The Department of
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Conservation

A River Management Plan for the Broughton Catchment

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Foreword

South Australia's water resources are fundamental to the economic and social wellbeing of the State. Water resources are an integral part of our natural resources. In pristine or undeveloped situations, the condition of water resources reflects the equilibrium between rainfall, vegetation and other physical parameters. Development of surface and groundwater resources changes the natural balance and causes degradation. If degradation is small, and the resource retains its utility, the community may assess these changes as being acceptable. However, significant stress will impact on the ability of a resource to continue to meet the needs of users and the environment. Degradation may also be very gradual and take some years to become apparent, imparting a false sense of security.

Management of water resources requires a sound understanding of key factors such as physical extent (quantity), quality, availability, and constraints to development. The role of the Resource Assessment Division of the Department of Water, Land and Biodiversity Conservation is to maintain an effective knowledge base on the State's water resources, including environmental and other factors likely to influence sustainable use and development, and to provide timely and relevant management advice.

Bryan Harris
Director, Knowledge and Information
Department of Water, Land and Biodiversity Conservation

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Executive Summary

A river management plan for the Broughton catchment is one of three plans being prepared by the Mid North Rivers Management Planning Project (MNRMPP) for the Wakefield, Broughton and Light River systems in the Mid North of South Australia.

The MNRMPP evolved from community concerns about watercourse condition, water quality, stream flows and the lack of an integrated, catchment-wide approach to water resource management.

The project aims to achieve healthy rivers by planning for better watercourse management and determining environmental water requirements. The EPA project team spent a year in the Broughton catchment:

- assessing the current condition of watercourses and identifying priority management issues;
- assessing the environmental water requirements of water dependent ecosystems;
- working with landholders and regional organisations to develop strategies for better watercourse management; and
- increasing community awareness and understanding of river management issues.

The Broughton catchment is located in the Mid North region of South Australia, approximately 130 km north of Adelaide and encompasses an area of 5671 km^2. Broughton River begins at the junction of Yakilo Creek and Hill River and flows in a westerly direction past the towns of Yacka, Koolunga and Redhill before discharging to the sea at Port Davis. Its main tributaries are Yakilo Creek, Hutt River, Hill River, Freshwater Creek, Bundaleer Creek, Rocky River and Crystal Brook.

The dominant land uses across the catchment are the production of grain crops and sheep grazing for wool production. Viticulture is a major land use in the higher rainfall area around the Clare Valley. Other land uses include forestry, lucerne crops, water reserves, conservation and dairying.

The most intensive use of groundwater and surface water resources is in the Clare Valley region for irrigating vineyards; controls on water resource use were introduced in the Clare Valley in 1996 when the area was prescribed. There is a high level of groundwater use in the Booborowie Valley for irrigation of lucerne crops. Around the township of Laura groundwater is used for pasture production and horticultural activities, and there is potential for increased use as interest in horticulture in the area is growing (D Williams, pers com). Outside the Clare and Booborowie valleys and the area around Laura, water resources are primarily diverted for stock and domestic use. Two large domestic supply storages, the Beetaloo and Bundaleer reservoirs, provide back up for the main supply of town water from the River Murray.

The Broughton River system is located in a semi-arid climatic zone and watercourses are characterised by a highly variable flow regime. Consequently, the native plants and animals found in the system are generally tolerant of a range of environmental conditions. The river system supports a wide variety of riverine environments from ephemeral channels to continuously flowing streams. In particular, the groundwater dependent permanent pools and baseflow along the river's main channel and other sites along the major tributaries are crucial for maintaining the health and diversity of aquatic plants and animals.

Since European settlement the catchment has undergone significant changes and the condition of Broughton River and its tributaries has been significantly modified from the natural state, in large part by human activities. Riverine environments have been altered by vegetation clearance, the loss of in-stream complexity due to channel modification, erosion and deposition of sediment; stock grazing, the introduction of exotic plants and animals and changes to the natural water regime.

Water regimes across the catchment have been modified by activities such as the construction of large reservoirs and weirs such as the Beetaloo and Bundaleer reservoir systems, diversion of floodwaters, channel modifications and levee banks, irrigation from farm dams and groundwater use. Improved land management practices designed to reduce runoff and retain water on paddocks have also lead to some decrease in surface runoff and stream flows. Improved land management has had a positive benefit in decreasing catchment and stream erosion.

The effects of farm dams, improved land management and groundwater use have been magnified by recent climatic conditions. The rainfall over the 17 years from 1982 to 1999 has not been conducive to producing large amounts of runoff nor recharging the groundwater in the catchment. Consequently, flows and groundwater levels in all areas of the catchment, whether experiencing significant water resource development or not, have been affected.

The project determined the environmental water requirements necessary to maintain water dependent ecosystems for the Broughton River system at a low level of risk. Environmental water requirements were assessed using the Scientific Panel Habitat Assessment Method developed for the project. Based on these environmental water requirements, water resource allocation and management strategies can be developed to ensure that the catchment's groundwater and surface water resources are equitably shared with the environment.

Environmental water requirements based on seven key flow bands — groundwater, baseflow, low flows, mid flows, high to bankfull flows, overbank and catastrophic flows — were identified for different river geomorphic zones (see tables in Appendix E). Chapters 8–14 provide a broad overview of these requirements for the geomorphic zones located within each subcatchment. The variability of the Broughton River system, together with lack of long-term scientific data, imposed limitations on the process of assessing environmental water requirements. The recommended requirements represent an estimate based on best available data and a process of monitoring and further research is essential.

The key issues threatening environmental water requirements in the catchment include the:

- impacts of farm dams and groundwater extraction in the Clare Valley region;
- potential for future water resource development (e.g. dams and groundwater use) in other areas of the catchment;
- lack of control over development outside of the Clare Valley Prescribed Water Resources Area;
- impacts of the Beetaloo reservoir on flows along Crystal Brook; and
- potential impacts of groundwater use for lucerne crops on groundwater dependent ecosystems in the Booborowie Valley.

The project team assessed the riparian condition of the major watercourses of the Broughton catchment and, in consultation with landholders, identified and prioritised the significant watercourse management issues for each subcatchment. These issues and recommended subcatchment management priorities and strategies are outlined in Chapters 8–14.

Watercourse condition varies considerably between different reaches, from near natural to degraded condition. Examples of areas in near natural condition and considered important riverine habitat include Appila Springs, Mary Springs, the lignum swamp habitats along lower Broughton River and Broughton River, Zone 6. These key assets have high recreational, community and ecological values, and are considered to be a priority for protection and enhancement. In contrast, the more degraded reaches along Appila, Pine and Narridy creeks and the tributaries of Booborowie and Yackamoorundie creeks, are badly eroded and lack native watercourse vegetation.

Changes in watercourse geomorphology across the catchment since European settlement — deepening and widening of watercourse channels, raising of bed levels due to sedimentation and changes in the channel course — have typically been a response to the widespread clearing of vegetation and direct interventions such as channelisation, levee banks, sand and gravel extraction, and the construction of dams and weirs. Bank erosion and erosion heads associated with active bed erosion were identified as significant management issues at a number of sites across the catchment. Approximately 3% of the total length of watercourses surveyed showed signs of active bed and bank erosion.

Seven key native watercourse vegetation communities were identified: riverine forests and woodlands, riverine shrublands, lignum swamps, mangrove forests and samphire marshes, sedgelands, reedbeds, and submerged aquatic vegetation. The native vegetation has been modified to some extent on more than 90% of the watercourses surveyed and is lacking or highly degraded along 48% of the watercourses. This has significant implications for water quality and river health as native vegetation plays a crucial role in preventing erosion, trapping sediment and pollutants, and providing food and habitat. Key threats include degradation and a lack of regeneration due to clearance, cropping and grazing, invasion by exotic plants, channel modification and altered flow regimes.

A snapshot survey of native fish populations recorded only low numbers of native fish in five species and, in terms of the fish ecology, the river system is in a fair to poor condition. Factors influencing the low numbers of native fish may include habitat degradation, lack of flow events suitable for breeding and migration, predation and competition from introduced species, man-made barriers to migration and poor water quality.

More than 240 macro-invertebrates were collected from the catchment. Most of the species were tolerant of a wide range of environmental conditions. They are widespread and common in South Australian rivers. The macro-invertebrate survey indicated that the catchment is relatively healthy in terms of macro-invertebrate ecology. This is largely due to the presence of permanent flowing water along several reaches of Broughton River and its major tributaries. There is a strong relationship between macro-invertebrate diversity and permanent flow across the catchment. A management priority is to maintain this permanent flow wherever it occurs in the river system.

Broughton River provides habitat for a number of frog species, most of which are common and widespread across South Australia. Factors likely to impact on frog populations include habitat destruction, poor water quality and changes to water regimes.

Management of watercourses should adopt a rehabilitation goal to return, as far as possible, the vegetation, structure, hydrology and water quality to a ‘natural’ state. Improvements to these elements in turn will lead to improvements in the organisms living in, and relying on, the watercourses. The key watercourse management requirements for the catchment may be summarised as:

- protecting and enhancing areas of important riverine habitat and remnant vegetation and regular monitoring of these areas to assess condition;
- establishing locally indigenous native vegetation by revegetation or encouraging regeneration;
- reducing grazing pressure on in-stream and riparian zones;
- controlling invasive and dense infestations of weeds and exotic trees, particularly if adjacent to an area of remnant vegetation or important riverine habitat;
- replacing weeds and exotic trees with locally indigenous watercourse vegetation;
- establishing native watercourse vegetation to protect bed and banks from erosion;
- using riparian buffer strips to reduce sediment and nutrient delivery to watercourses;
- monitoring erosion heads and areas of poor bank stability to assess if they are still actively eroding and whether they threaten upstream or downstream assets;
- undertaking erosion control works where erosion is severe and threatening high value assets;
- using best practice design of in-stream structures, channelisation or alteration of watercourses to account for the water regime, channel stability and ecology of the watercourse; and
- instituting sound land management practices, such as contour banking, minimum tillage and improved pasture management, that minimise surface runoff and prevent erosion.

Effective management to improve the health of watercourses in the Broughton catchment requires an integrated approach that combines flow, land and watercourse management. Chapter 15 contains the principal recommendations for actions to address catchment scale issues including land, water resource and watercourse management, the need for integration of management approaches, effective extension and technical support, funding, and monitoring and evaluation.

The plan provides a basis for landholders, community groups, regional organisations and government agencies to work together to achieve sustainable management of the water resources and watercourses of the Broughton catchment. It contains important baseline information and targets local river or watercourse management needs by assessing the condition of the river, identifying management issues, and developing options for watercourse management based on community and ecological priorities. It provides valuable information for water resource and development planning by scientifically assessing the water requirements of water dependent ecosystems. Finally, the plan makes recommendations for addressing catchment scale water resource, watercourse and land management issues that impact on the river system.

CHAPTER 1 INTRODUCTION

1.1 The Mid North Rivers Management Planning Project

The Mid North Rivers Management Planning Project (MNRMPP) evolved from community consultation meetings conducted in 1996 by South Australia's Department of Environment and Natural Resources (now Department for Environment and Heritage (DEH)) in partnership with the Clare Valley Water Resources Planning Committee. At these meetings landholders expressed concerns about the watercourse condition, water quality, streamflows and the lack of an integrated, catchment-wide approach to water resource management. These concerns were supported by the Department of Primary Industries and Resources SA (PIRSA), soil conservation boards, local government, and animal and plant control boards.

The project aims to maintain and improve the health of the Wakefield, Broughton and Light rivers by determining environmental water requirements and planning for better watercourse management. A project team was formed in the Environment Protection Agency (EPA) to produce a river management plan for each of these three rivers including this one for the Broughton River.

The specific objectives of the MNRMPP are to:

- develop river management plans that incorporate recommendations for watercourse management and an assessment of environmental water requirements;
- integrate watercourse management actions of landholders and key stakeholders;
- integrate watercourse management and environmental water requirement issues into other regional and district planning and implementation strategies; and
- increase community understanding of watercourse management and environmental water requirement issues.

The project, which began in May 1998, was funded by the Natural Heritage Trust and DEH. Key local stakeholder organisations provided advice and direction through a project reference group comprising representatives from:

- PIRSA;
- Clare Valley Water Resources Planning Committee;
- soil conservation boards;
- local government;
- animal and plant control boards;
- Department for Water Resources (DWR; now Department of Water, Land and Biodiversity Conservation (DWLBC)); and
- DEH.

The long-term outcomes of this project for the Wakefield, Broughton and Light rivers include improved health and diversity of the riverine ecosystems, reduced erosion and sedimentation, improved water quality, and reduced livestock and weed management problems.

1.2 A river management plan for the Broughton catchment

1.2.1 PURPOSE

The management plan for the Broughton catchment is a decision-making tool for landholders and stakeholders with an interest in river management. It aims to:

- provide baseline information on the condition and function of the riverine ecosystems;
- provide strategic direction for river management in the catchment;
- facilitate the integration of river management objectives with other regional plans and strategies; and
- increase community understanding of river management issues.

The plan can be applied at a local, subcatchment level as well as at a broader catchment scale. It has been structured to meet the needs of landholders who have a watercourse running through their property and of stakeholder organisations involved with long-term and day-to-day planning that affects the Broughton River and its tributaries.

The plan targets river or watercourse management needs locally by assessing the condition of the river (its key assets and threats), identifying management issues, and developing strategies for watercourse management based on landholder and stakeholder priorities. It provides valuable information for water resource allocation and management by scientifically assessing the environmental water requirements for water-dependent ecosystems along the Broughton River and its tributaries. The plan also discusses catchment-scale issues and provides recommendations based on catchment-wide water management requirements.

1.2.2 CATCHMENT LOCATION AND DESCRIPTION

The Broughton catchment is located in the Mid North region of South Australia, approximately 130 km north of Adelaide, and encompasses an area of 5671 km^2. It is the major drainage system of the region and one of the largest river systems contained wholly within South Australia. The Broughton River begins at the junction of Yakilo Creek and Hill River and flows in a westerly direction past the towns of Yacka, Koolunga and Redhill before discharging to the sea at Port Davis. Its main tributaries are Yakilo Creek, Hutt River, Hill River, Freshwater Creek, Bundaleer Creek, Rocky River and Crystal Brook (Map 1.1).

Most of the catchment is used for dryland agriculture, involving the production of grain crops (wheat, barley and field peas), and running sheep and cattle. Cropping intensity increased dramatically during the 1970s and the early 1980s, and remains high today (Mary-Anne Young, pers comm 2000). Sheep grazing for wool production is the main livestock enterprise and is the dominant land use on the non-arable lands (West Broughton Soil Conservation Board 1992). Since the 1970s, irrigated vineyards have become a major land use in the higher rainfall area around the Clare Valley. Irrigated vineyards and olive groves are now being established in other high rainfall areas such as the Beetaloo and Bundaleer valleys. Other land uses include forestry, lucerne crops, water reserves, conservation and dairying.

Historically, the focus of water resource management in the catchment has been to provide good quality water for irrigation, urban and industrial use, and stock and domestic needs. The impact of water resource, agricultural and urban development on the health of riverine ecosystems has received little consideration. Consequently, while this development has brought significant social and economic benefits, there has also been significant impact on, and modification of, the river and its in-stream, floodplain, wetland and estuarine ecosystems. It is not only biodiversity and ecological values that are affected but also the capacity to use water resources and the river system for purposes such as agriculture and recreation.

1.2.3 POLICY AND PLANNING CONTEXT

The need to ensure the long-term integrity of rivers and wetlands as functioning ecosystems has been widely recognised at State and national levels. In 1994 the Council of Australian Governments (COAG) endorsed a strategic framework to introduce important water reforms. Under this agreement, providing water for the environment was legally recognised as an essential component of any water allocation system and any future water resource developments were required to be ecologically sustainable.

The *National principles for the provision of water for ecosystems* (ARMCANZ and ANZECC 1996) provides a basis for considering environmental water requirements as part of water allocation decisions.

The policies endorsed through the COAG water reform agenda and the ARMCANZ–ANZECC principles are reflected in South Australia's *Water Resources Act 1997*, which provides an important legal framework for water resource and watercourse management in South Australia. The object of the Act recognises the need to protect water dependent ecosystems and their biodiversity.

Water resources and watercourses are managed through various statutory water management plans and other powers. The *State Water Plan* (Department for Water Resources and State Water Plan Steering Committee 2000a,b) sets the strategic direction for water resource management in South Australia. All other water management plans must be consistent with this plan, including:

- catchment water management plans prepared by catchment water management boards;
- water allocation plans prepared for prescribed water resources by catchment water management boards or water resources planning committees; and
- local water management plans prepared by local councils.

The *State Water Plan* outlines statewide policies for managing the health of water dependent ecosystems, including water for the environment and watercourse (riparian zone) management. The plan's goal for the integrated management of waterbodies and associated water dependent ecosystems is to maintain or improve the condition of these systems, to ensure the long-term integrity of their ecological functions and dependent biodiversity, and to achieve their ecologically sustainable use, including the highest value use of water (Department for Water Resources and State Water Plan Steering Committee 2000a).

The plans developed by the MNRMPP are an important step in achieving this goal for the Wakefield, Broughton and Light River systems. The plans describe the environmental water requirements for these systems and identify watercourse management issues, priorities and management options based on the assessment of watercourse condition, landholder and stakeholder consultation and technical input from river management specialists. The plans are not statutory documents but are important decision-making tools and sources of information for government agencies, regional organisations, community groups and landholders. For example, they will provide valuable information for the development of statutory water management plans under the *Water Resources Act 1997*.

1.2.4 ENVIRONMENTAL WATER REQUIREMENTS

A catchment is made up of a range of water dependent ecosystems such as estuaries, lakes and wetlands, rivers and streams. These systems require water to maintain their physical features such as channel shape and water quality, their communities of plants and animals and the associated ecological processes. Environmental water requirements can be defined as 'descriptions of the water regimes needed to sustain the ecological values of aquatic ecosystems at a low level of risk' (ARMCANZ and ANZECC 1996, p 4) or the natural flows or releases of water required to meet the needs of dependent ecosystems (Boulton and Brock 1999).

The Broughton River system has a certain level of water resource development and flow regulation (farm dams, weirs, reservoirs, bores and levee banks) which has modified the natural water regime. The need for water for agriculture, industry and domestic uses means that in most cases full restoration or protection of the natural flow regime is not possible.

Determining environmental water requirements therefore involves identifying those flows or features of the natural water regime that are most important for maintaining or improving the condition of water dependent ecosystems. The features of natural water regimes that are significant for maintaining physical river features, plants and animals and ecological processes include:

- water volume;
- water quality;
- the frequency, duration and velocity of flows;
- variability of flows;
- seasonal patterns and timing of flows; and
- the length of low flow or no flow periods.

The environmental water requirements of water dependent ecosystems in the Broughton River system have been identified by the MNRMPP (see Chapter 5 and 6).

Identifying environmental water requirements is only one step in ensuring that the water needs of the environment are met. 'Environmental water provisions' refers to that part of the environmental water requirements that can be met at any given time. Providing water to the environment is part of a complex water allocation and management process that must balance social, economic and environmental needs. These competing needs may place constraints on the provision and effectiveness of environmental water requirements.

In South Australia the goal of providing water for the environment is to sustain and, where necessary, restore ecological processes, habitats and biodiversity of water dependent ecosystems (Department for Water Resources and State Water Plan Steering Committee 2000a). This goal cannot be achieved if the water is being provided to a degraded environment. The health of riverine ecosystems is dependent not only on meeting environmental water requirements but also on protecting water quality, maintaining and rehabilitating habitat and biodiversity, and practising good land and watercourse management.

1.2.5 WATERCOURSE MANAGEMENT

Watercourse management refers to the watercourse rehabilitation or protection measures required to address threats to river health. Such threats may include loss of native vegetation, accelerated bed and bank erosion, poor water quality, stock and weed management problems, and the loss of habitat and biodiversity. The terms 'watercourse' and 'riparian zone' are often used interchangeably when referring to watercourse management activities. The riparian zone simply refers to 'any land which adjoins, directly influences or is influenced by a body of water' (LWRRDC 1999, p. A:2).

Watercourses and the riparian zone are sensitive areas that often require a different management approach from other components of the landscape (Bell and Priestley 1998). In the past there has been little focus on the importance and proper management of watercourses and riparian lands. The tendency has been to treat rivers and creeks as drains — removing water from the surrounding land. More recently, however, the importance of healthy watercourses has been recognised in preventing erosion, providing food and shelter for aquatic animals, maintaining biodiversity, protecting water quality, maintaining agricultural productivity, and for their recreation and aesthetic values (LWRRDC 1999).

Many landholders who have a watercourse running through their property are concerned about managing the watercourse well. However, a lack of time, money and technical know-how are often impediments to the better management of watercourses. The MNRMPP process brought landholders and stakeholders together to discuss their concerns and successes in managing watercourses. The project team assessed the condition of watercourses throughout the catchment and then used this information to identify watercourse management issues. This information was then used in community meetings to explain the issues and discuss management priorities and on-ground solutions.

Significant watercourse management issues are discussed in Chapter 7 and then in detail for each subcatchment in Chapters 8–14. Tables listing the management priorities and strategies for practical watercourse management are also provided in Chapters 8–14. These subcatchment management priorities and strategies can be used by the community as practical planning tools, as a guide for developing regional management priorities and as support for individuals or community groups seeking funding assistance for on-ground works.

1.2.6 COMMUNITY AND STAKEHOLDER INVOLVEMENT

There are several key stakeholder organisations with watercourse, water resource or land management responsibilities that directly or indirectly affect the watercourses within the Broughton catchment. For example, local councils can have direct effects through flood mitigation activities and indirect effects as a result of planning decisions. Soil conservation boards, through their district plans, have the ability to implement land management measures that help prevent degradation of watercourses. Map 1.2 shows the extent of jurisdiction of councils in the catchment. State government agencies such as DEH, DWLBC and PIRSA also have river and land management responsibilities. The legal rights and responsibilities of stakeholder organisations with river management obligations are discussed in Appendix A.

The different responsibilities of the organisations make it difficult to achieve a coordinated and integrated approach to water resource and watercourse management in the catchment. In addition, no one organisation has the overall responsibility for implementing the management options recommended in this report. To overcome this, a key objective of the planning process was to integrate watercourse management and environmental water requirement issues into both the regional and district plans and the implementation strategies of stakeholder organisations. The Project Reference Group played a key role in ensuring this integration.

Ultimately, however, landholders with property adjacent to a watercourse are at the forefront of improving the health of the river system. Rivers will only be better managed if landholders and stakeholder organisations have an opportunity to influence management actions and if the wider community understands the importance of improved water resource and watercourse management. The MNRMPP conducted a comprehensive community and stakeholder involvement process to raise awareness and to involve all potential users of the plan throughout the process. Landholders and stakeholders were involved in identifying watercourse management issues and determining priorities for management as well as contributing valuable local information such as rainfall and flow records. Key stakeholders were also consulted to determine their information needs on water resource and land management issues that affect the river catchment.

1.3 Using the plan

Table 1.1 provides a guide for landholders, community groups and key stakeholders using and integrating the information contained in the plan. For example, for landholders and community groups the plan can be used to provide information about watercourse management problems, priorities and potential solutions and as a tool to access funding for on-ground works. The sections of the plan that deal with these issues include Chapter 7 which discusses the results of the watercourse survey and explains the significant watercourse management issues and Chapters 8–14 which discuss subcatchment management issues, priorities and options (see Table 1.1).

For stakeholders, the plan offers river management information that can assist with both operational and strategic planning (see Table 1.1). At an operational level, the watercourse management priorities identified in the plan can help stakeholder groups plan work program priorities. The plan can assist with strategic planning on river management issues by providing baseline information and a technical basis on which to base decisions.

Table 1.1 Target audiences and uses of the information provided by the plan

Target audience	Information uses	Key chapters
Landholders and community groups: e.g. Landcare groups, Waterwatch groups	• Identification and location of watercourse management issues at a subcatchment and catchment level • Options for improving watercourse management practices • General catchment and subcatchment information • Supporting documentation for funding applications	Chapters 5, 7 Chapters 8–14
Local government: Clare and Gilbert Valleys; Mt. Remarkable; Port Pirie Regional; Goyder Regional; Northern Areas; Orroroo and Carrieton, Wakefield Regional	• Decision making on development applications • Local water management plans under the *Water Resources Act 1997* • Plan amendment reports • Management of river based assets such as bridges, culverts and public reserves/council land adjacent watercourses • Flood mitigation • Stormwater drainage	Chapters 5–15
Clare Valley Water Resources Committee	• Water allocation plans — preparation and review • Monitoring and education	Chapters 5, 6, 15

Target audience	Information uses	Key chapters
Soil conservation boards: West Broughton; Hummocks; Mt Remarkable	• Integration into review of soil conservation board district plans • Accessing funding for and implementing on-ground riparian works	Chapters 7, 15 Chapters 8–14
Animal and plant control boards: Northern; Lower Flinders; Lower North; Goyder; Upper North	• Integration into district plans and weed control work programs • Location and extent of watercourse weeds	Chapters 7, 15 Chapters 8–14
Mid North Regional Development Board	• Integration into regional development plans	Chapters 5, 7, 15
INRM Committee Northern and Yorke Agricultural District	• Baseline information on the water resources and condition of the riverine environment • Priorities and recommendations for management and monitoring	Chapters 5-7 Chapters 8-14 Chapter 15
PIRSA	• Use in property management planning and extension advice • Technical river management information	Chapters 7, 15 Chapters 8–14
DEH	• State of the Environment reporting • Monitoring of water quality and ecosystem health • Biodiversity planning	Chapters 5, 6, 7, 15
DWLBC	• State of the Environment reporting • State Water Plan policies, reporting and monitoring • Water management plans (e.g. water allocation plans, local water management plans)	Chapters 5, 6, 7, 15
SA Water	• Operational management of reservoirs • Impacts of structures (e.g. reservoirs, weirs and aqueducts)	Chapters 5, 6, 15

A glossary of terms is included at the end of the plan and a list of abbreviations given at the front. Detailed technical information on biota and geomorphic flow requirements and environmental flow requirements for each river geomorphic zone have been included in the appendices. Links to other chapters are noted in the text.

Chapter 1 provides background information on the MNRMPP, an introduction to the plan and background on the Broughton catchment

Chapter 2 presents a brief overview of river processes and concepts to assist with understanding the more technical sections of the plan

Chapter 3 gives an outline of the methods used to consult with the community, to identify watercourse management issues and to determine environmental water requirements.

Chapter 4 discusses the results of the community consultation including the community's goals for a healthy watercourse and views on barriers to achieving better watercourse management.

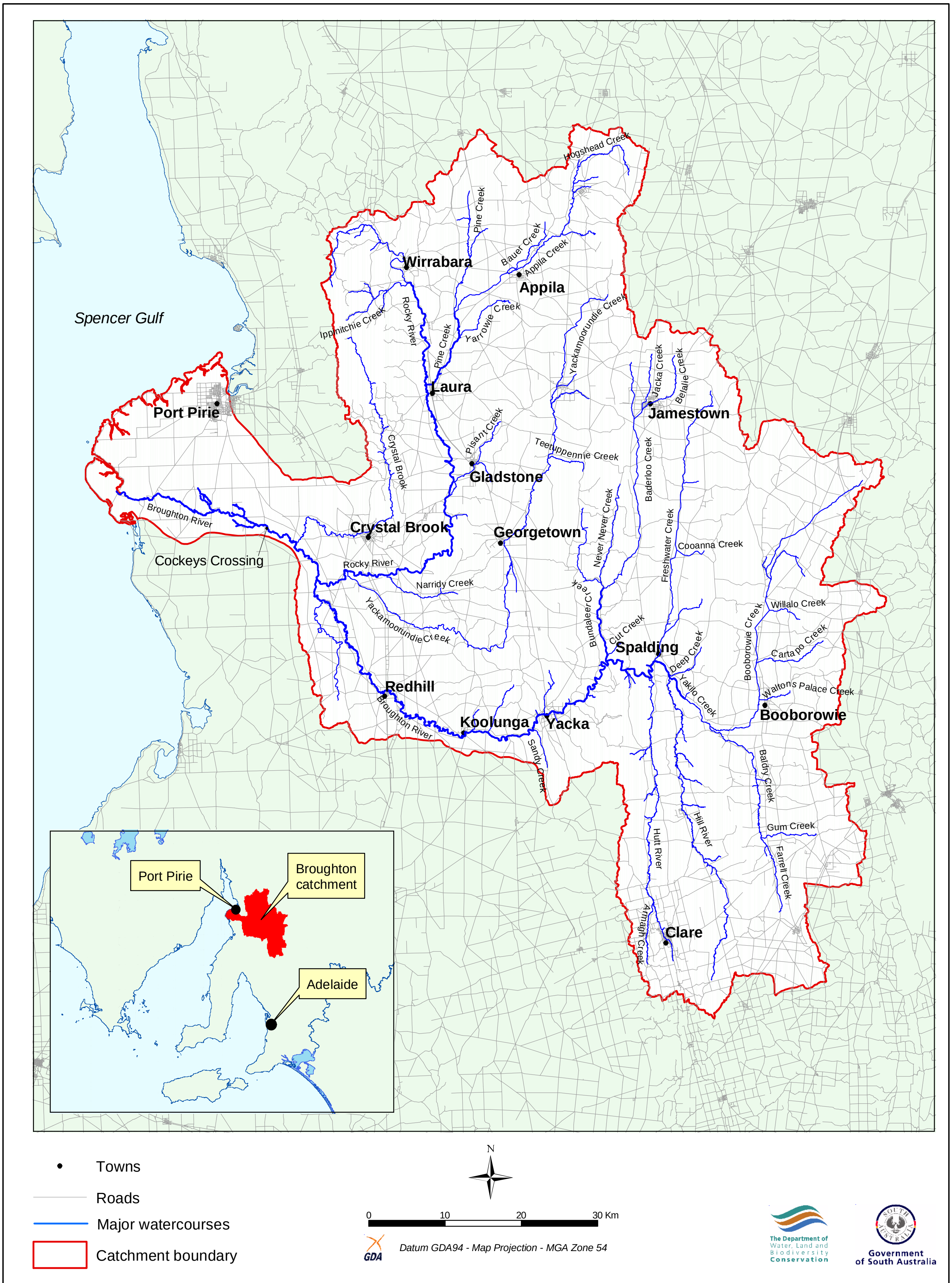
Chapter 5 presents the results of the ecological and geomorphological studies commissioned by the project teams and discusses the environmental water requirements to support geomorphic processes, plants and animals, and associated ecological processes.

Chapter 6 discusses the catchment water resources and hydrology, provides a catchment overview of environmental water requirements and compares recorded flow data with recommended environmental water requirements for three sites.

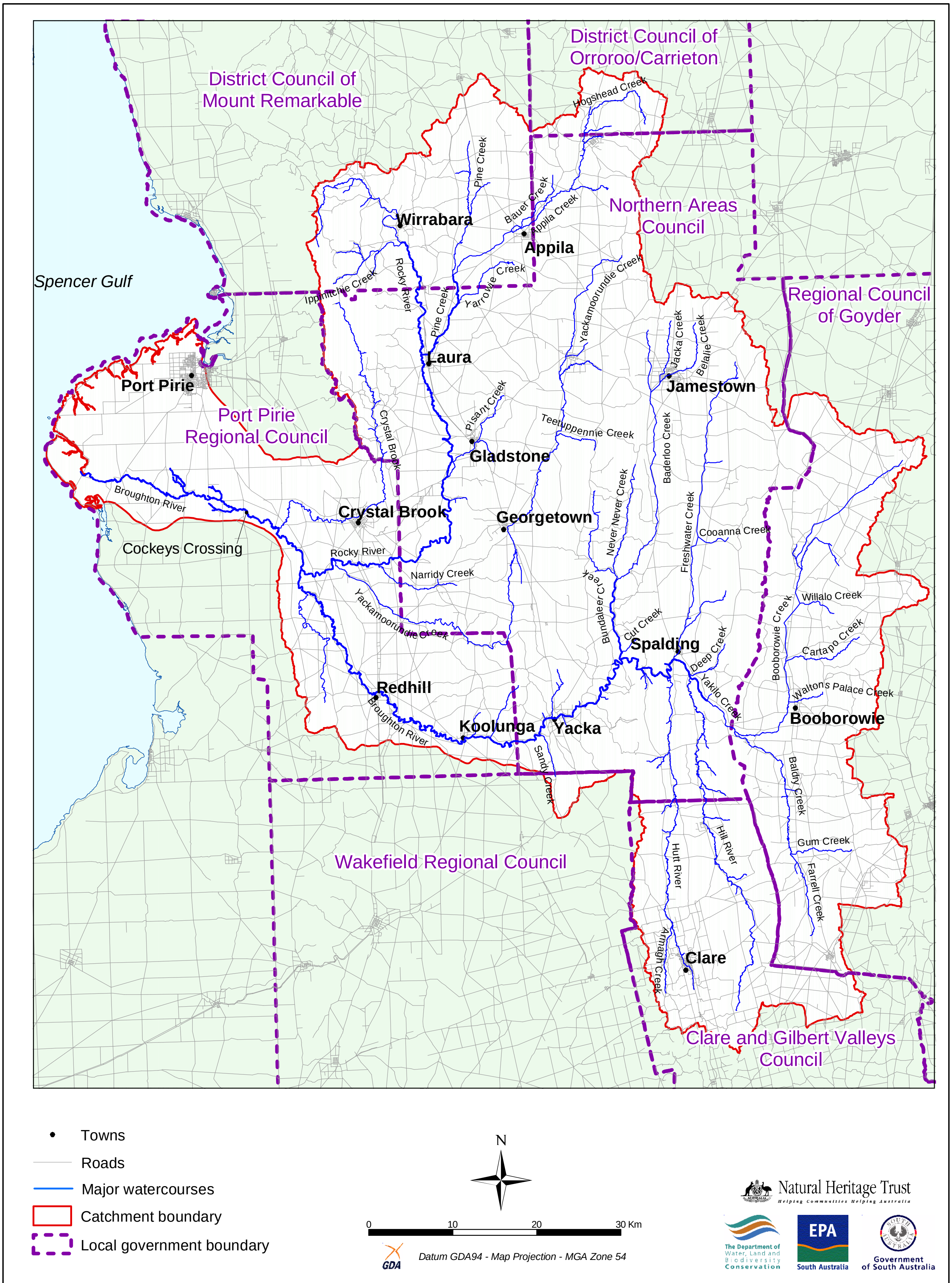
Chapter 7 presents the results of the assessment of watercourse condition, discusses the significant management issues and presents an overview of key management strategies to address these issues.

Chapters 8–14 present information specific to each subcatchment of the Broughton catchment. Each chapter describes the key water dependent ecosystems and processes, and the associated environmental water requirements for each geomorphic zone, discusses the significant management issues, and lists the recommended management priorities and strategies for watercourses in each subcatchment. An outline of key knowledge gaps and monitoring requirements is also provided.

Chapter 15 presents an overview of the condition of the Broughton catchment and its tributaries based on the studies undertaken for the project, discusses key knowledge gaps and monitoring requirements, and provides important management recommendations.



Map1.1: Location and watercourses of the Broughton catchment



Map1.2: Local government boundaries in the Broughton catchment

CHAPTER 2 INTRODUCTION TO RIVER PROCESSES

2.1 Introduction

This chapter provides general reference information on river ecosystem components and processes and explains commonly used terms.

2.2 Structure and function of river ecosystems

A river is a dynamic system with complex physical and biological processes that are constantly undergoing change. A good understanding of these processes is crucial to sound river management. There are five interacting elements that determine the structure and function of river ecosystems — physical features (e.g. channel shape), water quality, water quantity, condition of the riparian zone and of the floodplain, and the plants and animals living in the stream (Rutherford et al. 1999). A change to any of these elements can have a significant effect upon other parts of the system. As a consequence, when addressing a river management problem it is essential to ensure that the remedy employed does not cause problems elsewhere.

2.2.1 PHYSICAL CHARACTERISTICS AND HABITATS

Flow regimes and geomorphic processes such as erosion, sediment transport and deposition play an important role in determining in-stream, riparian and floodplain environments. The material transported and deposited by rivers in the channel and in the riparian zone and floodplain forms key physical features that are the basis of river habitats. Some typical physical features found in the in-stream environment include benches, bars, pools, riffles and runs (Figure 2.1) (Brierley et al. 1996). Different features offer different habitat and feeding opportunities for plants and animals.

Habitats are places where animals and plants live. Deep pools, shallow riffles, aquatic plants, woody debris and large rocks are some in-stream habitat types. Different habitats will favour different types of animals and plants. For example, the types of animals present in a shallow riffle will tend to differ from those present in a deep pool. Certain plants, e.g. reeds such as *Typha* spp., prefer areas of still or slow moving water while other aquatic plants thrive in shallow running water (Gooderham and Jerie 1999).

Many animals require a variety of different habitats for day-to-day life or for different stages of their life cycle. The ability to freely move between different habitats is important. For example, some species of freshwater fish use the estuary to breed and then migrate upstream for adult growth. On a day-to-day basis, fish may also need areas for feeding, areas to shelter from predators and refuges from flood or drought. Aquatic insects also use different habitats during their lifecycles. For example some mayfly species live among cobbles in fast flowing water as nymphs, spend their adult stage among riparian vegetation and then return to the stream to lay their eggs (Gooderham and Jerie 1999).

A watercourse with diverse habitats will support a greater range of organisms than a less complex watercourse. One of the impacts of European settlement and associated land use change, has been the simplification of riverine habitats by clearance of riparian vegetation, loss of in-stream complexity due to channelisation, incision and deposition of sediment, and loss of flow variability due to dam construction (Gooderham and Jerie 1999).

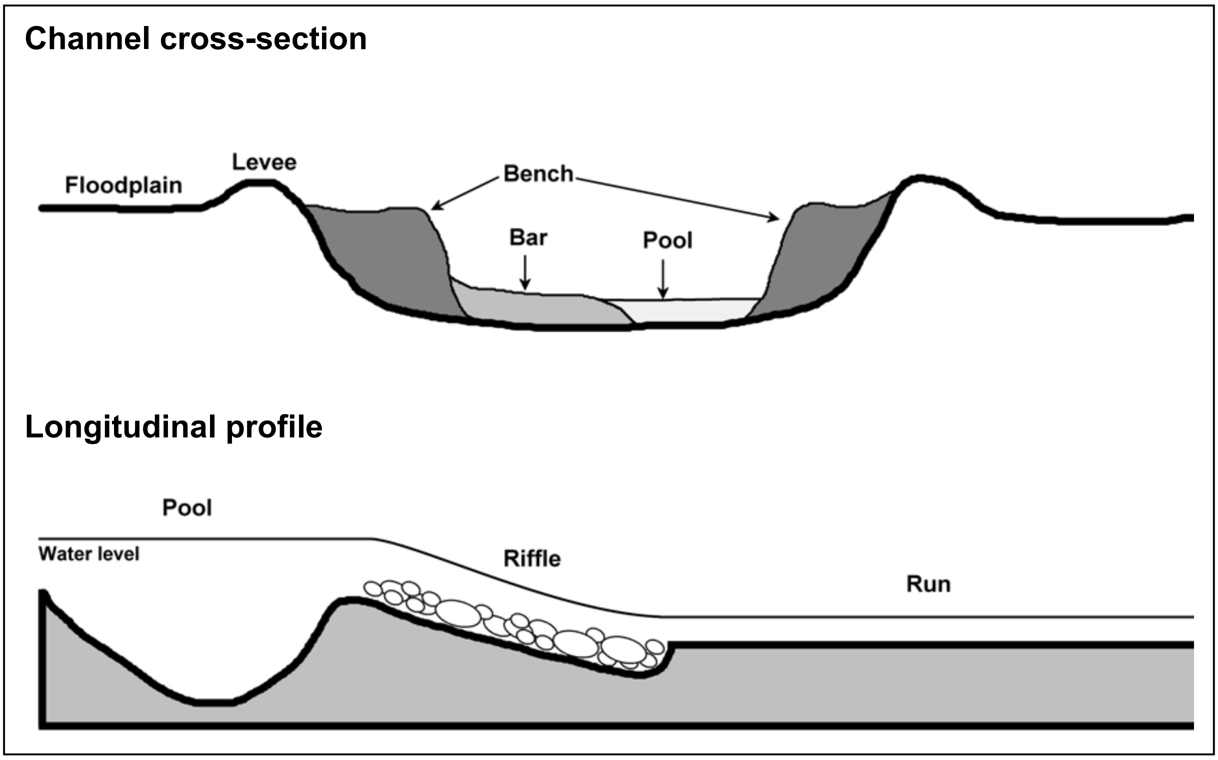


Figure 2.1 Schematic cross-section and longitudinal profile of a watercourse showing common physical features

2.2.2 WATER QUALITY AND TEMPERATURE

Water quality is vital for maintaining the health of aquatic ecosystems. Plants and animals can tolerate a certain range of water quality but outside that range their ability to survive is diminished greatly. If water quality declines, sensitive organisms will be lost while more tolerant organisms, including fish such as the introduced eastern gambusia (*Gambusia holbrooki*), will tend to dominate. Water quality can be affected by adjacent land use, the presence of livestock, the capacity of the riparian zone to act as a buffer and provide shade, sewage effluent, urban stormwater pollution and industrial wastewater (Gooderham and Jerie 1999).

Water temperature is a lifecycle control factor of aquatic and terrestrial invertebrates that use the stream for all or part of their lifecycle. Changes to water temperature give environmental cues that can trigger different parts of an animal's lifecycle. For example, aquatic insects emerge from the river in warmer water temperatures. If the water temperature changes dramatically (e.g. through the removal of the riparian vegetation that provides shading) then temperature sensitive species will be less likely to survive.

2.2.3 WATER REGIME

The water regime has a direct effect on plants and animals through the cycle of flood and drought, as a cue for migrations and lifecycle changes, and by providing connections with floodplain habitats. For example, reeds and rushes may rely on a period of low flow to establish on the bank of a watercourse and river red gums (*Eucalyptus camaldulensis*) can require periods of flooding for regeneration. Water regime is also an important factor determining the physical shape and character of a watercourse and thus maintaining in-stream habitats (Gooderham and Jerie 1999).

Rivers in semi-arid climatic zones such as the Broughton River are characterised by a high degree of variability in water regimes over time and over the different areas of the catchment. The native plants and animals in the watercourse have had to adapt to these cycles of drought and flood. It is this variability which helps maintains the biodiversity of riverine ecosystems (Thoms 1998). The range and variability of flows are just as important as the volume of flows within a system. Other important characteristics include timing, extent, frequency, duration, depth and the rate of rise and fall of flow events. A change to one or more of these components of the water regime is generally marked by a reduction in habitat complexity and the diversity of plants and animals.

Streamflow may have a component of baseflow that is provided by groundwater discharge. In river systems in low rainfall areas, this baseflow is likely to be vital to the composition and maintenance of in-stream and riparian ecosystems by supporting in-stream and riparian vegetation during dry seasons (Hatton and Evans 1998). Groundwater in-flows can play an important role in maintaining water quality and quantity.

Shallow groundwater can also play an important role in supporting riverine ecosystems. In-stream, riparian and wetland vegetation may depend to varying degrees on shallow groundwater to sustain growth during dry periods. For example, river red gums along inland rivers often depend on shallow groundwater for survival (Hatton and Evans 1998). In addition, fauna which have the ability to spend part of their lifecycle below the river bed ('hyporheic fauna') require subsurface flows.

2.2.4 RIPARIAN ZONE AND FLOODPLAIN

The riparian zone is generally defined as the ribbon of land adjacent to, and influenced by, a watercourse (Figure 2.2). This zone is a critical link between terrestrial and aquatic ecosystems. Riparian vegetation includes the terrestrial vegetation adjacent to the stream as well as aquatic and semi-aquatic plants on the edge of the stream bank. Riparian vegetation plays a critical role in the ecology of the river by providing organic matter and habitat, acting as a filter for sediment and pollutants, protecting banks from erosion, providing shade, and influencing channel shape and flow (Kapitzke et al. 1998).

The riparian zone and the floodplain (land adjacent to the watercourse that is periodically flooded) play significant roles in the ecology of the river environment. When the floodplain is inundated it provides a habitat for macro-invertebrates and for fish spawning. As the flood recedes, leaf litter and other detritus, which provide important sources of food, are transported into the watercourse (Gooderham and Jerie 1999).

Some riparian and floodplain plants require periods of flooding for survival and for regeneration. Incision of a watercourse can lead to a dramatic change in the flooding regime, which can alter riparian and floodplain vegetation communities and affect the animals that rely on that vegetation (Gooderham and Jerie 1999).

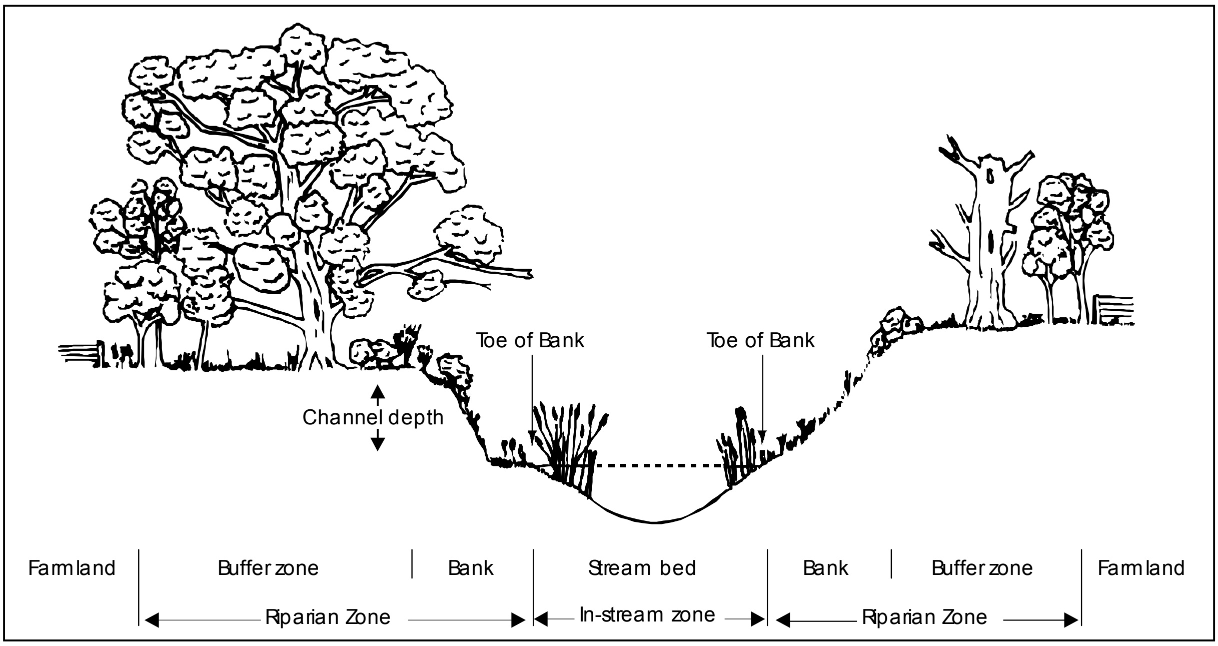


Figure 2.2 Typical cross-section of a watercourse showing the location of the riparian zone

2.2.5 IN-STREAM PLANT AND ANIMAL COMMUNITIES

In-stream plants (aquatic and semi-aquatic species) are an essential component of the river ecosystem. These plants provide food and habitat for fish, birds and invertebrates, act to stabilise sediment, improve water quality and reduce flow velocities and erosion potential (Kapitzke et al. 1998). In-stream animals can be very diverse and include species of invertebrates (e.g. snails, worms, shrimps and insects) and vertebrates (e.g. fish, amphibians, reptiles, birds and mammals). Within the river ecosystem, animals and plants use each other for food, shelter and recycling of waste matter (Gooderham and Jerie 1999). A food web is a simple way of describing the flow of nutrients and interactions between plants and animals in a community (Figure 2.3).

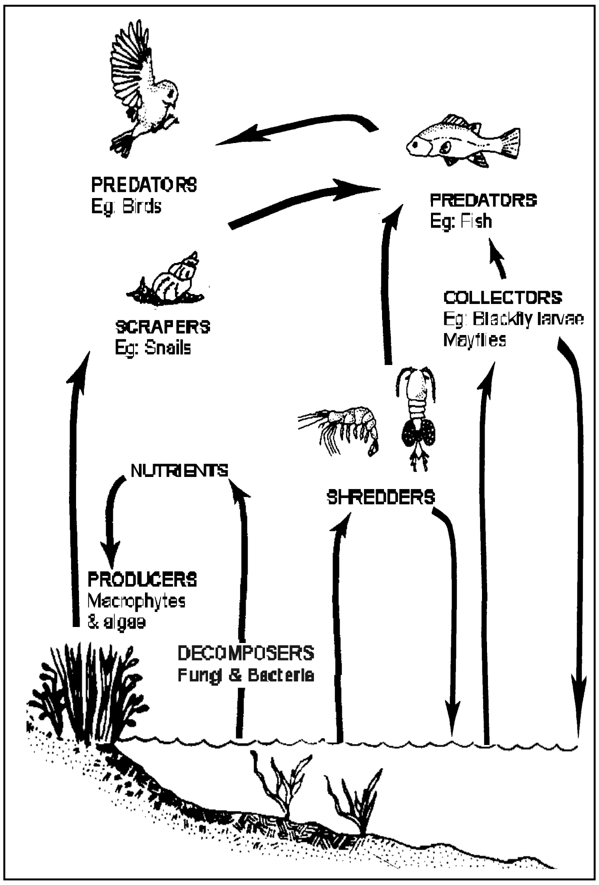


Figure 2.3 The interactions between plants and animals in a community with arrows showing nutrient flows (adapted from Gooderham and Jerie 1999)

Algae and plants form the basis of the food web. They produce their own energy from sunlight and raw chemicals and provide food for other organisms. In the in-stream environment, aquatic and semi-aquatic flowering plants (macrophytes) and algae are an important source of food for herbivores. Plants along the riverbanks also provide large amounts of organic matter (leaf litter and woody debris) to the in-stream ecosystem (Gooderham and Jerie 1999).

Herbivores occupy the next level in the food web. 'Scrapers' graze on algae and decomposers such as fungi and bacteria. 'Shredders' consume plant leaves and stems and old or dead plant material or detritus. The latter group includes invertebrates such as aquatic snails, freshwater crayfish and a variety of other invertebrates such as the larvae of insects. Above the herbivores in the food web are the predators. They are usually the larger invertebrates and animals such as fish, frogs, lizards and birds. All parts of the food web need to be supported for a healthy ecosystem (Gooderham and Jerie 1999).

2.3 What makes a healthy river?

A healthy river or watercourse ecosystem is generally defined as one with a community of plants and animals and associated ecosystem processes that are comparable to the natural or undisturbed habitats of the region (Karr and Dudley 1981). A healthy river or watercourse will contain a diversity of plants and animals, a significant proportion of which will be intolerant of degraded conditions, such as poor water quality and lack of habitat diversity (Gooderham and Jerie 1998). The type of plant and animal species present can be a good indicator of river health. The presence of a variety of sensitive species indicates that the river is in good condition; if only species tolerant of degraded conditions are present, this suggests that the condition of the river is poor. Fish and macroinvertebrates are often used as indicators of river health.

In general, the health of a river ecosystem relies on a balance between water regime, physical characteristics and processes, and ecology. Three key relationships can be drawn between these factors. The water regime (e.g. flow depth, velocity, energy) affects the shape and structure of the river and floodplain. River shape and structure, in turn, determine the type of physical habitat available and, consequently, the type of animal and plant communities. River shape and structure, and the nature of the river ecosystem also influence the water regime (e.g. in-stream vegetation increases channel complexity, reduces flow velocities and traps sediment).

CHAPTER 3 PROJECT METHODOLOGY

3.1 Introduction

This chapter presents an overview of the river management planning process for the Broughton catchment and outlines the methods used to identify watercourse management issues, determine environmental water requirements and consult with the community.

3.2 Overview of the planning process

The planning process adopted by the MNRMPP has three key components: assessing watercourse management priorities and options, determining environmental water requirements and involving the community and key stakeholders (Figure 3.1). The process of community and stakeholder involvement was concurrent with, and an integral part of, determining watercourse management priorities and options, and assessing environmental water requirements for the Broughton River system.

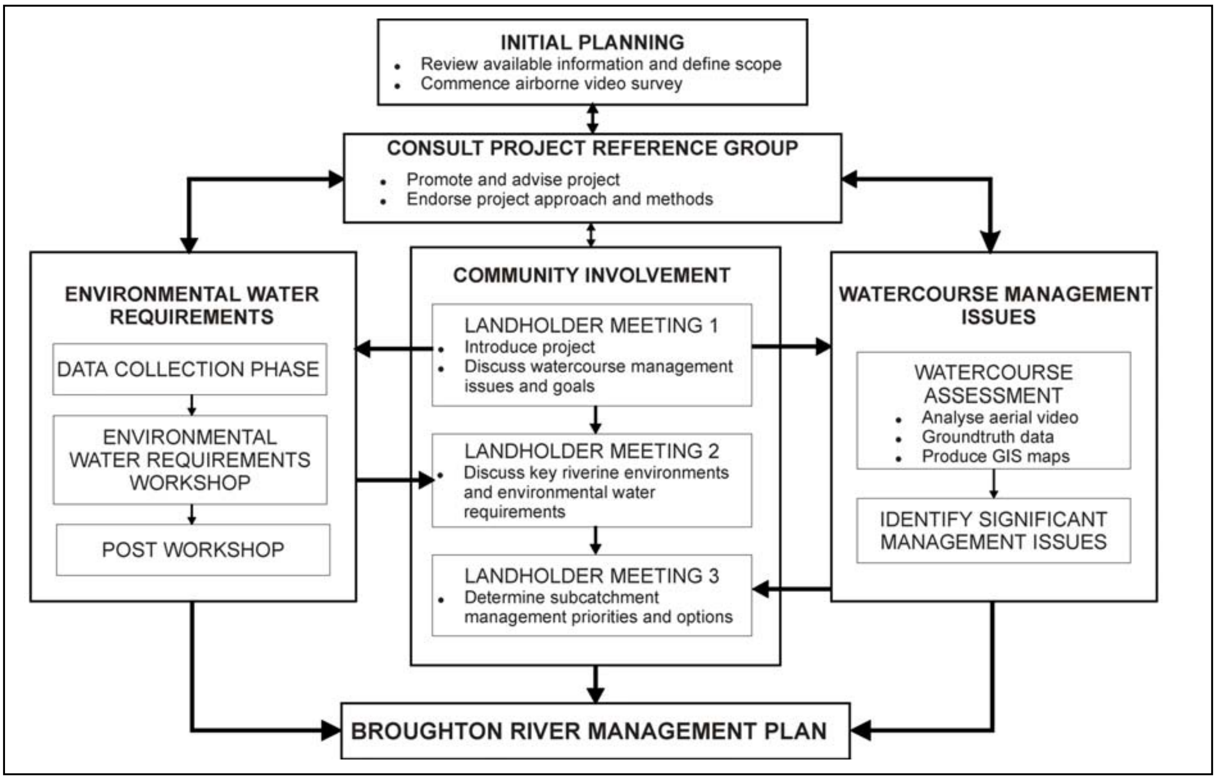


Figure 3.1 The Broughton River management planning process

Work in the Broughton catchment began with an airborne video survey of the catchment in May and June 1999. The project team analysed the video coverage of the watercourse corridor and its major tributaries to determine the current condition of the watercourses. This data was used to produce maps of watercourse condition for discussion at the community consultation meetings, to identify watercourse management issues and to select representative sites for the assessment of environmental water requirements.

Key stakeholders, through representation on the project reference group, played an important role in directing the initial and ongoing phases of the project. They facilitated the involvement of stakeholder organisations in the project and ensured an exchange of information and advice between the organisations and the project team.

The assessment of watercourse condition and environmental water requirements were integrated with community consultation and involvement. A series of community meetings provided landholders with the opportunity to:

- identify what they considered to be the key watercourse management issues along their stretch of watercourse;
- contribute their local knowledge on the condition of Broughton River;
- consider outcomes of the river condition assessment and prioritise management issues; and
- understand the catchment processes at work by viewing the management of the river in a broad context rather than at just their local or property level.

Data collection and interpretation for assessing environmental water requirements was conducted after the first community meetings. Landholders provided valuable local knowledge of rainfall, flows and changes over time. The project team commissioned field studies and technical reports on macro-invertebrate, fish and vegetation across the catchment. Data on frog populations was supplied from the EPA's Frog Census program. The team, in consultation with the ecologist and the geomorphologist on the scientific panel (see Section 3.6) conducted habitat assessments at representative sites throughout the catchment. Recorded and modelled hydrological data was collected and analysed.

A multidisciplinary scientific panel of experts considered this information and determined the water requirements necessary to maintain the ecological health of the river and its major tributaries. The information was also used to present an overview of key riverine environments, catchment hydrology and environmental water requirements at the second series of community meetings.

The project team then began collecting and interpreting data to assess watercourse conditions. It considered the issues and concerns raised at the initial community meetings as part of this process. Watercourse management issues for each subcatchment and potential management options were discussed at the third series of community meetings where landholders had the opportunity to participate in determining the priorities and strategies for watercourse management.

The final planning stage was preparing the river management plan for the Broughton catchment. A draft version was reviewed by the project reference group and members of the scientific panel, and a DEH and DWLBC internal review panel, before the final plan was produced.

3.3 Surveyed watercourses and subcatchment definitions

The project surveyed and assessed more than 1161 km of watercourses (Map 3.1) defined as fourth order and larger by the Strahler stream ordering system (Strahler 1964). In this system, unbranched watercourses originating at a source are termed first order streams. When two watercourses of the same order join, a stream of that order plus one is formed.

To facilitate community involvement and watercourse assessment, the catchment was divided into the following seven subcatchments (Map 3.1) on the basis of drainage and property boundaries, land use and social networks:

- Booborowie and Baldry
- Hutt and Hill
- Bundaleer and Freshwater
- Upper Rocky
- Lower Rocky and Crystal Brook
- Yackamoorundie
- Lower and Mid Broughton.

Information on each of these subcatchments is presented in Chapters 8–14.

3.4 Community and stakeholder involvement

3.4.1 PROJECT REFERENCE GROUP AND STAKEHOLDER INVOLVEMENT

Key stakeholder organisations were involved primarily through the project reference group which comprised local representatives of soil conservation boards, animal and plant control boards, local government, the Clare Valley Water Resources Planning Committee, PIRSA, DEH and DWR. The group, which met monthly, provided a local advisory role to the project team and facilitated the integration of river management information into the plans and work programs of their organisations. It also promoted the project to member organisations and to the wider community.

Members of key stakeholder organisations were invited to attend the project's community meetings. The project team also held meetings or gave specific presentations to stakeholder organisations and local community groups to inform them about the project and to gain an understanding of their concerns.

3.4.2 COMMUNITY INVOLVEMENT

The process of community involvement was adapted from that used successfully by the Riparian Zone Management Project in the Mount Lofty Ranges (Department of Environment and Natural Resources 1997a,b). All landholders with property adjacent to a fourth order or larger watercourse were contacted directly and invited to be involved in the project. The wider catchment community was informed of the progress of the project through articles and advertisements in local newspapers and community newsletters and through radio interviews.

Consultation was conducted at a subcatchment level. This had a number of advantages: landholders within each subcatchment generally had similar management issues and concerns and consultation at the subcatchment level could focus on local issues; and the small numbers involved ensured greater landholder involvement.

The project reference group helped the project team establish contact with key landholders ('catchment champions') who had strong community links and a good knowledge of local issues. These landholders provided valuable advice on local activities and issues, and appropriate times and locations for the community meetings.

Three rounds of community consultation were held for each subcatchment. In the initial round, nine separate meetings were held across the Broughton catchment. Some meetings were combined as the project progressed — if two meetings were being held in the one subcatchment or the issues and nature of the river system were very similar. Six separate meetings were held in the second and third round of community meetings. Outcomes from the meetings are presented in Chapter 4.

Round 1 meetings

The first round of community meetings was held in August and September 1999. Following a presentation about the project, the initial meetings discussed the data collection methods and identified watercourse management issues of importance to local landholders. Participants were asked the following questions:

- What do you see are the watercourse management issues in your subcatchment?
- What is the condition of watercourses in your subcatchment?
- What condition would you like the watercourses in your subcatchment to be in?
- What are the barriers to better watercourse management?

Through a simple voting process, participants were then able to prioritise watercourse management issues of importance to them and identify key barriers to better management. Feedback from the meeting was provided to all key stakeholders, riverine landholders and participants. Community responses to the questions are discussed in Chapter 4.

Round 2 meetings

The second round of meetings in February and March 2000 provided landholders with an overview of the geomorphology, ecology and hydrology of the catchment and discussed key riverine environments and their environmental water requirements. An overview of information presented at the meeting was sent to all key stakeholders, riverine landholders and participants.

Round 3 meetings

Stakeholder organisations, riverine landholders and participants from the previous meetings were invited to a final round of meetings in April 2000 where they were presented with the key management issues identified through the watercourse assessment process. The importance of each issue, the options for management and the general principles for determining management priorities were discussed. Landholders then voted on the priorities for the watercourse in their subcatchment. This community and technical information enabled the project team to rank the options for watercourse management in the subcatchments.

Not all landholders could attend this round, so a summary of the outcomes of the voting process and the priority list of issues were mailed to every landholder for their comments.

3.5 Watercourse assessment methods

3.5.1 WATERCOURSE SURVEY

The watercourse survey was designed to provide a rapid assessment of the bio-physical condition of the larger watercourses in the catchment. The survey method used aerial video for the initial visual assessment of watercourse conditions. This assessment data was then interpreted to identify significant management issues.

The survey focused on the fourth order and larger watercourses (Strahler 1964) because of time and resource constraints.

The airborne video survey used a Seeker Seabird observation plane with a video camera installed under the passenger side. Flights were undertaken on fine, sunny days as cloud cover severely reduced the clarity and resolution of the video. The plane flew at a height of approximately 1000–1500 feet above ground level, which provided a good resolution of the watercourse parameters while enabling the pilot to track the watercourse easily. A video recorder captured the colour image as well as the corresponding global positioning system (GPS) data. GPS data were also recorded by an onboard laptop computer and later downloaded to a geographic information system (GIS).

Data was coded from the video on to 1:20 000 base maps produced using ESRI ArcInfo and ArcView GIS. Watercourse parameters that were assessed include:

- density and type of riparian and in-stream vegetation coverage;
- location and density of exotic trees and weeds;
- large-scale bed and bank erosion;
- channel features such as incision and channelisation;
- baseflow and pools;
- stream works, including bridges and culverts; and
- adjacent land use.

The base maps included GPS points to aid the location of the video image data. Coding methods to analyse the video image were adapted from methods used previously by riparian zone management projects (Department of Environment and Natural Resources 1997a,b).

The data taken from the video was verified by two weeks of fieldwork and the information further refined through consulting landholders. The corrected data was entered into ArcInfo GIS and then converted to ArcView GIS coverages for storage, display and analysis. GIS coverages created from coding of the aerial videos were used to produce maps of the watercourse condition (Maps 7.1–7.6).

3.5.2 SCOPE AND LIMITATIONS

The aerial survey, analysis of the video, and fieldwork undertaken between May 1999 and February 2000 represents a 'snapshot' of the condition of the larger watercourses of the Broughton catchment at that time.

The airborne video survey provided a rapid and cost-effective method for obtaining an overview of the watercourse condition and habitat types across the catchment. However, this technique has limitations. Difficulties associated with flying a meandering watercourse meant that only 85–90% of the watercourses surveyed were captured on video. In areas of dense vegetation it was not possible to observe all watercourse parameters. Attempts to assess these areas through fieldwork did not cover all surveyed watercourses. As a consequence, some data was extrapolated for the unobserved sections of the watercourse. Riparian weeds were particularly difficult to assess. The survey was biased towards detecting weeds (such as boxthorn and artichoke) which have distinct growth or colour patterns that can be detected by air. In addition, density classes based on crown cover may not always be a good indication of the severity of the weed infestation.

3.5.3 IDENTIFYING AND PRIORITISING WATERCOURSE MANAGEMENT ISSUES

The project team used the data from the survey to identify significant management issues along the surveyed watercourses while focusing on ecological rehabilitation prospects. This management goal often means it is more effective to protect natural remnants than to focus effort on badly degraded watercourses (Rutherford et al. 1999). Overall, prevention is generally more effective than cure: it is easier to implement and less costly than repairing the damage. To determine the significant management issues, the project team used a set of general principles and guidelines (Appendix F). Briefly these include:

- protect assets such as important riparian habitat or remnant vegetation;
- protect or rehabilitate streams in the best general condition before those in poor condition, i.e. stop further deterioration before repairing the existing damage;
- consider the scale of the problem as issues that may be significant at a property level may not be significant at a catchment scale;
- consider the impact of the issue on upstream and downstream reaches; and
- consider the costs of management action against the ecological benefits.

The significant management issues identified through the watercourse assessment process for each subcatchment were presented to landholders at the third round of meetings. The importance of each issue, the strategies for management and the general principles for determining management priorities were discussed. Landholders were asked to participate in a simple voting process to determine management priorities for their subcatchment. They were aided by maps illustrating the watercourse condition and the extent and location of the watercourse management issues identified by the project team. A summary of the outcomes of the voting process and a draft priority list of issues was mailed to all landholders and key stakeholders for their comment.

A table highlighting the priority management issues and strategies was produced for each subcatchment (Chapters 8–14). The results of the watercourse condition assessment and the significant management issues identified are discussed on a catchment basis in Chapter 7 and shown on Map 7.7. These issues can be placed into three main categories: conservation, vegetation management and channel stability. Chapters 8–14 discuss issues specific to each subcatchment.

3.6 Assessment of environmental water requirements

Current best practice for assessing environmental water requirements in Australia is to conduct multidisciplinary studies involving panels of specialist scientists. The extent of new data collection and field investigations depends on the timeframe and resources (Arthington 1998). The ‘Scientific Panel Habitat Assessment Method’ employed in this study adapts this generic approach to:

- meet data, time and resource constraints;
- be applicable to unregulated, ephemeral river systems;
- provide a whole of catchment understanding of the river’s physical and ecological components, processes and functions;
- develop flow benchmarks where future changes could be modelled and subsequent impacts quantified; and
- incorporate community input.

The method is based on classifying the river system into river process (geomorphic) zones. The underlying assumption is that each zone will have a unique assemblage of river morphologies and physical habitats and that the ecological components and processes for these zones will also differ. Data is collected on representative habitats within these zones and studies of vegetation, fish, frog and macro-invertebrate populations are undertaken at sites across a catchment. Hydrological data is recorded and modelled for the different zones. A multidisciplinary scientific panel is assembled to review the data and use their professional knowledge and expertise to determine the critical flow parameters for each geomorphic zone.

The approach was based on the following ecological and management principles:

- maintain the natural variability in connections between habitats;
- maintain the natural variability in carbon/food sources;
- maintain and improve the physical and ecological condition of the Broughton River system;
- maintain the natural variability of flows (duration, frequency and seasonality);
- maintain the system's natural biodiversity and, where appropriate, restore biodiversity values in degraded areas;
- do not give human constructed structures or habitats priority over natural habitats (in terms of flows and managing the river system); and
- give priority to the areas of better biological and physical condition.

It involved three essential phases: initial data collection, the scientific panel and post-workshop (Figure 3.2).

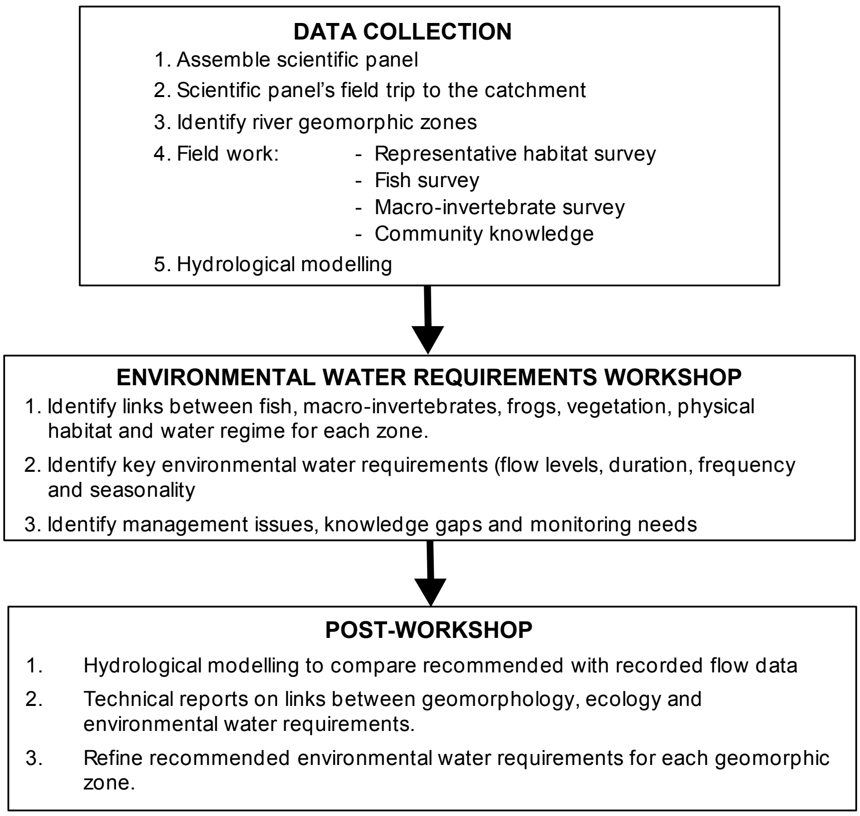


Figure 3.2 Process for determining environmental water requirements

3.6.1 DATA COLLECTION PHASE

Most of the data collection for the assessment of environmental water requirements for the Broughton catchment on fourth order and larger watercourses as defined by Strahler (1964) was carried out between September 1999 and February 2000.

Scientific panel catchment tour

The assessment began with the scientific panel inspecting the Broughton catchment in September 1999. The field inspection provided first-hand observations of the river and its tributaries and was an opportunity for panel members to exchange ideas and observations. The scientific panel included a geomorphologist, ecologist, hydrologist, aquatic biologists and the project team (Table 3.1).

Table 3.1 Members of the scientific panel

Participant	Field of expertise/role	Organisation
Dr Sandra Brizga	Geomorphologist	S Brizga & Associates Pty Ltd
Lance Lloyd	Ecologist	Lloyd Environmental Consultants
Chris Madden	Aquatic biologist (Monitoring River Health Initiative)	Australian Water Quality Centre, SA Water
Peter Goonan	Aquatic biologist	EPA, DEH
Dave Cresswell	Hydrologist	DWR (now DWLBC)
Diane Favier	Project team	EPA, DEH
Glen Scholz	Project team	EPA, DEH
Jason VanLaarhoven	Project team	EPA, DEH

Identification of geomorphic zones

The project geomorphologist studied the geomorphic characteristics of the catchment (Brizga 2000a) and subdivided the major rivers and streams in the Broughton catchment into geomorphic zones on the basis of:

- major tributary confluences;
- geology;
- natural channel and floodplain morphology;
- key landform units (Broughton River delta and estuary);
- water resource development; and
- channel incision.

Some 14 different geomorphic forms were identified and the watercourses within the catchment were divided into 31 separate geomorphic zones (see Chapter 5, Table 5.2, Map 5.2). The characteristics of the different geomorphic zones located in each subcatchment are described in Chapters 8–14.

Data collection

Habitat surveys

Field surveys were conducted at sites representative of the main physical habitats within each geomorphic zone. Longitudinal and cross-section profiles were taken at each site and data was collected on the following parameters: land use, channel/floodplain disturbance, floodplain and riparian zone width, baseflow characteristics, channel features, in-stream debris, substrate and floodplain, riparian and in-stream vegetation. Photographs were taken as a record of each site.

Ecological studies

Ecological studies were commissioned in order to collect and analyse data on key indicators (such as vegetation, fish, macro-invertebrates and frogs) across the catchment. The technical reports produced from these studies helped the scientific panel determine the water requirements of key dependent ecosystems and were used by the project team to assess the health of the catchment watercourses.

Ecologists from the Monitoring River Health Initiative (MRHI) analysed macro-invertebrate data from 63 samples collected from 12 MRHI sites in the catchment between 1994 and 1997. The data was initially analysed for the type of species present, species richness, abundance and distribution (Madden et al. 1999). The data was also run through a predictive computer model (AusRivAS) to assess the relative health of each site. The technical report produced provided information on the diversity and distribution of macro-invertebrate species and river condition, and recommendations on the water requirements of macro-invertebrate species of the Broughton River system.

A one-off survey of fish populations combined with rapid macro-invertebrate sampling was conducted at 10 MRHI sites in the catchment in December 1998 and January 1999. The resulting technical report (Hicks and Sheldon 1999) contained information on native fish populations, an index of the biotic integrity of the river at the survey sites and a discussion of the water requirements of fish populations.

Information on frog populations and lifecycle requirements was gathered through the Frog Census program managed by the EPA.

PIRSA Rural Solutions was commissioned to study pre-European riparian vegetation associations based on the remnant vegetation and historical sources. This provided information on the current vegetation associations as well as on the extent and types of pre-European vegetation associations. This information, together with the rehabilitation and revegetation requirements for each association, was included in a technical report by Brown and Kraehenbuehl (2000).

Community information

Information such as rainfall records, flood records, general observations relating to river flows and historical data was sought from local landholders. It supplemented the limited rainfall and gauged streamflow information available for the catchment.

Hydrological data and modelling

The catchment is gauged at three locations: Mooroola (south of Spalding), on Hutt River near Spalding and on Hill River near Hilltown (Map 3.1).

The Hutt and Hill River stations have the oldest hydrological records — starting in the 1960s — but the early records were not considered reliable. Good quality digital records from the three stations since 1974 were used to estimate environmental water requirements.

No stations exist downstream of the Mooroola gauging station or on other major tributaries. Flow data from these areas had to be estimated using a daily rainfall-to-runoff model. The hydrological modelling, by a senior DWR hydrologist, used WaterCress, a PC-based water balance model for designing and testing trial layouts of water systems with multiple sources of water. In this case the sources were the numerous subcatchments each with differing rainfall inputs. The model was calibrated by comparing modelled data with actual data (Cresswell 2000).

As rainfall varies greatly, and much of the catchment receives only 450–500 mm per year, modelling the runoff is difficult. In addition, stream losses cannot be estimated without recorded data so the model may overestimate the flows in some tributaries.

3.6.2 ENVIRONMENTAL WATER REQUIREMENTS WORKSHOP

The two-day environmental water requirements workshop provided a forum for the scientific panel to consider the physical, biological and hydrological data, and collaboratively determine the environmental water requirements for each geomorphic zone. All participants were provided with the data collected during the pre-workshop phase.

Based on analysis of the ecological studies, representative site surveys, geomorphological and hydrological data, the scientific panel identified the water requirements necessary for key indicator biota (fish, macro-invertebrates, vegetation and frogs) and ecological and geomorphic processes. This included a description of relevant flow bands or levels and the frequency, seasonality and duration of flows.

This information was then related to features (i.e. geomorphic features, habitats, vegetation, fish, frogs and macro-invertebrates) identified for each geomorphic zone to determine the environmental water regime for that zone. For example, characteristics such as breeding requirements were used to determine the areas that needed to be inundated at various flows and also the time of the flows to maximise an ecological response from the target species.

Water levels corresponding to key flow bands were identified on cross-sections taken at representative sites in each zone. For sites with good hydrological data, flow volumes corresponding to these water levels were calculated using slope values and Manning's formulae. These flow volumes were related back to data recorded at the gauging stations to determine actual flow frequencies and durations (Cresswell 2000). For all other sites the values for frequency and duration of different flow bands should be considered as first estimates based on the best available knowledge.

Assets, threats, watercourse management considerations, knowledge gaps and monitoring needs were also identified for each zone.

In the final stages of the workshop, the panel took a whole-of-catchment approach to determine critical influences on river health for each geomorphic zone. They compared the influence of environmental water requirements with other management issues and discussed the potential impact of continuing current management practices.

3.6.3 POST-WORKSHOP

Following the environmental water requirements workshop, considerable effort was put into refining the recommended environmental water requirements. The outcomes of the workshop were reviewed by all participants and refined in the light of further technical information.

The consequent ecology report integrated the outcomes of the workshop with the results of the ecological studies, habitat surveys and hydrological study and outlined the relationships between ecology and water regime in the catchment (Lloyd 2000). A final geomorpology report also discussed the geomorphology of the catchment and the water requirements necessary to maintain geomorphic processes (Brizga 2000a).

A series of tables outlining the environmental water requirements for each river geomorphic zone was prepared (Appendix E) listing the important flow bands (e.g. baseflow, mid flow) and associated key ecological and geomorphic functions (e.g. migration of fish, channel maintenance) as well as frequency, duration and seasonality characteristics, for each zone. Where possible a description of the extent and depth of the water is also provided. See Chapters 8–14 for an overview of the environmental water requirements for each zone.

Where recorded flow data was available, the environmental water requirements specified by the scientific panel were compared with the current flow regime and the 'natural' flow regime (the cleared catchment with no farm dams). The natural flow regime was modelled using a simple computer model that accounts for the amount of water trapped in farm dams. The modelling does not take into account other impacts on flows including climatic variation and land management practices.

The location of the three gauging stations in the Broughton River system means it is possible to calculate current and natural flow occurrences for three river zones only: Broughton River Zone 6, Hutt River Zone 1 and Hill River (see Chapter 6). Comparing the actual flow data with the environmental water requirements recommended by the scientific panel provided an insight into the accuracy of the environmental water requirements specified by the panel and the impacts of farm dams on the requirements for three geomorphic zones along Broughton, Hutt and Hill rivers.

A technical hydrology report detailed the hydrology of the catchment and the modelling of the water regime (Cresswell 2000). Where applicable, the tables outlining the environmental water requirements for each river geomorphic zone of the Broughton River system were refined based on the results of this modelling.

3.6.4 LIMITATIONS AND ASSUMPTIONS

The assessment of environmental water requirements represents a simplification of a complex ecological system based on the best data and knowledge then available. As a result, the requirements determined are preliminary estimates because we have limited knowledge of the ecology and flow relationships within Broughton River (and elsewhere). The requirements do, however, provide an initial and important basis for protecting the natural values of the catchment's streams and wetland habitats.

Many of the estimates of frequency and durations were based on fish requirements. Fish were considered a reasonably conservative indicator and it was assumed that if fish requirements were met then most other ecological requirements would also be met.

The approach to describing the environmental water requirements and their importance attempts to link key functions with a particular flow band. This is often a simplification as several different flows may be significant for a particular function. For example, sediment transport is mainly driven by high flows, though smaller flows will have an influence. Similarly, the functions of different flow bands will change depending on the form of the channel. A flow event that reaches bankfull in a zone with a shallow channel may only reach a mid flow level in a narrow, deeply incised channel.

Similarly, environmental water requirements are described in terms of key components of the water regime (extent and depth, frequency, duration and seasonal factors). This does not take into account other features of the water regime that may be important (e.g. variability, the rates of rise and fall of a flow event, the time since the last flow event, the sequence of flow events).

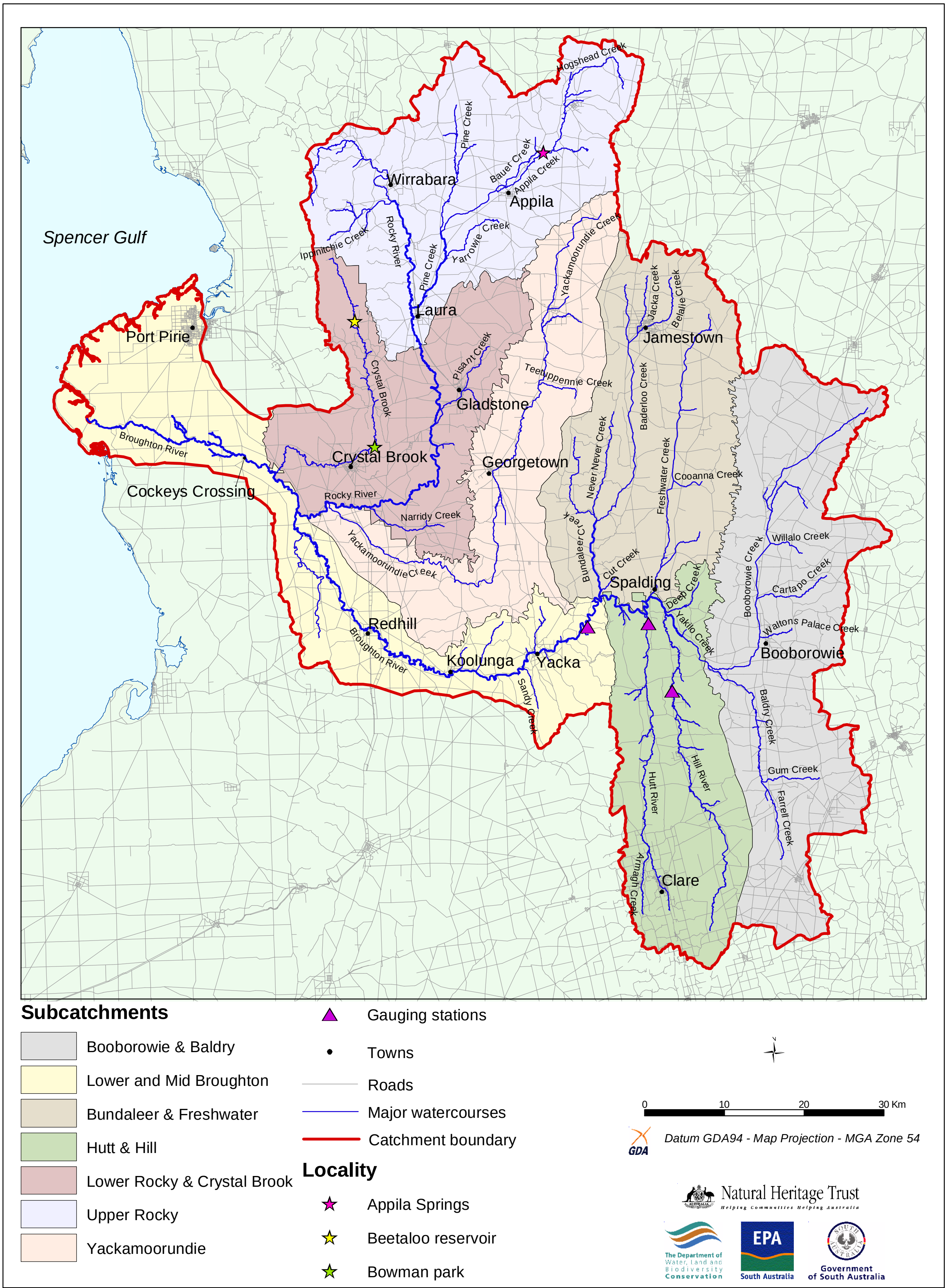
3.7 Summary

The project team's planning process had three key components: assessment of watercourse condition and identification of management issues, assessment of environmental water requirements, and community and stakeholder involvement. Community and stakeholder involvement was an integral part of the entire planning process.

Studies of riverine habitats, macro-invertebrates, fish, frogs and vegetation, and hydrological modelling, combined with the expertise of a scientific panel, determined the environmental water requirements of water dependent ecosystems across the catchment. See Chapter 5 and Appendices C and D for the results of the technical studies and Chapters 8–14 and Appendix E for the recommended environmental water requirements for each geomorphic zone.

Significant watercourse management issues were determined by assessing watercourse conditions from data collected through airborne video survey and fieldwork. Management priorities and strategies for each subcatchment were determined in consultation with the landholders. The results of the assessment and significant management issues are discussed on a catchment basis in Chapter 7 and for each subcatchment in Chapters 8–14.

Further details on the methods used in the technical studies which support this plan are in the technical reports by Hicks and Sheldon (1999), Madden et al. (1999), Brown and Kraehenbuehl (2000), Lloyd (2000), Cresswell (2000) and Brizga (2000a).



Map 3.1: Surveyed watercourses and subcatchments in the Broughton catchment

CHAPTER 4 COMMUNITY CONSULTATION

4.1 Introduction

This chapter presents an overview of the outcomes of the community consultation process (see Chapter 3 for methodology). Details of the local community's concerns about the watercourses in each subcatchment are discussed in Chapters 8–14.

Improved river management will be achieved if the local catchment community develops an ownership of the management problems and their solutions. This will only occur if the community understands the importance of improved river management and if individuals can influence management actions.

Landholders, community members and key stakeholders within the Broughton catchment were consulted on a subcatchment basis to determine local watercourse issues, their vision for an improved watercourse environment and the challenges they may face in managing the watercourse. During the course of the project more than 380 people attended meetings and more than 850 riverine landholders and stakeholders were contacted by mail.

4.2 Management issues, barriers and goals

At the first meetings participants were asked the following questions: 'What do you see as the watercourse management issues in your subcatchment?'; 'What is the condition of watercourses in your subcatchment?'; 'What condition would you like the watercourses in your subcatchment to be in?'; and 'What are the barriers to better watercourse management?'.

Perceptions of the current condition of watercourses in the catchment varied depending on which subcatchment the respondent lived in. Some believed the watercourses in their subcatchment were in good condition, although a lack of rainfall and a decrease in flows were considered to be impacting on water quality and river health. Other watercourses were considered to be in poor condition because of a lack of vegetation or active erosion. Others felt that the condition of their watercourse had improved over time or at least was no worse than 20–25 years ago.

In general, issues of concern and their importance differed among the subcatchments and these are discussed further in Chapters 8–14. However a number of issues, listed below in order of importance, did emerge as common concerns across the entire catchment:

- decrease in flow and lack of water in the river;
- poor water quality;
- erosion;
- weeds;
- impacts on groundwater;
- increased growth of reeds;
- river salinity;
- flooding;
- uncontrolled development;
- stock impacts; and
- debris in the river.

Changes to the water regime — an observed decrease in surface flows and springs, and waterholes drying up — were of most concern to landholders across the catchment. The lack of flow was considered due mainly to a lack of rain over the last eight years and increased usage, particularly the impact of farm dams and irrigation development in the Clare Valley.

Poor water quality was the next most important issue with a great deal of concern being expressed over the impact of fertiliser and chemical use. Bed and bank erosion and weeds along the watercourse were also considered significant problems in most of the subcatchments.

A common theme that emerged when participants were asked to indicate their vision for an improved river system was that the watercourses in the catchment should not be in any worse condition than they are at present. Key management objectives identified during the community meetings include:

- enhancing the natural qualities and characteristics of the river system, including more native vegetation and wildlife;
- improving water quality;
- improving water quantity;
- controlling weeds in the watercourses;
- maintaining a balance between reed beds and waterholes in the river system; and
- achieving a sustainable balance between development and the riverine environment.

Participants were asked for their views on what was preventing them achieving the objectives of an improved river system. The most important barriers to watercourse management identified were:

- lack of community awareness, knowledge and information about how the river functions and how to improve its management;
- lack of funds to address watercourse management issues;
- the problem of economic viability vs environmental management (e.g. conflicts between agricultural use and environmental needs);
- lack of manpower to address watercourse management issues; and
- no catchment management planning and a lack of coordination and communication among organisations and individuals involved in river and water resource management.

4.3 Summary

Feedback from the community gained during the consultation process indicated that most people were aware of problems along their watercourses and would like to see the condition of their watercourses improved. The process provided valuable information on the community's goals for managing their watercourses and identified major barriers, such as a lack of knowledge, funds and support, no integrated management and conflict over uses that need to be addressed in order to achieve changes on the ground.

CHAPTER 5 WATER DEPENDENT ECOSYSTEM COMPONENTS AND PROCESSES

5.1 Introduction

This chapter presents the results of the technical studies commissioned by the project. Key water dependent ecosystem components and processes, and their environmental water requirements for watercourses in the Broughton catchment are described. These requirements are based on the life history and habitat needs of the plants and animals as well as the current understanding of the relationship between geomorphology and flows. This information forms the basis of the overall assessment of the environmental water requirements for the catchment (Chapter 6 and Chapters 8–14).

The water regime in the catchment can be categorised into seven key flow bands (Table 5.1), which have been used to describe the water requirements of dependent ecosystem components and processes discussed in this chapter.

Table 5.1 Flow bands used to describe key environmental water requirements

Flow band	Description
Groundwater table	The groundwater intersects the stream bed and expresses itself as permanent water in the low lying parts of the stream bed. There is no flow but the stream bed and pools are kept permanently wet.
Baseflow	There are two aspects of baseflow — permanent and seasonal pulse flow. Permanent baseflow is that part of the flow regime that is constantly flowing, often at a very low level and driven by groundwater. The seasonal pulse baseflow is that part of the flow regime which is expressed with a sharp rise following seasonal rain.
Low flow	Low flows lie between seasonal baseflow and mid flows, and are mostly derived from surface flows but can have a significant baseflow component. Flows tend to be frequent and have a long duration.
Mid flow	Mid flows are typically those that cover the bed of the stream and up to about half the height of reeds in the stream or on the stream edge. Some of the lowest in-channel benches may be flooded, creating further habitat.
High to bankfull flows	High flows are those that generally fill ¾ of the channel to bankfull within the stream and can have little flows spilling onto the floodplain. All in-stream benches are inundated creating further habitat for macro-invertebrates, plants and fish.
Overbank flow	Flows greater than bankfull and inundating the floodplain where this exists.
Catastrophic flow	These are large, infrequent floods that cause significant stream bed and channel rearrangement and alter or reset the habitat.

5.2 Geomorphology

Geomorphology encompasses those geological and topographical features and processes (such as sediment transport and erosion) that determine the shape, form and physical habitats along a watercourse. The water regime is a key driver of geomorphic processes and strongly influences the geomorphology of a watercourse, which is an important determinant of the aquatic habitat type and availability. Assessing the water regime required to maintain essential geomorphic processes is therefore an important step in determining environmental water requirements.

5.2.1 GEOMORPHIC FEATURES

The Broughton catchment has two distinct landscape features: the hills and valleys of the southern Flinders Ranges and northern Mount Lofty Ranges; and the flat coastal plain (Map 5.1). These large-scale features control the drainage system of the catchment and influence the channel form and behaviour of the watercourses.

The stream valleys of the southern Flinders Ranges and northern Mount Lofty Ranges include floodplains and alluvial fans. Floodplains are situated adjacent to the watercourse channels and vary greatly in width. Alluvial fans occur where the main watercourses and tributaries emerge from narrow valleys into wider valleys. Watercourses in the alluvial fans range between two extreme types: no defined channel with all flow overland across the fan surface; and deeply incised channels capable of containing very large flood flows. Examples of these channel types can be seen in the unincised and incised reaches of Appila Creek as it flows out of the Narien Ranges and onto the valley floor (Brizga 2000a). The alluvial fans are high-risk areas for erosion because of their steep gradients and the unconsolidated sediments over which flow occurs.

The influences of geology and landscape features can be seen in the behaviour of Broughton River and three of its major tributaries. Rocky River and Yackamoorundie Creek initially flow in a southerly direction parallel to the north–south alignment of the Northern Mount Lofty Ranges. At the western edge of the Mount Lofty Ranges, these two watercourses then turn sharply to the west to flow through rocky gorges. Broughton River also flows through a gorge west of Spalding. The alignment of these gorges is roughly perpendicular to the north–south alignment of the ranges. Crystal Brook is also controlled by the underlying geology and flows at first in a southerly direction parallel to the alignment of the southern Flinders Ranges and before turning sharply to the west. Crystal Brook does not flow through a gorge after turning westward. Geological factors may have caused or contributed to a unique habitat of permanent springs and reedbeds where the streams turn westward in all four rivers (Brizga 2000a).

The coastal plain west of the ranges can be divided into two main sections:

- a riverine section, which includes the lower zones of Crystal Brook, Yackamoorundie Creek, Rocky River and Broughton River downstream of Koolunga; and
- the Broughton River delta which extends from about 1 km downstream of Cockeys crossing to the coast.

Along the riverine section of Broughton River downstream of Koolunga, there is a single, deep channel of varying capacity bordered by a broad floodplain. Traces of a major historical change in watercourse location (avulsion) can be seen on the floodplain near Merriton. The riverine plains of river red gums, which require flooding for germination, in this area suggest that flood events break the banks and inundate the area. The lower zones of Crystal Brook, Yackamoorundie Creek and Rocky River also have broad floodplains.

The Broughton River delta fans out towards the coast, where it extends in breadth from south of Deep Creek to Port Pirie. The delta is regularly flooded and the deposition of sediment and changes in the river's course are characteristic. It is likely that before settlement this area would have resembled a large coastal swamp with several river channels. There are numerous tidal streams along the coastal edge of the delta through which the river discharges in overland flows during large floods.

Since European settlement significant changes in river and watercourse geomorphology in many parts of the catchment include deepening and widening of watercourse channels, raising of bed levels due to sedimentation and changes in the channel course. Extensive stream erosion has occurred along a number of major watercourses, including parts of Freshwater, Bundaleer, Pine and Appila creeks, as well as widespread incision of more minor tributaries. As a result of watercourse and catchment erosion, high rates of sediment deposition have occurred along a number of watercourses, for example parts of Booborowie and Yackamoorundie creeks. Significant sedimentation was observed upstream of weirs along the Bundaleer, Freshwater and Yakilo creeks. Elevated sediment inputs may be a factor influencing the growth of dense reedbeds in areas of deposition. The Broughton River appears to be changing course at the upstream end of its delta. This is a natural process but it is not known how activities such as the diversion of floodwaters for irrigation, may have affected it.

Human activities, which have contributed and continue to contribute to these geomorphic changes, include direct interventions such as excavation, channelisation and levee banks, clearing of watercourse and floodplain vegetation, construction of dams and weirs, extraction of surface and groundwater, grazing and removal of in-stream reedbeds. Chapter 7 contains the results of the survey of current channel condition and stability, and a discussion of bed and bank erosion processes and management needs.

5.2.2 GEOMORPHIC ZONES

Based on the underlying geology, channel and floodplain characteristics, key landforms, channel incision and hydrology, watercourses in the Broughton catchment can be divided into distinct river geomorphic zones (Brizga 2000a). Each zone possesses unique physical and hydrological characteristics that influence the plants and animals found there and distinguish that area from other parts of the river system. Flow regimes, habitats and ecological processes will differ. As a result, environmental water requirements will also differ among zones with different geomorphic characteristics.

The geomorphic zones of the watercourses in the catchment show a range of different channel forms (Map 5.2). These can be grouped according to their distinguishing hydrological characteristics and range from watercourses that flow for most or all of the year to ephemeral watercourses that flow only occasionally and dry out for extended periods. In between these two extremes are intermittent watercourses that stop flowing for a part of the year and differ from ephemeral zones in that pools do not necessarily dry out (Table 5.2). A detailed list of the geomorphic zones and their locations is provided in Appendix B.

5.2.3 GEOMORPHIC PROCESSES AND WATER REQUIREMENTS

All of the watercourses in the Broughton catchment have intermittent or ephemeral reaches, and flows are characterised by a high degree of variation between years. As a result, geomorphic processes are also episodic with little erosion and sedimentation in most years but high rates of erosion and sedimentation during infrequent major flood events (Brizga 2000a). Key geomorphic processes include: maintaining wetted habitats (e.g. riffles and pools); sediment transport; removal of fines from riffles; channel maintenance; scouring of pools; bank erosion and stream incision; and floodplain processes (e.g. avulsion).

A more detailed description of the flow requirements needed to maintain the geomorphic processes discussed below is included in Appendix C.

Table 5.2 Channel forms and geomorphic zones of the Broughton River system

Distinguishing hydrological characteristic	Channel forms	Geomorphic zone
Tidal influence	Estuary (tidal channels)	Broughton River Zone 1
Delta (non-tidal)	Delta (multiple channels and broad floodplain)	Broughton River Zone 2
Permanent & semi-permanent watercourse	Major river with continuous baseflow	Broughton River Zones 3–6
	Major tributary with continuous baseflow	Hutt River Zone 1
	Incised stream with continuous baseflow	Freshwater Creek Zone 1, Bundaleer and Baderloo Creeks Zone 1, Belalie Creek Zone 1
Intermittent watercourse	Major tributary with discontinuous baseflow	Rocky River Zone 1 and 2
	Discontinuous baseflow	Yakilo and Baldry Creeks; Rocky River Zone 4; Appila Creek Zone 2; Yackamoorundie Creek Zone 3
	Chain of ponds	Hutt River Zone 2; Hill River
	Incised stream with discontinuous baseflow	Freshwater Creek Zone 2; Baderloo Zone 2
	Discontinuous baseflow with constrained floodplain	Yackamoorundie Creek Zone 2
Ephemeral watercourse	Small channel with swampy floodplain	Booborowie Creek; Freshwater Creek Zone 3; Baderloo Creek Zone 3; Belalie Creek Zone 2; Rocky River Zone 3; Yackamoorundie Creek Zone 1
	Small channel with constrained floodplain	Crystal Brook Zone 2
	Minor stream subject to incision	Pine Creek; Appila Creek Zone 1
	Incised meandering channel	Crystal Brook Zone 1

Maintaining wetted habitat

Low to mid flows (of longer duration) are important for maintaining flow over rock bar and riffle habitats. Flows of all magnitudes, including groundwater levels, are important for filling and maintaining pool habitats. If the volume or frequency of flows decreases then pools and riffles may dry out more often or for longer periods of time. Changes in groundwater levels could also have significant implications. Falling levels may increase the risk of aquatic habitats drying out. Rising levels could result in areas that dry out naturally staying wet for a longer period (Brizga 2000a).

Sediment transport

Mid, high, overbank and catastrophic flows are all important for the transport of sediment. Different flow events and velocities will move different types of sediment. For example, high flows move large sediment (such as gravel) and mid to high flows will transport finer particles (such as sand). Large floods are significant because they transport the largest volumes of sediment and are important for sediment delivery to the estuary (Brizga 2000a).

Removal of fines from riffles

High to overbank flows are required to remove fine sediments from riffle surfaces and from the spaces between gravels. These flows are important in maintaining riffle and cobble/gravel substrate habitats. A reduction in the flow capable of moving sediment is likely to result in a silting up of the habitat (Brizga 2000a), which impacts on the habitat's ability to support riffle-dwelling animals.

Channel maintenance

High flows are important to maintain a channel and inhibits vegetation encroachment and channel siltation. This flow is commonly the bankfull flow in alluvial rivers. In rivers with large channels there is often a bench corresponding to this level (Brizga 2000a). If the frequency of the flow event is reduced the channel may begin to silt up and vegetation may move into the channel.

Scouring of pools

Large floods (on average 1-in-20 years) are important for scouring pools (except for those pools formed by floods larger than those under the current climatic regime). This prevents sedimentation in the pool environment. Hydraulic information for specific reaches is required to define the size of flows capable of scouring pools more accurately (Brizga 2000a).

Bed and bank erosion

Naturally occurring bed and bank erosion is important in the natural channel morphology. Medium and high flows play a significant role in the bank erosion process, such as bank slumping and erosion of sediment from the toe of the bank. Stream incision caused by erosion head retreat and bed deepening generally occurs in large floods (Brizga 2000a).

Floodplain processes

The floodplain processes include erosion, sedimentation and changes to the channel course. Overbank flows that inundate the floodplain are important for driving these processes. Changes due to levee banks, channelisation or incision will affect the processes. Channel maintenance flows are also important because if a channel begins to fill with sediment or if vegetation begins to encroach, the channel will have a reduced flow capacity and a greater proportion of the flow will be forced out onto the floodplain (Brizga 2000a). This can result in extensive flooding.

5.3 Ecological components and processes

5.3.1 VEGETATION COMMUNITIES AND FLOW REQUIREMENTS

Watercourse vegetation includes plants that grow in the stream channel and on the channel banks. These plants generally prefer conditions of high soil moisture and are able to withstand flooding, hence their location. Different communities or associations of plants occur along and across a watercourse, based on the soil type, soil moisture availability, flow dynamics and flooding regimes. These factors are influenced by river geomorphology and thus vegetation communities will tend to vary among different geomorphic zones.

Based on the technical studies conducted by the project team and Brown and Kraehenbuehl (2000), seven key vegetation communities were identified for the purposes of determining environmental water requirements for the catchment. These communities and their flow requirements are described below. Appendix D provides more detailed descriptions of the vegetation flow requirements, including frequency, duration and seasonality. The current condition of watercourse vegetation in the catchment and associated management issues are discussed in Chapter 7.

Map 5.3 provides a guide to the location of these communities across the catchment. This map illustrates the estimated pre-European location and extent of major vegetation associations based on field studies of remnant vegetation, previous vegetation studies and historical materials.

Riverine forests and woodlands

Open forests and woodlands of river red gum (*Eucalyptus camaldulensis*) and Broughton willow (*Acacia salicina*) are widespread along Broughton and Rocky rivers and Crystal Brook. Along the lower reaches of Broughton River, the river red gum woodlands are associated with lignum (*Muehlenbeckia florulenta)*, samphire and chenopod species (*Halosarcia pergranulata, Chenopodium nitrariaceum*). Open forests and woodlands of South Australian blue gum *(E. leucoxylon*) and peppermint box (*E. odorata*) can be found along the upper reaches of Rocky River, Appila Creek, and Hutt and Hill rivers (Map 5.3). These forests and woodlands typically have understoreys of sclerophyllous shrubs, saltbush and/or native grasses (Brown and Kraehenbuehl 2000).

Open forests and woodlands of native pines (*Callitris glaucophylla*) and Broughton willow can be found along Pisant and Pine creeks. Low woodlands of Broughton willow are believed to have existed along the lower and middle reaches of the Hutt and Hill rivers although very few traces of this native vegetation association remain today (Map 5.3) (Brown and Kraehenbuehl 2000).

Riverine forests and woodlands dominated by river red gums are dependent on flooding for recruitment, maintenance and establishment. Overbank and floodplain flows are required for major recruitment events, at least once every 10–50 years and preferably in the winter–spring period. Activities that reduce the frequency of overbank flow events, such as in-stream structural works, incision and altered flow regimes, will impact on the maintenance and recruitment of these forests and woodlands.

Riverine shrublands

The shrublands of the Broughton River system consist of species such as elegant wattle (*A. victoriae*), golden wattle (*A. pycnantha*), native apricot (*Pittosporum phylliraeoides*), native myrtle (*Myoporum montanum*), weeping emubush (*Eremophila longifolia*) and sweet bursaria (*Bursaria spinosa*). They tend to occur in the lower rainfall areas of the catchment, typically along, for example, Yackamoorundie, Pine, Appila, Booborowie, Baldry, Freshwater and Bundaleer creeks (Map 5.3) (Brown and Kraehenbuehl 2000). Vegetation clearance, cropping and grazing have resulted in the loss of many of these shrub species from these watercourses and only isolated remnants remain.

Flooding across in-stream benches, bank slopes and riparian zones every 1-in-10 to 1-in-20 years is important for the recruitment, establishment and growth of many shrubland species (Lloyd 2000). Consequently, the mid to high flows of 5–14 days in spring and summer are important water requirements. Short duration mid and high flows every one to two years will water these shrubs.

Lignum swamps

Lignum (*Muehlenbeckia florulenta*) occurs as an understorey in river red gum woodlands or as floodplain shrublands in association with samphire and chenopod species. Lignum swamps are common in flooded areas and are an important habitat for land animals. In times of flood they provide important breeding and habitat areas for birds, fish and macro-invertebrates. These vegetation communities are found mainly on the riparian zone and coastal floodplain of the Broughton River downstream of Cockeys crossing. Small communities of lignum also exist on in-stream benches near Koolunga.

Lignum tends to be abundant in low-lying areas subject to flooding every 3–10 years. It is dependent upon flooding events to sustain growth and trigger flowering and seed set (Craig et al. 1991; Lloyd 2000). Ideally, lignum requires high and overbank flows every 1-7 years on average to establish and maintain the species in the long term (Lloyd 2000). Structural works such as levee banks and channelisation or other activities that reduce the frequency of floodplain flooding are likely to impact significantly on lignum communities.

Mangrove forests and samphire marshes

Mangrove (*Avicennia marina*) forests are located at the Broughton estuary and samphire (*Sarcocornia* sp., *Halosarcia* sp.) marshes on the tidal flats. Seagrass is present in the tidal channel. Mangrove forests provide an important breeding ground and habitat for fish, birds and macro-invertebrates and protect the coastline from the erosive influence of the marine environment. Samphire marshes provide organic matter to the estuary food chain, filter sediment from land-based runoff and are an important habitat for insects, small vertebrates and birds (Rose and McComb 1995; Department of Land and Water Conservation 1992).

Regular seasonal flows that connect the river to the estuary are necessary for transporting sediment, nutrients and organic matter. The sediment maintains the mudflats that support the mangrove forests. The nutrients and organic matter provide a valuable food source for estuarine plants and animals. Although the distribution of samphire marshes is influenced largely by tidal inundation, river flooding also plays a role (Murray et al. 1995). These areas also rely on the nutrients, organic matter and silt that originate higher up in the catchment.

Mid flow events are important as these connect the Broughton River with its estuary. There is no connection under baseflow conditions, as the connecting channel is ephemeral. High to overbank flows transport sediment to the estuary. Large floods (catastrophic flows) are also important. During these events, Broughton River floods onto the low-lying samphire marshes and discharges through the numerous tidal streams along the coast.

Sedgelands

Rushes *(Juncus* spp. and *Eleocharis* spp.) and sedges (*Cyperus* spp.) make up the sedgeland communities present in and adjacent to many watercourses within the Broughton River system (Lloyd 2000). When regular low flows are present, sedgelands provide habitats for frogs and macro-invertebrates within the in-stream and riparian zones of a watercourse.

The distribution and composition of sedgeland communities depends on soil moisture and surface water levels. Where there is permanent water or the groundwater table is close to the surface, the lower bank and in-stream vegetation is typically a sedgeland of rushes and sedges in association with a reedbed (closed herbland) dominated by common reed (*Phragmites australis*) and bulrush (*Typha* spp.). Sedgeland communities occur along sections of Baderloo, Baldry, Yakilo, Yackamoorundie creeks, and Hutt, Hill, Rocky and Broughton rivers (Map 7.2).

Regular low flows that inundate channel bars and low banks are required to ensure recruitment, establishment and growth of sedgeland species (Lloyd 2000). At least one low-flow event is required every one to two years to maintain soil moisture levels (Lloyd 2000). A major impact has been the channelisation of streams and the resultant reduced frequency of the floodplain wetting which sustains these communities.

Reedbeds

The in-stream reedbeds of the Broughton catchment consist of a range of plants such as common reed, bulrush, club-rushes (*Bolboschoenus caldwelli* and *Schoenoplectus* spp.), rushes and sedges. Dense reedbeds tend to dominate areas that are characterised by permanent baseflow and/or groundwater combined with high sediment loads. The largest extent is along Broughton, Rocky, Hutt and Hill rivers. Other major areas occur along the confluence of Appila and Pine creeks, and along Baldry and Yackamoorundie creeks (see Chapter 7, Map 7.2).

Reedbeds provide food and shelter for fish, frogs, macro-invertebrates and birds (e.g. clamorous reed warbler). Hydrologically, reedbeds reduce water velocity along the edges of channels, prevent erosion and increase the duration of flooding (Boulton and Brock 1999). They require groundwater or baseflows to maintain an almost permanently wet environment. Annual low flows that increase the area of a wetted habitat are important for germination, recruitment and establishment (Lloyd 2000).

Submerged aquatic vegetation

Submerged aquatic vegetation communities consist of plants such as pondweed (*Potamageton pectinatus*), lepilaena (*Lepilaena* sp.) and charophytes (e.g. *Chara* spp., *Lamprothamnion* spp. and *Nitella* spp). Submerged plants provide important food and shelter for aquatic macro-invertebrates, fish and frogs. The greatest extent of submerged aquatic vegetation occurs in the permanent water section of the Broughton River from Spalding to Redhill, and the lower reaches of Rocky River. However, submerged aquatic vegetation has been observed in most watercourses across the catchment where there is permanent or semi-permanent water, including sites along the Hill and Hutt rivers and Bundaleer, Belalie, Pisant, Freshwater and Baldry creeks (Madden et al. 1999).

The presence of permanent water is critical in the distribution and condition of these plants (Lloyd 2000). Submerged aquatic vegetation requires permanent water for maintenance although some species can tolerate periods of drying out. The seasonal low flows of winter and spring are required to increase the habitat and stimulate the growth of vegetation and associated fauna (Lloyd 2000). Seasonal low flows refer to the rise in water levels following seasonal rain: they can be derived from either groundwater or surface flows.

5.3.2 MACRO-INVERTEBRATES

Macro-invertebrates are common stream animals. They include insects and insect larvae, snails, worms and crustaceans. They are key species for maintenance of the river ecosystem, breaking down vegetation and waste matter to release nutrients and providing an important food source for many other animals. The diversity and number of macro-invertebrates in a watercourse are determined by flow regime, habitat availability and water quality. Some species can be particularly sensitive to salinity, pollution and habitat changes. As such, they provide important information on flow patterns, watercourse condition and environmental flow requirements.

Macro-invertebrate species

More than 240 types of macro-invertebrates have been collected from the Broughton catchment. These were predominantly species tolerant of a wide range of environmental conditions, good colonisers, and common and widespread in South Australia. The number and type of species are very similar to those in the Wakefield and Gawler River systems (Madden et al. 1999).

The most common macro-invertebrate groups were segmented worms, round worms, amphipods, midge larvae, springtails and larvae of a species of caddisfly (*Cheumatopsyche* sp.). A large number of some less widely distributed animals such as hydrobiid snails, blackfly larvae, little basket shells, water boatmen, baetid mayflies and mites were also recorded (Madden et al. 1999).

Several species in the catchment are not common in South Australia. Protecting the biodiversity and conserving the habitats where these species are found is an important management consideration.

A particular species of bristle worm appears to be endemic to the catchment. Bristle worms are common marine animals but few are known to occupy freshwater habitats. This species was found along Broughton River at Frome crossing, Redhill, Cockeys crossing and south of Spalding, and in Rocky River south of Crystal Brook township. These sites are characterised by the presence of permanent water flow and fine mineral particles (gravel, sand and silt) in the substrate (Madden et al. 1999).

The water boatman (*Diaprepocoris barycephala*), a wetland species, is rarely collected from streams (Madden et al. 1999). However, specimens were found in Bundaleer Creek downstream of Bundaleer reservoir. It is likely the extensive reedbeds along the lower reaches of Bundaleer Creek provide an important habitat and may serve as a refuge for this species (Madden et al. 1999).

The larvae of a species of micro-caddisfly (*Orphninotrichia maculata)* were collected at Mary Springs above Beetaloo reservoir. Their distribution in South Australia is limited. They have previously been found only on the Fleurieu Peninsula, in Jacob Creek in the Barossa Valley, a site in the Mount Lofty Ranges and several sites in the Flinders Ranges (Wells 1985; Madden et al. 1999; McEvoy and Madden 1999). These larvae require a very specialised habitat: they eat attached algae and are usually found on the faces of natural or artificial waterfalls.

River health

The results of the macro-invertebrate study indicate that most sites sampled in the Broughton catchment are relatively healthy compared with other river systems in South Australia. The exceptions are Hutt River (downstream from the Clare wastewater treatment plant) and the Broughton River at Cockeys crossing (Madden et al. 1999) which had a low diversity of macro-invertebrates and fewer sensitive species. The Hutt River site is very degraded: nutrient concentrations of the water are extremely elevated, bank scouring and the deposition of silt is widespread and the stones in the bottom of the stream are very embedded. At Cockeys crossing, the water is deep, due to steep banks, and there is little variety in the habitat which consists mostly of sand and common reed (Madden et al. 1999).

Several sites in the catchment had a particularly high diversity of macro-invertebrates and/or support animals not found elsewhere in the system. The combination of permanent flowing water and high quality habitat is important and these areas have high ecological and conservation value. Bowman Park on Crystal Brook is one area of relatively high diversity due to the permanent water supplied by springs at this site. Mary Springs, an unusual and important site located above Beetaloo reservoir, is at the head of a spring that discharges into a small, forested watercourse containing stands of rushes and reeds (Madden et al. 1999). The site is protected as part of the water supply catchment for Beetaloo reservoir and is relatively undisturbed. Certain species of stoneflies (*Dinotoperla evansi*), caddisflies and dragonflies were only found at this site. These insects require areas of good flow and stony substrates and are usually absent from disturbed sites (Madden et al. 1999). Other species such as dixid midge larvae were found in greater numbers here than at any other site in the catchment.

Subsurface macro-invertebrates

The water-saturated sediment below the bed of a watercourse — the hyporheic zone — provides a habitat for some specialised subsurface species and a potential refuge for some surface animals (Boulton and Brock 1999). There is no information on the location or fauna of hyporheic zones in the Broughton catchment. However, it is likely that a hyporheic zone is present along the Broughton River delta and may provide an important refuge for surface animals during dry periods, allowing them to recolonise the stream when flow is present. Bristle worms are a unique feature of this catchment and possibly may use the hyporheic zone, as marine bristle worms are generally sediment dwellers. The zone may have formed the pathway for bristle worms to move from the marine environment to the bed of Broughton River (Madden et al. 1999).

Pest organisms

Three introduced species of macro-invertebrate have been collected from the catchment: two snails, *Physa acuta* and *Potamopyrgus antipodarum*, and an unidentified species of proboscis worm. Both snails are common and abundant in Australian freshwaters and appear to be spreading actively (Smith 1996; Schreiber 1998). Information on their interaction with native species is lacking. The largest numbers were in samples from Broughton and Hutt rivers south of Spalding and in Crystal Brook at Bowman Park (Madden et al. 1999).

Surveys have revealed high levels of infestation of the parasite, *Thelohania* in yabby populations in Broughton River. A study in 1989 revealed 38% of yabbies were infested with the parasite; a subsequent survey found that all 1220 yabbies studied were affected (O'Donoghue et al. 1990; Les Gray, PIRSA, pers comm). The parasite affects the muscle tissue resulting in discolouring, flesh spoilage and death but *Thelohania*-infected yabbies are not a risk to human health (Fisheries Western Australia 1999). The parasite thrives in slow-moving or still waters that are rich in organic matter. It is thought to spread by healthy yabbies feeding on infected individuals. The impact on the yabby population in the Broughton catchment may have implications for other fauna and flora, particularly fish, birds and mammals that use them as a food source.

O'Donoghue et al. (1990) recommended that yabbies from within the catchment should not be transported elsewhere in the State. It also recommended that any enterprise established in the Mid North should take all precautions to prevent the introduction or migration of wild yabbies into its culture facilities.

Relationship between flow, diversity and distribution

There was a positive relationship between permanent baseflow and the diversity of macro-invertebrate fauna in the catchment. The permanency of flow is important for fauna at sites where this occurs as many of the species require flow for feeding. The continual discharge is also important for maintaining water quality (Madden et al. 1999). Sites of high macro-invertebrate diversity occur along Bundaleer Creek (south of Bundaleer reservoir), Crystal Brook (Bowman Park), Mary Springs (above Beetaloo reservoir) and Broughton River (Frome crossing and Redhill) — all areas with permanent baseflow.

Annual and seasonal variation in flow was also an important factor in determining the number and diversity of fauna. For example, at most sites the number and diversity of animals recorded was higher in wetter years. Each year the number and diversity of animals recorded was higher in spring — a wetter season — than in the preceding autumn (Madden et al. 1999).

Several species showed distribution patterns that can be clearly linked to habitat and flow regime. The caddisfly (*Lingora aurata*) is usually collected from cool, flowing streams with gravel or sandy substrates. This species was present only at sites with permanent or semi-permanent flowing water — the Broughton River at Redhill and Hutt River south of Spalding. A species of moth (family Pyralidae) that feeds on submerged aquatic plants was found at sites along Rocky River (Bulling crossing and Laura), Broughton River (Redhill and Frome crossing) and Mary Springs only. These sites provide a suitable habitat as they have dense stands of submerged and emergent aquatic plants.

Stoneflies were found at Mary Springs only. These fauna prefer undisturbed sites with stony substrate, freshwater and good flow. A group of amphipods (family Ceinidae) that favours still or slowly flowing waters was widespread in the catchment but was not found at Mary Springs which is a permanently flowing spring. Freshwater shrimp (*Paratya australiensis*) that favour still, protected waters were found at Cockeys crossing, and the Hutt and Hill rivers. These sites have deep pools and good cover in the form of overhanging banks and emergent aquatic plants for the shrimp to shelter in and feed.

Environmental water requirements

Several aspects of the natural flow regime are important for maintaining macro-invertebrate populations, including the size and the duration of flow events, the time of year and how often they occur. Variability of flow ranging from periods of no or low flow to large flood events is also important. In the catchment, the presence of permanent pools and almost continuous flow along sections of Broughton River and its tributaries is a key requirement for macro-invertebrate species. While this permanent aquatic habitat is important, many catchment species can tolerate periods of no flow and many have developed mechanisms that allow them to cope with the variability and even unpredictability of flow (Williams 1980; Sheldon 1999 cited in Madden et al. 1999)

Key flow requirements for macro-invertebrates are as follows:

- Groundwater which supports permanent pools and baseflows (see below) is important in maintaining permanent aquatic habitats. These areas are of particular importance as refuges during dry periods. Populations of macro-invertebrates species that are not adapted to survive drying out take refuge in these areas during summer. Groundwater can also extend the duration of flow into summer months due to the gradual release of winter recharge.

- The continuous baseflows in Broughton River from Spalding to Cockeys crossing, in the lower reaches of Hutt and Rocky rivers, and in Bundaleer and Freshwater creeks, are critical to supporting macro-invertebrate fauna at these sites (Lloyd 2000). Much of this continuous flow is groundwater dependent allowing it to persist over summer months and in drier periods. Many species require flow for feeding and the continual discharge is also important in maintaining water quality in all habitats (Madden et al. 1999).
- Mid to overbank flows that inundate emergent aquatic plants (reedbeds and sedgelands) are important for many species that use these plants to lay eggs. Maintaining emergent aquatic plants is also important for those macro-invertebrates that require surface sites to rest upon and harden their wings. Groundwater, baseflows and mid flows are important in maintaining emergent aquatic plants.
- No flow periods can be important for those macro-invertebrates that require a drying out phase to trigger egg production or the development of a resistant stage. These eggs and resistant stages are important in the drought tolerance of the population and their recovery after a major drought. Maintaining the natural variability of flow is therefore an important environmental water requirement.

Macro-invertebrate flow requirements, including frequency, duration and the seasonal changes are described in more detail in Appendix D.

5.3.3 FISH

Fish are particularly sensitive to changes in their environment and are good indicators of watercourse condition. The species, number and distribution of fish in a river will be largely determined by flow regime, habitat type and condition, water quality, food supply and levels of predation and competition (Mosley 1983; Cambray et al. 1989).

Fish species

A survey of fish in the Broughton River system recorded five species of native fish in February 1999: blue spot goby (*Psuedogobius olorum*), mountain galaxia (*Galaxias olidus*), yellow-eyed mullet (*Aldrechetta forsteri*), hardyhead (*Atherinosoma microstoma*) and congolli (*Psuedaphritis urvilli*) (Table 5.3) (Hicks and Sheldon 1999). The blue spot goby was widely distributed; it was found in the freshwater reaches of Broughton and Rocky rivers as well as in the estuary. Mountain galaxia, a totally freshwater species, was recorded in Broughton and Hutt rivers. The yellow-eyed mullet, hardyhead and congolli were recorded in the estuary. Exotic species recorded included redfin (*Perca fluviatilis*), goldfish (*Carassius auratus*) and eastern gambusia (*Gambusia holbrookii*) (Table 5.3).

Other introduced fish species known to inhabit the system but not recorded in the survey include brown and rainbow trout. Trout are released annually into the Broughton River upstream of Koolunga and into the lower reaches of Bundaleer Creek (Ian Fitzgerald, SAFFA, pers comm). Interestingly, it appears that few trout survive downstream of Redhill; this may be due to high summer water temperatures and lower summer flows below this point. Murray cod, callop and European carp were not recorded in the survey but they have been introduced into the river system previously (Hicks and Sheldon 1999; Lloyd 2000).

Table 5.3 Fish species recorded in the Broughton catchment, February 1999 (Hicks and Sheldon 1999)

Status	Common name	Scientific name	Distribution
Native	Blue spot goby	*Psuedogobius olorum*	Estuary, Broughton River, Rocky River
	Mountain galaxia	*Galaxias olidus*	Broughton River, Hutt River
	Congolli	*Psuedaphritis urvilli*	Estuary
	Hardyhead	*Atherinosoma microstoma*	Estuary
	Yellow-eyed mullet	*Aldrechetta forsteri*	Estuary
Exotic	Eastern gambusia	*Gambusia holbrooki*	Broughton River, Rocky River, Hutt River
	Goldfish	*Carassius auratus*	Broughton River, Rocky River
	Redfin perch	*Perca fluviatilis*	Hutt River

The number and diversity of native fish were very low. Based on a review of fish species ranges (Lake 1978; Allen 1989; Harris 1995; McDowell 1996), fewer native species than expected were recorded. Native fish comprised less than 1% of the fish numbers observed or captured. Only 57 native fish were recorded, against 6005 non-native fish. The most abundant fish — more than 90% of the fish observed or captured — was the introduced eastern gambusia.

Impact on native fish

The results from the fish survey suggest that, in terms of native fish ecology, the catchment is in fair to poor condition. This may be due to predation, competition, habitat degradation, water quality, and poor breeding and migration opportunities (Hicks and Sheldon 1999).

None of the native species recorded have critical habitat or migration requirements; generally they are robust and tolerate a broad salinity range. The absence of fish with strong migration requirements, such as the common galaxia (*Galaxias maculatus*), may suggest insufficient connectivity between the Broughton estuary and freshwater reaches during the annual spring recruitment of juvenile fish. Alternatively, it may be that this species is highly affected by predation by other introduced species, particularly trout (Hicks and Sheldon 1999).

The presence of large numbers of eastern gambusia at most sites sampled may be indicative of some level of habitat degradation as these fish can live in environments unsuitable for native fish. They are very tolerant of a wide range of temperatures and salinities (up to twice that of seawater), and can survive at very low oxygen levels (McDowell 1996). Yet the survival of trout in the main channel of the Broughton River suggests that the water quality is reasonable and that there are abundant macro-invertebrates for the fish to feed on.

Competition for food and shelter and predation by exotic species has the potential to significantly impact on native fish populations (Zaret 1980; Fletcher 1986; Lloyd 2000; Hicks and Sheldon 1999). The small native fish have not evolved to cope with introduced species and may not be able to co-exist with introduced predators such as trout, redfin and eastern gambusia. For example, the blue spot goby is susceptible to predation and requires good vegetation to provide protective cover (Lloyd 2000).

Trout feed throughout the water column and migrating species, such as the galaxia and hardyhead, are at particular risk of predation from these fish. Trout also compete with the galaxia species for food (Hicks and Sheldon 1999). Eastern gambusia has the ability to breed rapidly and compete with small native fish for resources and space (Hicks and Sheldon 1999). They inhabit the shallow margins of slow-moving waterbodies and exclude small native fish from this zone by fin nipping and forcing them to seek deeper water where they are more susceptible to predation. Fin nipping also removes a fish's protective mucous coating leaving it susceptible to infection and decreasing its chances of catching food.

Currently there is insufficient information on fish populations and distribution throughout the catchment to pinpoint the causes of low native fish numbers and diversity. Further studies of fish populations are required to determine more accurately the influence of flow regime and other environmental factors on native fish in the catchment.

Environmental water requirements

Fish are a good indicator for determining environmental water requirements in a river system. The flow needs of other water dependent plants and animals will generally be met by the flow requirements allocated for the survival of fish communities (Cambray et al. 1989). Flows are important for maintaining the fish habitat, for providing spawning or migration cues, for recruitment and for moving between habitats. Key fish habitat types within the Broughton River system include riverine pools, riffles, runs, reservoirs and swampy floodplains.

The following environmental water requirements for fish in the Broughton catchment are based on the requirements of fish recorded in the survey and of species not recorded but expected to occur in the catchment:

- Groundwater and baseflows are important to maintain permanent and semi-permanent fish habitats such as pools, riffles and runs. Permanent aquatic habitats are particularly important refuges during dry periods.
- Low flows are important for connecting habitats, fish development and recruitment, and allowing the local migration of fish species. Low flows caused by the recession of a mid or high flow event are important for the development of juvenile fish following spawning and hatching.
- Mid and high flows in later winter and spring are important cues for breeding as they increase the amount of food resources and habitat available for spawning and hatching. These flows are also important in allowing migration both to the sea and from refugia to recolonise other habitats. In general, a flow with a duration of two to four days provides the cue for breeding and then four to seven days would be required for spawning and hatching. These durations may be met by a single flow event or a sequence of flow events where suitable aquatic habitats exist.

  Migratory fish, such as common galaxias, require connectivity with the estuary for spawning and development in the juvenile and adult stages. Most require a mid to high flow to the sea once in late autumn/early winter and again in late spring, and at least once every three years to complete their lifecycle (Hicks and Sheldon 1999). The rate of fall of a flow event is also important in the migration process, as this can lead to fish being stranded in environments detrimental to their survival.
- Overbank flows of a suitable duration are also a cue for breeding, allowing migration to the sea and increasing available habitat. For example, flows that flood the lignum swamp

along the lower reaches of the Broughton River delta would allow fish breeding in these areas.

Whether a flow event meets the flow requirements of a fish species will depend not only on the size of the event but also the time since the last flood event (frequency), the time of year (season) and the length of time of the flow (duration). Appendix D contains more detailed descriptions of the water requirements for native fish.

5.3.4 FROGS

The Broughton River system provides habitat for a number of frog species (Table 5.4). With the exception of Bibron's toadlet (*Pseudophryne bibroni*), most of the species are common and widespread across South Australia. Important habitats for frogs are rivers, creeks, permanent pools, ponds, reedbeds, swamps and shallow flood-out areas. Emergent and submerged aquatic plants provide shelter and breeding areas for frogs. For example, species such as the eastern banjo frog and brown tree frog lay their eggs attached to floating or emergent vegetation. Frogs feed mainly on terrestrial macro-invertebrates (S Walker, EPA, pers comm).

Table 5.4 Frog species of the Broughton catchment

Common name	Scientific name
Common froglet	*Crinia signifera*
Eastern banjo frog	*Limnodynastes dumerilli*
Spotted grass frog	*Limnodynastes tasmaniensis*
Brown tree frog	*Litoria ewingi*
Bibron's toadlet	*Pseudophryne bibroni*
Painted frog	*Neobatrachus pictus*

Frogs prefer still or slow-flowing water. They tend to use the water's edge for their habitat but they can breed on the floodplain or shallow flood-out areas, when floodwaters extend that far, or if there is sufficient rainfall to provide a suitable habitat such as a shallow pool (Lloyd 2000). The species recorded in the catchment generally breed after the winter–spring rains (S Walker, EPA, pers comm 2000).

The key environmental water requirements for frogs include the following:

- Groundwater and baseflow provide permanently wet habitats for frogs and maintain emergent and submerged aquatic vegetation which is needed for shelter and breeding.
- Mid to high flows are important for inundating reedbeds, bars, benches and shallow flood-out areas. This will increase the area suitable for the frog's habitat and breeding.
- Overbank flows will allow flooding onto the floodplain, thus increasing the habitat area and breeding opportunities. For example, Bibron's toadlet tends to occupy land that is subject to inundation and species such as the painted frog are opportunistic breeders that can take advantage of water in roadside ditches and paddocks (Lloyd 2000; S Walker, EPA, pers comm 2000).

Water requirements for frogs are described in more detail in Appendix D.

5.3.5 OTHER HYDROLOGICAL CONSIDERATIONS

In addition to the environmental water requirements for plants, animals and geomorphic processes described above, and in Appendices C and D, other aspects of the water regime are important. These include the rate of rise and fall of the flow event, the time since the last flow event and the sequence of flow events. Hydrological variability is a natural feature of the water regime in the catchment. In this respect periods of drying out and no flow are also important for plants and animals. This natural complexity makes it difficult to predict the effect of a flow event.

5.4 Summary

Seven components of the water regime or key flow bands have been identified as important for the Broughton River system. Figure 5.1 provides a schematic representation of the key flow bands and typical functions in relation to a cross-section of a watercourse.

The typical functions that these flow bands perform have been defined based on the information discussed in this chapter (Table 5.5). These represent a simplification of a complex system and a particular function may be driven by a number of different flow bands: the relationships listed are considered to be the most typical.

Table 5.5 Key flow bands and typical functions associated with them; the functions will differ for different river geomorphic zones

Flow band	Typical functions
Groundwater	Maintaining reedbed communities Maintaining pools for aquatic flora and fauna habitats Maintaining sedgeland communities (riparian or in-stream)
Baseflow	Creating and maintaining riffle habitats Maintaining water quality Connecting habitat for local movement of aquatic flora and fauna
Low flow	Breeding and recruiting macro-invertebrates and frogs Inundating shallow habitat for frogs, macro-invertebrates and fish Transporting nutrients and organic matter Developing and recruiting fish
Mid flow	Spawning and hatching fish Migrating and redistributing fish Maintaining and recruiting riparian vegetation Developing and recruiting large scale fish Transporting sediment
High to bankfull flows	Breeding and spawning fish (if followed by sustained mid-flows) Flooding lignum swamp habitats to provide habitat for fish, macro-invertebrates and frogs Maintaining and recruiting riparian vegetation Removing sediments from riffle substrate Maintaining channels Scouring pools Transporting sediment

Flow band	Typical functions
Overbank flow	Maintaining and recruiting floodplain vegetation e.g. river red gums Resetting habitat and scouring pools Inundating floodplain habitats Transporting nutrients and organic matter (lateral and longitudinal) Transporting sediment to estuary
Catastrophic flow	Making major structural channel change and resetting habitat Transporting sediment, nutrients and organic matter to estuary Inundating tidal channels and flats in estuary and delta

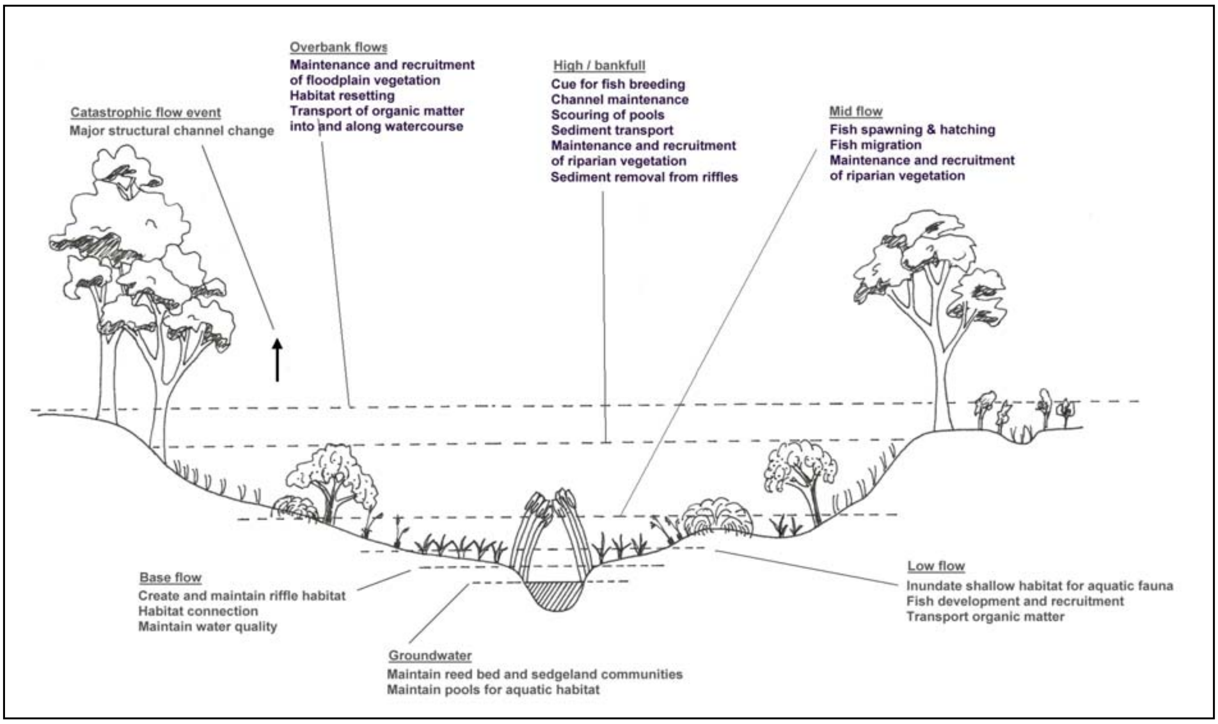
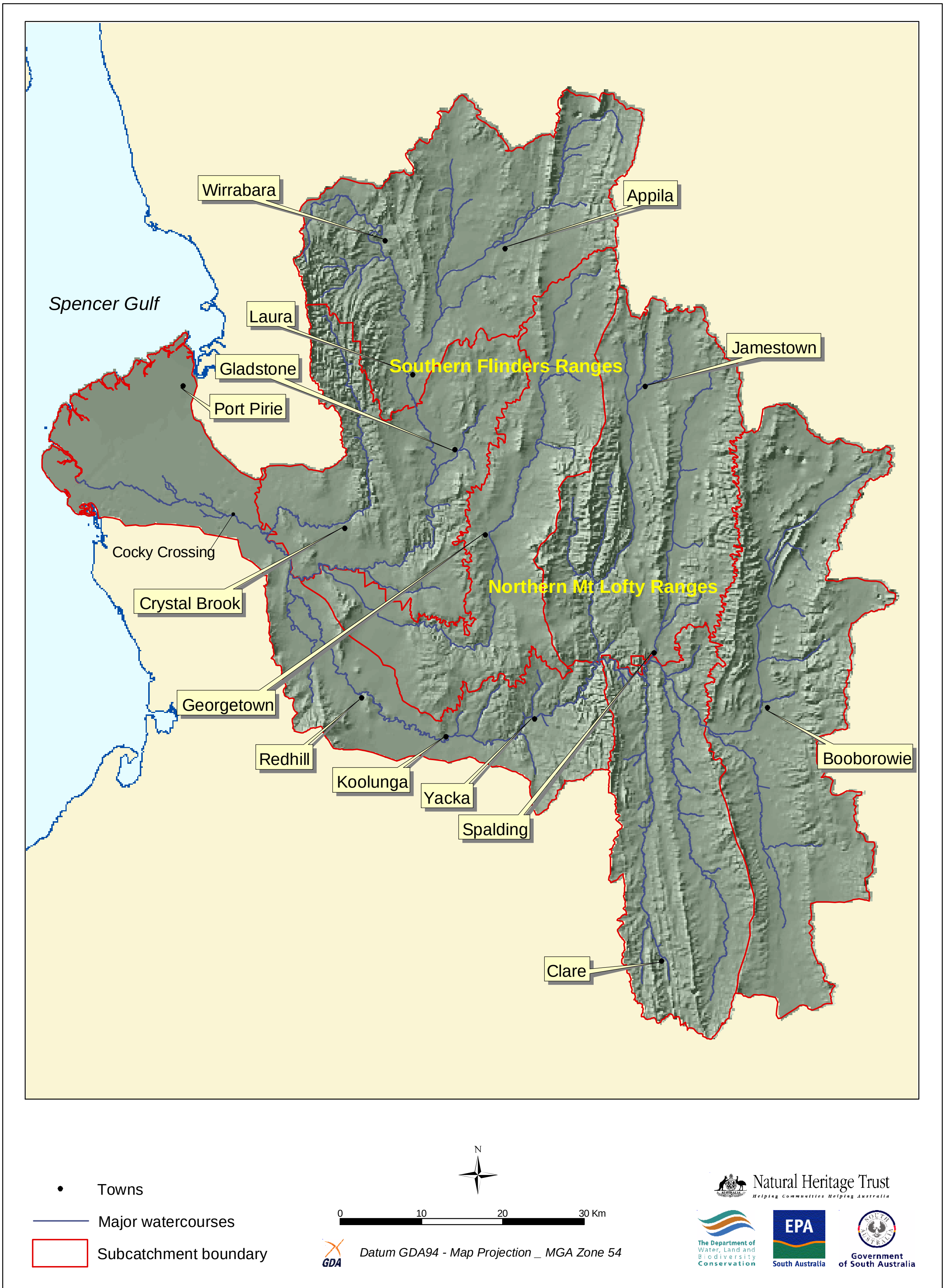
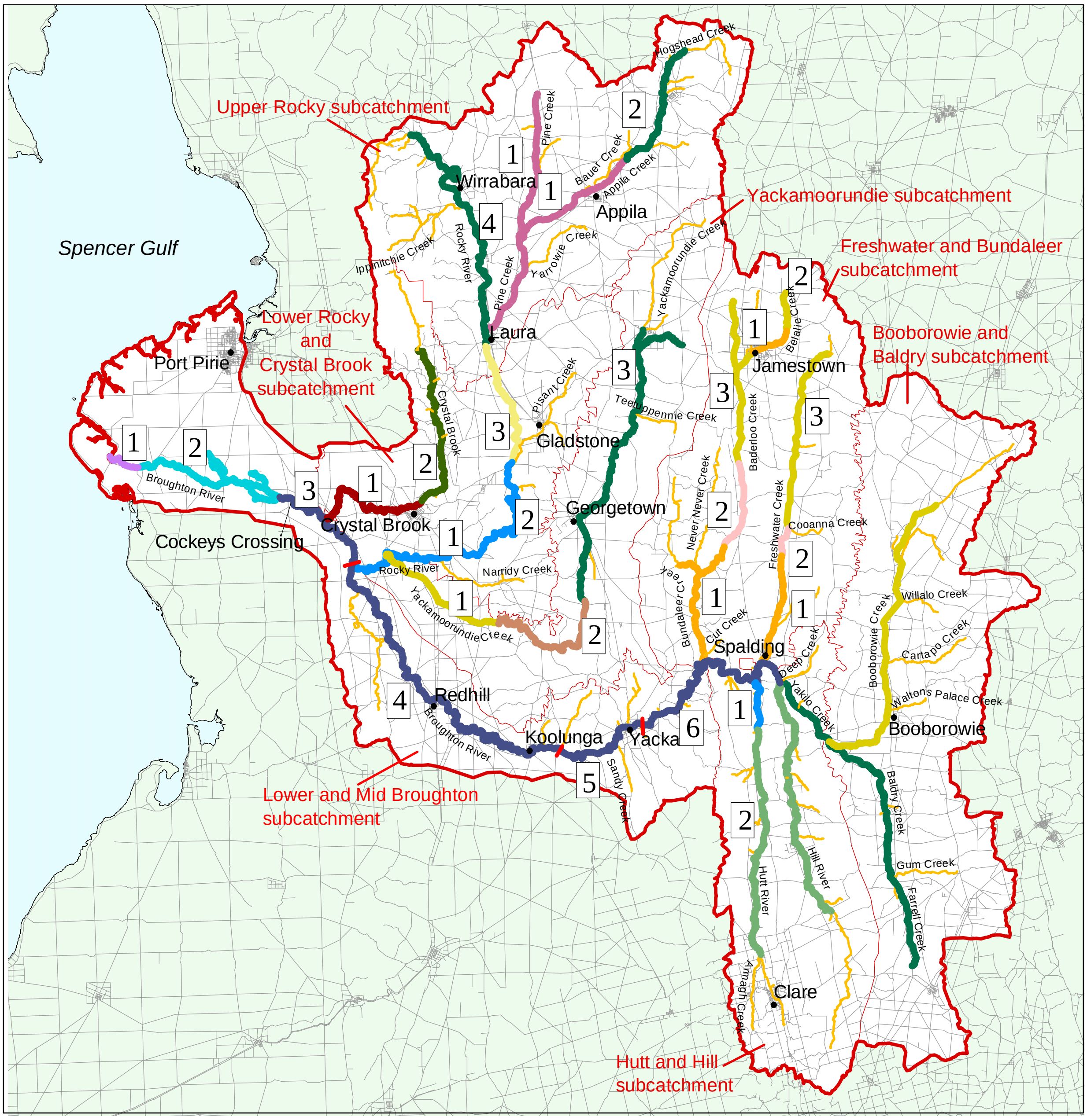


Figure 5.1 Typical flow bands and functions within the Broughton River system



Map 5.1: Topography of the Broughton catchment



Geomorphology

- Estuary
- Delta
- Major river with continuous baseflow
- Major tributary with continuous baseflow
- Discontinuous baseflow
- Discontinuous baseflow with constrained floodplain
- Incised meandering channel
- Incised stream with continuous baseflow
- Incised stream with discontinuous baseflow
- Small channel with constrained floodplain
- Small channel with swampy floodplain
- Small dry channel with swampy floodplain
- Chain of ponds
- Minor stream subject to incision
- Unclassified stream

- • Towns
- Roads
- Catchment boundary

N

0 10 20 30 Km

Datum GDA94 - Map Projection _ MGA Zone 54

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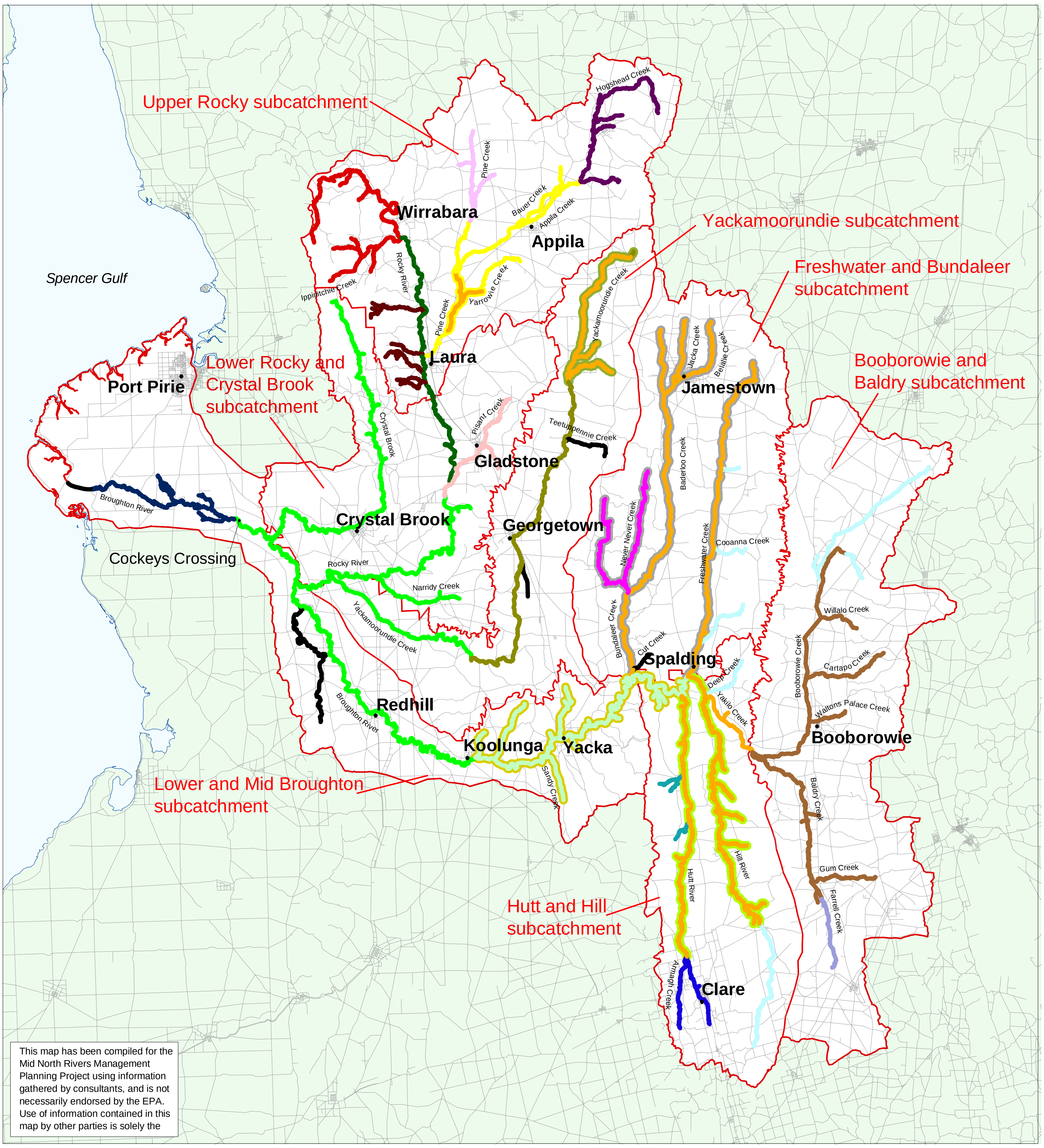
Map 5.2: Geomorphic zones of watercourses in the Broughton catchment



Inner bank/stream vegetation

- Open forest - *Eucalyptus camaldulensis*
- Open forest - *Eucalyptus camaldulensis, Acacia salicina*
- Open forest - *Acacia salicina, Eucalyptus camaldulensis*
- Low open forest - *Eucalyptus leucoxylon, Eucalyptus odorata*
- Low open forest - *Eucalyptus leucoxylon, Eucalyptus cladocalyx, Eucalyptus microcarpa, Callitris glaucophylla*
- Low open forest - *Acacia salicina, Callitris glaucophylla, Eucalyptus oleosa*
- Low woodland - *Eucalyptus camaldulensis, Myoporum montanum, Muehlenbeckia florulenta*
- Low woodland - *Eucalyptus leucoxylon, Eucalyptus odorata*
- Low woodland - *Eucalyptus leucoxylon, Allocasuarina verticillata, Acacia pycnantha*
- Open woodland - *Eucalyptus camaldulensis, Allocasuarina verticillata*
- Open woodland - *Eucalyptus leucoxylon, Allocasuarina verticillata*
- Woodland - *Eucalyptus leucoxylon, Eucalyptus camaldulensis*
- Woodland - *Eucalyptus leucoxylon, Allocasuarina verticillata, Acacia pycnantha*
- Woodland - *Callitris glaucophylla, Acacia salicina, Eucalyptus odorata*
- Tall open shrubland - *Acacia victoriae, Myoporum montanum, Bursaria spinosa*
- Tall open shrubland - *Acacia victoriae, Pittosporum phyllraeoides, Bursaria spinosa, Eremophila longifolia*
- Tall open shrubland - *Pittosporum phylliraeoides, Dodonaea viscosa, Bursaria spinosa*
- Closed herbland - *Phragmites australis*/sedgeland *Juncus krausii, Cyperus gymnocaulus*
- Unsurveyed

Outer bank vegetation

- Low woodland - *Acacia salicina*
- Tall open shrubland - *Acacia victoriae, Myoporum montanum*
- Tall open shrubland - *Acacia victoriae, Myoporum montanum, Bursaria spinosa*
- Tall open shrubland - *Acacia victoriae, Pittosporum phylliraeoides, Bursaria spinosa, Eremophila longifolia*
- TAll open shrubland - *Eremophila longifolia, Acacia pycnantha, Bursaria spinosa*

- Towns
- Roads
- Catchment boundary
- Subcatchment boundary

Natural Heritage Trust
The Department of Water, Land and Biodiversity Conservation
EPA South Australia
Government of South Australia

0 10 20 30 Km

N

Datum GDA94 - Map Projection _ MGA Zone 54

Map 5.3: Pre-European vegetation along watercourses of the Broughton catchment

CHAPTER 6 CURRENT WATER REGIME AND ENVIRONMENTAL WATER REQUIREMENTS

6.1 Introduction

This chapter reviews the surface and underground water resources in the Broughton catchment, including the water regime, water quality and current water resource impacts. The recommended environmental water requirements for three geomorphic zones are compared with actual flow data to determine if requirements are currently being met. The modelled data of the 'natural' flow regime is examined to determine the extent to which farm dam developments impact on environmental water requirements in these zones. The implications of this information for managing water resources in the Clare Valley region are discussed.

6.2 Catchment hydrology

6.2.1 RELATIONSHIP BETWEEN RAINFALL AND FLOW PATTERNS

Rainfall in the catchment is strongly influenced by variations in topography: it varies from sub-humid in the ranges to semi-arid on the coastal plain (Sard 1996). The average annual rainfall varies from 325 mm on the coast to 650 mm in the Clare Valley and reaches 700 mm at Wirrabara (Map 6.1) (Cresswell 2000). The catchment has a reliable average autumn–spring rainfall pattern with about 70% of the total annual rain falling between April and October. There are often thunderstorms, usually of monsoonal origin, between December and March. They deliver high volumes of rain in short periods of time (West Broughton Soil Conservation Board 1992).

Both rainfall runoff and discharge from groundwater influence streamflows in the catchment. The variability of annual rainfall across the catchment is reflected in streamflow patterns. The Broughton River system is characterised by a defined seasonal pattern of flow with its highest monthly flows between May and October and lowest monthly flows between November and April. Flows are generally characterised by rapid rises and falls in response to rainfall: they are rarely constant over a day (Cresswell 2000). Most of the watercourses stop flowing during the summer–autumn period. While some such as Yackamoorundie Creek dry out completely, others such as Hill River often contain permanent pools. Importantly, several reaches with perennial or permanent flow are supported by groundwater; for example, Broughton River downstream of Spalding to just below Cockeys crossing is a permanent flowing stream over most of its length.

Gauging

The catchment has three gauging stations only: the Mooroola gauging station on Broughton River (south of Spalding), a station on Hutt River near Spalding and another on Hill River near Hilltown (Map 6.1). Thus flow data is not available for Broughton River downstream of the Mooroola gauging station or along its major tributaries. Data for these other areas had to be estimated using a daily rainfall-to-runoff model. Modelling the runoff is difficult because most of it is generated during individual, large rainfall events and there is little information about stream losses to the groundwater table. Therefore, modelled data may overestimate flows in some tributaries.

Streamflow amount and variability

Examination of the relationship between rainfall recorded at Clare and flows measured at the Mooroola gauging station shows that an annual rainfall of greater than 500 mm is required to generate flows in Broughton River (Figure 6.1). Flows increase substantially when the rainfall is greater than 600 mm. The average annual rainfall of 650 mm at Clare results in small to moderate flows in Broughton River. High flows require above average rainfall events. Rainfall and flow relationships are similar for other areas of the catchment.

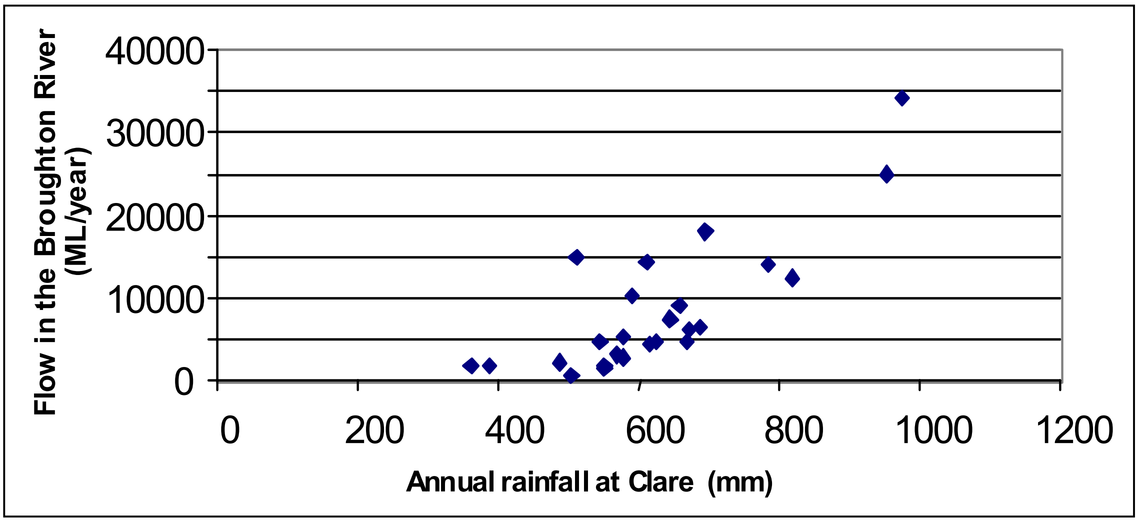


Figure 6.1 Relationship between the flow in Broughton River (recorded at the Mooroola gauging station) and annual rainfall recorded at Clare

The local groundwater aquifers that maintain river flows and pools over the dry summer months also rely on years of above average rainfall for recharge (D Cresswell, pers comm). Groundwater is recharged when there is sufficient rainfall for water to filter down to the groundwater table.

The median annual flow for Broughton River is estimated at 46,500 ML. However, flows vary considerably from year to year (Figure 6.2). For example, the total annual flow varied from 4260 ML in 1977 to 113,000 ML in 1992.

Variable rainfall patterns across the catchment cause considerable variation in streamflows (Table 6.1). The Hutt and Hill rivers and Rocky River, which originate in the higher rainfall areas of the Clare Valley and around Wirrabarra respectively, are important sources of flows to the Broughton River and provide relatively regular winter flows. The rest of the catchment mainly contributes during wet years and heavy rainfall events caused by summer thunderstorms. The annual rainfall for the catchment downstream of Crystal Brook township is relatively low — an average of 350 mm per year. This area has limited flows to the Broughton River (Cresswell 2000).

Effects of climate variation on flows

When annual flows since 1974 are compared with the annual rainfall, it is apparent that recent climatic conditions have had a significant impact on surface flows in the catchment. In only one year between 1982 and 1998 (1992) has the rainfall level substantially exceeded the 600 mm needed for reasonable flows. The result has been relatively low streamflows; the lack of any major aquifer recharge events since that year has also meant a decrease in baseflow (D Cresswell, pers comm).

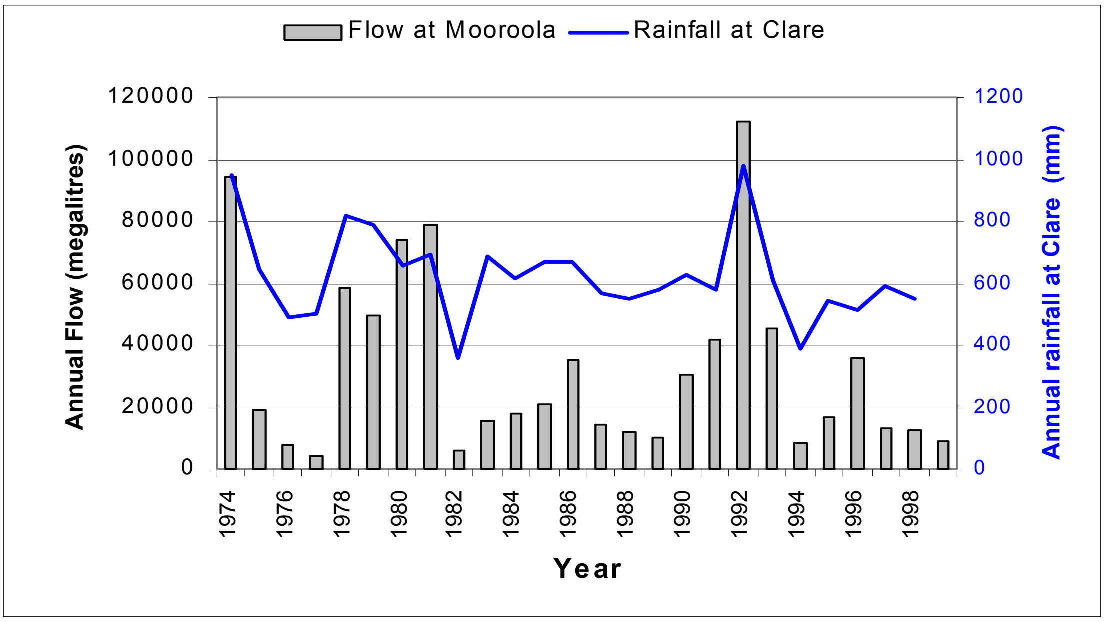


Figure 6.2 Annual flow in Broughton River (recorded at Mooroola gauging station) compared with the annual rainfall at Clare

Table 6.1 The flow contribution of major tributaries to Broughton River

Tributary	Catchment area (km^2)	mean flow (ML/year)	median flow (ML/year)	Source of data
Hill River	230	6,040	3,490	gauged
Hutt River	280	8,900	5,110	gauged
Bundaleer Creek	461	6,580	4,690	modelled
Booborowie Creek	590	4,930	3,110	modelled
Freshwater Creek	271	3,500	2,540	modelled
Baldry Creek	403	5,190	2,390	modelled
Broughton at Mooroola	–	35,150	20,940	gauged
Rocky River	1,395	15,840	11,740	modelled
Yackamoorundie Creek	559	5,670	3,150	modelled
Crystal Brook	161	3,140	1,640	modelled
Total catchment	5,220	64,330	46,540	

A graph of Clare rainfall since 1896 also provides some insight into flow conditions in the Broughton River (Figure 6.3). The peaks and troughs of rainfall variation can be seen clearly. Between 1950 and 1980 the annual rainfall was far more variable than it is today. The rainfall was often much more or much less than the average of 650 mm. The watercourses would have regularly flowed at high levels during high rainfall years and, as conditions were favourable for recharge to groundwater, the baseflow would have remained strong. The period between 1925 and 1939 was probably the driest period on record: most years received well below the average annual rainfall. This was more than likely also a period of reduced river flows. The period from 1946 to 1980 represents one of the wettest periods.

Some people may remember it as a period of flows higher than those of recent years. The region is currently experiencing a dry period with an annual rainfall of less than the median for nine years in the past decade (Figure 6.3).

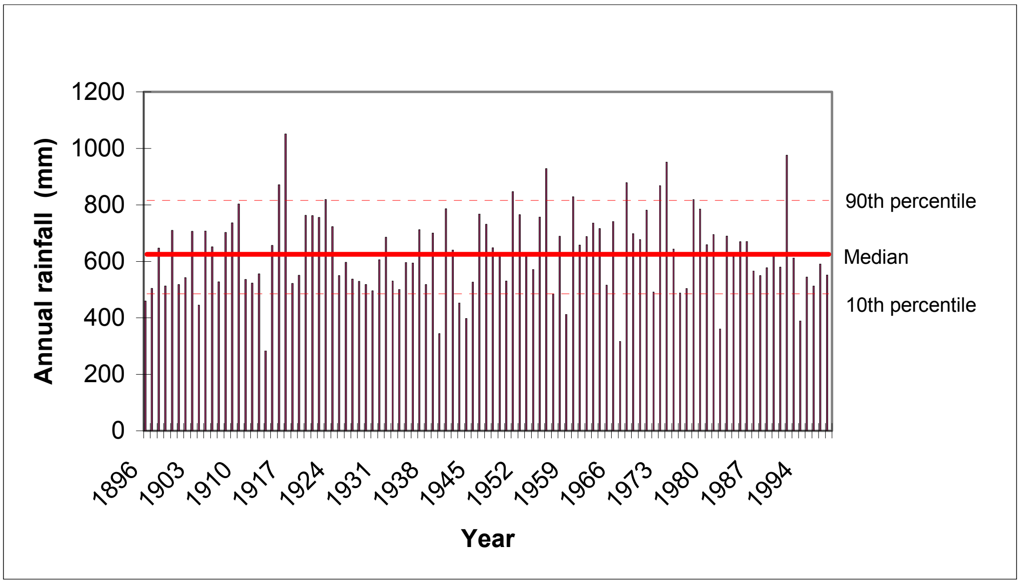


Figure 6.3 The annual rainfall recorded at Clare from 1896 to 1998

6.2.2 RELATIONSHIP BETWEEN GROUNDWATER AND FLOWS

A number of ecosystems in the Broughton catchment are highly dependent on groundwater, which maintains baseflow and permanent pools, and supports aquatic plants. Generally the catchment can be divided into two main groundwater aquifer systems: fractured rock aquifers in the northern Mount Lofty Ranges and sedimentary aquifers along the coastal plain. However, several small sedimentary aquifers are located within the ranges in the Booborowie valley and in the Yackamoorundie Creek valley in the Georgetown area (D Clarke, pers comm 2000).

The two main types of aquifers have different characteristics. Groundwater in fractured rock aquifers moves mainly through random fractures in the rock and water yield to wells is thus irregular. The amount of water stored can be affected greatly by seasonal conditions. Extraction from a fractured rock aquifer has a very localised effect. Sedimentary aquifers generally store more water than fractured rock aquifers of an equal volume. The effect of extraction is more consistent over the entire area influenced by a sedimentary aquifer.

Where the river bed is lower than the groundwater table, springs occur and water discharging into the river results in baseflow and permanent pools. This is called a ‘gaining’ stream. Where the level of the groundwater table is lower than the river bed, water can be lost from the river bed — a ‘losing’ stream.

Discharge to the river from the groundwater table maintains a permanent baseflow along most of the length of the Broughton River downstream of Spalding to just downstream of Cockeys crossing (Map 6.2). The main sources of this discharge appear to be the Broughton River near Spalding and the lower reaches of Bundaleer and Freshwater creeks and Hutt River. It is likely that groundwater discharges into the Broughton River from Spalding to Yacka. There appears to be little discharge either to or from the Broughton River from Yacka to Cockeys crossing. Downstream of Cockeys crossing, the river becomes a losing stream and often stops flowing (Cresswell 2000). This reach of the river is ephemeral and the Broughton River has no connection to the estuary under baseflow conditions (Brizga 2000a).

Since recording began at the Mooroola gauging station, the Broughton River has never ceased to flow. This indicates that the baseflow is relatively secure unless significant groundwater extraction occurs in the baseflow source areas around Spalding. Baseflow levels naturally vary throughout the year increasing as evaporation decreases with the onset of winter. Baseflow also varies according to the rainfall of the previous year. Higher minimum baseflow follows high rainfall years (Cresswell 2000).

Baseflow is perennial along the lower reaches of the Rocky and Hutt rivers and of the Bundaleer, Freshwater and Yakilo creeks, and along sections of the Belalie and Farrell creeks where the hydrogeological conditions support groundwater recharge and discharge (Map 6.2). Permanent pools in other intermittent reaches of the catchment reflect local groundwater levels. It is possible that the Booborowie area was also a major baseflow-producing area prior to irrigation developments there. Significant volumes of groundwater are now taken from the small alluvial basin and little flow passes downstream (Cresswell 2000). It is likely that baseflow in the Broughton River has increased since European settlement, with increased incision lowering the bed further into the groundwater table and the watertable rising as a result of vegetation clearance (Sard 1996).

Groundwater monitoring in fractured rock aquifers in the Clare Valley began in 1987–88. Although there are often large seasonal variations, the monitoring shows that groundwater volume and quality has remained stable. For example, groundwater tables fall considerably during summer but are readily recharged by an average winter rainfall of ≥650 mm. Water levels vary seasonally by up to 5 m with the groundwater table at its lowest in October–November and its highest in April–May.

The variations in groundwater levels in the Clare Valley can be related to annual rainfall variations (Figure 6.4). In February 2000 the levels were the lowest they had been for a decade due to below average rainfall over the previous three years. Above average rainfall during winter and spring 2000 saw the groundwater table recover to its highest level since 1996.

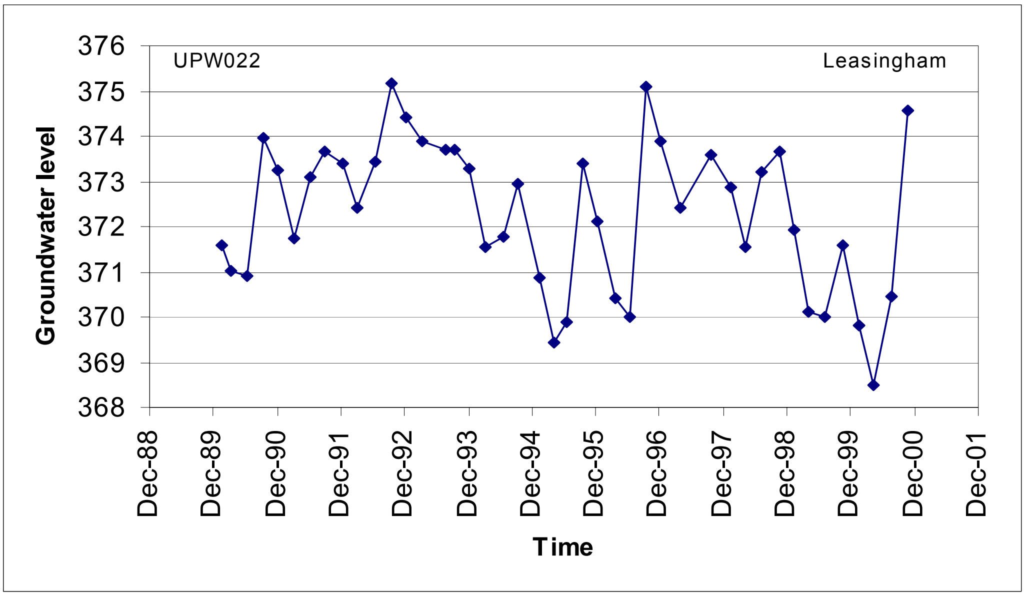


Figure 6.4 Inter-annual variations in groundwater levels of a well in the Clare Valley

6.2.3 WATER RESOURCE DEVELOPMENT

Farm dams and wells

Water resource development varies across the catchment. The highest level of groundwater and surface water use is in the Clare Valley region for the irrigation of vineyards. Groundwater is heavily used in the Booborowie Valley for irrigating lucerne crops. Small properties around the township of Laura use groundwater for pasture production and horticultural activities, and there is potential for increased use as interest in horticulture in the area is growing (M Williams, pers comm 2000). Water resources outside of these areas are diverted primarily for stock and domestic use.

The Clare Valley has become a major growth area for viticulture over the past two decades and pressure on local water resources has increased correspondingly. For example, there was an approximate seven-fold increase in applications for annual well permits between 1996 and 1998. The rapid development sparked community concern over the sustainability of the water resources. Consequently, on 27 July 1995 a one-year moratorium was placed on any expansion of the use of surface and groundwater (under Section 40 of the *Water Resources Act 1990*). Then on 25 July 1996 the watercourses and groundwater resources under moratorium were prescribed, thus introducing controls over the construction of farm dams and bores. A policy document for the allocation of water resources in the Clare Valley, developed as an interim water allocation plan for the Clare Valley Prescribed Water Resources Area, led to a sustainable water harvest level being adopted for taking surface water and groundwater.

The *Water allocation plan for the Clare Valley Prescribed Water Resources Area* (Clare Valley Water Resources Planning Committee 2000) was adopted on 22 December 2000 under the *Water Resources Act 1997*. The plan's policies aim to manage surface and groundwater use to ensure sustainable use and to protect the needs of water dependent ecosystems.

The total capacity of farm dams in the Clare Valley Prescribed Water Resources Area, including licensed dams, and stock and domestic dams, was estimated to be 6500 ML in 1999–2000. In addition, licensed water use from groundwater was estimated to be 1750 ML and 1500 ML from watercourses and surface water.

There is little information on the extent, capacity and distribution of farm dams and wells within the rest of the Broughton catchment.

Reservoirs

The Beetaloo and Bundaleer reservoirs were constructed to provide domestic water supplies. The two small reservoirs are used as a back up to the main supply from the River Murray. SA Water manages the reservoirs and attempts to maintain them at no less than 35% capacity. Constructed in 1890, Beetaloo reservoir is an on-stream storage of 3150 ML capacity. Bundaleer reservoir, constructed in 1902, is an off-stream storage with a capacity of 6370 ML and is supplied via an aqueduct system from Bundaleer and Baderloo creeks. In the past, diversions were also taken via an aqueduct from Yakilo and Freshwater creeks but high salinity levels have caused these diversions to stop (Rolls and Williamson 1991).

6.2.4 IMPACTS ON THE FLOW REGIME

Both climatic variation and human activity have affected the flow regime of the Broughton River watercourses. A series of dry years over the past 15 years, with one or two exceptions, has resulted in decreasing flows and declining groundwater tables throughout the catchment regardless of the level of water resource development. At the same time it is clear that the flow regime in the system has been modified from its pre-European condition due to activities such as:

- water resource development, including dams and weirs, direct extraction by pumping, irrigation and groundwater extraction;
- land use changes and land management practices; and
- channel modifications.

The magnitude of the climatic effect has made it difficult to distinguish the effects of farm dams and other human activities. In particular it has distorted the perception of the effects of farm dams and groundwater extraction in the area. It has also coincided with the implementation of improved land management practices such as contour banking, reduced stocking and improved pasture management, all of which substantially reduce the amount of runoff within the catchment (Cresswell 2000). The decreased flows and spring activity along watercourses of the catchment relate to a combination of causes.

Land use and land management practices

Vegetation clearance and agricultural development have had significant impact on the watercourses and water regimes in the catchment. In the 1850s, with land clearing, surface runoff and recharge to groundwater increased. Surface flow and groundwater levels would have initially risen in response to this land use change. Over time, land management practices such as long fallow periods, stubble burning and overstocking have also contributed to increased rainfall runoff, soil loss and stream erosion and to changes to the groundwater table.

Since the 1940s farming practices and land management has gradually and significantly improved with contour banking, minimum tillage, reduced stocking and improved pasture management. These activities are designed to hold more water on the catchment and have helped reduce the amount of surface runoff and soil erosion. The overall effect would be to decrease surface water and groundwater dependent flows, which may ameliorate excess flows to some extent. Further study is necessary to assess the full impact of improved farming practices on surface runoff, groundwater recharge and flows (Cresswell 2000).

Water resource development

Dams and weirs

Dams and weirs have had several adverse impacts, including:

- altering flows downstream — in volume and timing, frequency and duration;
- changing habitats from a flowing to a standing water habitat;
- trapping sediment and reducing sediment transport downstream;
- changing the quality of impounded water; and
- imposing barriers to the movement of fish and other aquatic biota.

Large reservoirs, in particular, have the greatest impact and have the potential to affect a range of flows. Beetaloo reservoir, situated on Crystal Brook, has modified the downstream flow regime — the low flow pattern has changed and the high and medium flows have declined. Some low flow occurs for a small section below the dam wall because of releases from the scour valves (the timing and volume of these are currently determined by operational considerations). The reservoir acts as a sediment trap and captures most of the sediment emanating from its catchment. Thus the sediment load of Crystal Brook immediately downstream is reduced. Further downstream, the impact on the flow regime and sediment load decreases as a result of flows into Crystal Brook from its tributaries (Brizga 2000a).

Bundaleer reservoir has a periodic effect on flows in Bundaleer Creek. During medium flow events, good quality water is taken out of the system and directed to the reservoir via an aqueduct. This reduces the occurrence of medium flow events downstream of the off-take weir. The weirs constructed on Bundaleer, Freshwater and Yakilo creeks as part of the aqueduct system that feeds the reservoir have altered flows and reduced the transport of sediment downstream. Evidence of sediment deposition upstream of all three weirs is obvious.

Farm dams

Farm dams alter flows and sediment transport on the smaller streams on which they are situated. Where there are several farm dams there can be a significant cumulative reduction in downstream river flows. The impact of farm dams is greatest on low to mid flows and in below average rainfall years. The dams also delay flow. Farm dams have less effect on high flow events (Cresswell 2000). The magnitude of the effect also depends to an extent on the preceding season: an empty dam will trap a larger proportion of flow than a full one.

Most of the dam development in the Broughton catchment is within the Clare Valley. Most on-stream dams are in the upper parts of the Hutt and Hill subcatchment on smaller watercourses. There are several larger off-stream dams which pump off-peak water from the River Murray pipeline and/or take water from the Hutt and Hill rivers during high flows and flood events.

Farm dams in the valley are unlikely to have affected groundwater levels and permanent summer baseflow because the groundwater sources for this flow are located downstream of most of the dams. Low and mid flows are likely to be affected by dam developments because they are mainly generated in the upper catchment where most of the dams are located. The magnitude of these impacts would be greatest for the Hutt and Hill rivers.

On-stream dams in the Clare Valley have reduced the median flow in Hutt River by an estimated 24% and in Hill River by 21%. In the Broughton River, the effect has been to reduce median flows at the Mooroola gauging station by an estimated 9% (Cresswell 2000). The median refers to the typical flow in these systems as measured at the gauging stations for Hutt, Hill and Broughton rivers. Whether or not these changes represent a greater than acceptable impact requires further investigation and long-term monitoring. The effects of farm dams on the environmental water requirements for Broughton, Hutt and Hill rivers is discussed in Section 6.4.1

Pumping of surface water and groundwater

Water regimes can be affected by direct pumping from pools and watercourses and by groundwater extraction. Pumping can cause a rapid fluctuation of water levels and result in overall decreases in water levels and in the extent of aquatic habitat. Groundwater pumping near watercourses can potentially reduce baseflows and lower permanent pool levels.

Much of the Broughton River system, in particular the baseflow and permanent pools along the main channel, is influenced by groundwater from low capacity fractured rock aquifers. Extraction is likely to have localised effects in these aquifers and related surface waters. For example, groundwater extraction in the Clare Valley may affect local watercourses but it is not likely to affect baseflow in the Broughton River which is influenced by groundwater from local sources.

Agricultural development for lucerne production has had a significant impact on flow regimes and riverine ecosystems in the Booborowie area. Anecdotal evidence suggests that the valley used to be a vast expanse of swamps and marshes with the groundwater table within 2 m of the surface. Significant groundwater pumping for the lucerne industry, established in the 1920s, led to a fall in the groundwater table to about 8–9 m below the surface by the 1950s (Clarke 1990; Flint 1972). Before irrigation development in the area it is probable that there was significant baseflow in the lower reaches of Booborowie Creek (Cresswell 2000). Groundwater in this area is taken from a sedimentary aquifer and has relatively widespread effects within the Booborowie Valley. The valley today is a much drier landscape. Continued monitoring and investigation of the sustainable yield of the groundwater resource in this area is highly recommended.

Channel modifications

Channel modifications such as channelisation, result in the realignment, straightening or deepening of the natural watercourse. Channelisation has been extensive in areas of the catchment that either had no defined channel or only a small channel bordered by a frequently inundated floodplain. Channels were generally modified to help develop agriculture in swampy or frequently flooded areas. Typically, the modifications increase the velocity and volumes of flow within the channel and often initiate bed and bank erosion. Channelisation and the associated incision reduces the frequency of overbank flooding, which has implications for floodplain habitats and any associated wetlands (Brizga 2000a).

Levee banks constructed along channelised reaches reduce the potential for overbank flooding. Typically, they increase the potential for incision by confining flows and changing the hydraulics of the floodplain (resulting in a less frequent flooding).

Levees as part of the irrigation scheme on the coastal plains of Broughton River have had a different effect on flows. They were built to enable floodwater to spread on to the floodplain, thus reducing the erosive potential of the flows. This may have implications for channel changes on the delta (Brizga 2000a).

6.3 Water quality

Water quality data from the catchment is patchy (Table 6.2). Data is available for all gauging station sites from the early 1970s but there are extensive gaps in the record. No data is available from the Hutt or Broughton River sites after the early 1990s. The overall water quality can be described as poor to moderate based on the classification used by the Environment Protection Agency (1998). However, the water quality is highly variable and dependent on flow, and this can make data interpretation quite complex. Salinity levels are generally high and the water is unsuitable for potable use, livestock or irrigation.

6.3.1 SALINITY

High stream salinities, a feature of the catchment, are most likely due to the influence of groundwater on baseflows and permanent pools. Salinity recording in the catchment is limited and based on individual grab samples taken at the gauging stations. Sampling is more common during low flow events which represent the normal condition of this semi-arid region. The salinity levels decrease with increasing water flow. During periods of mid to high flow, the water quality of the Broughton River can be very fresh but the low flows are more saline. Daily Broughton River flows have been categorised for salinity (Table 6.3; Cresswell 2000).

Table 6.2 Water quality indicators (range and median values)

Indicator	Hutt River near Spalding GS507502			Hill River near Andrews GS507501			Broughton River Mooroola gauging station GS507504		
	Range	*Median*	*Water quality classification*	*Range*	*Median*	*Water quality classification*	*Range*	*Median*	*Water quality classification*
pH	7–9.4	8.1	Good	6.3–8.6	7.9	Good	6.8–8.8	8.2	Good
Salinity as conductivity (µS/cm)	255–9990	3939	Poor	319–13 700	5029	Poor	390–12 100	4886	Poor
Salinity (mg/L)	300–5692	2385	Poor	311–7915	3100	Poor	949–6949	3143	Poor
Turbidity (NTU)	0.4–270	2.1	Moderate	0.37–270	3.4	Poor	0.28–295	1.2	Good
Nitrate (mg/L)	0.01–0.95	0.02	Moderate	0.01–2.01	0.02	Moderate	0.01–1.09	0.01	Moderate
TKN (mg/L)	0.33–69.2	0.775	Moderate	0.26–3.39	0.94	Moderate	0.09–1.92	0.535	Moderate
Phosphorus total (mg/L)	0.005–1.96	0.033	Moderate	0.012–0.885	0.0455	Moderate	0.005–0.291	0.018	Good
Total organic carbon (mg/L)	2–40	14	Poor	5–37	14	Poor	3–35	10	Moderate
Colour (hazen units)	1–155	20	Moderate	1–188	30	Poor	5–70	11	Moderate
Iron (mg/L)	0.005–62	0.3	Moderate	0.005–36	0.31	Moderate	0.005–25	0.1	Moderate
Copper (mg/L)	0.005–0.05	0.016	Poor	0.005–0.115	0.009	Moderate	0.005–0.075	0.01	Moderate

Table 6.3 Percentage of daily flows within salinity ranges (Cresswell 2000)

Quality range (salinity)	Daily flow within the range (%)
Fresh (<500 mg/L)	38
Marginal (500–1500 mg/L)	29
Brackish (1500–5000 mg/L)	33

Salinity trends for the gauging stations vary greatly over time: a notable peak in salinity in the early 1980s corresponded to the severe drought of 1982–83. The only significant change over time is at the Mooroola gauging station on the Broughton River, which showed an annual increase in salinity of 50 µS/cm (estimated 32 mg/L annually) between 1972 and 1991 (Jolly et al. 2000). In general, however, there is insufficient data to determine any trend in salinity levels for watercourses across the catchment. Regular monitoring and further detailed studies are recommended in order to determine the causes of variations in the trends and to identify any increases that may impact on the use of the resource.

Random salinity sampling elsewhere in the catchment indicates that baseflow salinity levels vary significantly between watercourses. For example, the levels in Rocky River tend to be higher than in the Broughton River; Crystal Brook and Bundaleer Creek have the lowest salinity levels; and Baderloo and Freshwater creeks and Hutt River have moderate salinity levels (D Clarke, pers comm).

6.3.2 COMMUNITY WATER MONITORING

Waterwatch groups have collected water quality data (pH, temperature, salinity, turbidity, phosphates and nitrates) in the catchment since 1997. Most monitoring sites have permanent baseflow. The community monitoring data also records naturally high salinity levels for the Broughton River in the range of 1000–8000 mg/L for most sites. Turbidity levels are generally low with higher turbidity readings recorded in times of high flow. Nutrient levels are generally low with the exception of a few sites with increased levels. High phosphate levels have been recorded during times of high flows (S Heaslip, Waterwatch, pers comm).

6.4 Environmental water requirements

Seven important flow bands — groundwater, baseflow, low flows, mid flows, high to bankfull flows, overbank and catastrophic flows — were identified for the Broughton River and its tributaries. Detailed environmental water requirements including desirable flow durations and frequencies have been recommended for each geomorphic zone based on best available data on the relationships between flow and geomorphic and ecological functions (see Appendix E). Chapters 8–14 provide a brief overview of the requirements for the geomorphic zones located within each subcatchment.

The recommended environmental water requirement can be used to:

- indicate which flow events should be protected and monitored in order to provide a basis for assessing the impacts of water resource development; and
- develop hypotheses to test assumptions on the environmental water requirements of biota and geomorphic and ecological processes in different geomorphic zones.

These recommendations represent the desirable requirements for the plants and animals along the different geomorphic zones. Monitoring of flows is necessary to determine if the current water regimes are consistent with and meet these requirements; that is, to test the recommendations and, in particular, to determine if the specified flow bands, frequencies and durations occur under natural conditions.

6.4.1 VALIDATING THE ENVIRONMENTAL WATER REQUIREMENTS

The environmental water requirements for the Broughton River Zone 6, Hutt River Zone 1 and Hill River are outlined in this section. The actual flows as measured at the three gauging stations in the catchment are compared with the recommended environmental water requirements. Impacts and threats to these requirements in the zones are discussed.

Farm dams in the Clare Valley are likely to be a significant influence on whether the environmental water requirements are met. Consequently, the current flow regime with farm dams and the ‘natural’ regime (defined as a cleared catchment with no farm dams) were compared with the recommended requirements.

Groundwater and permanent baseflow

Groundwater tables intersecting the streambed are important for maintaining permanent pools and baseflow in the catchment. Baseflow maintains streamflow over summer and is permanent in the Broughton River Zone 6 and semi-permanent in the lower reaches of the Hutt River Zone 1. Permanent pools exist along the Hutt and Hill rivers. Variability in the baseflow level over time is typical of a natural flow regime. The levels will rise as evaporation decreases and soil moisture increases during late autumn–winter.

The greatest potential risks to baseflow and permanent pools are from direct pumping from the watercourse and/or withdrawal of water from local aquifers. Groundwater levels can be affected either by direct extraction from the aquifer or by a substantial increase in the areas of lucerne production adjacent to the watercourses. Groundwater use near Booborowie Creek and the Hill and Hutt rivers is likely to have reduced baseflow and groundwater levels over the past 20 years. However, little is known of the impact local agriculture has had on the permanence of flow or permanent pools.

Mooroola gauging station records show that baseflow in the Broughton River has not stopped during the past 24 years. Thus the baseflow in the Broughton River Zone 6 is relatively secure at the current level of groundwater use. To date, the high salinity of local groundwater has limited its use. However, the areas supporting baseflow in the Broughton and Hutt rivers do not lie within a prescribed area and so there are few controls on development. Protecting the sources of baseflow in the main channel of the Broughton River should be a high priority for management.

The importance of years of above-average rainfall to maintain groundwater levels and permanent baseflow has been noted. The last 15 years of mostly below average rainfall have probably had the most significant impact on baseflow in the Broughton and Hutt rivers.

Low flows/seasonal baseflow

Low flows typically provide a minimum flow to cover the bed of the channel for long periods. Low flow events are a direct response to rainfall but also are related to a seasonal rise in baseflow that peaks over the winter months. This seasonal rise may be important for maintaining low flows over longer periods of time. Low flows are considered important for the breeding and recruitment of frogs and macro-invertebrates, transport of nutrients and organic matter and fish development and recruitment.

Low flows are likely to be affected by farm dam developments, as much of this flow is generated in the upper catchment where most of the dams are located. The size of the impact would be greatest for the Hutt and Hill rivers. The greatest risks are from an increasing area of the catchment being controlled by farm dams and from the diversion of low flows from the watercourses. Ensuring the main sections of the Hutt and Hill rivers remain free from on-stream farm dams is an important strategy for ensuring low flows reach the Broughton River.

Groundwater use is likely to impact on the seasonal baseflow component of the low flow band. The effect of this would be to reduce the duration of these flows.

Several tributaries other than the Hutt and Hill rivers, such as Freshwater and Bundaleer creeks, contribute to baseflow and surface flows in the Broughton River Zone 6. There is the potential for development in these areas where the salinity of the water is suitable for irrigation. As these tributaries lie outside the Clare Valley Prescribed Water Resources Area, there are few controls regulating groundwater and surface water use.

Low flow environmental water requirements currently appear to be met for the three zones (Table 6.4). However, as low flows are particularly important for the ecological maintenance of the catchment, ongoing monitoring of the flow levels and biota responses is necessary.

Mid flows

Mid flows are driven primarily by rainfall runoff and typically have flow heights around 50–75% of reed height. These flows were considered by the scientific panel to be particularly important for fish breeding and migration and for maintaining riparian vegetation.

Table 6.4 Recommended environmental water requirements compared with current flow regimes

	Broughton River Zone 6	Hutt River Zone 1	Hill River
Environmental water requirement recommendation	Annual low flows with median duration of 70 days, with at least one low flow event that lasts for 15-20 days (Natural variability is important and duration requirements may not be met in drought years)	Annual low flow in winter and spring	Annual low flows occurring in winter–spring Some periods of no flow during drought years
Current flow regime (with farm dams)	*Environmental water requirements met* Low flows occur annually. Median duration equals 85 days. Flow events with a duration of 15–20 days occur on average once every 1.6 years.	*Environmental water requirements met* Annual low flows occur in winter and spring. Flow regularly ceases in summer.	*Environmental water requirements met* Low flows occur annually in winter and spring. Periods of no flow in winter and spring occur on average once every six years.
Natural flow regime (without farm dams)	Little change	Low flow would occur earlier in the season. Duration of flows maybe increased.	Low flow would occur earlier in the season. Duration of flows maybe increased.
Possible impact indicators	Decrease in duration of flow events	Increase in duration of no flow periods	Increase in frequency and duration of no flow periods

Farm dams affect mid flows. These flows will be most reduced in dry years and will delay flow. The greatest effect on flow occurs early in the winter season when dams are empty; the effect progressively lessens throughout winter. This has the potential to delay the start of mid flows, which may in turn affect the ecology of the river system. A comparison of the current flow regime (recorded data) with the modelled 'natural' flow regime (without farm dams) indicates that the dams reduce flow durations in the mid flow range (Figure 6.5). The effect is greater in the Hutt and Hill rivers than in the Broughton River and is greatest in dry years.

The recommended environmental water requirements to sustain biological populations, particularly native fish, appear to be just met (Table 6.5). Modelling shows that the frequency and duration of flow events suitable for fish breeding are increased when the impact of farm dams is removed. It is likely, therefore, that the optimum flow events required to ensure maximum or increasing populations in the Hutt and Hill rivers may have been affected by dam development. Whether or not this signifies a greater than acceptable impact in the long term requires further monitoring and investigation. In addition, long periods of flow are related to sequential rainfall days. Consequently, the impact of climate variability must be considered.

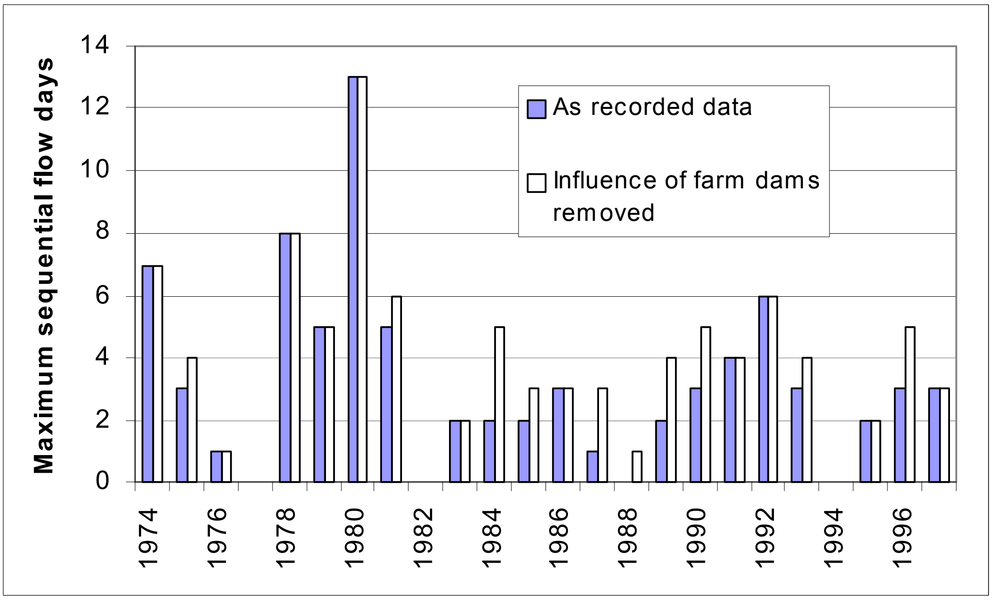


Figure 6.5 Maximum duration of a daily 1.85 cumec event in each year (Hutt River)

Table 6.5 Recommended environmental water requirements compared with current flow regime

	Broughton River Zone 6	**Hutt River Zone 1**	**Hill River**
Environmental water requirement recommendation	*Sustaining flow events* Flows in winter–spring on average once every three years for 4–10+ days (Optimum flow events = annual flows in winter–spring with a duration of 5–20 days)	*Sustaining flow events* Flows in winter–spring on average once every three years for 4–10+ days (Optimum flow events = annual flows in winter–spring with a duration of 5–20 days)	*Sustaining flow events* Flows in winter-spring on average once every three years for 4–10+days (Optimum flow events = annual flows in winter–spring with a duration of 5–20 days)
Current flow regime (with farm dams)	*Environmental water requirements just met* Mid flows that occur for 4 or more days occur on average once every 2½ years.	*Environmental water requirements just met* Mid flows that occur for 4 or more days occur on average once every 3 years.	*Environmental water requirements just met* Mid flows that occur for 4 or more days occur on average once every 2½ years.
Natural flow regime (without farm dams)	For some years the length of flow duration would be extended.	The frequency of long duration mid flows is increased. Mid flows that occur for 4 or more days occur on average every 2 years.	The frequency of long duration mid flows is increased Mid flows that occur for 4 or more days occur on average every 2 years.
Possible impact indicators	Significant decrease in duration of mid flow events	Significant decrease in frequency and duration of mid flows	Significant decrease in frequency and duration of mid flows

The risk to the mid flows is caused by the over control of the catchment by farm dams, particularly those in areas of greatest rainfall. Farm dam development should be managed to ensure that they contribute some flow each year. More importantly, some areas should be left free of farm dams so that the catchment as a whole retains some of its natural variability.

Ongoing monitoring of mid flows to ensure that flow volumes, duration, frequency and seasonality meet environmental water requirements and remain within natural variability is essential. Further investigation of the responses of biota, particularly native fish is also important.

High to bankfull flows

High to bankfull flows typically inundate approximately 50–100% of the stream channel at various sites. Bankfull flows typically occur once every two years and are of particular importance in maintaining watercourse channels, sustaining riparian processes and fish breeding.

The impact of farm dams is reduced for higher flow events. Impacts may still be significant in the drier years, as less of the catchment will be contributing to runoff until the dams fill. Within the Broughton and Hill rivers no significant effect on the duration of flows was noted in the high flow band. In Hutt River the dams reduced the number of days on which high flow events occurred (Figure 6.6). The recommended environmental water requirements are being met (Table 6.6). The difference in impact for the Hutt and Hill rivers may be because most of the farm dams along Hill River are located off-stream.

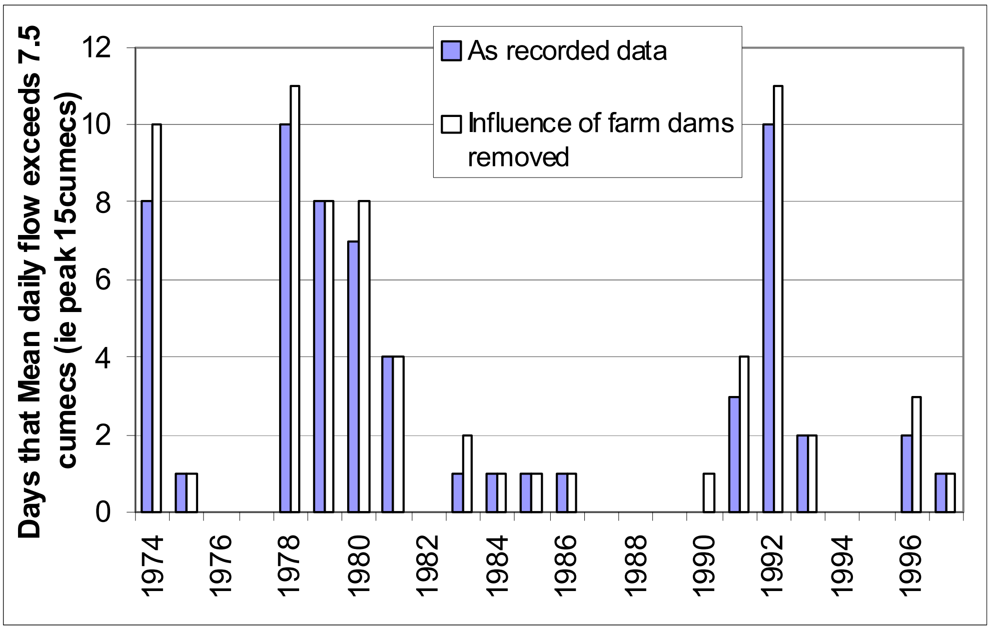


Figure 6.6 Number of days each year that the mean daily flow exceeds 7.5 cumecs (assumed peak of 15 cumecs)

Farm dams that trap large volumes of runoff are the greatest risk to high flow bands. Where the total volume of dams within a catchment exceeds the average annual runoff, significant reductions of the high flow events can be expected. Limiting the size of on-stream dams and ensuring that a significant area of the subcatchment is free from dams are important. Leaving part of the subcatchment free to flow would retain some of the natural flow variability.

Consequently, off-stream dams with a limited diversion capability may offer the best alternative to protect high flows.

Table 6.6 Recommended environmental water requirements compared with current flow regimes

	Broughton River Zone 6	Hutt River Zone 1	Hill River
Environmental water requirement recommendation	*Sustaining* Bankfull flows in winter–spring on average once every five years for 2–4+ days	*Sustaining* Bankfull flows in winter–spring on average once every three years for 2–4+ days	*Sustaining* Bankfull flows in winter–spring on average once every three years for 2–4+ days
Current flow regime (with farm dams)	*Environmental water requirements met* High bankfull flows for 2 or more days on average once every 5 years	*Environmental water requirements just met* High-bankfull flows for 2 or more days on average once every 3½ years	*Environmental water requirements met* High-bankfull flows for 2 or more days on average once every 2½ years
Natural flow regime (without farm dams)	Little change	The number of days that high to bankfull flows occur is increased. There is some increase in the frequency of high-bankfull flows that have a duration of 2 or more days: they would occur on average once every 3 years.	Little change
Possible impact indicators	Significant decrease in frequency and duration of high bankfull flows	Significant decrease in frequency and duration of high bankfull flows	Significant decrease in frequency and duration of high bankfull flows

Overbank and catastrophic flows

Overbank flows are important for floodplain and geomorphic functions. Catastrophic flows — large, infrequent flood events — cause significant streambed and channel rearrangement and reset the in-stream and floodplain habitats.

Farm dams are likely to have little to no impact on overbank and catastrophic flows. In general, the volume of water trapped in the dams is small compared with the volume in large flow events.

These flow bands, particularly the overbank flows, are most likely to be at risk from large-scale incision of the watercourse channels, which would have occurred as a result of widespread vegetation clearance and changed land use since European settlement. Watercourse incision has reduced the frequency of floodplain flows: larger flow events are needed before the water floods out on to the floodplain.

A lack of data prevents the accurate modelling of the occurrence and duration of the large flow events. In addition the watercourses and associated floodplains have been significantly modified. It appears that the recommended environmental water requirements for overbank and catastrophic floods for the Broughton, Hutt and Hill rivers are being met (Table 6.7). However it is important to continue to monitor these flow bands and to initiate good watercourse management practices to prevent further accelerated incision of the watercourses.

Table 6.7 Recommended environmental water requirements compared with current flow regimes

	Broughton River Zone 6	**Hutt River Zone 1**	**Hill River**
Environmental water requirement recommendation	*Overbank–catastrophic* Equal to or greater than the 1992 event Likely to have an ARI of 1:20 to 1:50	*Overbank* Overbank flows occur on average once every 5 years for a period of ~1 day during winter–spring *Catastrophic* Equal to or greater than the 1992 event Likely to have an ARI of 1:20 to 1:50	*Overbank* Overbank flows occur on average once every 5 years for a period of ~1 day during winter–spring *Catastrophic* Equal to or greater than the 1992 event Likely to have an ARI of 1:20 to 1:50
Current flow regime (with farm dams)	*Environmental water requirements met*	*Environmental water requirements met*	*Environmental water requirements met*
Natural flow regime (without farm dams)	Little or no change	Little or no change	Little or no change
Possible impact indicators	Significant decrease in frequency of overbank flows due to channel incision	Significant decrease in frequency of overbank flows due to channel incision	Significant decrease in frequency of overbank flows due to channel incision

6.5 Summary

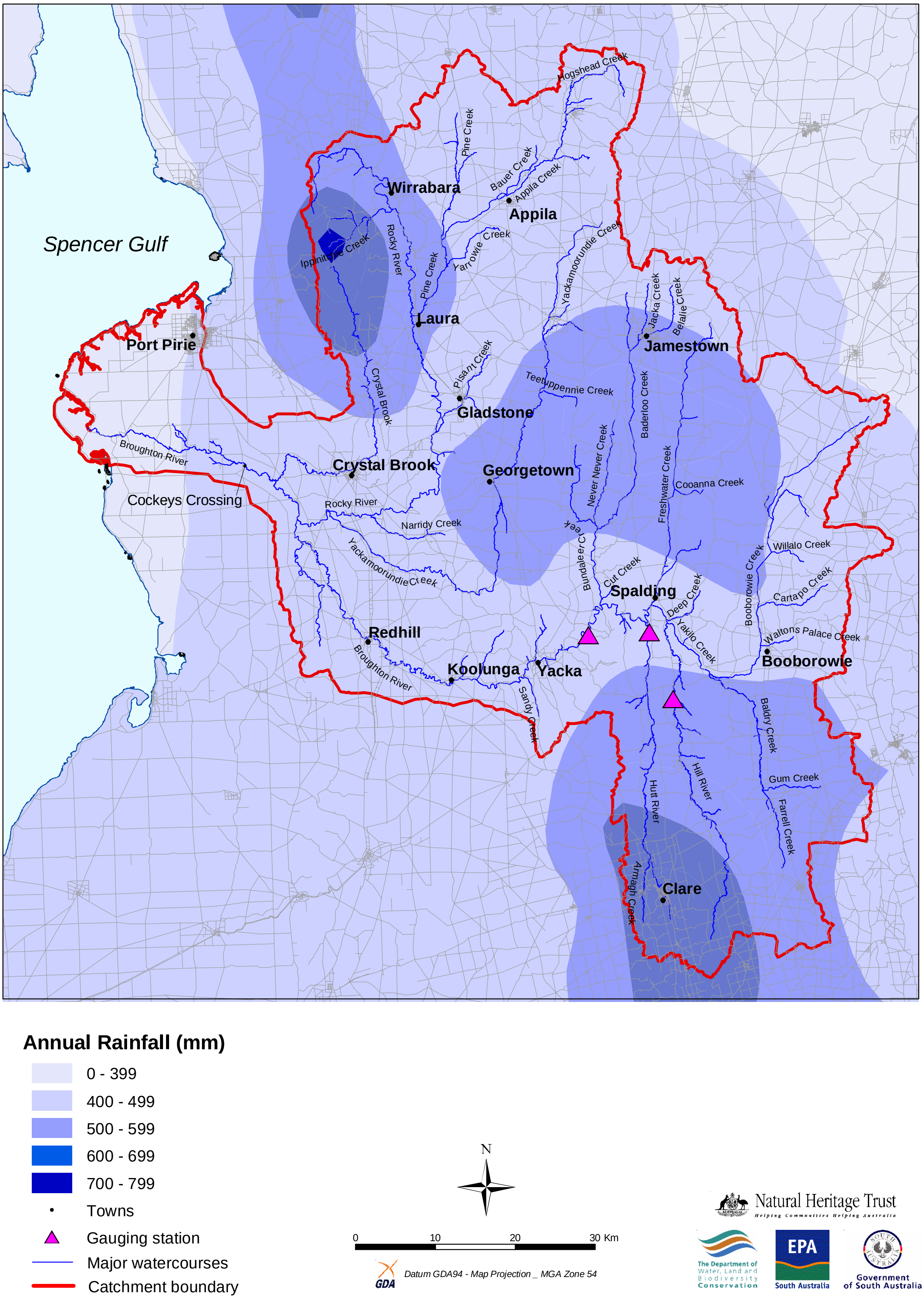
Water regimes in the catchment are highly variable in response to annual rainfall and groundwater discharge patterns. While many watercourses dry out over summer, many also contain permanent pools or maintain permanent baseflow supported by groundwater. The Hutt, Hill and Rocky rivers are important tributaries and supply a significant proportion of the surface flow in the main channel of the Broughton River. The permanent baseflow along the Broughton River is driven primarily by groundwater discharge from the Spalding area. Other important baseflow areas include the lower reaches of the Rocky and Hutt rivers and Bundaleer, Freshwater and Yakilo creeks, and sections of Belalie and Farrell creeks.

Climatic variation, water resource development such as farm dams, weirs, reservoirs and groundwater use, channel modification, land use change and farming practices have all impacted upon natural water regimes. Management of the human impacts on water regimes is important to ensure the water needs of the environment are met. In particular, the maintenance and protection of areas of permanent pools and baseflow should be a key management objective.

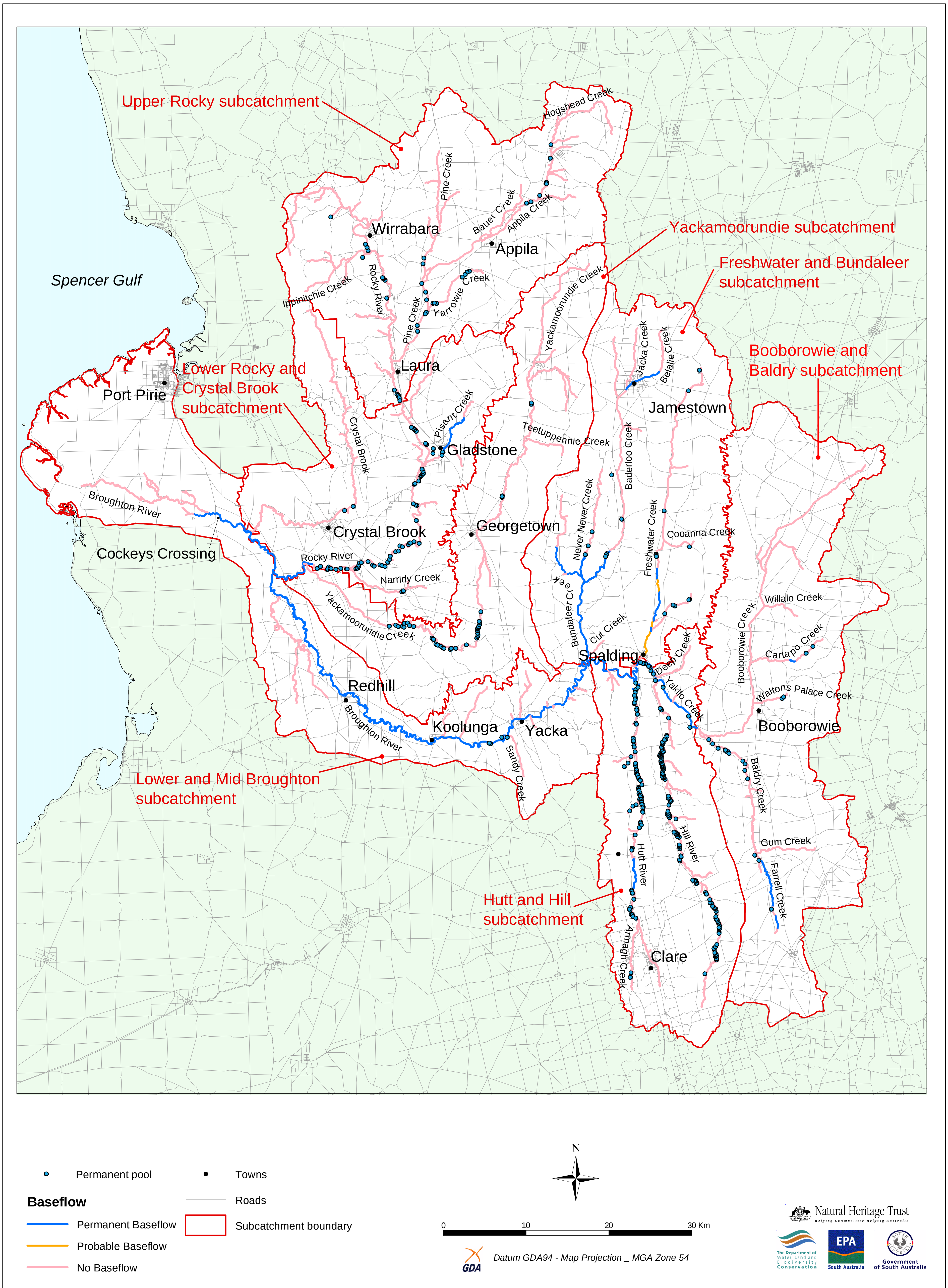
Seven important flow bands — groundwater, baseflow, low flows, mid flows, high to bankfull flows, overbank and catastrophic flows — were identified for the Broughton River and its tributaries. Detailed environmental water requirements, including flow volumes, duration, frequency and seasonality have been determined for different geomorphic zones across the catchment.

A comparison of the recommended environmental water requirements with recorded flow data for three geomorphic zones — Broughton River Zone 6, the Hutt River Zone 1 and Hill River — indicates that requirements for these sites currently appear to be met. However, low and mid flows are at risk from farm dam development in the Clare Valley and there are indications that mid flow requirements are only just being met.

Ongoing monitoring and investigations are critical to identify any future impacts, to ensure that requirements continue to be met and to improve understanding of the flow responses of riverine biota.



Map 6.1: Annual rainfall in the Broughton catchment



Map 6.2: Permanent pools and baseflow in watercourses of the Broughton catchment

CHAPTER 7 WATERCOURSE MANAGEMENT

7.1 Introduction

Through the assessment of the condition of fourth order and larger watercourses in the Broughton catchment, significant management issues were identified. This chapter discusses those issues, outlines the management strategies required to address them and summarises the key management needs. These issues are discussed in detail for each subcatchment in Chapters 8–14.

7.2 Results of the watercourse survey

To assess the condition of fourth order and larger watercourses, the project team recorded data for the following parameters:

- condition of watercourse vegetation — remnant vegetation, lack of native vegetation, in-stream vegetation, weeds and exotic trees;
- channel condition — bank and bed stability, and location of erosion heads;
- structures — threatened structures and structures that have a detrimental impact; and
- land use — adjacent to the riparian zone and watercourses with unrestricted stock access.

7.2.1 WATERCOURSE VEGETATION

Riparian vegetation

The location, structure and density of riparian vegetation along the surveyed watercourses of the catchment can be compared with the probable location and extent of watercourse vegetation before European settlement (Map 7.1, Map 5.3). The native riparian vegetation has been significantly modified from its original condition. Of the watercourses surveyed, 48% lack native vegetation and the dominant vegetation type is annual exotic grasses with either no overstorey or a very sparse overstorey of trees or shrubs (Table 7.1). Very few areas of intact native grassland were observed along the watercourses.

Riverine forests and woodlands were observed along 28% of the surveyed watercourses and tall shrublands along only 7%. The extent of riverine forests, woodlands and tall shrublands is estimated to have been reduced to less than 50% of their pre-European extent. The condition of the remaining forest and woodland communities varied across the catchment but all have been modified to some degree. In most areas the overstorey structure still remains intact. However, understorey vegetation has been significantly altered by factors such as clearance, grazing and weed invasion.

Sedgeland vegetation associations in varying condition cover approximately 14% of the surveyed watercourses. These swampy type environments generally occur along wide, shallow watercourses in areas supported by groundwater, for example, on Booborowie, Baldry, Yakilo and Yackamoorundie creeks and within the gorge environments of the Hutt, Rocky and Broughton rivers. Their natural extent has been reduced by channelisation and agricultural development.

Areas of chenopod, samphire and lignum (*Muehlenbeckia florulenta)* shrubland are located along the lower reaches of the Broughton River. These vegetation communities are also understorey to river red gum (*Eucalyptus camaldulensis*) woodlands along these reaches. The vegetation appears to be in relatively good condition. There is some invasion of weeds, including boxthorn (*Lycium ferocissimum*) and silver nightshade (*Solanum elaeagnifolium*) (Brown and Kraehenbuehl 2000), and some impact from stock grazing.

The native riparian vegetation has been modified as a result of land and river management practices, the most significant of which have been land clearance and stock grazing. Other impacts include cropping, altered flow regimes and invasion by exotic trees and weeds. Grazing, in particular, appears to impact on the regeneration of both overstorey species and understorey shrub layers. Very few juvenile plants were observed in heavily grazed areas.

The lack of native riparian vegetation and the need to protect remnant native vegetation are significant management issues.

Table 7.1 Condition and type of riparian vegetation in the Broughton catchment

Riparian vegetation type	Length (km)	Percentage of surveyed watercourse
Dense[a] native tree overstorey (closed forest)	74	7.5
Mid-density[b] native tree overstorey (open forest)	143	14.4
Sparse[c] native tree overstorey (woodland)	58	5.8
Dense[a] native shrub overstorey (tall closed shrubland)	4	0.4
Mid-density[b] native shrub overstorey (tall shrubland)[c]	30	3.0
Sparse[c] native shrub overstorey (tall open shrubland)[b]	33	3.3
Annual grasses with very sparse[d] overstorey of trees/shrubs (grassland/cropping)	479	48.4
Sedgeland	140	14.1
Chenopond shrubland	8	0.8
Lignum shrubland	3	0.3
Samphire shrubland	4	0.4
Revegetation	11	1.2
Other	5	0.5

Percentage of coverage: a = >70%; b = 30–70%; c = 10–30%; d = <10%

In-stream vegetation

In-stream vegetation such as reeds, rushes and sedges are an essential part of the river ecosystem. Medium density to dense reedbeds were observed along 28% of the watercourses surveyed in the catchment (Map 7.2, Table 7.2). Reedbeds tend to occur along watercourses maintained by a shallow groundwater table or spring-fed baseflow. In the catchment the reedbeds are of two main types: reedbeds dominated by two species, common reed (*Phragmites australis*) and bulrush (*Typha* spp.); and reedbeds supporting a diverse range of reeds, sedges and rushes.

Observations by landholders suggest that the extent of reedbeds dominated by common reed and, to a lesser extent, bulrush has considerably expanded (Brizga 2000a). This could be part of an ecological response to changes in the landscape brought about by human activities. For example, land clearing and erosion has increased the amount of light, sediment and nutrients entering the watercourse, which has provided a favourable environment for reedbed species to proliferate. In addition, over the past decade agricultural practices have changed: there is a greater emphasis on intensive crop rotation and a reduction in the number of domestic stock carried within the region. The consequent reduction in grazing pressure may have allowed these species to spread more widely along the watercourses. The excessive growth of reedbeds was not considered a significant management issue for the catchment.

Table 7.2 Density and extent of in-stream vegetation in the Broughton catchment

In-stream vegetation	Length (km)	Percentage of surveyed watercourse
Dense[a] in-stream vegetation	69	7
Medium density[b] in-stream vegetation	213	21
Sparse[c] in-stream vegetation	115	12
No in-stream vegetation present[d]	94	9
Not observable	503	51

Percentage of coverage of channel: a = >80%; b = 30–80%; c = >5–<30%; d = <5%

Riparian weeds

Riparian weeds — usually introduced species — are nuisance plants that impact adversely on the river ecosystem. The survey methods used meant only the larger woody weeds and wild artichoke (*Cynara cardunculus*) could be identified. Accurate identification was limited mainly to areas with a sparse overstorey canopy cover. Riparian weeds were observed along 21% of the watercourses, with dense to medium density infestations affecting 2% of these areas (Map 7.3). Weed species detected included boxthorn, wild artichoke, wild rose (*Rosa rubiginosa*) and blackberry (*Rubus fruticosus).* Except for wild rose, these species are proclaimed weeds under the *Animal and Plant Control (Agricultural and Other Purposes) Act 1986*.

Exotic trees

Exotic trees are introduced species that are not in balance with the local river ecosystem. Exotic trees were observed along 8% of the watercourses. Species identified include ash (*Fraxinus* spp.), olives (*Olea* spp.), pine trees (*Pinus* spp.), pepper trees (*Schinus* spp.), poplars (*Populus* spp.), tamarisk (*Tamarix* sp.) and willows (*Salix* spp.) (Map 7.4). Ash was the only species significant on a catchment scale: sparse to very sparse densities were observed along 5% of the watercourses. Exotic tree species tend to be located in towns and the higher rainfall areas near Wirrabarra and Clare. Exotic trees are a significant management issue along watercourses where infestation was dense or areas of good vegetation were threatened.

7.2.2 CHANNEL CONDITION AND STABILITY

Bank erosion occurs naturally in a dynamic system like a watercourse. Excessive erosion indicates the system is 'out of balance' and is responding to altered channel conditions. Factors accelerating erosion include human activities (such as land clearance, channel modification and stock access), the steepness of the banks, soil type and whether the banks and bed are vegetated. The survey of watercourse condition in the Broughton catchment focused on erosion and poor stability involving human activity.

Bank stability

Almost 82% of the watercourses have good bank stability (Table 7.3). Approximately 13% of the watercourses have banks classified in 'moderate' condition (Map 7.5). These banks have some obvious damage to their structure and vegetation. They could undergo active erosion if they are not managed to control grazing and ensure a cover of protective vegetation. Watercourses recorded as 'rocky gorges' or 'incised spurs' should be considered as having banks in good condition because of their low potential to erode (Table 7.3). Some 3% of the watercourses appeared to be actively eroding: they had little effective vegetation and were classified as having poor stability (Table 7.3, Map 7.5). Many of these areas of bank erosion are associated with erosion heads and bed deepening events. Bank erosion and poor bank stability are a significant management issues at several sites across the catchment.

Table 7.3 Bank stability parameters in the Broughton catchment

Bank stability	Percentage of surveyed watercourses
Good — good vegetation cover, no significant damage to bank structure or vegetation, stable toe	81.8
Moderate — discontinuous vegetation, some obvious damage to bank structure and vegetation, generally stable toe, usually moderate to steep batter	12.7
Poor — evidence of active erosion, little effective vegetation, unstable toe, usually steep to vertical batter	3.0
No natural bank formation — rocky gorge, incised spurs or dams	0.5
Not observed	2.0

Erosion heads and bed erosion

An erosion head is a short, steep section of a stream bed that erodes in an upstream direction (Kapitzke et al. 1998). It results in a lowering of the channel bed and bank erosion. Movement of an erosion head is generally initiated at a downstream point by activities that lower or disturb the bed of the watercourse. The erosion heads observed across the catchment are generally associated with areas of moderate to poor bank stability (Map 7.5). Areas where bed erosion appeared particularly active include sections of the Appila, Bauer, Pine, Narridy and Yackamoorundie creeks. Rock bars can form natural control structures limiting the extent of erosion. Erosion heads and bed erosion are significant management issues in the catchment (Map 7.5).

In-stream structural works

Bed and bank erosion can result in damage to man-made structures. At the same time, poorly aligned or designed structures can initiate erosion. Structures surveyed include fords, culverts, bridges, weirs, dams, stock crossings, and bed and bank stabilisation works.

The stability of the structures observed is illustrated in Map 7.6. In general, most structures had a moderate to high stability rating. There were some low stability bridges and fords on the eastern tributaries of Booborowie Creek, the upper and lower reaches of Yackamoorundie Creek, and the upper reaches of Rocky River and Pine Creek

(Chapters 8-14). Where these structures have been associated with erosion problems, they have been identified as significant management issues in the catchment.

7.3 Significant watercourse management issues

The assessment of watercourse condition identified significant management issues in the catchment. The principles and guidelines used by the project team to identify the significant issues and set priorities for management are outlined in Appendix F (see also Table 7.4 for a summary of their nature and extent, and Map 7.7 for locations).

Table 7.4 Significant watercourse management issues in the Broughton catchment

Watercourse management issue	Length or number of sites	Percentage of surveyed watercourses
Poor native watercourse vegetation	281.1 km	28.2
Good native watercourse vegetation (improve and maintain)	161.5 km	16.2
No significant management issue	160.8 km	16.1
Riparian weeds	157.8 km	15.8
Exotic trees	60.1 km	6
Important riverine habitat (protect and enhance)	51.5 km	5.2
Other (cultivated watercourses)	42.6 km	4.3
Poor bank stability	37.0 km	3.7
Remnant vegetation (protect and enhance)	14.1 km	1.4
Salinity	6.7 km	0.7
Side gully erosion/gully heads	11.3 km	1.1
Erosion heads	21 sites	–
Structures causing or threatened by erosion	8 sites	–

7.3.1 CONSERVATION MANAGEMENT ISSUES

Protecting watercourses with high conservation values should be a high priority for management. It is much more effective, in terms of cost and ecological benefits, to protect these areas than to manage them poorly and have to rehabilitate them (LWRRDC 2000). The benefits of protection and management include maintaining and improving the biodiversity of the region as well as protecting a natural asset. These areas are often the only surviving remnants of the original watercourse habitats. They not only have high conservation and ecological values but also have high recreation, aesthetic and community values, for example, Appila Springs. In general, managing and protecting areas of important riparian habitat were rated as a high priority by the landholders (see Chapters 8–14).

Protecting important riverine habitat

Areas of important riverine habitat within the catchment are characterised by a diversity of in-stream and riparian vegetation, a range of in-stream physical habitats (such as pools, riffles and channel bars) and, typically, permanent or semi-permanent water (Plate 7.1). These areas support a high ecological biodiversity, are important refuges during harsh periods and provide a stable environment from which species can recolonise.

Important riverine habitats in the catchment are shown on Map 7.7. They include:

- a large area of low-lying lignum and chenopod shrubland associated with river red gum forests located along the Broughton River from Cockeys crossing to the estuary of Port Davis (important for birds, fish and macro-invertebrates, particularly in times of flood);
- sedgeland environments within the Rocky River Gorge (with a diverse range of plant species and permanent water);
- woodland or sedgeland environments with permanent water along the lower reaches of the Hutt River and at Appila Springs;
- the forest habitats at Bowman Park on Crystal Brook and along the Broughton River at Whitecliffs; and
- woodland and shrubland environments along the upper reaches of Pisant Creek, along the Broughton River near the Mooroola gauging station, at Freshwater weir and along a tributary of the Yackamoorundie Creek (adjacent to the Koolunga–Crystal Brook road).

Maintaining and enhancing these areas may require livestock being managed, for example by fencing, to ensure they have minimal impact on the environment; removing and controlling exotic trees and weeds; managing threats such as sediment deposition from upstream erosion; and ensuring that the natural pattern of streamflow is maintained. Regular monitoring is required in order to detect problems or deterioration.

Plate 7.1 An example of an important riverine habitat area in the Upper Rocky subcatchment with diverse in-stream and riparian vegetation and a range of in-stream physical components such as pools, riffles and rock bars

7.3.2 VEGETATION MANAGEMENT ISSUES

Healthy watercourse vegetation is an essential element of a healthy river ecosystem. Well-vegetated banks slow surface runoff, which prevents sediments, pollutants and nutrients from entering the watercourse. Vegetation stabilises and protects the bed and banks from the erosive force of water. The vegetation provides shade, lowers water temperatures and regulates algal growth. Leaves and branches are both food sources and habitats for aquatic and terrestrial animals (Davies and Bunn 1999). Healthy vegetation also enhances recreational and aesthetic values (LWRRDC 2000).

Protecting remnant vegetation

Remnants of original watercourse vegetation in good condition are a priority for protection (Plate 7.2). These areas support a diverse range of plant and animal communities and provide valuable seed reserves which can re-establish vegetation downstream. As most of the riparian vegetation across the catchment has been cleared or modified, these areas have a high ecological value. They may often be the only significant remnants present in the landscape. In managing the health of the stream, conserving remnant vegetation is more effective and preferable to re-establishing new vegetation.

Plate 7.2 An area of remnant vegetation on a tributary of Rocky River in the Upper Rocky subcatchment

Remnant vegetation sites requiring protection are shown on Map 7.7. Areas were identified along:

- a tributary of upper Rocky River;
- Crystal Brook below Beetaloo reservoir;
- the junction of Rocky and Broughton rivers;

- the upper reaches of Pisant Creek; and
- Appila Creek within the common of Tarcowie.

Most of the areas have some protection from clearing and grazing activities. Managing remnant vegetation requires threats from within the reach, such as grazing and exotic plant invasion, and from upstream or downstream, such as erosion heads, to be identified and controlled (Section 7.5).

Improving/maintaining good watercourse vegetation

Improving river health requires areas of good watercourse vegetation to be maintained and improved. Areas in the catchment contain vegetation in good condition (Map 7.7) that has been impacted by degrading processes such as clearing adjacent land, invasion of exotic species and pressure from livestock grazing (Plate 7.3). In general, these sites will continue to deteriorate unless there is active intervention to revegetate and control threats.

Most of this vegetation is fragmented and lacks diversity in terms of structure (grasses, shrubs and trees) on the banks and floodplain. Typically, areas of good vegetation fall into two categories: reaches with a healthy native overstorey (typically >30% coverage) and a degraded understorey; and reaches with diverse in-stream vegetation but with degraded riparian vegetation (overstorey and understorey layers). An example of the former is a forest with a dense eucalyptus overstorey that lacks the shrub understorey layer because of clearance or grazing. An example of the latter is an area with in-stream reeds and sedges but missing overstorey trees or shrubs along the banks. In many of these areas where a part of the vegetation structure has been removed, weed species such as boxthorn, wild rose and wild artichoke have become established.

Plate 7.3 Good watercourse vegetation along Crystal Brook in the Lower Rocky and Crystal Brook subcatchment which has a native overstorey of river red gums but an understorey dominated by exotic grasses and herbs

Areas of eucalypt forest in good condition but with a modified understorey can by found along:

- Crystal Brook;
- Rocky River north of Gladstone and north of Wirrabara;
- Yackamoorundie Creek through the gorge; and
- Appila Creek from Appila Springs to north of Tarcowie.

Areas with good in-stream vegetation but degraded native vegetation on the banks occur along:

- Broughton River downstream of Spalding and Yacka; and
- sections of Yakilo, Baderloo, Bundaleer, Yackamoorundie and Pine creeks.

Managing grazing in the riparian zone and removing invasive weeds together with encouraging natural regeneration and/or revegetation will improve the condition of these areas. Management outcomes will require ongoing maintenance to ensure weeds and vermin do not impact on any rehabilitation works or further degrade the site.

Poor native watercourse vegetation

The most common watercourse management issue in the catchment was a lack of native vegetation or native vegetation in a degraded condition (Map 7.7, Plate 7.4). Vegetation clearance, cultivation within or in close proximity to the riparian zone, weed invasion and stock grazing are major causes of the loss of native watercourse vegetation.

Plate 7.4 A section of a watercourse in the Lower Rocky and Crystal Brook subcatchment shows a lack of native riparian vegetation on the channel banks and floodplain. This watercourse is in poor ecological condition, with little food and shelter for native birds and animals and no protection from stream erosion.

A lack of native vegetation indicates poor ecological health of both land-based and water-dependent ecosystems. In general, introduced plant species such as annual grasses and weeds do not provide the riparian zone with the vegetative cover required to stabilise watercourse soils and banks. Sediment and nutrients are easily mobilised downstream thereby reducing water quality, causing sedimentation of pools and, perhaps, increasing the growth of reeds. Areas lacking native vegetation provide little food or shelter for native birds and animals. A lack of vegetation cover over permanent water increases light and water temperatures, which can promote algal growth and create unsuitable conditions for in-stream flora and fauna (Davies and Bunn 1999).

Poor native watercourse vegetation is an issue affecting all watercourses in the catchment. Particularly large sections of degraded or absent native vegetation were identified along:

- Hutt and Hill rivers;
- Bundaleer, Baderloo, and Freshwater creeks;
- the middle and lower reaches of Yackamoorundie Creek;
- the middle reaches of Broughton River; and
- sections of Rocky River, and Pisant, Pine and Appila creeks.

Revegetating and encouraging natural regeneration are necessary to improve areas of poor native watercourse vegetation. Threats such as livestock grazing and invasion by weeds and exotic trees need to be managed. These management strategies are discussed in Section 7.5.

Riparian weeds

Watercourses are an effective conduit for spreading weeds. Weed invasion into natural ecosystems is a major threat to the conservation of biological diversity. Weed species compete strongly with native plant species and do not provide a full range of food and habitat requirements for native animals. Most weed species do not effectively stabilise watercourse banks and many provide a refuge for vermin. Weeds can also impact on agricultural production in areas adjacent to the riparian zone.

In determining whether riparian weeds were a significant issue along watercourses, consideration was given to the density of the plant coverage, the invasiveness of the plant species, whether the weed was a proclaimed plant, the threat to the integrity of native or remnant vegetation and the length of watercourse affected.

One of the most affected areas along the Broughton River is from Koolunga to downstream of Cockeys crossing (Map 7.7). Boxthorn, the key weed species identified, affects not only this area but the lignum swamp area downstream where the key issue is protecting the riverine habitat. Wild artichoke is a problem along Broughton River (from the Mooroola gauging station downstream to Yacka), sections of Hutt and Hill rivers, and Bundaleer, Belalie, Freshwater, Booborowie and Baldry creeks (Plate 7.5). Wild rose is a problem along the upper reaches of Rocky River near Wirrabara. Riparian weeds, including wild thistle, were also an issue along sections of Yackamoorundie Creek.

To maintain a healthy watercourse, riparian weeds require initial control and removal and ongoing management (see Section 7.5).

Plate 7.5 A section of a watercourse in the Booborowie and Baldry subcatchment showing artichoke infestation

Exotic trees

Exotic tree species along watercourses can spread rapidly in that environment, overtaking local species and establishing themselves in inappropriate areas. For example, willow and tamarisk can regenerate from dislodged branches and the large number of seeds produced by ash trees allow them to spread rapidly. Where exotic trees form dense thickets, the normal flow of the watercourse can be obstructed causing erosion and flooding problems. Exotic trees tend to cast a dense shade that prevents undergrowth; as a consequence plant and habitat diversity is reduced. The deciduous leaf drop in late autumn produces a sudden increase of organic material. This material breaks down rapidly releasing large quantities of nutrients and results in the deoxygenation of the water. In general, exotic trees provide a much poorer living environment and do not meet the food and shelter requirements of native insects and animals. Biological monitoring in South Australia has shown that the number and diversity of aquatic insects and fish are greatly reduced under ash and willow trees compared with native vegetation.

Exotic trees were not considered a significant issue at all of the sites where they were identified throughout the catchment (Map 7.4, Plate 7.6). In determining this, consideration was given to the density of coverage, the invasiveness of the tree species, the threat to the integrity of native or remnant vegetation and the length of watercourse affected.

Plate 7.6 An infestation of exotic trees along a watercourse in the Lower Rocky and Crystal Brook subcatchment

Exotic trees such as ash and, to a lesser extent, pine were a significant issue along the upper reaches of Rocky River and its major tributaries. The source of these species appears to be the Wirrabara forest. Many of the trees appeared to be at the juvenile stage: controlling action now may prevent later problems. Ash trees were also significant along Never Never Creek, apparently spreading from the Bundaleer forest, and the upper reaches of the Hutt and Hill rivers. Tamarisk trees were significant along the Broughton River downstream of Koolunga and almond trees have spread in the upper reaches of Bauer Creek.

Exotic trees require initial control and ongoing management to reduce impacts on riverine ecosystems and prevent spreading along the watercourse. Management strategies are discussed in Section 7.5.

7.3.3 EROSION AND CHANNEL STABILITY ISSUES

Erosion is a natural process that can be greatly accelerated by human activities that alter streamflows or disturb the stream channel. Erosion can result in channel deepening and widening, the destruction of physical habitats, threats to in-stream structures, and increased sediment loads, which impact on water quality and aquatic habitats. Management strategies are discussed in Section 7.5.

Poor bank stability and bank erosion

Poor bank stability, indicating active bank erosion, is a significant management issue along watercourses in the catchment (Plate 7.7). Factors which can contribute to accelerated bank erosion include the removal of vegetation, stock grazing, excavation, channelisation, obstructions to stream flow and changes to the flow regime. Poor bank stability is often associated with the upstream movement of an erosion head.

Significant areas of poor bank stability and active bank erosion were located along:

- Appila Creek and its tributary Bauer Creek;
- sections of Yackamoorundie Creek and some of its eastern tributaries, including Teetuppennie Creek;
- sections of Narridy Creek; and
- the eastern tributaries of Booborowie Creek (Map 7.7).

Plate 7.7 Poor bank stability in the Upper Rocky subcatchment: note the slumping of the bank into the watercourse

Erosion heads and side gully erosion

Bed erosion is generally initiated at a downstream point by activities that lower or disturb the bed of the watercourse. This is generally caused by in-stream excavation, channelisation or an increase in the volume or velocity of flow within the channel. As the erosion event travels upstream it takes the form of a locally high gradient or a ‘waterfall’, and is called an erosion head or nick point (Carter 1995). When the episode of bed erosion passes a tributary or side gully, these areas undergo bed deepening as they adjust to the new bed level.

Bed erosion can cause an overall deepening and widening of the watercourse. Bank erosion follows the passage of an episode of bed deepening and, in general, banks will continue to erode and widen until they adjust to a new stable slope. The eroded sediment that is carried downstream can increase flooding and reed growth, and can smother important aquatic habitats.

Erosion heads associated with active bed erosion were identified as significant management issues at a number of sites throughout the catchment (Map 7.7). In many cases the erosion heads were associated with localised and/or extensive bank erosion (Plate 7.8), significantly along sections of Appila, Pine, Yarcowie and Narridy creeks. These watercourses are high risk areas for erosion because of their steep gradients and the unconsolidated alluvial sediments over which flow occurs.

Plate 7.8 A large erosion head in the Upper Rocky subcatchment: the channel has deepened and widened as the erosion head has moved upstream. The watercourse channel above the erosion head is barely discernible.

Gully erosion occurs on long, steep slopes adjacent to main watercourses and is associated with active erosion heads that form incised gullies extending from the watercourse. These gullies are likely to considerably deepen and widen in heavy rainfall events. Often there is little vegetation along these slopes to slow flows, protect the soil and impede erosion processes. Extensive areas of side gully erosion were evident along the middle reaches of Freshwater Creek. Other areas of side gully erosion include a section along Pisant Creek, the lower reaches of Narridy Creek and a tributary of Broughton River west of Yacka.

Structures causing or threatened by erosion

Bed and bank erosion can result in damage to in-stream man-made structures. At the same time, poorly aligned or designed bridges, culverts and weirs can initiate erosion (Plate 7.9). Culverts that are under capacity for the flood discharge of the watercourse result in upstream flooding and damage as water flows over the structure. Poorly aligned structures can redirect streamflow into the bank thereby causing bank erosion. Structures that fail to reduce the energy of water flow can cause large scour holes and bank erosion downstream.

Plate 7.9 An undercapacity culvert that has caused downstream erosion and scouring in the Upper Rocky subcatchment

Structures causing or threatened by erosion are a significant management issue at only a few sites in the catchment (Map 7.7). Active bed and bank erosion is evident along the eastern hill tributaries of Booborowie Creek directly downstream of several ford crossings, indicating that erosion events moved upstream and were halted by the ford. There is a ford crossing along the lower reaches of Yackamoorundie Creek which shows evidence of outflanking of the structure and scouring of the channel bed below the ford.

At Pine Creek at the crossing on the Wirrabara–Appila road a culvert is causing downstream bank erosion and scouring. This is possibly due to the culvert being under capacity and increasing the velocity of water passing through the structure. The subsequent erosion is outflanking the structure. Similarly along a tributary of the Broughton River north of Yacka, the first culvert crossing on the Yacka–Gladstone road is associated with downstream bank erosion and scouring. The erosion may have been caused initially by bed erosion downstream that has eroded back and is being halted by the culvert. This structure is being outflanked and the culvert is possibly exacerbating local erosion. The sites are not in critical condition at present. However, investigating and assessing them is recommended. Erosion stabilisation strategies for the Yacka site will be costly and involve re-engineering the structure.

7.3.4 OTHER ISSUES

Cultivation of watercourses

The cultivation of watercourses refers to the situation where the watercourse has been cultivated as part of the surrounding cropping land (Plate 7.10) and generally occurs in smaller order streams. It can occur in higher order streams where the terrain is level, the watercourses are shallow and the streamflow is of low energy. In the catchment the cultivation of watercourses occurs mainly along Freshwater, Booborowie and Baderloo creeks and their tributaries.

Cultivation increases the delivery of sediment and nutrients to the watercourse. It has the potential to become a significant management issue in adverse conditions. High rainfall runoff events during periods when the soil has been cultivated and is lying fallow can result in soil erosion and the transport of sediment downstream. Nutrients such as phosphorus and nitrogen attach themselves to sediment and sediment transport can lead to increased nutrient delivery to watercourses. Cultivated channels are particularly susceptible to erosion in summer when the soil surface cover is low and heavy thunderstorm events occur. Maintaining a perennial cover of grasses would reduce the potential for erosion and sediment transport and promote filtration.

Plate 7.10 A section of a watercourse in the Booborowie and Baldry subcatchment that has been cultivated and is barely visible in the centre of the paddock

Salinity

Salinity becomes an issue when broad-scale clearance of deep-rooted perennial vegetation results in increased recharge and rising groundwater tables. When the groundwater table nears the surface, the rise of water through the soil by capillary action leads to soil salinisation and waterlogging. This process is known as dryland salinity. Rising groundwater can also result in a greater movement of saline groundwater into watercourses causing increased stream salinities.

Salinity is a significant issue along the upper reaches of Baldry Creek. At this site the surface salt was visible and discussions with landholders indicated that it was a problem of concern. Seepage from the surrounding hills may be a factor in elevating the groundwater table below Baldry Creek. In general, the watercourse survey methods were not designed to detect complex catchment-scale issues such as dryland salinity. Thus this issue may be under-represented in this study.

Although salinity levels will vary over time, high stream salinities are a feature of the watercourses in the catchment. The levels tend to be elevated during dry periods when evaporation is high and there is less flow. Monitoring of salinity levels at the gauging stations shows a large variation over time with a notable peak in salinity in the early 1980s corresponding to the drought of 1982–83 (Jolly et al. 2000). There is insufficient data to determine salinity trends for the catchment. Further studies are required.

Rehabilitation of saline sites needs to be assessed carefully. Important management tools in some locations will be to minimise recharge by protecting the existing vegetation or planting deep-rooted perennial vegetation or deep-rooted pastures such as lucerne. On land that has become saline, removing stock and allowing salt-tolerant native plants to establish will reduce wind and water erosion by maintaining soil surface cover. Revegetating these areas to their original condition may no longer be possible; using species adapted to saline conditions may be necessary. Where drainage works are being considered to rehabilitate saline waterlogged land by diverting or transferring the water, the downstream impact on water quality and vegetation needs to be considered.

No significant watercourse issue

Some areas — primarily ephemeral, shallow and well-grassed watercourses — have no particular ecological value and have adequate vegetation cover. For these areas there would be little adverse affect on the watercourse if current management practices continue.

7.4 Other management considerations

Several activities and issues identified by the project team were either outside the scope of the original assessment of watercourse condition or were activities that contributed to the management issues discussed above. These activities and issues and their potential impact on watercourse condition are discussed below.

7.4.1 CHANNEL MODIFICATIONS

Channelisation and levee banks

Watercourses are often channelised to prevent flooding, improve drainage and/or increase the amount of land available for agriculture (Plate 7.11). Levee banks are commonly constructed along watercourses to confine flooding.

Channelisation can realign, straighten or deepen the natural watercourse (Kapitzke et al. 1998). Channelisation and the confining of flows by levee banks will increase the velocity and volumes of flow within the watercourse. This can lead to an increase in bed and bank erosion.

Channelisation is a common contributing factor to watercourse erosion in the Broughton River. Not only does it increase flow velocity, it also interferes with the natural meander pattern of a watercourse. This is a particular problem in areas with unconsolidated alluvial soils. Watercourse erosion has a major effect on floodplain and wetland environments: the frequency of overbank flooding required to maintain these systems is reduced.

Channelisation has a major impact on in-stream watercourse habitats, and aquatic plants and animals. In many cases of channelisation, the natural watercourse has been straightened and deepened to drain water from low-lying, frequently inundated areas supporting sedgeland environments. This has completely changed the local ecology by reducing the level of soil moisture and frequency of flooding.

Plate 7.11 A section of watercourse that has been channelised in the Bundaleer and Freshwater Creek subcatchment

Sand and gravel extraction

In-stream sand and gravel extraction occurs along the Broughton River in the Yacka area. Extraction sites can become sediment traps and may lead to erosion as a direct result of the bed deepening.

Dams and weirs

Dams and weirs alter downstream flow regimes and, hence, sediment supply and transport. This impacts on natural geomorphic processes and alters the channel structure and form. These impacts need to be considered when constructing in-stream dams and weirs, which can also be barriers to the migration of fish and other aquatic animals.

Beetaloo reservoir traps virtually all of the sediment entering the dam and would reduce sediment supply and transport immediately below the dam (Brizga 2000a). Farm dams located throughout the catchment will have similar impacts on the small streams on which they are located: trapping sediment and altering the pattern of flows and sediment transport.

Large weirs on Bundaleer, Freshwater and Yakilo creeks were originally constructed as part of an aqueduct scheme to transport flow to off-stream storage in Bundaleer reservoir. These weirs impact on downstream flow regimes and are sediment traps (Plate 7.12). There is evidence of considerable sedimentation upstream of these three major weirs.

Plate 7.12 Bundaleer weir in the Bundaleer and Freshwater subcatchment: the bed level above the weir is significantly higher than below because of the amount of sediment transported from upstream and trapped by the weir. The weir is a significant barrier to fish migration.

7.4.2 LAND USE AND LAND MANAGEMENT PRACTICES

Past and present land use and land management practices adjacent to watercourses within the catchment have a direct and indirect impact on the health of the watercourses. The catchment was first settled through pastoral leases in the 1840s: pastoralism gave way to cereal agriculture in the 1860s. By the 1930s much of the catchment had been cleared of native vegetation (Sard 1996). This clearance was followed by intensive cropping and grazing with a resultant increase in rainfall runoff and rates of erosion. For example, Neil and Foggarty (in Sard 1996) estimated that the sediment yield from cultivated land, overgrazed pasture and pine plantations is 20 times that of an area of native forest while eroded catchments yield about 50 times the amount of sediment. Increased flows and larger floods associated with greater rainfall runoff and the removal of riparian vegetation resulted in dramatic increases in watercourse erosion and channel widening and deepening.

From 1870 to the 1940s the use of the wheat-fallow system, involving continuous cropping, stubble burning and intensively cultivated fallows of 9 to 10 months destroyed the soil structure and left soils exposed to wind and rain. The result was widespread, severe soil and gully erosion and greatly reduced crop yields. The damage is still evident in many areas of the catchment (West Broughton Soil Conservation Board 1992).

Farming practices altered during the 1940s and 1950s with the adoption of the ley farming system, involving rotation of crops with improved pastures (West Broughton Soil Conservation Board 1992). Contour banking to reduce erosion was introduced as a land management practice in the catchment from the mid-1940s. Contour banks slow overland flows and substantially reduce the susceptibility of the land to erosion, in turn reducing the silt transport into watercourses. The use of contour banking peaked in the period from 1978 to 1985 (C Rudd PIRSA pers comm). Soil conservation schemes initiated during this time addressed soil erosion issues in affected areas, for instance the Pisant Creek Group Conservation Scheme (Young et al. 1978).

Other land management practices that help manage soil erosion and surface runoff, such as stubble retention and minimum tillage, have steadily increased and are now used to some extent by most farmers in the catchment. These conservation farming practices have proven to be extremely effective in increasing resistance to water erosion and slowing surface runoff. For example, comparison of flood damage along Narridy Creek following similar large rainfall events 54 years apart showed that the damage caused in 1995 was minor compared to the extensive paddock erosion and gullying that followed the 1941 event (Moore 1995).

The results of the watercourse survey indicate that land use in areas adjacent to more than 95% of the surveyed watercourses in the catchment remains cropping and/or grazing. Horticultural practices were observed along 2% of the watercourses and urban development occurs along approximately 1%.

Most grazing properties allow livestock unrestricted access to a watercourse. This has a significant impact on watercourse vegetation and stream bed and bank stability (Plate 7.13). For example, grazed banks erode three to six times faster than ungrazed banks (Trimble 1994). Stock grazing prevents the regeneration and growth of native plant species and can promote high levels of weed invasion. Stock also affect water quality by increasing sediment load and turbidity due to bed and bank erosion, and the deposition of faecal material into the stream (Bell and Priestley 1998).

Where cropping is carried out right to the edge of the banks of the watercourse, this leaves no vegetation buffer to slow and filter surface runoff and trap sediment and nutrients from entering the watercourse (Plate 7.14). This increased rate of delivery of sediment and nutrients to the watercourse can cause sedimentation and smothering of aquatic habitats, poor water quality, and the excessive growth of reedbeds and nuisance plants.

Water quality impacts can arise from inputs of agricultural chemicals and urban stormwater. The use of fertilisers and pesticides for broad-scale agriculture across the catchment means that nutrients and other chemicals will always be present in the environment. These enter the watercourses dissolved in water, adhering to small soil particles or contained within plant and animal material, including manure (Pen 1999). These impacts are probably increased in areas where there is no riparian buffer strip to filter runoff.

Management strategies such as options for minimising soil erosion and surface runoff, livestock management and vegetated riparian buffer strips are discussed in Section 7.5.

Plate 7.13 Unrestricted stock access and overgrazing, such as along this watercourse in the Lower Rocky and Crystal Brook subcatchment, can increase the susceptibility of beds and banks to erosion. Grazing prevents regeneration of the watercourse vegetation.

Plate 7.14 Cropping to the edge of a watercourse, such as along this one in the Lower Rocky and Crystal Brook subcatchment, leaves no vegetated buffer to slow runoff and prevent the input of sediment, nutrients and chemicals from the surrounding paddocks.

7.4.3 REEDS — FRIEND OR FOE?

Anecdotal evidence from landholders suggests that common reed and bulrush reedbeds are more extensive than they have been in the past (Plate 7.15). Some concern was expressed that the excessive growth of these reeds has caused siltation and has obstructed the normal flow of the watercourse as well as decreasing the size of permanent pools and restricting stock access to good drinking water.

Plate 7.15 Common reed almost completely covers the in-stream zone of this section of a watercourse in the Lower Rocky and Crystal Brook subcatchment. Note the lack of any native shading riparian vegetation.

These species are a natural part of the river ecosystem. However, their excessive growth can be a symptom of past disturbance and/or poor land management. These species prefer fine sediment, high levels of nutrients and direct sunlight. Large amounts of topsoil and nutrients entering the watercourse from surrounding paddocks, sediment being deposited from upstream erosion, a lack of vegetative cover to shade the watercourse and decreased stocking rates provide an ideal environment for them to proliferate.

Management options for controlling reeds require a careful consideration of costs and benefits. Reeds do provide habitat for aquatic macro-invertebrates, frogs and birds. In addition, they stabilise the bed and banks of the watercourse and trap sediments preventing their release downstream. Reeds, rushes and sedges are native vegetation and their removal may require approval under the *Native Vegetation Act 1991*.

Revegetation can be an important long-term control method. Shading in the watercourse will be significant in controlling the growth of reedbeds. For example, stands of emergent macrophytes were shown to increase significantly at sites where the forest canopy cover was less than 50% (Canfield and Hoyer 1988). The burning and grazing currently used as short-term control methods can have negative impacts on the ecology of the river system. For example, waterbirds use reedbeds as nesting sites in spring to early summer, and the methods may simply encourage stronger growth the next year. Such active intervention can release trapped sediments as the vegetation binding the sediment is removed.

The growth of reedbeds in eroded areas can be a stage in the recovery process of the river system. In-stream vegetation helps stabilise the bed and banks of the stream by trapping sediment and decreasing flow velocities. Reedbeds are often a symptom of past erosion and over time can help stability and increase habitat diversity in degraded areas. Such change will occur over several, if not many, decades. The process may be enhanced by revegetating banks and floodplains, and undertaking river rehabilitation works.

7.5 Management strategies

Watercourses in the catchment have been significantly modified from their pre-European state. These changes, and community and production needs, mean it is not realistic to try to restore the catchment to pre-European condition. As far as possible, the goal of managing the watercourses should be to return the vegetation, structure, hydrology and water quality of the streams to a 'natural' state. Improving these elements will lead to improvements in the organisms living in, and relying on, the streams and to human needs and sustainable agriculture (LWRRDC 1999). This management goal also reflects the catchment community's vision for improving the river system (Chapter 4).

7.5.1 MANAGING AND REHABILITATING WATERCOURSE VEGETATION

Managing and rehabilitating watercourse vegetation can have many benefits, such as contributing to healthy riverine ecosystems, providing wildlife habitat, bed and bank stability, controlling nuisance plants and protecting water quality. In the catchment, management and rehabilitation is likely to require a combination of natural regeneration, revegetation, and grazing and weed management. Many aquatic and semi-aquatic species such as sedges, reeds and rushes will re-establish quickly and naturally once grazing pressure is removed and weeds controlled (Myers 1999). Native shrubs and trees are less likely to regenerate naturally and may have to be planted or seeded directly.

Revegetation and natural regeneration

Sound technical advice and a planned revegetation program are essential. Specific information on appropriate species and planning should be sought from the local revegetation officer. In developing a revegetation plan, the following factors should be considered in order to maximise benefits:

- Have a clear set of objectives for management — restoring habitat, reducing erosion, improving water quality or a combination of these — as different approaches may be required to achieve different objectives (LWRRDC 2000).
- An understanding of the original vegetation structure and composition is helpful in selecting appropriate species. In normal conditions, local indigenous species are often the most suitable for the site.
- Ensure structural diversity by planting a range of species, including aquatic plants, reeds, rushes, sedges, grasses, shrubs and trees in appropriate locations.
- Implement initial and ongoing weed and exotic tree control and grazing management practices.

- Select techniques appropriate for the site and resources such as natural regeneration, direct seeding or tubestock planting (LWRRDC 2000).
- Revegetate at least 10–15 m from the top of the watercourse bank as, generally, a minimum width of 10 m is required to effectively filter sediments and nutrients from catchment runoff.

In revegetating watercourses in the catchment, particular consideration must be given to the composition of the original vegetation. For example, it would not be appropriate to plant tree and shrub species if the original vegetation structure was a grassland. Where possible, indigenous plant species which occur naturally in an area should be used because of their intrinsic role in the river ecosystem. Native plant species will help to maintain or re-establish habitat for wildlife and protect stream banks from erosion. They are also better adapted to local conditions and have a higher survival rate. Planting indigenous species will help to preserve plant species that may be locally rare or endangered and provide new seed banks for local species (Carr et al. 1999). Map 5.3 describes the estimated pre-European distribution of vegetation associations and species throughout the catchment and is a useful guide for revegetation.

It is important to select the right plant for the right location within the riparian zone (Figure 7.1). Aquatic and semi-aquatic species, sedges, reeds and rushes play a critical role in bank stability by holding and protecting the toe of the bank. Native shrubs and grasses are found on the banks and floodplain. Larger trees should be planted on the upper banks and floodplain zone.

The bed and banks of a watercourse must be stabilised before attempting revegetation or vegetation management. At the same time vegetation can be part of the solution for erosion issues. Well planned revegetation, especially on the toes and mid-section of the bank can greatly assist in stabilising eroding channels.

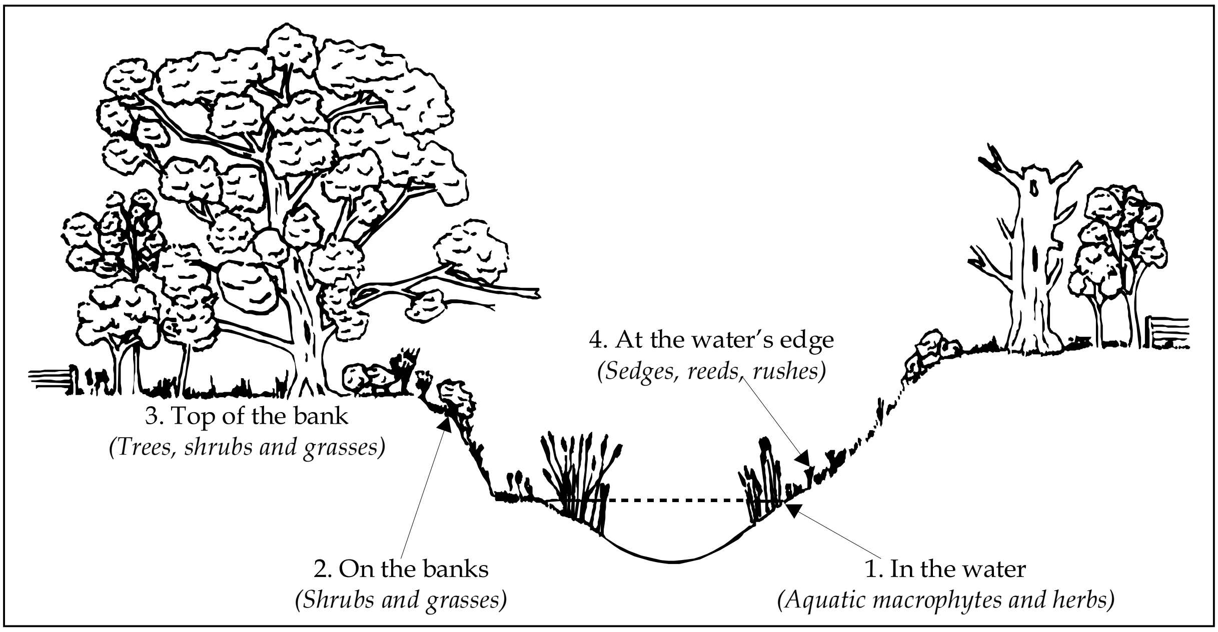


Figure 7.1 Planting zones for riparian vegetation

Weed management

Weed control and ongoing management is essential for protecting and maintaining a healthy riparian zone. Importantly, weed control should be linked with a program of revegetation. Where weed coverage is particularly dense it may be necessary to undertake a 2–3 year program of weed control before revegetation. Effective weed control is essential for establishing plants when revegetating (Carr et al. 1999). Weeds can be controlled by methods such as spot spraying and mechanical or hand removal. The technique chosen will depend on the type of weed species, the site and the density of the infestation.

Care should be taken when controlling or removing weeds. Where native vegetation is lacking, some weeds such as boxthorn can act as a refuge for small native birds. Care should also be taken not to initiate erosion when removing weeds by disturbing the bed or banks of a watercourse. To minimise impacts on aquatic flora and fauna, use only herbicides registered for use near watercourses (for example, Roundup Biactive®).

For dense infestations, the best strategy is to control or remove manageable sections over a period of time (as opposed to mass removal) followed by an organised program of revegetation. Advice should always be sought from the local animal and plant control boards on recommended methods of control.

Important ongoing weed management options over the long term include maintaining an intact native vegetation canopy to shade out weed species and preventing or minimising disturbance to the ground and riparian vegetation such as that caused by stock grazing. Minimising disturbance limits the opportunities for weeds to invade.

Exotic tree management

The control of exotic trees to prevent further invasion along the watercourse is important. Long-term planning is critical. Control strategies will vary depending on the type of species (ability to spread and cause damage), the density and extent of distribution, the site and the ease of removal. A small number of a highly invasive tree species may require immediate removal, while a large extent of densely growing trees would require a long-term and staged control program.

To maximise the environmental benefits of removing exotic trees, the trees should be replaced with suitable vegetation in a staged process. The mass removal of a heavy infestation of trees at one time can initiate erosion, increase light levels and water temperatures, and impact upon birds and animals that use the trees for their habitat. Time is required to establish native riparian vegetation.

Control methods will depend on the tree species. Methods include poisoning by injecting herbicide and then cutting down the tree when dead; cutting down the tree and immediately painting the stump with undiluted herbicide; or cutting down the tree, allowing the stump to reshoot and spraying the regrowth with herbicide. Only use herbicides recommended for use near watercourses. Timing is important; poisoning is most effective during the growing period from October to April.

Riparian buffer strips

Watercourse vegetation can be a buffer to slow runoff and trap sediment and nutrients. The effectiveness of vegetation depends on the width, the form of vegetation and the slope of the land (Pen 1999). For example, grasses and low shrubs are a more effective buffer than trees. Planting vegetated buffer strips 10–50 m wide has achieved nutrient filtration rates of

50–100% (Pen 1999). Buffer strips can be grazed as long as grazing is controlled to maintain groundcover and prevent damage to the soil surface.

Many areas in the catchment are cultivated and cropped right to the edge of the watercourse. A buffer strip of grasses along the watercourses in these areas could help to reduce sediment and nutrient loads substantially. The cultivation of shallow watercourses also has the potential to accelerate erosion and transport sediment and nutrients downstream. Maintaining a perennial cover of grasses would reduce this potential and promote filtration.

7.5.2 MANAGEMENT OF LIVESTOCK

Reducing or excluding livestock access can have a dramatic effect on the recovery of watercourse vegetation and channel stability. Long-term monitoring by landholders has indicated slow recovery within two years and significant recovery to a state approaching the natural state of the stream within eight years (Bell and Priestley 1998).

To lessen the impact of livestock grazing, the timing, duration and intensity of grazing along the watercourse needs to be controlled. Fencing and the provision of an alternative water supply are the most obvious means of control. Electric fencing is an inexpensive and low maintenance option. Where fencing is not possible the time stock spend in the riparian zone can be limited by, for example, locating alternative watering points away from the stream (Bell and Priestley 1998).

The fences should be located well away from the stream and parallel to the direction of flow. If this means large areas are excluded, controlled grazing management of the zone may be necessary, for example limiting the time spent in the zone and restricting grazing to late autumn–winter. Fences across the direction of flow are inevitable and there are several flood resistant fencing options, the simplest including suspension fences and drop down fences (Bell and Priestley 1998).

Some of the benefits of controlling stock access to the riparian zone are:

- reduced bed and bank erosion;
- better grazing management;
- healthier riparian environment;
- improved water quality; and
- improved recreation and aesthetic values (Bell and Priestley 1998).

Some of the disadvantages are the costs involved if a substantial length of fencing and the establishment of alternative watering points.

7.5.3 MANAGEMENT OF EROSION ISSUES

All erosion issues can be controlled but at a cost. Careful consideration should be given to the costs compared with the benefits that will be gained. Fencing to restrict stock and revegetation with local indigenous plants is often the most cost-effective means of controlling bed and bank erosion. Well-vegetated watercourses are much more resistant to erosion.

Vegetation alone may not be sufficient where erosion threatens a high value asset (such as an area of high conservation value or in-stream infrastructure), or the watercourse is very unstable or in an area with high flow velocities. In these situations complementary engineering solutions should be considered. It is important to understand the nature of the site and the erosion processes at work and to target management strategies appropriately.

For example, most bank erosion is associated with active erosion at the 'toe' of the bank. Control strategies need to target this location. If stream works are being considered to control erosion, it is important to seek professional advice and to be aware that council approval may be required.

Bank erosion should be controlled by dealing with the cause first, followed by stabilisation and protection of the bank. Stabilisation and protection can be achieved by revegetation and where necessary the use of soft engineering techniques such as alignment fences or rocks positioned at the base or toe of the bank.

Bank erosion control methods work by reducing flow velocities adjacent to the bank and increasing the erosion resistance of the bank. For example, in-stream and riparian vegetation reduces flow velocities by resisting flow and strengthens the bank by binding soil with root systems. Emergent aquatic plants can play an important role by binding soil and trapping sediment at the toe of the bank.

Depending on the severity of the erosion, erosion heads and bed erosion can be controlled with grade control structures and/or revegetation. The structures, such as rock chutes and drop weirs, halt the migration of the erosion head and stabilise the bed enabling in-stream vegetation to become established. In many cases minor bed erosion can be controlled through revegetation and allowing in-stream vegetation to regenerate.

Erosion heads can also be naturally controlled by becoming 'locked up' in control structures such as rock bars, bridges and fords or the root mass of trees. These structures act as a form of grade control, stopping movement of the erosion head upstream. In such cases, care must be taken when removing trees or repairing in-stream structures to avoid triggering a new episode of bed deepening.

7.5.4 LAND MANAGEMENT PRACTICES

Watercourse management cannot be viewed in isolation from land management practices within the catchment; the two are inseparable. Significant soil surface management improvements such as contour banking, stubble retention, minimum tillage and improved pasture management practices throughout the catchment since the late 1970s have reduced the rates of surface runoff and soil loss. This has also reduced the amount of flood flows and sediment, nutrients and pollutants entering the watercourses.

Management practices aiming to minimise the volume and rate of surface runoff from a paddock should continue to be implemented. Ideally these should be implemented with practices such as riparian buffer strips that slow runoff and trap sediment and nutrients. Options for minimising surface runoff and sediment and nutrient loads to watercourses are outlined in Table 7.5.

Table 7.5 Management options for minimising surface runoff and sediment and nutrient loads to watercourses

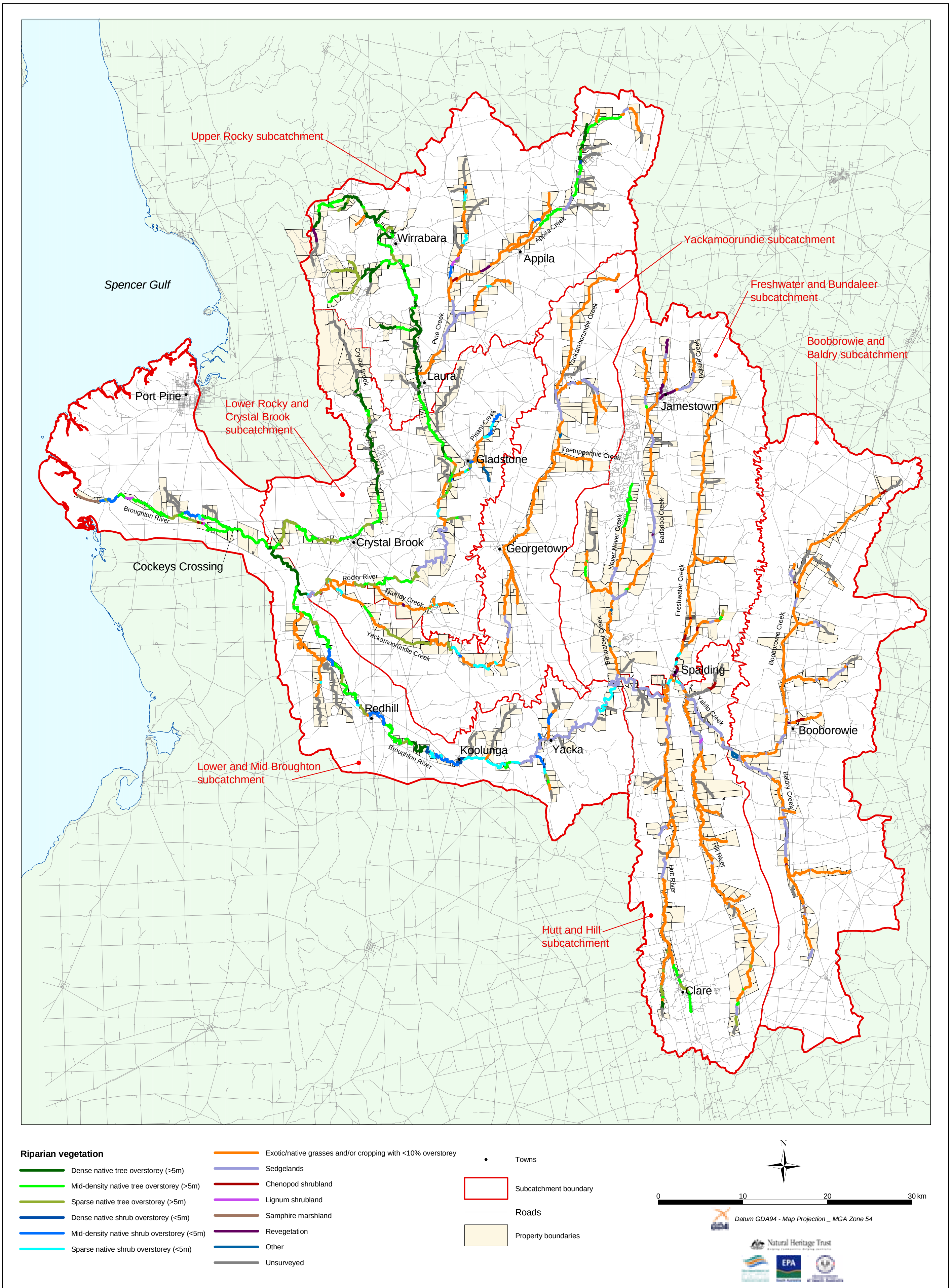
Agriculture	Management options
Cultivation	• contour banks, minimum tillage and stubble retention • direct drilling • grassed waterways • vegetated riparian buffer strips
Pasture	• maintain good pasture cover at all times • direct drill deep rooted perennial pasture species

7.6 Summary

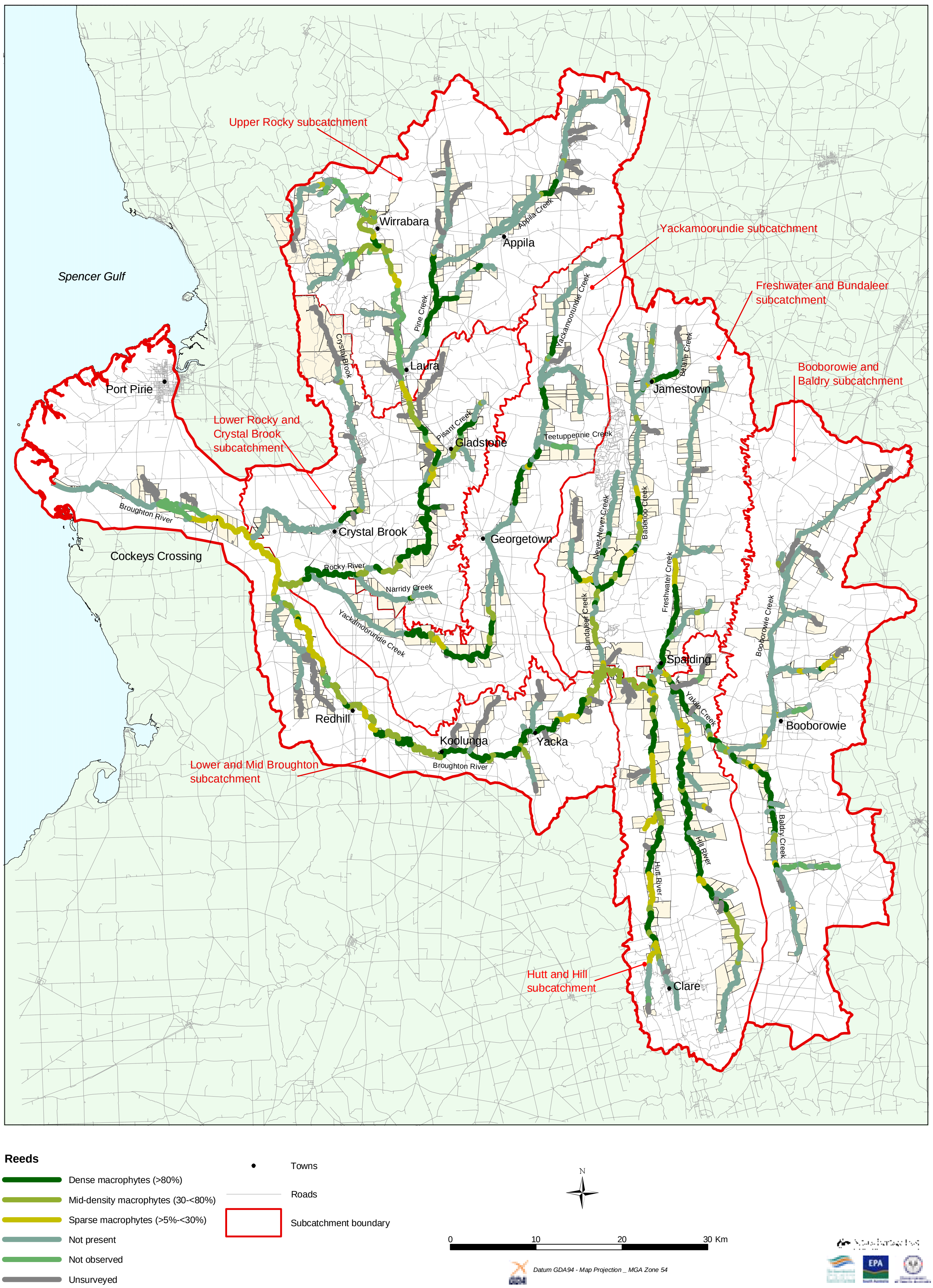
The survey of watercourse condition across the catchment has identified a number of significant management issues that require active management intervention. An overview of general management strategies required to address these issues has been provided. Any on-ground rehabilitation activities will need to be guided by an appropriate management approach based on local conditions and the particular site or issue being addressed.

The key watercourse management requirements for the catchment may be summarised as follows:

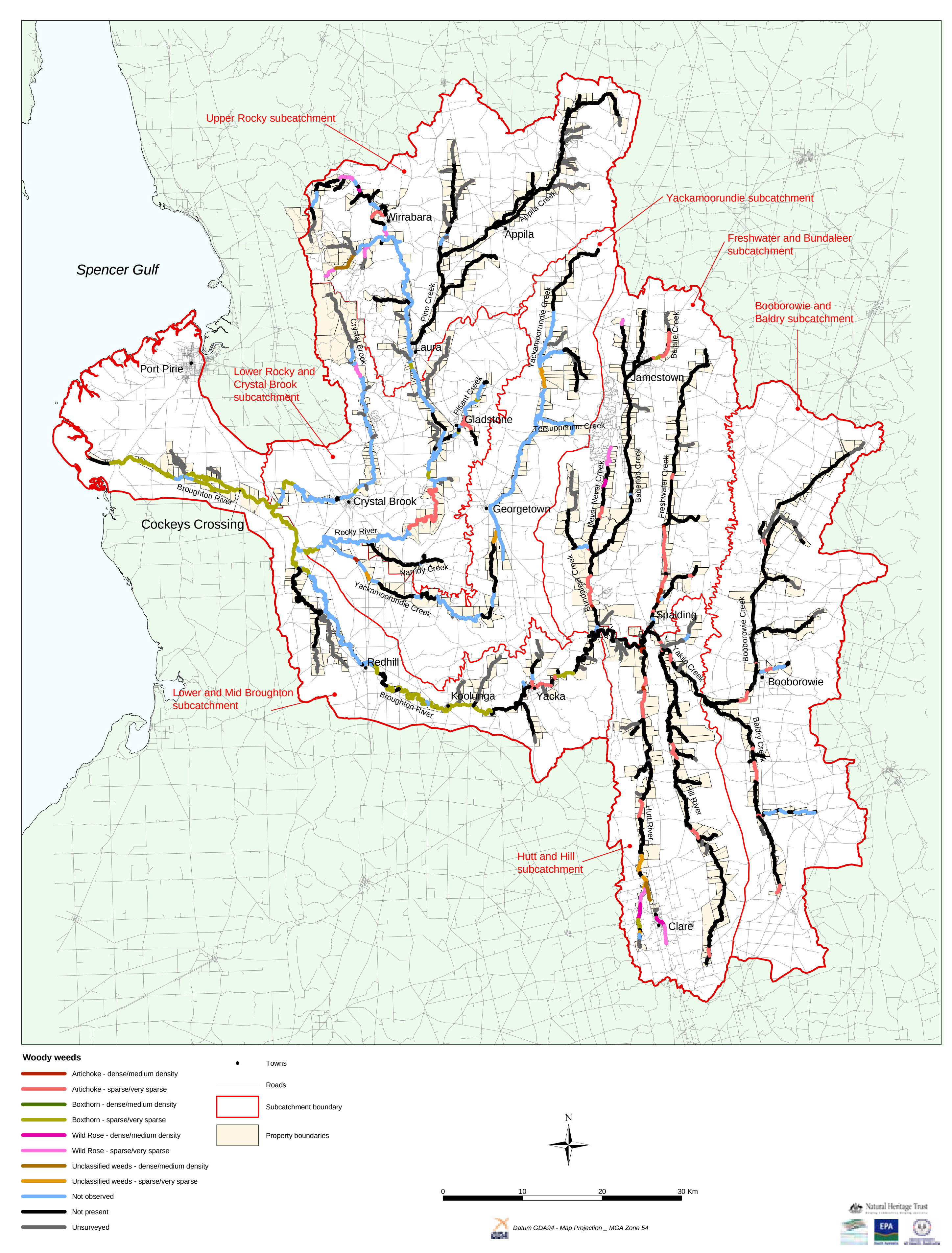
- protecting and enhancing areas of important riverine habitat and remnant vegetation and regular monitoring of these areas to assess condition;
- re-establishing locally indigenous native vegetation by revegetation or encouraging regeneration;
- reducing grazing pressure on in-stream and riparian zones;
- controlling invasive and dense infestations of weeds and exotic trees, particularly if adjacent to an area of remnant vegetation or important riverine habitat;
- replacing weeds and trees with locally indigenous watercourse vegetation;
- establishing native watercourse vegetation to protect bed and banks from erosion;
- using riparian buffer strips to reduce sediment and nutrient delivery to watercourses;
- monitoring erosion heads and areas of poor bank stability to assess if they are still actively eroding and whether they threaten upstream or downstream assets;
- undertaking erosion control works where erosion is severe and threatening high value assets;
- using professionally designed in-stream structures, channelisation or alteration of watercourses that account for the water regime, channel stability and ecology of the watercourse; and
- implementing land management practices, such as contour banking, minimum tillage and improved pasture management, that minimise surface runoff and prevent erosion.



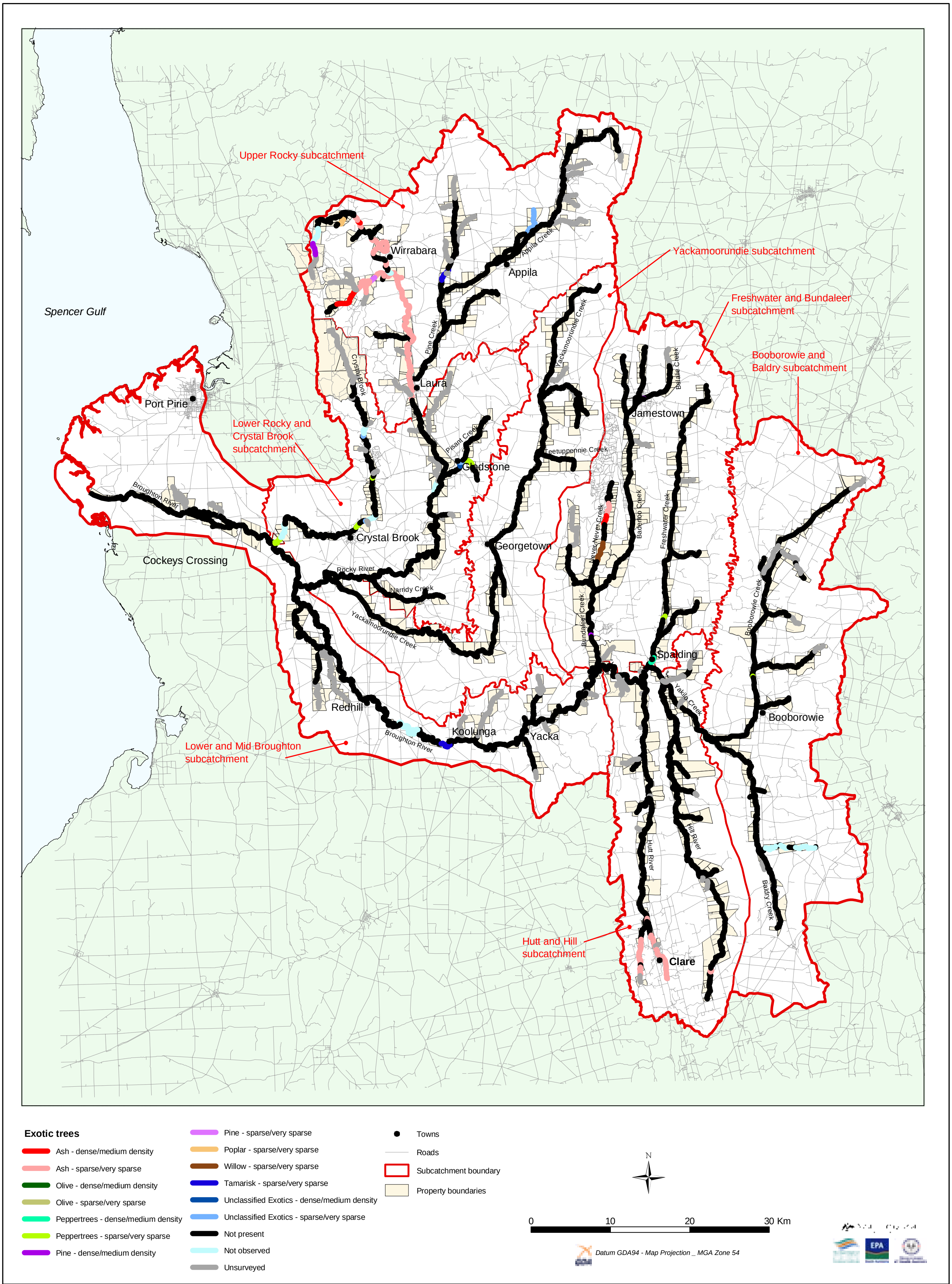
Map 7.1: Distribution and density of riparian vegetation in the Broughton catchment



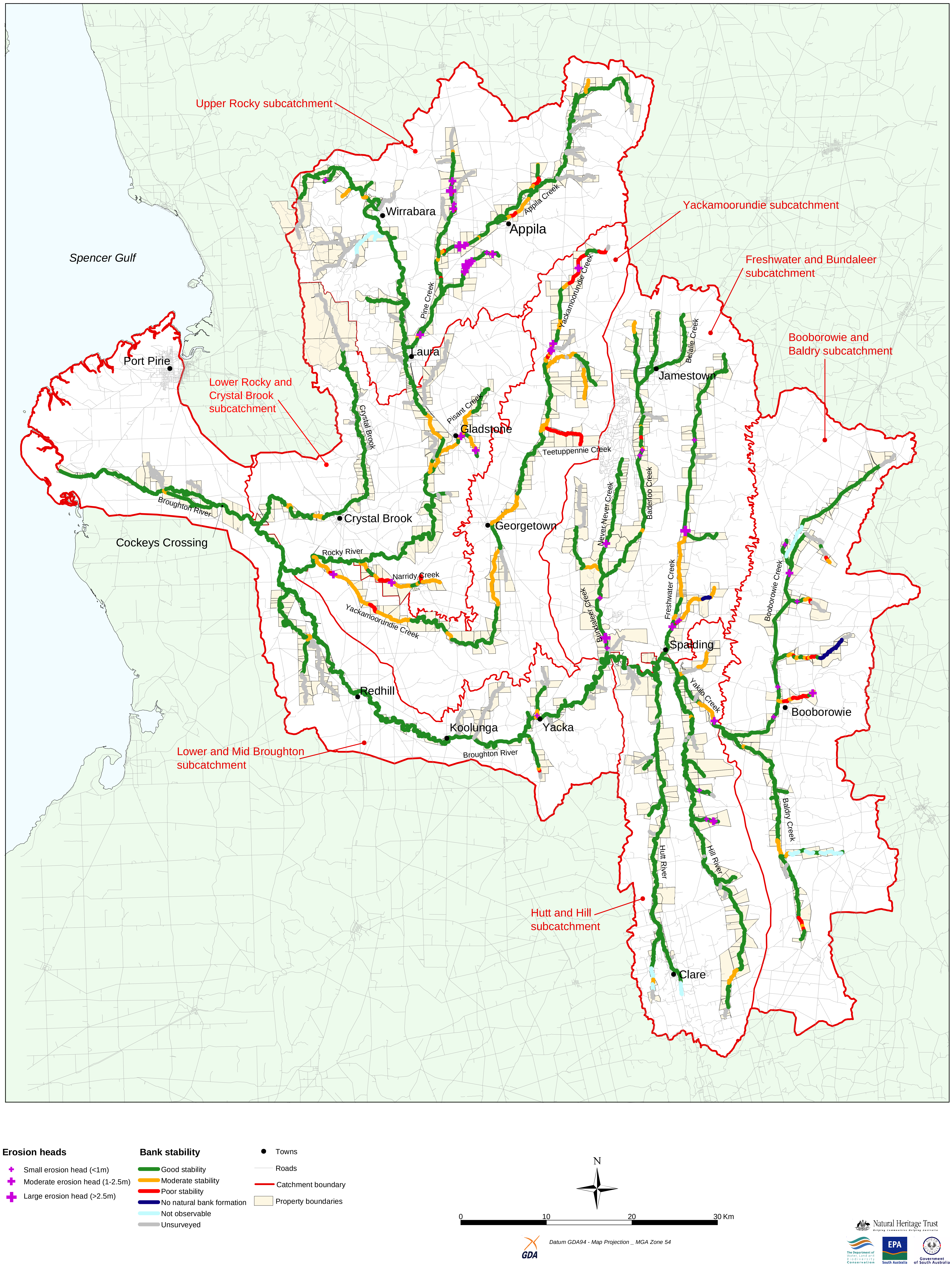
Map 7.2: Extent of reedbeds along watercourses of the Broughton catchment



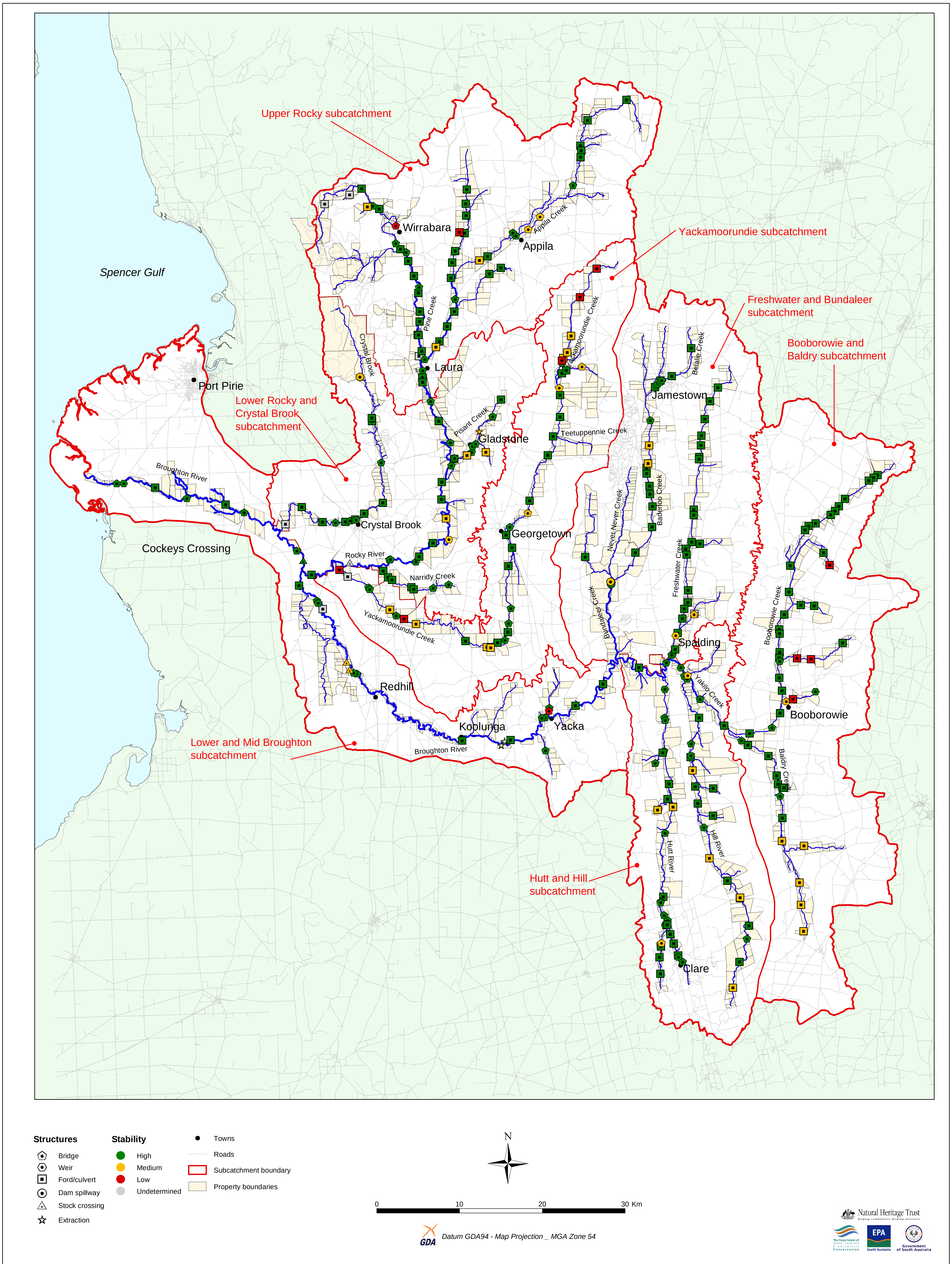
Map 7.3: Distribution and density of riparian weeds in the Broughton catchment



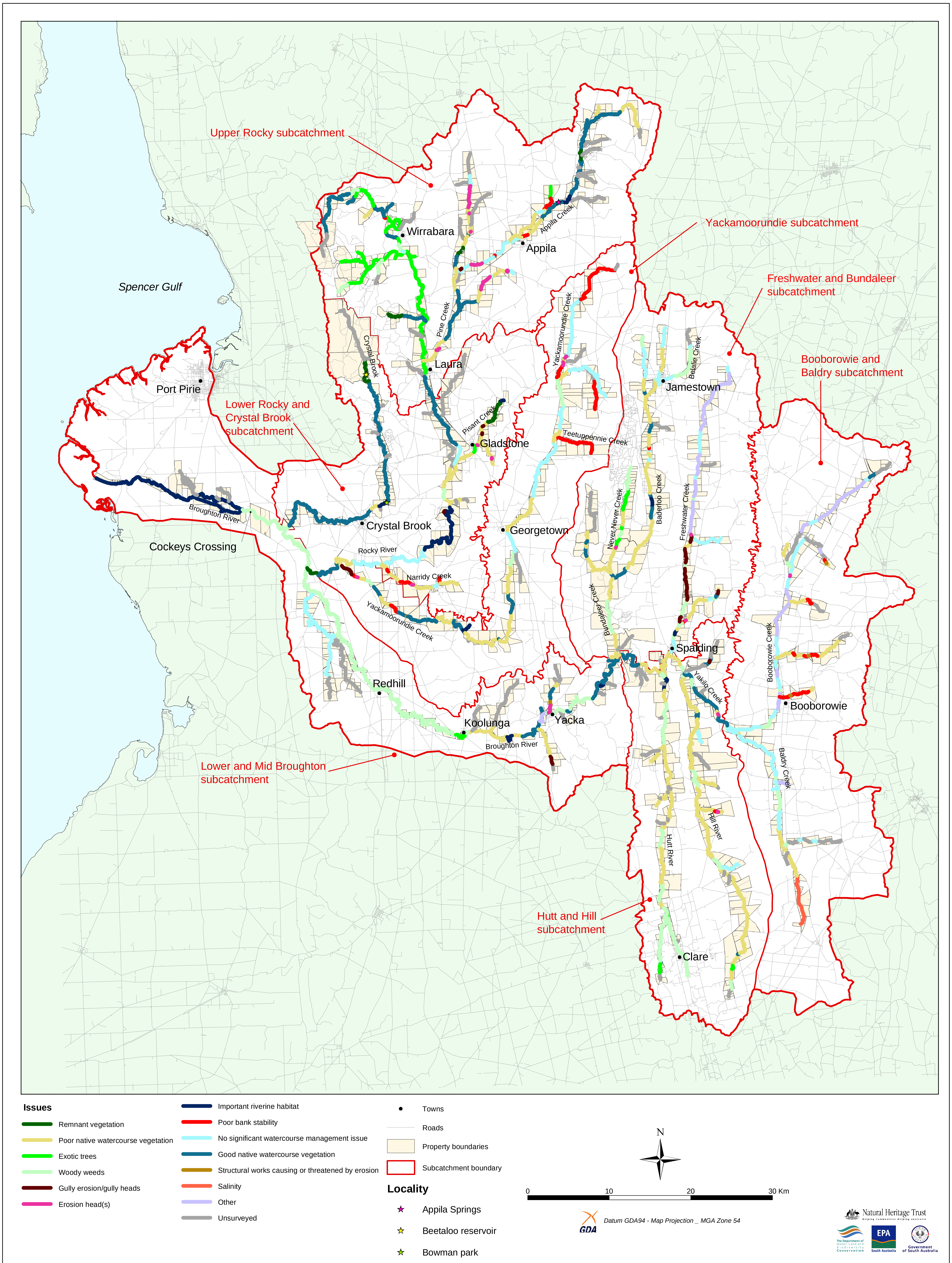
Map 7.4: Distribution and density of exotic trees along watercourses of the Broughton catchment



Map 7.5: Bank stability and erosion heads along watercourses of the Broughton catchment



Map 7.6: Location and stability of structural works in the Broughton catchment



Map 7.7: Significant watercourse management issues in the Broughton catchment

CHAPTER 8 THE LOWER AND MID BROUGHTON SUBCATCHMENT

8.1 Introduction

This chapter discusses the watercourse management and environmental water requirements for the Lower and Mid Broughton subcatchment. The key water dependent physical and ecological environments and processes for the river geomorphic zones within this subcatchment are described. This includes the vegetation, fish and macro-invertebrates in the area. The important flow bands needed to maintain the environments, processes and associated plants and animals are described for each zone. Appendix E contains a more detailed description of the environmental water requirements including recommended frequency, duration and seasonality of flows.

The chapter describes key management issues that impact on the watercourse environments and outlines the environmental water requirements of these environments. The priorities and strategies for watercourse management based on the input of landholders and the results of the survey of watercourses in the subcatchment are tabled. The chapter closes with a discussion of information gaps and monitoring needs that have been highlighted by the project.

The Broughton River starts at the confluence of the Hill River and the Yakilo Creek and flows westward to enter Spencer Gulf at Port Davis. The river passes the towns of Spalding, Koolunga, Yacka and Redhill. Below Spalding it flows through a gorge in the Yackamoorundie Range. The river valley widens upstream of Yacka, but there is a short gorge-like section approximately 2 km downstream of Yacka. An important change in the river's character occurs near Koolunga where the river emerges onto an alluvial plain. The change in geomorphology is accompanied by a change in riparian vegetation: river red gums (*Eucalyptus camaldulensis*) become dominant in the riparian zone. The catchment area increases markedly at the confluence with the Rocky River which is the main contributor of flows and sediments from the northern part of the catchment.

The Lower and Mid Broughton subcatchment includes Broughton River downstream of its junction with Bundaleer Creek.

The river in this subcatchment can be divided into the Broughton River delta and Broughton River upstream of the delta. These two areas can be further divided into six river geomorphic zones on the basis of river channel form and hydrology (Map 5.2; Section 5.2):

Broughton River delta

- Zone 1 — Broughton estuary
- Zone 2 — non-tidal section of the delta

Broughton River upstream of the delta

- Zone 3 — upstream end of the delta to Rocky River
- Zone 4 — Rocky River to downstream of Koolunga
- Zone 5 — downstream of Koolunga to upstream of Yacka
- Zone 6 — upstream of Yacka to the confluence of Hill River and Yakilo Creek (see also Chapter 9 on the Hutt and Hill subcatchment).

The dominant land use within this subcatchment is cropping and grazing and currently water resource development is limited.

8.2 *Water dependent ecosystems and processes*

8.2.1 FISH

Native fish species found in the Broughton River estuary include yellow-eyed mullet (*Aldrechetta forsteri*), hardyhead (*Atherinosoma microstoma*), congolli (*Psuedaphritis urvilli*) and blue spot goby (*Psuedogobius olorum*) (Hicks and Sheldon 1999). Congolli is a marine species mainly that, as a strong migrating species, commonly moves into freshwater. Given connecting flows, congolli could colonise large areas of the Broughton River system. They prefer to migrate from freshwater to the estuary to spawn. Blue spot gobies are found in freshwater but can also migrate to estuaries to spawn. Yellow-eyed mullet and hardyheads are primarily estuarine species.

Native fish recorded in Broughton River upstream of the delta include mountain galaxias, blue spot goby and congolli. Native fish numbers were low. Exotic species recorded include goldfish (*Carassius auratus*) and eastern gambusia (*Gambusia holbrookii*) (Hicks and Sheldon 1999). Blue spot gobies prefer slow moving water with a good growth of submerged macrophytes. The preference of blue spot gobies and congolli to migrate to the estuary to spawn is not a definitive part of their lifecycle. Mountain galaxias (*Galaxias olidus*) are a wholly freshwater species that prefers cooler waters and move from pool habitats to riffles to spawn. They fare poorly from predation and competition by trout when they coexist. Chapter 5 has further information on the fish of the Broughton catchment.

It is possible that the construction of works along the Broughton River may inhibit fish migration. For example, a small crossing downstream of Cockeys crossing acts as a weir and produces a permanent pool that extends for approximately 4 km upstream. The crossing may be high enough to impact upon fish migration from the estuary. More investigation is necessary to determine the impact of such structures on fish migration in the river.

The river is stocked annually with trout. The area between the river’s junction with Hutt River down to Redhill is the primary area for trout. The impact of the distribution of trout on native fish is not known.

8.2.2 MACRO-INVERTEBRATES

A study by Madden et al. (1999) indicated that the Broughton River is relatively healthy for macro-invertebrates. Sites in Zone 6 had higher numbers of species than expected, while Cockeys crossing (Zone 2) was classified as mildly impaired, possibly because the deep pools provide poor quality habitat.

Invertebrates with unusual or restricted distributions were found in the river. These include: bristle worms (Polychaeta) which are not usually found in freshwater habitats; a moth from the family Pyralidae that is generally found in wetlands with dense stands of reeds; and a species of caddisfly (*Lingora aurata*) which is typically found in cool, flowing streams. Other species that typically require flowing water were also recorded, including mayflies, dixid midge larvae and amphipods from the family Eusiridae. A freshwater shrimp that likes slow-moving, protected areas was collected at Cockeys crossing.

The health and diversity of macro-invertebrate species in the river is due to the presence of permanent groundwater dependent flows. Many species such as caddisflies (*Cheumatopsyche* sp.) require flow for feeding and the continual discharge is important for maintaining water quality.

8.2.3 BROUGHTON RIVER DELTA

A delta is a depositional landform created by a river depositing sediment into a receiving waterbody. The Broughton River delta begins a short distance downstream of Cockeys crossing and fans out towards the coast where it extends in breadth from south of Deep Creek to Port Pirie. Spencer Gulf is the receiving waterbody for the river.

Zone 1

Geomorphology and hydrology

Zone 1 (the Broughton estuary; Map 5.2) is characterised by tidal flows, and mangrove-fringed channels bordered by saline coastal flats. There is no freshwater baseflow. Freshwater inputs to the estuary only occur during medium and high flows. Local landholders indicate that in large floods the flows spread extensively across the delta surface and discharge to the sea via several tidal channels and not just by the main tidal channel of the Broughton River (Plate 8.1).

Human activities since European settlement do not appear to have significantly altered the river channel shape, form and structure in this zone. Catchment erosion, including erosion of tributary streams, may have led to elevated sediment inputs. A jetty at Port Davis is the only infrastructure development in this zone.

Plate 8.1 The Broughton River estuary at Port Davis, Zone 1: the estuary is characterised by shallow deposition, tidal flows and mangrove-fringed channels bordered by saline coastal flats.

Vegetation

The largely intact vegetation communities include mangrove (*Avicennia marina*) forests along the river channel and samphire (*Sarcocornia* sp., *Halosarcia* sp.) marshes on the tidal flats.

Seagrass is present in the tidal channel. These mangrove forests provide important breeding grounds and habitat for fish, birds and macro-invertebrates, and protect the coastline from the erosive influence of the marine environment. Samphire marshes provide organic matter to the estuary food chain, filter sediment from land-based runoff and are important habitat for insects, small vertebrates and birds (Rose and McComb 1995; Department of Land and Water Conservation 1992).

Although the distribution of samphire marshes is largely influenced by tidal inundation, river flooding also plays a role (Murray et al. 1995). These areas are reliant on the nutrients, organic matter and silt that originate higher up in the Broughton catchment. Regular seasonal flows are required to convey the sediment which maintains the mudflats that support the mangrove forests and organic matter. This provides a valuable food source for estuarine plants and animals.

Important flow bands

- *Mid flows* are important for connecting the estuary to the freshwater reaches of the river and for the migration of native fish species between these environments.
- *High flows* spread across the low-lying areas of mangrove forests and samphire swamp. These flows are important for the migration and breeding of native fish, the creation of aquatic habitats and the transport of sediment, nutrients and organic matter from the catchment to the estuary.
- *Overbank flows* are important for inundating the riparian zone and as a cue for the large-scale migration and breeding of native fish. They also transport sediment, nutrients and organic matter and maintain channel geomorphic processes.

Zone 2

Geomorphology and hydrology

The river in Zone 2 (the non-tidal section of the delta; Map 5.2) is characterised by a network of small streams, anabranches and flood runners. The river divides into a northern and a southern channel approximately 1.5 km downstream of Cockeys crossing. The southern channel began to form when a weir was constructed on the original channel in the late 19th century. The original weir was replaced by sluice gates in the 1930s, which are still used to regulate flow to either channel. The southern channel is well defined at its upstream and downstream ends; in between lies a lignum (*Muehlenbeckia florulenta*) swamp area with some ill-defined channels that becomes inundated when the river is about half-full at Cockeys crossing. The river becomes a single channel again at Butlers Bridge before dividing again further downstream where it flows through sand dune country.

The upper reaches of the river in Zone 2 appear to have continuous baseflow but this is lost to groundwater approximately 3 km downstream of Cockeys crossing. Physical habitats include pools, riffles (when flows occur), anabranches, flood runners and floodplains. The river is about 8 m deep at the Cockeys crossing bridge and gradually diminishes in size downstream from this point. Landholders reported that large flood events typically break out near O'Shaughnessys bridge and begin to spread widely from each side of the river below Cockeys crossing.

Human activities have altered the river channel shape and form in this zone. The biggest impact has been from the irrigation works constructed to divert and spread floodwater, including weirs, sluice gates, diversion channels and levee banks. Catchment erosion upstream, including incision of tributary streams, may have led to elevated sediment inputs.

The river system flows intermittently to the sea. Anecdotal evidence suggests that widespread flooding across the coastal plain, which then discharged to the sea through tidal channels, occurred in the 1937, 1941, 1974 and 1992 floods. P Clarke (pers comm 2000) indicates that smaller connecting flows to the sea have occurred on three occasions in the last four years. Nonetheless, there are long periods with no connection; there has been no connection for the last 18 months (P Clarke, pers comm 2000).

Vegetation

Zone 2 is characterised by river red gum forests with an understorey of lignum and Broughton willow (*Acacia salicina*) along the stream channel, and lignum and saltbush shrublands (swamps) along the floodplain (Plate 8.2). Lignum swamps are an important habitat for animals and in times of flood they provide important breeding and habitat areas for birds, fish and macro-invertebrates. Lignum tends to be abundant in low-lying areas that are subject to flooding every three to ten years. Lignum is dependent upon flooding events to sustain growth and trigger flowering and seed set (Craig et al. 1991; Lloyd 2000). This unique swamp habitat is a high priority for management and protection, in particular maintenance of the flooding regime.

The in-stream vegetation is sparse with common reed (*Phragmites australis*) being the dominant species. Boxthorn (*Lycium ferocissimum*) and wild artichoke (*Cynara cardunculus*) are significant weeds in this zone.

Plate 8.2 Lower reaches of Broughton River, Zone 2 showing river red gums along the main river channel in the background and the lignum and saltbush shrublands along the floodplain in the foreground

Important flow bands

- *Baseflow* is driven by groundwater and in this zone flows constantly for most of the year. This flow increases as evaporation decreases and soil moisture increases in the winter months. It is extremely important for maintaining permanent aquatic habitats such as pools and aquatic vegetation.
- *Low flows* tend to have a long duration and are particularly important in this zone for the breeding and recruitment of native fish and frogs, especially if they follow a mid flow event. They are also important for maintaining aquatic plants and for increasing the area of aquatic habitat available.
- *Mid flows* are particularly important for maintaining the lignum swamp habitat. This band is therefore a key flow for breeding of native fish, frogs and macro-invertebrates. Mid flows are an important minimum flow for the migration of fish between the estuarine and freshwater environments and for geomorphic processes such as sediment transport and bank erosion.
- *High flows* tend to be bankfull flows within the upper reaches of the zone and flood out onto low-lying areas in the lower reaches. These flows are important for maintaining the lignum swamp habitat. They are particularly important for transporting organic matter and sediment to the estuary and for the migration of fish between the estuarine and the freshwater environments. They also maintain important geomorphic processes such as scouring of pools and channel formation.

8.2.4 BROUGHTON RIVER UPSTREAM OF THE DELTA

Zones 3 and 4

Geomorphology and hydrology

In Zone 3 (upstream end of the Broughton River delta to Rocky River; Map 5.2) the river is bordered by alluvial plains and the channel is deep (≥5 m). In this zone there is perennial baseflow and the in-stream physical habitat includes permanent pools, riffles and reedbeds (Plate 8.3). Upstream catchment erosion, including incision of tributary streams, may have led to elevated sediment inputs. Landholders' comments indicate that in the early 20th century floods occurred that silted up part of the river.

In Zone 4 (Rocky River to downstream of Koolunga, Map 5.2), the river is bordered by a broad floodplain and the channel is deep (≥5 m). In this zone there is perennial baseflow and the in-stream physical habitat includes permanent pools and reedbeds. Catchment erosion, including erosion of tributary streams, may have led to elevated sediment inputs to this section of the river. Traces of a pre-historical anabranch downstream of Redhill and a horseshoe-shaped depression formed by a meander cutoff near Merriton are evidence of major pre-historical changes to the river channel.

Vegetation

Zones 3 and 4 lie within a floodplain environment. They are characterised by a dense to mid-dense coverage of river red gums with an understorey dominated by Broughton willow. The river red gums are dependent on flooding for recruitment, maintenance and establishment. They are either isolated large trees or are restricted to a narrow zone of mature trees along the riverbank. It appears that grazing is having an impact on the regeneration of young tree species. Understorey shrubs and grasses have also been impacted by grazing and weed invasion. Key riparian weeds species in these zones include boxthorn, which is widespread, and wild artichoke.

Plate 8.3 Broughton River at Cockeys crossing, Zone 3: the zone is characterised by a deep channel bordered by broad alluvial plains. There is perennial baseflow through this zone and in-stream physical habitats include permanent pools and reedbeds. The river in Zone 4 has similar characteristics.

The depth of permanent water in these zones restricts the growth of emergent aquatic plants to the edges of pools or shallow riffles and runs, and coverage varies from 5% to 80% of the in-stream zone. The common reed (*Phragmites australis*) and bulrush (*Typha* sp.) are the dominant species.

Important flow bands

- *Baseflow* is driven by groundwater and flows constantly for most of the year. The flow increases as evaporation decreases and soil moisture increases in the winter months. Baseflow is extremely important for maintaining permanent aquatic habitats, aquatic vegetation and water quality.
- *Low flows* are important for developing and recruiting fish, and the local migration of fish and macro-invertebrates. They also maintain water quality and emergent aquatic plants, and increase the area of aquatic habitat available for plants and animals.
- *Mid flows* are important for fish breeding and migration; they increase the amount of habitat available for fish to breed. The flows are important for transporting sediment, nutrients and organic matter and for maintaining water quality.

- *Bankfull and overbank flows* that inundate areas of the floodplain are important for river red gum recruitment and maintenance. The flows are important for geomorphic processes such as scouring of pools and maintaining natural channel-forming processes.

Zone 5

Geomorphology and hydrology

In Zone 5 (downstream of Koolunga to upstream of Yacka; Map 5.2) the river flows in a more defined valley than in Zone 4. The valley width varies considerably but is generally wider than in Zone 6. There is perennial baseflow and in-stream physical habitats include permanent pools and reedbeds (Plate 8.4) (Brizga 2000a). Near Yacka the river is different to the rest of the zone — a wider valley floor is occupied by extensive reedbeds. In the remainder of the zone, the valley floor is narrower and the river channel more defined, although extensive reed beds still occur. In-stream sand and gravel extraction in this zone has impacted on the structure and form of the river channel (Brizga 2000a).

Plate 8.4 The Broughton River at White Cliffs, Zone 5: the river is confined within a defined valley. The physical features in this zone are baseflow, permanent pools and reedbeds.

Significant changes in channel morphology appear to have occurred at Yacka. Photographs from the late 19th century show that the channel had a bare gravel bed near the railway bridge (Alley 1967). Anecdotal information suggests that the river once had large, deep pools in areas where today the bed is covered by dense growth of emergent aquatic plants (reedbeds). Photograph evidence indicates that the reedbeds were present in 1967 (Alley 1967).

The width of the valley indicates that the area at Yacka is a natural deposition zone and there is evidence of sedimentation. However, it is difficult to determine whether the late 19th century gravel beds or the extensive reedbeds of today are the natural state. Further investigations are necessary to clarify the natural condition and the chronology of change and its causes.

Vegetation

The watercourse vegetation in Zone 5 is different from Zone 4. Zone 5 is characterised by native shrublands of Broughton willow, native myrtle (*Myoporum montanum*) and elegant wattle (*Acacia victoriae*), and sedgelands of rushes *(Juncus kraussi, Bolboschoenus caldwelli)* and sedges *(Cyperus* sp.). The sedges and rushes are typically located on benches and banks and sedgelands begin to dominate the system about 5 km downstream of Yacka. The in-stream zone contains extensive reedbeds (covering greater than 80% of the in-stream zone) dominated by common reed and bulrush.

The reason for the absence of river red gums along the river in this zone is not known but it may relate to the flooding regime. Flows in this zone are largely confined to within the river channel whereas in downstream zones overbank flooding is more common. The changes in vegetation and flooding regimes are distinct differences between Zones 4 and 5.

Watercourse vegetation throughout Zone 5 has been modified to varying degrees by grazing, weed invasion and catchment erosion. In some reaches grazing and cropping extends to the edge of the watercourse and stock have access to the river bed. The extent of reedbeds may have increased historically because of elevated sediment levels.

Important flow bands

- *Groundwater* maintains soil moisture and permanent pools where the groundwater table intersects the river bed. This is important in the Yacka area for maintaining the extensive reedbeds along the river.
- *Baseflow* is driven by groundwater and flows constantly for most of the year. The flow increases as evaporation decreases and soil moisture increases in the winter months. Baseflow is extremely important for maintaining permanent aquatic habitats such as pools, riffles and vegetation, and for maintaining water quality.
- *Low flows* are important for the recruitment of fish and for the breeding and recruitment of frogs. They also maintain water quality and emergent aquatic plants (reedbeds), increase the area of aquatic habitat available and support the local movement of fish and macro-invertebrates.
- *Mid flows* are important for fish breeding and migration; they increase the amount of habitat available for fish to breed. The flows are important for removing sediment from riffle environments, for transporting sediment, nutrients and organic matter, and for maintaining water quality.
- *Bankfull and overbank flows* that inundate areas of the floodplain are important for recruiting and maintaining riparian shrubland vegetation. The flows are important for geomorphic processes such as scouring of pools and maintenance of natural channel-forming processes.

Zone 6

Geomorphology and hydrology

Zone 6 (upstream of Yacka to the confluence of the Hill River and Yakilo Creek; Map 5.2) is characterised by the gorge that the Broughton River has cut through the Yackamoorundie Range. There is perennial baseflow through this zone and in-stream physical habitats include permanent pools, reedbeds, rock bars and boulder riffles (Plate 8.5). The river is bordered by a narrow floodplain of variable width. Catchment erosion, including erosion of tributary streams, may have raised sediment inputs in this zone.

Plate 8.5 The Broughton River at Mooroola gauging station, Zone 6: in this zone the river cuts a gorge through the Yackamoorundie Range. The zone's features are perennial baseflow, rock bars and boulder riffles, permanent pools and reedbeds.

Vegetation

Watercourse vegetation throughout the zone is characterised by sedgelands with or without a sparse native shrub overstorey. The sedgelands include extensive reedbeds (covering more than 80% of the in-stream zone) dominated by common reed and bulrush associated with sedges and rushes such as *Juncus kraussii*, *Bolboschoenus caldwellii* and *Cyperus gymnocaulus*. Native shrub overstorey present along the banks includes common species such as Broughton willow and lignum. Native grasses are also present throughout this zone.

Watercourse vegetation throughout the zone has been modified to varying degrees by grazing and weed invasion. In some reaches, grazing and cropping extends to the edge of the watercourse. The extent of reedbeds may have increased historically due to elevated sediment levels.

Studies of pre-European vegetation suggest that the original vegetation in Zone 6 was an open forest dominated by Broughton willow and river red gum (Brown and Kraehenbuehl 2000). A tall open shrubland of elegant wattle and native myrtle is likely to have been the typical vegetation on the slopes leading away from the watercourse.

A significant proportion of the zone was considered important riverine habitat for fish, birds, frogs and macro-invertebrates. There is a diverse range of vegetation, including shrubs, native grasses and groundcovers, and submerged and emergent aquatic vegetation. For example, the highest emergent aquatic plant richness (reeds, sedges and rushes) recorded in the catchment by the macro-invertebrate survey was in this zone at the Mooroola gauging station (12 species) and Frome Crossing (11 species) (Madden et al. 1999).

Important flow bands

- *Groundwater* maintains soil moisture and permanent pools where the groundwater table intersects the river bed. This is vitally important in this zone for maintaining permanent pools and baseflow, and supporting the diversity of aquatic plants and animals. The soil moisture supports the riparian sedgelands and in-stream reedbeds.
- *Baseflow* in this zone is permanent and is important for maintaining permanent pools, reedbeds and flow over riffles. The seasonal increase in baseflow in winter–spring is important for recruiting fish and increasing the area of habitat available for macro-invertebrates.
- *Mid flows* are important for native fish breeding; they increase the amount of habitat available for fish to breed. The flows are important for the local migration of native fish and macro-invertebrates, and for maintaining water quality.
- *Bankfull flows,* depending on their duration, are important for inundating the floodplain, and for recruiting and establishing riparian and floodplain vegetation. The flows are important for transporting sediment and other geomorphic processes, removing sediment from riffle environments and maintaining natural channel-forming processes.
- *Catastrophic flow* or large flood events are important for recruiting and establishing floodplain vegetation, scouring pools, major structural channel change and resetting of habitats.

8.3 Management issues

Landholders in the Lower and Mid Broughton subcatchment were very concerned with the lack of flows along the Broughton River and, as a consequence, poorer water quality. This affects not only the riverine environment but also the landholders' ability to use river water for both livestock and flood irrigation. Water resources for irrigation further upstream in the Clare Valley area and the impacts of this development on downstream flows are important issues. Other management concerns raised included weeds, excessive reed growth, increased algal blooms over summer, stock management along the river and pollution (rubbish in the river, chemical and fertiliser use, and town effluent).

To maintain the health of the river system in this subcatchment, the environmental water requirements must be met and other watercourse and land management issues addressed.

8.3.1 ISSUES AFFECTING ENVIRONMENTAL WATER REQUIREMENTS

Water resource development

Water resource development in the subcatchment is limited. Along the lower Broughton River some floodwaters are used opportunistically for irrigating pasture, lucerne and other crops. Some river water is pumped for irrigation but this is limited to periods where the salinity of the river is low, often during high flow events.

Since the late 19th century, landholders have been diverting and regulating flows along the lower reaches of the river for flood irrigation. Sluice gates, embankments, weirs and diversion channels have been used extensively along the main channel and its anabranches to divert floodwaters onto the surrounding land. A Lower River Broughton Irrigation Trust was established in the 1930s to control the regulation of floodwaters. The trust was disbanded in the early 1990s. In recent years, the flood irrigation system has fallen into disrepair and is currently operated on an *ad hoc* basis.

The future management of this system of regulation is likely to have significant implications for the health of the lignum swamp habitats in the lower reaches of the river. The unique swamp habitat is a high priority for management and protection; it needs to be maintained with an appropriate flooding regime.

Permanent baseflow, permanent pools and reedbed habitats in this subcatchment rely on a healthy groundwater table in the locality. Baseflow in the main channel of the river has not ceased over the past 24 years, indicating that it is relatively secure (Cresswell 2000). The greatest risks to this baseflow include direct extraction of water from local aquifers and pools, and the extensive planting of crops such as lucerne that use the groundwater. Direct pumping from permanent pools is likely to have an impact on water levels and hence on associated plants and animals. However, areas supporting the baseflow in the river do not lie within a prescribed area and so there is little control over future development.

Landholders indicated that the best floods originate in the Clare Valley and the flows take about 48 hours to reach the lower reaches of the Broughton River. The Hutt and Hill rivers are important sources of flows but they are not the only streams to contribute. Northern streams such as Freshwater and Bundaleer creeks and Rocky River are also important contributors to surface flow. Data indicates that on average, the Hutt and Hill rivers contribute 40% of the median flow in the river downstream of Spalding and 23% of the median flow in the river downstream of its confluence with Rocky River.

The number of farm dams in the Clare Valley has often been cited as the reason for recent reduced flows in the Broughton River. While permanent baseflow in the river is unlikely to be affected by these dams, low and mid flows certainly will be. The dams will delay flows and have the greatest impact in dry years. They will have much less effect on high to catastrophic flows which occur when the system is ‘wetted up’ and the dams are full. Hydrological data indicates that the dams in the Clare Valley have reduced the median flow in the Broughton River by approximately 9%. The size of this impact has been distorted by climatic conditions in which the rainfall of the past 15 years (with the exception of one or two wet years) has not produced runoff in the catchment. Improved land management practices have also resulted in a decrease in surface runoff.

Whether or not the impact of farm dams represents a greater than acceptable impact on surface flows is difficult to determine at this stage. A comparison of flow data recorded at the Mooroola gauging station with the environmental water requirements recommended by this project indicates that under current conditions the requirements are being met (Chapter 6).

Further monitoring and investigation to determine whether farm dams have a greater than acceptable impact on the riverine ecosystems is strongly recommended.

8.3.2 WATERCOURSE MANAGEMENT PRIORITIES AND STRATEGIES

Ensuring environmental water requirements are being met will not result in a healthy river system unless the ecosystems dependent on these requirements are maintained and protected. Consequently, the project assessed the condition of the major watercourses of the Lower and Mid Broughton subcatchment and, in consultation with landholders, identified significant watercourse management issues. The location of these issues in the subcatchment is illustrated in Map 8.1.

Table 8.1 lists the significant watercourse management issues in order of priority and outlines strategies for their management. High, medium and low priorities have been set largely in terms how much improvement in watercourse health is possible for the cost and effort required. Thus a low priority issue is not insignificant; it may simply not require immediate attention or it may incur costs that outweigh the benefits on a subcatchment scale. Appendix F contains a discussion of the principles and guidelines used to help determine priorities.

Community priorities for management, based on votes by landholders at a meeting on 12 April 2000, are also listed in Table 8.1. Management of these issues will largely be the responsibility of landholders, regional organisations and the local community, and these priorities indicate community views and interests in undertaking river rehabilitation works.

Significant watercourse management issues

Significant areas of important riverine habitat occur along the Broughton River downstream of Cockeys crossing, at White Cliffs and the Mooroola gauging station (downstream of Spalding). These areas have a range of native vegetation, in-stream physical habitats and permanent or semi-permanent aquatic habitats. The lignum swamp environment along the river in Zone 2 is an important habitat for land animals and when flooded provides breeding and habitat areas for waterbirds, fish and macro-invertebrates. These areas are a key assets giving these reaches of the river a higher recreational, community and ecological value. They should be considered a high priority for management.

An important area of remnant vegetation is located along the lower Rocky River where it joins with the Broughton River. The vegetation is similar to that thought to have existed in the area before European settlement. Seed sources in such areas are important for recolonisation and revegetation.

Areas of native vegetation in good condition but which have been modified by degrading processes such as weed invasion and/or stock grazing are located along the Broughton River and its tributaries from downstream of Yacka and where the river passes through Yackamoorundie Range. Typically these areas have good in-stream vegetation but lack native vegetation on the banks and floodplain or have a good cover of native overstorey but lack an understorey layer of shrubs and grasses. Managing these remnant and good vegetation areas through fencing, removing weeds and allowing natural regeneration or revegetation would produce significant ecological benefits for relatively little effort or cost.

Table 8.1 Management priorities and strategies for the Lower and Mid Broughton subcatchment

Management issue (length)	Management strategies	Sub-catchment health priority	Community priority
Protection of important riverine habitat (31.5 km)	• Monitor the site regularly to observe any changes or threats (e.g. photo points, Waterwatch) • Control threatening processes such as weeds and livestock access • Revegetate with local indigenous species, if necessary, where vegetation has been modified • Manage upstream or downstream threatening processes (e.g. weed dispersal, erosion)	High	Medium
Protection of remnant vegetation (1.6 km)	• Manage stock to avoid damage to vegetation and to allow natural regeneration • Remove or control weeds and limit the opportunity for weeds to invade • Monitor the site regularly	High	High
Improving/maintaining areas of good native vegetation (16.5 km)	• Revegetate and/or encourage natural regeneration • Manage livestock to avoid damage to vegetation and allow natural regeneration • Remove or control weeds and limit the opportunity for weeds to invade • Monitor the site regularly	High	Medium
Riparian weed removal and control (species observed include boxthorn and artichoke) (74.2 km)	• Remove by hand, spraying, burning or mechanical techniques depending on the site and the density of the infestation: care is needed to prevent disturbance to the watercourse bed and banks • Control by: - regular spot spraying (using herbicides recommended for use near a waterway) or hand removal - shading out weeds by retaining canopy cover and avoiding disturbance to the natural vegetation - excluding livestock to prevent disturbance to ground and riparian vegetation • Allow natural regeneration or revegetate with local native species to re-establish habitat, prevent erosion and allow riparian shading	Medium	High
Poor native watercourse vegetation (13 km)	• Revegetate with a full range of local native plants, including groundcovers, grasses, shrubs and trees • Leave a vegetated buffer strip between cultivated areas and the watercourse — at the very least, a good continuous grass cover • Manage livestock to avoid damage to vegetation and encourage natural regeneration	Medium	Medium

Management issue (length)	Management strategies	Sub-catchment health priority	Community priority
Exotic tree removal and control (1.7 km)	• Remove by cutting down and/or poisoning with a suitable herbicide (depending on the species and its location) • Do not remove all trees in a heavily infested area at the one time • Replace exotic vegetation with suitable native species	Medium	Medium
Poor bank stability (0.1 km)	• Restrict livestock access and revegetate for long-term stabilisation: choose areas where vegetation has most chance of establishing • Choose native species useful for erosion control (e.g. that can grow at the toe of the bank, produce a dense root mat and handle flooding) • Seek professional advice for engineering works (e.g. rock riprap, gabions, battering) which may be needed where erosion threatens a high value asset or is severe • If bank erosion is due to bed deepening (erosion head), control bed deepening processes before attempting to stabilise bank erosion	Low	Medium
Side gully erosion/gully heads (1 km)	• Monitor site to determine if erosion is active • Revegetate for long-term stabilisation: choose areas where vegetation has most chance of establishing • Seek professional advice for erosion control works (e.g. rock chutes, drop structures) which may be needed together with revegetation where erosion threatens a high value asset or is severe	Low	Low
Erosion heads (1 site)	• Monitor site to determine if erosion is active • Restrict stock access, revegetate or encourage vegetation within the channel for long-term stabilisation • Choose native species that grow within the channel, produce a dense root mat and can handle flooding • Seek professional advice for erosion control works (e.g. rock chutes, drop structures) which may be needed together with revegetation where erosion threatens a high value asset or is severe	Low	Low
Stream works causing or threatened by erosion (1 site)	• Monitor site to determine if erosion is active • Ensure stream works (e.g. culverts, fords, bridges) are located on straight and stable parts of a watercourse, are correctly aligned, have secure footings and are designed to handle the flow capacity • Seek professional advice for erosion control works (e.g. rock chutes, drop structures) which may be needed together with revegetation where erosion threatens a high value asset or is severe	Low	Low
Salinity (not identified)	• Further investigate dryland, groundwater and surface water salinity trends to determine the extent and causes of salinity • Management of high stream salinities may require adequate environmental flows to maintain water quality	Unknown	High

Riparian weed removal and control was the most important community priority along the river. Riparian weeds affect more than 36% of the watercourses surveyed in this subcatchment (Map 7.3). Boxthorn, in particular, is a widespread and significant problem. The areas of highest density lie within the lower reaches of the river. Artichoke is also a problem. Targeted control is needed that takes density and extent of infestation into account.

Controlling tamarisk (*Tamarix* sp.) trees is a significant management problem in the subcatchment (Map 7.4). Exotic trees impact on river habitats, can cause flooding and can spread rapidly along the watercourse. In general, they are not widespread in this subcatchment. However, tamarisk is a significant threat because it is difficult to control and can spread rapidly through the 'rooting' of broken branches.

Several sites have poor or no native watercourse vegetation, including an area along the river upstream of Koolunga and along Sandy Creek, a tributary of the Broughton River. Vegetation at these sites has been highly modified by clearance, stock grazing and weed invasion.

Bed and bank erosion are not extensive issues in this subcatchment. Over 76% of the surveyed streams were classified as having good bank stability (Map 7.5). Gullying and bank erosion occurs along the upper reaches of Sandy Creek and was identified as a significant issue here. An erosion head, indicating bed erosion, is located along a northern tributary of the Broughton River at Yacka.

Stream works causing, or being threatened by erosion are a significant issue at only one site. Along a tributary of the Broughton River north of Yacka, the first culvert crossing on the Yacka–Gladstone road is associated with downstream bank erosion and scouring. Initially the erosion may have been caused by bed erosion downstream that has eroded back and is being halted by the culvert. This structure is being outflanked and the culvert is possibly exacerbating local erosion. The site is not in a critical condition but an investigation and assessment of the site is recommended. The erosion stabilisation strategies for the site will involve re-engineering the structure and are likely to be costly.

Salinity was an important issue for the community. However, there is insufficient data to determine salinity trends for the subcatchment. High stream salinities are a feature of the Broughton catchment although the levels show large variations over time. Salinity levels increase in the pools during dry periods, reducing water quality and impacting on stock watering. For example, a notable peak in salinity in the early 1980s corresponded to the drought of 1982–83 (Jolly et al. 2000). A lack of floodplain flows can cause a rise in soil salinity resulting in vegetation dieback. Maintaining adequate environmental flows would be important for lowering salinity levels.

8.4 Monitoring and information gaps

In general more information is required on the water regime and flow requirements of the plants and animals living in the river system. For example, little is known about the lifecycle and flow requirements of native fish. It is expected that certain fish species migrate to the estuary to breed but this has not been confirmed by field studies. Under the conditions in the catchment, this may not be an essential part of their lifecycle and they may have adapted to breed in upstream reaches. Other information gaps include the reasons for the low numbers of native fish, the impact of trout and other exotic species on the native fish population and the impacts of barriers to migration such as weirs.

Further investigations of the plants and animals found within the lignum swamp habitats of the catchment would greatly improve knowledge and assist in management. In particular, there needs to be a greater understanding of their lifecycle needs in the context of the hydrological and ecological processes in these areas.

Landholders have observed an increase in reeds, particularly common reed and bulrush, in Zones 5 and 6. Whether reeds are increasing or not, and if so the possible causes needs to be investigated.

To better define flow requirements for geomorphological purposes, more information on the physical effects of high flows, including erosion, deposition and substrate maintenance, are required. Specifically, the size of floods required to scour out pools and to scour out reedbeds needs to be examined.

A better understanding of geomorphic and flow processes in the lower reaches of the river is required. For example, more information is required to determine minimum flows at which the estuary is connected to the river upstream and the magnitude of flows required to deliver sediment to the estuary and maintain avulsion processes at the upstream end of Zone 2. Aerial photography of floods may provide important input to such hydraulic studies.

Little is known about the deposition of sediment and extensive reedbed development at Yacka. It is difficult to determine what the natural state should be: a gravel bed as observed in the late 19th century or the extensive reedbeds of today. If this is considered to be an important issue then the chronology of this change and its causes, including the role of natural hydrological factors and human impacts, needs to be investigated.

8.5 Summary

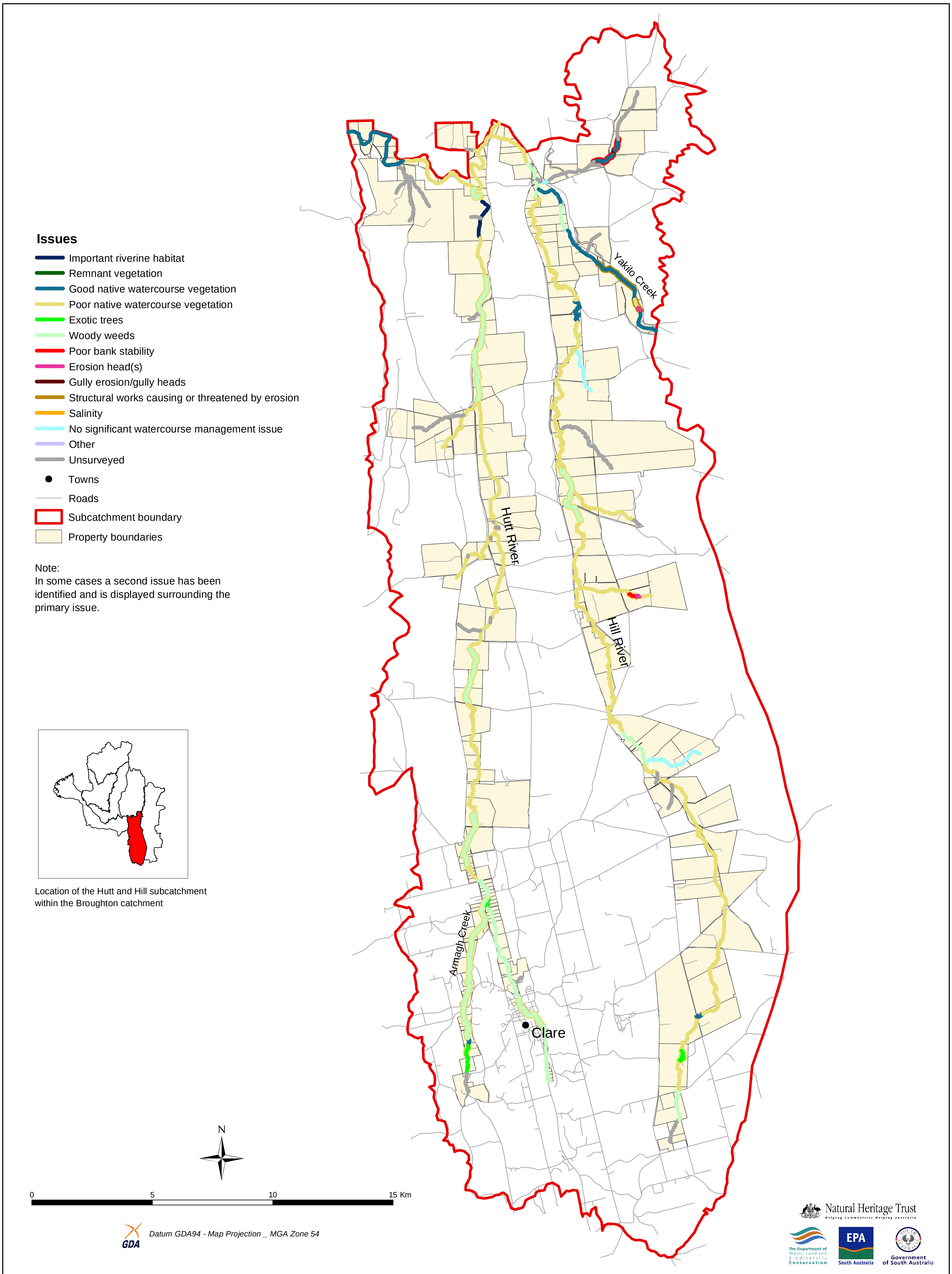
The Lower and Mid Broughton subcatchment encompasses a variety of water dependent ecosystems, from mangrove and samphire environments and lignum swamp habitats in the lower reaches to riparian forests and shrublands in the upper reaches. These environments have all been modified by human activities such as clearing, grazing, weed invasion and water resource development. Managing the environmental water requirements therefore needs to be combined with the rehabilitation of the watercourses.

Watercourse management priorities include protecting and rehabilitating areas of important riparian habitat and remnant vegetation, improving weed management and revegetating areas lacking native vegetation to improve the habitat, recreational and biodiversity values.

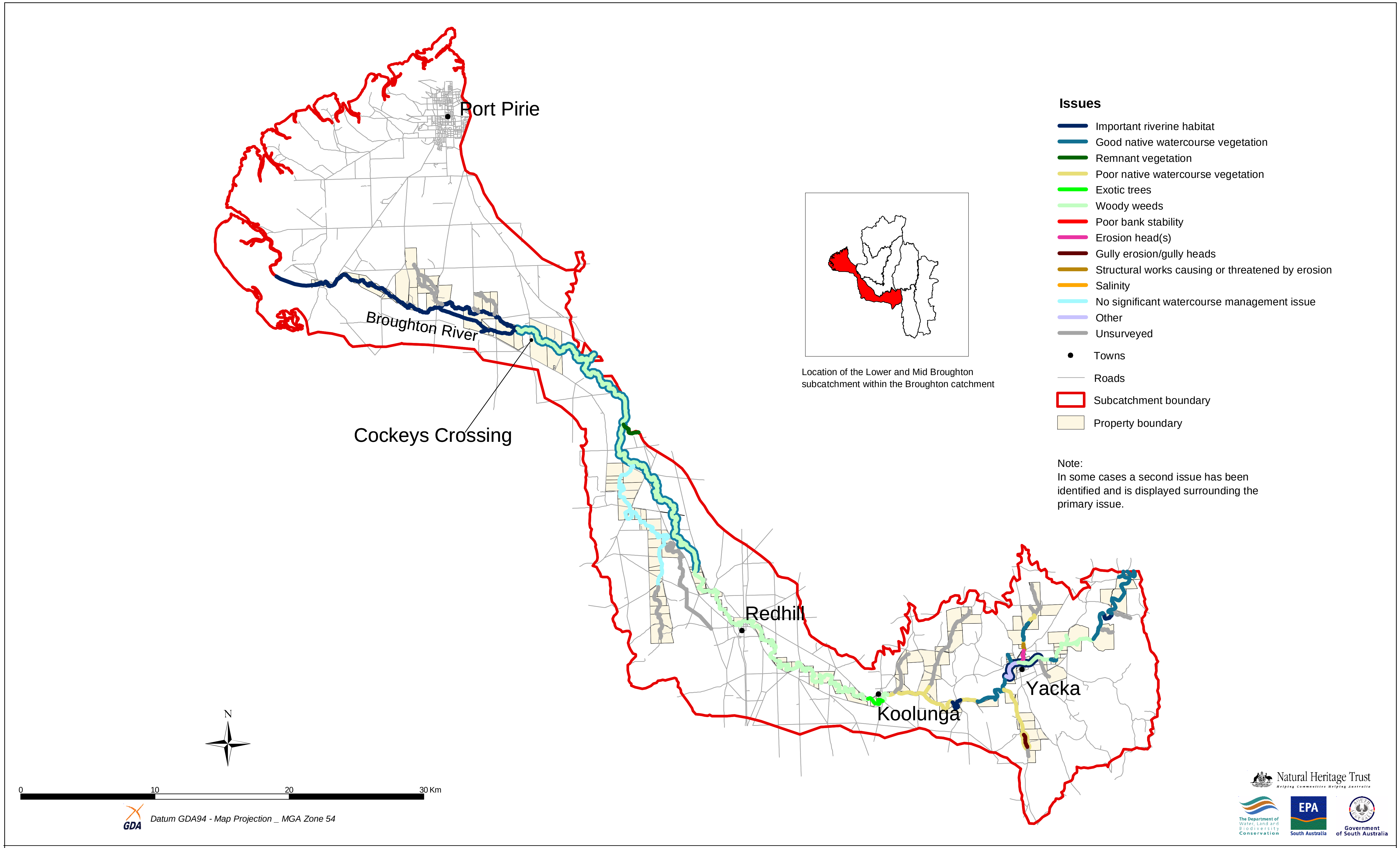
A priority for managing the water resource is the maintenance of permanent pools and continuous baseflow in the sections of the river where they occur. Permanent flow is particularly important for ensuring the health and diversity of macro-invertebrate species. The health and diversity of native fish and aquatic plants also depend on the permanent aquatic habitats.

Farm dams in the Clare Valley have some impact on low and mid flows. This impact has been magnified largely because of recent climatic conditions. The current environmental water requirements appear to be met but monitoring and further investigation is required.

Planning to control water resource development in at-risk areas of the catchment and to ensure environmental water requirements are met is crucial. Monitoring is required to collect the data necessary to determine the impact of water resource development and the effectiveness of water allocation planning.



Map 9.1: Watercourse management issues in the Hutt and Hill subcatchment



Map 8.1: Watercourse management issues in the Lower and Mid Broughton subcatchment

CHAPTER 9 THE HUTT AND HILL SUBCATCHMENT

9.1 Introduction

This chapter discusses the watercourse management and environmental water requirements for the Hutt and Hill subcatchment. The key water dependent physical and ecological environments and processes for the river geomorphic zones within this subcatchment are described. This includes the vegetation, fish and macro-invertebrates in the area. The important flow bands needed to maintain the environments, processes and associated plants and animals are described for each zone. Appendix E contains a more detailed description of the environmental water requirements including recommended frequency, duration and seasonality of flows.

The chapter describes key management issues that impact on the watercourse environments and outlines the environmental water requirements of these environments. The priorities and strategies for watercourse management based on the input of landholders and the results of the survey of watercourses in the subcatchment are tabled. The chapter closes with a discussion of information gaps and monitoring needs that have been highlighted by the project.

The major watercourses within the subcatchment are the Hutt and Hill rivers, Armagh Creek, the lower reaches of Yakilo Creek, the upper reaches of the Broughton River and Deep Creek. The Hutt and Hill rivers begin within the Clare Valley and flow northward to the Broughton River, which is formed where Yakilo Creek joins the Hill River.

Land uses within the subcatchment include urban development on the Hutt River as it passes through Clare and viticulture along the upper reaches of that river and, to a lesser extent, along the upper reaches of Hill River. The rest of the watercourse runs through cropping and grazing land, except along the Broughton River near its confluence with the Hutt River where the steep land restricts use to grazing.

9.2 Water dependent ecosystems and processes

9.2.1 HUTT RIVER

The Hutt River and its tributary, Armagh Creek, begin in the northern Mount Lofty Ranges near the township of Clare. Armagh Creek joins the river 5 km downstream of Clare. The Hutt River flows in a south–north aligned valley that is strongly influenced by geological structural controls. Two river geomorphic zones have been identified for the River (Map 5.2; Section 5.2):

- Zone 1 —Broughton River confluence to the road bridge 8 km south of Spalding.
- Zone 2 —road bridge 8 km south of Spalding upstream to Armagh Creek.

Fish and macro-invertebrates

The fish survey commissioned by the project sampled fish species at the junction of Zones 1 and 2 of the Hutt River (Hicks and Sheldon 1999). Native species were restricted to mountain galaxias (*Galaxias olidus*), which were greatly outnumbered by non-native fish species such as eastern gambusia (*Gambusia holbrookii*) and redfin (*Perca fluviatilis*). Further studies should be carried out to determine the range of these species and their migratory needs. See Chapter 5 for further information on native fish of the Broughton catchment.

Macro-invertebrate sampling at the same site revealed the population to be diverse and in reference condition. This indicates that the area is relatively healthy in terms of the associated macro-invertebrate population (Madden et al. 1999). The permanency of flow in Zone 1 is important for supporting a range of macro-invertebrates that require flow for feeding (e.g. caddisflies of the *Cheumatopsyche* genus).

One unexpected species of macro-invertebrate was collected at this site. The caddisfly (*Lingora aurata*) is usually collected from cool, flowing streams with gravel or sandy substrates. It has been recorded from numerous sites in the southern Mount Lofty Ranges, on Kangaroo Island and in the South East of the State but not from other areas of South Australia (Monitoring River Health Initiative 2001). The Broughton catchment appears to be the northern boundary of the distribution of this species.

The macro-invertebrate survey also sampled a site in Zone 2 downstream of the Clare wastewater treatment plant and found it to have mildly impaired macro-invertebrate diversity. Hutt River was found to be very degraded at this site, with elevated nutrient concentrations, bank scouring and the deposition of silt causing the embedding of the stony bottom (Madden et al. 1999). Stormwater runoff could also affect downstream water quality and this impact should be monitored.

Zone 1

Geomorphology and hydrology

In Zone 1 (Broughton River confluence to the road bridge 8 km south of Spalding; Map 5.2) the Hutt River valley is narrow and carved into bedrock. This zone has a semi-permanent baseflow and more diverse physical and aquatic habitats than Zone 2. In-stream physical habitats include reedbeds, pools, rock bars and a section of braided stream (Plate 9.1).

Plate 9.1 Hutt River, Zone 1: this area of braided channels has permanent baseflow and supports a diverse range of in-stream vegetation and habitats. Most of this zone was classified as important riverine habitat.

Vegetation

The watercourse vegetation along most of Zone 1 is a herbland and sedgeland complex with a diverse range of plant species. The in-stream vegetation is a herbland dominated by plants such as the common reed (*Phragmites australis*) and bulrush (*Typha* spp.) but other reeds, rushes and sedges are present. The sedgeland plants, located on the banks and in-stream benches, are dominated by rushes (e.g. *Juncus kraussii, Bolboschoenus caldwellii*) and sedges (e.g. *Cyperus gymnocaulus*). Along the outer banks, the vegetation is dominated by exotic annual grasses with less than 10% overstorey of trees and shrubs.

The semi-permanent baseflow and permanent pools in this area together with the diverse physical habitats and plant species make this a good aquatic habitat for macro-invertebrates, frogs and some bird species.

As the Clare Valley has been used for agriculture, grazing, crops and horticulture since the 1850s, the watercourse vegetation along this zone has been modified significantly. The study of pre-European vegetation concluded that the watercourse vegetation was likely to have been a low woodland dominated by Broughton willow (*Acacia salicina*) and other shrub species on the outer banks with a herbland/sedgeland complex in the in-stream zone (Brown and Kraehenbuehl 2000). The herbland/sedgeland complex would have been similar to that which exists today but would not have been as abundant.

Important flow bands

- *Groundwater* maintains soil moisture and permanent pools where the groundwater table intersects the river bed. This is very important in this zone as the permanent pools and soil moisture support the riparian sedgelands and in-stream reedbeds.
- *Baseflow* is almost continuous with a seasonal increase over winter–spring. The seasonal increase in baseflow is important for fish recruitment and development, maintaining water quality and increasing the area of aquatic habitat available for fish and macro-invertebrates.
- *Mid flows* are important for native fish breeding and would increase the amount of habitat available for fish to breed. The flows are important for the local migration of fish and macro-invertebrates, and for maintaining water quality.
- *Bankfull flows* are important for recruiting and establishing riparian vegetation, especially sedgelands. Depending on the duration of the flow events, they are likely to be important for local fish migration. The flows are important for geomorphic processes such as sediment transport and maintaining natural channel-forming processes.
- *Overbank flows* extending onto the floodplain are important for recruiting and establishing native floodplain vegetation where it is present. They also transport sediment, nutrients and organic matter and maintain natural channel-forming processes.
- *Catastrophic flows* or large flood events are important for scouring pools, major structural channel change and resetting habitats.

Zone 2

Geomorphology and hydrology

In Zone 2 (bridge 8 km south of Spalding upstream to Armagh Creek; Map 5.2) the Hutt River valley is wider than in Zone 1 and the river has a wide floodplain. Channel morphology is variable, ranging from meandering reaches featuring chains of pools separated by reedbeds to relatively straight reaches that may have resulted from channelisation. Along the middle reaches of the zone, the river channel has a box-shaped form and the physical habitat diversity is limited. Key in-stream habitats include reedbeds and permanent pools (Plate 9.2).

The flow regime of the watercourses in the river may have changed in recent years as a result of extensive viticulture and water resource development. This may have geomorphological implications in the longer term. Median flows have been reduced by approximately 24% (Cresswell 2000). Studies of rivers in the eastern states suggest that such a level of change may be associated with an increased risk of geomorphological impacts (S Brizga, pers comm 2000).

Plate 9.2 Hill River: this view is typical of both Hill River and Hutt River, Zone 2 and shows the reedbeds dominated by common reed and bulrush interspersed with permanent pools. There is little or no native vegetation on the banks and cropping extends right to the edge of the watercourse.

Vegetation

As the Clare Valley has been used for agriculture, grazing, crops and horticulture since the 1850s, the watercourse vegetation along the zone has been modified significantly. In particular, the native watercourse and floodplain vegetation along the zone has been changed greatly through past clearance and the practice of cropping paddocks to the top of the banks. Wild artichoke (*Cynara cardunculus*) is a key riparian weed species along the lower and middle reaches of the zone.

The lower and middle reaches of Zone 2 are typically a chain of pools separated by dense reedbeds dominated by common reed and bulrush. The diversity of in-stream vegetation is relatively low, particularly in comparison with Zone 1. The riparian vegetation is now dominated by annual exotic grasses or crops with less than 10% overstorey (61% of the zone) (Map 7.1). Some small stretches of sedgeland dominated by the rush, *Juncus kraussii*, still exist. The abundance of this rush in some areas can indicate high salinity levels (D Kraehenbuehl, pers comm 2000). There is not sufficient data to determine if this is so and whether or not stream salinity levels have increased along Hutt River.

The amount of fine sediment and nutrient input into the system is likely to have increased since European settlement because the native vegetation along the watercourse has been replaced with agricultural crops. Native low shrubs and grasses act as a filter that traps runoff sediment and nutrients during rainfall events. The increased input of sediment and nutrients creates a habitat preferred by species of common reed and bulrush and this is likely to be an important factor supporting their proliferation.

Prior to European settlement the lower and middle reaches of the watercourse were likely to have been a closed herbland/sedgeland complex with the in-stream zone dominated by the common reed and rushes (e.g. *J. kraussii*) and sedges (e.g. *Cyperus gymnocaulos)*. A low woodland dominated by Broughton willow would have existed along the banks (Brown and Kraehenbuehl 2000).

The upper reaches of Zone 2 are characterised by a dry channel with no or sparse reeds (emergent macrophytes). The watercourse vegetation is typically a low woodland dominated by South Australian blue gum (*Eucalyptus leucoxylon*) and peppermint box (*E. odorata*). The native understorey shrub layer appears to be missing and exotic weeds such as fennel (*Foeniculum vulgare*), wild rose (*Rosa rubiginosa*), boxthorn (*Lycium ferocissimum*) and broom (*Cytisus scoparius*) dominate. Anecdotal evidence suggests that there is a significant mistletoe infestation which may be affecting the health of eucalypt trees in this area.

Important flow bands

- *Groundwater* maintains soil moisture and permanent pools where the groundwater table intersects the river bed. This is very important in this zone as the permanent pools and soil moisture support the riparian sedgelands and in-stream reedbeds.
- *Seasonal low flows* result from surface flows with a seasonal increase in baseflow. These flows are important for fish recruitment and development, maintaining water quality, connecting pool environments and increasing the area of aquatic habitat available for fish and macro-invertebrates.
- *Mid flows* are important for native fish breeding and increase the amount of habitat available for fish to breed. The flows are important for the local migration of fish and macro-invertebrates, and for maintaining water quality.
- *Bankfull flows* are important for maintaining water quality and for geomorphic processes such as sediment transport and maintaining natural channel-forming processes. Depending on the duration of the flow events, they are likely to be important for local fish migration.
- *Overbank flows* extending onto the floodplain are important for recruiting and establishing native floodplain vegetation where it is present. The lack of riparian vegetation along sections of the Hutt River may limit this function. They also transport sediment, nutrients and organic matter and maintain natural channel-forming processes.
- *Catastrophic flows* or large flood events are important for scouring pools, major structural channel change and resetting habitats.

9.2.2 HILL RIVER

Geomorphology and hydrology

The Hill River rises in the northern Mount Lofty Ranges about 8 km east of Clare. It flows north and joins Yakilo Creek to form the Broughton River. The south–north valley alignment is strongly influenced by geological structural controls. The river is considered to be a single river geomorphic zone (Map 5.2; Section 5.2).

The river has a natural ‘chain of pools’ form, with pools separated by reedbeds. The watercourse has a wide floodplain. Channelisation in some areas needs to be monitored for any erosion that may result from the stream works. Sediment deposition in the system is likely to have increased since European settlement.

The flow regime of the watercourses has probably changed in recent years as a result of extensive viticulture and water resource development and there may be geomorphological implications in the long term. Median flows have reduced by about 21% (Cresswell 2000), a level of change which studies elsewhere suggest may be associated with an increased risk of geomorphological impacts (S Brizga, pers comm 2000).

Vegetation

The watercourse vegetation along the Hill River and its tributaries is highly modified. In particular, the native watercourse and floodplain vegetation has been changed greatly through past clearance and the practice of cropping paddocks to the top of the banks. Riparian vegetation is dominated by annual exotic grasses or crops with less than 10% overstorey (83% of the area). A significant stretch of sedgeland vegetation in the lower (northern) reaches of the river is associated with a small stand of lignum (*Muehlenbeckia florulenta*). There are some small stretches of sedgelands and eucalyptus overstorey along the upper reaches (the southernmost 15 km). Wild artichoke is a key riparian weed species.

The in-stream vegetation consists typically of dense reedbeds of relatively low diversity dominated by the common reed and bulrush (approximately 55% of the area). The abundance of the rush, *J. krausii* in some areas may indicate high salinity levels (D Kraehenbuehl, pers comm 2000). There is not sufficient data to determine if this is so and whether or not salinity levels have increased along the river.

The amount of sediment and nutrient input into the system is likely to have increased since European settlement because the buffer strip of native vegetation along the watercourse has been replaced with agricultural crops. Native low shrubs and grasses act as a filter that traps runoff sediments and nutrients during rainfall events. This input creates a habitat preferred by the common reed and bulrush and is likely to be an important factor supporting their proliferation.

Prior to European settlement, most of the lower and middle reaches of the river were probably closed herblands dominated by common reed, rushes (e.g. *J. kraussii*) and sedges (e.g. *Cyperus gymnocaulus)*, with Broughton willow growing along the banks (Brown and Kraehenbuehl 2000). The upper reaches of the river are likely to have been an open woodland of South Australian blue gum and drooping sheoak (*Allocasuarina verticillata*) (Brown and Kraehenbuehl 2000).

Fish and macro-invertebrates

Macro-invertebrate sampling at the Hill River gauging station revealed the population to be diverse and in reference condition (Madden et al. 1999), indicating that the area has a healthy macro-invertebrate population probably due to the presence of permanent water. This water should be protected to maintain these macro-invertebrate populations.

No fish survey was conducted for the river but it is likely that the permanent pools support similar species to those found in the Hutt River, which has a very similar environment. Future monitoring programs should include a more extensive fish survey.

Important flow bands

- *Groundwater* maintains soil moisture and permanent pools where the groundwater table intersects the river bed. This is very important in this zone as the permanent pools and soil moisture support the riparian sedgelands and in-stream reedbeds.
- *Seasonal low flows* result from surface flows with a seasonal increase in baseflow. These flows are important for fish recruitment and development, maintaining water quality, connecting pool environments and increasing the area of aquatic habitat available for fish and macro-invertebrates.
- *Mid flows* are important for native fish breeding and increase the amount of habitat available for fish to breed. The flows are important for the local migration of fish and macro-invertebrates, and for maintaining water quality.
- *Bankfull flows* are important for maintaining water quality and for geomorphic processes such as sediment transport and maintaining natural channel-forming processes. Long duration bankfull flows are likely to be important for fish migration locally.
- *Overbank flows* extending onto the floodplain are important for recruiting and establishing native riparian and floodplain vegetation such as riparian sedgelands. The lack of riparian vegetation along sections of Hill River may limit this function. The flows also transport sediment, nutrients and organic matter and maintain natural channel-forming processes.
- *Catastrophic flows* and large flood events are important for scouring pools, major structural channel change and resetting habitats.

9.2.3 YAKILO CREEK

Geomorphology and hydrology

Yakilo Creek begins at the confluence of Booborowie and Baldry creeks and joins the Hill River to become the Broughton River. Yakilo Creek drains from the east of the catchment and flows northwest through a gap between the Camels Hump and the Brown Hill Ranges. This creek is considered to be a single river geomorphic zone (Map 5.2; Section 5.2).

The significant sedimentation apparent upstream of Broughton weir, located on Yakilo Creek, is attributable to erosion further upstream in Booborowie and Baldry creeks (Brizga 2000a). The weir was constructed to divert water via an aqueduct system into Bundaleer reservoir. This watercourse was probably a shallow marshland in its natural state. Sections of Yakilo Creek have been channelised to drain these marshes and enable cropping.

Vegetation

The vegetation along Yakilo Creek has been modified by agricultural practices, including clearance, channelisation and cropping. The vegetation is currently a sedgeland/herbland complex (95% of the zone). In-stream vegetation is dominated by the common reed and the banks of the watercourse support sedges and rushes (e.g. *J. kraussii, C. gymnocaulus*) (Brown and Kraehenbuehl 2000). The banks also support native and exotic grass species.

Similar marshland environments are likely to have existed originally along Booborowie Creek.

A threatened grass species, Spalding blown grass (*Agrostis limitanea*), occurs in a section along Yakilo Creek. Only two populations of this species have been recorded — at this site and one another site near Tarlee. These populations are threatened by grazing and weed invasion (especially *Phalaris* sp.) (Graham et al. 2001).

Recently, sections of Yakilo Creek have been channelled to drain the creek flats for cropping of lucerne. The high volume of water required by lucerne, along with channelisation, will impact on the hydrology and lower the groundwater table. Over time this is likely to alter the sedgeland/herbland marsh environments that use the shallow groundwater table. Channelisation also increases the risk of erosion. The magnitude of this risk will depend on the soil type and the flow regime.

Fish and macro-invertebrates

No macro-invertebrate or fish survey was carried out for Yakilo Creek. However, it is likely that permanent water and a few permanent pools support some species. The lack of habitat diversity makes it unlikely that the populations will be diverse.

Important flow bands

- *Groundwater* provides soil moisture to support the riparian sedgelands and in-stream reedbeds along Yakilo Creek.
- *Baseflow* is important to maintain permanent flowing aquatic habitats and emergent aquatic plants.
- *Mid flows* are important for maintaining water quality and increasing the amount of aquatic habitat for aquatic flora and fauna.
- *High to bankfull flows* are important for recruiting and establishing riparian sedgeland plants. The flows also transport sediment and organic matter, scour pools and drive natural channel-forming processes.

9.2.4 BROUGHTON RIVER

Geomorphology and hydrology

Zone 6 of Broughton River (upstream of Yacka to the confluence of Hill River and Yakilo Creek; Map 5.2) is characterised by the gorge that the Broughton River has cut through the Yackamoorundie Range (see also Chapter 8). There is perennial baseflow through this zone and in-stream physical habitats include permanent pools, reedbeds, rock bars and boulder riffles. The river is bordered by a narrow floodplain of variable width. Catchment erosion, including incision of tributary streams, may have raised sediment inputs (Brizga 2000a). For example, a member of the South Australian Fly Fishers Association has reported large amounts of sediment entering the river from Freshwater Creek during heavy rainfall events.

This zone falls within both the Hutt and Hill subcatchment and the Lower and Mid Broughton subcatchment and has been discussed in Chapter 8.

Vegetation

Watercourse vegetation throughout the zone has been modified to varying degrees by grazing and weed invasion. In some reaches grazing and cropping extends to the edge of the watercourse. The extent of reedbeds may have increased historically because of raised sediment levels. Vegetation varies from annual exotic grasses with less than 10% overstorey to sedgelands with or without a sparse native shrub overstorey. The sedgelands include extensive reedbeds (covering more than 80% of the in-stream zone) dominated by common reed and bulrush associated with sedges (such as *C. gymnocaulos*) and rushes (including *J. krausii* and *Bolboschoenus caldwelli*). Native shrub overstorey along the banks includes common species such as Broughton willow, lignum and cutting grass (*Gahnia trifida*).

Studies of pre-European vegetation suggest that the original vegetation in Zone 6 was an open forest dominated by Broughton willow and river red gum (Brown and Kraehenbuehl 2000). A tall open shrubland of elegant wattle (*A. victoriae*) and native myrtle (*Myoporum montanum*) is likely to have been the typical vegetation on the slopes leading away from the watercourse.

Fish and macro-invertebrates

A significant proportion of the zone was considered important riverine habitat for fish, birds, frogs and macro-invertebrates. The permanent baseflow supports pool, riffle and reedbed environments and there is a diverse range of native watercourse vegetation, including shrubs, native grasses and groundcovers, and submerged and emergent aquatic vegetation. For example, the highest macrophyte richness (reeds, sedges and rushes) recorded in the catchment by the macro-invertebrate survey was in this zone at the Mooroola gauging station (12 species) and Frome crossing (11 species) (Madden et al. 1999).

Native fish species found include mountain galaxias and blue spot goby. The latter prefer slow moving water with a good growth of submerged macrophytes. Blue spot gobies can migrate to the estuary to spawn although this is not a definitive part of their lifecycle. Mountain galaxias prefer cool waters and move from pool habitats to riffles to spawn. The species does not compete well with trout.

Exotic species recorded include goldfish and eastern gambusia (Hicks and Sheldon 1999; SA Museum, pers comm). Although trout were not captured by the fish survey, several of the deep waterholes along the zone are stocked annually with fingerlings (Anon, pers comm).

Macro-invertebrate sampling, at the river south of Spalding and at Frome crossing, indicated that the zone is healthy in terms of its macro-invertebrate population. The health and diversity of macro-invertebrate species in the river is due to the permanent groundwater dependent flows (baseflow). Many species, such as a type of caddisfly (*Cheumatopsyche* sp.), require flow for feeding and the continual discharge is important for maintaining water quality.

Invertebrates with unusual or restricted distributions were found in the zone. These include bristle worms (Polychaeta) which are not usually found in freshwater habitats, a moth from the family Pyralidae which is generally found in wetlands with dense stands of macrophytes and the caddisfly (*Lingora aurata*) which is typically found in cool flowing streams. Other species that typically require flowing water, including mayflies, dixid midge larvae and amphipods from the family Eusiridae, were recorded in the river south of Spalding.

Important flow bands

- *Groundwater* maintains soil moisture and permanent pools where the groundwater table intersects the river bed. This is vitally important in this zone as the permanent pools, baseflow and soil moisture support the riparian sedgelands and in-stream reedbeds, and the diversity of aquatic plants and animals.

- *Baseflow* in this zone is permanent and is important for maintaining permanent pools, reedbeds and flow over riffles. The seasonal increase in baseflow in winter–spring is important for recruiting fish and increasing the area of habitat available for macro-invertebrates.
- *Mid flows* are important for native fish breeding. They increase the amount of habitat available for fish to breed. The flows are important for the local migration of native fish and macro-invertebrates, and for maintaining water quality.
- *Bankfull flows* are important for the inundation of the floodplain, and for recruiting and establishing riparian and floodplain vegetation, depending on the duration of these flow events. The flows are important for geomorphic processes such as sediment transport, removal of sediment from riffle environments and maintaining natural channel-forming processes.
- *Catastrophic flows* or large flood events are important for recruiting and establishing floodplain vegetation, scouring pools, major structural channel change and resetting of habitats.

9.2.5 DEEP CREEK

Geomorphology and hydrology

Deep Creek, a tributary of the upper reaches of the Broughton River, was surveyed along only part of its length because of accessibility issues. The tributary was therefore not assigned a geomorphic zone (Map 5.2). The sections observed revealed a deeply incised and ephemeral watercourse, with some limited areas of developing gully erosion. Flow events tend to be brief, with peak flows lasting for up to two hours and sustained flows for approximately one day.

Vegetation

There is no in-stream vegetation and the habitat for fish, frogs and macro-invertebrates is limited. Depending on the duration of water availability, opportunistic macro-invertebrates may be able to breed in ephemeral pools after flow events.

An area of chenopod shrubland (species unknown) was identified along the middle reaches. Studies of pre-European vegetation suggest that the vegetation along the creek would have been open woodland of South Australian blue gum and drooping sheoak (Brown and Kraehenbuehl 2000).

Important flow bands

Environmental water requirements were not determined for this watercourse.

9.3 Management issues

A key management concern for landholders within the Hutt and Hill subcatchment was pollution, including chemicals, septic tank overflow and rubbish. A lack of knowledge about how the river system functions and its hydrology, water use and ways of managing the system were also key management issues. Other important issues were weed infestation, lack of flow, drying up of springs, bank and bed erosion, water use by viticulture, lack of community awareness, exotic trees and eucalyptus dieback.

9.3.1 ISSUES AFFECTING ENVIRONMENTAL WATER REQUIREMENTS

In recent years the Clare Valley, which encompasses the upstream reaches of the Hutt and Hill Rivers, has become a major growth area for viticulture and pressure on local water resources has increased. Watercourses and groundwater in the region were prescribed in July 1996 and surface water was prescribed in October 1999. The Clare Valley Prescribed Water Resources Area has controls over the construction of dams and wells, and the taking of water within the prescribed area. The *Water Allocation Plan for the Clare Valley Prescribed Water Resources Area* (Clare Valley Water Resources Planning Committee 2000) was adopted on 22 December 2000, and includes a framework of policies to provide for the sustainable use of water resources and to protect the needs of water dependent ecosystems.

Water resource development has altered the flow regimes of the Hutt and Hill rivers. For example, the total capacity of licensed dams in the area is approximately 4000 ML and the estimated capacity of stock and domestic dams in 1999–2000 was around 2500 ML. Farm dams in the valley have reduced the median flow in Hutt River by 24% and in Hill River by 21% (Cresswell 2000). Median flow is a measure of the typical flow along the rivers (at least 50% of events are greater than the median and at least 50% are less than the median). The impacts of farm dams will be greatest on low to mid flows and will be greater in dry years. Dams delay flow but have less impact on higher flow events.

The magnitude of this impact has been distorted by recent climatic conditions. Dry years over the past 15 years, with one or two exceptions, have resulted in lower flows and falling groundwater tables across the Broughton catchment. To some extent this has distorted the perceived effects of farm dams in the valley. Other factors such as improved land management (e.g. contour banking), reduced stocking and improved pasture management have also reduced the amount of runoff generated within the catchment (Cresswell 2000).

Whether or not the impacts of farm dams represent a greater than acceptable impact on surface flows is beyond the scope of this study. A comparison of flow data recorded at the Hutt and Hill gauging stations with the environmental water requirements recommended by this project indicates that, under current conditions, requirements are being met (see Chapter 6). However, the mid flow requirements are just being met and this flow band is the most likely to be affected by future dam development. Further monitoring and investigation to determine whether the impact of farm dams represents a greater than acceptable impact on riverine ecosystems over time is recommended strongly.

Baseflow and permanent pools provide important aquatic habitats. In particular semi-permanent flow in sections of the Broughton and Hutt rivers is important for supporting a diverse range of macro-invertebrate species that require flow for feeding. The greatest risk to these groundwater dependent pools and baseflow is the potential extraction of water from local aquifers and direct pumping of water from pools (Cresswell 2000). Controls on extraction from groundwater sources and pumping from permanent pools may be required.

The water allocation plan for the prescribed area sets limits on water resource development but there is little control on development outside the area. The impacts on water dependent ecosystems must be considered when assessing any future development within or outside the prescribed area. Similarly, the impacts of development on water regimes inside and outside the prescribed area require effective monitoring.

9.3.2 WATERCOURSE MANAGEMENT PRIORITIES AND STRATEGIES

Ensuring environmental water requirements are being met will not result in a healthy river system unless the ecosystems dependent on these requirements are maintained and protected. For example, unless degraded riparian and floodplain habitats along Hutt and Hill rivers are rehabilitated, the ecological functions of larger flows in these zones are limited. Consequently, the project assessed the condition of the major watercourses of the Hutt and Hill subcatchment and, in consultation with landholders, identified significant watercourse management issues (see Map 9.1 for locations).

Table 9.1 lists the significant watercourse management issues in order of priority and outlines strategies for their management. High, medium and low priorities have been set largely in terms how much improvement in watercourse health is possible for the cost and effort required. Thus a low priority issue is not insignificant; it may simply not require immediate attention or it may incur costs that outweigh the benefits on a subcatchment scale. Appendix F contains a discussion of the principles and guidelines used to help determine priorities.

Community priorities for management, based on votes by landholders at a meeting on 12 April 2000 are also listed in Table 9.1. Management of these issues will largely be the responsibility of landholders, regional organisations and the local community and these priorities indicate community views and interests in undertaking river rehabilitation works.

Significant watercourse management issues

An area of important riverine habitat was identified along Zone 1 of the Hutt River. The semi-permanent baseflow and permanent pools in this area together with the diversity of physical habitats and sedgeland plant species make this a good aquatic habitat for macro-invertebrates, frogs and some bird species. The vegetation has been modified by agricultural practices but it is likely that the banks once supported a low woodland environment (Brown and Kraehenbuehl 2000).

Throughout the subcatchment, areas were identified as having watercourse vegetation that has been modified or is threatened by agricultural practices but is likely to respond well to rehabilitation works. These areas have been classified as having good native watercourse vegetation and include sedgelands along the Broughton River and Yakilo Creek, chenopod shrubland along Deep Creek, lignum shrubland along Hill River and eucalyptus woodland along Armagh Creek. Threats include channelisation, weeds, excessive mistletoe and grazing that prevents regeneration. These areas have a higher habitat value, especially for birds and macro-invertebrates, than more degraded areas but their value is diminished because of their limited extent. Simply rehabilitating such isolated patches of vegetation, without linking them, may have limited benefits.

Possibly the most significant issue affecting ecosystem health along Hutt and Hill rivers is the lack of native vegetation along most of the watercourses. Cropping to the top of the banks in some areas means there is no buffer strip of vegetation to slow and filter runoff and to trap sediment and nutrients. The vegetation has other key functions — providing food and shelter, stabilising banks and moderating the climate of the watercourse by shading. Where possible, fencing and encouraging natural regeneration and/or revegetation should be considered to improve water quality and river health.

Table 9.1 Management priorities and options for the Hutt and Hill subcatchment

Management issue (length)	Management strategies	Sub-catchment health priority	Community priority
Protection of important riverine habitat (1.78 km)	• Monitor the site regularly to observe any changes or threats (e.g. photo points, Waterwatch) • Control threatening processes such as weeds and stock access • Revegetate with local indigenous species, if necessary, where vegetation has been modified • Manage upstream or downstream threatening processes (e.g. weed dispersal, erosion)	High	High
Lack of native vegetation (95 km)	• Revegetate with a full range of local native plants, including groundcovers, grasses, shrubs and trees • Leave a vegetated buffer strip between cultivated areas and the watercourse — at the very least, a good continuous grass cover • Manage stock to avoid damage to vegetation and encourage natural regeneration	High	Medium
Riparian weed removal and control (species observed include boxthorn and wild artichoke) (38.2 km)	• Remove by hand, spraying, burning or mechanical techniques depending on the site and the density of the infestation: care is needed to prevent disturbance to the watercourse bed and banks • Control by: - regular spot spraying (using herbicides recommended for use near a waterway) or hand removal - shading out weeds by retaining canopy cover and avoiding disturbance to the natural vegetation - excluding livestock to prevent disturbance to ground and riparian vegetation • Allow natural regeneration or revegetate with local native species to re-establish habitat, prevent erosion and allow riparian shading • Link with a program of exotic tree control along the upper Hutt River and Armagh Creek	High (in reaches near Clare)	High
Exotic tree removal and control (2.6 km)	• Remove by cutting down and/or poisoning with a suitable herbicide (depending on the species and its location) • Do not remove all trees in a heavily infested area at the one time • Replace exotic vegetation with suitable native species • Link with a program of riparian weed control along the upper Hutt River and Armagh Creek	High (in reaches near Clare)	Medium
Improving/maintaining areas of good native vegetation (includes remnant vegetation) (15.5 km)	• Revegetate and/or encourage natural regeneration • Manage livestock to avoid damage to vegetation and to allow natural regeneration • Remove or control weeds and limit the opportunity for weeds to invade • Monitor the site regularly	Medium	High
Erosion heads (1 site)	• Monitor site to determine if erosion is active • Restrict stock access, revegetate or encourage vegetation within the channel for long-term stabilisation	Low	Medium

Management issue (length)	Management strategies	Sub-catchment health priority	Community priority
	• Choose native species that grow within the channel, produce a dense root mat and can handle flooding • Seek professional advice for erosion control works (e.g. rock chutes, drop structures) which may be needed together with revegetation where erosion threatens a high value asset or is severe		
Poor bank stability (0.4 km)	• Restrict livestock access and revegetate for long-term stabilisation: choose areas where vegetation has most chance of establishing • Choose native species useful for erosion control (e.g. that can grow at the toe of the bank, produce a dense root mat and handle flooding) • Seek professional advice for engineering works (e.g. rock riprap, gabions, battering) which may be needed where erosion threatens a high value asset or is severe • If bank erosion is due to bed deepening (erosion head), control bed deepening processes before attempting to stabilise bank erosion	Low	Medium
Gully erosion/gully heads (1 site)	• Monitor site to determine if erosion is active • Revegetate for long-term stabilisation: choose areas where vegetation has most chance of establishing • Seek professional advice for erosion control works (e.g. rock chutes, drop structures) which may be needed together with revegetation where erosion threatens a high value asset or is severe	Low	Medium
Stream works causing or threatened by erosion (not identified)	• Monitor site to determine if erosion is active • Ensure stream works (e.g. culverts, fords, bridges) are located on straight and stable parts of a watercourse, are correctly aligned, have secure footings and are designed to handle the flow capacity • Seek professional advice for erosion control works (e.g. rock chutes, drop structures) which may be needed together with revegetation where erosion threatens a high value asset or is severe	Low	Low
Salinity (not identified)	• Further investigate dryland, groundwater and surface water salinity trends to determine the extent and causes of salinity • Management of high stream salinities may require adequate environmental flows to maintain water quality	Unknown	High

Riparian weeds were considered a high priority issue by the landholders. The project used survey techniques which meant that only larger, generally woody, species could be detected easily. Weeds such as wild rose, fennel and boxthorn were identified along the upper reaches of the Hutt River and Armagh Creek near Clare. These species are associated with exotic trees which were an issue, in particular ash trees, along the upper reaches of the Hutt and Hill rivers. The invasion by weeds and exotic trees is considered to be a threat to the eucalyptus woodland along these reaches. Wild artichoke was identified along the lower reaches of the Hutt and Hill rivers, Broughton River and Yakilo Creek. Controlling weeds and exotic trees, particularly along the upper reaches of Hutt and Hill rivers and Armagh Creek, is an important issue for rehabilitating the rivers and preventing downstream spread.

Salinity was voted as an issue within this subcatchment, although landholders were not certain if salinity levels were increasing. Some areas of sedgelands dominated by the rush, *J. krausii* may indicate saline areas. High stream salinities are a feature of the Broughton catchment and salinity levels show large variations over time. The salinity levels of pools will increase in dry periods and surface flows are important in providing a freshwater flush and lowering these levels. For example, a notable peak in salinity in the early 1980s corresponded to the drought of 1982–83 (Jolly et al. 2000). There is currently insufficient data to determine salinity trends for the subcatchment. Ensuring that environmental flows are met would be important for maintaining water quality, especially with respect to salinity.

Bed and bank erosion were not significant management issues in the subcatchment. Most of the watercourses (80%) were assessed as having banks with good stability and the rest were classified as moderate stability or were unsurveyed (Map 7.5). Erosion heads were identified along the eastern tributaries of Hill River but only two of them were considered to be a significant management issue. They have the potential to erode back upstream in large flow events and are associated with bank erosion downstream. An area of gullying erosion along Deep Creek was considered to be a significant management issue.

9.3.3 OTHER ISSUES

Landholders within the Hutt and Hill subcatchment were very concerned about pollution from farm chemicals and septic tank overflow. The dominance of the common reed and bulrush along the middle and lower reaches of the Hutt and Hill rivers may indicate elevated levels of nutrients and fine sediment. Nutrient concentrations in the Hutt River downstream of Clare were extremely high and the deposition of silt was widespread (Madden et al. 1999). Possible sources of the nutrient and sediment, such as stormwater or wastewater from Clare, or input from surrounding paddocks or in-stream erosion, need to be investigated.

Further investigation of diffuse pollution risks in the catchment is required to determine the extent and significance of this issue. Using riparian buffer strips to filter runoff from surrounding paddocks may be an effective management strategy.

Sections of Yakilo Creek have been channelised to drain the shallow groundwater table and enable cropping (see also Booborowie Creek in Chapter 10). This channelisation and the growing of crops such as lucerne which use groundwater, could change Yakilo Creek from a marshy sedgeland to an annual grassland. Channelisation can also result in bed and bank erosion that can affect upstream and downstream users.

9.4 Monitoring and information gaps

Effective river management requires a sound knowledge of the river system. River systems are dynamic and function on a range of timescales. Limited long-term data means that management recommendations should be reviewed in the light of information collected over a longer timescale.

In general, more information is required on the current water regime, geomorphic processes and the flow requirements of the plants and animals that live in the watercourses of the subcatchment. This would enable a better definition of the flow requirements for geomorphological and ecological purposes. Specific investigations are needed to determine:

- native fish populations and their lifecycle requirements;
- the movement and sources of sediment through the system;
- the processes that maintain the ‘chain of pools’ stream form along Hutt and Hill rivers; and
- the extent and source of nutrients in the watercourses.

In addition, flow weighted water quality sampling (especially of nutrients) to determine the impact of stormwater and the Clare wastewater treatment plant, could provide useful information.

Within the scope of this study it was difficult to assess the impact of water resource development in the Clare Valley on water dependent ecosystems and processes. Effective and targeted monitoring over a long period of time is required. Developing a monitoring strategy should take into account not only surface and groundwater hydrology and quality, but also biological indicators that provide information on the ecosystem response to changes in the water regime.

9.5 Summary

The Hutt and Hill subcatchment encompasses a variety of watercourse environments from eucalyptus woodlands in the upper reaches of the Hutt and Hill rivers, reedbeds and a chain of pools in the lower reaches, and continuous groundwater dependent flow in the upper reaches of the Broughton River. Important riverine habitats exist along the lower reaches of the Hutt River and the upper reaches of the Broughton River where there is relatively healthy watercourse vegetation and permanent water.

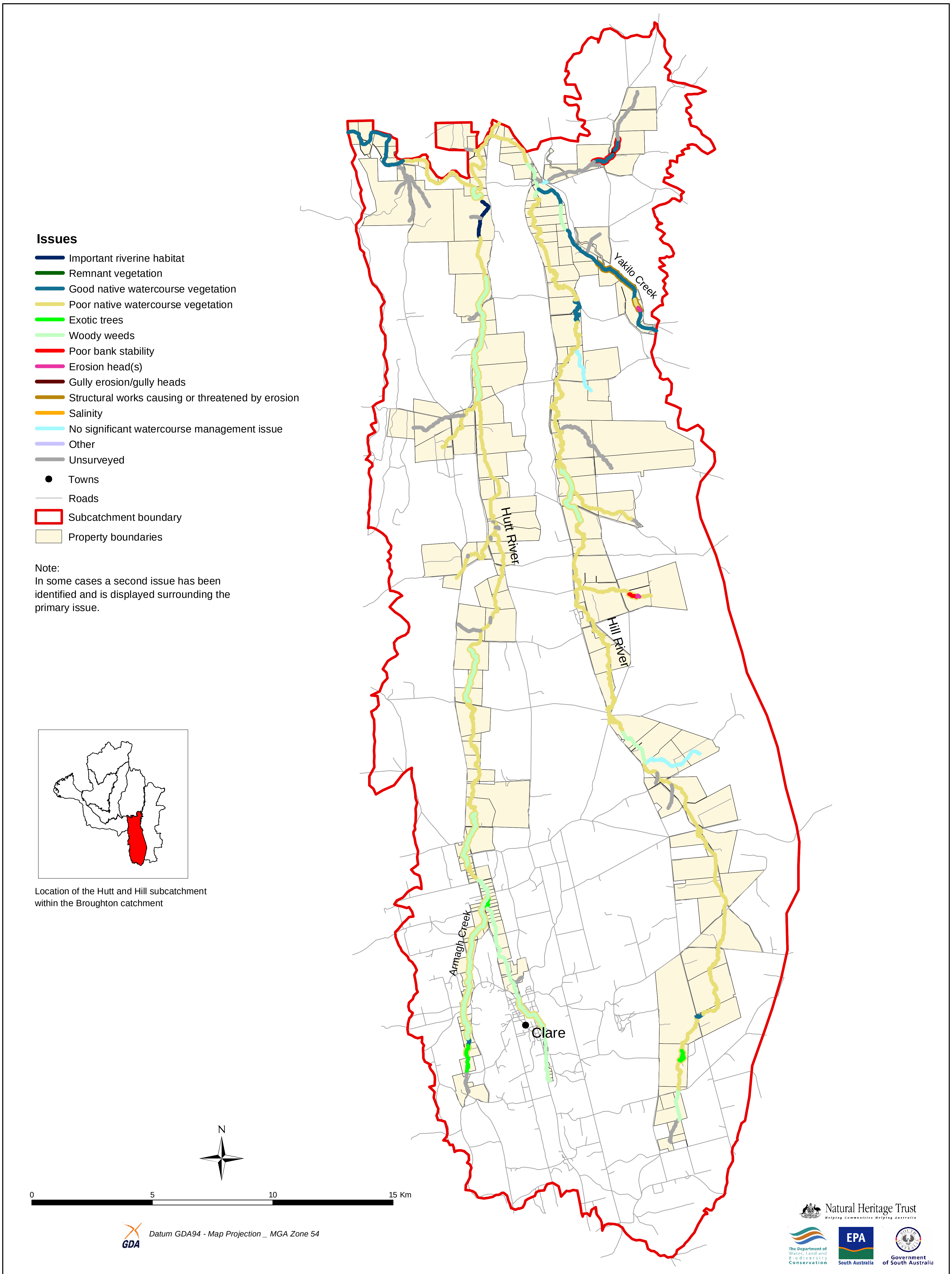
Most of the watercourse environments, however, have been modified significantly and the biodiversity of the system is low, particularly in native watercourse vegetation. Native fish numbers are low. The Hutt River downstream of Clare has impaired macro-invertebrate diversity because of elevated nutrient and sediment levels.

Clearance and cultivation to the edge of the watercourse, channelisation, weeds, poor water quality and altered flow regimes are some of the key threats to the riverine ecosystems within the subcatchment. Managing these is critical. Priority issues include protecting and maintaining important riverine habitats, revegetating areas lacking native vegetation and managing riparian weeds. Issues that require further investigation include monitoring diffuse pollution (particularly farm chemicals) and nutrient levels.

Managing water resource developments such as groundwater use and farm dams in the Clare Valley is a priority for the subcatchment. Farm dams impact on low and mid flows and the impact has been magnified by recent climatic conditions. Permanent pools and continuous baseflow should be maintained in the sections of the river where they occur.

These permanent aquatic habitats are particularly important for ensuring the health and diversity of macro-invertebrate species, native fish and aquatic plants.

The recommended environmental water requirements currently appear to be met but control over further water resource development, sound monitoring and further investigations are required. Management structures to control water resource development outside as well as within the prescribed area are required. Ongoing monitoring is necessary to collect data to assess the impacts of development and the effectiveness of water resource management policies and to facilitate adaptive management.



Map 9.1: Watercourse management issues in the Hutt and Hill subcatchment

CHAPTER 10 THE BOOBOROWIE AND BALDRY SUBCATCHMENT

10.1 Introduction

This chapter discusses the watercourse management and environmental water requirements for the Booborowie and Baldry subcatchment. The key water dependent physical and ecological environments and processes for the river geomorphic zones within this subcatchment are described. This includes the vegetation, fish and macro-invertebrates in the area. The important flow bands needed to maintain the environments, processes and associated plants and animals are described for each zone. Appendix E contains a more detailed description of the environmental water requirements including recommended frequency, duration and seasonality of flows.

The chapter describes key management issues that impact on the watercourse environments and outlines the environmental water requirements of these environments. The priorities and strategies for watercourse management based on the input of landholders and the results of the survey of watercourses in the subcatchment are tabled. The chapter closes with a discussion of information gaps and monitoring needs that have been highlighted by the project.

The major watercourses within the Booborowie and Baldry subcatchment are Booborowie Creek (which drains from the north), Baldry Creek (which drains from the south) and the upper 700 m of Yakilo Creek (which begins at the confluence of Booborowie and Baldry creeks). The major tributaries of Booborowie Creek include Willalo, Cartapo and Waltons Palace creeks. Gum Creek is the one major tributary of Baldry Creek. The subcatchment drains the easternmost section of the Broughton catchment. See Chapter 9 for more information on Yakilo Creek.

Watercourses within the subcatchment run through cropping/grazing land. Most of the agricultural land in the Booborowie Valley has been planted with lucerne. Large sections of Booborowie Creek have been cultivated and are no longer discernible from the surrounding landscape.

10.2 Water dependent ecosystems and processes

10.2.1 BOOBOROWIE CREEK

Geomorphology and hydrology

Booborowie Creek arises in the southern Flinders Ranges, and drains southward to join Baldry Creek to form Yakilo Creek. The Booborowie Valley reflects the underlying geology and runs parallel to the main fold lines. The lower reaches, cutting across the main direction of folding, flow westward through a gap between the Camels Hump and Brown Hill ranges. This creek is considered to be a single geomorphic zone (Map 5.2; Section 5.2).

Booborowie Creek is an ephemeral watercourse and is generally a small, often poorly defined, dry grassy channel (Plate 10.1). The major tributaries feeding into the creek from the east are also ephemeral. All have sections that are deeply incised, lack vegetative cover and are actively eroding (Plate 10.2). Deeply incised sections in several tributaries are directly downstream of ford crossings. Landholder observations that these sections have changed little over the past 30 years (P Broad, pers comm 2000) suggests that the ford crossings may have halted further upstream progress of the associated erosion heads and that erosion has stabilised to some extent.

Plate 10.1 Booborowie Creek: the ephemeral channel and lack of native watercourse vegetation is typical of Booborowie Creek.

Plate 10.2 A typical tributary of Booborowie Creek: these ephemeral tributaries lack native vegetation and show severe bank and bed erosion. These areas are likely to be a major cause of downstream sedimentation.

Booborowie Creek and its floodplain have been subject to sedimentation as a result of the extensive erosion of its catchment and tributaries. Some channelisation has been carried out to divert floodwaters and drain the floodplain to enable the cultivation of lucerne (Brizga 2000a). For example, a section of Waltons Palace Creek was channelised to divert floodwaters from Booborowie township. This has caused a very deep and unstable incision that is still actively eroding. The tributary is a likely major source of sediment for downstream areas.

Vegetation

Booborowie Creek and its tributaries are ephemeral watercourses. Waterholes were only observed along Waltons Palace Creek and Cartapo Creek. However, anecdotal evidence suggests that in the early years of the 20th century, the valley was one large expanse of swamps and marshes with a very shallow groundwater table (Flint 1972). The combination of drought years, irrigation and the growth of lucerne crops is a possible cause for a large drop in standing water levels (Clarke 1990), with the subsequent loss of these swamp habitats.

The riparian zone is degraded along the entire length of the creek and its tributaries due to a lack of native vegetation. Large sections of watercourse have been cultivated. The riparian vegetation is now dominated by extensive stretches of annual grassland (annual exotic grasses or crops with less than 10% overstorey (66% of zone)) with small sections of sedgeland (13% of zone) and cottonbush (*Maireana aphylla*) shrubland (3% of zone) (Map 7.1). There are limited infestations of sparse wild artichoke (*Cynara cardunculus*) along Booborowie Creek and Waltons Palace Creek. Emergent aquatic plants, mainly common reed (*Phragmites australis*) and bulrush (*Typha* spp.), grow sparsely in the lower reaches of the Booborowie Creek, along Waltons Palace Creek and Cartapo Creek.

The pre-European vegetation of the northern reaches of the creek was likely to have been an open woodland dominated by South Australian blue gum (*Eucalyptus leucoxylon*) and drooping sheoak (*Allocasuarina verticillata*) (Brown and Kraehenbuehl 2000). The lower reaches were likely to have been tall open shrubland consisting of native apricot (*Pittosporum phylliraeoides*), native hop (*Dodonaea viscosa*) and sweet bursaria (*Bursaria spinosa)* (Map 5.3). Most of the vegetation has been cleared for agricultural purposes.

Fish and macro-invertebrates

No fish or macro-invertebrate surveys were conducted along the creek or its tributaries. It is unlikely that fish exist along the watercourse because of the lack of permanent water. However, opportunistic macro-invertebrates that respond rapidly to the presence of water may breed after rainfall events.

Important flow bands

- *Mid flows* at this extent create a temporary shallow aquatic habitat across the bed of the watercourses that opportunistic macro-invertebrates may use for breeding. The flows are important in moving nutrients, sediments and pollutants through the system.
- *Bankfull and overbank flows* are important for recruiting and establishing riparian sedgeland plants. The flows also transport sediment and organic matter, and drive natural channel-forming processes.

10.2.2 BALDRY AND YAKILO CREEKS

Geomorphology and hydrology

Baldry Creek and the uppermost 700 m of Yakilo Creek are part of this subcatchment. Baldry Creek arises in the northern Mount Lofty Ranges and drains northward to join Booborowie Creek and form Yakilo Creek. The Baldry valley reflects the underlying geology and runs parallel to the main fold lines. The downstream reaches cut across the main direction of folding and flow westward through a gap between Camels Hump and Brown Hill ranges. This creek is considered to be a single geomorphic zone (Map 5.2, Section 5.2).

Baldry Creek, particularly the lower reaches, and the most upstream section of Yakilo Creek typically have a wide channel with reaches of dense reedbeds (Plate 10.3). Sections in the upper reaches of Baldry Creek have been channelised and sedimentation is likely to have occurred as a result of catchment erosion (Brizga 2000a). Areas of sedimentation are particularly evident in the upstream reaches of the creek, where the channel is very wide and bare of vegetation. These areas are a potential cause of sedimentation for downstream areas.

Plate 10.3 Downstream reaches of Baldry Creek: these areas consist of dense reedbeds dominated by the common reed with a thin line of riparian sedges surrounded by cropping land. Upstream reaches lack in-stream and riparian vegetation and may cause sedimentation in the lower areas.

Vegetation

Baldry Creek has regular winter flows, some permanent pools in its downstream reaches, and large stretches of permanent groundwater seeping in the upstream reaches that provide aquatic habitat. The regular winter flows and groundwater seeps have been observed to have very high salinity levels. This is particularly evident in upstream reaches of Baldry Creek where a salt crust has formed in the watercourse bed. Salinity remediation works such as constructing drains and revegetating with saltbush have been carried out in this area. Regular winter flows, although saline, are still important to flush salts through the system to prevent it building up in the channel. Salinity levels within this zone should be monitored.

Reedbeds, dominated by common reed and bulrush, cover 35% of the in-stream zone of Baldry Creek. They extend along the uppermost section of Yakilo Creek and continue upstream intermittently for about 15 km along Baldry Creek. Permanent baseflow in Yakilo Creek, regular winter flows and the presence of waterholes in the lower reaches of Baldry Creek support these macrophyte beds and provide aquatic habitat.

Watercourse vegetation along Baldry Creek alternates between stretches of native sedgeland (31% of zone) and areas that have a poor cover of native vegetation and are dominated by exotic annual grasses (61% of zone). The exception is a stretch of samphire marshland in the upper reaches where salinity levels are very high. There are some limited infestations of sparse wild artichoke along Baldry and Gum creeks.

The pre-European vegetation of the northern reaches of Baldry Creek was likely to have been a low woodland dominated by South Australian blue gum and golden wattle *(Acacia pycnantha)* (Brown and Kraehenbuehl 2000). The lower reaches were likely to have been a tall open shrubland consisting of native apricot, native hop and sweet bursaria (Map 5.3). Most of the vegetation has been cleared for agricultural purposes.

Fish and macro-invertebrates

No fish or macro-invertebrate surveys were conducted for Baldry Creek. There is permanent water and so populations may exist but it is likely that the composition of any population along Baldry Creek is restricted by the high salinity level.

Important flow bands

- *Groundwater* is very important in this zone for maintaining permanent pools along Baldry Creek and providing soil moisture to support the riparian sedgelands and in-stream reedbeds along Baldry and Yakilo creeks.
- *Baseflow*, found along Yakilo Creek only, is important for maintaining permanent aquatic habitats and emergent aquatic plants.
- *Mid flows* maintain water quality and increase the amount of aquatic habitat for aquatic flora and fauna.
- *High to bankfull flows* are important for recruiting and establishing riparian sedgeland plants. These flows transport sediment and organic matter, scour pools and drive natural channel-forming processes.

10.3 Management issues

The primary management concern for landholders within the subcatchment was the weed infestations along the watercourse, particularly on the tributaries. Other management issues include flooding, a lack of knowledge on both the function of the groundwater table and salinity in the system, erosion, siltation of culverts and watercourses, and rubbish in the tributaries.

10.3.1 ISSUES AFFECTING ENVIRONMENTAL WATER REQUIREMENTS

There is no gauging station along Booborowie, Baldry or Yakilo creeks and runoff rates, flow volumes, frequencies and duration are largely not known; nor are the interactions between groundwater and surface flows for these watercourses. Substantial infiltration to the groundwater in the Booborowie Valley is likely.

Surface water resource development in the subcatchment is limited to some small dams in the lower reaches of Baldry Creek. Further development is unlikely because of the high salinity levels in Baldry Creek and the ephemeral nature of Booborowie Creek.

There is extensive use of groundwater within the Booborowie Valley, primarily for irrigating lucerne crops. Anecdotal evidence from the early 1900s suggest that the valley, historically, was a large expanse of diverse swamps and marshes. Early settlers struck water while digging postholes for fencing. With an abundance of water, intensive lucerne cropping began in the 1920s and is believed to have caused a long term lowering of the groundwater table (Cobb and Smith 1977). In the 1970s, Flint (1972) reported groundwater levels to be around 8–9 m below ground level. Clarke (1990) indicated that extraction rates in the valley during the late 1980s were about 1200 ML/annum, and that this extraction, along with water used for lucerne crops, was the most likely cause for recorded falls in standing water levels.

Groundwater extraction and development of the land for agriculture has had a significant impact on the water regimes and riverine ecosystems in this area. The valley today is a much drier landscape than it once was. Monitoring and investigation are needed to determine the sustainable yield of groundwater in this area.

10.3.2 WATERCOURSE MANAGEMENT PRIORITIES AND STRATEGIES

Ensuring environmental water requirements are being met will not result in a healthy river system unless the ecosystems dependent on these water requirements are maintained and protected. Consequently, the project assessed the condition of the major watercourses of the subcatchment and, in consultation with landholders, identified significant watercourse management issues (see Map 10.1 for locations).

Table 10.1 lists the significant watercourse management issues in order of priority and outlines strategies for their management. High, medium and low priorities have been set largely in terms how much improvement in watercourse health is possible for the cost and effort required. Thus a low priority issue is not insignificant; it may simply not require immediate attention or it may incur costs that outweigh the benefits on a subcatchment scale. Appendix F contains a discussion of the principles and guidelines used to help determine priorities.

Community priorities for management, based on votes by landholders at a meeting on 13 April 2000 are listed in Table 10.1. Management of these issues will largely be the responsibility of landholders, regional organisations and the local community and the priorities indicate community views and interests in undertaking river rehabilitation works.

Table 10.1 Management priorities and options for the Booborowie and Baldry subcatchment

Management issue (length)	Management strategies	Sub-catchment health priority	Community priority
Lack of native watercourse vegetation (20.9 km)	• Revegetate with a full range of local native plants, including groundcovers, grasses, shrubs and trees • Leave a vegetated buffer — at the least, a good continuous grass cover — between cultivated areas and the watercourse • Manage livestock to avoid damage to vegetation and to encourage natural regeneration	High	–
Improving/maintaining areas of good native vegetation (includes remnant vegetation) (2 km)	• Manage livestock to avoid damage to vegetation and to allow natural regeneration • Remove or control weeds and limit the opportunity for weeds to invade • Monitor sites regularly	Medium	High
Erosion heads and poor bank stability (7.5 km)	• Monitor sites to determine if erosion is active • Restrict stock access — revegetate or encourage vegetation within the channel for long-term stabilisation • Choose native species that can grow within the channel, produce a dense root mat and handle flooding • Seek professional advice for erosion control works (e.g. rock chutes, drop structures) which may be needed together with revegetation where erosion threatens a high value asset or is severe	Medium	High
Stream works causing, or threatened by, erosion (5 sites)	• Monitor sites to determine if erosion is active • Ensure stream works (e.g. culverts, fords, bridges) are located on straight and stable parts of a watercourse, are correctly aligned, have secure footings and are designed to handle the flow capacity • Seek professional advice for erosion control works (e.g. rock chutes, drop structures) which may be needed together with revegetation where erosion threatens a high value asset or is severe	Medium	High
Salinity (6.7 km)	• Further investigate dryland, groundwater and surface water salinity trends to determine the extent and causes of salinity	Medium	-
Riparian weed removal and control (species observed include wild artichoke) (8.6 km)	• Remove by hand, spraying, burning or mechanical techniques depending on the site and the density of the infestation: care is needed to prevent disturbance to watercourse bed and banks • Control by: - regular spot spraying (using herbicides recommended for use near a waterway) or hand removal - shading out weeds by retaining canopy cover and avoiding disturbance to the natural vegetation - excluding livestock to prevent disturbance to ground and riparian vegetation • Allow natural regeneration or revegetate with local native species to re-establish habitat, prevent erosion and allow riparian shading	Low	Low
Other — cultivated watercourses (22.2 km)	• Maintain a perennial cover of grasses to reduce the potential for erosion and sediment transport	Low	–

Significant watercourse management issues

Protecting areas of good vegetation is a significant management issue for the upper reaches of Booborowie Creek and Yakilo Creek. Along Booborowie Creek there is chenopod shrubland dominated by cottonbush and along Yakilo Creek there are sedgelands dominated by the *J. kraussii* rush. Remnant sedgelands are located along a third order tributary of Baldry Creek. These areas are important on a subcatchment scale as the overall lack of watercourse and floodplain vegetation limits the habitat value of the watercourses in the subcatchment. They support a diversity of watercourse plant species that may be lacking in other areas of the subcatchment and are remnants of the original native riparian vegetation. They have a higher habitat value than more degraded areas and play a role in channel stability and in filtering runoff.

Wetter areas with a diversity of vegetation structures across the riparian zone support macro-invertebrates, reptiles and birds. The drier areas are likely to be important for opportunistic aquatic biota that respond rapidly to flows. These can be important processes for the long-term survival of macro-invertebrates and nutrient processing with significant implications for downstream processes as well.

The lack of native watercourse vegetation or vegetation in poor condition was a significant issue across 20% of the watercourses. Poor watercourse vegetation means the habitat value of the watercourse is limited. In addition, these areas are prone to erosion in large flow events. In some areas the practice of cropping paddocks to the top of the banks or cultivating through the watercourse has not retained a buffer strip of perennial vegetation to slow and filter runoff and to trap sediment and nutrients.

Approximately 21% of the watercourses are cultivated and no longer discernible from the surrounding landscape (classified as *Other* on Maps 10.1 and 7.7). Potential erosion issues can arise with watercourse cultivation when there is little to no vegetation cover (such as after ploughing). The large volumes of rainfall runoff in storm events follow the drainage line, thereby increasing the potential for significant erosion. Ideally, these areas should retain a vegetative cover to slow runoff and prevent soil erosion.

Riparian weeds are a significant management issue along 8% of the watercourses in the subcatchment. The main weed infestation observed was wild artichoke. Landholders suggest that onion weed (*Asphodelus fistulosus*) and nightshade (*Solanum* spp.) are becoming a problem in the lower middle reaches of Booborowie Creek and along its tributaries.

The stability of most watercourses in the subcatchment was classified as good (76%). Some watercourses were classified as having moderate (8%) or poor stability (5%). Poor bank stability, an indicator of active bed and bank erosion, is a significant issue along several tributaries flowing from the eastern hills into Booborowie Creek. In these tributaries the deeply incised sections are directly downstream of a ford crossing, indicating that the erosion event has moved upstream and been halted by the ford. The stability of these areas should be addressed before any revegetation is attempted. This ongoing erosion is a likely major source of sediment to downstream areas.

The small (<1 m) to moderate (1–2.5 m) sized erosion heads along Booborowie Creek are relatively stable. They do not appear to be actively eroding or are located downstream of rock bars or other control features. These are not a significant management issue.

Based on landholders' comments and observations of surface salt along the channel, salinity was considered a significant issue along approximately 7 km of the upper reaches of Baldry Creek. Groundwater monitoring in the Booborowie Valley since the early 1970s has shown an increase in groundwater salinity levels in 70% of the bores monitored until 1997 (Clarke 1990). The trend since then has been to decreasing salinity levels (D Clarke, pers comm 2000). The reasons for this are not known. Further studies are required to determine groundwater and surface water salinity trends in the subcatchment and along the Baldry Creek in particular.

No significant watercourse management issues were recorded along 35% of the watercourses. Typically these areas were dry grassy or reedy channels.

10.3.3 OTHER ISSUES

Channel modifications

Channelisation and drainage to enable cropping along the creek flats have modified the watercourses in the subcatchment significantly. Channelisation of the Booborowie Creek watercourse was implemented to divert floodwaters and drain the floodplain to enable the cultivation of lucerne. A section of Waltons Palace Creek, which was channelised to divert floodwaters from the town of Booborowie, has caused a very deep and unstable incision that is still actively eroding.

10.4 Monitoring and information gaps

Effective river management requires a sound knowledge of the river system. River systems are dynamic and function on a range of timescales. Limited long-term data means that management recommendations should be reviewed in the light of information collected over a longer timescale. The priority monitoring issues for the Booborowie and Baldry subcatchment are:

- groundwater usage, levels and salinity trends;
- water quality monitoring (surface and groundwater);
- surface flow hydrology (duration, frequency and quantity); and
- physical effect of high flows (including erosion, deposition and substrate maintenance).

Several gaps and limitations in the current data are also apparent. Special research projects, which address particular questions and gaps in our knowledge, are essential to develop a sounder information base for river management. The investigations needed to enable better management of the Booborowie and Baldry subcatchment are:

- the extent of sediment movement from eroded tributaries in the subcatchment to Yakilo Creek and the Broughton River;
- surface–groundwater interactions;
- the role of surface flows as they relate to the ecology of the system (fauna and flora);
- the impact of groundwater usage on in-stream vegetation;
- the reasons for recent (since 1997) decreases in groundwater salinity levels;
- the impact of lucerne crops on local flows and salinity; and
- the presence of temporary freshwater swamps after rainfall events and their use by macro-invertebrates.

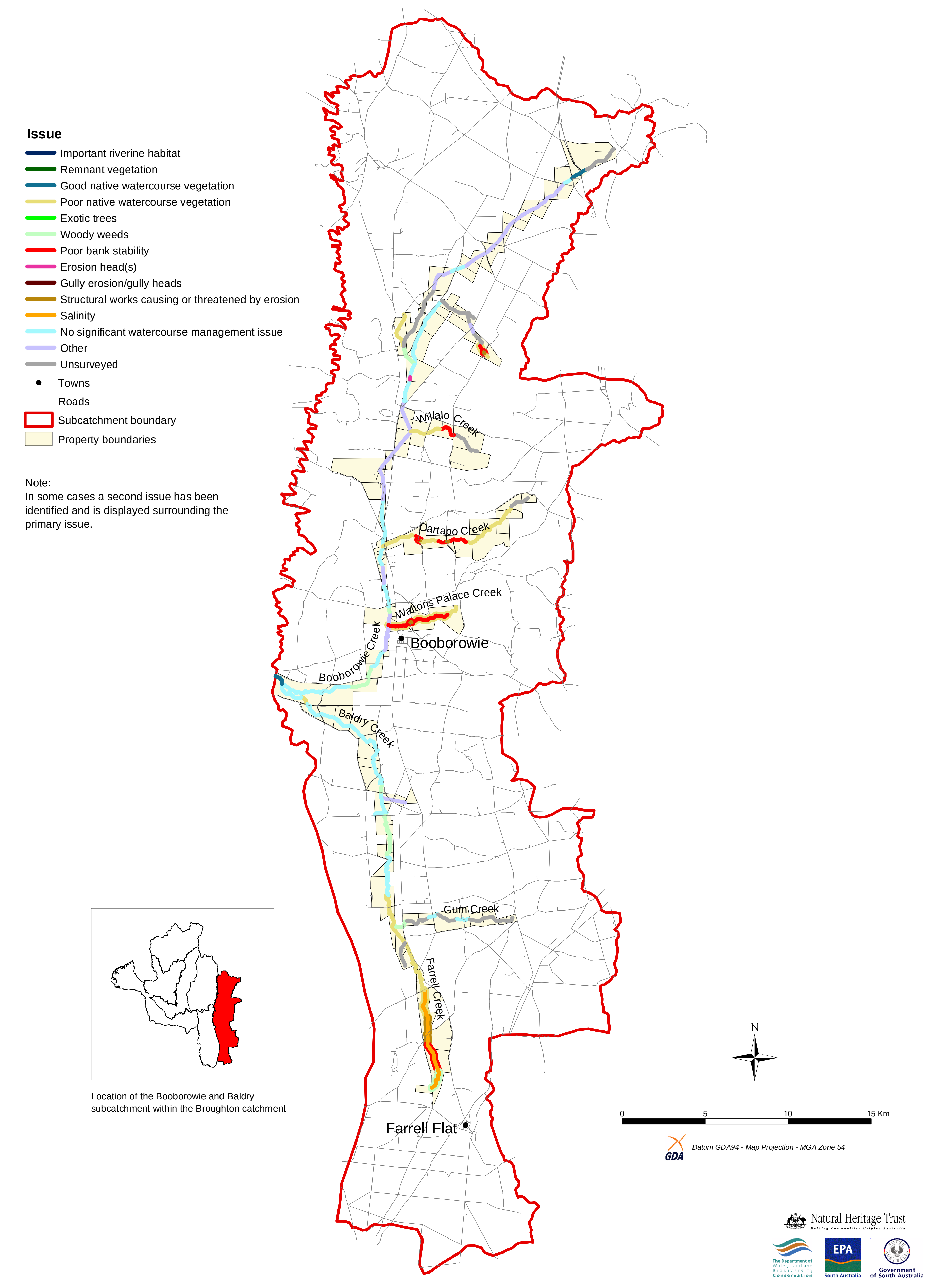
10.5 Summary

Watercourses in the Booborowie and Baldry subcatchment once encompassed a variety of environments ranging from open woodlands in the upper reaches of Booborowie Creek and low woodlands in the upper reaches of Baldry Creek, through to tall open shrublands in the lower reaches of both watercourses and their tributaries.

However, most of the watercourses in the subcatchment have been modified significantly. The biodiversity of the system is low, particularly in native vegetation. The riverine environment of Booborowie Creek has changed dramatically since European settlement because of the extensive lowering of the groundwater table. Landholders noted that the Booborowie Creek environment has changed from a series of marshes and swamps to a dry, ephemeral watercourse with little native vegetation. While dry years have had an effect, the most likely cause is the extensive extraction of groundwater for irrigating lucerne crops.

No fish or macro-invertebrate surveys were carried out in the subcatchment. It is unlikely that fish exist in the area because of the lack of permanent water and very high salinity levels. Macro-invertebrate populations would also be expected to be restricted for the same reasons.

Threats to the health of watercourses within the subcatchment include: the clearance of vegetation and the cultivation of crops to the edge of, and within, watercourses; channelisation; erosion; sedimentation; and the presence of weeds. Managing these threats is very important. The priorities include: revegetating areas lacking native watercourse vegetation; improving and maintaining areas of good native vegetation; managing erosion heads, poor bank stability, and stream works causing, or threatened by erosion; and further investigation of groundwater usage, levels and salinity trends.



Map 10.1: Watercourse management issues in the Booborowie and Baldry subcatchment

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CHAPTER 11 THE FRESHWATER AND BUNDALEER SUBCATCHMENT

11.1 Introduction

This chapter discusses the watercourse management and environmental water requirements for the Freshwater and Bundaleer subcatchment. The key water dependent physical and ecological environments and processes for the geomorphic zones within this subcatchment are described. This includes the vegetation, fish and macro-invertebrates in the area. The important flow bands needed to maintain the environments, processes and associated plants and animals are described for each zone. Appendix E contains a more detailed description of the environmental water requirements including recommended frequency, duration and seasonality of flows.

The chapter describes key management issues that impact on the watercourse environments and outlines the environmental water requirements of these environments. The priorities and strategies for watercourse management based on the input of landholders and the results of the survey of watercourses in the subcatchment are tabled. The chapter closes with a discussion of information gaps and monitoring needs that have been highlighted by the project.

The subcatchment includes the Freshwater and Bundaleer creek systems which are major tributaries of the Broughton River. The major tributaries of the Bundaleer Creek system are Never Never and Baderloo Creeks. Belalie Creek and Jacka Creek, also in the subcatchment, are major tributaries of Baderloo Creek.

The dominant land use within the subcatchment is cropping and grazing. There is some urban development along Belalie and Jacka creeks where they flow through Jamestown and along Freshwater Creek where it flows through Spalding.

11.2 Water dependent ecosystems and processes

11.2.1 FRESHWATER CREEK

Freshwater Creek rises in the northern Mount Lofty Ranges near Jamestown and flows south towards the Broughton River. The north–south alignment of the creek follows the pattern of folding of the ranges. Rainfall-driven surface flows through the creek contribute to the Broughton River mostly during heavy summer storm events. The creek also contributes groundwater dependent baseflows for most of the year. The Freshwater Creek valley contains extensive deposits of alluvium (Brizga 2000a), thus there is a high potential for erosion. The creek has been divided into three river geomorphic zones (Map 5.2; Section 5.2):

- Zone 1 — Broughton River to 10 km upstream of Spalding.
- Zone 2 — 10 km upstream of Spalding to 1 km upstream of Washpool Road.
- Zone 3 — upstream of Zone 2.

Zones 1 and 2

Geomorphology and hydrology

The stream channel in Zones 1 and 2 (Broughton River to 1 km upstream of Washpool Road; Map 5.2) is deeply incised, more than 20 m deep in sections, with extensive sections of deep gullying erosion. Zone 1 is characterised by permanent baseflow and in-stream physical habitats include reedbeds, permanent pools and riffles (Plate 11.1). Zone 2 does not have permanent baseflow but supports reedbeds and some pool environments. Key habitats within the incised channel include reedbeds, pools, sedgelands and rock bars (Plate 11.2) (Brizga 2000a).

Plate 11.1 Freshwater weir on Freshwater Creek, Zone 1: this zone is characterised by permanent baseflow and dense reedbeds. This site was considered an important riverine habitat with pools, flowing water, and a diversity of in-stream and riparian vegetation.

It is likely that the natural watercourse in these zones has been altered as a result of incision. The cause of this incision is not known although the straightness of some sections suggests that channelisation may have been a contributing factor (Brizga 2000a). Gully erosion and incision along the main channel and tributaries have released large amounts of sediment that are deposited in downstream reaches of Freshwater Creek and the Broughton River (South Australian Fly Fishers Association, pers comm). This is particularly evident at the Freshwater weir which has been significantly infilled with sediment from upstream erosion. Several large erosion heads indicating bed deepening were identified along Freshwater Creek. One of these separates Zone 2 from Zone 3. Several large rock bars in Zone 1 have acted as erosion control structures to halt the headward progression of the bed erosion.

Vegetation

The watercourse vegetation along Zones 1 and 2 is highly modified. Exotic annual grasses or crops with less than 10% overstorey cover more than 80% of the watercourse. Along the lower reaches, some small areas have a sparse shrub overstorey and chenopod shrublands dominated by cottonbush (*Maireana aphylla*) and lignum (*Muehlenbeckia florulenta*). Dense stands of common reed (*Phragmites australis*) and bulrush (*Typha* spp.) dominate the in-stream vegetation over the length of the zones. A range of other rushes and sedges (such as *Bolboschoenus caldwellii, Carex appressa, Cyperus gymnocaulus*) are also found in the in-stream zone (Brown and Kraehenbuehl 2000). Wild artichoke (*Cynara cardunculus*) is a significant weed species along watercourses in Zone 1 — it affects at least 22% of watercourses. There is some revegetation through Spalding, including native and exotic trees (such as peppertree, *Schinus areira*).

Plate 11.2 Freshwater Creek, Zone 2 showing reedbed habitats and riparian vegetation dominated by the chenopod *Mairiana aphylla.* This zone has a deeply incised channel with extensive areas of deep gully erosion.

Prior to European settlement, the in-stream vegetation along Freshwater Creek would most likely have been a closed herbland/sedgeland complex (Brown and Kraehenbuehl 2000). The herbland dominated by common reed and the sedgeland dominated by rushes (e.g. *Juncus kraussii*) and sedges (e.g. *Cyperus gymnocaulus)*. The bank vegetation was probably a tall open shrubland, dominated by weeping emubush (*Eremophila longifolia*), golden wattle (*Acacia pycnantha*) and sweet bursaria (*Bursaria spinosa*). Open woodlands of South Australian blue gum *(Eucalyptus leucoxylon*) and drooping sheoak (*Allocasuarina verticillata*) were probably present along the smaller tributaries.

Fish and macro-invertebrates

Permanent baseflow, pools and reedbeds along Zone 1 provide important habitats for aquatic flora and fauna. The shallow groundwater table along Zone 2 supports reedbeds and some pool environments (Plate 11.2). No macro-invertebrate and fish surveys were conducted for Freshwater Creek but it is likely that the permanent water and associated in-stream and aquatic vegetation in Zone 1 would support macro-invertebrates and some native fish populations. However, Freshwater weir located in the middle reaches of Zone 1 presents a barrier for any migrating fish populations.

Important flow bands — Zone 1

- *Baseflow* in this zone flows almost continuously with a seasonal increase over winter–spring. Baseflow is very important for maintaining flow over riffles and supporting a diverse range of habitats for macro-invertebrates, frogs and, possibly, native fish. Also, it is important for maintaining hyporheic environments (where present) and providing soil moisture to support the riparian sedgelands and in-stream reedbeds.
- *Seasonal low flows* are a result of surface flows and a seasonal increase in baseflow. The flows are important in increasing the area of the aquatic habitat available for fish, frogs and macro-invertebrates, in recharging the hyporheic zone and in maintaining water quality.
- *Mid flows* are important for the migration of native fish (below the Freshwater weir) and the migration of macro-invertebrates. They are also important for increasing the area of the aquatic habitat available for fish, frogs and macro-invertebrates.
- *High flows* are important for transporting sediment, organic matter and nutrients, for removing fine sediments from riffle zones and for channel-forming processes. The flows also play a role in recruiting and establishing riparian vegetation, especially riparian sedgelands.

Important flow bands — Zone 2

- *Groundwater* maintains soil moisture and permanent pools where the groundwater table intersects the river bed. This is important in this zone for supporting permanent aquatic habitats, in-stream reedbeds and hyporheic environments.
- *Mid flows* are important for increasing the area of aquatic habitat available for fish, frogs and macro-invertebrates. If there are populations of native fish upstream of the weir, the flows would be important for their local migration and breeding.
- *Bankfull flows* are important for transporting sediment, organic matter and nutrients, for removing fine sediments from riffle zones, for scouring pools and for channel-forming processes. The flows also play a role in recruiting and establishing riparian vegetation, especially riparian sedgelands

Zone 3

Geomorphology and hydrology

Zone 3 (upstream of a major erosion head at Kanowna Hut; Map 5.2) is a shallow, dry grassy channel (Plate 11.3) that contrasts with the incised nature of Zones 1 and 2. The watercourse is ephemeral with grassy beds and extensive cultivated sections that are indistinguishable from the surrounding landscape. Sedimentation may have occurred in this zone as a result of soil erosion in the catchment (Brizga 2000a).

The creek in this zone has no permanent aquatic habitat. When flow does occur, it is unlikely that water persists long enough to permit the breeding of opportunistic macro-invertebrates.

Vegetation

No significant areas of native watercourse vegetation remain. Annual exotic grasses with less than 10% overstorey comprise the dominant vegetation along the watercourses of the zone. Large sections of the watercourse have been cultivated.

The current lack of native watercourse vegetation makes it difficult to determine the original vegetation along this zone. It is estimated that before European settlement the vegetation was probably a tall open shrubland, dominated by weeping emubush, golden wattle and sweet bursaria (Brown and Kraehenbuehl 2000). Open woodlands of South Australian blue gum and sheoak were probably present along the smaller tributaries.

Plate 11.3 Freshwater Creek Zone 3: this mostly dry grassy channel is cultivated in many places. In this photograph the watercourse has been channelised and straightened.

Important flow bands

Sections of the watercourse in Freshwater Creek Zone 3 are quite shallow. Therefore bankfull and overbank flows in this zone will result in mid and high flows respectively in downstream zones.

- *High bankfull flows* are important for transporting organic matter and nutrients to downstream zones and for recruiting and maintaining riparian vegetation. However, the poor condition of the riparian vegetation limits the importance of this function without rehabilitation.

- *Overbank flows* are important for transporting sediment and channel-forming processes. The poor condition of the riparian and floodplain vegetation limits the ecological functions of these flows. If healthy native vegetation was present the flows would be important for connecting the floodplain to in-stream environments and for maintaining riparian and floodplain vegetation.

11.2.2 BUNDALEER, BADERLOO AND BELALIE CREEKS

Bundaleer and Baderloo creeks arise in the northern Mount Lofty Ranges and flow south towards the Broughton River. Belalie Creek is a major tributary of Baderloo Creek. Like Freshwater Creek, their valley alignments reflect geological structural controls. Alluvial deposits occur in the valley floors, although they are less extensive than in the Freshwater Creek valley. Rainfall-driven surface flows through these systems contribute to the Broughton River mostly during heavy summer storm events. The lower reaches of Bundaleer Creek appear to contribute a permanent baseflow to the Broughton River.

The Bundaleer–Baderloo–Belalie Creek system has been divided into three river geomorphic zones (Map 5.2; Section 5.2):

- Zone 1 — Bundaleer and Baderloo creeks to the Washpool (lower 6 km); Belalie Creek from its confluence with Jacka Creek to 6 km upstream of Jamestown.
- Zone 2 — Baderloo Creek from the Washpool to the ford adjacent to Bundaleer forest.
- Zone 3 — Baderloo Creek upstream of Zone 2; sections of Belalie Creek upstream and downstream of Zone 1.

Zones 1 and 2 (Bundaleer, Baderloo and Belalie creeks)

Geomorphology and hydrology

The watercourse channel in Zone 1 along Bundaleer and Baderloo creeks (lower 6 km to the Washpool; Map 5.2) is moderately to deeply incised and characterised by permanent baseflow. The natural channel shape has been modified substantially by stream incision (Brizga 2000a). Channelisation may have caused or contributed to this incision. The significant amount of silt build-up behind Bundaleer weir on Bundaleer Creek suggests extensive soil erosion upstream. The weir affects stream geomorphology by disrupting the transport of sediment downstream (Brizga 2000a). A large erosion head in the lower reaches of Bundaleer Creek indicates that bed deepening processes are still active in this zone.

Belalie Creek in Zone 1 (from confluence with Jacka Creek to 6 km upstream of Jamestown; Map 5.2) varies from a channel constrained by rolling hills north of Jamestown to a moderate channel with a floodplain downstream of this area. The natural physical characteristics of the channel at Jamestown have been changed by stream incision and engineering works. Levee banks have been constructed along the creek through Jamestown to prevent flooding as have weirs to provide permanent pools as part of the town's parklands. Key habitats in Zone 1 include continuous baseflow, reedbeds and some sedgeland environments (Plate 11.4).

Key habitats in Zone 2 (Baderloo Creek from the Washpool to the ford adjacent to Bundaleer forest; Map 5.2) include permanent pools, reedbeds and sedgelands. The zone is moderately incised. It is characterised by areas of significant in-stream vegetation supported by a shallow groundwater table but contains no permanent baseflow (Plate 11.5). Permanent waterholes are also a feature of the zone. The natural channel shape and physical habitats have been modified substantially by stream incision (Brizga 2000a) and channelisation.

Plate 11.4 Bundaleer Creek, Zone 1: the watercourse is moderately to deeply incised and has permanent baseflow. The in-stream vegetation is characterised by reedbeds dominated by common reed and bulrush with a range of other rushes and sedges. There is little native vegetation on the banks.

Plate 11.5 Baderloo Creek, Zone 2: the watercourse in this zone is moderately incised and characterised by areas of reedbeds supported by a shallow groundwater table interspersed with areas of dry, grassy channel.

The in-stream vegetation is characterised by extensive, dense to mid-dense stands of emergent aquatic plants dominated by common reed and bulrush with a range of other rushes and sedges (such as *B. caldwellii, Isolepsis cernua* and *Schoenoplectus pungens*). High levels of sedimentation from localised and upstream erosion may be creating ideal habitats for the more common emergent aquatic plants.

The pre-European vegetation is likely to have been a tall open shrubland of weeping emubush, golden wattle and sweet bursaria located on the banks (Brown and Kraehenbuehl 2000). A closed herbland and sedgeland complex dominated by common reed, rushes and sedges would have grown along the lower banks and benches. Woodlands dominated by South Australian blue gum, sheoak and golden wattle would probably also have been present along the upper reaches of Bundaleer Creek upstream of its confluence with Baderloo Creek.

Fish and macro-invertebrates

Macro-invertebrate sampling in Zone 1 just below Bundaleer weir, indicates that this area is relatively healthy in terms of the associated macro-invertebrate population (Madden et al. 1999). The permanent baseflow of good quality water and the range of in-stream vegetation in Zone 1 support a significant diversity of macro-invertebrates. In particular, the permanency of flow in this zone is important for supporting macro-invertebrate species that require flow for feeding (e.g. caddisflies of the genus *Cheumatopsyche*).

This site was the only point where the water boatman (*Diaprepocoris barycephala*) was found. This wetland species is rarely collected from streams (Madden et al. 1999) The extensive reedbeds upstream and downstream of the site could serve as a refuge for this species (Madden et al. 1999).

No sampling was conducted in Zone 2, but the pools and reedbeds would provide suitable habitats for fish and macro-invertebrate populations. Fish populations were not surveyed for watercourses in the subcatchment. Fish are probably present but Bundaleer and Freshwater weirs would be barriers to their migration.

Water quality monitoring of Belalie Creek (Zone 1) within Jamestown indicated regular periods of elevated nutrient levels and associated algal blooms, and consistent high salinity levels of 5150–6250 μS/cm (estimated 3296–4000 mg/L) (S Heaslip, pers comm 2000). Any macro-invertebrate and fish populations in this area could be affected detrimentally by these concentrations.

Important flow bands — Zone 1 (Bundaleer, Baderloo and Belalie creeks)

- *Baseflow* in this zone flows almost continuously with a seasonal increase over winter–spring. Baseflow is very important for maintaining flow over riffles and supporting a diverse range of habitats for macro-invertebrate, frogs and, possibly, native fish. Also, it is important for maintaining hyporheic environments (where present) and providing soil moisture to support the riparian sedgelands and in-stream reedbeds.
- *Seasonal low flows* are a result of surface flows and a seasonal increase in baseflow. The flows are important for increasing the area of the aquatic habitat available for fish, frogs and macro-invertebrates, recharging the hyporheic zone and maintaining water quality.
- *Mid flows* are important for the migration of native fish (below the weir) and of macro-invertebrates. They are also important for increasing the area of the aquatic habitat available for fish, frogs and macro-invertebrates.

- *High flows* are important for transporting sediment, organic matter and nutrients, for removing fine sediments from riffle zones and for channel-forming processes. The ecological functions of high flows will be limited because of the modification of riparian and floodplain vegetation and the construction of works to prevent flooding.

Important flow bands — Zone 2 (Baderloo Creek)

- *Groundwater* maintains soil moisture and permanent pools where the groundwater table intersects the river bed. It is important in this zone for supporting permanent and semi-permanent aquatic habitats, including pools, in-stream reedbeds and hyporheic environments.
- *Mid flows* are important for increasing the area of aquatic habitat available for frogs and macro-invertebrates, and for maintaining connectivity between pool environments.
- *Bankfull flows* will maintain native riparian and floodplain vegetation where it exists. These flows are important for transporting sediment, organic matter and nutrients, for scouring pools and for channel-forming processes.

Zone 3 (Baderloo and Belalie creeks)

Geomorphology and hydrology

Baderloo Creek in Zone 3 (upstream of Zone 2; sections of Belalie Creek upstream and downstream of Zone 1; Map 5.2) is ephemeral with little aquatic habitat and is characterised by a dry grassy channel (Plate 11.6). The watercourse channel varies in depth and alternates between a shallow, a moderate and a deeply incised channel. Conditions have been modified substantially because of stream incision and extensive channelisation in some sections. Areas along the upper reaches have been levee banked. Belalie Creek in Zone 3 is also ephemeral with little aquatic habitat. Channel depth is moderate (1–3 m).

Vegetation

The watercourse vegetation is highly modified and comprises annual exotic grasses or crops with less than 10% overstorey. Woody weeds are restricted to a small stretch of sparse wild rose (*Rosa canis*) in the uppermost reaches. There are some limited areas of closed sedgelands. These areas may be important for opportunistic aquatic biota with resting stages that respond rapidly to flows, hatching and growing to maturity to complete their life cycle. These can be important processes for the long-term survival of macro-invertebrates and for nutrient processing and can have significant implications for downstream processes.

It is estimated that the pre-European vegetation would have been similar to that in Zones 1 and 2. The watercourse vegetation would have been a tall open shrubland dominated by weeping emubush, golden wattle and sweet bursaria (Brown and Kraehenbuehl 2000).

Important flow bands

Sections of the watercourses in Zone 3 (Baderloo Creek and Belalie Creek) are quite shallow. Therefore bankfull and overbank flows will result in mid and high flows respectively in downstream zones.

- *Mid flows* are important for connectivity between upstream and downstream aquatic habitats and to allow the migration of aquatic plants and animals.
- *Bankfull flows* are important for maintaining water quality (by flushing saline areas) and for transporting sediment, organic matter and nutrients.

- *Overbank flows* are important for transporting sediment, organic matter and nutrients, and for channel-forming processes. The poor condition of the riparian and floodplain vegetation limits the ecological functions of the flows. If healthy native vegetation was present the flows would be important for connecting the floodplain to in-stream environments and for maintaining riparian and floodplain vegetation.

Plate 11.6 Baderloo Creek, Zone 3: an ephemeral watercourse with little significant aquatic habitat characterised by a dry grassy channel. The watercourse vegetation is highly modified and comprises annual exotic grasses or crops with less than 10% overstorey.

11.2.3 JACKA CREEK

Geomorphology and hydrology

Jacka Creek, a tributary of Belalie Creek, is an ephemeral watercourse with a dry grassy channel. No geomorphic zones were assigned to this creek (Map 5.2; Section 5.2). Some sections of the creek have been channelised and its lower reaches have been banked with levees to prevent flooding in Jamestown. It is likely that the lower reaches of the creek would once have been shallow, swampy and easily flooded. There is no permanent aquatic habitat. It is unlikely that, when flow does occur, water persists long enough to allow successful breeding of opportunistic macro-invertebrates.

Vegetation

Watercourse vegetation along Jacka Creek has been highly modified. There has been some revegetation along its lower and upper reaches. Other areas were classified as annual exotic grasslands with less than 10% overstorey. Similar to other watercourses in the subcatchment, the pre-European vegetation of this area may have been a tall open shrubland dominated by weeping emubush, golden wattle and sweet bursaria (Brown and Kraehenbuehl 2000).

Important flow bands

The watercourses were not characterised as part of the geomorphological classification and environmental water requirements have not been determined.

11.2.4 NEVER NEVER CREEK

Geomorphology and hydrology

Never Never Creek is constrained by hills and forms a narrow valley. Most of the watercourse structure is controlled by bedrock and erosion is limited to areas of localised alluvial deposits. The channel depth varies from deep to moderate incision. No geomorphic zones have been assigned to this creek (Map 5.2; Section 5.2).

The upper reaches of Never Never Creek are ephemeral and the lower reaches appear to be dry with sedgeland vegetation. The middle reaches, however, have permanent pools, macrophyte beds and semi-permanent baseflow. It is likely that flow during winter–spring connects these pool habitats for most of the season but this flow stops during summer.

Vegetation

The condition and type of the watercourse vegetation is variable. The lower reaches are characterised by sedgelands. The middle reaches have been modified significantly with a cover of annual exotic grasses or crops with less than 10% overstorey. Along the upper reaches, immediately adjacent to the watercourse channel, the dominant vegetation is a mid-dense overstorey of South Australian blue gum with an understorey of sedges and rushes. The surrounding outer banks support a tall shrubland of sheoak, sweet bursaria and golden wattle on the surrounding banks. This vegetation, although modified, is in relatively good condition and is a good indicator of the pre-European vegetation of the area. Key threats include exotics trees (such as ash, *Fraxinus* spp., willow, *Salix* spp) and weeds (such as wild artichoke and wild rose, *Rosa rubiginosa*) that are present in the middle and upper reaches of the creek.

The pre-European vegetation along Never Never Creek was probably woodland dominated by South Australian blue gum, sheoak and golden wattle along the inner banks (Brown and Kraehenbuehl 2000). The outer banks would have supported a tall open shrubland dominated by weeping emubush, golden wattle and sweet bursaria.

Important flow bands

The watercourses were not characterised as part of the geomorphological classification and environmental water requirements have not been determined.

11.3 Management issues

Landholders within the subcatchment were very concerned about springs drying up, the long-term lowering of the groundwater table and reduced surface stream flows. Bed and bank erosion and weeds along the watercourse were considered significant management issues while chemicals in the waterways, flooding and pools filling in with reeds and algae were also raised.

11.3.1 ISSUES AFFECTING ENVIRONMENTAL WATER REQUIREMENTS

Between 1898 and 1903 diversion weirs were constructed on the lower reaches of Freshwater and Bundaleer creeks as part of an aqueduct system to supply the off-stream Bundaleer reservoir. The reservoir has a capacity of 6374 ML; in November 1999 it held 1600 ML (G Hogben, SA Water, pers comm).

Diversions from Bundaleer Creek occur when the flow and salinity levels are suitable. Flow is no longer diverted from Freshwater Creek because of elevated salinity levels (Rolls and Williamson 1991) and that section of the aqueduct has been sold to the Department for Recreation and Sport and it is now part of the Mawson Trail (G Hogben, SA Water, pers comm 2000).

The Freshwater and Bundaleer weirs have altered the flow regimes of the creeks and have most impact on mid and high flows. They are also sediment traps and prevent the transport of sediment along the system. There is evidence of considerable sedimentation upstream of the weirs, both of which are barriers to fish migration along the creeks.

Other than dams for livestock and domestic purposes, there is little other water resource development in the subcatchment.

Protecting and maintaining groundwater levels and baseflow is one of the most critical water resource management issues for the subcatchment. Baseflow from Freshwater and Bundaleer creeks is an important contributor to baseflows in the main channel of the Broughton River. It is also a critical factor in maintaining healthy and diverse riverine ecosystems in the lower reaches of these creeks.

11.3.2 WATERCOURSE MANAGEMENT PRIORITIES AND STRATEGIES

Ensuring environmental water requirements are being met will not result in a healthy river system unless the ecosystems dependent on these requirements are maintained and protected. In this subcatchment, for example, catchment and stream erosion has caused sedimentation of in-stream habitats. Consequently, the project assessed the condition of the major watercourses in the subcatchment and, in consultation with landholders, identified significant watercourse management issues (see Map 11.1 for locations).

Table 11.1 lists the significant watercourse management issues in order of priority and outlines strategies for their management. High, medium and low priorities have been set largely in terms how much improvement in watercourse health is possible for the cost and effort required. Thus a low priority issue is not insignificant; it may simply not require immediate attention or it may incur costs that outweigh the benefits on a subcatchment scale. Appendix F contains a discussion of the principles and guidelines used to help determine priorities.

Community priorities for management, based on votes by landholders at a meeting on 11 April 2000, are listed in Table 11.1. Management of these issues will largely be the responsibility of landholders, regional organisations and the local community and the riorities indicate community views and interests in undertaking river rehabilitation works.

Table 11.1 Management priorities and strategies for the Freshwater and Bundaleer subcatchment

Management issue (length)	Management strategies	Sub-catchment health priority	Community priority
Protection of important riverine habitat (1.5 km)	• Monitor the site regularly to observe any changes or threats (e.g. photo points, Waterwatch) • Control threatening processes such as weeds and livestock access • Revegetate with local indigenous species, if necessary, where vegetation has been modified • Manage upstream or downstream threatening processes (e.g. weed dispersal, erosion)	High	Medium
Improving/maintaining areas of good native vegetation (includes remnant vegetation) (9.5 km)	• Revegetate and/or encourage natural regeneration • Manage livestock to avoid damage to vegetation and to allow natural regeneration • Remove or control weeds and limit the opportunity for weeds to invade • Monitor the site regularly	High (especially along Never Never Creek)	Medium–high
Exotic tree removal and control (4.6 km)	• Remove by cutting down and/or poisoning with a suitable herbicide (depending on the species and its location) • Do not remove all trees in a heavily infested area at the one time • Replace exotic vegetation with suitable native species	High (impacting on areas of good native vegetation)	Low
Gully erosion/gully heads (7.6 km)	• Investigate sites to determine if erosion is active and to locate the cause of erosion • Restrict stock access, allow natural regeneration and revegetate in areas where vegetation has most chance of establishing for long-term stabilisation • Seek professional advice for erosion control works (e.g. rock chutes, drop structures) which may be needed, together with revegetation, where erosion threatens a high value asset or is severe	High	High
Erosion heads (3 sites)	• Monitor sites to determine if erosion is active • Restrict stock access, revegetate or encourage vegetation within the channel for long-term stabilisation • Choose native species that grow within the channel, produce a dense root mat and can handle flooding • Seek professional advice for erosion control works (e.g. rock chutes, drop structures) which may be needed together with revegetation where erosion threatens a high value asset or is severe	Medium (high for Freshwater Creek)	High

Management issue (length)	Management strategies	Sub-catchment health priority	Community priority
Riparian weed removal and control (species observed include boxthorn, wild artichoke) (21.8 km)	• Remove by hand, spraying, burning or mechanical techniques depending on the site and the density of the infestation: care is needed to prevent disturbance to watercourse bed and banks • Control by: - regular spot spraying (using herbicides recommended for use near a waterway) or hand removal - shading out weeds by retaining canopy cover and avoiding disturbance to the natural vegetation - excluding livestock to prevent disturbance to ground and riparian vegetation • Allow natural regeneration or revegetate with local native species to re-establish habitat, prevent erosion and allow riparian shading	Medium (maybe high where impacting on native vegetation)	High
Lack of native vegetation (51 km)	• Revegetate with a full range of local native plants, including groundcovers, grasses, shrubs and trees • Leave a vegetated buffer strip between cultivated areas and the watercourse — at the very least, a good continuous grass cover • Manage livestock to avoid damage to vegetation and to encourage natural regeneration	Medium	Medium
Poor bank stability (1 km)	• Restrict livestock access and revegetate for long-term stabilisation: choose areas where vegetation has most chance of establishing • Choose native species useful for erosion control (e.g. that can grow at the toe of the bank, produce a dense root mat and can handle flooding) • Seek professional advice for engineering works (e.g. rock riprap, gabions, battering) which may be needed where erosion threatens a high value asset or is severe • If bank erosion due to bed deepening (erosion head), control bed deepening processes before attempting to stabilise bank erosion	Low	High
Stream works causing or threatened by erosion (not identified)	• Monitor site to determine if erosion is active • Ensure stream works (e.g. culverts, fords and bridges) are located on a straight and stable part of the watercourse, are correctly aligned, have secure footings and are designed to handle the flow capacity • Seek professional advice for erosion control works (e.g. rock chutes, drop structures) which may be needed together with revegetation where erosion threatens a high value asset or is severe	Low	Low
Salinity (not identified)	• Further investigate dryland, groundwater and surface water salinity trends to determine the extent and causes of salinity	Unknown	Low
Other — cultivated watercourses (12.7 km)	• Maintain a perennial cover of grasses to reduce the potential for erosion and sediment transport	Low	—

Significant watercourse management issues

The area downstream of Freshwater Creek weir is an important riverine habitat because of the diverse shrub cover (most probably the result of revegetation), in-stream vegetation and the presence of permanent flowing water and pools.

Although not classified as an important riverine habitat because of its highly modified condition, Bundaleer Creek downstream of the weir does provide an important aquatic habitat for macro-invertebrate species. The permanent baseflow of good quality water and the range of in-stream vegetation in Zone 1 support a significant diversity of macro-invertebrates (Madden et al. 1999). Sampling at a site below the weir revealed a diverse and healthy macro-invertebrate population. These factors should be considered in managing this section of watercourse.

The areas supporting native vegetation in moderate to good condition across the subcatchment are important because of their scarcity. Although the vegetation has been modified it is likely to respond well to rehabilitation efforts.

These areas include sedgelands at the junction of Bundaleer and Baderloo creeks and sections of the middle and upper reaches of Baderloo Creek. Sedgelands in areas of permanent water represent remnants of original vegetation and key aquatic habitats in a zone where the original channel shape and vegetation has been modified considerably.

Mid-dense stands of South Australian blue gum and sheoak along the upper reaches of Never Never Creek are also in good condition though they have been modified by grazing and have been invaded by weeds and exotic trees. A similar, small section of native trees exists along the upper reaches of a lower tributary of Freshwater Creek. These areas are remnants of pre-European vegetation as well as being important sources of seed for revegetation. They would respond well to weed control and natural regeneration.

Lack of native watercourse vegetation and vegetation in poor condition was a widespread issue in the subcatchment. The absence of native vegetation makes it difficult to determine the original vegetation. Cropping to the top of the banks in some areas means there is no buffer strip of vegetation to slow and filter runoff and to trap sediment and nutrients. For example, sediment and nutrient inputs, and bank erosion along Freshwater Creek are exacerbated by the lack of vegetation and the proximity of cropping/grazing lands to the watercourse. The native vegetation has other key functions: providing food and shelter, stabilising banks and moderating the climate of the watercourse by shading. Fencing and encouraging natural regeneration and/or revegetation should be considered where possible to improve water quality and river health.

Landholders considered riparian weeds to be an important issue. The project survey techniques meant that only larger, generally woody, species such as boxthorn, wild rose, and wild artichoke could be detected easily. Wild artichoke and wild rose were considered a significant problem along the middle and upper reaches of Never Never Creek. The weed infestation is associated with invasion by exotic trees such as ash and willow. Sparse to dense stands of wild artichoke were identified as an issue along the lower reaches of Freshwater and Bundaleer creeks. Wild artichoke and boxthorn were identified as issues along the middle reaches of Belalie Creek and wild rose was an issue along the uppermost reach of Baderloo Creek.

Exotic trees were not a widespread problem in this subcatchment but willow and ash are management problems along the middle and upper reaches respectively of Never Never Creek. These exotic trees threaten an area of good native vegetation and are associated with invasion by woody weeds in these areas. Their management is a high priority for these reaches.

Most of the watercourses (77%) were assessed as having banks of good stability and the rest were classified as moderate stability (13%) or poor stability/actively eroding (1%). Areas of poor bank stability were found along a tributary of Freshwater Creek, which has a short stretch of bank erosion downstream of a small erosion head, and in the middle reaches of Baderloo Creek where bank erosion occurs downstream of a ford.

Gullying erosion was a significant problem along the lower, deeply incised reaches of Freshwater Creek. This erosion is caused by active erosion heads which form incised gullies that radiate out from the main watercourse. These gullies are likely to deepen and widen considerably in heavy rainfall events. There is little vegetation along the banks to protect the soil and slow these erosion processes.

Erosion heads, the cause of bed deepening and widening, were identified along the major watercourses of the subcatchment. Some of these are currently stable as they are locked up in control points such as rock bars and/or fords or culverts. Three erosion heads are significant issues (Map 11.1).

A large erosion head at the boundary of Zones 2 and 3 on Freshwater Creek appears to be eroding upstream in a fan-like formation. The downstream area is deeply incised but the upstream area has good bank stability and a shallow channel. There appear to be no controls to halt the progression of the head and there is the potential for considerable bed deepening and release of sediment during large flow events.

An erosion head in the lower reaches of Bundaleer Creek is significant enough to be potentially damaging to watercourse bed stability. There does not appear to be any controlling feature upstream that would halt the erosion process.

A large erosion head in Never Never Creek one-third upstream from the junction with Bundaleer Creek, is resulting in severe bed deepening and widening, and is also undermining the causeway of a fire track access road. Upstream of the erosion head the stream bed is shallow and composed of alluvial deposits, which will continue to erode unless the erosion head is stabilised. These sites need to be assessed by an engineer before on-ground works start to determine the most cost effective action.

In general, erosion and associated sedimentation appear to be significant problems mainly along Freshwater Creek. This includes gully erosion and the progression of bed erosion along the creek. Poor bank stability in some areas also contributes to the lack of native vegetation because the plants are unable to establish on steep, eroding banks. Fine sediments can create an ideal habitat for the growth of reedbeds dominated by common reed and bulrush.

Apart from the causeway along Never Never Creek no other stream works such as bridges, fords or culverts were identified as significant issues causing, or being threatened by, erosion processes. There is a section of poor bank stability in the middle reaches of Baderloo Creek downstream of a ford. The ford may be one of many factors contributing to this area of bank erosion by increasing the speed of water flow.

There is insufficient data to determine salinity trends for the subcatchment. Landholders have reported some dryland salinity problems adjacent to Baderloo Creek south of Jamestown. This may be contributing to increased levels of salinity, particularly in first flush flows along Baderloo and Bundaleer creeks. Ensuring environmental flows are met is likely to be important for maintaining water quality, especially salinity.

Significant sections of the upper reaches of Freshwater Creek have been cultivated (classified as *Other* on Maps 11.1 and 7.7). Cultivating watercourses is a potentially erosive activity should heavy rainfall events occur after ploughing and before a vegetative cover has re-established. On balance, all vegetation should be allowed to persist within these sections of watercourse for as long as possible in order to minimise the potential for large water erosion events.

No significant watercourse management issues were recorded along areas of the upper reaches of Freshwater, Belalie, Jacka and Baderloo creeks. Typically these areas had a well grassed but poorly defined watercourse channel.

11.3.3 OTHER RELATED ISSUES

A number of issues were identified that were considered to be either a result of or contributing to the significant issues discussed above.

Channel modification

Natural conditions in Bundaleer and Baderloo creeks have been modified substantially by stream incision, which may have been caused by or influenced by channelisation. Channelisation is the alteration of the natural course of a watercourse through realignment, straightening or deepening. It is generally associated with agricultural drainage or flood mitigation. Typically, these modifications increase the velocity and volumes of flow within the watercourse and often initiate bed and bank erosion (Kapitzke et al. 1998).

Sedimentation

Extensive soil erosion in the subcatchment may have led to sedimentation in the main streams. This is particularly evident by the large amount of sediment build-up behind the weirs in Bundaleer and Freshwater creeks.

Water quality

Water quality monitoring of Belalie Creek through Jamestown indicates elevated nutrient levels which may be related to stormwater runoff from the town. The causes of the elevated levels need to be investigated, as do strategies for managing and improving water quality in the creek.

11.4 Monitoring and information gaps

Fish surveys were not conducted in the subcatchment. There is suitable aquatic habitat along the watercourses and it is likely that native fish, in particular species such as mountain galaxias (*Galaxias olidus*), do exist. The weirs on Freshwater and Bundaleer creeks will limit the migration of any fish species present. Investigations of the fish populations in the creeks and the impact of the weirs as barriers to fish migration are required. Only one site, along Bundaleer Creek, was analysed for macro-invertebrate species and more widespread sampling is required.

Little is known about the local groundwater system and its interaction with surface flow. Understanding the recharge processes, water flow and the effects of groundwater extraction are essential for effective management. Hyporheic (sub-surface) fauna are likely in these systems. The presence and function of a hyporheic zone in the system is another information gap.

Effective river management relies on a sound knowledge of the river system. River systems are dynamic and function on a range of timescales. Limited long-term data means that management recommendations should be reviewed in the light of information collected over a longer timescale. The monitoring requirements for the Freshwater and Bundaleer subcatchment include:

- future changes of the incised channel and any headward progress of erosion heads into unincised reaches;
- the physical effect of high flows, including erosion, deposition and substrate maintenance;
- surface flow hydrology (duration, frequency and level);
- groundwater usage and levels;
- water quality monitoring for salinity, nutrients and toxicants; and
- river health, including macro-invertebrates, fish, riparian, in-stream and aquatic vegetation.

11.5 Summary

Watercourses of the Freshwater and Bundaleer subcatchment once encompassed a variety of environments including the closed herblands along the main channel of Freshwater Creek, the lower reaches of Bundaleer Creek, and along the Baderloo, Jacka and Belalie creeks. Eucalypt woodlands were found only along Never Never Creek and the upper reaches of Bundaleer Creek. Tall open shrublands existed along the banks of all areas.

However, most of the watercourses in the subcatchment have been significantly modified. The biodiversity of the system is low, particularly in native watercourse vegetation, and vegetation along these zones is highly modified. Exotic annual grasses or crops with less than 10% overstorey form most of the riparian vegetation cover. Small stretches of riparian sedgelands and chenopod shrublands are scattered sparsely throughout the subcatchment.

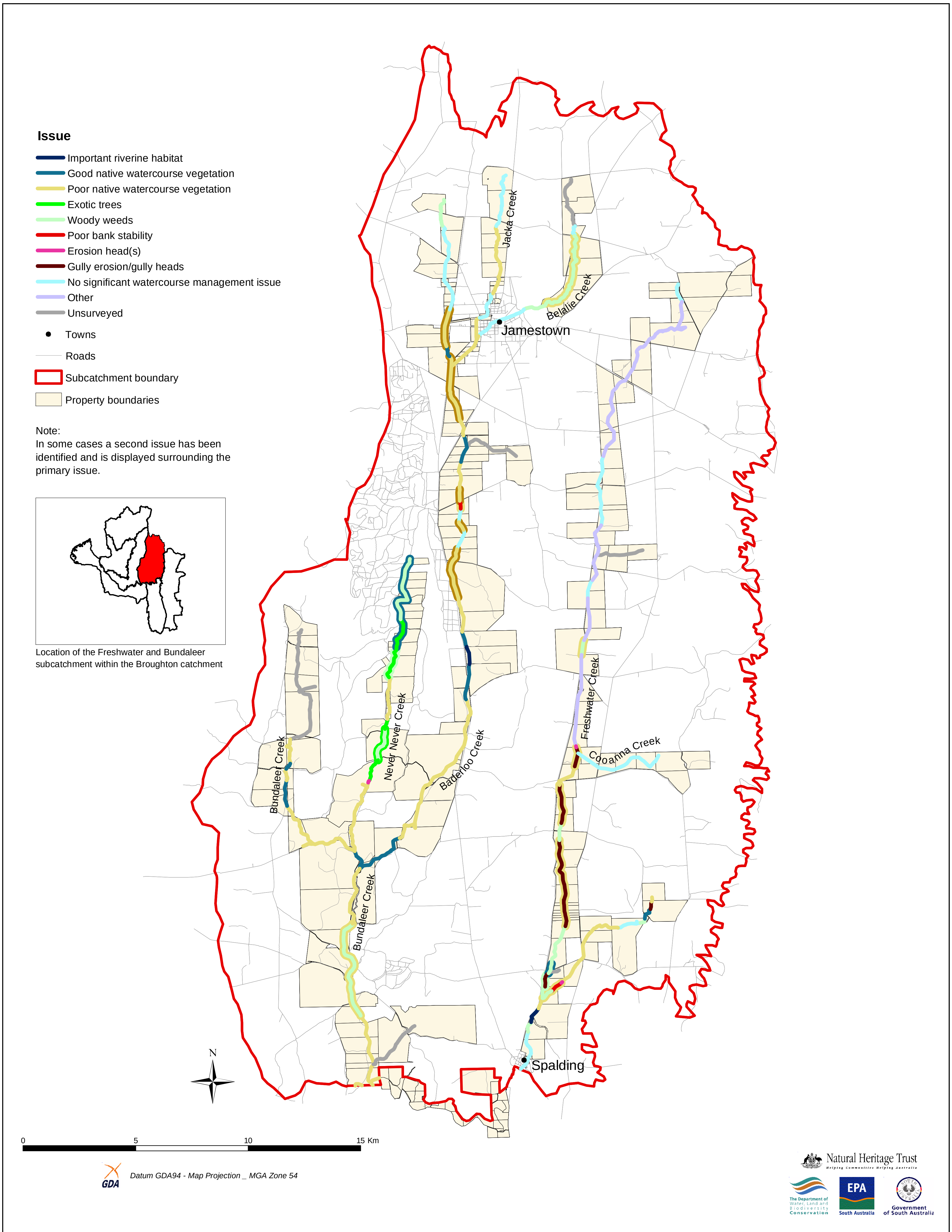
While dry in-stream environments dominate the subcatchment, dense stands of common reed and bulrush dominate the in-stream vegetation in its wetter sections. These areas are found in the lower reaches of Freshwater Creek, along the mid sections of Belalie Creek, and around the junction of Bundaleer, Never Never and Baderloo creeks.

Wild artichoke is a significant weed species along the watercourses in the subcatchment. Exotic trees such as ash and willow are significant issues along Never Never Creek.

Macro-invertebrate surveys below Bundaleer weir indicate that the area is in healthy condition. This is most likely because of permanent baseflow and a range of in-stream vegetation. No fish surveys were carried out in the region but fish are likely to exist in the areas of permanent water. The weirs on Bundaleer and Freshwater creeks are major barriers to fish migration and will restrict the fish populations above the weirs.

Threats to the health of watercourses in the subcatchment include: cultivation to the edge of, and within, watercourses; channelisation; erosion; and sedimentation. Managing these threats is very important. The priorities are protection of important riverine habitat, maintaining areas of good native vegetation, exotic tree control and control of gully erosion.

Many issues remain to be investigated, including monitoring of the incised channel and the headward progression of erosion into unincised reaches.



Map 11.1: Watercourse management issues in the Freshwater and Bundaleer subcatchment

CHAPTER 12 THE YACKAMOORUNDIE SUBCATCHMENT

12.1 Introduction

This chapter discusses the watercourse management and environmental water requirements for the Yackamoorundie subcatchment. The key water dependent physical and ecological environments and processes for the river geomorphic zones within this subcatchment are described. This includes the vegetation, fish and macro-invertebrates in the area. The important flow bands needed to maintain the environments, processes and associated plants and animals are described for each zone. Appendix E contains a more detailed description of the environmental water requirements including recommended frequency, duration and seasonality of flows.

The chapter describes key management issues that impact on the watercourse environments and outlines the environmental water requirements of these environments. The priorities and strategies for watercourse management based on the input of landholders and the results of the survey of watercourses in the subcatchment are tabled. The chapter closes with a discussion of information gaps and monitoring needs that have been highlighted by the project.

The major watercourse within the subcatchment is Yackamoorundie Creek, a major tributary of Rocky River. The dominant land uses along the watercourse are grazing and cropping with some urban development around the towns of Caltowie and Georgetown. The water resource is used primarily for stock watering.

12.2 Water dependent ecosystems and processes

Yackamoorundie Creek rises in the southern Flinders Ranges upstream of Caltowie and flows south through Georgetown. West of Caltowie the creek turns sharply westwards and passes through a gorge. The creek follows this westward alignment below the gorge until it joins Rocky River, southwest of the town of Crystal Brook. The creek has been divided into three river geomorphic zones (Map 5.2; Section 5.2) that reflect geological and geomorphological differences:

- Zone 1 — Rocky River to the downstream end of the gorge.
- Zone 2 — the gorge.
- Zone 3 — the upstream end of the gorge to Caltowie.

12.2.1 ZONE 1

Geomorphology and hydrology

In Zone 1 (Rocky River to the downstream end of the gorge; Map 5.2) the creek flows through a quaternary alluvial plain to its confluence with Rocky River. It appears to have had a small, ill-defined natural channel with a broad floodplain; now channelisation has been carried out in places and some sections are incised.

Vegetation

The creek in this zone is ephemeral. There is no in-stream vegetation and the habitat for fish, frogs and macro-invertebrates is limited. In-stream physical habitats include a dry grassy or gravelly channel.

The riparian vegetation has been impacted heavily by clearing and grazing. The creek supports a sparse native overstorey of river red gum with no understorey shrub layer and a groundcover of predominantly exotic grasses or crops (Plate 12.1). No regeneration of river red gums appears to be occurring. A lack of vegetation on the creek banks leaves them susceptible to erosion in flood events. Riparian weeds observed in this zone include wild artichoke (*Cynara cardunculus*) and thistle.

More understorey shrub species are likely to have been present along this section of the creek but they have been impacted upon by long-term grazing. Before European settlement, species likely to have grown in the area include Broughton willow (*Acacia salicina*), drooping sheoak (*Allocasuarina verticillata*), sweet bursaria (*Bursaria spinosa*), weeping emubush (*Eremophila longifolia*) and golden wattle (*Acacia pycnantha*) (Brown and Kraehenbuehl 2000).

Plate 12.1 Yackamoorundie Creek, Zone 1 showing the overstorey of river red gums, dry channel and lack of native understorey

Important flow bands

- *Mid flows* are important for connecting the upstream and downstream aquatic habitats (the permanent pool habitats in Zone 2 and Rocky River). The flows allow the migration of aquatic plants and animals, including fish. It is not known, however, if native fish are present in the permanent aquatic habitats located along Zone 2 of the creek.
- *High bankfull flows* are important for transporting organic matter and nutrients to downstream zones and for the migration of native fish species (where present).
- *Overbank flows* are important for recruiting and maintaining river red gums, for transporting sediment, nutrients and organic matter, and for channel-forming processes. If healthy native vegetation were present then these flows would be important for

connecting the floodplain to in-stream environments and for maintaining the riparian and floodplain vegetation. The condition of the riparian and floodplain vegetation has been modified highly by grazing and cropping. Without rehabilitation of this vegetation, the importance of these flows is limited.

12.2.2 ZONE 2

Geomorphology and hydrology

The watercourse in Zone 2 (the east–west gorge through the northern Mount Lofty Ranges; Map 5.2) may have been affected by sediment liberated by catchment erosion. The extent of the reedbeds may have increased over time.

The lower reaches of Zone 2 are dry with a cobbly substrate. Groundwater in the upper reaches supports permanent pools and macrophyte beds dominated by the common reed (*Phragmites australis*). In-stream physical habitats include riffles, pools, a dry grassy channel, macrophyte beds and sedgelands. The permanent pools and in-stream vegetation provide important aquatic habitat for fish, frogs, macro-invertebrates and birds.

Vegetation

The condition of the riparian vegetation is variable. In some areas this vegetation is in relatively good condition with structural and floristic diversity and an intact understorey layer. For example, along the lower reaches the vegetation is dominated by a sparse overstorey of river red gum (*Eucalyptus camaldulensis*) and Broughton willow (Plate 12.2). The vegetation changes further upstream to a native shrub overstorey with key species such as the elegant wattle (*Acacia victoriae*), native myrtle (*Myoporum montanum)*, Broughton willow and sweet bursaria. The native shrub overstorey cover varies from sparse to dense. Other areas have been modified greatly by clearance and grazing and there is little vegetation diversity. These areas currently support annual exotic grasses or crops with less than 10% overstorey (Map 7.1).

Fish and macro-invertebrates

No macro-invertebrate or fish sampling was conducted for the project within this zone. However, the presence of permanent pools and reedbeds would provide suitable habitats for native fish and macro-invertebrates.

This zone has areas of important riparian and aquatic habitat that are a high priority for conservation.

Important flow bands

- *Groundwater* maintains soil moisture and permanent pools where the groundwater table intersects the river bed. This groundwater is very important in this zone for supporting permanent and semi-permanent aquatic habitats, including pools, in-stream reedbeds and hyporheic environments.
- *Mid flows* are important for maintaining water quality, increasing the area of the aquatic habitat available for frogs and macro-invertebrates, and for maintaining connectivity between pool environments. Therefore, the flows are important for the migration of native fish and macro-invertebrates that maybe present in the zone.

- *Bankfull flows* are important for maintaining native riparian vegetation where it exists. The flows are also important for transporting sediment, organic matter and nutrients, for scouring pools and for channel-forming processes.
- *Catastrophic flows* or large flood events are important for recruiting and establishing riparian and floodplain vegetation. They are also important for scouring of pools, major channel changes and resetting of habitat, and floodplain processes such as erosion and sedimentation.

Plate 12.2 Yackamoorundie Creek, Zone 2 showing the reedbed habitat and overstorey of river red gums and Broughton willows

12.2.3 ZONE 3

Geomorphology and hydrology

In Zone 3 (the upstream end of the gorge to Caltowie; Map 5.2) the creek follows the north–south alignment determined by geological structural controls. It contains extensive deposits of quaternary alluvium and colluvium. The zone includes a variety of stream forms, ranging from a very small, in places ill-defined, channel to a large incised channel. Sections of the natural channel have been altered by channelisation, incision and inputs of sediment liberated by catchment and watercourse erosion (Brizga 2000a)

The creek in Zone 3 alternates between a dry grassy channel (Plate 12.3) and reedbeds dominated by common reed and sedgelands. The reedbeds, supported by groundwater, provide some habitat for macro-invertebrates, frogs and birds.

Vegetation

The riparian vegetation in the zone has been significantly modified. The vegetation along the watercourse is mainly annual exotic grasses or crops with less than 10% overstorey. There are some areas of sedgelands dominated by the rush, *Juncus krausii* and the sedge, *Cyperus gymnocaulos*. Apart from the reedbeds, there is very little habitat for aquatic or other animals. The common riparian weeds observed include thistle.

The lack of native vegetation makes it difficult to determine the original vegetation types along the watercourse. Remnant vegetation sites suggest that before European settlement the riparian vegetation would have been a tall open shrubland of elegant wattle, native myrtle and sweet bursaria. Where the groundwater table is close to the surface the in-stream vegetation would have been similar to that of today — a closed herbland dominated by common reed in association with sedgelands dominated by the rush, *J. krausii* and the sedge, *C. gymnocaulos* (Brown and Kraehenbuehl 2000).

Plate 12.3 Yackamoorundie Creek, Zone 3 showing the incised dry, grassy channel with no native watercourse vegetation

Important flow bands

- *Groundwater* maintains soil moisture and supports in-stream reedbeds which are the key aquatic habitat along the zone where the groundwater table intersects the river bed.
- *Mid flows* are important for transporting organic matter and sediment, and for the migration of macro-invertebrates between reedbed habitats.
- *Bankfull to overbank flows* are important for transporting sediment, for channel-forming processes, for connecting the floodplain to in-stream environments, and for maintaining

riparian and floodplain vegetation. However, the ecological functions of the flows are limited by the poor condition of the riparian and floodplain vegetation.

12.3 Management issues

Landholders within the subcatchment raised several concerns about the condition of Yackamoorundie Creek. Of most concern were: erosion; the lack of flow in the creek; and the lack of regeneration of the native riparian vegetation. The excessive growth of reeds, the silting up of the creek because of reeds slowing the water down, and fewer waterholes were also of concern. Concern was expressed as to whether the excessive growth of reeds was caused by increased nutrients in the system.

12.3.1 ISSUES AFFECTING ENVIRONMENTAL WATER REQUIREMENTS

There is little water resource development in the subcatchment other than dams for stock and domestic purposes. No gauging data is available for Yackamoorundie Creek. Therefore flow statistics could not be calculated for the environmental water requirements of the zone.

Key issues affecting the water regime include channelisation and the construction of levee banks along sections of the watercourse. Typically these modifications confine flows within the watercourse channel, increasing the velocity and volumes of flow. This often initiates bed and bank erosion and reduces the frequency of overbank flooding. The latter can impact adversely on the riparian and floodplain vegetation and any floodplain wetlands.

In areas where the channel has been modified the native riparian and floodplain vegetation is lacking or is in poor condition. In most cases cropping and grazing extend to the edge of the bank. Thus the ecological functions of bankfull to overbank flows are extremely limited. Fencing and rehabilitating the riparian and floodplain vegetation is currently a higher priority for this watercourse than restoring the flooding regime.

Groundwater is particularly important for maintaining aquatic habitats such as permanent pools in Zone 2 and reedbed habitats in Zone 3. The withdrawal of water from local aquifers by direct extraction or by planting crops that use the groundwater table would affect these pools and reedbeds.

Mid and bankfull flows are likely to be important for fish and macro-invertebrate migration and breeding, particularly in Zone 2. However, there is little information on the macro-invertebrate and native fish populations along the creek. Further investigation of these populations is necessary.

12.3.2 WATERCOURSE MANAGEMENT PRIORITIES AND STRATEGIES

Ensuring environmental water requirements are being met will not result in a healthy river system unless the ecosystems dependent on these requirements are maintained and protected. Consequently, the project assessed the condition of the major watercourses in the subcatchment and, in consultation with landholders, identified significant watercourse management issues (see Map 12.1 for locations).

Table 12.1 lists the significant watercourse management issues in order of priority and outlines strategies for their management. High, medium and low priorities have been set largely in terms how much improvement in watercourse health is possible for the cost and effort required. Thus a low priority issue is not insignificant; it may simply not require immediate attention or it may incur costs that outweigh the benefits on a subcatchment scale. Appendix F contains a discussion of the principles and guidelines used to help determine priorities.

Community priorities for management, based on votes by landholders at a meeting on 13 April 2000, are listed in Table 12.1. Management of these issues will largely be the responsibility of landholders, regional organisations and the local community and the priorities indicate community views and interests in undertaking river rehabilitation works.

Significant watercourse management issues

Important riverine habitats were identified along a tributary entering the Yackamoorundie gorge and a small section of the gorge itself (Zone 2). This area had a range of native vegetation, in-stream physical habitats and semi-permanent aquatic habitats. Most of the creek through the gorge has modified native vegetation that is in relatively good condition. These sites have a range of native groundcovers, understorey shrubs (including Broughton willow) and an overstorey dominated by river red gums. They are assets giving this part of the river a high recreational, community and ecological value; they should be a high priority for management.

Areas of native watercourse vegetation in good condition included an area of sedgeland upstream of Yackamoorundie gorge and an area dominated by river red gums downstream of the gorge. These areas have been modified to differing degrees by human activities such as land clearance, grazing and weeds. The area downstream of the gorge was characterised by an overstorey of river red gums and an understorey now dominated by native and exotic grasses, groundcovers and weeds. The understorey shrub layer is almost completely absent. Little or no regeneration of the river red gums or understorey shrubs was observed. These areas would respond well to weed and stock control and revegetation.

The lack of native vegetation or native vegetation in poor condition was a widespread issue affecting approximately 28% of the watercourses (Map 12.1). The natural system has been modified by clearance, grazing and, in some areas, cropping to the edge of the watercourse. These areas were typically a dry channel with little native vegetative cover on the banks. They generally provide poor habitats and have a high potential for bank erosion. If no buffer strip of native or exotic vegetation exists, then runoff and sediment and nutrient transport from surrounding agricultural land is not filtered.

The highest priority for managing watercourse vegetation is to protect the areas which are in good condition. Management is cost effective compared to rehabilitating degraded areas and it provides significant benefits for water quality, physical condition and riverine ecology.

Riparian weeds were considered an important priority by the landholders. The project survey techniques meant that only larger, generally woody, species could be detected easily, in this case wild artichoke and species of thistle. No exotic tree species were identified during the field survey and landholders voted these as a low priority issue.

Approximately 13% of the surveyed watercourse banks in the subatchment were assessed as having poor stability, indicating active bank erosion. Poor bank stability (Map 12.1) was identified as a significant issue along:

- the upper reaches of the Yackamoorundie Creek (north of Caltowie);
- downstream of the railway crossing at Caltowie, along an upper reach tributary;
- along most of Teetupennie Creek; and
- at two sites along the lower reaches of the Yackamoorundie Creek just upstream of its confluence with Rocky River.

The three main causes of poor bank stability and bank erosion in the subcatchment are most likely to be channelisation, bed deepening events and intensive grazing. Watercourses are often channelised in order to avoid flooding or to increase the area of land available for agricultural purposes. However, channelisation can result in a complex set of responses (such as bed and bank erosion) that affect upstream and downstream users. Intensive stock grazing along some areas has resulted in an absence of protective vegetation leaving banks bare and susceptible to erosion. Along other reaches bank erosion has been a result of the upstream movement of an erosion head (bed deepening).

Four erosion heads were considered significant. Two are located along the Yackamoorundie Creek as it flows though Caltowie; one of these is located below a road culvert and may be a potential threat to this structure. A third erosion head is located upstream of Caltowie; and the fourth on the lower reaches where the creek has been channelised. These all have the potential to migrate upstream followed by subsequent bank erosion.

Erosion can have significant impacts both upstream and downstream. It is likely that sections of the creek in all zones have been affected by sediment liberated by watercourse and catchment erosion. For example, sediment deposition along the lower Yackamoorundie Creek where it has been channelised has resulted in the bed level of the creek being higher than the surrounding land.

The strategies employed to manage bed and bank erosion will depend on the site and the nature of the erosion process. Watercourse vegetation helps beds and banks to resist erosive forces. Most of the sites could be managed by fencing to allow natural regeneration or revegetation. Complementary engineering solutions may be required where the erosion is threatening a high value asset or in high risk areas.

Most of the watercourses were classified as having moderate (41%) or good stability (47%). Areas of moderate bank stability have the potential to undergo active erosion if they are not managed to ensure a cover of protective vegetation and if threatening processes such as intensive grazing and destabilising earthworks are not controlled.

Gully erosion is a problem in a section of lower Yackamoorundie Creek. Gully erosion tends to originate at the foot of long slopes where flows naturally accumulate. In this area there appears to be little vegetation, particularly groundcover, to slow the flow and prevent erosion.

A significant proportion of the subcatchment has no major watercourse management issues. These areas are usually the shallow, dry grassed or cropped watercourses or shallow reedy watercourses with stable banks.

Stream works such as bridges, fords and culverts were generally classified as high or medium stability (Map 7.6). The project identified one ford threatened by erosion, which was being outflanked and was scouring out below the road.

Salinity was voted as an issue by landholders although there was some uncertainty as to whether salinity levels were increasing or not. High stream salinities are a feature of the Broughton catchment and salinity levels show large variations over time. For example, a notable peak in stream salinities in the early 1980s corresponded to the drought of 1982–83 (Jolly et al. 2000). Currently, there is insufficient data to determine salinity trends for this subcatchment.

Table 12.1 Management priorities and options for the Yackamoorundie subcatchment

Management issue (length)	Management strategies	Sub-catchment health priority	Community priority
Protection of important riverine habitat (1.6 km)	• Monitor the site regularly to observe any changes or threats (e.g. photo points, Waterwatch) • Control threatening processes such as weeds and livestock access • Revegetate with local indigenous species, if necessary, where vegetation has been modified • Manage upstream or downstream threatening processes (e.g. weed dispersal, erosion)	High	High
Improving/maintaining areas of good native vegetation (includes native remnants) (12.3 km)	• Revegetate and/or encourage natural regeneration • Manage livestock to avoid damage to vegetation and allow natural regeneration • Remove or control weeds and limit the opportunity for weeds to invade • Monitor sites regularly	High	High
Riparian weed removal and control (7.8 km)	• Remove by hand, spraying, burning or mechanical techniques depending on the site and the density of the infestation; care is needed to prevent disturbance to watercourse bed and banks • Control by: - regular spot spraying (using herbicides recommended for use near a waterway) or hand removal - shading out weeds by retaining canopy cover and avoiding disturbance to the natural vegetation - excluding livestock to prevent disturbance to ground and riparian vegetation • Allow natural regeneration or revegetate with local native species to re-establish habitat, prevent erosion and allow riparian shading	Medium	High
Lack of native vegetation (34.6 km)	• Revegetate with a full range of local native plants, including groundcovers, grasses, shrubs and trees • Leave a vegetated buffer strip between cultivated areas and the watercourse — at the very least, a good continuous grass cover • Manage livestock to avoid damage to vegetation and to encourage natural regeneration	Medium	Medium
Salinity (not identified)	• Ensure adequate environmental flows to maintain water quality • Provide alternative livestock watering points	Unknown	Low

Management issue (length)	Management strategies	Sub-catchment health priority	Community priority
Poor bank stability (21.6 km)	• Fence and revegetate or allow natural regeneration for long-term stabilisation: choose areas where vegetation has most chance of establishing • Choose native species useful for erosion control (e.g. that can grow at the toe of the bank, produce a dense root mat and can handle flooding) • Seek professional advice for engineering works (e.g. rock riprap, gabions, battering) which may be needed where erosion threatens a high value asset or is severe • If bank erosion is because of bed deepening (erosion head), control bed deepening processes before attempting to stabilise bank erosion	Medium	Medium
Erosion heads (4 sites)	• Monitor sites to determine if erosion is active • Restrict stock access, revegetate or encourage vegetation within the channel for long-term stabilisation • Choose native species that grow within the channel, produce a dense root mat and can handle flooding • Seek professional advice for erosion control works (e.g. rock chutes, drop structures) which may be needed where erosion threatens a high value asset or is severe	Medium	Low
Gully erosion/gully heads (1 site, 1.8 km)	• Fence and revegetate or allow natural regeneration for long-term stabilisation: choose areas where vegetation has most chance of establishing • Seek professional advice for erosion control works (e.g. rock chutes, drop structures) which may be needed where erosion threatens a high value asset or is severe	Medium	Low
Stream works causing or threatened by erosion (1 site)	• Ensure stream works (e.g. culverts, fords and bridges) are located on a straight and stable part of the watercourse, are correctly aligned, have secure footings and are designed to handle the flow capacity • Seek professional advice for engineering works (e.g. rock riprap, gabions, battering) which may be needed where erosion threatens a high value asset or is severe	Low	Low
Exotic tree removal and control (not identified)	• Remove by cutting down and/or poisoning with a suitable herbicide (depending on the species and its location) • Do not remove all trees in a heavily infested area at the one time • Replace exotic vegetation with suitable native species	Low	Low

12.4 Monitoring and information gaps

The extent of changes over time in the area occupied by reedbeds is an important unknown for the subcatchment. Little is known on sediment transport through the system, or the impact on aquatic habitats of sediment inputs from catchment and watercourse erosion.

Fish surveys were not conducted in the subcatchment. Information on the location and species of native fish, if present, and whether they migrate between Rocky River and permanent pools in Zone 2 is lacking. Similarly, there is little information on macro-invertebrate species and their migration and flow requirements. Other information gaps include the existence of hyporheic environments along the watercourse, particularly in Zone 2, and the role of groundwater in supporting riverine environments.

The physical and ecological effects of different flow bands must be investigated to enable the environmental water requirements to be refined. This requires not only information on water quality, groundwater levels and stream flow hydrology but also the monitoring of aquatic flora and fauna ecology, habitat conditions and morphological processes.

12.5 Summary

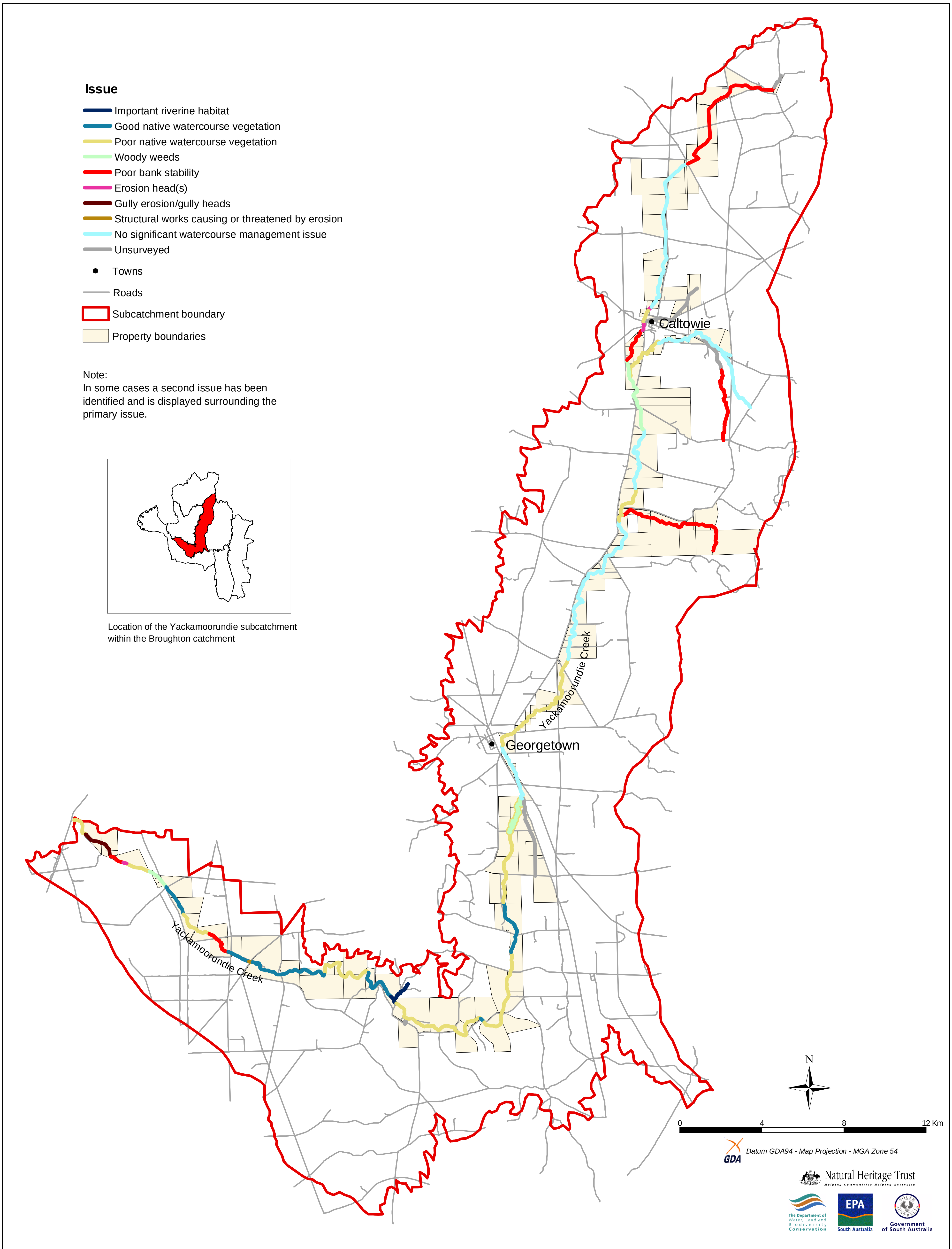
Yackamoorundie Creek varies from a dry ephemeral creek in its lower reaches to areas of permanent pools and reedbed habitats alternating with a dry, grassy channel in its middle and upper reaches. Where the creek flows through the gorge (Zone 2), relatively healthy riparian vegetation, in-stream reedbeds and permanent pools make this an important refuge for aquatic plants and animals. The area is a priority for maintenance and rehabilitation.

Water resource development is limited and the main threat to the environmental water requirements is from channel modification, particularly channelisation and the construction of levee banks. Managing the water resource is a lower priority for the subcatchment in preference to dealing with watercourse management needs.

To improve river health, the key issues for the subcatchment are rehabilitation and protection of significantly modified riparian vegetation. Management will require restricting stock access, controlling riparian weeds, encouraging natural regeneration and, for many sites, revegetating actively with local native species. Excessive growth of the common reed is a concern for landholders. In the absence of other riparian and in-stream vegetation, this reedbed ‘monoculture’ does provide some habitat for frogs, macro-invertebrates and birds. Long-term management should focus on revegetation and addressing the causes of excessive reed growth such as increased sediment and nutrient input and increased light associated with erosion and lack of riparian vegetation.

Erosion issues are significant compared to other subcatchments in the Broughton catchment. Many instances of erosion could be addressed with fencing to reduce grazing pressure and revegetation. Engineering solutions such as grade control structures may be required where there is bed deepening and where the expense may be warranted to protect a high value asset.

Further investigations of native fish and macro-invertebrates species along Yackamoorundie Creek would help refine ecological values and management options for the subcatchment.



Map 12.1: Watercourse management issues in the Yackamoorundie Creek subcatchment

CHAPTER 13 THE LOWER ROCKY AND CRYSTAL BROOK SUBCATCHMENT

13.1 Introduction

This chapter discusses the watercourse management and environmental water requirements for the Lower Rocky and Crystal Brook subcatchment. The key water dependent physical and ecological environments and processes for the river geomorphic zones within this subcatchment are described. This includes the vegetation, fish and macro-invertebrates in the area. The important flow bands needed to maintain the environments, processes and associated plants and animals are described for each zone. Appendix E contains a more detailed description of the environmental water requirements including recommended frequency, duration and seasonality of flows.

The chapter describes key management issues that impact on the watercourse environments and outlines the environmental water requirements of these environments. The priorities and strategies for watercourse management based on the input of landholders and the results of the survey of watercourses in the subcatchment are tabled. The chapter closes with a discussion of information gaps and monitoring needs that have been highlighted by the project.

The major watercourses within the subcatchment include the lower section of Rocky River, from its confluence with the Broughton River upstream to 4 km south of Laura, Crystal Brook, and Pisant and Narridy creeks (Map 3.1). The dominant land uses along the watercourses are grazing and cropping with urban development around the towns of Gladstone and Crystal Brook.

13.2 Water dependent ecosystems and processes

13.2.1 LOWER ROCKY RIVER

The Rocky River rises in the southern Flinders Ranges near Wirrabara and is joined by its major tributary, Pine Creek, near Laura. The river flows at first in a southerly direction, entering a gorge at the western edge of the northern Mount Lofty Ranges, south of Gladstone before turning sharply west to flow into the Broughton River. On either side of the gorge, the river has a broad valley containing extensive deposits of Quaternary alluvium. Four river geomorphic zones have been identified (Map 5.2; Section 5.2):

- Zone 1 — Broughton River to the downstream end of Rocky River Gorge.
- Zone 2 — Rocky River gorge (Huddleston–Narridy Rd to Huddleston–Georgetown Rd).
- Zone 3 — upstream of the gorge to Laura township.
- Zone 4 — upstream of Laura township.

Zones 1–3 occur within the Lower Rocky and Crystal Brook subcatchment. Zone 4 is located within the Upper Rocky subcatchment (see Chapter 14).

The habitats of the lower Rocky River (Zones 1–3) are diverse. Key in-stream physical habitats include reedbeds, pools, riffles, braided channels and sand bars. The condition of the native riparian vegetation varies. Major threats include past vegetation clearance, uncontrolled stock access and weed invasion. The riparian vegetation ranges from a mid dense to sparse overstorey of native trees (mainly river red gums, *Eucalyptus camaldulensis*), sedgelands, exotic or native grasses and/or crops and some areas of sparse native shrubs (Map 7.1). Most of the in-stream zone of the river is covered by mid-dense to dense stands of reeds (Map 7.2).

Zones 1 and 2

Geomorphology and hydrology

In Zone 1 (Broughton River to the downstream end of Rocky River Gorge; Map 5.2), the Rocky River has a meandering channel bordered by broad plains formed in Quaternary alluvium. Anecdotal evidence suggests that the small, lower floodplain bordering the river floods annually, while larger floods inundate the broad, higher level floodplain. Near its confluence with the Broughton River, Rocky River passes through a confined section cut through a low range. Groundwater discharges to the river and supports permanent baseflow in this zone. The river here also receives rainfall driven surface flows from Yackamoorundie and Narridy creeks, mostly during heavy summer storm events. Key in-stream physical habitats include reedbeds, pools, riffles, braided channels and sand bars.

While the extent of post-European settlement geomorphological change is not known, the evidence does not suggest any dramatic changes (Brizga 2000a). Bank stability was classified as good. Landholders suggested localised deposition of sand in pools in recent floods.

In Zone 2 (Rocky River gorge; Map 5.2) the river is constrained within a narrow bedrock valley with narrow floodplains in some areas. The groundwater table is close to the surface and supports baseflow (in some areas), reedbeds and deep pools. The river channel is wide (typically 60 m) and shallow and the diverse in-stream physical habitats include pools, reedbeds, braided channels and rock bars. Reedbeds may have increased in extent over time.

The permanent pools and baseflow in Zones 1 and 2 are important for aquatic flora and fauna and maintain aquatic habitats over summer months and during dry periods. The continual discharge is also important for maintaining water quality.

Vegetation

The dominant riparian vegetation association along Zone 1 is an open forest of river red gums. The condition of riparian vegetation varies. Along some reaches few trees or shrubs remain and the dominant vegetation is exotic annual grasses. In other reaches there is a healthy overstorey of river red gums but few understorey species such as acacias and native grasses. Some patches of remnant vegetation with a range of species and structural layers exist, for example near the confluence of the Rocky and Broughton rivers (Plate 13.1). The key weed species observed were boxthorn (*Lycium ferocissimum*) and wild artichoke (*Cynara cardunculus*).

Typically the in-stream vegetation comprises a variety of rushes, reeds and sedges with common reed (*Phragmites australis*) and bulrush (*Typha* spp.) as the dominant species. This vegetation covers approximately 60% of the in-stream section of the watercourse. Submerged aquatic vegetation was recorded in the permanent pools and areas of continuous flow.

In Zone 2, where the river flows through the gorge, the vegetation changes. Here the riparian vegetation is a closed sedgeland dominated by the rush, *Juncus krausii* and the sedge, *Cyperus gymnocaulos* with a few scattered trees and shrubs (Plate 13.2). The key weed species observed was wild artichoke. Dense reedbeds cover approximately 90% of the in-stream section of the watercourse. The reedbeds comprise a range of reeds, rushes and sedges (such as common reed, *Schoenoplectus pungens, Bolboschoenus caldwelli,* and *Cyperus* spp.). Submerged aquatic vegetation was recorded in pools and runs.

Plate 13.1 Rocky River, Zone 1 with the river red gum open forest and permanent pool environments

Plate 13.2 Rocky River, Zone 2 showing extensive reedbeds and sedgelands, sparse trees and shrubs and permanent pool environments. This area was identified as important riverine habitat.

Fish and macro-invertebrates

Macro-invertebrate sampling classified lower Rocky River sites in Zones 1 and 2 as being in near reference condition and, therefore, as relatively healthy (Madden et al. 1999). The permanency of flow in the lower Rocky River is important for supporting a range of macro-invertebrate species, particularly species such as caddisflies (*Cheumatopsyche* sp.) that require flow for feeding. Several invertebrates with unusual or restricted distributions were found (Madden et al. 1999). These included bristle worms (Polychaeta) which are not usually found in freshwater habitats and a moth from the family Pyralidae that is generally found in wetlands with dense stands of macrophytes. The moth builds a case from pieces of emergent aquatic plants, which are common in these zones. Amphipods from the family Eusiridae, found most often in permanently flowing streams, were collected in Zone 1.

Blue spot goby (*Psuedogobius olorum*), a native fish, and the exotic species of goldfish (*Carassius auratus*) and eastern gambusia (*Gambusia holbrooki*) were recorded in the lower Rocky River during the fish survey (Hicks and Sheldon 1999). Blue spot gobies prefer slow-moving water with a good growth of submerged aquatic plants. They can migrate to the estuary to spawn although this is not a definitive part of their lifecycle.

Important flow bands — Zone 1

- *Baseflow* in this zone flows almost continuously with a seasonal increase over winter–spring. It is very important for maintaining flow over riffles and supporting a diverse range of macro-invertebrate species. It is also important for maintaining permanent pool habitats for fish and submerged aquatic plants and for providing soil moisture to support the riparian sedgelands and in-stream reedbeds.
- *Low flows* result from surface flows and a seasonal increase in baseflow. They are important for fish recruitment and development, maintaining water quality, connecting pool environments and increasing the areas of aquatic habitat available for fish and macro-invertebrates.
- *Mid flows* are important for native fish breeding. They increase the areas of habitat available for fish breeding. The flows are important in the local migration of these fish and macro-invertebrates, and for recruiting and establishing native riparian vegetation, especially sedgelands. They also play a key role in the natural bank erosion processes and are thus important for maintaining the natural channel morphology.
- *Overbank flows* extending onto the floodplain are important for recruiting and establishing native floodplain vegetation where present. The flows transport nutrients, organic matter and sediment, scour pools and maintain natural channel-forming processes.

Important flow bands — Zone 2

- *Groundwater and baseflow* support permanent pools and continuous flow in some reaches within this zone. Baseflow is very important for maintaining flow over riffles and supporting a diverse range of macro-invertebrate species. Groundwater is important for maintaining permanent pool habitats for fish and submerged aquatic plants and for providing soil moisture to support the riparian sedgelands and in-stream reedbeds.
- *Low flows* result from surface flows and a seasonal increase in baseflow. The flows are important for fish recruitment and development and for maintaining water quality. Low flows connect pool environments and increase the areas of aquatic habitat, including riffle environments, available for fish and macro-invertebrates.

- *Mid flows* are important for native fish breeding. They increase the areas of habitat available for fish breeding. The flows are important in the local migration of these fish and macro-invertebrates, and for recruiting and establishing riparian sedgelands. They also maintain water quality and remove fine sediments from riffle substrates.
- *High to bankfull flows* that inundate the riparian zone are important for recruiting and establishing native riparian vegetation. The flows transport nutrients, organic matter and sediment, scour pools and maintain natural channel-forming processes.

Zone 3

Geomorphology and hydrology

Zone 3 (upstream of the gorge to Laura township; Map 5.2) is characterised by a generally broad valley containing Quaternary alluvial deposits. The river here is ephemeral with some permanent pools. Considerable variations in channel and floodplain morphology are evident. Immediately upstream of the gorge, the river is characterised by a wide channel with extensive reedbeds, similar to the Broughton River at Yacka. Further upstream, the channel is sinuous and narrow with a relatively wide floodplain. In-stream physical habitats include a dry gravel bed (which has pool and riffle habitats at times of flow), reedbeds and pools.

Drains have been excavated on the floodplain where it is relatively wide. It is not known if the drains are situated in important floodways. While the extent of post-European settlement geomorphological change to the main channel of the river is not known, it is likely that sedimentation occurred in areas favourable to deposition, such as the wide reedbeds upstream of the gorge (Brizga 2000a). Bank stability ranges from moderate to good.

Vegetation

In the lower reaches of this zone, the riparian vegetation is highly modified and is characterised by exotic annual grasses with scattered trees or shrubs (less than 10% overstorey). The in-stream section of the watercourse contains extensive reedbeds dominated by common reed and bulrush. Upstream of the confluence with Pisant Creek, the vegetation type changes to that of an open forest of river red gums (Plate 13.3). The in-stream vegetation is less dense and more diverse although still dominated by common reed and bulrush. Here the in-stream vegetation covers approximately 50% of the in-stream zone. Submerged aquatic vegetation was observed in the permanent pools.

Along all reaches, the native understorey vegetation of shrubs and native grasses is highly modified because of vegetation clearance and grazing. Key weed and exotic species observed include boxthorn and peppertrees (*Schinus areira*).

Important flow bands

- *Groundwater* maintains soil moisture and permanent pools where the groundwater table intersects the river bed.
- *Mid flows* are important for fish recruitment and development and for the migration of fish and macro-invertebrates. The flows are also important for connecting pool environments and increasing the areas of aquatic habitat available for fish and macro-invertebrates.
- *High to bankfull flows* are important as a cue for native fish breeding and for watering riparian vegetation. The flows are also important for maintaining water quality and for geomorphic processes such as transporting sediment, removing fine sediment from riffle substrates and maintaining natural channel-forming processes. Depending on the

duration of the flow events, they are likely to be important for fish and macro-invertebrate migration.

- *Overbank flows* are important for floodplain inundation and recruitment of river red gums. The flows are important for scouring pools and transporting nutrient, sediment and organic matter from the floodplain to the watercourse and along the river system.

Plate 13.3 A typical view of Rocky River, Zone 3 showing a permanent pool, in-stream vegetation, river red gums and wide floodplain. Native riparian vegetation, particularly understorey shrubs and groundcovers, has been modified significantly.

13.2.2 CRYSTAL BROOK

Crystal Brook rises in the southern Flinders Ranges and its north–south alignment from its headwaters to Bowman Park reflects geological structural controls. At Bowman Park, the stream turns sharply westward and follows this general alignment downstream to its confluence with the Broughton River. Two geomorphic zones have been identified on Crystal Brook between Broughton River and Beetaloo reservoir (Map 5.2; Section 5.2):

- Zone 1 — Broughton River to the town of Crystal Brook.
- Zone 2 — the town of Crystal Brook to Beetaloo reservoir.

Beetaloo reservoir, an in-stream storage constructed in 1890 and with a capacity of 3150 ML, is located on the upper reaches of the Crystal Brook. The reservoir is now offline and its water is no longer used, however plans are being made to bring the reservoir back online (K Billington, SA Water pers comm, 2003).

Zone 1

Geomorphology and hydrology

Crystal Brook in Zone 1 (Broughton River to the town of Crystal Brook; Map 5.2) has a relatively deep (~5 m) meandering channel bordered by alluvial plains. Along the upper reaches near the town of Crystal Brook, there is a narrow incised floodplain. A horseshoe-shaped depression formed by an old meander cutoff is evident along the lower reaches. The watercourse is ephemeral and there is no permanent aquatic habitat. The dry channel bed, which contains gravels and finer sediments, is grassed over in some areas.

While there is no evidence to suggest any significant changes have occurred in the channel morphology since European settlement, it is suspected that reduced flooding as a result of the Beetaloo reservoir may have implications in the longer term.

Vegetation

The native riparian vegetation is modified and is typically an open forest of river red gums with an understorey of annual exotic or native grasses (Plate 13.4). Very few understorey shrub species were observed. These include Broughton willow (*Acacia salicina*), ruby saltbush (*Enchylaena tomentosa*) and cotton bush (*Maireana aphylla*). The regeneration of river red gums is limited, possibly because of current grazing practices and a lack of regenerating flow events. Considerable natural regeneration may occur in the area with controlled grazing and appropriate climatic conditions.

Plate 13.4 A typical view of Crystal Brook, Zone 1 showing a dry, meandering channel with an overstorey of river red gums. The impact of stock grazing, notably the absence of native understorey vegetation and young river red gums, is evident.

Studies of pre-European vegetation suggest that the original vegetation in Zone 1 was an open forest dominated by Broughton willow and river red gum (Brown and Kraehenbuehl 2000). Shrub species likely to be found in the understorey would have included native myrtle (*Myoporum montanum*), bullock bush (*Alectryon oleifolius*) and elegant wattle (*Acacia victoriae*).

Important flow bands

- *Mid flows* are important for connecting the upstream and downstream aquatic habitats from Bowman Park to the Broughton River and for fish migration (if native fish are present). The flows are also important for creating aquatic habitats, transporting organic matter and watering riparian vegetation.
- *High to bankfull flows* are important for watering riparian vegetation and maintaining water quality. The flows are also important for geomorphic processes such as transporting sediment and maintaining natural channel-forming processes. Depending on the duration of the flow events, they could be important for fish migration (if native fish are present).
- *Overbank flows* are important for inundating the floodplain and for recruiting river red gums. The function of these flows will be limited by the condition of the floodplain vegetation. The flows are also important for transporting nutrients, organic matter and sediment from the floodplain to the watercourse and along the river system.

Zone 2

Geomorphology and hydrology

In Zone 2 (town of Crystal Brook to Beetaloo reservoir; Map 5.2) Crystal Brook flows in a confined valley, with narrow floodplains in some areas. Throughout most of the zone the watercourse is relatively shallow (~1 m) and has a dry cobble and boulder bed, with localised bedrock outcrops. With adequate flows, key physical habitats, particularly for macro-invertebrate species, include riffles, rock bars and shallow pools. Where the groundwater table is close to the surface at Bowman Park, extensive reedbeds and permanent pools occur.

Vegetation

Typical native riparian vegetation is an open forest dominated by river red gums (Plate 13.5). The native vegetation is generally in better condition than in Zone 1 with a range of trees, shrubs and groundcovers, although some reaches have been affected by grazing. An uncommon species of emergent aquatic plant, *Cladium mariscus*, was found at Mary Springs above Beetaloo reservoir and at sites along Crystal Brook below the reservoir.

An area of important riverine habitat is located at Bowman Park. Groundwater at this site supports permanent pools and reedbeds and there is a diverse range of riparian vegetation. Bulrush and common reed dominate the in-stream vegetation. An increase in reeds at this site observed by landholders has resulted in a decrease in the size of the pools.

Studies of pre-European vegetation suggest that the original vegetation in Zone 2 was an open forest dominated by Broughton willow and river red gum but also containing peppermint box (*Eucalyptus odorata*) and white cypress pine (*Callitris glaucophylla*) (Brown and Kraehenbuehl 2000). Shrub species likely to be found in the understorey include native myrtle, native apricot (*Pittosporum phylliraeoides*) and elegant wattle.

Plate 13.5 A typical view of Crystal Brook, Zone 2 showing a dry, cobble and boulder stream bed and river red gum open forest with a modified, but relatively intact, native understorey. Riparian weeds such as wild rose are visible.

Fish and macro-invertebrates

Macro-invertebrate sampling at Bowman Park indicated a relatively high diversity of species because of the permanent spring-fed water supply. Members of the mayfly family, Leptophlebiidae, which are only present at sites with good flow, were found at Bowman Park (Madden et al. 1999).

Mary Springs is the head of a spring that discharges rapidly into a small channel containing stands of rushes and reeds. Macro-invertebrate sampling there showed an area with a high diversity of species, including several not found elsewhere in the catchment — a micro-caddisfly larvae (*Orphninotrichia maculata)* which is usually found on waterfalls, stoneflies (*Dinotoperla evansicaddis*), caddisflies (*Apsilochorema* sp.) and dragonflies from the family Gomphidae. These animals prefer sites with good flow and stony substrates and are usually absent from disturbed sites. Other species of note include a moth of the family Pyralidae commonly found in wetlands with dense stands of macrophytes (Madden et al. 1999). This moth builds a case from pieces of emergent aquatic plants, which are common at the site.

No fish sampling was conducted for the project within this zone. It is unlikely that there would be suitable habitats for native fish.

Important flow bands

- *Groundwater* maintains soil moisture and permanent pools, where the groundwater table intersects the river bed. Groundwater is very important in this zone for maintaining permanent pools and providing soil moisture to support the in-stream reedbeds (e.g. at Bowman Park).

- *Low flows* are important for fish recruitment and development and macro-invertebrate breeding. Low flows connect pool environments, maintain flow over riffles and increase the areas of aquatic habitat available for fish and macro-invertebrates.
- *Mid to bankfull flows* are important as a cue for native fish breeding and for local migration of macro-invertebrates. The flows are also important for maintaining reeds, rushes and sedges and for transporting organic matter and sediment.
- *Overbank flows* are important for recruitment of river red gums and other floodplain processes, including transporting organic matter, sediment and nutrients. The flows are important for geomorphic processes such as removing fine sediments from riffles and maintaining channel morphology.
- *Catastrophic flows* or large flood events are important for recruitment of river red gums and scouring pools as well as maintaining channel-forming processes.

13.2.3 PISANT CREEK

Geomorphology and hydrology

Pisant Creek has a predominantly dry channel interspersed with an area of permanent baseflow and reedbeds along its middle reach which provides important in-stream habitats. The creek has a well defined channel with sections that are incised and/or have been channelised. Bank stability was classified as either good or moderate, with moderate stability corresponding to the areas of incision (Map 7.5). No geomorphic zone was assigned to this creek (Map 5.2; Section 5.2).

Vegetation

The condition of the riparian vegetation along the creek is variable. Along the lower reaches the vegetation is highly modified and is mainly exotic annual grasses or crops with less than 10% trees and shrubs (Map 7.1). Exotic trees, mainly pines and peppertrees, are found along the creek through Gladstone (Map 7.4). Along the middle reaches, groundwater supports permanent baseflow and dense stands of emergent aquatic plants dominated by common reed and bulrush.

Significant areas of remnant vegetation along the upper reaches of the creek (Plate 13.6) have key overstorey species such as red mallee (*Eucalyptus oleosa*), peppermint box, native pines (*Callitris* spp.) and Broughton willow. In the upper reaches, sites of permanent springs are areas of important riverine habitat. Anecdotal evidence suggests that the regeneration of this native vegetation has been affected by stock grazing.

Important flow bands

Environmental water requirements were not determined for this watercourse.

Plate 13.6 A typical view of the upper reaches of Pisant Creek with remnant native watercourse vegetation

13.2.4 NARRIDY CREEK

Geomorphology and hydrology

The ephemeral Narridy Creek has a predominantly dry channel but an area of reedbeds and pools supported by groundwater is located downstream of Narridy bridge. Key in-stream physical habitats include reedbeds and some deep pools (Plate 13.7).

The original creek of a small, ill-defined channel with a broad floodplain has been significantly modified. A number of sections along its middle reaches are now deeply incised. Channelisation and/or levee banking have been carried out in a number of sections along the length of the creek (Plate 13.8). Bank stability was typically classified as either poor or moderate (Map 7.5). No geomorphic zone was assigned to this creek (Map 5.2; Section 5.2).

Vegetation

Native riparian vegetation along the creek has been highly modified. The dominant vegetation type is now exotic annual grasses or crops with less than 10% trees and shrubs (Map 7.1). An area of good aquatic habitat downstream of Narridy bridge where there is a permanent pool and extensive reedbeds, has Broughton willow as the dominant overstorey species along the creek banks.

Important flow bands

Environmental water requirements were not determined for this watercourse.

Plate 13.7 The permanent pool and reedbed habitat along a section of Narridy Creek. Riparian vegetation is dominated by Broughton willow.

Plate 13.8 An incised and eroded section of Narridy Creek caused by modifications to the channel. A large erosion head is located some metres upstream of this site.

13.3 Management issues

Landholders within the subcatchment were concerned with the lack of flow — both decreased surface flows and drying up of springs. Other issues of concern were riparian weeds, particularly wild artichoke, hoary cress (*Cardaria draba*) and boxthorn; livestock preventing natural regeneration; erosion; pollution and rubbish; and the impacts of dams.

13.3.1 ISSUES AFFECTING ENVIRONMENTAL WATER REQUIREMENTS

Beetaloo reservoir has significantly altered the range of flows along Crystal Brook. Surface flows are more infrequent, smaller in volume and less sustained. The implications for downstream environments include reduced sediment transport rates and volumes, a reduction in scouring flood flows, and changes to plant and animal communities. A key environmental water management issue could be the release of water from the reservoir. Some water is released regularly from scour valves to clean the pipes. The feasibility of releasing water through these valves for environmental purposes needs investigation in order to assess the benefits and potential impacts of such releases.

Landholders were particularly concerned about decreased flow and spring activity along Rocky River. This situation is most probably caused largely by recent climatic conditions where the rainfall of the past 15 years (with the exception of a couple of wet years) has not been sufficient to produce runoff or recharge the groundwater aquifers. Improved land management practices have also led to a decrease in surface runoff. The impacts of existing water resource developments are likely to be small in comparison, but they should not be discounted. Further investigation is required.

While water resource development for irrigation appears limited, little is known about the levels of use of surface and groundwater resources. Also, there is the potential for future irrigation developments for watering crops such as olives and vines though this may be limited by the salinity of the water. Current levels of use in the subcatchment and potential future needs should be assessed, particularly for possible impacts on environmental water requirements.

Groundwater is particularly important for maintaining permanent baseflow, permanent pools and reedbed habitats in the subcatchment. Important groundwater dependent habitats exist at Bowman Park and the lower reaches of the Rocky River. Withdrawing water from local aquifers by direct extraction or by planting of crops that use the groundwater table could have a significant impact on these important aquatic habitats.

The development of farm dams will impact most on the low and mid flows that have several important ecological functions. The impact, which will be greatest in dry years, will delay flow and shorten the duration of flow events. Similarly, the construction of in-stream structures such as weirs will impact on flows, reduce sediment transport and may prevent fish migrating along watercourses.

There is little control over the construction of farm dams and bores. Some form of control needs to be established so their impact on water dependent ecosystems and processes and on downstream users can be considered and managed. The flow regime and the health of aquatic ecosystems also need to be monitored. Currently no gauging of flows or recorded flow data exists for any of the watercourses in the subcatchment.

Determining environmental water requirements for Pisant and Narridy creeks was beyond the scope of this project. There is little water resource development that would impact on the flow regime of these systems. The main issues affecting river health along these watercourses relate to watercourse management, rather than management of the water regime (see below).

13.3.2 WATERCOURSE MANAGEMENT PRIORITIES AND STRATEGIES

Ensuring environmental water requirements are being met will not result in a healthy river system unless the ecosystems dependent on these requirements are maintained and protected. Consequently, the project assessed the condition of the major watercourses in the subcatchment and, in consultation with landholders, identified significant watercourse management issues (see Map 13.1 for locations).

Table 13.1 lists the significant watercourse management issues in order of priority and outlines strategies for their management. High, medium and low priorities have been set largely in terms how much improvement in watercourse health is possible for the cost and effort required. Thus a low priority issue is not insignificant; it may simply not require immediate attention or it may incur costs that outweigh the benefits on a subcatchment scale. Appendix F contains a discussion of the principles and guidelines used to help determine priorities.

Community priorities for management, based on votes by landholders at a meeting on 13 April 2000, are listed in Table 13.1. Management of these issues will largely be the responsibility of landholders, regional organisations and the local community and the priorities indicate community views and interests in undertaking river rehabilitation works.

Significant watercourse management issues

Significant areas of important riverine habitat include Bowman Park, the Rocky River gorge and the upper reaches of Pisant Creek. These areas had a range of native vegetation, in-stream physical habitats and permanent or semi-permanent aquatic habitat. Areas of significant remnant vegetation were identified along Crystal Brook just below and above Beetaloo reservoir and along the upper reaches of Pisant Creek. These areas are key assets and give these reaches a higher recreational, community and ecological value. They are a high priority for management.

Riparian vegetation considered modified but in a good-to-moderate condition was identified along most of Crystal Brook, the lower reaches of Rocky River (near its confluence with the Broughton River) and along the Rocky River north of Gladstone. Typically these areas were characterised by an overstorey of river red gums and an understorey dominated by native and exotic grasses, groundcovers and weeds. Clearance, grazing and weeds have modified these areas. The understorey shrub layer is almost completely absent and little or no regeneration of river red gums or understorey shrubs was observed.

Riparian weeds were considered an important priority by the landholders. The project survey techniques meant that only larger, generally woody, species could be detected easily. Weeds observed include wild artichoke, boxthorn and wild rose (*Rosa canis*).

Exotic trees were not a significant problem in the subcatchment. Pines, peppertrees and palms are located along the Rocky River through Gladstone township. These trees may have social or aesthetic significance for the town and their control or removal would need to consider this.

Table 13.1 Management priorities and options for the Lower Rocky and Crystal Brook subcatchment

Management issue (length)	Management strategies	Sub-catchment health priority	Community priority
Protection of important riverine habitat (13.5 km)	• Monitor the site regularly to observe any changes or threats (e.g. photo points, Waterwatch) • Control threatening processes such as weeds and livestock access • Revegetate with local indigenous species, if necessary, where vegetation has been modified • Manage upstream or downstream threatening processes (e.g. weed dispersal, erosion)	High	High
Protection of remnant vegetation (7.4 km)	• Manage stock to avoid damage to vegetation and allow natural regeneration • Remove or control weeds and limit the opportunity for weeds to invade • Monitor the site regularly	High	High
Improving/maintaining areas of good native vegetation (49.2 km)	• Revegetate and/or encourage natural regeneration • Manage livestock to avoid damage to vegetation and allow natural regeneration • Remove or control weeds and limit the opportunity for weeds to invade • Monitor the site regularly	High	Medium
Poor native watercourse vegetation (32.5 km)	• Revegetate with a full range of local native plants, including groundcovers, grasses, shrubs and trees • Leave a vegetated buffer strip between cultivated areas and the watercourse — at the very least, a good continuous grass cover • Manage livestock to avoid damage to vegetation and to encourage natural regeneration	Medium	Medium
Riparian weed removal and control (species observed include boxthorn, wild artichoke and wild rose) (1.2 km)	• Remove by hand, spraying, burning or mechanical techniques depending on the site and the density of the infestation: care is needed to prevent disturbance to watercourse bed and banks • Control by: - regular spot spraying (using herbicides recommended for use near a waterway) or removal hand - shading out weeds by retaining canopy cover and avoiding disturbance to the natural vegetation - excluding livestock to prevent disturbance to ground and riparian vegetation • Allow natural regeneration or revegetate with local native species to re-establish habitat, prevent erosion and allow riparian shading	Medium	High

Management issue (length)	Management strategies	Sub-catchment health priority	Community priority
Poor bank stability (2.8 km)	• Revegetate for long-term stabilisation: choose areas where vegetation has most chance of establishing • Choose native species useful for erosion control (e.g. that can grow at the toe of the bank, produce a dense root mat and can handle flooding) • Seek professional advice for engineering works (e.g. rock riprap, gabions, battering) which may be needed where erosion threatens a high value asset or is severe • If bank erosion is because of bed deepening (erosion head), control bed deepening processes before attempting to stabilise bank erosion	Medium	Medium
Erosion heads (3 sites)	• Monitor sites to determine if erosion is active • Restrict stock access, revegetate or encourage vegetation within the channel for long-term stabilisation • Choose native species that grow within the channel, produce a dense root mat and can handle flooding • Seek professional advice for erosion control works (e.g. rock chutes, drop structures) which may be needed where erosion threatens a high value asset or is severe	Medium–low (medium on Narridy Creek)	Low
Exotic tree removal and control (1.1 km)	• Remove by cutting down and/or poisoning with a suitable herbicide (depending on the species and its location) • Do not remove all trees in a heavily infested area at the one time • Replace exotic vegetation with suitable native species	Low	Medium
Side gully erosion/gully heads (3 sites)	• Revegetate for long-term stabilisation: choose areas where vegetation has most chance of establishing • Seek professional advice for erosion control works (e.g. rock chutes, drop structures) which may be needed where erosion threatens a high value asset or is severe	Low	Medium
Stream works causing or threatened by erosion (not identified)	• Ensure stream works (e.g. culverts, fords and bridges) are located on a straight and stable part of the watercourse, are correctly aligned, have secure footings and are designed to handle the flow capacity • Seek professional advice for engineering works (e.g. rock riprap, gabions, battering) which may be needed where erosion threatens a high value asset or is severe	Low	Low
Salinity (not identified)	• Further investigate dryland, groundwater and surface water salinity trends to determine the extent and causes of salinity • Managing high stream salinities may require adequate environmental flows to maintain water quality	Unknown	Low

Native watercourse vegetation in poor condition was an issue along the lower and middle reaches of Pisant Creek, Rocky River downstream of Gladstone and Narridy Creek. These areas provide poor habitat and have a high potential for bank erosion because protective vegetation is absent. The natural system has been modified by clearance, grazing and, in some areas, cropping to the edge of the watercourse. Where no buffer strip of vegetation exists, runoff and sediment and nutrient transport from surrounding agricultural land is not slowed and filtered.

Poor bank stability, indicative of active bank erosion, was identified as a significant issue along Narridy Creek and its tributary. Human activities have triggered bed-deepening and bank erosion along approximately 1 km of watercourse. A large erosion head was observed at the upstream end of this affected area. The watercourse channel is incised to a depth of 5 m with vertical banks that make it difficult to establish stabilising vegetation.

In general, poor bank stability was not a widespread issue for other watercourses in the subcatchment. Most watercourses were classified as having good bank stability.

Side gully erosion and bed deepening were significant at particular sites but were not widespread problems in the subcatchment. Three erosion heads, indicating bed deepening, were identified. The erosion head on Narridy Creek has resulted in significant incision and associated bank erosion (see above). This still active erosion head is up to 3 m high and is likely to move further upstream during large flood events. It is possible that an upstream ford may control further headward erosion. Two erosion heads were located on a tributary of Pisant Creek: one upstream of the confluence with the creek and the other in its upper reaches. The second erosion head has caused bank erosion downstream. Two sites of side gully erosion were located along Pisant Creek and large gullies have opened up along drainage lines at these sites.

Stream works such as bridges, fords and culverts were classified as high or medium stability; none were identified as causing or threatened by erosion. However, landholders voted this as an issue of concern in the subcatchment.

Salinity was voted as an issue by landholders. High stream salinities are a feature of the Broughton catchment and salinity levels show large variations over time. For example, a notable peak in stream salinities in the early 1980s corresponded to the drought of 1982–83 (Jolly et al. 2000). Maintaining adequate environmental flows is important for lowering salinity levels. Currently, there is insufficient data to determine salinity trends for the subcatchment.

13.3.3 OTHER ISSUES

Some sections of Pisant and Narridy creeks have been channelised and levee banks have been constructed along the channelised section of Narridy Creek. Typically these modifications increase the velocity and volumes of flow within the watercourse and often initiate bed and bank erosion (Kapitzke et al. 1998). The modifications to these watercourses will increase the risk of erosion that could affect upstream and downstream landholders.

13.4 Monitoring and information gaps

An important information gap for Rocky River concerns flow hydrology and water quality data. Monitoring of groundwater and surface water quality, especially salinity trends, is required. More information is needed on the current water regime, including the interaction between groundwater and surface flows.

Investigating the physical and ecological effects of different flow bands is necessary in order to refine environmental water requirements identified in this report. This requires not only information on water quality, groundwater levels and stream flows but also monitoring of aquatic flora and fauna ecology, habitat conditions and geomorphological processes.

Other information needs for Rocky River include data on the movement and impacts of sediment generated by upstream erosion such as along Pine and Appila creeks; more detailed studies of fish species, their ecology and flow requirements; and information on hyporheic environments in the river system.

An important information gap for Crystal Brook relates to the feasibility of environmental water releases from Beetaloo reservoir. Further investigation of the flow regime, the quality and volume of water that could be released, and the impact of its release on the ecology and geomorphology of the downstream watercourse are necessary before recommendations regarding environmental releases could be made.

Little is known about the native fish populations and their ecology in Beetaloo reservoir and along Crystal Brook. Hyporheic environments are likely to exist along Crystal Brook but this requires investigation. Similarly, it is not known if the extensive reedbeds around Bowman Park are a natural feature or if they have developed as a result of encroachment due to a decrease in the frequency of scouring flows because of the reservoir.

The environmental water requirements for riverine environments along Pisant and Narridy creeks were not determined. This may be considered an information gap. Key monitoring issues are aquatic flora and fauna ecology, habitat conditions and morphological processes in the important riverine habitat and remnant vegetation areas in the upper reaches of Pisant Creek. Monitoring erosion processes, including sedimentation downstream, is important for Narridy Creek.

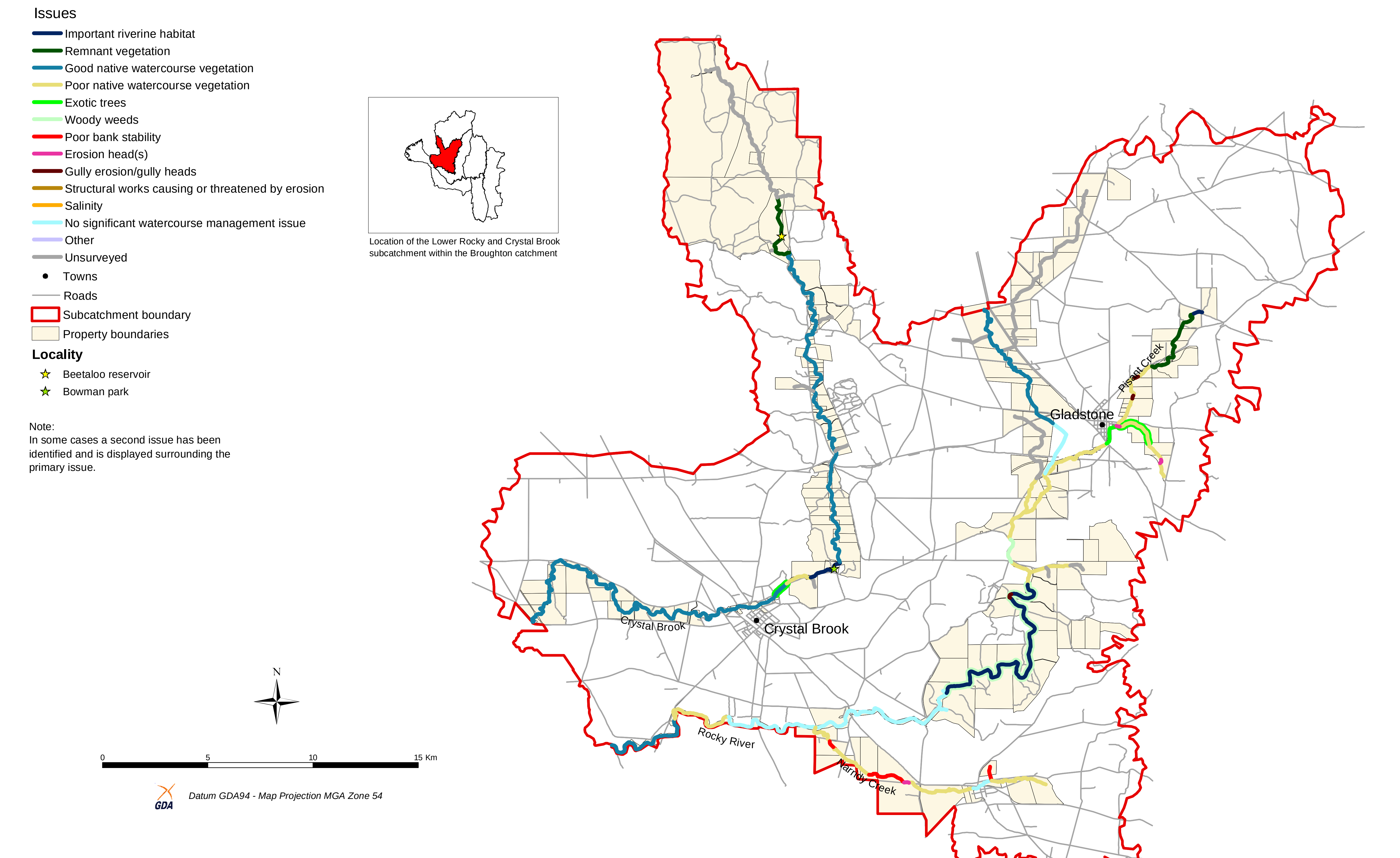
13.5 Summary

The diverse habitat types along the watercourses of the Lower Rocky and Crystal Brook subcatchment include dry channels, reedbeds, pools, riffles, braided channels and sand bars. The riparian vegetation ranges from eucalypt forests to sedgelands and reedbeds. Watercourse conditions vary from almost pristine (such as Mary Springs) to modified significantly (such as areas lacking native riparian vegetation, and the incised and eroded areas on Narridy Creek). Major threats include altered water regimes, vegetation clearance, uncontrolled livestock access, weed invasion, and channelisation, erosion and sedimentation in some areas.

Beetaloo reservoir has had a major adverse impact on the environmental water requirements for Crystal Brook, particularly in Zone 2 (Map 5.2). The potential for environmental water releases from the reservoir requires investigation.

Water resource development for irrigation is limited now but there is increasing pressure to develop water resources for irrigating crops such as olives and vines. Further investigation of the potential for water resource development and the associated impact on environmental water requirements and the sustainability of the resource is needed. The entire range of requirements is important and needs to be maintained. Protecting the groundwater resource is particularly vital in order to maintain the important permanent baseflow, pools and reedbed habitats in the subcatchment. The limited controls over development and use of water resources in this subcatchment, is a matter of concern.

Priority watercourse management issues for the subcatchment are to maintain and rehabilitate the areas of important riverine habitat and areas of remnant and good condition riparian vegetation. Areas with high ecological values include Bowman Park, Rocky River Gorge and the upper reaches of Pisant Creek. Good management will need to address threats such as grazing, weed and exotic tree invasion, and channelisation and encourage natural regeneration or active revegetation with local native species.



Map13.1: Watercourse management issues in the Lower Rocky and Crystal Brook subcatchment

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The Department of Water, Land and Biodiversity Conservation
EPA South Australia
Government of South Australia

CHAPTER 14 THE UPPER ROCKY SUBCATCHMENT

14.1 Introduction

This chapter discusses the watercourse management and environmental water requirements for the Upper Rocky subcatchment. The key water dependent physical and ecological environments and processes for the river geomorphic zones within this subcatchment are described. This includes the vegetation, fish and macro-invertebrates in the area. The important flow bands needed to maintain the environments, processes and associated plants and animals are described for each zone. Appendix E contains a more detailed description of the environmental water requirements including recommended frequency, duration and seasonality of flows.

The chapter describes key management issues that impact on the watercourse environments and outlines the environmental water requirements of these environments. The priorities and strategies for watercourse management based on the input of landholders and the results of the survey of watercourses in the subcatchment are tabled. The chapter closes with a discussion of information gaps and monitoring needs that have been highlighted by the project.

The Upper Rocky subcatchment includes the towns of Wirrabara in the north and Laura in the south. It is bounded to the west by the southern Flinders Ranges and to the east by the Narien Range near Tarcowie. The major watercourses within the subcatchment are Rocky River and Pine, Appila, Bauer and Yarrowie creeks (Map 3.1).

Major land uses in the subcatchment include a mix of cropping and grazing. Small areas limited to grazing occur within the gorge sections of Appila Creek and the upper reaches of Rocky River. Riparian areas of the upper reaches of Pine Creek are characterised by ephemeral, shallow depressions and have been cultivated.

14.2 Water dependent ecosystems and processes

14.2.1 UPPER ROCKY RIVER

Rocky River rises in the southern Flinders Ranges near Wirrabara and flows in a southerly direction to meet the Broughton River south of Crystal Brook. Pine Creek is a major tributary and joins upper Rocky River north of Laura. Most reaches of Rocky River are encompassed in a single geomorphic zone, Zone 4 (Map 5.2; Section 5.2; see Chapter 13 for Zones 1–3 which were identified along the lower reaches of the river).

Zone 4

Geomorphology and hydrology

Zone 4 of Rocky River (upstream of Laura township; Map 5.2) begins in a narrow bedrock valley near Wirrabara. The valley widens as the river flows downstream with deposits of Quaternary alluvium becoming more extensive. The in-stream physical habitats include dry gravel beds, pools and reedbeds. There is no evidence to suggest major channel changes since European settlement (Brizga 2000a).

The river in the zone alternates between a dry, gravelly channel and wetter areas where the groundwater table is close to the surface and supports reedbeds and deep pools. Bulrush

(*Typha* spp.) and common reed (*Phagmites australis*) are the dominant species in the mid-dense to dense stands of reeds. The reedbeds and permanent pools are important habitats for aquatic plants and animals, and they provide refuges during dry periods (Plate 14.1).

Plate 14.1 A view of Rocky River, Zone 4, (6 km north of Laura) showing the in-stream environment of permanent pools and reedbeds. River red gums dominate the riparian zone and exotic trees (ash) can be seen on the right.

Vegetation

The watercourse vegetation is an open forest dominated by river red gums with an understorey dominated by elegant wattle (*Acacia victoriae*) and cotton bush (*Maireana aphylla*) (Brown and Kraehenbuehl 2000). The vegetation is modified and most areas lack understorey shrub species because of the impact of grazing and clearance. Exotic trees, in particular ash (*Fraxinus* sp.), are a significant and widespread problem along the river in the zone. The most dense infestations are in Wirrabara Forest and from here the trees have spread to the lower reaches.

Fish and macro-invertebrates

Macro-invertebrate and fish sampling was not undertaken in the zone. Macro-invertebrates and fish species found in the lower zones of the river are discussed in Chapter 13.

Important flow bands

- *Groundwater* maintains soil moisture and permanent pools, where the groundwater table intersects the river bed. This supports the habitat for aquatic flora and fauna within pools and in-stream reedbeds.

- *Mid flows* are important for connecting pool environments and increasing the area of the aquatic habitat. The flows enable fish and macro-invertebrates to migrate and develop. They are also important for flushing pools, leaching accumulated salts through the stream bed and maintaining water quality.
- *High to bankfull flows* are important as a cue for native fish breeding and for watering river red gums (*Eucalyptus camaldulensis*) and Broughton willow (*Acacia salicina*). The flows are also important for geomorphic processes such as transporting sediment, removing fine sediment from riffle substrates and maintaining natural channel-forming processes.
- *Overbank flows* are important for floodplain inundation and recruiting river red gums. The flows are important for scouring pools and transporting nutrient, sediment and organic matter from the floodplain to the watercourse and along the river system.

14.2.2 PINE AND APPILA CREEKS

Pine Creek is a tributary of Rocky River; Appila Creek is a tributary of Pine Creek. Both streams rise in the southern Flinders Ranges in the northern section of the Broughton catchment. The extensive deposits of Quaternary alluvium, which form broad plains in their lower reaches, are an important feature of these creeks. Extensive erosion has occurred in their catchments, including the incision of streams flowing across the broad alluvial fans. The implications for downstream sedimentation have been limited by the discontinuous nature of the incision, which means that much of the eroded sediment is likely to be stored in the alluvial fan and floodplain deposits immediately downstream of the incised reaches (Brizga 2000a).

Three river geomorphic zones have been identified (Map 5.2; Section 5.2):

- Pine Creek, Zone 1 — Rocky River to the headwaters.
- Appila Creek, Zone 1 — junction with Pine Creek to Appila Springs.
- Appila Creek, Zone 2 — upstream of Appila Springs to the headwaters.

Pine Creek Zone 1

Geomorphology and hydrology

The channel morphology of Pine Creek, Zone 1 (Rocky River to the headwaters; Map 5.2) is variable. The creek in its upstream reaches has a substantial defined channel, whereas near its confluence with Rocky River there is no defined natural channel and a drain defines the watercourse. In-stream physical habitats include dry grassy beds, reedbeds and pools. Sections of the creek have been channelised and other areas have undergone stream incision. Catchment erosion, including the ongoing and significant incision of Appila Creek and other tributaries of Pine Creek, is likely to have caused sedimentation in the lower reaches.

Vegetation

Agricultural development has significantly modified most of the native watercourse vegetation through the zone. The condition of watercourse vegetation in the zone is generally poor. Annual exotic grasses or crops with less than 10% overstorey are found along much of the watercourse. Some areas of remnant native shrubland vegetation are located in the middle reaches of the zone.

Vegetation studies indicate that before European settlement (Map 5.3), the upper reaches would have been woodlands dominated by native pines (*Callitris glaucophylla*), Broughton willow and peppermint box (*Eucalyptus odorata*). The lower reaches were typically open shrublands dominated by elegant wattle, emubush (*Eremophila longifolia*), sweet bursaria (*Bursaria spinosa*) and saltbush species (*Atriplex* sp., *Maireana* spp.) (Brown and Kraehenbuehl 2000).

Poor watercourse vegetation and dry shallow creek beds mean aquatic habitat in the zone is limited largely to areas where the groundwater supports reedbeds and permanent pools (Plate 14.2). Common reed and bulrush dominate the in-stream vegetation in these areas. Sedgelands dominated by the rush, *Juncus krausii* and the sedge, *Cyperus gymnocaulos* are located on the banks and drier areas. These areas are important for supporting aquatic plants and animals and as refuges in dry periods. A dense reedbed was observed along the section of Pine Creek between its junctions with Appila and Yarrowie creeks, where it is likely that sediments generated by upstream erosion are deposited and retained.

Plate 14.2 Pine Creek at Stakes Corner: this reach is characterised by a wide shallow stream bed, with common reed and bulrush dominating the in-stream vegetation.

Fish and macro-invertebrates

No fish or macro-invertebrate sampling was conducted for Pine Creek.

Important flow bands

- *Groundwater* maintains soil moisture and permanent pools, where the groundwater table intersects the river bed. This supports habitat for aquatic flora and fauna within pools and in-stream reedbeds.
- *Mid flows* are important for recruiting and establishing riparian vegetation. The flows also increase the area of aquatic habitats available for macro-invertebrates and frogs, and provide connections between pool environments. The flows improve water quality through flushing and diluting the more saline groundwater.
- *High to bankfull flows* are important for scouring pools, channel-forming processes and transporting nutrient, sediment and organic matter along the river system.

Appila Creek Zone 1

Geomorphology and hydrology

Appila Creek in Zone 1 (downstream of Appila Springs; Map 5.2) flows across broad alluvial plains. Bauer and Yarrowie creeks flow across the same plain and are in a similar geomorphic condition. The watercourses flow seasonally and have a variable channel form, including reaches of deep incision, small shallow channels and broad flood-out areas. The incised areas have a rectangular channel profile (Plate 14.3) and the unincised reaches have only a minor or no defined channel. The incision appears to have resulted from increased flow through diversion and/or channelisation. In-stream physical habitats include dry grassy beds.

Plate 14.3 Appila Creek near Appila, Zone 1: the watercourse in this zone is characterised by areas of significant incision interspersed with an undefined channel with broad flood-out areas. This incised area shows a typical rectangular channel profile that has eroded down to bedrock.

Bed deepening and bank erosion is still actively occurring along Appila, Bauer and Yarrowie creeks. Active erosion heads in the middle reaches of Appila and Yarrowie creeks can be expected to further extend the incised reach until they are stabilised or erosion is limited by natural controls such as rock bars. The erosive forces caused by the height difference between the top of the erosion head and the lower channel bed below may drive rapid erosion head retreat and associated bank erosion in major floods. The channel form and meander of recently incised reaches are in an early stage of development and are likely to change significantly before reaching a stable state.

Vegetation

Appila Creek runs out onto grassy plains 3 km below Appila Springs where it is joined by Bauer Creek, and further down by Yarrowie Creek. The creeks do not contain permanent water, have little in-stream vegetation and areas of active erosion. Before European settlement, watercourses in the zone were characterised by open shrubland vegetation dominated by elegant wattle, emubush, sweet bursaria and species of *Pittosporum* (Brown and Kraehenbuehl 2000). It is likely that initial agricultural development modified the environment from a tall shrubland to its current state of annual grassland. The practice of cropping paddocks to the top of the banks and grazing has modified the native watercourse vegetation greatly. A saltbush (chenopod) shrubland is located on the lower reaches of the zone before it joins Pine Creek.

The significant bed and bank erosion in the three creeks, combined with the dry channel and absence of native watercourse vegetation, means that the zone is a poor habitat for any flora or fauna. The stabilisation of the erosion sites is likely to be important for downstream environments as sediment stored in the zone will be mobilised during high flow events and deposited within downstream habitats.

Important flow bands

- *Mid flows* are important for recruiting and establishing riparian vegetation. They are also important for channel-forming processes.
- *High to bankfull flows* are important for channel-forming processes and transporting nutrient, sediment and organic matter along the river system.

Appila Creek Zone 2

Geomorphology and hydrology

Zone 2 of Appila Creek (upstream of Appila Springs to the headwaters; Map 5.2) has a variety of channel forms. Immediately above Appila Springs the creek passes through a bedrock gorge then the valley above it widens again to rolling hills. In-stream physical habitats include permanent pools, rock bars, reedbeds and dry grassy beds. There is no evidence to suggest major channel changes since European settlement (Brizga 2000a).

Vegetation

Watercourse vegetation in the zone is characterised by a woodland dominated by peppermint box gum and river red gums. The condition of the native watercourse vegetation is good with a mid-dense to dense overstorey of eucalypts. Understorey acacia shrub and groundcover layers have been modified by weeds, grazing and clearance.

Appila Springs is an important area. It has permanent water, diverse physical habitats (including pools and rock bars) and a diverse range of in-stream and watercourse vegetation. Bulrush, rushes (*Juncus* spp.) and sedges (*Cyperus* spp.) dominate the in-stream vegetation.

The creek upstream of Appila Springs has some areas of pools and baseflow but is mostly a dry channel. The areas of permanent water provide important aquatic habitats and support emergent aquatic plants such as bulrush, rushes and sedges (Plate 14.4).

Fish and macro-invertebrates

Macro-invertebrate sampling was conducted at Appila Springs in 1999 but this data is yet to be analysed. No fish sampling was undertaken for Appila Creek.

Plate 14.4 Appila Creek near Tarcowie, Zone 2: this zone is characterised mainly by riffles, rock bars and dry grassy beds with areas of pools and macrophyte beds. The condition of the native watercourse vegetation is good with a mid-dense to dense overstorey of eucalypts.

Important flow bands

- *Baseflow* in the zone flows almost continuously with a seasonal increase over winter–spring. Baseflow is important for maintaining flow over riffles and supporting a diverse range of habitats for macro-invertebrates and frogs. It is also maintains soil moisture which supports the riparian sedgelands and in-stream reedbeds.
- *Seasonal low flows* are a result of surface flows with a seasonal increase in the baseflow. The flows are important for increasing the area of aquatic habitat available for frogs and macro-invertebrates and for maintaining water quality.
- *Mid flows* are important for recruiting and establishing riparian vegetation. They provide a connection between pool environments and increase the area of the aquatic habitats for frogs and macro-invertebrates. The flows are also important for flushing pools, maintaining water quality and removing fine sediment from riffle substrates.

- *Bankfull flows* are important for recruiting and establishing riparian vegetation. These flows are also important for maintaining natural channel-forming processes, transporting sediment and scouring pools.

14.3 Management issues

Landholders within the Upper Rocky subcatchment were primarily concerned with reduced flows because of the lack of rain and increased usage. Uncontrolled development of the water resource, in particular bores removing water, was perceived as a management issue of concern. Encroaching reeds and poor water quality because of salinity and stagnation were also raised as important issues. Other management issues raised were weeds (such as boxthorn, *Lycium ferocissimum,* and artichoke, *Cynara cardunculus*), erosion heads causing bed and bank erosion, exotic trees, fewer springs flowing and debris.

14.3.1 ISSUES AFFECTING ENVIRONMENTAL WATER REQUIREMENTS

Rocky River

Water resource development in the subcatchment occurs within two areas: Laura and Wirrabara. Small properties around Laura use the local groundwater resources for pasture production and horticultural activities. These agricultural industries are limited at present. However, groundwater use may increase in the near future if interest in new horticultural and viticultural pursuits such as olives and vines in the area continue to grow.

Groundwater is also extracted in the Wirrabara area, mainly for the production of lucerne. Viticultural development is likely to expand in this area and will require surface and ground water resources.

Within this subcatchment there are no major weirs or impoundments and no other significant water resource developments.

Groundwater is particularly important to maintain permanent pools and reedbed habitats in the zone. Increasing groundwater extraction by direct extraction or by planting crops that use the groundwater table could have significant impact on springs, permanent pools and reedbed environments. Local landholders have concerns about the potential for further irrigation development along upper Rocky River for viticultural and horticultural activities. This situation needs to be monitored and managed to ensure that environmental flows are maintained and that there is minimal impact on riverine environments.

Developing surface water resources will impact mostly on low to mid flows. The impact will be greatest in dry years and will delay flow. In this zone, mid flows are important for maintaining water quality and connections between pools, and allowing fish and macro-invertebrates to migrate.

There is little control over the construction of farm dams and bores in this area and there is no gauging of flows or recorded flow data for any watercourse in the subcatchment. The level of water resource development, the flow regime and the health of the aquatic ecosystems need to be monitored. Impacts on water dependent ecosystems and processes, and downstream users, need to be considered before the water resources in this area are developed further.

Pine Creek

There is no water resource development along Pine Creek and no gauging station information for this watercourse. The main river health issues involving these watercourses relate to watercourse management rather than flow management (see below).

Appila Creek

There is no water resource development along Appila Creek (or Bauer and Yarrowie creeks) and little likelihood of any in the future because of the limited flows. There is no gauging station information for these watercourses. The main river health issues involving these watercourses relate to watercourse management rather than flow management (see below).

14.3.2 WATERCOURSE MANAGEMENT PRIORITIES AND STRATEGIES

Ensuring environmental water requirements are being met will not result in a healthy river system unless the ecosystems dependent on these requirements are maintained and protected. Consequently, the project assessed the condition of the major watercourses in the subcatchment and, in consultation with landholders, identified significant watercourse management issues (see locations on Map 14.1).

Table 14.1 lists the significant watercourse management issues in order of priority and outlines strategies for their management. High, medium and low priorities have been set largely in terms how much improvement in watercourse health is possible for the cost and effort required. Thus a low priority issue is not insignificant; it may simply not require immediate attention or it may incur costs that outweigh the benefits on a subcatchment scale. Appendix F contains a discussion of the principles and guidelines used to help determine priorities.

Community priorities for management, based on votes by landholders at a meeting on 11 April 2000, are listed in Table 14.1. Management of these issues will largely be the responsibility of landholders, regional organisations and the local community and the priorities indicate community views and interests in undertaking river rehabilitation works.

Significant watercourse management issues

The most important management issue was the protection of important riverine habitats and remnant vegetation. An important habitat area was identified at Appila Springs. Patches of remnant vegetation were identified along Appila Creek through Tarcowie common, a third-order stream north of Wirrabara (not indicated on Map 14.1), the middle reaches of Pine Creek and the upper reaches of the tributary of Rocky River north of Laura. Many of these areas have already been protected by fencing and the removal of livestock. Some sites are under Heritage Agreements. These areas provide important habitats for riverine plants and animals, are important seed sources and enhance the ecological and social values of the river. Protecting and maintaining these areas is a high priority for the subcatchment.

In a number of reaches the condition of native watercourse vegetation is relatively good but has been modified or is threatened by degrading processes such as cropping, grazing or invasion by exotic weed and tree species. These areas would respond well to rehabilitation.

Areas of good native vegetation include Appila Creek (downstream of Appila Springs to Hogshead Creek), the lower reaches of Pine and Yarrowie creeks, and Rocky River (upstream of Wirrabara and downstream of Laura).

Table 14.1 Management priorities and options for the Upper Rocky subcatchment

Management issue (length)	Management strategies	Sub-catchment health priority	Community priority
Protection of important riverine habitat (1.6 km)	• Monitor sites regularly to observe any changes or threats (e.g. photo points, Waterwatch) • Control threatening processes such as weeds and livestock access • Revegetate with local indigenous species, if necessary, where vegetation has been modified • Manage upstream or downstream threatening processes (e.g. weed dispersal, erosion)	High	High
Protection of remnant vegetation (5.1 km)	• Manage livestock to avoid damage to vegetation and to allow natural regeneration • Remove or control weeds and limit the opportunity for weeds to invade • Monitor sites regularly	High	High
Improving/maintaining areas of good native vegetation (56.9 km)	• Revegetate and/or encourage natural regeneration • Manage livestock to avoid damage to vegetation and to allow natural regeneration • Remove or control weeds and limit the opportunity for weeds to invade • Monitor sites regularly	High	High
Exotic tree removal and control (50.1 km)	• Remove by cutting down and/or poisoning with a suitable herbicide(depending on the species and its location) • Do not remove all trees in a heavily infested area at the one time • Replace exotic vegetation with suitable native species	High	Medium
Riparian weed removal and control (species observed include boxthorn and artichoke) (5.9 km)	• Remove by hand, spraying, burning or mechanical techniques depending on the site and the density of the infestation: care is needed to prevent disturbance to watercourse bed and banks • Control by: - regular spot spraying (using herbicides recommended for use near a waterway) or hand removal - shading out weeds by retaining canopy cover and avoiding disturbance to the natural vegetation - excluding livestock to prevent disturbance to ground and riparian vegetation • Allow natural regeneration or revegetate with local native species to re-establish habitat, prevent erosion and allow riparian shading	Medium	Medium

Management issue (length)	Management strategies	Sub-catchment health priority	Community priority
Erosion heads (9 sites)	• Monitor sites to determine if erosion is active • Restrict stock access, revegetate or encourage vegetation within the channel for long-term stabilisation • Choose native species that grow within the channel, produce a dense root mat and can handle flooding • Seek professional advice for erosion control works (e.g. rock chutes, drop structures) which may be needed together with revegetation where erosion threatens a high value asset or is severe	Medium (along Appila creek)	Medium
Poor bank stability (3.8 km)	• Restrict livestock access and revegetate for long-term stabilisation: choose areas where vegetation has most chance of establishing • Choose native species useful for erosion control (e.g. that can grow at the toe of the bank, produce a dense root mat and can handle flooding) • If bank erosion is because of bed deepening (erosion head), control bed deepening processes before attempting to stabilise bank erosion	Medium	Medium
Poor native watercourse vegetation (34.2 km)	• Revegetate with a full range of local native plants, including groundcovers, grasses, shrubs and trees • Leave a vegetated buffer strip between cultivated areas and the watercourse – at the very least, a good continuous grass cover • Manage livestock to avoid damage to vegetation and to encourage natural regeneration	Medium	Low
Side gully erosion/gully heads (1 site)	• Monitor sites to determine if erosion is active • Revegetate for long-term stabilisation; choose areas where vegetation has most chance of establishing. • Seek professional advice for erosion control works (e.g. rock chutes, drop structures) which may be needed together with revegetation where erosion threatens a high value asset or is severe	Low	Medium
Structural works causing or threatened by erosion (1 site)	• Monitor sites to determine if erosion is active • Ensure stream works (e.g. culverts, fords and bridges) are located on a straight and stable part of the watercourse, are correctly aligned, have secure footings and are designed to handle the flow capacity • Seek professional advice for erosion control works (e.g. rock chutes, drop structures) which may be needed together with revegetation where erosion threatens a high value asset or is severe	Low	Low
Salinity (not identified)	• Ensure adequate environmental flows to maintain water quality • Provide alternative livestock watering points	Unknown	Medium

Exotic trees are a widespread and significant management issue affecting most of Rocky River north of Laura. They are a problem because of their impact on river habitats, their potential to cause flooding and their ability to spread rapidly along the watercourse. Ash trees, in particular, are very invasive and ash seedlings are spreading down Rocky River. Discussions at the community meeting concluded that targeted control was the preferred control option because of the sparse but widespread nature of the ash. A cost-effective control program to remove all ash seedlings down to the northern extent of Laura and to instigate regular control programs to prevent new seedling recruitment should be considered.

Tamarisk (*Tamarix* sp.) plants were identified along Pine Creek near ‘Almond Corner’. The infestation is dense but limited to an area of 1 km of the watercourse. Tamarisk is difficult to control and can establish easily through ‘rooting’ of broken branches; it is thus a significant threat to the health of Pine Creek.

Riparian weeds were considered an important issue mainly in the upper reaches and northern tributaries of Rocky River. The project survey techniques meant that only large, woody, species could be detected easily. Weeds such as wild rose (*Rosa canis*) and artichoke were identified.

Bank erosion, bed deepening and gully erosion were significant problems along certain reaches of Pine and Appila creeks but were not widespread across other watercourses. Most of the watercourses assessed for bank stability had good bank stability (87%) and 6% had moderate bank stability. The 3% that have poor bank stability are located on the upper reaches of Pine Creek, the lower and middle reaches of Appila Creek, and the middle reaches of Yarrowie Creek. Most of these areas are associated with significant bed deepening and multiple erosion heads. The areas of most concern in the subcatchment were lower Appila Creek (near its confluence with Pine Creek) and the middle reaches of Yarrowie Creek.

Stabilisation measures to halt the retreat of a large erosion head would require structural works to protect the head zone against erosion. A further assessment would be required before any specific course of action could be recommended. The number and location of active erosion heads within the system needs to be determined. Stabilising a single erosion head may provide limited benefit if several active erosion heads are in operation. Hydraulic assessments are also needed to confirm the impact of various flow regimes. Rehabilitation, however, is likely to be costly. Weighing up the costs and benefits resulted in erosion issues being given a lower priority than protecting less degraded or remnant areas and dealing with riparian weed and exotic trees.

Bank erosion can be expected in the incised reaches, as the channel widens and natural battering processes reduce bank slopes. Bank stabilisation works are unlikely to be justified; because of the height of the banks and hydraulic loadings within the incised channel, major works are likely to be required in order to be effective. Revegetation and allowing natural regeneration of more stable areas is likely to be the most effective rehabilitation method for these sites.

Most stream works were assessed as being in a moderate to highly stable condition. Only a ford on Pine Creek (at the crossing on the Wirrabara–Appila road) is causing downstream erosion and scouring. This may be because the culvert is under capacity and thus increases the velocity of water passing through the structure. The subsequent erosion is outflanking the structure. The site is not in critical condition but an investigation and assessment is recommended.

Groundwater salinity levels around Laura and Wirrabara were a concern for the local community because an increase in salinity could result from groundwater pumping for irrigation. The community identified a need for more information on the groundwater resource and its capacity, particularly before any further groundwater developments occurred. There is insufficient data to determine salinity trends for the subcatchment.

Native watercourse vegetation in poor condition or absent was an issue along Pine, Appila and Yarrowie creeks. In particular, clearance, grazing and the practice of cropping paddocks to the top of the banks has had significant impact on the native watercourse vegetation. The seasonal and variable rainfall and the extensive vegetation clearance in this area since European settlement will make revegetation very challenging.

14.4 Monitoring and information gaps

The key knowledge gap for the Upper Rocky subcatchment is a lack of flow data for Rocky River. Other gaps include water quality trends for both surface and ground water, whether the zone supports hyporheic environments, and the impact and movement of sediment through the system from upstream erosion sites.

The monitoring priorities for Rocky River include the monitoring of surface flows and groundwater levels, and flow-related water quality monitoring for salinity, nutrients and pollutants. Monitoring sedimentation rates will improve our understanding of sediment delivery from incised channels along Pine and Appila creeks and the likely impact on in-stream habitats. The permanent pools along the upper Rocky River may support native fish. Further studies of the presence of fish in the zone and their migration habitats are required.

An important knowledge gap for Appila and Pine creeks concerns the current erosion processes along the watercourses and the need to undertake a risk assessment to determine management actions. For example, more information is required on the causes of the erosion, the location of erosion heads and control points, hydraulic loadings within incised reaches and at erosion heads, the rate of future erosion and the impact on surrounding land and assets. This information is critical to determining the management action required to address erosion issues. Other gaps include the diversity and distribution of aquatic animals around Appila Springs and the role of reedbeds in storing sediments from upstream erosion.

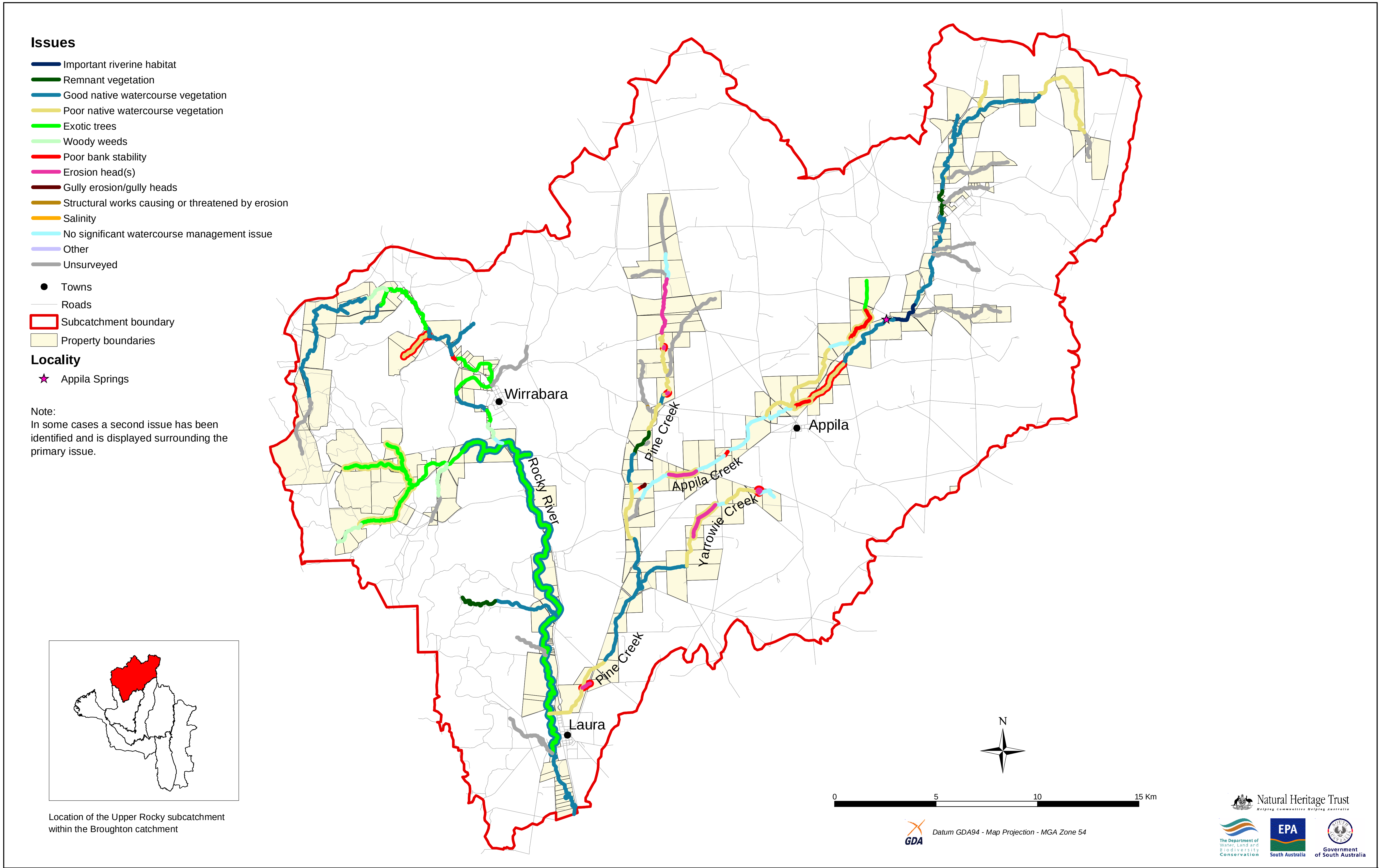
Monitoring priorities for Pine and Appila creeks include sediment transport and sedimentation rates in order to assess the degree of change because of erosion. Monitoring the physical effects of high flows (including erosion, deposition and substrate maintenance) will enable a better definition of flow requirements for geomorphological purposes for all watercourses in the subcatchment. Other suggestions include water quality monitoring for salinity, nutrients and pollutants and monitoring of the species and extent of emergent aquatic plants to determine if reedbeds are increasing or not.

14.5 Summary

The diverse habitat types in the Upper Rocky subcatchment include pools and reedbeds, riffles and rock bars, and dry grassy channels. Riparian vegetation ranges from eucalypt forests and open woodlands through to reedbeds and sedgelands. The watercourse condition varies from remnant areas such as Tarcowie Common and good areas such as Appila Springs through to significantly modified areas which lack native riparian vegetation and have incised and eroded reaches (such as along Appila Creek). Major threats include water resource development, exotic trees, weed invasion, uncontrolled livestock access, erosion and sedimentation, and a lack of native vegetation.

Water resource development for horticultural purposes is limited but there is increasing pressure for further development in the Laura and Wirrabara areas. The sustainability of groundwater resources in both these areas and the potential impact of farm dams on surface flow in the Wirrabarra hills need to be investigated. Protecting the groundwater resource is vital in order to maintain the subcatchment's permanent baseflow, pools and reedbed habitats. Surface flows are especially important for flushing permanent pools and leaching accumulated salt through the river bed. The lack of controls over development and the use of the water resources in this area are a concern.

The priority management issues for the subcatchment are to protect important riverine habitats and remnant vegetation, to maintain and rehabilitate areas of riparian vegetation in good condition and to manage exotic trees. Management options should address threats such as the spread of exotic trees, weeds, stream incision and erosion. As well, the options should encourage natural regeneration or active revegetation with local native species.



Map 14.1: Watercourse management issues in the Upper Rocky subcatchment

CHAPTER 15 CONCLUSIONS AND RECOMMENDATIONS

15.1 Introduction

This chapter presents the conclusions on the health of the Broughton River and its tributaries based on the studies for the project. Management needs for the Broughton catchment are discussed, management strategies recommended, and key knowledge gaps and monitoring needs outlined. For discussion of subcatchment issues and recommended management priorities and strategies see Chapters 8–14.

The stakeholder organisations and groups that this report recommends be involved in managing the catchment have been listed where possible. These organisations and individuals have responsibilities for watercourse, water resource and land management or have interests that directly or indirectly affect the river system:

- landholders;
- SA Water Corporation;
- Department for Environment and Heritage;
- Department of Water, Land and Biodiversity Conservation;
- Primary Industries and Resources, South Australia;
- Department for Transport and Urban Planning;
- Clare Valley Water Resources Planning Committee;
- soil conservation boards;
- animal and plant control boards;
- local government;
- Northern and Yorke Agricultural Districts Integrated Natural Resource Management Committee;
- Broughton and Wakefield Waterwatch; and
- Greening Australia.

Natural resource management arrangements in South Australia are currently undergoing reform with the passing of the NRM Act. This will bring together three acts – the *Animal and Plant control (Agricultural Protection and Other Purposes) Act 1986, Soil Conservation and Land Care Act 1989,* and *Water Resources Act 1997.* The Act enables the formation of regional NRM Boards which will take over the responsibilities of existing animal and plant control boards, soil conservation boards, catchment water management boards and interim INRM groups, and will therefore take on the responsibilities of the relevant groups for the associated recommendations outlined in this chapter. The Broughton catchment is within the Northern and Yorke Agricultural District Integrated Natural Resource Management Committee administrative region.

15.2 Overview of river condition

The Broughton catchment is located in a semi-arid climatic zone and watercourses are characterised by a highly variable flow regime. Many of the native plants and animals found in the system are tolerant of a range of environmental conditions. The river system is large and complex and supports a wide variety of riverine environments from ephemeral channels to continuously flowing streams. In particular, the groundwater dependent permanent pools and baseflow along the river's main channel and other sites along the major tributaries are crucial for maintaining the health and diversity of aquatic plants and animals.

Since European settlement the catchment has undergone significant changes and the condition of the Broughton River and its tributaries has been significantly modified from their natural state, in large part by human activities. The condition of the river system varies considerably between different reaches ranging from degraded to near natural condition.

The water regime of the catchment has undergone much change since European settlement. Land management practices such as vegetation clearance, overgrazing and long fallowing led to increased surface runoff and stream flows that in turn initiated catchment and stream erosion. In recent decades, improved land management practices designed to reduce runoff and retain water on paddocks are likely to have resulted in a slight decrease in stream flows. To some extent this has ameliorated some of the excess runoff generated by the changes introduced through settlement and agricultural development.

The use of water resources for irrigation and other purposes has increased over time. This has altered the natural flow regime, in particular, the volume, timing and frequency of flow events. Beetaloo reservoir has altered the flow regime along Crystal Brook. Farm dams in the Clare Valley have affected the flow of Hutt and Hill rivers and, to a lesser extent, the Broughton River. The weir and aqueduct system designed to feed flows into Bundaleer reservoir has altered flows and sediment transport along Freshwater and Bundaleer creeks. Flows in other areas of the catchment have been altered to some extent as a result of the diversion of floodwaters, channel modifications and levee banks.

The greatest use of the groundwater resource occurs in Clare and Booborowie valleys. The water is extracted from bores, pumped from pools and used directly by crops such as lucerne. Groundwater monitoring in the Clare Valley shows that although there are often large seasonal variations, groundwater volume and quality has remained stable. Groundwater levels have dropped in the Booborowie Valley (Flint 1972; Clarke 1990). High extraction rates along with water use by lucerne crops are the most likely cause of the falls.

The effects of farm dams, improved land management and groundwater use have been magnified by recent climatic conditions. Rainfall over the past 15 years has not been conducive to producing runoff nor recharging groundwater in the catchment. Consequently, flows and groundwater levels in all areas of the catchment, whether experiencing significant water resource development or not, have been affected.

Watercourse geomorphology has significantly changed across the catchment since European settlement — deepening and widening of watercourse channels, raising of bed levels due to sedimentation and changing channel courses. Typically, geomorphic changes have been a response to widespread vegetation clearing and direct interventions such as channelisation, levee bank construction, sand and gravel extraction, and the construction of dams and weirs.

Seven key native vegetation communities were identified in the catchment, including riverine forests and woodlands, riverine shrublands, lignum swamps, mangrove forests and samphire marshes, sedgelands, reedbeds, and submerged aquatic vegetation. Most of these have been modified significantly from their pre-settlement condition. Most watercourses (48%) now lack, or have a poor cover of native vegetation. It has been replaced by crops or exotic grasses with either no overstorey or a very sparse overstorey of trees or shrubs. Native watercourse vegetation, where present, has generally been reduced to a narrow strip adjacent to the watercourse. Typically, it is the understorey of shrubs and native grasses that is most affected. Threats and impacts include vegetation clearance, cropping to the edge of the watercourse, grazing, invasion by weeds and exotic trees, channelisation and altered flow regimes. Grazing, in particular, prevents the regeneration of plant species.

A snapshot survey of native fish populations recorded only low numbers of native fish, and found only five species: blue spot goby (*Psuedogobius olorum*), mountain galaxia (*Galaxias olidus*), yellow-eyed mullet (*Aldrechetta forsteri*), hardyhead (*Atherinosoma microstoma*) and congolli (*Psuedaphritis urvilli*). Species that rely on migration to and from the estuary were notably absent. The fish survey indicates that, in terms of fish ecology, the river system is in a fair to poor condition. Factors influencing the low numbers of native fish may include habitat degradation, lack of flow events suitable for breeding and migration, predation and competition from introduced species (e.g. eastern gambusia, *Gambusia holbrooki*), man-made barriers to migration and poor water quality.

More than 240 macro-invertebrates were collected from the catchment. Most species are tolerant of a wide range of environmental conditions, and are widespread and common in South Australian rivers. The numbers and types of species found are very similar to those found in the Wakefield and Gawler river systems (Madden et al. 1999).

The macro-invertebrate survey indicated that the catchment has a relatively healthy macro-invertebrate ecology. This is largely due to the presence of permanent flow along several reaches of the Broughton River and its major tributaries. There is a strong relationship between macro-invertebrate diversity and permanent flow across the catchment. A management priority is to maintain this permanent flow wherever it occurs in the river system. With the exception of the Hutt River, the survey indicated that there were few water quality impacts on macro-invertebrate populations across the catchment.

Several species found in the catchment are uncommon or have a limited distribution in South Australia. For example, a species of bristle worm appears to be found only in this catchment. Bristle worms are common marine animals but few are known to occupy freshwater habitats. A key management goal should be to protect the biodiversity and to conserve the habitats where these uncommon species are found.

The Broughton River provides habitat for a number of frog species including the common froglet (*Crinia signifera*), eastern banjo frog (*Limnodynastes dumerilli*), spotted grass frog (*Limnodynastes tasmaniensis*), brown tree frog (*Litoria ewingi*), painted frog (*Neobatrachus pictus*) and Bibron's toadlet (*Pseudophryne bibroni*). With the exception of Bibron's toadlet, most of these species are common and widespread across South Australia. Factors likely to impact on frog populations include habitat destruction, poor water quality and changes to water regimes.

15.3 Management needs and responsibilities

The goals for managing the watercourses in the catchment must be clearly understood. Community expectations, agricultural production needs and the significant changes that have already occurred in the catchment, mean that it is unrealistic to restore the catchment to its condition prior to European settlement. The challenge is to adopt a rehabilitation target to return, as far as possible, the vegetation, structure, hydrology and water quality of the streams to a 'natural' state. Improvements to these elements will in turn lead to improvements in the organisms living in, and relying on, the streams. This includes human needs and sustainable agriculture (LWRRDC 1999).

This management goal corresponds to the community views expressed in the public meetings held by the project. Broadly speaking, the community felt that management of the watercourses should aim to enhance the natural qualities and characteristics of the river system, including more native vegetation and wildlife. In addition, the community's view was that it is important to achieve a sustainable balance between development and the riverine environment.

As stated in Section 15.1, natural resource management arrangements in South Australia are currently undergoing reform with the preparation of the NRM Bill. Once the Bill is passed, a Regional NRM Board will be formed covering the Northern and Yorke Agricultural Districts that will take over the responsibilities of existing animal and plant control boards, soil conservation boards, and the interim INRM Committee. The recommendations outlined below that relate to these groups will then become the responsibility of the newly formed NRM Board.

Investment strategies developed by the NYAD INRM Committee that relate to the recommendations outlined below are shown in parentheses next to the relevant management recommendations. Appendix F shows investment strategies for the NYAD INRM committee.

15.3.1 WATERCOURSE MANAGEMENT

The condition of the watercourses varies considerably between different reaches ranging from degraded to near natural condition. Areas of significant ecological value include Appila Springs, Mary Springs, the lignum swamp habitats along the lower Broughton River and the Broughton River near the Mooroola gauging station. These areas are key assets, have high recreational, community and ecological values, and should be priorities for conservation. There are also areas that are degraded, including the reaches of Appila, Pine and Narridy creeks and tributaries of Booborowie and Yackamoorundie creeks which are all badly eroded and lacking in native vegetation.

Riparian and in-stream vegetation are key structural and functional parts of the riverine ecosystem. The riparian vegetation has been modified to some extent on more than 90% of the watercourses surveyed and is lacking or highly degraded along 48% of the watercourses. Key threats include degradation and a lack of regeneration due to cropping and grazing, invasion by exotic plants, channel modification and altered flow regimes. The lack of regeneration will lead to further loss as older trees and shrubs die. Protecting areas of remnant vegetation is very important for maintaining seed sources, biodiversity and ecological values. These sites are poorly conserved or threatened. Undertaking revegetation and natural regeneration, reducing grazing pressure and controlling weeds and exotic trees are key management requirements.

Accelerated bed and bank erosion associated with channel modifications, loss of vegetation, in-stream structures and livestock access is a significant management issue for several watercourses. Erosion threatens the riverine ecosystems by direct destruction, sedimentation of habitats and altered flow regimes; it contributes to poor water quality and the loss of links between in-stream environments and the floodplain. Some areas subject to erosion have stabilised but many areas remain largely untreated and activities that contribute to accelerated erosion (such as channelisation) persist. Key management requirements include:

- establishing local native watercourse vegetation to protect the bed and banks from erosion;
- ensuring channel modifications and stream works are properly engineered and constructed, and do not initiate erosion or contribute to habitat destruction; and

- undertaking erosion control works where erosion is severe and threatening high value assets.

Poor water quality is another factor that impacts on riverine ecosystems. While it was beyond the scope of this project to assess water quality directly, some evidence suggests that there are water quality issues in the catchment. Several watercourses do not have a riparian buffer strip to filter runoff, sediment and nutrients from the surrounding land; cropping and grazing activities extend to the edge of the watercourse. The macro-invertebrate study found elevated nutrient levels along Hutt River. Extensive reedbeds dominated by two species — common reed (*Phragmites australis*) and bulrush (*Typha* spp.) — throughout the catchment indicate possible high sediment and nutrient levels. In addition, the issues of salinity and pollution from farm chemicals were raised by landholders but were beyond the scope of the project to assess.

The watercourses of the Broughton catchment will continue to degrade unless remedial action is taken. Watercourse management issues and strategies for the catchment were discussed in Chapter 7 and priorities and strategies for each subcatchment were discussed in Chapters 8–14. Implementing these strategies for priority issues at a subcatchment level is crucial to improving watercourse condition.

Table 15.1 outlines recommended strategies for watercourse management at a catchment level including the most appropriate stakeholders to implement these recommendations.

15.3.2 WATER RESOURCE MANAGEMENT

Environmental water requirements to sustain the ecological values of the Broughton River system at a low level of risk have been determined for each of the different river geomorphic zones of the system (Chapters 8–14; Appendix E). These environmental water requirements are recommendations based upon the best available knowledge and provide invaluable information for water resource planning, management and monitoring. Ongoing monitoring, research and investigations are important to gather more data and to improve the understanding of the relationships between the water regime, geomorphology, and plants and animals of the catchment. In particular, the recommended requirements need to be compared with data from actual flow events and may need to be revised as new information becomes available.

Seven key flow bands (components of the water regime) which have ecological or geomorphological significance were identified. These include groundwater, baseflow, low flow, mid flow, high flow, bankfull flow and overbank flow. Flow bands of particular ecological importance include groundwater and baseflow that maintain continuous flow and permanent pools along the Broughton River and its major tributaries. Low and mid flow events along most watercourses are also important for ecological processes such as fish reproduction, connecting habitats and transport of nutrients. Higher flows tend to be more geomorphologically significant — in sediment transport, channel and habitat maintenance and floodplain linkages — as well as providing a number of ecological functions.

Table 15.1 Recommendations for watercourse management and suggested partners

Recommendations	Partners
1. Implement the priorities and strategies for watercourse management for each subcatchment as outlined in Chapters 8 to 14	All stakeholders (6.1-ii; 6.2-iii)*
2. Develop a weed control strategy for management of weed infestations in riparian zones that is catchment-wide and integrated with programs for managing agricultural weeds 3. Develop a targeted, catchment-wide management strategy to reduce areas of infestation and control the spread of exotic trees 4. Develop and promote best practice methods for controlling weeds and exotic trees in and around watercourses	NYAD INRM Committee, APCBs, DEH, PIRSA (8.1-v; 9.1-v, viii, xiii, xiv, xvii, xviii, xx, xxi, xxiv, xxv, xxvi, xxvii)*
5. Develop an integrated revegetation strategy for the catchment that incorporates strategies for enhancing and protecting riparian and in-stream vegetation	NYAD INRM Committee, DEH, PIRSA, Greening Australia (8.1-iii, iv)*
6. Assess the diffuse pollution risk in the catchment and if required develop a risk management strategy	NYAD INRM Committee, EPA (6.2-i)*
7. Investigate management options under the *Water Resources Act 1997* to control water-affecting activities (such as construction of dams, in-stream structures, destruction of vegetation and excavation)	NYAD INRM Committee, DWLBC, local government (6.1-v, vi, xiii, xiv, xv, xvi, xviii)*
8. Audit construction practices for stream works (such as bridges and culverts) to ensure best practice	Local government, Transport SA
9. Develop guidelines to assist local government in assessing development activities that may impact on watercourses 10. Revise local development plans to include policies to control development that may impact on riverine ecosystems (such as farm dams, in-stream structures, channel modifications and earthworks)	DWLBC, Planning SA, local government (6.1-v, vi, xiii, xiv, xv, xvi, xviii; 6.2-v, xii, xvi, xvii, xviii; 7.2-xvii, xviii; 8.3-xxii)*
11. Raise awareness of activities that cause watercourse erosion and impact on watercourse condition and landholder's legal responsibilities	NYAD INRM Committee, Local government, DEH, PIRSA, soil conservation boards, Clare Valley Water Resources Planning Committee (6.2-vi,vii,ix,x,xiv; 7.1-xi; 7.2-xv,xvi,xvii,)*
12. Monitor on-ground works to evaluate success, identify improvements and threats	All stakeholders (6.1-i; 6.2-ii; 6.3-i; 7.2-i, ii, iii; 8.1-i; 8.2-i, ii; 8.3-i, ii, iii, iv; 9.1-i, iii)*

* Actions relate to NYAD INRM Committee investment strategies (Appendix F) as noted (NYAD INRM Committee 2003)

Surface water and groundwater use and diversion in the catchment will alter water regimes and will need to be managed to ensure environmental water requirements are met. Table 15.2 summarises the potential impact of farm dams and groundwater use on key flow bands.

Table 15.2The potential impact of water use on key flow bands

Flow bands	On-stream dam	Off-stream dam	Groundwater use
Groundwater table	X	X	✓
Baseflow	X	X	✓
Low flow	✓	X*	✓
Mid flow	✓	✓	X
High flow	✓	X*	X
Bankfull flow	X	X	X
Overbank–catastrophic flow	X	X	X

✓ = potential impact; X = no or little impact

* Impact is low if appropriate diversion rules are applied.

Permanent pools and baseflow areas maintained by groundwater provide important aquatic habitats, particularly as refuges for plants and animals during dry periods. These areas should be a priority for protection. Groundwater use, including pumping from bores and pools, will need to be managed particularly near important groundwater recharge and discharge areas. Intensive growing of crops such as lucerne which tap into the groundwater table can also lower local groundwater levels. Monitoring is required in areas of high groundwater use, including areas where irrigation from groundwater is associated with intensive lucerne cropping, to ensure that this is not having an adverse impact on groundwater levels and associated permanent pools, baseflow and dependent ecosystems.

Farm dams are most likely to affect low and mid flow events. Modelling suggests that farm dams can delay flow occurring, reduce the flow peak, shorten the duration of low and mid flow events, and reduce natural flow variability. The size of farm dams, their location in a subcatchment and the amount of the catchment that remains free to flow are important factors influencing their effect on environmental water requirements. Dam development in subcatchments should be controlled to ensure that environmental flow requirements are met. Controls such as limiting construction of on-stream dams to smaller watercourses higher in the catchment, low flow bypasses, restricting the size of dams and leaving some areas of the subcatchment free of dams are important to protect low and mid flows and to maintain natural variability.

Large reservoirs and weirs such as Beetaloo reservoir and Bundaleer and Freshwater creek weirs also impact on environmental water requirements. These structures tend to affect all flow bands and interrupt sediment transport. They are also barriers to native fish migration through the system.

For three zones — Hutt River, Zone 1; Hill River; and Broughton River, Zone 6 — sufficient recorded flow data were available to compare actual flow events with the recommended environmental water requirements. Farm dams in the Clare Valley have reduced median flows in the Broughton River by 9%, in the Hutt River by 24% and in the Hill River by 21%. The comparison showed that requirements are being met for the three zones, although mid flow requirements are only just being met. This water requirement is likely to be threatened by continued farm dam development in the Clare Valley region. Controlling water resource development, and monitoring and investigating flows and ecosystem responses for these zones is highly recommended.

A water allocation plan to manage surface and groundwater resources is currently being implemented for the Clare Valley Prescribed Water Resources Area. The effectiveness of this plan needs to be monitored.

Outside of the prescribed area the lack of control over water resource development is an issue that requires attention. In areas identified as being at risk from increasing development pressure, investigation of the extent of groundwater and surface water use and assessment of the need for development control is required.

The key environmental water requirement issues in the catchment include:

- the impacts of farm dams and groundwater extraction in the Clare Valley region;
- protection of permanent pools and baseflow;
- the potential for future water resource development (e.g. dams and groundwater use) in other areas of the catchment;
- the lack of control over development outside of the Clare Valley Prescribed Water Resources Area;
- the impact of Beetaloo reservoir on flows along Crystal Brook; and
- the potential impacts of groundwater use for lucerne crops on groundwater dependent ecosystems in the Booborowie Valley.

Table 15.3 outlines recommended strategies for water resource management including the most appropriate stakeholders to implement these recommendations.

15.3.3 LAND MANAGEMENT

River management should not be viewed in isolation from land management practices within the catchment — the two are inseparable. A consequence of land clearing in the catchment has been increased surface runoff, which in turn intensifies the size and frequency of flood flows. Past and, in some areas, present poor land management practices have also contributed to increased surface runoff and soil erosion. The most obvious impacts have been accelerated soil loss, erosion and sedimentation of watercourses.

In many areas of the catchment cultivation and cropping reach right to the edge of the bank and at times into the actual watercourse. Leaving a riparian buffer strip of grasses and low shrubs along the watercourses in these areas could help to reduce sediment and nutrient loads substantially. Cultivating shallow watercourses has the potential to accelerate erosion and transport sediment and nutrients downstream. Maintaining a perennial cover of grasses would reduce this potential and promote filtration.

Management practices such as stubble retention and minimum tillage that aim to minimise the volume and rate of surface runoff from a paddock should continue, ideally alongside practices such as vegetated buffer strips that slow runoff and trap sediment and nutrients.

Table 15.3 Recommendations for water resource management, and suggested partners

Recommendation	Partners
13. Investigate management options under the *Water Resources Act 1997* to control water resource development and manage threats to environmental water requirements	NYAD INRM Committee, DWLBC, DEH, local government (6.1-v, vi, xiii, xiv, xv, xvi, xviii)*
14. Make areas of permanent pools and baseflow a high priority for management and monitoring (important baseflow areas include Broughton River downstream of Spalding, lower reaches of Rocky and Hutt rivers and Bundaleer, Freshwater and Yakilo creeks, and sections of Belalie and Farrell creeks).	NYAD INRM Committee, DWLBC (6.1-xviii)*
15. Investigate and monitor areas of significant or potential water resource development to determine impacts on water dependent ecosystems (priority areas include the Booborowie Valley and upper Rocky River).	NYAD INRM Committee, DWLBC (6.1-i)*
16. Control and monitor extraction of water from groundwater aquifers and pumping of water from permanent pools and baseflow areas	DWLBC, Clare Valley Water Resource Planning Committee (6.1-i,xviii)*
17. Investigate the possibility of environmental releases from Beetaloo reservoir	SA Water, DWLBC, NYAD INRM Committee (6.1-xv)*
18. Develop policies for farm dam location and construction that ensure environmental water requirements are provided for	NYAD INRM Committee, DWLBC (6.1-xv,xvi)*
19. Develop policies for construction of in-stream structures, such as weirs, that consider fish passage and low flow bypasses	NYAD INRM Committee, DWLBC, DEH, local government (8.1-xv)*

* Actions relate to NYAD INRM Committee investment strategies (Appendix F) as noted (NYAD INRM Committee 2003)

The salinity issues raised by landholders were beyond the scope of the project to assess adequately. Stream salinities and the extent of dryland salinity needs to be monitored to assess trends over time.

Table 15.4 outlines some key recommendations on land management including the most appropriate stakeholders to implement these recommendations.

15.3.4 INTEGRATED NATURAL RESOURCE MANAGEMENT

In the past, the number of organisations with responsibilities that affect river management in the catchment has made it difficult to achieve a coordinated and integrated approach to water resource and watercourse management. Roles and responsibilities for river management were often unclear and poorly understood. For example, landholders indicated that a significant barrier to improved watercourse management was lack of catchment management planning and a lack of coordination and communication among organisations and individuals involved in river and water resource management. There was no one organisation with the overall responsibility for implementing the management options recommended in this plan.

Table 15.4 Recommendations for land management, and suggested partners

Recommendations	Partners
20. Raise awareness of the impacts of land management practices on watercourses 21. Promote adoption of land management practices, e.g. contour banking, minimum tillage and improved pasture management, that minimise surface runoff and prevent soil erosion within the catchment	NYAD INRM Committee, PIRSA, soil conservation boards, DEH (6.2-xiv,xvii)*
22. Investigate and monitor trends in stream salinities and dryland salinity throughout the catchment	NYAD INRM Committee, DWLBC, PIRSA, DEH (6.2-ii; 6.3-i)*

* Actions relate to NYAD INRM Committee investment strategies (Appendix F) as noted (NYAD INRM Committee 2003)

The NYAD INRM committee (and future NRM Boards) has been established to address this issue with integrated NRM plans and well funded investment strategies.

An overall integrated natural resource management approach is essential to address the catchment-scale issues threatening watercourse health in the long term. Moreover, management goals for watercourses need to be synchronised with management goals for the entire catchment. A regional integrated natural resource management framework is required to coordinate and facilitate the implementation of this plan and other natural resource management plans within the catchment and ensure that management goals are consistent.

Table 15.5 outlines recommendations for improving integration and coordination of land, watercourse and water resource management practices across all key stakeholders.

15.4 Effective extension, technical advice and support

Most landholders and stakeholder organisations in the catchment were aware of watercourse management problems generally. But there was a limited understanding of how the watercourses work and the importance of aquatic ecosystems in the catchment. From the community consultation meetings, landholders noted that time, cost, and a lack of awareness and knowledge were barriers to their involvement in watercourse management activities. Many noted that some problems were too big for a person to tackle alone.

To maintain the momentum of community interest fostered by this project, landholders must be supported in undertaking the recommended works. This support could take the form of technical advice, community support and/or funding assistance.

15.4.1 FUNDING SUPPORT

There a number of groups, including Landcare, Greening Australia and Trees for Life, that can assist landholders by providing valuable information, support and access to funds. Natural resource management initiatives, such as the Natural Heritage Trust, National Action

Plan for Salinity and Water Quality and State Revegetation Grant Scheme, can provide funding and some technical support.

Individual landholders often experience difficulty in accessing funding schemes. To address this locally there have been on-ground riparian management works funding initiatives initiated by the West Broughton and Hummocks Soil Conservation Boards and PIRSA. The boards have obtained funding from the Natural Heritage Trust to provide landholder grants for on-ground works. Uptake of these funds has been successful and a number of landholders and community groups have commenced riparian rehabilitation projects under the scheme. Other organisations may also consider developing cost-sharing arrangements in the form of funding incentives to landholders for rehabilitation works.

Table 15.5 Recommendations for integration of management approaches, and suggested partners

Recommendations	Partners
23. Integrate the river management planning information in this document into the strategic and operational plans of: •NYAD INRM Committee •Clare and Gilbert Valleys Council •Mount Remarkable Council •Port Pirie Regional Council •Northern Areas Council •Goyder Council •Clare Valley Water Resources Planning Committee •West Broughton Soil Conservation Board •Goyder Soil Conservation Board •Northern Animal and Plant Control Board •Lower Flinders Animal and Plant Control Board •Goyder Animal and Plant Control Board •Mid North Regional Development Board •PIRSA, DWLBC and DEH	All stakeholders
24. Develop policy and planning frameworks which encourage integrated, best practice land, watercourse and water resource management practices across all stakeholder agencies	NYAD INRM Committee, DWLBC, DEH, local government, PIRSA, Planning SA
25. Define responsibilities and partnerships for management of watercourses and environmental water requirement issues	NYAD INRM Committee, DWLBC
26. Facilitate inter-agency cooperation and support to groups and organisations in the catchment 27. Include river management issues and management requirements as a key component of regional natural resource management plans 28. Develop regional consistency and integration of land and water management plans	NYAD INRM Committee

15.4.2 EXTENSION AND TECHNICAL ADVICE

Access to extension advice for selecting the most appropriate 'best practice' watercourse management techniques for their property can be a frustrating process for landholders in the Mid North. Extension support and technical advice on watercourse management issues is very limited. With the passing of the NRM Act, advice on the management of natural resources, including watercourses, will soon be facilitated by the NYAD INRM Committee.

A watercourse management extension program is required to continue to raise awareness of the ecological attributes of Mid North watercourses, instil an ethic of care, and promote the recommended catchment and watercourse management methods. Various tools need to be developed — one-to-one on-ground advice, field days, demonstration sites and reference materials such as fact sheets.

Training support on technical and practical aspects of watercourse management for officers of stakeholder organisations is important for delivering consistent and environmentally sound advice to landholders. Avenues should be provided for individuals to undertake training to improve their skills in watercourse management techniques.

Specialist watercourse management input and advice is often required but stakeholders indicated that it has been limited. During this project watercourse management officers in the EPA provided this service. Support beyond this project, however, is uncertain.

15.4.3 RAISING AWARENESS OF LEGISLATIVE REQUIREMENTS

Appendix A provides an overview of the legislative and policy requirements that have implications for the range of on-ground and planning activities for watercourses. Many landholders and organisations at all levels are not aware of these requirements. Steps need to be taken through an education program to improve the awareness of legislative rights and responsibilities. In addition, the community needs to be better informed of the appropriate agencies to contact for information.

15.4.4 WATERCOURSE MANAGEMENT TOOLS

Watercourse management manuals

The following manuals of general technical information and guidance on planning and implementing on-ground works can be useful for planning work at the property level:

- *Riparian land management technical guidelines* (LWRRDC 1999).
- *A rehabilitation manual for Australian streams* (LWRRDC 2000).
- *A guide to erosion control measures for small watercourses in the Mount Lofty Ranges* (Collingham and Carter 1995).
- *Watercourse processes: A guide for watercourse management in the Mount Lofty Ranges* (Carter 1995).

Practical watercourse management guides explaining local watercourse issues and on-ground rehabilitation options have been produced for specific regions such as the Mount Lofty Ranges. The development of a practical watercourse management manual appropriate to conditions in the Mid North would be invaluable.

Property management planning

Property management planning is a process whereby landholders, with the assistance of various advisers (financial, agronomist, land and water management), develop a whole-of-property plan. The plans aim to achieve increased productivity based on sustainable land management. They are most effective in areas where catchment and planning information is available. A good understanding of local catchment processes is essential to develop suitable management strategies. The lead agency providing property management planning assistance is PIRSA.

Table 15.6 outlines recommendations for raising awareness and supporting community involvement in river management.

Table 15.6 Recommendations for extension, technical advice and support, and suggested partners

Recommendations	Partners
29. Develop a watercourse management field manual which provides practical, technical guidelines for managing watercourses in the Mid North	NYAD INRM Committee, DEH (8.1-xv)*
30. Support community implementation of the management strategies and recommendations in this plan by funding and technical support	NYAD INRM Committee, PIRSA, soil conservation boards, APCB, DEH, Clare Valley Water Resources Planning Committee, local government
31. Improve community awareness and understanding of river management by developing effective education and awareness raising strategies, fostering existing programs (such as Waterwatch) and taking a coordinated approach to education and awareness raising	All stakeholders (6.1-xvi; 6.2-xiv; 6.3-ix; 8.1-xv; 8.2-v; 9.1-xxi,xxvii)*
32. Develop and implement a community and stakeholder education program to raise awareness of legislative rights and responsibilities under current natural resource management legislation	NYAD INRM Committee, DEH, DWLBC, PIRSA, Planning SA (6.1-xvi; 6.2-xiv; 6.3-ix; 8.1-xv; 8.2-v; 9.1-xxi,xxvii)*

* Actions relate to NYAD INRM Committee investment strategies (Appendix F) as noted (NYAD INRM Committee 2003)

15.5 Monitoring, knowledge gaps and future research

This management plan has used the best information available to develop a 'snapshot' assessment of the current condition of the catchment. River systems are dynamic and function on a range of timescales. Consequently, the plan's recommendations will need to be revised and adapted according to information collected over longer time scales.

The knowledge gaps and monitoring for each subcatchment discussed in Chapters 8–14 are summarised below for the whole catchment.

15.5.1 KNOWLEDGE GAPS

A sound understanding of watercourse and catchment conditions and the relevant processes forms the basis for decisions to improve management. During the course of the project several key knowledge gaps and limitations to the available data were identified (Table 15.7) Investigating these issues will improve the range and quality of information necessary for sound river management.

15.5.2 MONITORING AND EVALUATION

Effective monitoring and evaluation is an integral part of any management program. Adaptive management requires monitoring to improve knowledge of the system and related decision making. Although this project was not required to develop a detailed monitoring strategy, some broad ideas and suggestions are presented below.

Successful monitoring depends on selecting appropriate indicators and designing a sound monitoring system. The following need to be clearly defined: What is to be monitored? Why? How will the information gathered be incorporated into the management process? In systems with a high degree of variability such as the Broughton River, the timescales for monitoring and assessing change must be clearly understood. A strategic, integrated, catchment-wide approach is required with clear objectives for each monitoring action and a detailed reporting mechanism to ensure results are communicated and acted upon.

Table 15.7 Key knowledge gaps for managing watercourses in the Broughton catchment

Research area	Knowledge gaps
Water requirements of aquatic plants and animals	• Detailed studies of water requirements particularly in the ephemeral or intermittent streams in South Australia • Specific responses of plants and animals to different flow events in the catchment
Hyporheic environments	• Role as a refuge in dry periods; the presence and location of hyporheic zones; animals and their lifecycle; water requirements
Fish ecology of the Broughton River system	• Migration habits; lifecycle water requirements; the impacts of exotic fish species; migration barriers; threats • The impact of weirs on fish in the catchment
Reedbeds	• Causes of excessive growth of reedbeds dominated by common reed and bulrush; the long-term implications for river health and management requirements
Groundwater dependent ecosystems	• The role of pools and baseflow in maintaining the ecology of Broughton River • Effects of pumping from permanent pools; the impact on pool ecology of changes in water levels
Sediment transport processes within the system	• Sediment sources • Location and rates of erosion, deposition and their responses to various flows
Salinity	• Stream salinity trends and extent of dryland salinity
Surface water–groundwater interactions	• Location of groundwater recharge and discharge zones that influence baseflows in Broughton River and its tributaries • Effects of localised water extraction from wells adjacent to the watercourse on pools and baseflow • Effects of practices aimed at reducing recharge (to combat dryland salinity) on permanent pools and baseflows
Ecology and geomorphology of changes to the flow regime	• Effects of changes to baseflow and low and medium flows because of development; effect on water level, flow velocity, duration and frequency
Environmental releases from Beetaloo reservoir	• Feasibility of environmental releases from the reservoir and ecological and geomorphological implications

A monitoring approach that enables all sites to be compared to reference sites, where possible, is recommended. Reference sites allow for the 'natural' condition of river reaches to be best described.

Monitoring and evaluation should test the hypotheses established in developing the management strategies and actions. For example, the hypothesis that installing low-flow bypasses on dams will provide flows that achieve improved environmental conditions downstream needs to be assessed. Monitoring the results will include reporting on whether they were successful or not.

Establishing environmental water requirements for watercourses in South Australia is a new development. The timeframe and budget of the project limited the depth of the study as did the lack of long-term scientific data and comprehensive flow gauging. The environmental water requirements recommended in this plan need to be validated against actual flow data and ecosystem responses for the geomorphic zones in the catchment. At the same time, research and monitoring is needed to develop improved models of the relationship between the water regime and the geomorphology and plant and animals of the river system. New information will enable the requirements to be refined.

The expected outcomes of the project for the long-term are the improved health and diversity of riverine ecosystems, reduced erosion and sedimentation, improved water quality, and reduced livestock and weed management problems. In achieving these outcomes, the impacts of watercourse management interventions such as development controls under the Clare Valley Water Allocation Plan and environmental water provisions need to be assessed.

Some suggestions for monitoring priorities are:

- monitoring surface flows and improvements to the flow gauging network;
- groundwater hydrology and its role in surface water flows;
- regular sedimentation and erosion measurements at priority sites;
- extended ambient and flow-weighted water quality sampling (especially of nutrients, sediment and salinity);
- biota responses to flows (especially fish movement, distribution and breeding);
- regular river health assessments using assessment criteria developed for Mid North streams; and
- revegetation monitoring at key sites through regular photopoints (especially regeneration of river red gums (*Eucalyptus camaldulensis*) and other key riparian plants).

Groundwater and surface hydrology is a direct measure of the current conditions and future modifications to flows. These will form an essential base of the monitoring program which, with biological monitoring, will allow some of the plan's recommendations to be tested. The three station flow-gauging network in the catchment is not sufficient to assess the changes to flows caused by water resource development. More permanent and temporary gauging stations are required to define the hydrology of the catchment properly. As well, little is understood about groundwater hydrology and the interactions between groundwater and surface flows: improved monitoring is required for this.

Watercourse health audits using standard assessment criteria such as the methods developed for this project or an adaptation of the 'Index of Stream Condition' model developed in Victoria would enable benchmarking and an assessment of the success of any rehabilitation actions. The methods are integrated assessment tools that measure changes in hydrology, physical form, riparian zone, water quality and aquatic fauna.

River health monitoring is a direct assessment of environmental responses and conditions. This standard approach, established at the national scale, includes habitat, macro-invertebrates and macrophytes (Davies 1994).

The limited water quality data available is not linked to flows, which limits the ability to interpret the data. A water quality monitoring program targeted to flows is required as well as ambient water quality information. Such a program should seek to integrate relevant monitoring data recorded by Waterwatch.

Fish populations are important elements of the environment. They have been used as a key indicator for determining the environmental water requirements for the Broughton River system. Monitoring based on their water requirements (Appendix D) developed by this project would provide valuable information on fish responses to flow.

The regular measurement of sedimentation and erosion at high risk sites would indicate changes to channel form and habitat conditions. Changes in sedimentation and erosion may be indicative on a reach scale or may indicate local conditions (such as grazing on riverbanks) only.

Revegetation is a significant management requirement for the catchment. Simple photopoint monitoring and rapid field assessments of riparian and in-stream vegetation conditions could be used to monitor the adoption and success of revegetation works.

An important initiative by the major stakeholders associated with water management in South Australia has been establishing a State Water Monitoring Co-ordinating Committee and developing a framework of a coordinated Water Monitoring Program. The committee has initiated the State Water Monitoring Review to ascertain monitoring needs. Thus the information and recommendations in this plan should be considered as part of that review as should the development of future water monitoring programs.

Table 15.8 outlines recommendations for monitoring and evaluation at a catchment level including the most appropriate stakeholders to implement these recommendations.

15.6 Conclusion

This plan makes recommendations for watercourse management priorities and strategies and outlines the environmental water requirements necessary to maintain or improve watercourse habitats and their ecosystem processes. Understanding the requirements of the Broughton River system will provide valuable information for developing management plans such as the Clare Valley Water Allocation Plan. The watercourse management priorities and options can be used by the community and organisations for practical and strategic planning for action and to set priorities for individuals or groups seeking funding for on-ground works.

Integral to the development of this plan was the need to understand the complexity of the river system, its condition, ecological processes and management issues. In relation to baseline information, the data collected and analysed provides a ‘snapshot’ of the condition of the watercourses in the catchment. The field surveys and data analyses were completed within the scope of a one-year timeframe and budget limitations. Notwithstanding this, the environmental water requirements identified and quantified were determined through a sound scientific panel habitat assessment approach. The watercourse management priorities and strategies developed were based on the data collected and in consultation with landholders. In this sense they reflect ecological and community priorities. Further research and analysis will bolster understanding of the river system, particularly its long-term trends.

Table 15.8 Recommendations for monitoring and evaluation, and suggested partners

Recommendations	Partners
33. Encourage research and investigation to: •Address priority research areas as indicated in Table 15.6 •Develop flow responsive biological indicators for Mid North streams •test the hypotheses used to determine environmental water requirements	NYAD INRM Committee, DEH, DWLBC, Clare Valley Water Resources Planning Committee
34. As part of the State Water Monitoring Review, develop an integrated, regional water monitoring framework for the Broughton catchment and other Mid North catchments that includes monitoring of: •surface flows, baseflow and groundwater levels •surface and groundwater quality including nutrient levels, sediment, pesticides, salinity •aquatic ecosystem health and river geomorphic condition 35. Develop a program to review the condition of the river system over a 5–10 year period, such as an Index of Stream condition assessment	NYAD INRM Committee, State Water Monitoring Co-ordinating Committee, DEH, DWLBC, SA Water (6.1-i; 6.2-ii; 8.1-i)*
36. Undertake further detailed hydrological monitoring and modelling to determine the impacts of farm dams, groundwater extraction and land management practices on flow regimes and environmental water requirements in areas of significant or potential water resource development	NYAD INRM Committee, DWLBC (6.1-i)*
37. Monitor the effectiveness of the Clare Valley Water Allocation Plan in ensuring sustainable use, meeting environmental water requirements and protecting the health of water dependent ecosystems	Clare Valley Water Resources Planning Committee, DWLBC

* Actions relate to NYAD INRM Committee investment strategies (Appendix F) as noted (NYAD INRM Committee 2003)

Implementing the recommended watercourse management strategies and the environmental water requirements will require flexible and adaptive management based on the monitoring of outcomes. In particular, the interacting elements that determine river condition must be considered. These include physical characteristics, water quantity and quality, condition of the riparian zone and floodplain, and the diversity and numbers of plants and animals. Improving the management of the Broughton catchment will therefore require an integrated approach combining flow, land and watercourse management. A mechanism to achieve this outcome has been developed through the NRM Act, which empowers the NYAD INRM Committee to take a lead role in the integration and facilitation of natural resource management for the region.

GLOSSARY

Adaptive management

A learning by doing approach often used in situations where there is little knowledge and/or complexity and a need to implement some management changes sooner rather than later; uses the best available information for initial management, implements changes, monitors outcomes, and regularly evaluates and reviews management

Aerial video

Video footage taken using a video camera mounted on a small aircraft; used to observe and record the condition of major watercourses

Ambient water quality

The overall quality of water when all the effects that may impact upon the water quality are taken into consideration

Annual exceedence probability

The probability of exceeding a given flow rate within a period of one year; AEPs quoted have been derived from Log Pearson Type 3 distribution frequency analysis (annual series)

Aquatic macrophytes

Any non-microscopic plant that requires the presence of water to grow and reproduce

Aquifer

An underground layer of soil, rock or gravel able to hold and transmit water

AusRivAS

A rapid prediction system used to assess the biological health of Australian rivers

Bankfull

The flow at which water just fills the primary flow channel without overtopping the banks

Bar

A temporary deposit of sediment within a stream channel that may be exposed during low water periods (Figure 2.1)

Baseflow

Stream flow that is not directly affected by rainfall but may be maintained by groundwater recharge

Bed

The horizontal part of a channel between the toes of the high banks

Bench

Bank attached feature aligned with the geometry of the channel formed by lateral accumulation of sands and gravels; usually lining both banks (Figure 2.1)

Biodiversity

The variety of life forms: the different plants, animals and micro-organisms, the genes they contain and the ecosystems they form; usually considered at three levels: genetic, species and ecosystem diversity

Biota

All of the organisms at a particular locality

Council *of Australian Governments*

A council that sets national policy directions for Australia; consists of the Prime Minister, state premiers, territory chief ministers and the President of the Australian Local Government Association

Detritus

Dead organic material (e.g. leaf litter) that usually accumulates on the bed of waterbodies

Electrical conductivity

1 EC unit = 1 micro-Siemen per centimetre (μS/cm) measured at 25°C; commonly used to indicate the salinity of water

Ecological processes

All processes whether biological, physical or chemical that maintain the ecosystem

Ecological values

The natural ecological processes occurring within ecosystems and the biodiversity of these systems

Ecosystem

A biological system involving interaction between living organisms and their immediate physical, chemical and biological environment

Endemic

A plant or animal restricted to a certain locality or region

Environmental water provisions

That part of environmental water requirements that can be met; what can be provided at a particular time after consideration of existing users' rights, and social and economic impacts

Environmental water requirements

Descriptions of the water regimes needed to sustain the ecological values of aquatic ecosystems at a low level of risk; developed by applying scientific methods and techniques, or local knowledge based on many years of observation

Ephemeral

Temporary or intermittent, for example a creek that dries up during summer and flows in winter

Faecal coliform

A minute micro-organism occurring in the intestines of warm blooded animals; used as an indicator of faecal contamination in water

Flood runners

A generally straight channel that occurs on the floodplain and only carries water during floods

Floodplain

Land adjacent to streams that is periodically flooded; often includes seasonal and perennial wetlands (Figure 2.1)

Flow regime

The character of the timing and amount of flow in a stream

Flow weighted water quality sampling

Sampling based on measurement during flow events rather than measurement at specific times

Geomorphology

Study of landform and landscape development and function

Habitat

The natural place, and its physical and biological properties, where an animal or plant, or communities of plants and animals live

Hydraulic jump

Abrupt turbulent rise in the water surface caused by an obstruction or change in slope of the streambed

Hyporheic zone

Zone beneath the stream bed within which a complex of microscopic animals occur

Incised channel

A channel that has eroded its bed to the point where high banks are formed

Indigenous plant species

Plant species native to an area, i.e. that have not been introduced from another area

Lateral bar

A sediment deposit that develops adjacent to the stream bank

Levee

An artificial or natural linear ridge on a floodplain designed to hold back floodwater (Figure 2.1)

Life history

The history of changes undergone by an organism from inception or conception to death

Longitudinal stream profiles

Plot of the elevation of the channel bed, banks and water level versus horizontal distance

Macro-invertebrates

Animals without backbones typically of a size visible to the naked eye; aquatic macro-invertebrates are an important part of aquatic ecosystems

Macrophyte

A non-microscopic plant

Median (or 50^{th} percentile)

In an ordered distribution from highest to lowest, the value that has an equal number of events occurring above and below it; an indicator of the central tendency of the data

Monitoring River Health Initiative

A subprogram of the National River Health Program that provides a means of assessing the ecological condition of rivers and streams by using macro-invertebrates

Overstorey

Woody plants > 5 m tall, usually single stemmed

Percentile

The percentage of observations in a distribution that occur lower than or equal to a given value

Permanent pools

Pools of water in watercourses that are continually fed by groundwater discharge throughout the year

Point bar

A sediment deposit that develops on the inside of a bend

Pool

A deep body of still or slow moving water held back in a stream by a downstream control such as a bedrock or gravel bar (Figure 2.1)

Prescribed water resources

Water resources declared by regulation that can only be accessed by those in possession of a licence to take water issued by the Minister for Environment and Heritage; allocated according to a water allocation plan

Recruitment

Movement into an adult population usually by juveniles through breeding events but also through migration

Reed

A plant of the taxa: Typha, Phragmites, Juncus ignens and Eragrostis australasica

Riffle

Shallow, often stony areas, in streams that have rapid turbulent flow; these highly oxygenated areas are important habitat for macro-invertebrates (Figure 2.1)

Riparian

Pertaining to or situated on the banks of a watercourse (Figure 2.2)

River health

Capacity of the river ecosystem to sustain a normal and diverse suite of organisms and ecological processes

Run

Sections of streams that are channel like with an approximately constant width and depth (Figure 2.1)

Rush

Aquatic or semi-aquatic plants of the Juncaceae family; mostly tall and leafless with branching flower heads

Seasonal flows

River flows that occur on a seasonal basis, usually over the winter–spring period, although there may be some flow or standing water at other times

Sedges

Aquatic and semi-aquatic plants of the family Cyperaceae; mostly perennial grasses or rush-like herbs; common types include club-rush, bog-rush and sword-sedge

Sedimentation

The long-term filling of a stream channel, lake or estuary with sediment

State Water Plan

Policy document that sets the strategic direction for water resource management in the State and policies for achieving the objects of the Water Resources Act 1997; its contents are defined by the Act

Stream order

Used to indicate the size and flow of watercourses; under the system adopted in this report (the Strahler system) unbranched watercourses originating at a source are termed first order; when two watercourses of the same order join, a stream of that order +1 is formed

Terrace

A flat land surface above the general level of a stream's floodplain; usually the remains of an old floodplain or bed

Tributary

A river or creek that flows into a larger river

Understorey

Woody plants < 5 m tall, frequently with many stems rising at or near the base

Vegetation associations

A large climax community named after the dominant types of plant species

Water allocation plans

Plans developed by a catchment board or water resources planning committee that describe how water from a prescribed water resource will be allocated to licensed water users; must be developed through the consultation process specified in the Water Resources Act 1997

Water dependent ecosystems

Those parts of the environment in which the species composition and natural ecological processes are determined by the permanent or temporary presence of flowing or standing water; e.g. the in-stream areas of rivers, riparian vegetation, springs, wetlands, floodplains and estuaries

Sources: ARMCANZ and ANZECC (1996); Tootill (1984); Boulton (1999), Kapitske et al. (1998)

REFERENCES

Allen GR. 1989. *Freshwater fishes of Australia.* Tropical Fish Hobbyist Publications, Neptune City.

Alley NF. 1967. Cainozoic history of the middle Broughton drainage basin. BA (Hons), Department of Geography, University of Adelaide.

ARMCANZ and ANZECC. 1996. *National principles for the provision of water for ecosystems*. Occasional paper SWR No. 3, Sustainable Land and Water Resource Management Committee, Canberra.

Arthington AH. 1998. *Comparative evaluation of environmental flow assessment techniques: Review of holistic methodologies.* Occasional Paper 26/98. Land and Water Resources Research and Development Corporation, Canberra.

Bell I and Priestley T. 1998. *Management of stock access to the riparian zone*. Tasmania. Department of Primary Industries, Water and Environment.

Boulton AJ and Brock MA. 1999. *Australian freshwater ecology: processes and management*. Gleneagles Publications, Glen Osmond SA.

Boulton AJ and Lake PS. 1992. The ecology of two intermittent streams in Victoria, Australia. III. Temporal changes in faunal composition. *Freshwater Biology*, 27, 123–38.

Brierley GJ, Fryirs K and Cohen T. 1996. A geomorphic approach to catchment characterisation. *In* GJ Brierley, K Fryirs and T Cohen (eds), *Geomorphology and river ecology in south eastern Australia: An approach to catchment characterisation*. Graduate School of the Environment Working Paper 9603. Macquarie University, Sydney.

Brizga SO. 2000. Broughton River system: geomorphology and environmental water requirements. Unpublished report. South Australia. Department for Environment and Heritage, Adelaide.

Brizga SO. 2000. Burnett Basin WAMP: Proposed environmental flow performance measures. 2 volumes. Department of Natural Resources, Brisbane.

Brown W and Kraehenbuehl D. 2000. *Riparian rehabilitation and revegetation in the Light catchment.* Unpublished report to the Department for Environment, Heritage and Aboriginal Affairs. PIRSA, Adelaide.

Cambray JA, Alletson DJ, Kleynhans CJ, Petitjean MOG and Skelton PH. 1989. Flow requirements for fish. In: AA Ferrar (ed) *Ecological flow requirements for South African rivers,* pp 71–93. South African National Scientific Programmes Report No. 162, Pretoria.

Canfield Jr DE and Hoyer MV. 1988. Influence of nutrient enrichment and light availability on the abundance of aquatic macrophytes in Florida streams. *Canadian Journal of Fisheries and Aquatic Sciences*, 45, 1467–72.

Carr G, Lord R and Seymour S. 1999. Rehabilitation of disturbed stream frontages using natural vegetation templates — A case study on the Yarra River, Victoria. In: I Rutherfurd and R Bartley (eds), *The challenge of rehabilitating Australia's streams: Proceedings of the Second Australian Stream Management Conference*, Adelaide, 8–11 February 1999. Cooperative Research Centre for Catchment Hydrology, Adelaide.

Carter J. 1995. *Watercourse processes: A guide for watercourse managers in the Mount Lofty Ranges.* Water Resources Group, Department of Environment and Natural Resources, Adelaide.

Clarke DK. 1990. The Booborowie Valley Groundwater Resources. South Australia. Department of Mines and Energy. Report Book 83/90.

Cobb MA and Smith PC. 1977. Underground water in the Booborowie Valley. Department of Mines and Energy Report Book no. 77/22. Adelaide.

Collingham E and Carter J. 1995. *A guide to erosion control measures for small watercourses in the Mount Lofty Ranges*. Department of Environment and Natural Resources, Adelaide.

Craig AE, Walker KF and Boulton AJ. 1991. Effects of edaphicfactors and flood frequency on the abundance of lignum, *Muehlenbeckia florulenta*, on the River Murray floodplain, South Australia. *Australian Journal of Botany*, 39, 431–43.

Cresswell D. 2000. Broughton River scientific panel assessment of environmental flow: hydrology. Unpublished report to the Department for Environment and Heritage, South Australia.

Davies PE. 1994. River bioassessment manual: Version 1.0: National River Processes and Management Program, Monitoring River Health Initiative. LWRRDC, Canberra.

Davies PM and Bunn S. 1999. Restoring fundamental ecological processes in small, forested upland streams: The importance of riparian vegetation. *In* I Rutherford and R Bartley (eds), *The challenge of rehabilitating Australia's streams: Proceedings of the Second Australian Stream Management Conference*, Adelaide, 8–11 February 1999. Cooperative Research Centre for Catchment Hydrology, Adelaide.

Department for Water Resources and State Water Plan Steering Committee. 2000a. *State Water Plan 2000. South Australia, Volume 1: Policies for a sustainable future*. Department for Water Resources, Adelaide.

Department for Water Resources and State Water Plan Steering Committee. 2000b. *State Water Plan 2000. South Australia, Volume 2:* . Department for Water Resources, Adelaide

Department of Environment and Natural Resources. 1997a. *Torrens 1997 – An action plan for better water course management*. South Australia. DENR, Adelaide.

Department of Environment and Natural Resources. 1997b. *A watercourse management action plan for the Onkaparinga River catchment*. Riparian Zone Management Project, DENR, Adelaide.

Department of Land and Water Conservation. 1992. *Estuary management manual*, New South Wales Government, Sydney.

Clare Valley Water Resources Planning Committee. 2000. *Water allocation plan: Clare Valley Prescribed Water Resources Area*. South Australia. Department for Water Resources, Adelaide.

Environment Protection Agency. 1998. *Water monitoring report: Ambient water quality monitoring of South Australia's rivers and streams: Report No. 1*. Environment Protection Authority, South Australia.

Fisheries Western Australia. 1999. *Fish health notification:* Thelohania *found in WA yabbies*. Government of Western Australia, Perth.

Fletcher A. 1986. *Effects of introduced fish in Australia*. *In* P DeDecker and WD Williams (eds), *Limnology in Australia*, pp 231–238. CSIRO, Melbourne.

Flint RB. 1972. Report on vacational activities: Booborowie Valley Groundwater Survey. South Australia. Department of Mines, Groundwater Survey Engineering Division, Report no. 72/132.

Gooderham J and Jerie K. 1999. An introduction to stream ecosystems. In ID Rutherford, K Jerie and NA Marsh (eds) *A rehabilitation manual for Australian streams; Volume 1.* LWRRDC, Canberra, and Co-operative Research Centre for Catchment Hydrology, Melbourne.

Graham A, Opperman A and Innes RW. 2001. *Biodiversity plan for the northern agriculture districts*. Department for Environment and Heritage, South Australia.

Harris JH. 1995. The use of fish in ecological assessment. *Australian Journal of Ecology*, 20, 65–80.

Hatton T and Evans R. 1998. *Dependence of ecosystems on groundwater and its significance to Australia*. Occasional Paper No. 12/98. LWRRDC, Canberra.

Hicks D and Sheldon F. 1999. Biotic survey of the Broughton River. Unpublished report to the Department for Environment, Heritage and Aboriginal Affairs, South Australia.

Jackson PD and Williams WD. 1980. Effects of brown trout *Salmo trutta* L. on the distribution of some native fishes in three areas of southern Victoria, *Australian Journal of Marine and Freshwater Research*, 31, 61–8.

Jolly I, Walker G, Stace P, van der Wel B and Leaney R. 2000. *Assessing the impacts of dryland salinity on South Australia's water resources. A sub-project of the National Land and Water Resources Audit – Dryland Salinity Theme Project 1*. CSIRO Land and Water Technical Report 9/00. CSIRO, Adelaide.

Kapitzke IR, Pearson RG, Smithers SG, Crees MR, Sands LB, Skull SD and Johnston AJ. 1998. *Stream stabilisation for rehabilitation in North-East Queensland*. LWRRDC, Canberra.

Karr JR and Dudley DR. 1981. Ecological perspectives on water quality goals, *Environmental Management*, 5, 55–68.

Karr JR. 1981. Assessment of biotic integrity using fish communities, *Fisheries*, 6(6), 21–7.

Keain MB. 1976. *From where the Broughton flows – a history of the Spalding district*. Keain Publications, Spalding and Norton Summit.

Lake JS. 1978. *Australian freshwater fishes: An illustrated field guide*. Nelson, Melbourne.

LWRRDC. 1999. *Riparian land management technical guidelines*. 2 volumes. Land and Water Resources Research and Development Corporation, Canberra.

LWRRDC. 2000. *A rehabilitation manual for Australian streams*. Land and Water Resources Research and Development Corporation, Canberra.

Lloyd L. 2000. A report on the environmental water requirements and ecology of the Broughton River, SA. Unpublished report to the Department for Environment and Heritage, South Australia.

Madden C, McEvoy P, Tsymbal V and Venus T. 1999. Determination of environmental water requirements of the macroinvertebrates of the Broughton River catchment. Unpublished report to the Department for Environment, Heritage and Aboriginal Affairs, South Australia.

McDowell RM (ed). 1996. *Freshwater fishes of south-eastern Australia* (2nd ed). Reed, Sydney.

McEvoy P and Madden C. 1999. Determination of environmental flow requirements of the macroinvertebrate fauna of the Gawler River. Unpublished report to the Department for Environment, Heritage and Aboriginal Affairs, South Australia.

Monitoring River Health Initiative. 2001. Distribution and habitat preferences of macroinvertebrates in South Australia. Unpublished raw data. SA Water, Adelaide.

Moore S. 1995. The Narridy Creek flood of 14-1-95 and conservation farming. South Australia. Department of Primary Industries, Catchment Management Group.

Mosley MP. 1983. Flow requirements for recreation and wildlife in New Zealand rivers — a review. *NZ Journal of Hydrology*, 22(2), 152–74.

Murray R, Latchford JA and McComb AJ. 1995. Water regimes and marsh distribution. In: AJ McComb, HT Kobryn and JA Latchford (eds), *Samphire marshes of the Peel-Harvey estuarine system, Western Australia*. Murdoch University, Perth.

Myers R. 1999. The ABC of riparian plants: The importance of native, regional aquatic plants in stream rehabilitation. *In* I Rutherford and R Bartley (eds), *The challenge of rehabilitating Australia's streams: Proceedings of the Second Australian Stream Management Conference*, Adelaide, 8–11 February 1999. Cooperative Research Centre for Catchment Hydrology, Adelaide.

Northern and Yorke Agricultural District INRM Committee Inc. 2003. Integrated Natural Resource Management Plan for the Northern and Yorke Agricultural District. Northern and Yorke Agricultural District INRM Committee Inc.

O'Donoghue PJ, Beveridge I and Phillips P. 1990. *Parasites and ectocommensals of yabbies and marron in South Australia*. Commissioned report to South Australian Department of Fisheries, Adelaide.

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

Rolls JM and Williamson DR. 1991. The impact of dryland salinisation on the surface water resources of South Australia. In: *Proceedings of the International Hydrology and Water Resources Symposium*, Perth, October 2–4, 1991, The Institution of Engineers Australia National Conference Publication No. 91/22, pp. 42–47.

Rose TH and McComb AJ. 1995. The ecological significance of saltmarshes to the Peel-Harvey estuarine system. In: AJ McComb, HT Kobryn and JA Latchford (eds), *Samphire marshes of the Peel-Harvey estuarine system*, *Western Australia*. Murdoch University, Perth.

Rutherfurd I, Jerie K, Walker M and Marsh N. 1999. Don't raise the Titanic: how to set priorities for stream rehabilitation. In: I Rutherfurd and R Bartley (eds), *The challenge of rehabilitating Australia's streams: proceedings of the Second Australian Stream Management Conference*. Adelaide, 8–11 February 1999. Cooperative Research Centre for Catchment Hydrology, Adelaide.

Sard S. 1996. *Flood hazard in the Broughton River catchment*. BA (Hons) thesis, School of Geography, Population and Environmental Management, Flinders University of South Australia, Adelaide.

Schreiber S. 1998. Invasion of an exotic freshwater snail, *Water*, 25, 17.

Smith BJ. 1996. *Identification keys to the families and genera of bivalve and gastropod molluscs found in Australian inland waters*. Identification Guide no. 6. Cooperative Research Centre for Freshwater Ecology, Albury.

Strahler, AN. 1964. Quantitative geomorphology of drainage basins and channel networks. In VT Chow (ed), *Handbook of applied hydrology,* pp 4–39. McGraw-Hill, New York.

Thoms M. 1998. *Environmental flows.* Paper presented at CRCFE-AWWA Catchment Management Course. CRC for Freshwater Ecology and Australian Wastewater Association, Canberra.

Tootill, E. 1984. *Penguin dictionary of biology*. Penguin Books, London.

Trimble SW. 1994. Erosional effects of cattle on streambanks in Tennessee, USA, *Earth Surface Processes and Landforms*, 19, 451–64.

Wells A. 1985. Larvae and pupae of Australian Hydroptilidae (Trichoptera), with observations on general biology and relationships, *Australian Journal of Zoology supplementary series*, 113, 1–69.

West Broughton Soil Conservation Board. 1992. *District plan and three-year program*. South Australia. Department of Agriculture and National Soil Conservation Program, Adelaide.

Williams, WD. 1980. *Australian Freshwater Life*. MacMillan, South Melbourne.

Young GJ, Pearce PA, Phillips NF, Flower CE and Baker RM. 1978. The Pisant Creek Group Conservation Scheme. South Australia. Department of Agriculture and Fisheries, Soil Conservation Branch, Report no. S10/78.

Zaret TM. 1980. *Predation and freshwater communities*. Yale University Press, Newhaven, USA.

APPENDIX A – RELEVANT LEGISLATION

Introduction

Landholders and land and water managers have certain legal rights and responsibilities in managing water resources and watercourses. South Australia's *Water Resources Act 1997* deals specifically with water resources; other relevant legislation deals with environment protection, soil conservation, planning, native vegetation, and pest plants and animals.

Landowners – general duty of care

The *Water Resources Act 1997* places an obligation on landowners or occupiers to maintain a watercourse or lake in good condition. Landowners and occupiers have a duty to take reasonable steps to prevent damage to the bed and banks of a watercourse or lake and to the ecosystems that depend on the watercourse or lake.

Section 25 of the *Environment Protection Act 1993* requires that a person must not undertake an activity that pollutes, or might pollute, the environment unless all reasonable steps are taken to prevent or minimise any environmental harm that might occur.

Similarly, Section 8 of the *Soil Conservation and Land Care Act 1989* places a duty on landholders to 'take all reasonable steps to prevent degradation of the land'.

Native vegetation

The *Native Vegetation Act 1991* makes it an offence to clear native vegetation without the permission of the Native Vegetation Council. Some circumstances prescribed under the Act permit clearance (e.g. maintaining firebreaks). The Act also allows for incentives and assistance to landholders to help preserve and conserve native vegetation, to limit the clearance of vegetation and to encourage revegetation.

State government agencies

The main responsibility of the Department for Water Resources is the sustainable use and management of the State's water resources. The department administers several Acts to this end, including the *Water Resources Act 1997* and the *Water Conservation Act 1936*.

The Department for Environment and Heritage is concerned with the conservation, protection and enhancement of the State's environmental resources and natural and built heritage. Acts relating to watercourse management that the department is responsible for include the *Environment Protection Act 1993* and the *Native Vegetation Act 1991* and sections of the *Water Resources Act 1997.*

The Department of Primary Industries and Resources, South Australia (PIRSA) is the agency for primary industry development, natural resource management, and policy advice and support to ensure sustainable economic development for the State. PIRSA administers legislation applicable to watercourse management, including the *Animal and Plant Control (Agricultural Protection and Other Purposes) Act 1986* and the *Soil Conservation and Land Care Act 1989.*

Local government

Local councils often deal with watercourse management issues, including developments that may impact on a water resource or watercourse (such as dams and weirs), managing watercourse vegetation, drainage and environmental flows, pressures for an intensified use of land, tourism developments and recreational pursuits.

Councils are responsible for drainage (under the *Local Government Act 1999*) and other matters such as providing water services, protecting the council's area from natural and other hazards, managing, developing, protecting, restoring, enhancing and conserving the environment in an ecologically sustainable manner, and improving amenity. A council may also be responsible for 'water conservation reserves' declared under the *Water Conservation Act 1936*. Councils have the power under the *Public and Environmental Health Act 1987* to prosecute polluters of watercourses.

Under the *Water Resources Act 1997* a council can take necessary action if a landowner or occupier:

- fails to comply with a notice requiring that they maintain a watercourse or a lake in good condition (Section 14); or
- fails to comply with a notice requiring that they take reasonable steps to prevent damage to the bed and banks of a watercourse or lake and the ecosystems that depend on the watercourse or lake (Section 17).

Councils can prepare a local water management plan under the Act in order to deal with water resource or watercourse management issues. The key functions of a plan — a statutory document that allows the council to manage water resources and watercourses — include:

- issuing permits to control the water-affecting activities listed in Section 9 of the Act;
- addressing the council's responsibilities for land and watercourses on council-owned land; and
- integrating the power a council holds under other legislation it administers (such as the *Local Government Act 1999*, the *Development Act 1993* and the *Public and Environmental Health Act 1987*).

In addition, a council can amend development plans through the local water management planning process to ensure that both plans are consistent and to optimise use of the plans. This will allow a council to influence development to ensure that it does not have an adverse effect on surface water resources in the council area. Information about the water resources in the council area is crucial to planning and decision making.

The local water management plan can not limit the volume of surface water taken from a watercourse nor can it control the taking of groundwater or water taken for stock and domestic purposes. To control the taking of water, the resource would need to be prescribed under the *Water Resources Act 1997* and a water allocation plan prepared for that resource.

Water resources planning committee

The Clare Valley Water Resources Planning Committee was established to prepare a water allocation plan to manage the prescribed water resources in the Clare Valley in accordance with the *Water Resources Act 1997*. The plan outlines the criteria for granting water allocations, allowing transfers and issuing permits for water-affecting activities such as the establishment of dams, the use of imported water, obstructing a watercourse and so on.

The committee has also been delegated other functions by the Minister for Water Resources. These include reviewing the implementation of the water allocation plan, providing advice on water resource management for the prescribed water resource or areas linked to the prescribed water resource, facilitating the monitoring of the resource and assisting in developing information and awareness programs.

Soil conservation boards

The *Soil Conservation and Land Care Act 1989* allows for the establishment of soil conservation boards whose task is to help increase people's awareness of land conservation, and to provide advice and assistance for landholders.

Soil conservation boards must develop and implement a district plan that identifies land classes and land use, outlines land capability and preferred uses, identifies land management and degradation issues, and describes measures for rehabilitation and the prevention of degradation. Opportunities exist under district plans for recommending land management measures that prevent degradation of watercourses. For example, activities that slow surface runoff and prevent water and soil erosion of the land will also prevent sedimentation and erosion along watercourses. More specific measures include maintaining vegetation along watercourses to reduce erosion and soil loss, and to trap sediment and the associated nutrients washed off surrounding land. Maintaining or planting watercourse buffer strips with native species would also address the decline in native vegetation.

Animal and plant control boards

The *Animal and Plant Control (Agricultural Protection and Other Purposes) Act 1986* was proclaimed for the specific purpose of controlling animal and plants for the:

- protection of agriculture;
- protection of the environment; and
- safety of the public.

An animal and plant control board must ensure that the provisions of the Act are implemented and enforced within the area under its control. Boards can also develop and implement coordinated programs for the destruction and control of feral animals and noxious plants that are proclaimed under the Act. Landholders have a responsibility to control or destroy animals and plants proclaimed under the Act for their area.

Appendix A – Relevant legislation

APPENDIX B – GEOMORPHIC ZONES OF THE BROUGHTON RIVER SYSTEM

Table B.1 Descriptions of the Broughton River system geomorphic zones

River/stream *subcatchment*	Zone no.	Zone location/description (see Map 5.2)	Distinguishing features
Broughton River *Broughton; Hutt and Hill subcatchments* (Chapters 8 and 9)	1	Broughton estuary	Estuary (tidal)
	2	Non-tidal section of Broughton River delta	Delta
	3	Upstream end of Broughton River delta to Rocky River	Major river with continuous baseflow
	4	Rocky River to downstream of Koolunga	Major river with continuous baseflow
	5	Downstream of Koolunga to upstream of Yacka	Major river with continuous baseflow
	6	Upstream of Yacka to confluence of Hill River and Yakilo Creek	Major river with continuous baseflow
Yakilo and Baldry creeks *Booboorowie and Baldry; Hutt and Hill subcatchments* (Chapters 9 and 10)	1	Yakilo and Baldry creeks	Discontinuous baseflow
Booboorowie Creek *Booboorowie and Baldry subcatchment* (Chapter 10)	1	Booboorowie Creek is one zone	Small channel with swampy floodplain
Hill River *Hutt and Hill subcatchment* (Chapter 9)	1	Hill River is one zone	Chain of ponds
Hutt River *Hutt and Hill subcatchment* (Chapter 9)	1	Broughton River to bridge 8 km south of Spalding	Major tributary with continuous baseflow
	2	Upstream of bridge to Armagh Creek	Chain of ponds
Freshwater Creek *Freshwater and Bundaleer subcatchment* (Chapter 11)	1	Broughton River to 10 km upstream of Spalding	Incised stream with continuous baseflow
	2	10 km upstream of Spalding to 1 km upstream of Washpool Rd	Incised stream with discontinuous baseflow
	3	Upstream of Zone 2	Small channel with swampy floodplain

River/stream *subcatchment*	Zone no.	Zone location/description (see Map 5.2)	Distinguishing features
Bundaleer and Baderloo Creek *Freshwater and Bundaleer subcatchment* (Chapter 11)	1	Bundaleer Creek and Baderloo Creek to the Washpool (lower 6 km)	Incised stream with continuous baseflow
	2	Washpool to ford adjacent Bundaleer forest	Incised stream with discontinuous baseflow
	3	Baderloo Creek upstream of Zone 2	Small channel with swampy floodplain
Belalie Creek *Freshwater and Bundaleer subcatchment* (Chapter 11)	1	Belalie creek from confluence with Jacka creek to 6 km upstream of Jamestown	Incised stream with continuous baseflow
	2	Belalie Creek upstream and downstream of Zone 1	Small channel with swampy floodplain
Rocky River *Lower Rocky and Crystal Brook; Upper Rocky subcatchments* (Chapter 13 and 14)	1	Broughton River to Huddleston–Narridy Rd	Major tributary with discontinuous baseflow
	2	Huddleston–Narridy Rd to Huddleston–Georgetown Rd (Rocky River gorge)	Major tributary with discontinuous baseflow
	3	Huddleston-Georgetown Rd to Laura	Small channel with swampy floodplain
	4	Upstream of Laura	Discontinuous baseflow
Pine Creek *Upper Rocky subcatchment* (Chapter 14)	1	Rocky River to the headwaters	Minor stream subject to incision
Appila Creek *Upper Rocky subcatchment* (Chapter 14)	1	Downstream of Appila Springs	Minor stream subject to incision
	2	Upstream of Appila Springs to the headwaters	Discontinuous baseflow
Yackamoorundie Creek *Yackamoorundie subcatchment* (Chapter 12)	1	Yackamoorundie Creek to downstream end of gorge	Small channel with swampy floodplain
	2	Zone 1 to Narridy–Gulnare Rd (gorge)	Discontinuous baseflow with constrained floodplain
	3	Narridy–Gulnare Rd to Caltowie	Discontinuous baseflow
Crystal Brook *Lower Rocky and Crystal Brook subcatchment* (Chapter 13)	1	Broughton River to Crystal Brook	Incised meandering channel
	2	Crystal Brook to Beetaloo reservoir	Small channel with constrained floodplain

APPENDIX C – GEOMORPHOLOGY AND FLOWS IN THE BROUGHTON RIVER CATCHMENT

The key relationships between geomorphology and flows in the Broughton catchment are outlined in Table C.1. The flows important for geomorphology and hydraulic habitat maintenance are listed including a description of the key flow bands, the purpose of the flows, relevant hydrological criteria and why the flow is significant.

The optimum duration and frequency of relevant flows are not provided because these parameters cannot be identified without referring to natural duration and frequency or another benchmark level. There is no single optimum duration and frequency for any particular process, such as erosion or sediment transport, that would be applicable for all types of rivers and streams.

As a general principle, the greater the deviation from the natural flow regime, the greater the risk of significant changes. Investigations elsewhere suggest that there may be an increased risk of geomorphological and ecological changes if the relevant flow statistics deviate from the natural by more than 25% (Brizga 2000b). But there are likely to be variations in sensitivity between flow statistics and river systems. Further investigation of the impact threshold that may apply to watercourses in the Broughton catchment is required.

In addition to the flows important for geomorphology and hydraulic habitat maintenance indicated in Table C.1, flows which are significant for ecological processes are also relevant. Feedback effects occur between geomorphology and vegetation. For example, aquatic and riparian vegetation affects bed and bank resistance to erosion, as well as hydraulic roughness which affects flow velocities and, therefore, erosion and deposition processes. Vegetation zonations are affected by physical habitat structures (which are created and maintained by geomorphological processes). Therefore, environmental water requirements for vegetation have geomorphological relevance, and vice versa.

Table C.1 Links between geomorphology and flows in the Broughton catchment

Purpose of flows	Key flow bands	Relevant hydrological criteria	Significance
Maintenance of the wetted habitat (low flow control habitats such as riffles, rock bars and macrophyte beds)	Longer duration flows (low–medium flows) are more important than short-lived high flow events because they determine the wetted habitat conditions that prevail for most of the time. High flows may be important for channel and substrate maintenance.	Change in the magnitude of the duration of low and medium flows This can be quantified in a number of ways, including change in daily exceedence durations for flows of specific depths or wetted perimeters, or change in flow magnitudes for specific daily exceedence durations (e.g. 90%, 80%, 50%).	Related to the extent and hydraulic character (e.g. depth, velocity) of the wetted habitat
		Change in the duration of zero flow	Related to the length of time for which the wetted habitat occurs
		Change in the number and length of spells of low and zero flow	Related to the length of time for which the wetted habitat occurs
Maintenance of the wetted habitat (pools)	The whole water balance is important, not just flow. Flows of all magnitudes contribute to pool filling. Flow sequencing is important (e.g. the length of zero flow spells may affect the likelihood of pool dry-outs, notwithstanding interactions between pool levels and groundwater).	Change in flow volumes	Affects pool water balances — reduced flow volumes may mean increased likelihood of dry-outs
		Change in the number and length of spells of zero flow	Affects pool water balances — an increase in the number and/or length of zero flow spells may mean that pools are more likely to dry out
Channel maintenance	High flows are important, including bankfull discharge and the 1½ to 2-year ARI flow (which is commonly the bankfull discharge in alluvial rivers: in rivers with larger channels there is often a bench corresponding to this level).	Change in the frequency of bankfull discharge, as well as the 1½ or 2-year ARI flood (if bankfull discharge is significantly larger)	If flood frequency is reduced, vegetation encroachment into the channel and channel contraction may increase.
Maintenance of riffle substrate	High flows are required to remove fine sediments from riffle surfaces and interstices. Flow velocity/tractive force on the riffle surface needs to be sufficiently high to entrain the substrate.	Change in the frequency of floods exceeding sediment entrainment thresholds for the channel substrate	Affects the frequency of substrate entrainment: a reduction in the frequency of floods exceeding sediment entrainment thresholds means a reduction in the frequency of the removal of fines from the riffle surface and therefore possible increased silting of the riffles
Scouring of pools	Large floods may potentially scour out pools	Change in the frequency of large floods (e.g. 20-year ARI)	A reduction in the frequency of large floods may mean a reduction in the frequency of pool scouring

Purpose of flows	Key flow bands	Relevant hydrological criteria	Significance
Bank erosion	Medium and high flows are likely to be important. Key processes include wetting of banks and removal of sediment from toe of banks.	Change in the frequency and duration of medium and high flows	Reduced frequency of medium and high flows may mean reduced bank erosion rates due to reduced removal of sediment from toe of bank. However, if channel contraction occurs, the increase in hydraulic loadings resulting from the confinement of flows may at least partly cancel out this impact.
		Flood recession rates	Increased flood recession rates (e.g. rapid drawdown below reservoirs or sudden change in water levels because of pumping on flood recession) are likely to lead to an increased risk of bank erosion
Gully head erosion, stream incision	High flows (studies elsewhere have shown that erosion head retreat generally occurs in floods)	Change in frequency of high flows (e.g. 1½, 5 and 20-year ARI floods)	A reduction in the frequency of high flows may mean a reduction in the rate of gully retreat
Tributary incision	Synchronicity of flows between the main stream and tributaries	Change in flow regime seasonality Change in the frequency of a range of floods (e.g. 1½, 5 and 20-year ARI) in the main stream	Desynchronisation of flood events between main stream and tributaries may result in tributary incision due to lowered base level
Sediment transport	Flows which exceed sediment entrainment and transport thresholds: actual key flow magnitudes will depend on sediment sizes (e.g. medium–high flows for sand, high flows for gravel). In terms of total volumes of sediment transported, large floods are of key significance because they generally transport the largest volumes of sediment.	Change in the frequency and duration of competent flows (flows exceeding sediment entrainment thresholds). In the absence of information on competent flows, a range of medium and high flows should be examined.	Reductions in the frequency and duration of competent flows indicate likely reductions in sediment transport
Sediment delivery to the estuary	High flows generally transport most of the sediment.	Change in the frequency and duration of high flows (e.g. 1½, 5 and 20-year ARI and catastrophic floods*)	A reduction in flood frequency and duration means a reduction in the overall sediment transport capacity and, therefore, potentially reduced sediment delivery to the estuary
Avulsion	Overbank flows, especially major floods, are important (the key factor is the erosiveness of flows over the floodplain surface and in overflow channels) Channel maintenance flows are also relevant	Change in the frequency of large overbank floods (e.g. 20-year ARI and catastrophic floods*)	Reduced frequency of large floods may reduce rates of development of avulsions

* Catastrophic floods are associated with major erosion/sedimentation events. Average return intervals (ARIs) for these types of floods in specific parts of the catchment have not been identified.

APPENDIX D – REQUIREMENTS OF WATER DEPENDENT BIOTA

This appendix presents detailed lifecycle and water requirement information for plants and animals in the Broughton catchment.

Table D.1 provides definitions of the water requirement descriptions as used in the subsequent tables.

Table D.2 represents lifecycle information for native fish known or likely to inhabit the Broughton River and its tributaries.

Tables D.3 and D.4 summarise the water requirements of the plants and animals of the Broughton catchment. The tables have been used as the basis for assessing environmental water requirements for each geomorphic zone. The water requirements are preliminary because of the limited knowledge of the ecology and flow relationships within the Broughton River (and elsewhere). However, they do provide an initial basis to protect the natural values of the catchment's streams and wetland habitats.

The water requirements are based on the life history of the plants and animals inhabiting the aquatic environment of the catchment. While the biology of species in the catchment may not be well known for the locality, information on the same species in other locations is often available. In determining the key flow bands, timing and duration of flows, life history characteristics such as lifespan and breeding season are aligned with habitats inundated at various flows and when these flows should occur to maximise an ecological response from the target species. The ecological responses include:

- breeding cues (or germination in plants);
- recruitment (survival of larvae or seedlings);
- maintaining/sustaining populations; and
- growth of individuals.

On an ecological basis there are three types of water requirements. These are defined in Table D.1 to ensure common understanding. The range referred to in the tables is that between 'optimum', 'sustaining' and 'minimum' flows.

Table D.1 Definition of water requirement descriptions

Flow description	Definition (biological rationale)
Optimum	Flows (or features of flows) which if they did occur would ensure maximum or increasing populations
Sustaining	Flows (or features of flows) that are required to maintain species in the long term
Minimum/survival	Flows (or features of flows) which may enable short-term survival but if applied over longer time periods will result in species decline

Table D.2 Ecological requirements of key fish species actually or likely to inhabit the Broughton catchment (based on current knowledge; can only be considered as approximate until further research is conducted on these species in the catchment and elsewhere)

Fish species		Lifespan	Spawning season	Incubation duration*	Migration	Other
Common name	Scientific name					
Blue spot goby	*Psuedogobius olorum*	2–3 years	Oct–Jan	4 days	Local only	Need a hollow in, or a burrow under, rock or wood as a substrate for laying eggs
Mountain galaxias	*Galaxias olidus*	2–4 years	July–Oct	5–7 days	Upstream, if at all	Leaf litter required
Congolli	*Psuedaphritis urvilli*	>5years	Sept–Dec	Unknown	Upstream & downstream with increasing flows from June–Oct Needs further investigation	Susceptible to impacts from the presence of water flow barriers
Silverside	*Atherinosoma microstoma*	1 year	Sept–Feb	4–7 days[#]	Local only	Breeding probably occurs in the estuary or lower reaches of rivers
Big-headed gudgeon	*Philypnodon grandiceps*	4–7 years	Oct–Feb	4–6 days	Local only	Hard surfaces required as a substrate for laying eggs
Australian smelt	*Retropinna semoni*	1 year	Sept–Nov	9–10 days	Local only	Aquatic macrophytes required as a substrate for laying eggs
Common jollytail	*Galaxias maculatus*	2–3 years	July–Oct	2 weeks Eggs are laid and become stranded as flows recede; hatching occurs on next flood; able to delay hatching for at least 4 weeks	Downstream into the marine or estuarine environment with suitable flows Upstream in June–Oct from the estuary	Intertidal or riparian macrophytes required as a substrates for laying eggs; lays eggs on submerged vegetation in shallows and slow-flowing water

* Time that eggs take to develop into larvae (eggs require inundation at least for this period)

Table D.3 Flow bands and ecological requirements of vegetation communities

Vegetation community/ habitat	Key flow bands and location/lateral extent/depth	Purposes of flow bands	Average lifespan of species	Event frequency (range, sustaining requirement)	Event duration and seasonality (range, sustaining requirement)	Criteria for determining impacts/benefits
Reedbeds (emergent macrophytes)	*Groundwater–baseflow* To maintain a permanent wetted channel/permanent soil moisture	Maintenance of reedbeds (e.g. *Phragmites, Typha*, *Bolboscheonus*, *Schoenoplectus*)	5–10 years	Permanent	All year	Increasing salinity Duration of dry periods Species diversity of reeds Invasions of exotic *Typha*
	Low flows Inundation of stream channel and bars	Germination and recruitment of reedbed plant species Establishment and growth of reedbed plant species (above)	5–10 years	1:1 years	Range 9–12 months per year. Optimum requirement: all year	Senescence of stands Decreasing size of stands Lack of recruiting
Sedgelands*	*Low flows* Inundation of bars and low banks with shallow water	Maintenance and establishment of sedgeland plants (e.g. *Juncus*, *Eleocharis* and *Cyperus*) Increase in habitat and stimulation of vegetation and associated fauna growth	1–5 years	1:1–1:2 years 1:1 year sustaining	2–8 months 3 months for sustaining flows Note: Sediment needs to be damp — in one or several small events	Lack of establishing of vegetation on bars and benches Senescence of stands Lack of recruiting
Submerged aquatic macrophytes	*Groundwater table* To maintain permanent surface water	Maintenance of submerged aquatic vegetation (e.g. *Potamageton*, *Chara*, *Nitella*)	½–1 year	1:1 years permanent	All year (can dry out some years)	Lack of establishing of vegetation in stream bed
Submerged aquatic macrophytes	*Baseflow/low flows* Inundation of bars and low banks with shallow water	Increase in habitat and stimulation of vegetation and associated fauna growth	½–1 year	Flows required 1:2 at least provided some aquatic habitat exist in intervening period	Range 9–12 months per year, at least 6–9 months per year	Lack of establishing vegetation on bars and benches Senescence and lack of recruiting Species diversity decreasing

Vegetation community/ habitat	Key flow bands and location/lateral extent/depth	Purposes of flow bands	Average lifespan of species	Event frequency (range, sustaining requirement)	Event duration and seasonality (range, sustaining requirement)	Criteria for determining impacts/benefits
Lignum	*High–overbank flow* Inundation of benches and floodplains	Maintenance and establishment of lignum, chenopodium species Increase in habitat and stimulation of vegetation growth	3–20 years	1:3–1:10 years for recruiting/ maintaining 1:7 sustaining requirement	Up to 2–3 weeks at around 0.5 m depth; late winter–spring	Condition of plant Duration of dry spells Lack of recruiting
Riparian shrublands	*Mid–high flow* Inundation of benches and riparian zone to increase wetted habitat	Recruiting, maintaining and establishing riparian shrub species (e.g. *Myoporum* sp., Broughton willow (*Acacia salicina*), prickly wattle (*Acacia victoriae*)) Increase in habitat and stimulation of vegetation growth	15–50 years	1:10–1:20 years for recruiting Shorter flows (1–2 days) every 1–2 years will water these trees to some degree	<1–2 weeks. Duration requirements may be fulfilled by ponded water in depressions. Spring–summer	Duration of wet periods Establishing seedlings
Riparian woodlands/ forests	*Mid–high flows* Inundation root zone of large trees	Growth and health of *Eucalyptus camaldulensis*	>100 years	Shorter flows (1–2 days) every 1–2 years maybe required for maintaining health.	Days	Duration of wet event Senescence of mature trees and high levels of disease
Riparian woodlands/ forests	*High–overbank flows* Inundation of benches and floodplains with floodplain depressions being filled and soils wetted up	Recruiting, maintaining and establishing *Eucalyptus camaldulensis*	>100 years	Recruiting 1:10 to 1:50 years Watering flows every 2-3 years are required to ensure survival of trees if rainfall or groundwater sources are not available	Recruiting ~1 week. Duration requirements may be fulfilled by ponded water in depressions. June–Nov Sustaining for recruitment. Survival flows are required for ~1 day+	Duration of wet event Establishing seedlings

* Refers to sedgeland plants located in wetter parts of stream profile

Table D.4 Flow bands and ecological requirements of aquatic animal communities

Biota	Key flow bands and location/lateral extent/depth	Purposes of flow bands	Average life span of species	Event frequency (range, sustaining requirement)	Event duration and seasonality (range, sustaining requirement)	Criteria for determining impacts/benefits
Fish habitat	*Groundwater–baseflow* Pools inundated and channel bed wet	Maintenance of minimum water level and quality Inundation of areas of habitat and food resource	1–5 years	Frequent events annually. At least one event per year	Occurs for most of the year: low flow or dry in late summer	Salinity increases Species diversity Habitat availability
Fish breeding	*Mid–overbank flow* Inundation of bars, benches, riparian zones, flood runners and floodplains to increase habitat	High to overbank flows act as cue for breeding Follow-up mid flows allow hatching and recruitment (see below)	Most 2–5 years. 1 year only for smelt and hardyheads	1:1–1:5 years; sustaining flows at least 1:3 years; optimum 1:1 years	2–4 days for cue for breeding 4–7 days required for spawning and hatching	Species diversity Habitat availability Duration of inundation Extent of inundation Larvae present
Fish development and recruitment	*Low–mid flow* Inundation of bars, benches, and riparian zones to increase habitat	Provide habitat/shelter for fish larvae to develop to juveniles	Most 2–5 years; 1 year only for smelt and hardyheads	1:1–1:5 years; sustaining flows at least 1:3 years; optimum 1:1 years	2–4 weeks for development from larvae to juveniles	Habitat availability Duration of inundation Extent of inundation Larvae present
Fish redistribution (local and large-scale movement within freshwater reaches)	*Mid–high flow* Inundation of reedbeds, bars, benches and flood runners A sustaining of 20–30 cm water depth is generally required for fish movement	Local movement / pool connection events Long duration flows for large scale redistribution and recolonisation of habitats	1–5 years	1:1–1:5; sustaining flows are required at least 1:2 or 1:3 as longer return frequencies over long periods would lead to species decline	Local movement: 2 days–2 weeks Large scale: 1–3 weeks; 1 week for sustaining populations	Species diversity Habitat availability Duration of flows
Fish migration to the sea	*Mid–high flow*	Migration to sea		1:2 years	1–2 months	Duration of inundation Extent of inundation
Macro-invertebrate riffle habitat	*Low flow* Inundation of riffle zones	Create riffle habitats for riffle dwelling species	Months to a few years	Annual	>2 weeks–3 months Sustaining: 4 weeks	Extent and diversity of habitats available

Biota	Key flow bands and location/lateral extent/depth	Purposes of flow bands	Average life span of species	Event frequency (range, sustaining requirement)	Event duration and seasonality (range, sustaining requirement)	Criteria for determining impacts/benefits
Macro-invertebrate habitat	*Groundwater/baseflow* Pools inundated, channel bed wetted and flow over riffles	Maintenance of diverse aquatic habitats Maintain aquatic habitats as refuges during dry periods	Months to a few years	Permanent	Permanent	Extent and diversity of habitats available
Macro-invertebrate large recruiting events	*Mid flow – overbank flow* Flows through reedbed, benches to overbank to inundate dry habitat	Breeding events Inundation of bars, benches, flood runners and floodplains to create new habitat for recruiting Cleaning riffles to maintain habitat diversity	Months to a few years	Annual to 1:2 years Sustaining: 2:3 years	1–3 weeks Sustaining: 1 week	Species diversity Habitat availability Duration of inundation Extent of inundation Larvae present
Macro-invertebrate population loss events	*No flow; high–overbank flow*	Population loss event Prevention of dominance by single species Habitat forming flows	Months to a few years	1:3 maximum (dry); 1:1–1:2 is OK (high flow)	1–2 months (no flow); hours–days (high flow)	Duration of dry event Velocity of high flow event
Frog habitat	*Groundwater–baseflow* Pools inundated and channel bed wet	Maintenance of minimum water level and quality Inundation of areas of habitat and food resource	1–5 years	Permanent (can withstand short periods of drying up)	Occurs for most of the year: low flow or dry in late summer	Salinity increases Species diversity Habitat availability
Large-scale frog breeding	*Low–high flow* Inundation of reedbeds, bars, benches and flood runners A sustaining of 20–30 cm water depth is generally required for frog breeding	Increase in habitat area Increase in food resources	1–5 years	1:1–1:5; sustaining flows are required at least 1:3	4–6 weeks	Species diversity Habitat availability Duration of flows

APPENDIX E – RECOMMENDED ENVIRONMENTAL WATER REQUIREMENTS

The recommended environmental water requirements for each river geomorphic zone of the Broughton catchment are outlined in the following tables (E.1–E.27). The information is based on current knowledge of geomorphic and aquatic plant and animal responses to flows in the catchment (Appendices C and D). Chapters 8–14 provide a simplified discussion of the key flow bands for each zone.

These tables can be used:

- to indicate which flow events are important to protect and monitor;
- to provide a basis for assessing the impacts of water resource development; and
- as a basis to set up hypotheses to test assumptions regarding the environmental water requirements of biota and geomorphic processes in different river zones.

Each table describes the flow bands, ecological and geomorphological functions, and the frequency, duration and seasonality of the flows. The key functions considered in determining the frequency and duration of flows are indicated in bold. Many of the estimates of frequency and duration were based on fish requirements. As fish requirements are a conservative indicator, it is assumed that if these are met then most other ecological requirements will also be met.

The tables present desirable flow bands, frequency and duration for ecological and geomorphological functions. Lack of flow gauging for most of the catchment means that most of the specified frequencies and durations have not been checked against recorded flow data to see if they occur under natural conditions. Relating recommended environmental water requirements to recorded flow data has only been possible for the three gauged sites in the catchment (see Chapter 6).

While an attempt was made to indicate the functions linked to a particular flow band, several different flows may be significant for a particular function. For example, sediment transport is mainly driven by high flows but baseflows are also influential. Similarly, the functions of different flow bands will change depending on the form of the channel. A flow that is bankfull in a zone with a shallow channel and a wide floodplain may be of a mid flow level in a narrow, deeply incised channel.

Table E.1 Broughton River Zone 1 (estuary/tidal)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Mid flow	Depth of up to 50 cm# in channels connecting the estuary to the upstream river	• **Migration of fish to/from estuary** (if connects to sea)	5:1–1:3 Sustaining = 1:2	Weeks to months Sustaining = 2 weeks	Late winter–early summer
High flow	Spreading across the low areas of the mangroves and samphire swamp; half bankfull at Cockeys crossing survey site	• **Migration of fish to/from estuary** • **Development and recruitment of native fish** • **Create habitat for aquatic flora and fauna** • **Samphire growth** • Nutrient transport • **Sediment delivery to estuary**	1:1–1:5 Sustaining = 1:3	1–4 weeks Sustaining = 7–10 days	Late winter–early summer
Overbank flow	Overbank and spreading across samphire and low-lying areas; bankfull at Cockeys crossing survey site	• **Trigger for fish migration and breeding** • **Transport of organic matter** • **Channel maintenance** • Sediment delivery to estuary	1:1–1:5 Sustaining = 1:3	2–10 days Sustaining = 4 days	Late winter–early summer

* *Based on information supplied by Peter Clarke via Glen Scholz*

Table E.2 Broughton River Zone 2 (perennial)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Baseflow	At least 30 cm (up to 70 cm) in the base of river channel (as measured at Cockeys crossing survey site)	• **Maintain pools** • **Maintain macrophytes** • Create aquatic habitat	Permanent (at 30 cm), fluctuating up to 70 cm several times per year	Permanent (at 30 cm), rising to 70 cm for 2–3 week periods	Permanent (fluctuations to 70 cm in late winter–spring)
Low flow	Approximately one-quarter bankfull at Cockeys crossing survey site; inundates the red gum and reed zones along the creek edge and swamp	• **Maintain macrophytes** • **Recruitment of fish and frogs following a mid flow** • **Create aquatic habitat**	1:1 to 1:3 Sustaining = 1:2	1–4 weeks Sustaining = 7–10 days	Late winter–spring
Mid flow	Approximately one-half bankfull at Cockeys crossing survey site; flowing within the river channel and over in channel benches; floods out in swamp to edge of lignum	• **Breeding of fish, frogs and macro-invertebrates** • **Flood lignum and swamp vegetation** • Migration of fish • Habitat creation and connectivity • **Sediment transport — sand** • **Bank erosion**	1:3–1:5 Sustaining = 1:4	1–2 weeks Sustaining = 5–7 days	Late winter–spring
High flow (bankfull)	Bankfull, mainly in channel but also in flood runners and low floodplain areas	• **Transport organic matter and sediment to the estuary** • **Migration of fish** • Maintain water quality and habitat within pools • **Scouring of pools** • **Channel maintenance** • **Avulsion**	1:5–1:20 Sustaining = 1:10–1:15	2–21 days Sustaining = 1 week	Late winter–summer

Table E.3 Broughton River Zones 3 and 4 (perennial)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Baseflow	Flow within channel which fills pools and covers most of the streambed	• **Maintain pools** • **Maintain aquatic habitat** • Maintain water quality • Maintain macrophyte beds	Permanent	Permanent (with fluctuations up and down around a mean level)	Higher in late winter and spring
Low flow	Approximately one-quarter bankfull, within the river channel and over low in-channel benches	• **Maintain water quality** • **Increase habitat area** • **Maintain macrophytes** • **Fish development and recruitment** • Migration of macro-invertebrates and fish • Maintain aquatic habitat	2:1–1:2 Sustaining = 2:3	2–4 weeks or longer Sustaining = 2 weeks	Late winter–spring
Mid flow	Approximately half bankfull from within the river channel and over in-channel benches	• **Trigger for fish breeding and migration** • **Increase habitat area (among reeds)** • **Transport organic matter** • **Maintain water quality** • Maintain macrophyte beds • Migration of macro-invertebrates • Removal of fines • Sediment transport	1:1–1:5 Sustaining = 1:3	2–10 days Sustaining = 4 days	Late winter–summer
Bankfull–overbank flow	Bankfull to overbank flow that inundates floodplain runners or floodplain	• **Increase habitat area** • **Red gum recruitment and maintenance** • **Scouring of pools** • **Channel maintenance** • **Bank erosion (Zone 3)** • **Avulsion (Zone 4)**	1:10–1:15	1 week or longer* Sustaining = 4–5 days*	Late winter–summer

* *Duration requirements may be fulfilled by ponded water in depressions.*

Table E.4 Broughton River Zone 5 (perennial; includes Yacka wetland*)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Groundwater (Yacka only*)	Sediment and river bed damp or wet	• **Maintain macrophytes** • Maintain aquatic habitat	Permanent	Permanent	Permanent
Baseflow	Covers runs and riffles by about 0.25 m	• **Maintain pools** • **Maintain aquatic habitat** • **Maintain water quality** • Maintain macrophyte beds • Transport of organic matter (for filter feeders) • Maintain riparian vegetation	Permanent	Permanent	Permanent but with spring increase in water level
Low flow	Covers river bed to about 50–75% of reed height	• **Maintain water quality** • **Maintain aquatic habitat** • **Increase habitat area** • **Maintain macrophytes** • **Fish development and recruitment** • **Frog breeding and recruitment** • Migration of macro-invertebrates • Migration of fish	1:1–1:5 Sustaining = 1:3	1–3 weeks Sustaining = 2 weeks	Winter–early summer
Mid flow	Inundating the channel about 50–75% of bankfull	• **Increase habitat area (among reeds)** • **Migration of fish (e.g. galaxiids)** • **Trigger for fish breeding** • Migration of macro-invertebrates • Maintain pools • Maintain macrophyte beds • Transport organic matter • Maintain water quality • **Removal of fines** • **Sediment transport**	1:1–1:5 Sustaining = 1:3	2–10 days Sustaining = 4 days	Late winter–spring

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Bankfull–overbank flow	Bankfull to overbank flows	• **Maintenance/recruitment of riparian shrubland vegetation** • Channel maintenance flow • Sediment transport • Floodplain inundation • Increase habitat area • Transport organic matter • **Scouring of pools** • **Channel maintenance**	Sustaining = 1:10–1:15	<1–2 weeks# Sustaining =1 week#	Spring–summer

**Yacka wetland zone is a unique habitat in this reach.*

#Duration requirements may be fulfilled by ponded water in depressions.

Table E.5 Broughton River Zone 6 (perennial)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Ground–water table	Fills the pools — not necessarily flowing; riverbed damp or wet	• **Maintain permanent pools** • **Provide soil moisture to maintain sedgelands and macrophytes**	Permanent	Permanent	All year
Baseflow (Permanent)	Covers much of riverbed with water in most pools.	• **Maintain macrophyte beds** • **Maintain aquatic habitat** • **Maintain pools** • Maintain water quality	Permanent	Permanent	All year
Baseflow/ seasonal low flow	Covers riverbed to inundate lowest benches and most pools and riffles	• **Maintain water quality** • **Increase habitat area (for macro-invertebrates and macrophytes)** • **Fish development and recruitment** • Inundate bench to increase habitat area	Requires a flow >0.6 cumecs to occur for durations of 15–20 days each year* Modelling shows this occurs in 6 of 7 years	Median: 70 days per year* Range = 0–200 days	A pulse on top of permanent baseflow during winter–spring
Mid flow	About 50% of reed height	• **Trigger fish breeding** • **Local migration of fish (e.g. galaxiids)** • **Increase habitat area (among reeds)** • Migration of macro-invertebrates • Maintain aquatic habitat • Maintain water quality	1:1–1:5 Sustaining = 1:3	2–10+ days Sustaining = 4 days	Late winter–spring
Overbank flow	Inundating at least to just over the riparian zone but optimally to inundate the floodplain to cover grasses (~30–50cm)	• **Increase habitat area (depending on duration), related to floodplain inundation** • **Recruitment and establishment of riparian and floodplain vegetation (lignum and grasses)** • **Channel maintenance flow** • **Sediment transport** • **Removal of fines from riffles**	1:3–1:7 Sustaining = 1:5–1:6	2–20days Sustaining = 2 days	Late winter–spring

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Catastrophic flow	Very large flow above the 1992 flood level	• **Recruitment and establishment of floodplain vegetation (lignum, Broughton willow)** • **Scouring of pools** • **Floodplain processes (e.g. erosion, sedimentation, avulsion)** • **Major habitat resetting flow** • Channel maintenance	~1:20–1:50 years	At least 2 days of inundation (might include tail flows) to soak ground for seed germination	Winter–spring

**Variability is important and a natural part of the environment to which these organisms are adapted; in drought years these flows may not occur at all.*

Table E.6 Hutt River Zone 1 (perennial)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Ground–water table	River bed wetted and pools filled	• **Maintain macrophytes** • **Maintain pools** • **Maintain aquatic habitat**	Permanent	Permanent	Permanent (in summer it is critical to maintain water level in pools)
Baseflow/ seasonal low flow	Low flow across stream bed (with seasonal increase in winter)	• **Fish development and recruitment** • **Maintain aquatic habitat** • **Habitat connections** • **Maintain water quality** • Maintain aquatic habitat	Annual	Almost continuous flow (seasonal increase in flow needs to occur for minimum of 2–4 weeks)	Winter–spring has pulse in flow
Mid flow	About 50% of reed height	• **Trigger for fish breeding** • **Increase habitat area (in reeds)** • **Maintain water quality** • **Migration of fish (e.g. galaxiids)** • Transport organic matter • Maintain aquatic habitat • Migration of macro-invertebrates	1:1–1:5 Sustaining = 1:3	2–10 days Sustaining = 4 days	Late winter–spring
Bankfull flow	Bankfull flow	• **Recruitment and establishment of riparian vegetation** • **Local fish migration** • **Maintain sedgelands** • Migration of macro-invertebrates • Increase habitat area • **Transport sediment and organic matter** • **Channel maintenance**	1:1–1:5 Sustaining = 1:3	2–4+ days Sustaining = 2 days	Late winter–spring

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Overbank flow	Floodwaters extend into floodplain	• **Floodplain and riparian zone inundation** • **Transport of organic matter** • Increase habitat area • **Channel maintenance** • **Sediment transport**	1:3–1:7 Sustaining = 1:5–1:6	1–5 days Sustaining = 1 days	Late winter–spring
Catastrophic flow	>1992 flood	• **Scouring of pools** • **Habitat resetting flow**	Large floods ≥20-year ARI	–	–

Table E.7 Hutt River Zone 2 (intermittent)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Ground–water table	River bed wetted and pools filled	• **Maintain macrophytes** • **Maintain pools** • **Maintain aquatic habitat**	Permanent	Permanent	Permanent (in summer it is critical to maintain water level in pools)
Seasonal low flow	River bed wetted and pools maintained above groundwater table (surface flows plus seasonal increase in baseflow)	• **Fish development and recruitment** • **Maintain aquatic habitat** • **Habitat connections** • **Maintain water quality** • Maintain pools • Maintain macrophytes	Annual	Seasonal flows in winter–spring (low flow needs to occur on average for a 2–4 week minimum)	Winter–spring has pulse in flows
Mid flow	About 50% of reed height and inundating benches	• **Maintain water quality** • **Trigger for fish breeding** • **Local migration of fish** • Migration of macro-invertebrates	1:1–1:5 Sustaining = 1:3	2–10 days Sustaining = 4 days	Late winter–spring
High flow (Bankfull)	Bankfull	• **Maintain water quality** • Migration of macro-invertebrates • Migration of fish • **Channel maintenance** • **Sediment transport**	1:1–1:5 Sustaining = 1:3	2–4+ days Sustaining = 2 days	Late winter–spring
Overbank flow	Inundating some floodplain	• **Floodplain and riparian zone inundation** • **Transport of organic matter** • Increase habitat area • **Channel maintenance** • **Sediment transport**	1:3–1:7 Sustaining = 1:5–1:6	1–5 days Sustaining = 1 days	Late winter–spring
Catastrophic flow	>1992 flood	• **Scouring of pools** • **Habitat resetting flow** • Sediment transport	Large floods ≥20-year ARI	–	–

Table E.8 Hill River (intermittent)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Ground-water table	River bed wetted and pools filled	• **Maintain macrophytes** • **Maintain pools** • **Maintain aquatic habitat**	Permanent	Permanent	Permanent (in summer it is critical to maintain level in pools)
Seasonal low flow	River bed wetted and pools maintained above groundwater table (surface flow plus seasonal increase in baseflow)	• **Maintain aquatic habitat** • **Habitat connections** • **Maintain water quality** • **Developing and recruiting fish** • Maintain macrophytes	Annual	Seasonal flows in winter–spring (low flow needed on average for a 2–4 week minimum)	Late winter–spring Pulse in flows
Mid flow	About 50–75% of reed height	• **Trigger for fish breeding** • **Maintain water quality** • Migration of macro-invertebrates • Migration of fish	1:1–1:5 Sustaining = 1:3	2–10 days Sustaining = 4 days	Late winter–spring
High flow (bankfull)	Bankfull	• **Maintain water quality** • Migration of macro-invertebrates • Migration of fish • **Channel maintenance** • **Sediment transport**	1:1–1:5 Sustaining 1:3	2–4+ days Sustaining = 2 days	Late winter–spring
Overbank flow	Inundating at least remnant riparian sedgeland plus some floodplain	• **Floodplain zone inundation** • **Sedgeland inundation (riparian zone**) • **Transport of organic matter** • Increase habitat area • **Channel maintenance** • **Sediment transport**	1:2–1:5 Sustaining = 1:3	1–2 days Sustaining = 1 days	Late winter–spring
Catastrophic flow	>1992 flood	• **Scouring of pools** • **Habitat resetting flow** • Sediment transport	Large floods $\geq$20-year ARI	–	–

Table E.9 Baldry and Yakilo creeks (intermittent)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Ground–water	River bed wetted and pools filled	• **Maintain macrophytes** • **Maintain pools (Baldry)**	Permanent	Permanent	Permanent
Baseflow (Yakilo only)	Baseflow with late winter/early spring pulse	• **Increase habitat area** • Maintain macrophytes	Permanent (stops flowing sometimes but remains wet) Sustaining = 4:5	Duration pulse 0.5–2 weeks Sustaining = 4–7 days	Late winter–spring
Mid flow	About 50–75% of reed height	• **Increase habitat area** • **Maintain water quality** • Maintain macrophytes	3:1 to 2:3 Sustaining = 1:1	1–2 weeks Sustaining = 3–4 days	Late winter–spring
High flow (bankfull)	Bankfull	• **Recruiting and establishing sedgeland flora** • **Transport organic matter** • Maintain water quality • **Sediment transport** • **Scouring pools (Baldry)** • **Channel maintenance**	1:1 to 1:3 Sustaining 1:2	1–10 days Sustaining = 1.5 days inundation	Late winter–spring

Table E.10 Booborowie Creek (ephemeral)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Mid flow	Shallow water across the stream bed (with episodic flows)	• **Create temporary aquatic habitat for macro-invertebrates** • **Water quality (downstream)** • **Nutrient/sediment movement** • Maintain macrophytes	2:1 to 2:1 Sustaining = 1:2	1–2 weeks Sustaining = 3–4 days	Late winter–spring
High flow (Bankfull–overbank)	Bankfull to overbank flows	• **Recruiting and establishing sedgeland flora** • **Transport organic matter** • **Sediment transport** • **Channel maintenance**	1:1 to 1:3 Sustaining 1:2	1–10 days Sustaining = 1.5 days inundation	Late winter–spring

Table E.11 Freshwater Creek Zone 1 (perennial)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Baseflow	River bed wetted; continuous flow	• **Maintain hyporheic zone** • **Maintain macrophytes** • **Maintain wetted aquatic habitat** • Maintain water quality • Maintain biota • Maintain connectivity	Permanent (at least damp)	Permanent (Sustaining = 8–12 months; damp rest of time)	Permanent but may dry out in summer
Baseflow/ seasonal low flow	Intermittent pulse flow up to 0.25 m in depth	• **Increase wetted habitat area** • **Recharge/clean hyporheic zone** • **Maintain water quality** • Maintain fauna • Maintain macrophytes	~3:1–1:1 Sustaining = 1:1	2 days–2 weeks Sustaining = 4–7 days	Late winter–spring
Mid flow	About 50–75% of reed height	• **Inundate bench to create habitat** • **Connectivity between upstream and downstream habitats (including bugs)** • **Migration of mountain galaxiids (spring flow) in lower half of zone**	2:1 to 1:2 Sustaining = 1:2	1–2 weeks Sustaining = 5–7 days	Late winter–spring
High flow	Flooding over benches and riparian zones	• **Recruitment and establishment of sedgeland flora** • **Transport of organic matter** • **Connectivity between upstream and downstream habitats** • **Maintain rock bar habitats and riffles (inundation; removal of fines**) • **Sediment transport** • **Channel maintenance**	1:1 to 1:3 Sustaining = 1:3	1–10 days Sustaining = 1–2 days	Late winter–spring

Table E.12 Freshwater Creek Zone 2 (intermittent)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Ground–water table	River bed wetted	• **Maintain hyporheic zone** • **Maintain wetted habitat** • **Maintain macrophytes**	Permanent (at least damp)	Permanent Sustaining = 8–12 months (damp rest of time)	Permanent but may dry out in summer
Mid flow	About 50–75% of reed height	• **Inundate bench to create habitat** • **Weir in Zone 1 prevents migration of mountain galaxiids (spring flow) past this point; if populations exist above weir then migration would occur in this zone**	2:1 to 1:2 Sustaining = 1:2	1–2 weeks Sustaining = 5–7 days	Late winter–spring
Bankfull flow	Bankfull plus some flooding into riparian zones and floodplain	• **Recruiting and establishing sedgeland flora** • **Transport organic matter** • **Maintain rock bar habitats and riffles (inundation; removal of fines)** • **Sediment transport** • **Scouring of pools** • **Channel maintenance**	1:1 to 1:3 Sustaining 1:3	1–10 days Sustaining = 1–2 days	Late winter–spring

Table E.13 Freshwater Creek Zone 3 (ephemeral)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
High–bankfull	Bankfull	• **Transport organic matter** • * **Riparian zone maintenance**	1:1 to 1:3 Sustaining = 1:2	0.5–10 days Sustaining = 1–2 days	Late winter–spring
Overbank flow	Flowing higher than banks spilling into riparian zones and floodplain zones	• * **Riparian and floodplain regeneration** • * **Floodplain inundation** • * **Connect floodplain to in-stream zone** • Nutrient and organic matter inputs and transport • **Channel maintenance** • **Sediment transport**	1:1 to 1:3 Sustaining = 1:3	0–5 days Sustaining = 1 day	Late winter–spring

[*] *Current poor condition of riparian and floodplain vegetation limits importance of these functions without rehabilitation.*

Table E.14 Bundaleer and Belalie creeks Zone 1 (perennial)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Baseflow	Continuous flow across bed of stream	• **Maintain hyporheic zone** • **Maintain wetted aquatic habitat (e.g. pools and riffles)** • **Maintain macrophytes** • Maintain water quality	Permanent (at least damp)	Permanent (Sustaining = 8–12 months; damp rest of time)	Permanent but may dry out in summer
Baseflow/ seasonal low flow	Intermittent pulse flow up to 0.25 m in depth	• **Increase wetted habitat** • **Recharge/clean hyporheic zone** • **Maintain water quality** • Maintain fauna • Maintain macrophytes	Approx 3:1 to 1:1 Sustaining = 1:1	2 days–2 weeks Sustaining = 4–7 days	Late winter–spring
Mid flow	About 50–75% of reed height	• **Connectivity between habitats** • **Migration of galaxiids** • **Increase habitat for macro-invertebrates**	2:1 to 1:2 Sustaining = 1:2	1–2 weeks Sustaining = 5–7 days	Late winter–spring
High flow	>2 m deep to below bankfull (incised stream)	• **Transport of organic matter** • Maintain riffles • Maintain rock bar habitats • **Scouring of pools** • **Sediment transport** • **Channel maintenance**	1:1 to 1:3 Sustaining = 1:3	0.5–10 days Sustaining = 1 day	Autumn, winter and spring

Table E.15 Baderloo Creek Zone 2 (intermittent)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Ground–water table	River bed wetted	• **Maintain hyporheic zone** • **Maintain wetted habitat** • **Maintain macrophytes** • Maintain connectivity	Every year (1:1)	6–8 months of the year	Permanent but may dry out in summer
Mid flow	About 50–75% of reed height	• **Inundate bench to increase habitat and macro-invertebrate populations** • Connectivity between pools	1:1 to 1:2 Sustaining = 1:2	1–2 weeks Sustaining = 3 days	Late winter–spring
Bankfull flow	Bankfull to overbank flows	• **Transport of organic matter** • **Maintain remnant floodplain vegetation (where it exists)** • Connectivity with other habitats (lateral and longitudinal) • **Scouring of pools** • **Sediment transport** • **Channel maintenance**	1:2 to 1:3 Sustaining = 1:3	1–10 days Sustaining = 1–2 days	Late winter–spring

Table E.16 Baderloo and Belalie creeks Zone 3 (ephemeral)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Mid flow	Mid level flows to approximate depth of 30 cm (with episodic flows)	• **Connectivity between upstream and downstream aquatic habitats**	1:1 to 1:5 Sustaining = 1:3	1–3 weeks Sustaining = 7 days	Late winter–spring
Bankfull flows	High to bankfull flows	• **Transport organic matter** • **Maintain water quality (flush saline first flows downstream)**	1:1 to 1:3 Sustaining = 1:2	1–10 days Sustaining = 2–5 days	Late winter–spring
Overbank flow	Flowing out into the riparian and floodplain zones	• **Floodplain inundation*** • **Connect floodplain to in-stream zone*** • Nutrient and organic matter inputs and transport • **Channel maintenance** • **Transport sediment**	1:2 to 1:5 Sustaining = 1:5	0–5 days Sustaining=0.5–1 days	Late winter–spring

**Current poor condition of riparian and floodplain vegetation limits importance of these functions without rehabilitation.*

Table E.17 Yackamoorundie Creek Zone 1 (ephemeral)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Mid flow	Mid level flow up to a depth of 30 cm (with episodic flows)	• **Migration for some fish species# (if present)** • **Connectivity to downstream areas** • River red gum watering	1:1 to 1:5 Sustaining = 1:3	1–3 weeks Sustaining = 1 week	Late winter–spring
High flow–bankfull	Near to bankfull	• **Transport organic matter** • **Migration for some fish species# (if present)**	1:1 to 1:5 Sustaining = 1:3	1–3 weeks Sustaining = 7 days	Late winter–spring
Overbank flow	Above bankfull flowing into nearby floodplain	• **River red gum recruitment and maintenance** • ***Floodplain inundation** • ***Connect floodplain to in-stream zone** • **Nutrient and organic matter inputs and transport** • **Sediment transport** • **Channel maintenance**	1:3 to 1:10 Sustaining = 1:5 to 1:7 (could extend to 1:20 if no improvements in floodplain vegetation desired)	1–5 days Sustaining = 1–2 days Duration requirements may be fulfilled by ponded water in depressions	Late winter–spring

#Fish may not be able to travel through this zone but suitable habitats do exist upstream and downstream.
**Floodplain vegetation is modified by grazing and cropping.*

Table E.18 Yackamoorundie Creek Zone 2 (intermittent)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Ground–water table	River bed wetted and pools filled	• **Maintain aquatic habitat** • **Maintain macrophytes** • **Maintain pools** • Habitat connections	Every year (1:1)	9 months of the year	Permanent but may dry out in summer
Mid flow	About 50–75% of reed height	• **Maintain water quality** • **Transport organic matter** • **Migration of macro-invertebrates** • **Migration of some fish species (if present)** • **Increase habitat area** • Maintain macrophytes • Habitat connections	1:1 to 1:5 Sustaining = 1:2	1–2 weeks Sustaining = 5–7 days	Late winter–spring
Bankfull flows	Typically bankfull flows (depending on size of channel)	• **Maintenance of riparian vegetation (Broughton willow, river red gum trees and sedgelands)** • Maintain water quality • Transport organic matter • **Scouring of pools** • **Sediment transport** • Channel maintenance	1:2 to 1:20	1–5 days Sustaining = 1–2 days Duration requirements for may be fulfilled by ponded water in depressions	Spring–summer
Catastrophic flow	> 1992 flow levels	• **Recruitment and establishment of riparian vegetation** • **Floodplain processes (e.g. erosion, sedimentation)** • **Habitat resetting** • Scouring of pools • Channel maintenance	Large floods– ≥20 year ARI	–	Late winter–spring

Table E.19 Yackamoorundie Creek Zone 3 (intermittent)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Ground–water table	Shallow water within stream bed with at least damp sediments	• **Maintain macrophyte beds** • **Maintain in-stream habitat such as reeds and wetted habitat**	Annual + Sustaining = 1:1	Most of the year	Late winter–spring
Mid flow (annual flows)	Near bankfull	• **Transport organic matter** • **Migration of macro-invertebrates** • Sediment transport	1:1–1:2 Sustaining = 1:2	1–7 days Sustaining = 1–2 days	Late winter–spring
Bankfull – overbank flow	Bankfull to overbank	• **Floodplain inundation*** • **Connect floodplain to in-stream zone*** • **Sediment transport** • **Channel maintenance**	1:2 to 1:10 Sustaining = 1:5 to 1:7 (could extend to 1:20 if no improvements in floodplain vegetation desired)	0–5 days Sustaining = 1–2 days	Late winter–spring

**Current poor condition of riparian and floodplain vegetation limits importance of these functions without rehabilitation.*

Table E.20 Rocky River Zone 1 (perennial)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Baseflow	River bed wetted and continuous flow; pools filled	• **Maintain macrophytes** • **Maintain pools** • **Flow over riffles** • Maintain aquatic habitat	Permanent	Permanent	Year round; would have late winter/early spring pulse
Low flow	About 50% of reed height	• **Increase habitat area** • **Maintain water quality** • **Flow over riffles** • **Maintain macrophytes** • **Development and recruitment of fish** • Transport of organic matter • Migration of macro-invertebrates	Several times per year Sustaining = annual	2–4 weeks Sustaining = 2+ weeks	Late winter–spring
Mid flow	Inundation of benches (about 100% reed height)	• **Trigger for fish breeding** • **Recruitment of riparian sedges and other riparian species** • **Migration of fish** • **Increase habitat area** • Maintain water quality • Maintain macrophytes • Transport of organic matter • **Bank erosion** • Sediment transport	1:1 to 1:5 Sustaining = 1:2	1–3 weeks Sustaining = 7–10 days	Late winter–spring
Overbank flow	≥1992 flood — bankfull with some floodplain inundation	• **Recruitment and establishment of floodplain vegetation** • Transport of organic matter • Resetting flows • Floodplain inundation • **Channel maintenance** • **Sediment transport** • **Scouring of pools**	~1:10 to 1:20 or greater Sustaining = 1:20	–	winter–spring

Table E.21 Rocky River Zone 2 (intermittent)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Ground-water/baseflow	River bed wetted and pools filled with continuous flow in some reaches	• **Maintain macrophytes** • **Maintain pools/riffles** • Maintain aquatic habitat	Permanent	Permanent but may stop flowing in summer	Year round
Low flow	About 50% of reed height	• **Maintain and increase aquatic habitat** • **Maintain water quality** • **Flow over riffles** • **Migration, development and recruitment of fish** • Maintain macrophytes • Migration of macro-invertebrates • Transport of organic matter	3:1 to 1:1 Sustaining = Annual	1–3 weeks Sustaining = 2+ weeks	Late winter–spring
Mid flow	About 50–75% of reed height (~1 m deep at disused gauging station weir)	• **Maintain and increase aquatic habitat** • **Maintain water quality** • **Migration of macro-invertebrates** • **Migration and breeding (trigger) of fish** • **Recruitment of sedges** • **Flow over riffles and removal of fines** • Maintain macrophytes • Transport of organic matter	1:1 to 1:5 Sustaining = 1:2	2–10 days Sustaining = 4 days	Late winter–spring
High flow (bankfull)	Bankfull flows that inundate riparian zone	• **Recruitment/establishment of riparian vegetation** • **Sediment and organic matter transport** • **Channel maintenance** • **Flushing/scouring of pools** • **Removal of fines (riffles)**	1:2 to 1:5 Sustaining = 1:3	1–5 days Sustaining = 1–2 days Duration requirements may be fulfilled by ponded water in depressions	Late winter–spring

Table E.22 Rocky River Zone 3 and 4 (intermittent)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Groundwater table	River bed wetted in some locations and pools filled	• **Maintain aquatic habitat (includes pools)** • **Maintain macrophytes**	Every year (1:1)/ permanent	Permanent (some pools would dry down in summer)	Permanent but may dry out in summer
Mid flow	Low flow channel filled (about 50% of reed height)	• **Increase aquatic habitat** • **Connectivity between pools** • **Migration of macro-invertebrates and fish** • **Development and recruitment of fish** • Connectivity to downstream areas	1:1 to 1:3 Sustaining = 1:2	1–3 weeks Sustaining = 10 days	Late winter–spring
High–bankfull flow	Three-quarter bankfull to bankfull flows	• **Maintain water quality** • **Maintain riparian vegetation (red gum trees and some Broughton willow)** • **Trigger for fish breeding** • Migration of macro-invertebrates and fish • **Channel maintenance** • **Transport sediment and organic matter** • **Removal of fines (riffles)**	1:1 to 1:5 Sustaining = 1:3	2–10 days Sustaining = 4 days	Late winter–spring
Overbank flow	Overbank flows into nearby floodplain environments	• **Floodplain inundation and river red gum recruitment** • **Nutrient and organic matter inputs and transport** • Create aquatic habitat • Connect floodplain to in-stream zone • **Scouring of pools** • Channel maintenance • Sediment transport	1:5–1:20 Sustaining = 1:10	1–5 days Sustaining = 1 day Duration requirements may be fulfilled by ponded water in depressions	Late winter–spring

Table E.23: Crystal Brook Zone 1 (ephemeral)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Mid flow	Mid level flows up to approximate maximum depth of 30 cm	• **Connecting aquatic habitat areas (Bowman Park to Broughton River**) • **Create aquatic habitat** • **Fish migration (if present)**[#] • **Transport organic matter** • River red gum watering	1:1 to 1:3 Sustaining = 1:2	1–4 weeks Sustaining = 7 days	Late winter–spring
High flow	Three-quarter bankfull to bankfull flows	• **Maintain water quality** • **Maintain riparian vegetation (river red gum trees; Broughton willow)** • **Fish migration (if present)**[#] • Transport organic matter • **Channel maintenance** • **Sediment transport** • **Bank erosion**	1:2 to 1:5 Sustaining = 1:3	2 days–2 weeks Sustaining = 1 week	Late winter–spring
Overbank flow	Flooding out into the nearby floodplain	• [*]**Connect floodplain to in-stream zone** • **Nutrient and organic matter inputs and transport** • [*]**Floodplain inundation and river red gum recruitment** • Create aquatic habitat • Channel maintenance • Sediment transport • Bank erosion	1:5–1:20 Sustaining = 1:10	1–5 days Sustaining = 1 day Duration requirements may be fulfilled by ponded water in depressions	Late winter–spring

[#]*Fish may not be able to travel through this zone but suitable habitats do exist upstream and downstream.*
[*]*Floodplain vegetation is modified by grazing and cropping.*

Table E.24 Crystal Brook Zone 2 (intermittent)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Groundwater table (only at Bowman Park)	River bed wetted in some locations and pools filled	• **Maintain aquatic habitat (includes pools)** • **Maintain macrophytes**	Every year (1:1)/ permanent	Permanent (some pools would dry down in summer)	Autumn–spring (pulse in spring)
Low flow	Very shallow flows in base of the stream	• **Maintain pools and aquatic habitat** • **Flow over riffles** • **Macro-invertebrate breeding (extended winter baseflow)** • **Fish development and recruitment** • Transport of organic matter	1:1 to 1:2 Sustaining = 1:1	1–3 weeks Sustaining = 10 days	Late winter–spring
Mid flow–bankfull	Mid bankfull flows	• **Trigger for fish breeding** • **Migration of macro-invertebrates** • **Maintain macrophytes** • Transport of organic matter and sediment	1:1 to 1:5 Sustaining = 1:3	2–10 days Sustaining = 4 days	Late winter–spring
Overbank flow	Bankfull and flowing into nearby floodplain environments	• **Floodplain inundation and habitat creation** • **River red gum maintenance and recruitment** • Migration of macro-invertebrates • **Sediment and organic matter transport** • **Channel maintenance** • **Removal of fines (riffles)**	1:3–1:7 Sustaining = 1:5–1:6	2–20 days Sustaining =2 days	Late winter–spring
Catastrophic flow	Flowing across floodplain >1992	• **Recruitment of river red gum trees** • Transport of organic matter • **Scouring of pools** • **Floodplain processes (e.g. erosion, sedimentation, avulsion)** • Channel maintenance	1:10 to 1:50 Sustaining 1:20	–	Late winter–spring

Table E.25: Pine Creek (intermittent)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Groundwater table	River bed wetted and pools filled	• **Maintain aquatic habitat (includes pools)** • **Maintain macrophytes** • Maintain water quality	Every year (1:1)/ permanent	Permanent (some pools would dry down in summer)	Permanent (summer period critical for pools to be maintained)
Mid flow	About 50–75% of reed height	• **Recruitment and establishment of riparian vegetation** • **Increase habitat area** • **Macro-invertebrate breeding and maintenance** • **Maintain water quality** • Transport organic matter • Habitat connection	2:1 to 1:2 Sustaining = 1:2	1–3 weeks Sustaining = 1 week	Late winter–spring
High flow	Bankfull	• **Recruitment and establishment of riparian vegetation** • Scouring of pools • Transport of organic matter • Resetting flow • **Channel maintenance** • **Sediment transport**	1:2 to 1:5 Sustaining = 1:3	1–5 days Sustaining = 1–2 days	Late winter–spring

Table E.26 Appila Creek Zone 1 (ephemeral)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Mid flow	About 50–75% of reed height; also across the low flow channel	• **Recruitment and establishment of riparian vegetation** • **Increase habitat area** • Transport organic matter • Habitat connection	1:1–1:3 Sustaining = 1:2	1–10 days Sustaining = 1–2 days	Late winter–spring
High flow	Bankfull	• **Recruitment and establishment of riparian vegetation** • Transport of organic matter • **Channel maintenance** • **Sediment transport** • **Gully head erosion/stream incision**	1:2 to 1:5 Sustaining = 1:3	1–5 days Sustaining = 1–2 days	Late winter–spring

Table E.27 Appila Creek Zone 2 (intermittent)

Key flow bands	Lateral extent/height and description	Key functions	Frequency (no. of events:years) (range and sustaining)	Duration (range and sustaining)	Seasonality
Ground-water	River bed wetted and pools filled	• **Maintain macrophytes** • **Maintain pools and aquatic habitat, including rock bar habitat** • Maintain water quality • Transport of organic matter	Permanent	Permanent	Year round (critical in summer)
Baseflow/ seasonal low flow	Intermittent pulse flow up to 30 cm in depth	• **Maintain water quality** • **Maintain macrophytes** • Maintain pools • Maintain the aquatic habitat	Annual	1–3 weeks Sustaining = 1 week	Late winter–spring
Mid flow	About 50–75% of reed height; also across the low flow channel	• **Recruitment and establishment of riparian vegetation** • **Increase habitat area** • **Maintain water quality** • **Migration and breeding of macro-invertebrates** • Transport organic matter • Habitat connection • **Removal of fines (riffles)**	1:1–1:2 Sustaining = 1:2	1–3 weeks Sustaining = 1 week	Late winter–spring
High flow	Bankfull	• **Recruitment and establishment of riparian vegetation** • Transport of organic matter • **Channel maintenance** • **Sediment transport** • **Scouring of pools**	1:2–1:5 Sustaining = 1:3	1–5 days Sustaining = 1–2 days	Late winter–spring

APPENDIX F – NYAD INRM COMMITTEE RECOMMENDED MANAGEMENT ACTIONS

The following tables show the recommended management actions outlined in the Integrated Natural Resource Management Plan developed by the Northern and Yorke Agricultural District Integrated Natural Resource Management (NYAD INRM) Committee (2003). Overlap between the management actions below and those of this project are shown in Chapter 15.

NYAD INRM Plan Section 6.1 – Achieving Sustainable Water Supplies and Use

Resource Condition Targets:

6.1A Water regimes restored to a level sufficient to sustain significant dependent ecosystems throughout the region by 2015

Management Targets:

6.1.1 Sustainable limits for surface & ground water determined by 12 /05

6.1.2 Dependent ecosystems & their water requirements identified by 6/04

6.1.3 Water use within sustainable limits throughout the region by 6/07

Recommended Management Actions and Link to Current Investment Program:

Management Actions (from Plan)

Benchmarks & Monitoring
• Establish regional water quantity data base for surface and groundwaters, quantifying water resources and levels of use and dependent ecosystems and their water requirements, and monitoring programs
On-Ground Actions
• Implement relevant recommendations from the Mid North rivers project reports to develop improved water regimes to support dependent ecosystems
• Develop and implement programs for the re-use of effluent and stormwater
• Incorporate best practice water conservation principles to new development and to the upgrading and construction of infrastructure
Planning & Investigations
• Maintain support for programs to develop more efficient water use options for irrigation & industry
• Review the impact of irrigation, stock and domestic use on water resources in the region
• Develop a river management plan for catchments at risk (such as the Willochra catchment)
• Complete regional inventory of water dependent ecosystems and their water requirements (both surface & ground)
• Investigate impacts associated with water importation
• Investigate potential biodiversity/ revegetation offsets for water use in the region
• Develop regional action plan for provision of water to dependent ecosystems
• Ensure flood management planning takes into consideration natural resource issues
• Review potential economic instruments to promote more efficient use of water resources
Capacity Building
• Develop and promote regional guidelines for improved water use efficiency
• Implement cooperative partnerships with industry to ensure that water use for production and industry purposes complies with sustainability objectives
• Expand community education programs re environmental flow requirements and on methods to reduce the level of use/ wastage of water resources
• Develop and implement water conservation opportunities, focusing on improved community skills and commitment
Legislation and its Implementation
• Ensure that there are adequate controls across the region to regulate water use and water affecting activities, to safeguard dependent ecosystems and provide long-term security for water users

NYAD INRM Plan Section 6.2 - Achieving Water Quality Improvement

Resource Condition Targets:

6.2A Maintenance or a progressive reduction below critical levels in average & peak nutrient loads (N&P),turbidity levels & other contaminants including pesticides, heavy metals & hydrocarbons in streams throughout the region, with clear targets determined by 12/04

6.2B Progressive improvement in river health as measured by key biological indicators, with targets determined by 12/04

Management Targets:

6.2.1 Identify thresholds for N, P, turbidity and other relevant / potential contaminants by 12/04.

6.2.2 Continue erosion control works at known critical or strategic areas & develop clear targets for erosion control by 6/07

6.2.3 Implement program to fence / protect priority remnant riparian vegetation and fence & revegetate strategic riparian areas based upon Mid North Rivers project & regional Biodiversity Plan by 6/07

Recommended Management Actions and Link to Current Investigation Program:

Management Actions (from Plan)

Benchmarks & Monitoring

- Develop and apply the Risk Assessment Framework for Water Resource Management to develop priorities for investment in on-ground actions, investigations, extension and compliance programs
- Strategically invest in regional monitoring and assessment programs for water quality (and catchment characteristic attributes affecting water quality) to establish subcatchment level benchmarks and targets and develop on-ground works monitoring and evaluation systems

On-Ground Actions

- Implement management plan for riparian zone protection and restoration in accordance with recommendations from Mid North Rivers Management Planning Project
- Develop and invest in strategic programs to improve domestic waste water systems management
- Develop and invest in programs to reduce contamination of stormwater run-off
- Continue erosion control works at known critical or strategic areas: Develop clear regional targets for erosion control through Risk Assessment Framework
- Implement program to fence / protect priority remnant riparian vegetation and fence and revegetate strategic riparian areas: Develop clear regional targets for erosion control through Risk Assessment Framework

Investigations

- Complete riparian zone surveys and management planning for the major catchments in the region
- Develop regional plan for riparian zone protection & revegetation, including actual and potential erosion sites based on Risk Assessment Framework and biodiversity plan
- Investigate key relationships between land use/management practices and water quality parameters to support the development of codes of practice and guidelines for sustainable land management and industry development
- Investigate impact of modified state of catchment on long-term survival of biota, including waterbirds and native fish
- Investigate impact of point source and diffuse contamination from urban and industrial areas upon watercourses and marine waters

Capacity Building

- Clarify roles and responsibilities between all authorities managing water resources in the region
- Ensure that regional extension programs provide the community with adequate information & skills development to adopt best practice in water quality management, taking into account biodiversity and other objectives
- Ensure an adequate level of community involvement in monitoring programs related to water quality

Legislation and its Implementation

- Ensure adequate resources for compliance activities addressing point and diffuse pollution issues
- Identify land use planning and development control mechanisms that could contribute to water quality improvement
- Implement Environment Protection (Water Quality) Policy or equivalent legislative program

NYAD INRM Plan Section 6.3 - Managing Groundwater Driven Salinity

Resource Condition Targets:

6.3A Halt the rise in saline groundwater levels in local & intermediate groundwater systems & the increase in salinity levels in surface water bodies by 2020

6.3B Achieve improved economic productivity in 50% of primary production lands affected by salinity by 2010

6.3C Demonstrate progressive improvement in condition of significant biodiversity areas by 2015

Management Targets:

6.3.1 Establish regional benchmarks & monitoring programs for salinity in surface & groundwaters & associated impacts on production, natural biodiversity & infrastructure by 6/04

6.3.2 Establish clear targets for on-ground works in priority salinity areas by 12/04

6.3.3 Implement priority actions arising from salinity mgmt plans to address RCTs by 12/07

Recommended Management Actions and Link to Current Investment Program:

Management Actions (from Plan)

Benchmarks & Monitoring

- Establish regional benchmarks and monitoring programs for salinity in surface and groundwater and associated impacts on production, natural biodiversity and infrastructure

On-Ground Actions

- Implement actions arising from salinity management plans to reduce and eventually halt the rise of saline groundwater and the increase in surface water salinity and, where appropriate, to implement living with salt options for increased productivity
- Fence remnant native vegetation in priority sub-catchments and initiate ongoing management programs for those areas

Investigations

- Complete salinity management plans for areas affected by and at risk from secondary dryland salinity
- Complete investigation of effects of salinity on public infrastructure in identified salinity areas
- Develop and promote innovative and productive solutions for treatment of salinity-affected and at risk areas, including “living with salt” in areas likely to be affected on a long-term basis
- Encourage actions to improve water use efficiency in irrigation practices
- Develop a risk assessment process for assessing potential impacts of proposed developments and other actions in terms of implications for salinity management.

Capacity Building

- Develop & implement integrated program involving NAP Salt Action Teams to raise community, industry and land manager awareness re salinity, to foster appropriate skills and to provide appropriate support for salinity management.

NYAD INRM Plan Section 7.1 - Managing Soil Structure, Fertility, Organic Matter and Acidity

Resource Condition Targets:

7.1A Soils supporting primary production reflecting optimum capability by 2015

7.1B Soils managed to support diverse soil biodiversity & natural ecosystems by 2015.

Management Targets:

7.1.1 Progressive increase in the number of properties incorporating best practice mgmt to sustain & enhance soil health & to limit the onset of acidification with clear targets set by 12/04

Recommended Management Actions and Link to Current Investment Program:

Management Actions (from Plan)

Benchmarks & Monitoring

- Establish representative monitoring programs at the property and regional levels

On-Ground Actions

- Implement a range of programs to maintain and improve soil health
- Develop and promote regional program for the monitoring, prevention and treatment of soil acidity
- Develop programs to encourage innovation in pasture, cropping and other primary production management practices for improved soil health and sustainability

Investigations

- Conduct research to further define areas in the NYAD at risk of soil acidity and appropriate preventative measures
- Conduct research to determine link between acid soils and other land management issues such as salinity and water quality
- Establish additional trials to demonstrate stubble, crop and pasture management in key areas
- Support investigation into innovative land management techniques
- Investigate, develop and promote non-acidifying fertilisers
- Develop techniques to overcome mice, white snails, herbicide resistant rye grass etc which do not rely on burning residues or increasing cultivation of soil

Capacity Building

- Maintain existing programs, including property management planning, to encourage best practice management to sustain and enhance soil health
- Expand the capacity of local and broader communities to value and address soil structure / organic matter and other soil and land management issues
- Ensure that regional support programs are in place to assist land managers in review options for treatment of soil acidity and in applying appropriate prevention and treatment methods
- Promote innovative approaches to improved soil health and sustainable production systems through partnerships between landholders, industry and Government

NYAD INRM Plan Section 7.2 - Managing Wind and Water Erosion of Soils

Resource Condition Targets:

7.2A Reduce incidence of sheet, rill & gully erosion events by 30% by 2015

7.2B Reduce area of sand hills with potential drift problems by 50% by 2015

Management Targets:

7.2.1 Adequate surface cover maintained over 80% of susceptible land for 10 months of the year

7.2.2 Adoption of reduced / no tillage & stubble retention on 80% of cropping land at risk of erosion by 2010

7.2.3 Grazing managed to maintain adequate levels of surface cover on 75% of land at risk by 2010

7.2.4 Perennial vegetation established on 80% of very high risk erosion areas by 2015

Recommended Management Actions and Link to Current Investment Program:

Management Actions (from Plan)

Benchmarks & Monitoring

- Map area of bare/drifting sandhills in region by 12/05 and monitor change in area of bare sandhills
- Record incidences of sheet, rill and gully erosion events in region
- Maintain monitoring of surface cover and soil condition on selected transects in region

On-Ground Actions

- Adoption of reduced / no tillage and stubble retention on 80% cropping land at risk of erosion
- Grazing managed to maintain adequate levels of surface cover on 75% of land at risk
- Interrow horticultural practices to maintain adequate levels of surface cover adopted on 80% of land at risk
- Runoff control structures present on 30% of Class IIIe land
- Perennial vegetation established on 80% of very high risk erosion areas
- 200 km of watercourses fenced off

Investigations
• Obtain more relevant data to assess impact of land management practices on rate of soil loss for region's soils and rainfall events • Obtain more quantitative data on effect of range of tillage practices on soil erodibility • Develop new design systems for contour banks to accommodate larger machinery • Develop techniques to overcome mice, white snails, resistant rye grass which do not rely on burning residues or increasing cultivation • Assess machinery developments / modifications which will increase land managers ability to adopt stubble retention and reduced / no tillage systems
Capacity Building
• Assist land managers to manage land to land capability, retain stubble, reduce tillage, manage grazing, plant perennial cover, install contour bank systems, plant wind breaks etc by provision of information and advice through demonstrations, trials, field days, workshops • Provide technical training in soil conservation / land management to providers of information and services
Legislation and its Implementation
• Implement development controls to ensure that changes in land use development applications demonstrate how land is to be managed in a manner that will not cause erosion • Implement legislation that will enable severe or potential problems to be rapidly addressed through controlling land managers' actions

NYAD INRM Plan Section 8.1- Managing Natural Ecosystems

Resource Condition Targets:

8.1A No further fragmentation of native vegetation by 6/05

8.1B 50% of areas of remnant native vegetation exceeding 10ha, within large remnant & threatened habitat areas protected under covenant by 2015

8.1C Progressive improvement in the **condition** of areas of biodiversity significance, with clear targets established by 12/04

8.1D Progressive increase in the **area** of biodiversity significance through habitat restoration and reconstruction programs, with clear targets by 12/04

Management Targets:

8.1.1 Mechanisms in place to ensure no further fragmentation of native vegetation by 6/05

8.1.2 Increase area subject to protective covenant by 20% by 6/05

8.1.3 Increase areas of biodiversity significance being actively managed (eg weeds, pest animals, fire control) by 3000ha by 6/08

8.1.4 Restore / reconstruct 5000ha of natural habitat in significant biodiversity areas by 6/09

Recommended Management Actions and Link to Current Investment Program:

Management Actions (from Plan)

Benchmarks & Monitoring
• Establish regional benchmarks & monitoring programs for selected biodiversity indicators
On-Ground Actions
• Expand programs for the conservation & management of native vegetation remnants outside of the protected areas network. Increase area subject to protective covenant by 20% • Regeneration and revegetation programs undertaken to link, expand and buffer remnant native vegetation: five year target of 5,000 ha revegetated in accordance with biodiversity objectives • Continue native vegetation re-establishment in known strategic areas and linkages for biodiversity purposes: also link with salinity, water quality and other objectives: establish clear revegetation targets • Expand programs for management of weeds and problem animals in priority biodiversity areas in accordance with regional biodiversity plan

Investigations & Planning
• Undertake comprehensive biological survey of the NYAD region • Review condition and management status of areas of native vegetation (including wetlands, salt lakes and watercourses) outside of the Protected Areas Network • Review effectiveness of current programs for the management of biodiversity in the protected areas network • Conduct further research into the ecological management of grasslands and grassy woodland ecosystems, including the role of grazing • Complete floristic mapping in the NYAD region • Develop guidelines and targets for the reconstruction of natural habitats in the region • Develop and implement fire management plans or statements for significant biodiversity areas • Investigate options for the management of land adjacent and close to reserves and large remnants for conservation / revegetation purposes • Undertake research into the significance and condition of other habitats such as moss rocks, ridgelines, cliff-faces etc.
Capacity Building
• Expand programs to provide community and land managers with information, skills and support in the protection, management and reconstruction of natural habitats • Produce regional codes of practice for recreational activities impacting on biodiversity
Legislation and its Implementation
• Ensure appropriate consultation mechanisms between Native Vegetation Council and planning authorities • Introduce amendments to Native Vegetation regulations to tighten clearance exemptions, provide scope for protection of revegetated areas, and to provide protection for dead native vegetation known to be of habitat value

NYAD INRM Plan Section 8.2 - Protecting and Managing Threatened Species & Ecological Communities

Resource Condition Targets:

8.2A Enhanced habitat for top 20% of priority threatened species & communities by 2010 & for all threatened species & communities by 2020

8.2B Progressive decrease in number of threatened species & communities due to recovery & long-term sustainability

Management Targets:

8.2.1 Recovery or management plans in place for all identified threatened species & communities in the region by 6/06

8.2.2 Recovery plans for top 20% of priority threatened species & communities initiated by 6/08

Recommended Management Actions and Link to Current Investment Program:

Management Actions (from Plan)

Benchmarks & Monitoring
• Establish a comprehensive information base on threatened species status and requirements, including identification of species most at risk of extinction • Establish a consistent monitoring and reporting framework on the performance of recovery programs, incorporating suitable indicator species/ populations for measuring outcomes
On-Ground Actions
• Implement existing recovery plans and threat abatement plans (ongoing), and link with broader actions as outlined in Section 8.1
Investigations
• Prepare and/or Recovery Plans for all priority threatened species and ecological communities that do not have a current plan
Capacity Building
• Provide increased information and support to land managers and community groups re actions to assist recovery of threatened species

NYAD INRM Plan Section 8.3 - Managing Coastal, Estuarine and Marine Systems

Resource Condition Targets:

8.3A Progressive improvement in the quality of marine & estuarine waters that are subject to diffuse and point-sourced land-based discharges, with clear targets established by 12/05

8.3B Progressive improvement in the condition of natural biodiversity in coastal, estuarine & marine systems through management of water quality, introduced pests & land use & mgmt: clear targets by 12/05

Management Targets:

8.3.1 Key discharge sources identified and management programs initiated with clear targets by 12/05

8.3.2 Marine, coastal & estuarine areas of particular biodiversity significance identified & mgmt programs initiated with clear targets by 12/05

8.3.3 Comprehensive planning basis in place for coastal, estuarine & marine biodiversity by 12/05

Recommended Management Actions and Link to Current Investment Program:

Management Actions (from Plan)

Benchmarks & Monitoring

- Establish marine and estuarine water quality monitoring program on a regional basis
- Establish register or database of pollution incidents, sources and their impact on the marine environment
- Establish representative monitoring program for terrestrial coastal and marine biodiversity focusing on areas subject to water contamination and other threatening processes
- Ensure that programs are in place to monitor the condition of fisheries stocks and ensure effective control programs are in place to achieve sustainability

On-Ground Actions

- Support and invest in programs to protect and rehabilitate marine, coastal and estuarine areas of particular biodiversity significance
- Support and invest in programs to reduce contamination of marine and estuarine waters
- Support and invest in relevant on-ground actions derived from the Our Seas and Coasts strategy
- Ensure that coastal stormwater management is included in environmental criteria for engineering design and works
- Ensure that program is in place to protect natural coast protection features eg dunes, reefs

Investigations & Planning

- Develop, through the SA Marine Protected Areas program and /or Marine Planning Program, a comprehensive Risk Assessment program for marine, coastal and estuarine biodiversity, identifying areas / communities at risk, threatening processes & management strategies
- Complete survey of habitat requirements of sea and shore-birds in the region
- Identify critical fish spawning and nursery areas with the objective of providing some protection by integration of these areas into fish management plans
- Ensure Investigation into factors contributing to decline in fish stocks and marine mammals
- Develop & implement a strategy to deal with marine pest incursions and to restrict the opportunity for new introductions
- Review potential impacts and management options associated with predicted sea level rises
- Develop a regional management plan for saltmarsh, mangrove and coastal dunes, wetlands and clifftop communities

Capacity Building

- Maintain existing partnerships between State agencies, Local Government and community groups (eg through the Coastcare Program) to develop and apply skills in managing coastal and marine biodiversity.
- Develop targeted program to encourage landholders and visitors to protect coastal and marine environments
- Establish partnerships to promote educational & research programs focusing on biodiversity conservation in marine, coastal & estuarine areas

Legislation and its Implementation

- Review current legislation relating to the development and management of coastal and marine areas to identify mechanisms to support improved biodiversity conservation
- Implement Environment Protection (Water Quality) Policy
- Ensure that relevant planning authorities have adequate support and advice in dealing with developments that may impact upon coastal, estuarine and marine biodiversity

NYAD INRM Plan Section 9.1- Managing Pest Plants, Problem Animals and Diseases

Resource Condition Targets:

9.1A Progressive improvement in the condition, integrity and viability of natural biodiversity and primary production systems, achieved through a progressive decrease in the impact of pest plants, problem animals & diseases: clear targets by 12/04

9.1B Pest plants (including environmental weeds), pest animals & diseases not impacting significantly upon primary production, significant biodiversity areas & sites for priority species & ecological communities by 2020.

Management Targets:

1.1 Halt & reverse spread of environmental weeds in large remnant and threatened habitat areas halted and reversed by 6/07

9.1.2 Maintain integrated programs for the management of pest plants, problem animals & diseases: establish clear mgmt targets by 12/04

9.1.3 Establish system for preventing introduction of new pests & diseases & for early detection and priority treatment of any introductions that do occur: by 6/05

Recommended Management Actions and Link to Current Investment Program:

Management Actions (from Plan)

Benchmarks & Monitoring

- Establish mapping systems to link with pest databases and incorporate into ongoing monitoring of environmental and agricultural weeds
- Map distribution & abundance of ranked agricultural weeds
- Ensure adequate benchmarks and monitoring programs in place for problem animals and diseases of natural biodiversity (including pests & diseases of marine systems)
- Ensure that there are adequate regional benchmarks, monitoring programs and data systems for pests and diseases of primary production

On-Ground Actions

- Establish a program for early detection of new weed species and new outbreaks of existing weed species and a contingency strategy for dealing with them
- Establish system for early detection and reporting of new pests and diseases or new outbreaks of existing pests and diseases in terrestrial and marine areas
- Support the implementation of local policies for control of animals that threaten natural biodiversity (eg foxes, rabbits, feral goats, uncontrolled cats, deer)
- Develop and maintain integrated weed control programs, linking with biodiversity, primary production, fire prevention & other objectives
- Maintain integrated programs for the control of problem animals, linking with biodiversity, production & other relevant objectives

Investigations

- Ensure that contingency plans are in place for pests and diseases that have a significant probability of entering the region
- Develop contingency plans for the management of potential new pests and diseases (eg Phytophthora)
- Ensure bio-security strategy in place for preventing the introduction of new pests and diseases
- Ensure strategy in place for preventing the introduction of new weed species and for the eradication of sleeper weeds
- Conduct regional review of strategies, programs and resources for the control of environmental weeds, with reference to the State Weeds Strategy of 1998

- Conduct regional review of strategies, programs and resources for the control of agricultural weeds
- Conduct regional review of strategies, programs & resources for the control of pest animals and diseases
- Support ongoing Weed Risk Assessment (WRA) program for priority environmental and agricultural weeds
- Support ongoing research into improved, targeted methods for control of the region's priority weeds
- Support ongoing research into improved targeted methods for control of priority pest animals and diseases in both terrestrial and aquatic systems

Capacity Building

- Investigate options for increasing awareness amongst land managers and the community regarding weed species & their management
- Ensure that co-ordinated programs are in place to provide land managers and community groups with relevant information and support for management of environmental pests
- Ensure that programs are in place to raise community awareness and skills regarding pest animals, relevant diseases and their control
- Develop an induction program/ communication strategy for land owners regarding problem animal and disease control
- Foster co-ordinated targeted programs between land holders across districts and regions for control of weeds & weed spread
- Develop targeted program for all land holders, lifestyle block owners and other key groups re responsibilities, methods and sources of support for pest plant and animal management
- Develop specific packages to encourage and support community involvement in the early detection of new pest introductions (including the marine environment)
- Develop regional capacity building strategy for increasing community and landholder awareness and capabilities of pests & diseases & their management

Legislation and its Implementation

- Review legislative options relating to the management of pest plants and animals
- Review scheduling arrangements under APC legislation as they apply to environmental weeds
- Review the effectiveness of current legislation in the prevention of weed introductions and management of existing weed problems
- Review legislative responsibilities and processes relating to the control of problem animals and pests, including vertebrate pests subject to the APC legislation and uncontrolled cats
- Ensure that mechanisms are in place to provide for input of advice to planning authorities re pest management implications of development applications
- Ensure that legal mechanisms are in place to identify notices on land relating to plant and animal control
- Review progress in implementation of State Weeds Strategy and ensure that strategic actions that have not yet been addressed are initiated

NYAD INRM Plan Section 10.1- Safeguarding Indigenous Cultural Values

Resource Condition Targets:

10.1A Areas, sites, items and other Indigenous cultural values safeguarded in NRM by 6/05

Management Targets:

10.1.1 Processes in place to ensure that Indigenous cultural values & assets are subject to appropriate risk assessment & protection by 12/04

Recommended Management Actions and Link to Current Investment Program:

Recommended Management Actions (from Plan)

Benchmarks & Monitoring

- Support local indigenous communities to research and inventory, historic sites and stories that relate to the history of the region and where appropriate, make this information available to visitors through interpretive material.

On-Ground Actions
• Develop conservation plans to facilitate appropriate management of Aboriginal cultural heritage sites • In co-operation with indigenous organisations and groups, identify opportunities to restore and protect historical and culturally significant sites.
Investigations
• Research and inventory, historic sites and stories that relate to the history of the region and where appropriate, make this information available to visitors through interpretive material.
Capacity Building
• Implement program to ensure that land managers, community groups and land management authorities have an adequate awareness re Indigenous cultural values and a commitment to ensuring that those values are taken into account • Develop appropriate partnerships with indigenous groups to facilitate a process to identify significant areas • Encourage and support cultural heritage surveys, which include archaeological and anthropological studies within the region • Develop and implement protocols for consultation with Indigenous communities regarding natural resource management actions in the region • Implement Cross Cultural Awareness Programs to inform the community of the significance of holistic land values to Indigenous people, and extend interpretive programs where appropriate to include cultural experiences for visitors • Develop appropriate inclusive communication strategy • Ensure that Indigenous communities have an input to relevant NRM actions to safeguard cultural values

NYAD INRM Plan Section 10.2 - Safeguarding Landscape Values

Resource Condition Targets:

10.2A Landscapes valued by the regional community safeguarded in NRM: clear targets by 6/05

Management Targets:

10.2.1 Develop a landscape mgmt strategy reflecting regional community objectives & establish processes to implement that strategy by 6/05

Recommended Management Actions and Link to Current Investment Program:

Management Actions (from Plan)

Benchmarks & Monitoring
• Establish regional landscape objectives for NRM
Investigations
• Review community priorities for landscape protection and enhancement and develop regional guidelines / code of practice
Capacity Building
• Develop and use regional landscape guidelines / code of practice as basis for improving community input to sustaining landscapes
Legislation and its Implementation
• Investigate opportunities for incorporation of landscape assessment in development plans and other relevant statutory processes

NYAD INRM Plan Section 10.3 - Safeguarding Significant Geological Assets

Resource Condition Targets:

10.3A Significant geological assets safeguarded in NRM by 6/05

Management Action Targets:

10.3.1 Develop an inventory of significant geological assets & establish processes to protect those assets by 6/05

Recommended Management Actions and Link to Current Investment Program:

Management Actions (from Plan)
Benchmarks & Monitoring
• Develop a comprehensive database of the significant geological assets in the region
On-Ground Actions
• Information and appropriate protective measures to maintain and promote the region's significant geological assets
Investigations
• Encourage research into the region's significant geological assets
Capacity Building
• Support community awareness and interest through public availability of appropriate information regarding the region's significant geological assets
Legislation and its Implementation
• Ensure appropriate legislation in place and enacted to protect significant geological assets