitrogen per year to the Hardy Inlet (Table 6.1). When combined, these sources represent the largest contribution of phosphorus and the second-largest contribution of nitrogen to the Scott River. Of these totals 79 per cent of phosphorus and 72 per cent of nitrogen is derived from irrigated dairy paddocks. For phosphorus this contribution is disproportionate to the area of land these paddocks occupy, as reflected by the high load per unit area. In some subcatchments this proportion is much higher; for example, the Four Acres subcatchment is a nutrient hotspot, contributing the second-largest load of both phosphorus and nitrogen to the Scott River. Irrigated dairy contributes 50 per cent of the phosphorus load and 20 per cent of the nitrogen load from this subcatchment.

Dairy shed effluent contributes two per cent of the phosphorus and one per cent of the nitrogen load.

Table 6.1 Summary of nutrient loads from Scott River dairy farms

Land use	Phosphorus load			Nitrogen load		
	tonnes	% of catchment load	kg/ha	tonnes	% of catchment load	kg/ha
Dryland dairy paddocks	0.84	7	0.67	5.0	6	3.97
Irrigated dairy paddocks	3.99	36	2.73	13.9	18	9.52
All dairy paddocks	4.83	43		18.9	24	
All dairy effluent	0.19	2		0.8	1	
Total	5.02	45		19.7	25	

Nutrient sources on the farm

Major nutrient sources from dairy farms include fertilisers, on-paddock manure, imported feed and effluent from the dairy sheds. Nitrogen fixation from pasture such as clover is also a source of nitrogen. Of these, fertiliser is the most significant source of phosphorus.

A review of fertiliser application rates recorded by DAFWA surveys has identified that although nitrogen application rates appear reasonable, some Scott River dairy farmers are applying up to five times the required amount of phosphorus in fertilisers each year (Martin Staines, pers. comm., DAFWA). The error appears to be related to the use of products that have higher phosphorus:nitrogen ratios than required. Adjusting these fertiliser regimes would deliver significant cost savings to these farmers in addition to major reductions in phosphorus export.

Nutrient management actions and goals

Action	Ten-year management goals	Focus areas for implementation
Implement best-practice fertiliser management at all dairy farms in the catchment.	100% adoption of best-practice fertiliser management across all dairy farms in the catchment.	All subcatchments except Molloy Island.
Subject to a feasibility assessment, implement best-practice effluent management at all dairies in the catchment.	Best-practice effluent management in place at all dairies in the catchment.	All subcatchments except Molloy Island.
Implement targeted riparian management.	Where relevant, implementation of all high-priority riparian management as identified in a river action plan for the Scott River.	Sections of tributaries that link up or extend existing areas of high-quality riparian vegetation.
When approved products are available, implement targeted soil amendment on soils with low PRI.	Trials in place to evaluate soil amendment on dairy farms with low-PRI soils.	Low-PRI soils on dairy paddocks in the Four Acres, Middle Scott and Dennis subcatchments.
Implement targeted retrofitting of rural drains on dairy farms.	Where relevant, implementation of all high-priority rural drain retrofitting projects as identified in a rural drainage management plan for the Scott River.	To be identified by a rural drainage management plan for the catchment.
Develop a code of practice for the WA dairy industry.	A dairy code of practice in place and adopted by all dairy farmers in the catchment.	All subcatchments except Molloy Island.

Challenges for nutrient management

The low milk prices experienced across Western Australia since 2008 have placed economic pressure on dairy farmers, reducing their ability to invest in improved infrastructure such as effluent management systems.

The combination of sandy soils and waterlogged conditions such as those experienced across much of the Scott Coastal Plain can complicate the effective management of dairy effluent.

Effective management tools for nutrients derived from on-paddock manure are still developing. Soil amendments may offer some potential for soils with low PRI, but commercially approved products are not currently available nearby.

There is pressure to expand irrigated dairy in the Scott River catchment. Further intensification of land use is likely to lead to elevated nutrient loads, given the small range of effective nutrient management tools currently available for implementation.

Beef and mixed grazing

Summary of status and trends

In the Scott River catchment beef and mixed grazing (cattle/sheep) properties occupy 75.2 ha, or 10.9 per cent of the total catchment area. This is the second-largest industry in the catchment in terms of land area (the largest is blue gum plantations). There are two areas of irrigated beef pasture in the catchment comprising 200 ha in total and one feedlot.

The beef cattle industry is the state's second-largest animal industry while sheep is the largest. About 65 per cent of Western Australian beef enters the domestic market with the balance exported (DAFWA 2009). Dryland beef farmers in the south tend to have a mixed income due to the low profitability of some farms, with the proportion of farmers reliant on beef for their income ranging from 20 to 60 per cent (DAFWA 2009). These economics have influenced land use change in the catchment during the past decade. Many beef farmers have chosen to lease all or part of their properties for blue gum plantations to provide a diversified and stable income. Future trends are difficult to predict because they depend on fluctuations in beef prices and the continued value of alternatives such as blue gum plantations. Similar to irrigated dairy, increases in the area allocated for irrigated beef are limited by the availability of water from the Yarragadee Aquifer.

Nutrient loads

Dryland beef and mixed grazing paddocks, together with irrigated beef paddocks and feedlots, are predicted to contribute an average of 3.70 tonnes of phosphorus and 32.2 tonnes of nitrogen to the Scott River each year. These figures equate to 33 per cent of phosphorus and 42 per cent of nitrogen loads from the catchment, representing the largest source of nitrogen. The vast majority of both phosphorus and nitrogen is derived from dryland grazing, which makes up the largest area of the Scott River catchment.

Table 6.2 Summary of nutrient loads from Scott River beef/mixed grazing farms

Land use	Phosphorus load			Nitrogen load		
	tonnes	% of catchment load	kg/ha	tonnes	% of catchment load	kg/ha
Dryland beef/mixed grazing paddocks	3.53	30	0.48	31.8	41	4.34
Irrigated beef paddocks	0.14	1	0.70	0.4	1	2.07
All beef/mixed grazing paddocks	3.67	31		32.2	42	
Feedlot effluent	0.03	<1		0.1	<1	
Total	3.70	32		32.3	42	

Nutrient sources on the farm

Major nutrient sources from beef and mixed grazing farms include fertilisers and on-paddock manure, although the nutrient sources in manure are derived from fertiliser and imported feed. Feedlots generally capture all of the effluent within the feedlot area in a similar manner to dairy sheds. Nutrient export from these areas therefore depends on the level of effluent management implemented. Nitrogen fixation from some pasture species is also a source of nitrogen. Of all these, fertiliser is the most significant source of phosphorus.

Nutrient management actions and goals

Action	Ten-year management goals	Focus areas for implementation
Implement best-practice fertiliser management at all beef and mixed grazing farms in the catchment.	100% adoption of best-practice fertiliser management across all beef and mixed farms in the catchment.	All subcatchments except Molloy Island.
Subject to a feasibility assessment, implement best-practice effluent management at the feedlot.	Best-practice effluent management in place at the feedlot.	Governor Broome subcatchment.
Implement targeted riparian management.	Where relevant, implementation of all high-priority riparian management as identified in a river action plan for the Scott River.	Sections of tributaries that link up or extend existing areas of high-quality riparian vegetation.
When approved products are available, implement targeted soil amendment on soils with a low PRI.	Trials in place to evaluate soil amendment on beef/mixed grazing farms with low-PRI soils.	Low-PRI soils on paddocks in the Four Acres, Middle Scott and Dennis subcatchments.

Implement targeted retrofitting of rural drains on beef/mixed grazing farms.	Where relevant, implementation of all high-priority rural drain retrofitting projects as identified in a rural drainage management plan for the Scott River.	To be identified by a rural drainage management plan for the catchment.

Challenges for nutrient management

- Many beef farmers have a mixed income, which reduces how much time they have for farm management.
- While the low profitability of some farms has a tendency to reduce fertiliser use, it also influences the capacity of farmers to invest in infrastructure such as fences around tributaries.
- Effective management tools for nutrients derived from on-paddock manure are still developing. Soil amendments may offer some potential for low-PRI soils, but commercially approved products are not available nearby.
- The combination of sandy soils and waterlogged conditions such as those experienced across much of the Scott Coastal Plain can complicate the effective management of effluent from feedlots.

Blue gum plantations

Summary of status and trends

In the Scott River catchment blue gum plantations now comprise a total of 9860 ha, or 14.3 per cent of the catchment area. Immature blue gums (under the age of five) make up about 40 per cent of this total. This proportion is important because only these trees are fertilised.

During the past decade a large number of blue gum plantations have been established across the high-rainfall areas of Western Australia's south-west and south coast. Currently these plantations are grown for the export of woodchips to Japan for the production of high-quality paper. Harvesting of the plantations usually occurs after 10 years, though sometimes earlier. After this time the stumps may be removed or in some cases they are simply coppiced to allow new growth and a second harvest from the same stump. An industry code of practice for timber plantations in Western Australia was established in 2006 (FIFWA 2006). This code of practice is now followed by the majority of companies.

Nutrient loads

Blue gum plantations contribute an estimated 2.12 tonnes, or 19 per cent of the phosphorus load to the Scott River. Of this contribution, 98 per cent of the load is derived from immature blue gums (those under the age of five). The proportions for nitrogen are similar. All blue gums are predicted to contribute 17 per cent (13.6 tonnes) of the nitrogen load, with 81 per cent of this derived from immature blue gums. The load per unit area contributed by establishing blue gums is just above that of dryland beef farming for phosphorus and just above irrigated beef for nitrogen. However, when the land use is considered as a whole (all established and non-established plantations) these ratios are considerably lower.

Table 6.3 Summary of nutrient loads from Scott River blue gum plantations

Land use	Phosphorus load			Nitrogen load		
	tonnes	% of catchment load	kg/ha	tonnes	% of catchment load	kg/ha
Immature blue gums	2.08	19	0.52	11.0	15	2.77
Mature blue gums	0.04	<1	0.01	2.6	3	0.44
All blue gums	2.12	19	0.15	13.5	18	1.37

Nutrient sources on the farm

Fertilisers are the primary source of nutrients from blue gum plantations. Fertiliser is applied at establishment and then two to three more times within the first five years of growth (e.g. a single application may be made at age three and then again at age five). After age five the trees are not fertilised again until harvesting. While blue gum fertiliser application rates are equivalent to some beef farms, they are less frequent both on a seasonal and annual basis. The inevitable soil disturbance that occurs during planting and harvesting is also likely to release nutrients from the soil, both via erosional processes and as a result of changes to the soil chemistry that occur during disturbance. Foliage that remains after harvesting or trimming operations is also a small source of nitrogen.

Nutrient management actions and goals

Action	Ten-year management goals	Focus areas for implementation
Implement best-practice fertiliser management at plantations in the catchment.	100% adoption of best-practice fertiliser management across all plantations in the catchment.	Dennis, Governor Broome, Four Acres and Upper Scott subcatchments.
Undertake industry trials to identify suitable fertiliser regimes for blue gum plantations in the catchment to minimise nutrient export while maintaining required production.	Fertiliser regimes identified for soils in the Scott River catchment to enable productive blue gum plantations to be grown while minimising export of phosphorus and nitrogen from fertilisers.	Dennis, Governor Broome, Four Acres and Upper Scott subcatchments.
Implement targeted riparian management.	Where relevant, implementation of all high-priority riparian management as identified in a river action plan for the Scott River.	Sections of tributaries that link up or extend existing areas of high-quality riparian vegetation.
When approved products are available, implement targeted soil amendment on soils with a low PRI.	Trials in place to evaluate soil amendment on blue gum plantations with low-PRI soils.	Low-PRI soils on plantations in the Four Acres, Governor Broome and Dennis subcatchments.

Challenges for nutrient management

There is limited technical information regarding suitable fertiliser regimes for plantations on varying soil types. Plantation managers and agronomists therefore need to make decisions about fertiliser application rates with substantially less information than is available for other agricultural land uses in the catchment.

Because of the limitations in technical information, at present the industry is not able to participate in fertiliser management programs such as those delivered by DAFWA as part of the *Fertiliser action plan.*

6.4 Further research needs

A long-term adaptive approach to the management of nutrient problems in the Scott River catchment will be important as land use and rainfall patterns change over time and as new management techniques become available. At present only a limited range of management practices are suitable for implementation in the Scott River catchment. It is hoped that with additional research a larger suite of management tools will become available over time. Projects that specifically address the shortfall in management knowledge are summarised below.

Paddock-scale trials of NUA (and other soil amendments) on pasture and blue gum plantations

Paddock-scale trials of NUA are needed to clarify phosphorus-reduction efficiency, animal health issues, costs of implementation and the appropriate methods of application. Such trials should also be undertaken on establishing blue gum plantations located on low-PRI soils.

Fertiliser trials on immature blue gum plantations

Improved technical information regarding the nutrient requirements of blue gums on varying soil types is needed. This would enable advice to be given on appropriate rates of fertilisation. Currently this technical information is insufficient to enable the plantation industry to participate in government extension programs (e.g. Fertcare by DAFWA) aimed at improving fertiliser management.

Research into lower fertiliser rates on perennial grasses

Trials to date on phosphorus efficiency rates for perennial grasses have used the same rates of fertilisation as annual grasses. While these trials have found that perennials have little impact on phosphorus losses from paddocks, there is a possibility that perennial pastures may not require the same levels of applied phosphorus (David Rogers, pers. comm., DAFWA). If perennials are found to be productive with lower fertilisation rates, they may still prove to be an effective nutrient management tool.

Monitoring to measure the effect of revegetated riparian buffers on in-stream TN and TP concentrations and loads

At present there is no catchment-specific information about the effect of revegetated buffers on in-stream nitrogen and phosphorus concentrations and loads. Monitoring of revegetation projects across a variety of soil types and locations in the landscape would provide information for prioritising future projects.

Evaluation of dairy effluent management systems on waterlogged soils

Waterlogged conditions complicate both the storage of dairy effluent and the ability to irrigate dairy paddocks with effluent during winter. There is a need to evaluate the feasibility, costs and nutrient-reduction benefits of implementing dairy effluent management systems on farms with a high proportion of waterlogged soils.

Investigating the interaction between surface water and groundwater systems in the Scott River catchment

The Scott River has experienced a gradual reduction in flow during the past 40 years. This pattern has also occurred in many other south-west waterways. Groundwater flows have also decreased during this time yet only marginal decreases in rainfall have occurred. An investigation into the surface water/groundwater interactions is needed to clarify the likely causes of reduced flows in the Scott River. The results of this investigation could then be included in a study of the Scott River's ecological water requirements.

Research into the role of tannins in controlling algal blooms in the Scott basin

Reduced flows in the Scott River have the potential to directly influence the system's ability to assimilate higher concentrations of nutrients. In addition, flows in the Scott River during the summer/autumn (low flow) period now appear to have much lower tannins than previously. This increases the risk of algal blooms since light penetration is greater with lower water colouration (Richard Pickett, pers. comm., DoW). It is possible that lower tannin concentrations may be a result of reduced groundwater flow, as much of the tannin in the Scott River is produced by mobilisation of humic substances as groundwater flows through the soil profile. Another sources of tannins is fulvic acid produced by the breakdown of native vegetation. The combined effects of high nutrient concentrations and reduced tannin staining in low flows from the Scott River may be a key driver of algal blooms in the Scott basin (Richard Pickett, pers. comm., DoW). Further studies are needed on the role of tannins in controlling algal blooms and the potential causes of reduced tannins in low flows from the Scott River.

6.5 Planning

Land use planning

As land use in the Scott River catchment changes over time, there will be a need to ensure that such changes do not lead to increases in phosphorus and nitrogen loads. New proposals for intensive agricultural pursuits will need to be carefully evaluated. Modelling tools such as those used in the preparation of this plan can greatly assist in the evaluation process. These tools should be used wherever possible to assess the likely impact of individual proposals.

Stage two of the *Hardy Inlet water quality improvement plan*

This water quality improvement plan deals only with stage one of the required nutrient management planning for the Hardy Inlet. Stage two will involve similar monitoring, modelling and evaluation of management options for the Lower Blackwood catchment and the Augusta townsite, but collection of baseline data before the project starts is needed. The stage-two area (labelled 'Lower Blackwood catchment') is shown in Figure 1.1. Completion of the stage-two water quality improvement plan will involve the following key tasks:

- collecting and updating land use data and future plans for land use change in the catchment area
- monitoring of water quality at additional points in the catchment; two years of data at new monitoring locations may be needed
- collation of other data layers required for water quality modelling, including nutrient surveys of the area's farmers, data on soil type, urban drainage information, and collation of data for all point sources of nutrients in the area
- initial stakeholder consultation and formation of a local advisory committee
- development and calibration of water quality modelling for the stage-two area
- assessment of management options via a cost/benefit analysis process
- preparation of a draft stage-two water quality improvement plan
- stakeholder consultation about the draft plan and finalisation after the comment period.

6.6 Monitoring

The preparation of this plan and the computer modelling to support its targets and recommendations would not have been possible without the water quality monitoring data collected by the Department of Water. Further updates to this plan will rely heavily on the availability of continued and updated water quality monitoring information. Failure to collect reliable water quality data for each waterway in the catchment in the years to come will preclude the ability to track the outcomes of implementing this plan. The minimum monitoring requirements to enable updates of this plan are:

- continued fortnightly water quality monitoring at all existing Department of Water monitoring sites in the Scott River catchment
- continued flow monitoring at the Brennan's Ford gauging station.

7 Implementation

7.1 Implementation principles

Adhering to a clear set of principles will be critical to ensuring the nutrient management measures and recommendations and ultimately the nutrient-reduction targets set out in this plan are achieved. These principles are strongly focused on the need for collaborative resourcing, and a joint agency, industry and all-of-government approach to this plan's implementation and water quality objectives. Given the broad range of measures proposed, this plan's success will depend on such an approach. The following are key principles of implementation:

a. Implementation will be based on an all-of-government approach with cross-agency cooperation, resourcing, support and involvement primarily between the Department of Water, Department of Planning (DoP), DAFWA, DEC, local governments and where relevant other government agencies and community and industry stakeholders.
b. Agricultural-based management measures will generally be implemented in a collaborative manner primarily between the Department of Water, DAFWA and relevant industry groups.
c. Implementation of agricultural-based management measures will focus on an agency, industry and community program of research, demonstration sites and extension of existing programs.

This collaborative approach will need to support the following implementation priorities:

a. Allocation of sufficient funds and resourcing to undertake the particular measures. This is particularly important for the monitoring, modelling, evaluation and test cases proposed.
b. Need to clearly identify priorities for monitoring so that some work continues even in periods of low funding. Detailed implementation plans need to identify such priorities based on resourcing and funding availability.
c. A focus on evaluating best-management practices in the catchment will be critical to the plan's implementation at an early stage. The current lack of analysis of certain management measures in the catchment is a key limitation for implementation. Once this shortfall can be overcome, aspects of the plan may need to be reviewed.
d. Establishment of case studies will be critical to addressing some of the key components that will influence implementation.

7.2 Implementation of management measures

Implementing the recommended management measures will require a strategic and prioritised approach to allocating resources for individual recommendations and reporting catchments. Table 7.1 brings together the catchment-wide management recommendations, industry recommendations, and the research requirements identified in this plan. The specific actions required to implement these recommendations are also provided. Appropriate lead agencies or organisations to manage each recommendation have also been suggested.

In terms of costs, it should be noted that estimates have only been provided for capital costs of implementation. Significant additional costs will be associated with the extensive promotion and coordination tasks required to achieve on-ground implementation of all recommendations and these should be factored into any financial planning as separate items. Similarly, cost estimates have not been provided for recommendations that:

- rely on factors such as agency or private industry staff time for implementation
- are likely to vary significantly in cost depending on site-specific factors
- rely on development of regulatory or policy approaches
- relate to research and development projects for which budgets are likely to develop and change over time.

Table 7.1 Implementation strategy

Management measure	Actions to aid implementation	Location	Estimated capital cost	Lead agencies/ organisations
	Critical actions			
1. *Improving fertiliser management throughout the catchment*	**1.1.** Continue soil testing and soil mapping programs in the Scott River to help farmers on grazing properties interpret soil tests. **1.2.** Provide regular educational opportunities to farmers to build understanding of the benefits of fertiliser management and how to interpret soil-test results. **1.3.** Undertake demonstrations and develop case studies on the environmental, production and economic benefits of improving fertiliser management. **1.4.** Develop a local catchment record of the proportion of farmers participating in best-practice fertiliser management across industries and subcatchments in the Scott River catchment. Aim for 100% adoption for all grazing properties in the first five years and 100% of all farmers within 10 years. **1.5.** Undertake fertiliser trials of blue gum plantations on soil types relevant to the Scott River catchment. **1.6.** Arising from these trials develop high-level technical advice regarding nutrient requirements of blue gums to enable this industry to participate in best-practice fertiliser management programs.	All subcatchments except Molloy Island	$113 000 (soil testing and advice)	DAFWA Lower Blackwood LCDC Industry groups

Management measure	Actions to aid implementation	Location	Estimated capital cost	Lead agencies/ organisations
	1.7. Undertake general fertiliser management trials to confirm optimum timing and quantity of application across a range of land uses and soil types.			
2. *Investigate nutrient hotspots in the catchment*	**2.1.** Undertake on-site investigations to further identify opportunities and develop assistance for on-site management of nutrient sources at known hotspots in the catchment.	Irrigated dairy in the Four Acres catchment.	Not costed	DoW
3. *Carefully evaluate proposals for further intensification of land uses in the catchment*	**3.1.** Assess intensive agricultural proposals to ensure that nitrogen loads in the catchment are not increased further and that actions in this plan to reduce existing phosphorus loads are not offset by additional loads from new intensive enterprises. **3.2.** Use modelling tools such as those presented in this plan to evaluate the likely impacts of individual proposals.	All subcatchments	Not costed	DoW
	Other actions			
4. *Develop and implement a rural drainage management plan for the Scott River catchment*	**4.1.** Assess rural drains in the catchment to identify opportunities and priorities for retrofitting rural drains with the aim of reducing nutrient export to the Scott River, while maintaining essential drainage functions. **4.2** Implement priority drainage projects identified in the plan.	Start with an assessment of deep drains in the Four Acres subcatchment and follow with other subcatchments.	Not costed	DoW
5. *Develop and implement a river action plan for the Scott River*	**5.1.** Undertake a survey of the foreshore vegetation of the Scott River and its tributaries. Use the survey information to: • identify priority areas that are viable for restoration, focusing on linking gaps in riparian vegetation on the main river channel and	All subcatchments except Molloy Island.	$430 000 (estimate based on interpretation	DoW Lower Blackwood

Management measure	Actions to aid implementation	Location	Estimated capital cost	Lead agencies/ organisations
	lower sections of the adjoining tributaries • develop appropriate species lists for revegetation of the foreshore • engage with landholders in priority areas identified for restoration. **5.2.** Deliver a flexible and high-level cost-sharing arrangement for implementation of targeted riparian management and stock control in the catchment that reflects the recommendations of the river action plan. **5.3.** Widely promote the benefits of riparian management to farmers through awareness programs and demonstration sites.		of aerial photos – to be confirmed following survey)	LCDC
6. *Assess and improve effluent management at dairy sheds and feedlots*	**6.1.** Undertake a feasibility assessment of all effluent systems in the catchment to ascertain limitations and the likely costs associated with upgrading these systems. **6.2.** Provide cost-sharing arrangements to implement or upgrade to best-practice dairy effluent management **6.3.** Widely promote the benefits of effluent management to farmers through awareness programs and demonstrations. **6.4.** Adopt an industry-based approach to promoting implementation of BMPs **6.5.** Review and revise the dairy industry's codes of practice for effluent management.	All subcatchments except Molloy Island.	$900 000 (estimate based on effluent upgrades at 5 dairies, to be confirmed by feasibility assessment)	Western Dairy DAFWA DoW
7. *Using approved soil amendments on sandy soils*	**7.1.** Continue trials of NUA to confirm phosphorus export and pasture productivity benefits, establish feasibility, and identify potential limitations and risks. Such trials should be undertaken on immature blue gum plantations and pasture located on low-PRI soils.	All subcatchments except Molloy Island.	$470 000 (transport/ spreading of NUA at 10	DAFWA

Management measure	Actions to aid implementation	Location	Estimated capital cost	Lead agencies/ organisations
	7.2. Encourage and assist Iluka to seek formal approval for widespread use of NUA in the Scott River catchment. **7.3.** Undertake promotion, education and demonstration of approved products and techniques where clear benefits can be demonstrated and risks have been evaluated.		tonnes/ha on blue gums with low-PRI soils)	
	Further research			
8. *Undertake priority research projects to improve knowledge about the Hardy Inlet system and how best to manage nutrients in the catchment*	**8.1.** Undertake trials using low fertiliser-application rates on perennial grasses to ascertain whether these grasses can deliver benefits for phosphorus management on pasture. **8.2.** Undertake rigorous local evaluation to determine the effectiveness of riparian management and stock control on nutrient export. **8.3.** Undertake research to evaluate dairy effluent management systems on waterlogged soils. **8.4.** Undertake research into the interaction between surface water and groundwater systems in the Scott River catchment. **8.5.** Undertake research into the role of tannins in controlling algal blooms in the Scott basin.	Scott River catchment, or other catchments with similar soils.	Not costed	DAFWA Lower Blackwood LCDC DoW
	Planning			
9. *Develop stage two of the Hardy Inlet water quality improvement plan*	**9.1.** Collect and update land use data and future plans for land use change in the catchment area. **9.2.** Monitoring of water quality at additional points in the catchment; two	Lower Blackwood catchment and the Augusta townsite.	Not costed	DoW

Management measure	Actions to aid implementation	Location	Estimated capital cost	Lead agencies/ organisations
	years of data at new monitoring locations may be needed. **9.3.** Collate other data layers required for water quality modelling, e.g. nutrient surveys of the area's farmers, data on soil type, stormwater drains and point sources of nutrients in the area. **9.4.** Undertake initial stakeholder consultation and formation of a local advisory committee. **9.5.** Develop and calibrate water quality modelling for the stage-two area. **9.6.** Assess management options via a cost/benefit analysis process. **9.7.** Prepare a draft stage-two water quality improvement plan. **9.8.** Undertake stakeholder consultation about the draft plan and finalise after the comment period.			
	Monitoring and review			
10. *Undertaking ongoing water quality monitoring in the catchment*	**10.1.** Continue fortnightly water quality monitoring at all existing monitoring sites. **10.2.** Continue flow monitoring at the Brennan's Ford gauging station.	All subcatchments.	Not costed	DoW
11. *Review progress towards implementation of management actions and water quality targets after five years.*	**11.1.** Maintain a record of progress towards implementation of management measures and actions. **11.2.** After five years assess progress towards the end-of-catchment phosphorus concentration and load targets.	All subcatchments.	Not costed	DoW Lower Blackwood LCDC

8 Review

Regular reviews of this water quality improvement plan will need to occur as new information becomes available. This new information has potential to stem from:

- outcomes of research and development projects that may support adjustment of nutrient targets, flow regimes or management practices
- amendments to water quality targets resulting from ongoing monitoring
- amendments to the subcatchment boundaries and drainage network once more detailed terrain data becomes available
- changes in rainfall patterns resulting in a need to adjust load targets, recalibrate models and re-run management scenarios and cost/benefit analyses
- changing market conditions affecting financial returns from management practices
- responses to new government initiatives or policies that may affect the potential for implementation of a range of management recommendations.

A comprehensive review is recommended every five years – with ongoing review, consolidation and implementation on an ongoing and annual basis. The stages, responsibilities and nature of the review process are summarised in Figure 8.1. This shows the Department of Water will be primarily responsible for future reviews.

The five-yearly review would involve the following processes:

1 **Collecting and compiling updated data on:**
   - land use and projected land use changes
   - subcatchment mapping and changes in catchment boundaries
   - updated water quality monitoring information
   - outcomes from new surveys of farmers and urban landholders about nutrient use and rates of adoption of management practices
   - new information from research, development and evaluation of management practices
   - outcomes from research about nutrient thresholds in the receiving waterways
   - updated information on changes to rainfall regimes resulting from climate change or water abstraction
   - compiled information on achievements to date from progress reporting.

2 **Updating and recalibrating water quality models to reflect the new data or upgrading these tools as improvements become available over time.**

3 **Using outcomes from the model to update information in the plan about:**
   - nutrient status
   - load reduction targets

- source separation analysis
- cost/benefit analysis
- management recommendations.

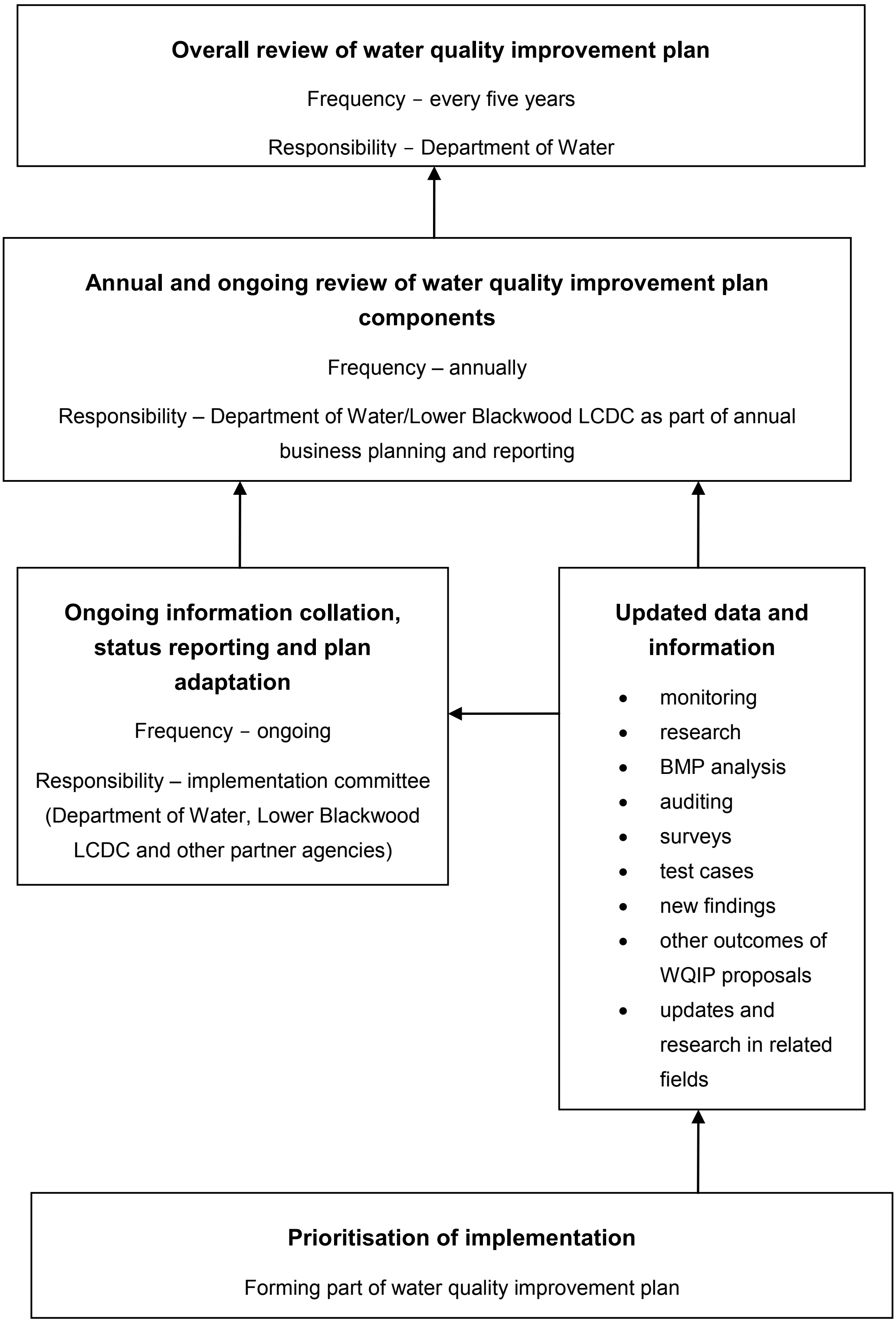


Figure 8.1 Framework for review of the water quality improvement plan

Shortened forms

ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAFWA	Department of Agriculture and Food Western Australia
DEC	Department of Environment and Conservation
DoW	Department of Water
LCDC	Land Conservation District Committee
PRI	phosphorus retention index
SRP	soluble reactive phosphorus
SWCC	South West Catchments Council
TEC	threatened ecological community
TN	total nitrogen
TP	total phosphorus
WAPC	Western Australian Planning Commission

Glossary

Biodiversity	Biological diversity or the variety of organisms, including species themselves, genetic diversity and the assemblages they form (communities and ecosystems). Sometimes includes the variety of ecological processes within those communities and ecosystems.
Catchment	Area of land from which rainfall runoff contributes to a single watercourse, wetland or aquifer.
Climate change	A change of climate attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.
Conditional purchase	A WA state program that allocated bush blocks to established and prospective farmers under specific terms of purchase and time-tables of development. These terms often included requirements for clearing for remnant vegetation.
Ecological values	Natural ecological processes occurring within water-dependent ecosystems and the biodiversity of these systems.
Ecosystem	A community or assemblage of communities of organisms, interacting with one another, and the specific environment in which they live and with which they also interact, e.g. a lake. Includes all the biological, chemical and physical resources and the interrelationships and dependencies that occur between those resources.
Environment	Living things, their physical, biological and social surroundings, and the interactions between them.
Extraction	Taking of water, defined as removing water from or reducing the flow of a waterway or from overland flow.
Flow	Streamflow in terms of m^3/yr, m^3/d or ML/yr. Also known as discharge.
Groundwater	Water that occupies the pores and crevices of rock or soil beneath the land surface.
Surface water	Water flowing or held in streams, rivers and other wetlands on the surface of the landscape.

Watercourse	a. Any river, creek, stream or brook in which water flows. b. Any collection of water (including a reservoir) into, through or out of which anything coming within paragraph (a) flows. c. Any place where water flows that is prescribed by local bylaws to be a watercourse. A watercourse includes the bed and banks of anything referred to in paragraphs (a), (b) or (c).
Water regime	A description of the variation of flow rate or water level over time. It may also include a description of water quality.
Waterways	All streams, creeks, stormwater drains, rivers, estuaries, coastal lagoons, inlets and harbours.

References

Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand 2000, *Australian and New Zealand guidelines for fresh and marine water quality*..

Brearley, A 2005, *Earnest Hodgkin's Swanland – Estuaries and coastal lagoons of south-western Australia*; Perth, Western Australia, University of Western Australia Press.

Department of Agriculture and Food Western Australia 2001, *Scott Coastal Plain: A strategy for a sustainable future*; Government of Western Australia.

—2009, *The Department of Agriculture and Food plan to support 2009–2012 livestock industry development*; Government of Western Australia.

Department of Environment and Conservation 2006, *Proposed Geographe Bay/Leeuwin-Naturaliste/Hardy Inlet Marine Park indicative management plan*; Government of Western Australia.

—2006, *Scott River ironstone community, Species and Communities Branch newsletter for threatened species and ecological communities conservation;* Government of Western Australia.

—2009, *Identification and investigation of acid sulphate soils and acid landscapes;* Government of Western Australia.

Degans, B & Wallace-Bell P 2009, *Acid sulfate soil survey of shallow regolith on the Scott Coastal Plain*; Department of Water, Government of Western Australia, Hydrogeological record series, report no. HG24.

Department of Water 2009, *South West groundwater areas allocation plan*; Government of Western Australia.

Forbes, V 2006, *Hardy Inlet condition statement*; Department of Water, Government of Western Australia.

—V 2010, *Hardy Inlet condition statement – updated report to community;* Department of Water, Government of Western Australia.

Goode, B & Irvine, C 2006, *A survey of Aboriginal social water requirements for the southern Blackwood Plateau and the Scott Coastal Plain southwest, Western Australia*; report submitted to Department of Environment and Department of Indigenous Affairs, Brad Goode & Associates Consulting Anthropologists & Archaeologists.

Hall, J 2010, *Scott River catchment hydrological and nutrient modelling – Supporting document for stage 1 of the Hardy Inlet water quality improvement plan*, Water Science Technical Series, report no. 37, Department of Water, Western Australia.

Irwin, R 2007, *Hydrogeology of the Scott Coastal Plain, Perth Basin*; Geological Survey of Western Australia, Department of Minerals and Energy.

Jeffery, RC 2010, *Molloy Island survey of soil properties and preliminary assessment of nutrient movement from septic tank leach drains;* consulting report by Soil Management Consultants P/L to the Shire of Augusta–Margaret River.

Kelsey, P 2002, *Aggregated emissions of total nitrogen and total phosphorus to the Blackwood and Scott river catchments*; Water and Rivers Commission.

Kitsios, A 2007, *CMSS modelling of the Scott River catchment*; Department of Water, Government of Western Australia.

McKergow, LA, Weaver, DM, Prosser, IP, Grayson & Reed, AEG 2003, 'Before and after riparian management: sediment and nutrient export from a small agricultural catchment, Western Australia'; *Journal of Hydrology*, 270: 253–272.

Pen, LJ 1999, *Managing our rivers*; Water and Rivers Commission, Perth.

Prior, SP & Beckley LE 2006, *Creel survey of the Blackwood estuary, 2005–2006*; Perth, Western Australia, Murdoch University, final report to the South West Catchments Council.

Richards, P 2010, 'The FAP soil testing program;' Department of Agriculture and Food *AgMemo South West Region*, Volume 34, issue 10: 9.

Rigby, P 1995*, Cape country*; Plantagenet Press, Fremantle, Western Australia.

Steele, J, Keipert, N & Summers, R 2009, Monitoring and evaluation of the effectiveness of riparian vegetation in the Peel Harvey catchment; unpublished report by the Department of Agriculture and Food

South West Catchments Council 2005, *South west regional strategy for natural resource management*; South West Catchments Council, Western Australia.

Water and Rivers Commission 2002, *Aggregated emissions of total nitrogen and total phosphorus to the Blackwood and Scott river catchments;* Government of Western Australia.

Wendling, LA & Douglas, GB 2009, *A review of mining and industrial by-product reuse as environmental amendments*; CSIRO: Water for a Healthy Country National Research Flagship.

Wendling LA., Douglas GB., Coleman S and Yuan, Zheng 2010, *Assessment of the ability of low-cost materials to remove metals and attenuate acidity in contaminated waters*, a report to the Water Foundation of Western Australia.

Western Dairy 2010, *Dairy 2010 situation and outlook: a snapshot of the Western Australian dairy industry;* Western Dairy.

Western Australian Planning Commission 1998, *Leeuwin-Naturaliste Ridge statement of planning policy*; Ministry for Planning, prepared for the Western Australian Planning Commission by the Ministry for Planning in conjunction with the Shire of Busselton and the Shire of Augusta–Margaret River.

Looking after all our water needs

Department of Water
168 St Georges Terrace, Perth, Western Australia
PO Box K822 Perth Western Australia 6842
Phone: (08) 6364 7600
Fax: (08) 6364 7601
www.water.wa.gov.au

XXXX XX 0812