A RIVER MANAGEMENT PLAN FOR THE WAKEFIELD CATCHMENT

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EPA South Australia

Department for Water Resources

A River Management Plan for the Wakefield Catchment

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Cover photographs:
Main photo: Pool and reedbed environment, Wakefield River (Transition zone).
Inset photos (from top): Sedgelands along the upper reaches of the Wakefield River (Chain of ponds zone); View of pool at The Rocks recreation reserve located in the mid-reaches of the Wakefield River (Mobile zone); River red gums line the lower reaches of the Wakefield River (Upper meandering zone).

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FOREWORD

In 1994, the Council of Australian Governments (COAG) endorsed key water resource policies and reforms to the water industry nationally. Provision of water for the environment and greater environmental accountability in water resource management underpins this water reform agenda. South Australia has adopted the COAG goal of providing water for the environment to sustain, and where necessary, restore ecological processes and biodiversity of water dependent ecosystems.

Water resource and agricultural development within the Wakefield River catchment have resulted in significant social and economic benefits. However, these benefits have been associated with significant impacts on the health of the river and its in-stream, floodplain, wetland and estuarine environments. It is not only ecological values that have been affected but also the capacity to use water resources for other purposes such as recreation and agriculture. For our rivers to be managed in a sustainable manner we need to understand the impacts of water resource and land management practices and the role stream flows play in supporting the ecosystems associated with our watercourses.

The Mid North Rivers Management Planning Project (MNRMPP) was initiated in response to local community concerns about watercourse condition, water quality, stream flows and the lack of an integrated, catchment-wide approach to water resource management. The project is a major initiative of the Department for Environment, Heritage and Aboriginal Affairs and aims to achieve healthy rivers by planning for better watercourse management and by determining environmental water requirements.

This innovative project is one of the first to assess environmental water requirements for semi-arid river systems in South Australia. It is pioneering in terms of the methods developed and the way it has linked environmental water requirements with riparian zone management needs.

The Mid North project team assessed the management needs of the Wakefield River system throughout the period from June 1998 to June 1999. The MNRMPP planning process brought landholders and key stakeholders in the Wakefield River catchment together to discuss their concerns and successes in managing their watercourses. The project team found that many landholders who live along the watercourses of the Wakefield River catchment are genuinely concerned about the level of degradation. These landholders face a number of real obstacles to better management of their watercourses. The principal barriers are financial costs, lack of time, and technical know-how to carry out the work.

The South Australian Government recognises the importance of community empowerment and active involvement in management of our natural resources. This plan can be used by the community and individuals as a practical management planning tool. At the same time, the understanding of the requirements of the water dependent habitats of the Wakefield River system is a significant contribution to water resource policy and planning in South Australia. The plan provides the basis for landholders, community groups, regional organisations and government agencies to work together to improve the management of the Wakefield River and its tributaries.

I wish to congratulate those landholders and organisations who became involved with the MNRMPP. They have demonstrated a willingness to be pro-active and innovative in the way they manage their river systems. I look forward to the improvements in river health that will come about from implementing the management options outlined in this plan.

The Hon Iain Evans MP
MINISTER FOR ENVIRONMENT AND HERITAGE

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- Phyllis Robinson, Local government
- Grant Roberts, Animal and plant control boards
- Jon Cameron-Hill, Clare Valley Water Resources Committee
- Mary-Anne Young, Primary Industries and Resources, SA (PIRSA)
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TABLE OF CONTENTS

List of Figures

List of Tables

List of Plates

List of Maps

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EXECUTIVE SUMMARY

The Mid North Rivers Management Planning Project (MNRMPP) was initiated by the Environment Protection Agency, Department for Environment, Heritage and Aboriginal Affairs (DEHAA) in response to local community concerns about water resources and watercourse management issues in the Mid North Region.

The project aims to achieve healthy rivers through better watercourse management and determination of environmental water requirements. The objectives of the project 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
- increase community understanding of watercourse management and environmental water requirement issues.

The project began in May 1998 and over three years will develop river management plans for the Wakefield, Broughton and Light Rivers in the Mid North of South Australia. The River Management Plan for the Wakefield Catchment is the first of the three plans to be produced under the MNRMPP.

The Wakefield River is located in the Mid North Region of South Australia, approximately 100 km north of Adelaide and has a catchment area of 690 km^2. Its major tributaries are the Eyre, Skillogalee, Pine, Rices, Hermitage and Woolshed Flat Creeks. One of three main ephemeral rivers in the Mid North, the Wakefield River catchment is flanked by the catchments of the Broughton River to the north and the Light River to the south.

The most intensive use of ground and surface water resources in the catchment occurs in the Clare Valley. In recent years the Clare Valley has become a major growth area for viticulture and pressure on local water resources has increased. Controls on dams and bores were introduced in 1996 when the area was prescribed. The prescribed area is known as the Clare Valley Prescribed Water Resources Area. Outside the Clare Valley grape growing area, water resource development is less intensive and the water resource is diverted primarily for stock and domestic use.

The Wakefield River system has been dramatically modified by the impacts of European settlement and the associated land use change. Riverine habitats have been altered through the clearance of native riparian and floodplain vegetation; the loss of in-stream complexity due to channelisation, incision and deposition of sediment; stock grazing; and the introduction of exotic plants and animals. The original flow regime of the river system has been modified by vegetation clearance, agricultural development, farm dams and groundwater extraction.

The project determined the environmental water requirements necessary to maintain essential ecological processes and biodiversity for the Wakefield River system. Environmental water requirements were assessed using the Scientific Panel Habitat Assessment Method developed for the project. The river was divided into geomorphic zones on the basis of gradient, stream power, valley dimensions, boundary material and sediment transport regimes. Each zone has a unique physical character and hence the hydrologic regime and structure of physical habitat and associated biological communities also differs. Data on physical habitat, macroinvertebrates, fish and vegetation was gathered for representative and key habitat sites within each zone. This data was used by a multi-disciplinary Scientific Panel workshop to determine the environmental water requirements for the riverine habitats identified.

Watercourse management requirements were determined from data on watercourse condition that was collected using survey techniques based on airborne video. Watercourse features that were assessed included riparian vegetation coverage, exotic trees and weeds, large-scale bed and bank erosion, pools, condition of stream works (eg bridges and culverts) and adjacent land use. Using this data, and through consultation with local landholders, priority watercourse management issues and management options were determined for each subcatchment of the Wakefield River system.

Community involvement was critical to the project's success. Landholders and key stakeholders were given the opportunity to be involved at all stages of the river management planning process from identifying watercourse problems to developing solutions. This local knowledge proved invaluable in providing information on stream flow, river health and management issues.

The condition of the river varied considerably between reaches. However, the overall conclusion of the assessment of watercourse condition and environmental water requirements was that the ecological health of the Wakefield River system is highly degraded. Despite this, there are a number of areas of significant ecological value eg The Rocks recreation reserve, and sections of the upper Wakefield River and the Skillogalee Creek.

The aquatic vegetation community is not diverse and, in many areas, is absent. Riparian vegetation, such as river red gums and native grasses, is healthy in some reaches but severely denuded in others. Submerged aquatic vegetation is found only in the few 'pristine' deep pools (eg at The Rocks) and includes charophytes and *Potamogeton pectinatus*. The predominant aquatic vegetation present in the system includes the emergent reed *Phragmites australis* and *Typha* spp. Both taxa form dense and sometimes impenetrable stands along sections of the main river channel (Sheldon et al, 1999).

A snapshot survey of fish populations found only low numbers of native freshwater fish. Species that rely on migration to and from the sea to maintain populations were notably absent. Native fish found included blue spot goby, found upstream and at the estuary, tandanus catfish at The Rocks, hardyhead, yellow-eyed mullet and sea mullet in the estuary (Hicks and Sheldon, 1998). Exotic species recorded included goldfish, gambusia (mosquito fish) and brown trout. There appear to be problems with predation and competition from exotic fish species (eg trout, mosquito fish). The presence of mosquito fish in the majority of sites studied in the Wakefield River, except for the estuary, suggests habitat degradation (Hicks and Sheldon, 1998).

More than 240 types of macroinvertebrates were collected from the Wakefield River system. Macroinvertebrates collected from the system were composed predominantly of species that are tolerant of a wide range of environmental conditions and are common and widespread in South Australian rivers (McEvoy and Madden, 1998). The most common macroinvertebrates were chironomid and simuliid larvae, nematode and oligochaete worms, springtails and flatworms. Hydrobiid snails, chironomids and caddis fly larvae (*Cheumatopsyche* sp.), which favour flowing water, also occurred in significant numbers. The caddis fly larvae and the less common *Simulium ornatipes* are riffle dwelling, filter feeders that play a critical role in making nutrients available to other fauna. Two taxa – a type of mayfly and a type of caddis fly larvae were found only in creeks (McEvoy and Madden, 1998).

The ecology of the Wakefield River is highly dependent on groundwater-fed baseflows and permanent pools. These areas of permanent surface water are of particular importance as refugia in dry periods (Sheldon et al, 1999).

Seven flow bands were identified as key environmental water requirements for the Wakefield River system. The Scientific Panel determined specific flow values for each flow band as well as the required frequency and duration of the flow event. While flows in the Wakefield River currently appear to support both the ecological functioning and physical processes of the river system, some flow requirements are only just being met. This understanding of the environmental water requirements of the Wakefield River system will contribute to water resource planning that will, amongst other issues, address water needs of the environment.

While the project has identified and quantified environmental water requirements through a scientifically defensible approach, it is important to note that the variability of the Wakefield River system, together with lack of long term scientific data, imposed limitations on the process of assessing environmental water requirements. These flow bands represent a 'first cut' and a process of monitoring and further research is essential.

As a result of the degraded condition of the riparian zone, it is crucial to consider improved watercourse management together with meeting water for the environment needs. The watercourse management priorities and options outlined in the plan were developed based on the data collected and in consultation with local landholders and, in this sense, reflect both ecological and community priorities. Common watercourse management issues include conservation of important riparian habitats, lack of native watercourse vegetation, control of riparian weeds and exotic trees, unrestricted stock access, poor bank stability and erosion heads. In particular, landholders indicated that their top management priority for each subcatchment was the conservation of areas of healthy riparian habitat. The watercourse management priorities and options outlined in the plan can be used by the community and key stakeholder organisations for both practical and strategic planning, and to set priorities for individuals or groups seeking funding for on-ground works.

The implementation of the recommendations for watercourse management and environmental water requirements will require flexible and adaptive management based on the monitoring of outcomes. In particular, a number of interacting elements that determine river condition must be considered. These include physical character, water quantity and quality, condition of the riparian zone and floodplain, and the diversity and population of plants and animals. Improvement of the management of the Wakefield River system therefore requires an integrated approach that combines flow, land and watercourse management.

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1. PROJECT BACKGROUND

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 the then Department of Environment and Natural Resources[1], in partnership with the Clare Valley Water Resources Planning Committee. At these meetings landholders expressed concerns about watercourse condition, water quality, stream flows and the lack of an integrated, catchment-wide approach to water resource management. These concerns were supported by Primary Industries and Resources SA (PIRSA), Soil Conservation Boards, Local Government and the Animal and Plant Control Boards.

The project aims to achieve healthy rivers through planning for better watercourse management and by determining environmental water requirements. Over three years, the project will develop river management plans for the Wakefield, Broughton and Light rivers in the Mid North of South Australia. The River Management Plan for the Wakefield Catchment is the first of the three plans to be produced under the MNRMPP.

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
- increase community understanding of watercourse management and environmental water requirement issues.

The project, which commenced in May 1998, is funded by the Natural Heritage Trust and the South Australian Department for Environment, Heritage and Aboriginal Affairs (DEHAA)[2]. Key local stakeholder organisations provide advice and direction through a Project Reference group comprised of representatives from:

- PIRSA
- Clare Valley Water Resources Planning Committee
- Soil Conservation Boards
- Local Government
- Animal and Plant Control Boards
- DEHAA.

[1] Renamed the Department for Environment, Heritage and Aboriginal Affairs in October 1997.
[2] Renamed the Department for Environment and Heritage on 15 February 2000.

The implementation of river management plans for the Wakefield, Broughton and Light Rivers, will, in the long term, improve the health and diversity of riverine ecosystems, reduce erosion and sedimentation, improve water quality and reduce stock and weed management problems.

1.2. A river management plan for the Wakefield catchment

1.2.1 Purpose

The river management plan for the Wakefield catchment is a decision making tool for landholders and key stakeholders with an interest in river management. The plan is applicable at both a local (river reach) and at a catchment scale. It has been structured to meet the needs of landholders who have a watercourse running through their property as well as stakeholder organisations involved with long term and day to day planning which affects the Wakefield River and its tributaries.

The plan targets local river management needs by assessing the condition of the river (ie the key attributes and key threats), identifying management issues, and developing options for river management based on landholder and stakeholder priorities. The overall river management needs for the Wakefield River were determined by identifying watercourse management issues and scientifically assessing environmental water requirements. It is the first document to merge scientific assessments of watercourse condition, landholder knowledge, local management priorities and an assessment of environmental water requirements for the Wakefield River and its tributaries.

1.2.2 Contents and layout

The plan has been divided into a number of 'stand alone' chapters so that it can be easily used by a wide range of community members and stakeholders with different management needs and capabilities. In particular, development of watercourse management priorities and options and the assessment of environmental water requirements each have a distinct management focus and are discussed in separate chapters. A glossary of terms is included (see Glossary).

- Chapter 1 — background information on the MNRMPP and introduction to the plan

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

- Chapter 3 — a descriptive overview of the Wakefield River catchment

- Chapter 4 — the methods used to identify watercourse management issues, consult with the community and determine environmental water requirements in the context of the overall project planning framework

- Chapter 5 — the results of the assessment of watercourse condition, a discussion of watercourse management issues and the watercourse management priorities and options for each subcatchment area within the Wakefield River catchment

- Chapter 6 — the results of the assessment of environmental water requirements for each river geomorphic zone, a description of key water dependent ecosystems and the physical and ecological environments for each zone and a discussion of the function and importance of key flow bands for the Wakefield River system

- Chapter 7 — an overall, integrated view of management priorities for the Wakefield River combining the water for environment needs and watercourse management issues

1.2.3 Background

Why do we need a river management plan?

Past management of water resources in the Wakefield River focused on providing supplies for irrigation, urban and industrial use, and stock and domestic water supplies. Little consideration was given to the environmental consequences of water resource development and the disposal of wastewaters back into the system. In addition, land use and land management practices impacted indirectly on watercourse vegetation, surface runoff and stream flows, bed and bank erosion processes and water quality.

Natural water regimes have been altered. Seasonal patterns of flows and the quantity and quality of water available have changed. Riverine habitats and vegetation have been significantly degraded. Consequently, while water resource and agricultural development has brought significant social and economic benefits, there has also been significant modification of the river and its in-stream, floodplain, wetland and estuarine ecosystems. It is not only ecological values that have been affected but also the capacity to use water resources for other purposes such as recreation and agriculture. Proper management of the Wakefield River system is essential to ensure its long term health and sustainability.

National and State policy background

It is widely recognised at both a state and national level, that there is a need to provide water for the environment to ensure the long-term integrity of rivers and wetlands as functioning ecosystems. In 1994, the Council of Australian Governments (COAG) endorsed a strategic framework to introduce reforms to achieve a sustainable water industry. Key components were water allocation systems that included allocations for the environment and greater environmental accountability of water resource developments.

The Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) and the Australia and New Zealand Environment and Conservation Council (ANZECC) produced the *National Principles for the Provision of Water for Ecosystems* in 1996. These national principles provide the basis for considering environmental water requirements as part of water allocation decisions.

The *Water Resources Act 1997* provides the 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. Environmental water requirements and watercourse management are achieved through the preparation of various water management plans and other powers. For example, under the Act, authorities have the power to develop statutory water management plans, such as Catchment Water Management Plans, Water Allocation Plans and Local Water Management Plans. All water management plans must be consistent with the State Water Plan, which is the State Government's key policy and strategic planning document for water resources management in South Australia. The river management plan for the Wakefield catchment will be an important information source for any statutory water management plans developed under the *Water Resources Act, 1997*.

What are environmental water requirements?

A catchment is made up of a range of water dependent ecosystems such as estuaries, lakes and wetlands, rivers and streams. All these systems require water to maintain their ecological processes and associated communities of plants and animals. 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, p4).

Determining environmental water requirements involves identifying those flows or aspects of the natural water regime that are most important for maintaining key ecosystem features and processes. Flow volumes must be considered as must flow frequency, duration, variability, seasonality and groundwater-surface flow interactions. Environmental water requirements for the Wakefield River system are described in Chapter 3.

Environmental water requirements can be used to inform water resource management decision making and to determine environmental water provisions. Environmental water provisions are that part of the environmental water requirements that can be met at any given time. This recognises that providing water for the environment must be balanced with the social and economic needs of the water resources.

What is watercourse management?

Watercourses are sensitive zones that require a different management approach from other areas of a property (Bell and Priestley, 1998). Watercourse management, is an important component of river management, and refers to watercourse stabilisation and rehabilitation measures needed to improve the physical and biological condition of a watercourse. There are many reasons to improve management of watercourses including preventing bed and bank erosion, improving water quality, addressing stock and weed management problems and improving habitat and biodiversity.

Most landholders that have a watercourse running through their property are genuinely concerned about good management of that watercourse. Despite this, lack of time, money and technical know-how are real impediments to better management of watercourses by landholders.

The MNRMPP planning process brought landholders and key stakeholders in the community together to discuss their concerns and successes in managing their watercourses. The project team assessed the condition of watercourses throughout the catchment and identified watercourse management issues. This information was used in community meetings to develop watercourse management priorities and options based on local issues and priorities.

Chapter 5 is therefore a useful management tool that identifies problems, management priorities and outlines options for practical watercourse management. The watercourse management priorities and options can be used by the community as practical property planning tools and as supporting documentation for individuals or community groups seeking funding for on-ground works (eg State Revegetation grants and Natural Heritage Trust funds).

1.2.4 Community and stakeholder involvement

Community involvement

A comprehensive community involvement process is an integral part of river management planning. Better watercourse management in the Wakefield River will only occur if the local community has an understanding of the importance of improved watercourse management and an opportunity to individually influence management actions. In addition, landholders' local knowledge and understanding of the river is an invaluable source of information.

The EPA project team between September and November 1998 conducted a series of community consultation meetings. The aim of these participative forums was to facilitate information exchange between landholders and the project team on the health of the river and to raise awareness about the 'what, where, how and why' of managing the Wakefield River and its tributaries. The community involvement process is outlined in Chapter 4.

Landholders were involved in identifying watercourse management issues and determining priorities for management as well as providing valuable local information on flood events and river flows. This bottom up approach attempts to develop a sense of community ownership and long term community commitment to improved management of the river.

Integration with key stakeholders

Key stakeholders in the Wakefield River catchment were consulted during the planning process to discuss their information needs on water resource and land management issues that affect the river. A Mid North Rivers Project Reference group was set up to provide a local advisory role to the EPA project staff and to facilitate the integration of the river management plans into the plans and work programs of their organisations.

The plan offers river management information that can assist stakeholders with both operational and strategic planning. At an operational level, the watercourse management priorities identified in the plan can help stakeholder groups plan work program priorities. The plan will assist stakeholders with strategic planning on river management issues by providing a technical basis for their decision making. Opportunities and examples of how key stakeholders can use and integrate information contained in the plan are outlined in Table 1.1.

Table 1.1: Opportunities for integration of river management information into stakeholder plans and implementation strategies.

Key Stakeholder	Integration Opportunities
Local Government: Clare and Gilbert Valleys Council Wakefield Regional Council	Strategic planning: • Local water management plans under the *Water Resources Act 1997* • Plan Amendment Reports Operational planning: • Management of river based assets eg bridges, culverts • Management of public reserves/council land adjacent watercourses • Flood mitigation • Stormwater drainage
Clare Valley Water Resources Committee	Water allocation plans
Lower North Soil Conservation Board	Integrate into review of the District Soil Conservation Board plan
Lower North Animal and Plant Control Board	Integrate into district plans and weed control work programs
Mid North Regional Development Board	Integrate into regional development plan
PIRSA	Use in property management planning and extension advice
DEHAA	Assessment of water resource condition and environmental water requirements will input to: • State of the Environment reporting • State Water Plan policies and reporting • Water resource management decision making

2. INTRODUCTION TO RIVER PROCESSES

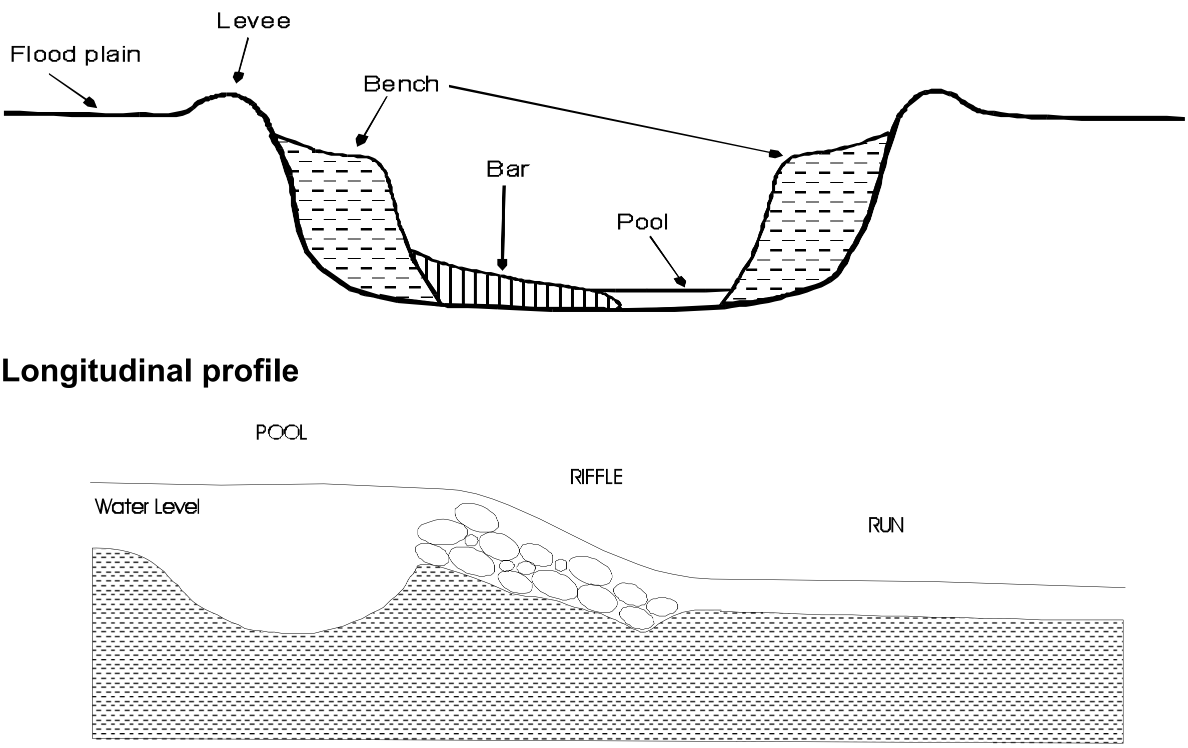
2.1. Structure and function of river ecosystems

A river is a dynamic, living 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 character, water quantity and quality, condition of the riparian zone and floodplain and the diversity and population of plants and animals living in the stream (Rutherford et al, 1999). Any changes to one of these elements can have significant impacts upon other parts of the system. When addressing a river management problem, it is essential to ensure that the remedy employed does not cause unintended repercussions elsewhere.

2.1.1 Physical character and habitat

The physical character of a river is primarily determined by geomorphic processes such sediment transport and flow size and velocity. The channel of a watercourse evolves to form the most efficient shape for the transport of the water and sediment supplied to it from the drainage basin or catchment. It is the material transported and deposited by rivers in the channel and in the riparian zone and floodplain that forms the basis of river habitat (Brierley et al, 1996). Some of the common physical features of a watercourse are illustrated in Figure 2.1.

Channel cross-section



Longitudinal profile

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

In-stream habitat refers to the physical features of a watercourse, such as the substrate (eg rock, sand, silt), the geomorphic features (eg channel bars, pools, riffles), the depth and velocity of water (eg deep pool or fast flowing riffle), the in-stream vegetation and structures such as woody debris and large rocks. Riparian vegetation and the floodplain are other important areas of habitat. Different habitats will support different animals and plants. For example, the animals present in a watercourse with a variety of riffle and pool habitats will differ from those present in a less complex channel. Certain plants, eg 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).

A river can be divided into different geomorphic zones based on the supply, storage and deposition of materials. Each zone will have a unique physical character and hence the structure of in-stream habitat and associated biological communities will also differ (Thoms, 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 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 amongst cobbles in fast flowing water as nymphs, spend their adult stage amongst riparian vegetation and then return to the stream to lay their eggs. Many macro-invertebrates drift downstream as part of their larval stage (Gooderham and Jerie, 1999).

A reach with a range of habitats, eg pools, riffles, rockbars, is likely to support a greater range and number of organisms than the same length of reach with a simple pool. One of the impacts of European settlement and associated land use change, has been the simplification of riverine habitats eg 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).

2.1.2 Water quality

Water quality is important for river condition. Different species have different ranges of water quality that they can tolerate. Outside this range their ability to survive is greatly diminished. If water quality declines, sensitive organisms will be lost while more tolerant organisms, such as Mosquito fish (*Gambusia spp*.), will tend to dominate. Water quality can be affected by: the adjacent landuse, the presence of stock, the capacity of the riparian zone to act as a buffer and to provide shade, sewage effluent, urban stormwater pollution and industrial wastewater (Gooderham and Jerie, 1999).

Water temperature is an important factor controlling the life cycle of aquatic and terrestrial invertebrates that use the stream for all or part of their life cycle. Changes to water temperature provide environmental cues that can trigger different parts of an animal’s lifecycle. For example, warmer water temperatures will trigger the emergence of aquatic insects from the river. However, if the water temperature changes dramatically, eg by removal of riparian vegetation that provides shading, then temperature sensitive species will not survive.

2.1.3 Water quantity and flow regime

Flow 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*) require periods of flooding for regeneration. Flow is also an important factor determining the physical shape and character of a watercourse and thus maintaining in-stream habitats (Gooderham and Jerie, 1999).

Semi-arid rivers such as the Wakefield River are characterised by extreme variability in river flows and the native vegetation and wildlife have adapted to cycles of drought and flood. It is this variability which maintains the biodiversity of riverine ecosystems (Thoms, 1998). The range and variability of flows are therefore just as important as the volume of water within a system. Other important flow characteristics include seasonal flow patterns, the size and frequency of flows, flow duration and the rate of rise and fall of a flow event. Changes to the natural flow regime, ie a change to one or more of these flow characteristics, are generally marked by a reduction in habitat complexity and the diversity of plants and animals.

Stream flow 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 inflows 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 *(E. camaldulensis*) occurring along inland rivers are dependent 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.

2.1.4 Riparian zone and floodplain

The riparian zone and the floodplain play significant roles in the ecology of the river environment. The riparian zone is generally defined as the ribbon of land adjacent to, and influenced by, a watercourse (Figure 2.2). It is widely recognised that 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 the channel shape and flow (Kapitzke et al, 1998).

The floodplain is land adjacent the watercourse that is regularly flooded. When the floodplain is inundated it provides habitat for macro-invertebrates and for fish spawning. As the flood recedes, leaf litter and other detritus is 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 effect the animals that rely on that vegetation (Gooderham and Jerie, 1999).

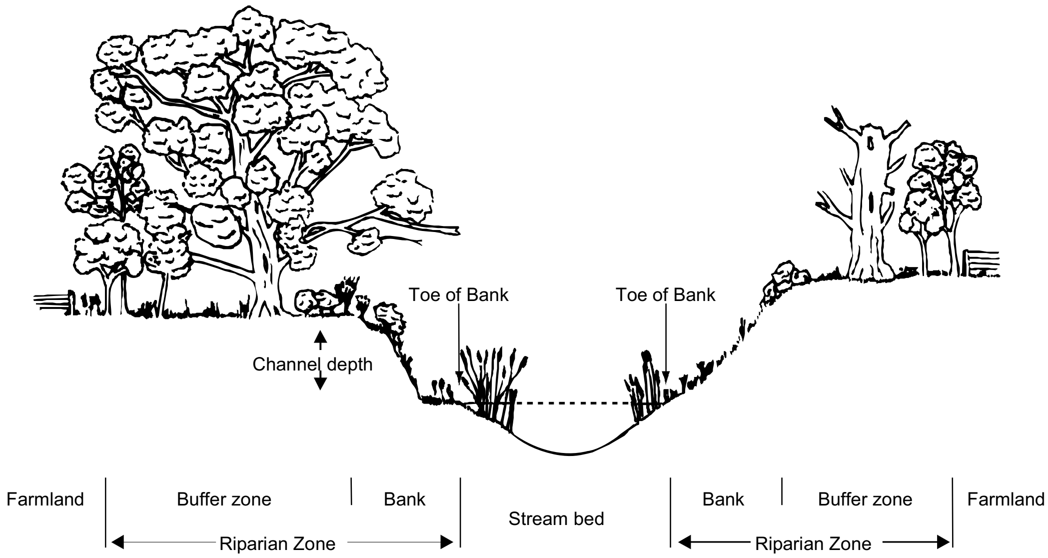


Figure 2.2: Typical cross-section of a watercourse showing the location of the riparian zone.

2.1.5 In-stream plant and animal communities

In-stream plants, ie 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, eg snails, worms, shrimps, insects, and vertebrates, eg 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)

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 banks or riparian zone of the river also provide large amounts of organic matter, eg leaf litter and woody debris, to the river ecosystem (Gooderham and Jerie, 1999).

Herbivores occupy the next level in the food web. There are two basic types. '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. They include 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. These 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).

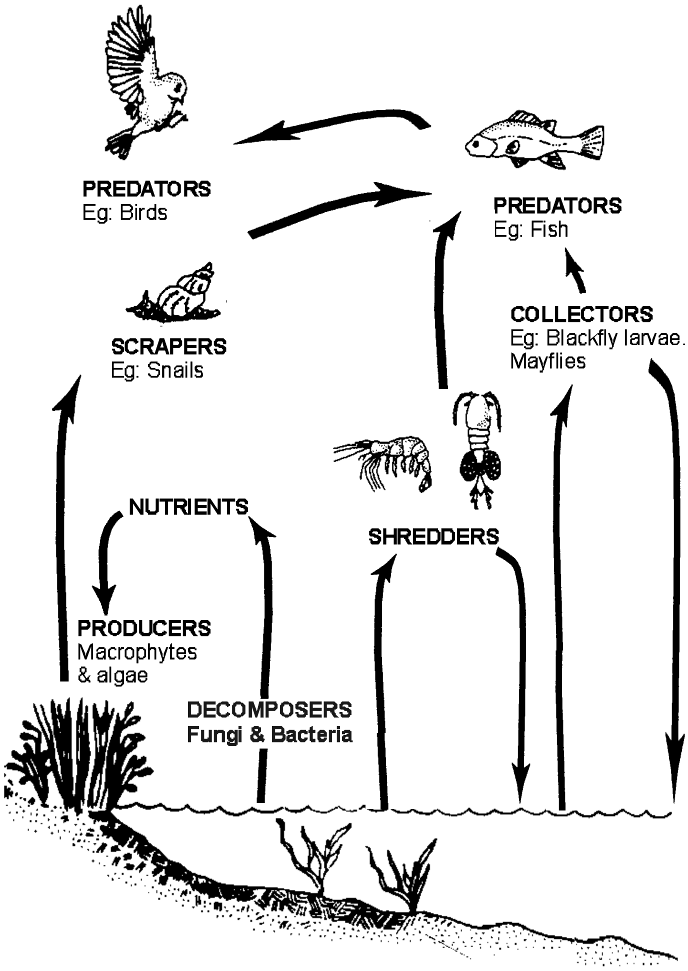


Figure 2.3: The interactions between plants and animals in a community
The arrows show nutrient flows.
Adapted from Gooderham and Jerie (1998).

2.2. Features of a healthy river

It is generally accepted that a healthy river or watercourse will contain a diversity of plants and animals, and that a significant proportion of these will be intolerant of degraded conditions, eg 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, while if only species tolerant of degraded conditions are present, this indicates 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 flow regime, geomorphology and river ecology. There are three key relationships that can be drawn between these factors. The flow regime, eg flow depth, velocity and energy etc, affects the shape and structure of the river and floodplain. River shape and structure, in turn, determines the type of physical habitat available and, consequently, the type of animal and plant communities. Finally, river shape and structure and the nature of the river ecosystem can influence flows, eg in-stream vegetation increases the channel complexity, slowing flows and trapping sediment.

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3. THE WAKEFIELD RIVER CATCHMENT

3.1. Location

The Wakefield River is located in the Mid North Region of South Australia, approximately 100 km north of Adelaide (Figure 3.1) and has a catchment area of 690 km^2. The local governments within the catchment are the Wakefield Regional Council, and the Clare and Gilbert Valleys Council. One of three main ephemeral rivers in the Mid North, the Wakefield River catchment is flanked to the north by the Broughton River catchment and to the south by the Light River catchment.

The Wakefield River flows in a southerly direction through Auburn before turning west to flow through Balaklava and into the Port Wakefield estuary. Its major tributaries are the Eyre, Skillogalee, Pine, Rices, Hermitage and Woolshed Flat Creeks. For the purpose of the MNRMPP, the catchment was divided into six subcatchments, Lower Wakefield, Hermitage and Woolshed Flat Creeks, Skillogalee Creek, Pine and Rices Creeks, Eyre Creek and Upper Wakefield (Figure 3.2).

3.2. Topography and climate

The elevation of the catchment ranges from sea level at the coast to approximately 600 m above sea level in the upper catchment. The catchment west of the Alma Range consists of a broad, gently sloping coastal plain at an elevation of less than 100 m. East of Halbury, the dominant topographic feature of the northern Mount Lofty Ranges forms a series of north–south ridgelines that have an elevation of approximately 600 m. At 610 m, Mount Horrocks is the highest topographic feature in the catchment and defines the headwaters for the Skillogalee and Eyre Creeks (Figure 3.3).

The rainfall pattern for the catchment is heavily influenced by topography (Figure 3.4). In the coastal flats from Port Wakefield to Balaklava, the average annual rainfall is approximately 300 mm. Eastward from these plains, the rainfall increases to 660 mm in the high rainfall country around Watervale. This area, having higher elevation and rainfall, supplies most of the water to the river. For most of the catchment the rainfall is less than 500 mm. The catchment has a steady winter rainfall pattern with intense thunderstorms occurring in the summer months (Lower North Soil Conservation Board, 1994).

3.3. Geology and soils

The beach at Port Wakefield is part of the St Kilda formation of light grey shelly beach ridge deposits. Relatively young in geological age (10,000 years), the sediment deposits have been formed from coastal wind and wave action. To the east, the plains around Bowmans and Balaklava consist of Quaternary sand and silt deposits that have been washed from the ancient rock formation of the Mount Lofty Ranges. At some locations, these deposits abut small discontinuous outcrops of the older Tertiary rock, which are characterised by quartz sands and sandy clays. One such outcrop runs in a north–south direction from Mount Templeton to the Wakefield River near Whitwarta and acts as a controlling feature for shallow groundwater.

The break in slope from the plains to the hills just east of Halbury signifies the change in age of the geological formations. To the west, lie the more recent Tertiary formations (65 million years) while the east contains ancient Proterozoic rocks (1.8 billion years). Two fault lines intersect the catchment slopes, indicating the uplift and plate movement that gave rise to the upper catchment hills. The Owen Fault line extends for approximately 8 km from Owen to the Wakefield River at The Rocks. The Alma Fault runs north from Hamley Bridge and along the eastern ridgeline of Skillogalee Creek subcatchment.

The *Lower North Soil Conservation Board District Plan* describes the Wakefield River catchment soils as being typical of the broader Mid North region (Lower North Soil Conservation Board, 1994). Red brown loams, loamy and sandy mallee soils are found on the plains in the 350-500 mm rainfall zone. Saline soils exist around the groundwater-fed Diamond Lake near Balaklava. The higher rainfall areas also have terra rossa and podsolic soils (red, grey-brown and yellow). Table 3.1 provides an overview of where the principal soil associations are situated and their land management issues.

Table 3.1: Soil associations in the Wakefield River catchment

Soil type	Location	Rainfall Zone (mm)
Red brown earths	East of Two Wells-Balaklava Road	350-500
Loamy mallee soils	Plains west of the ranges at Mallala, in the dune swales between Hamley Bridge and Port Wakefield	425
Sandy mallee soils	Port Wakefield, north of Balaklava	<425
Dark brown cracking clays	West of Saddleworth	425-500
Terra Rossa	On hard limestone on upper slopes around Watervale	450-500
Podsolics	Small area west of Auburn	500-650

3.4. Native vegetation

Most of the catchment has undergone significant vegetation change since agricultural development. Mallee scrub has been extensively cleared on the coastal and inland plains, as has grassy woodland and grassland vegetation in the ranges. Based on floristic vegetation mapping (Figure 3.5) it is estimated that remnant vegetation covers less than 10% of the catchment[3].

Rabbits, weeds, woodcutting and grazing (Lower North Soil Conservation Board, 1994) have degraded remnant native vegetation, particularly the understorey layer. Annual grasses and weeds have replaced most understorey species. Along watercourses, due to past erosion and sedimentation, the predominant in-stream vegetation includes the emergent reeds, *Phragmites australis* and *Typha* spp. that form dense and often impenetrable reed beds.

[3] This estimate does not take into account remnant grasslands which could be present in the hilly areas.

Figure 3.1:
Location of the
Wakefield River catchment

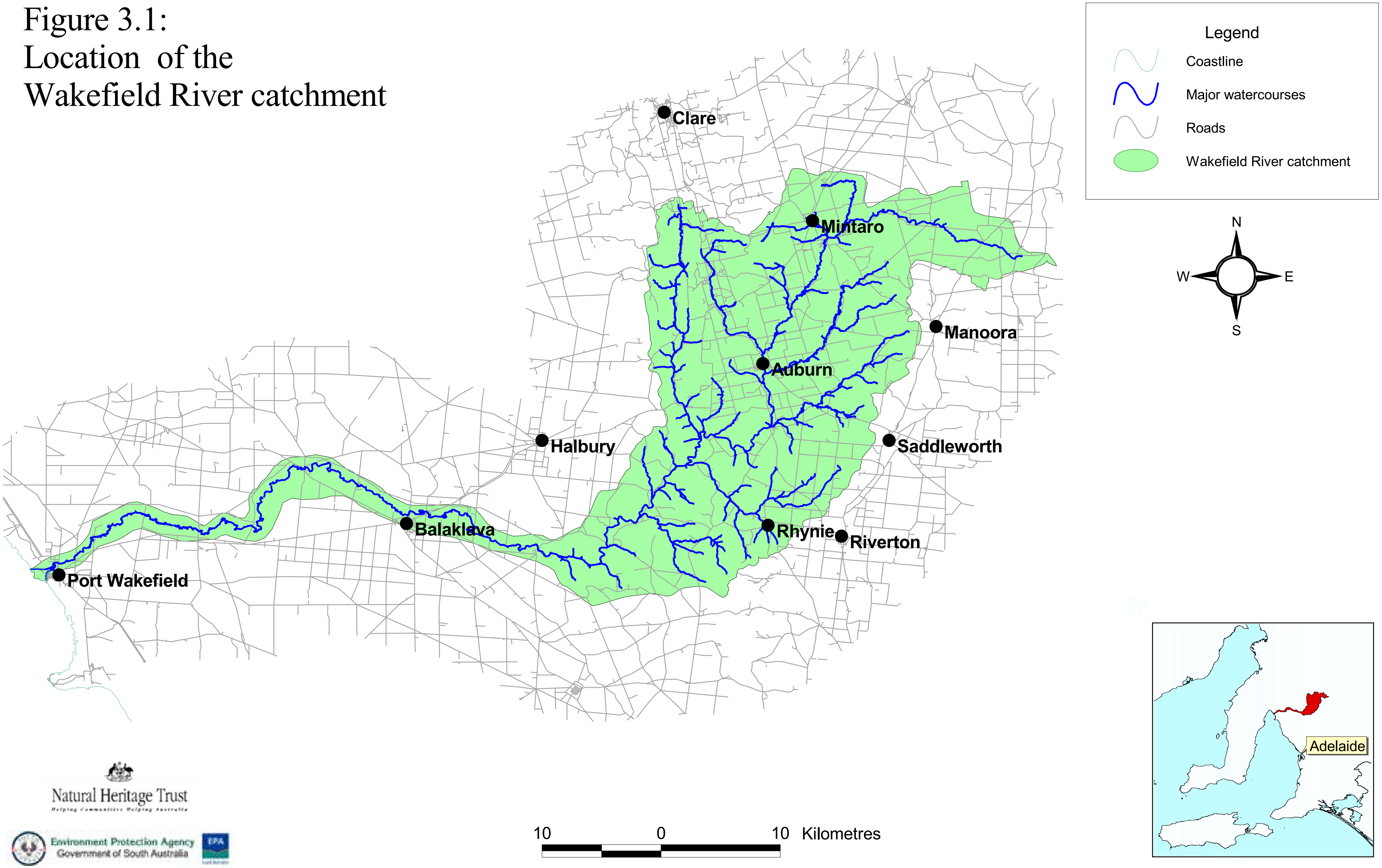

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Figure 3.2:
Surveyed streams and subcatchments in the Wakefield River catchment

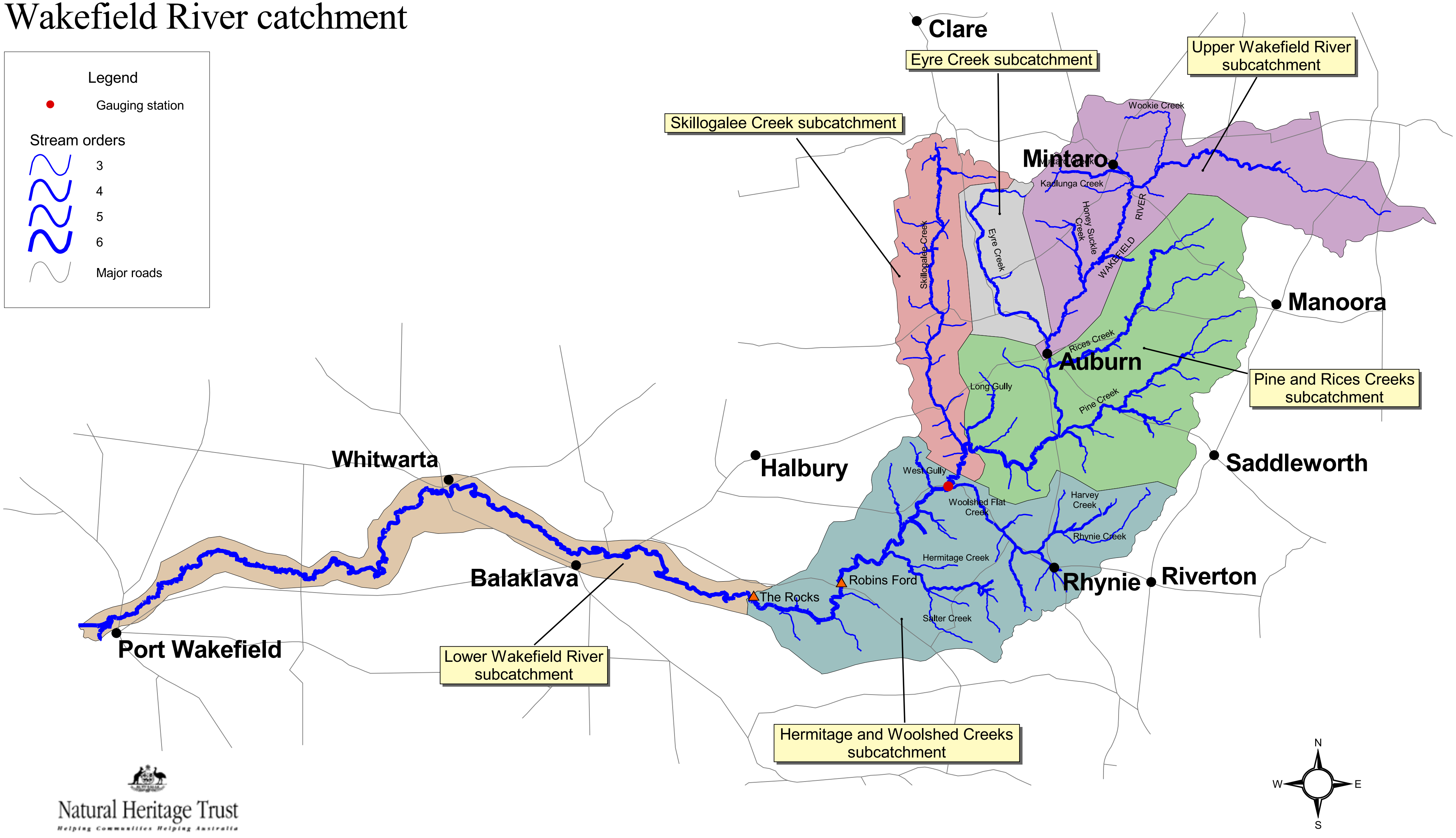

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Figure 3.3:
Topography of the
Wakefield River catchment

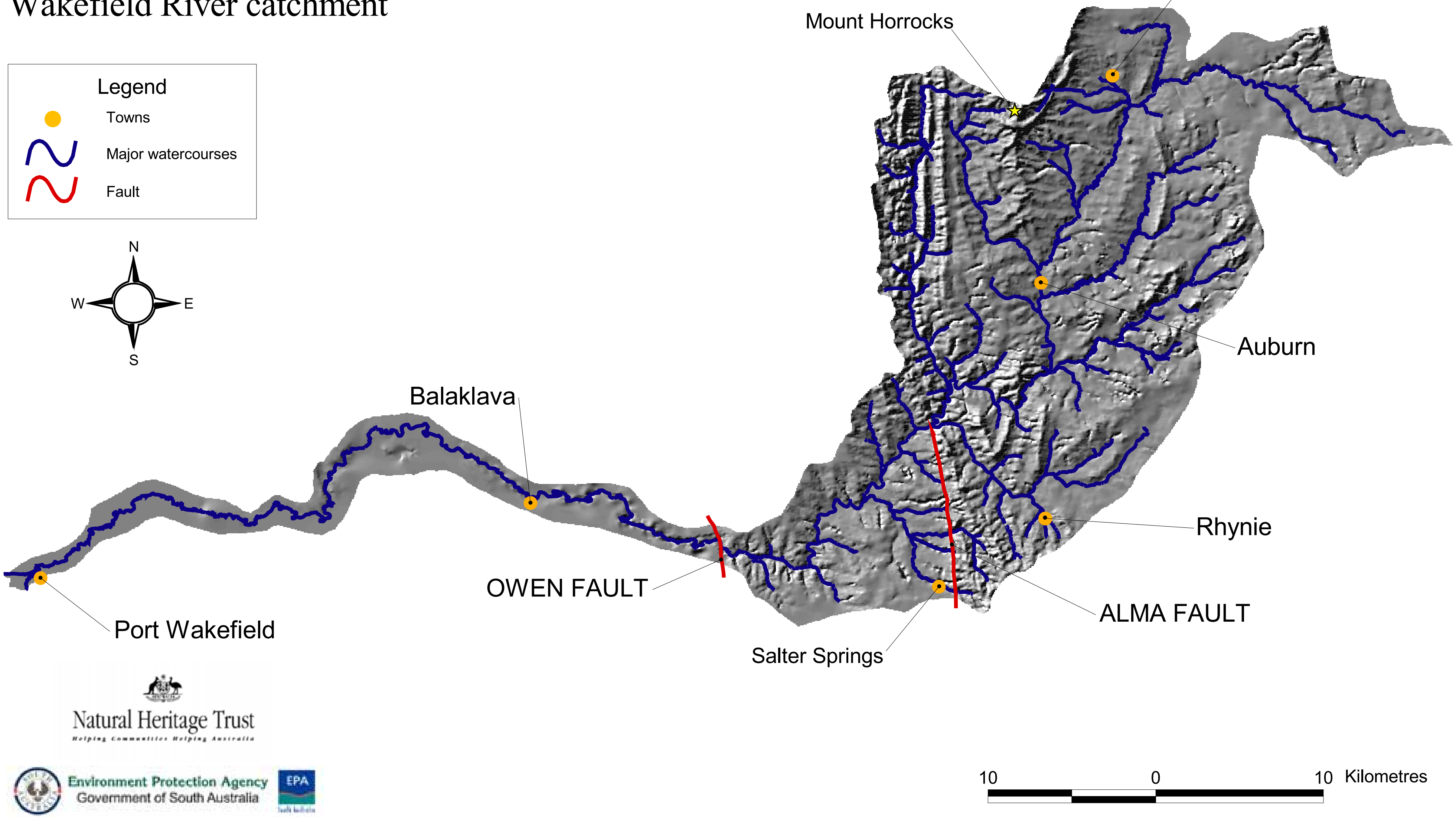

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Figure 3.4: Rainfall in the Wakefield River catchment

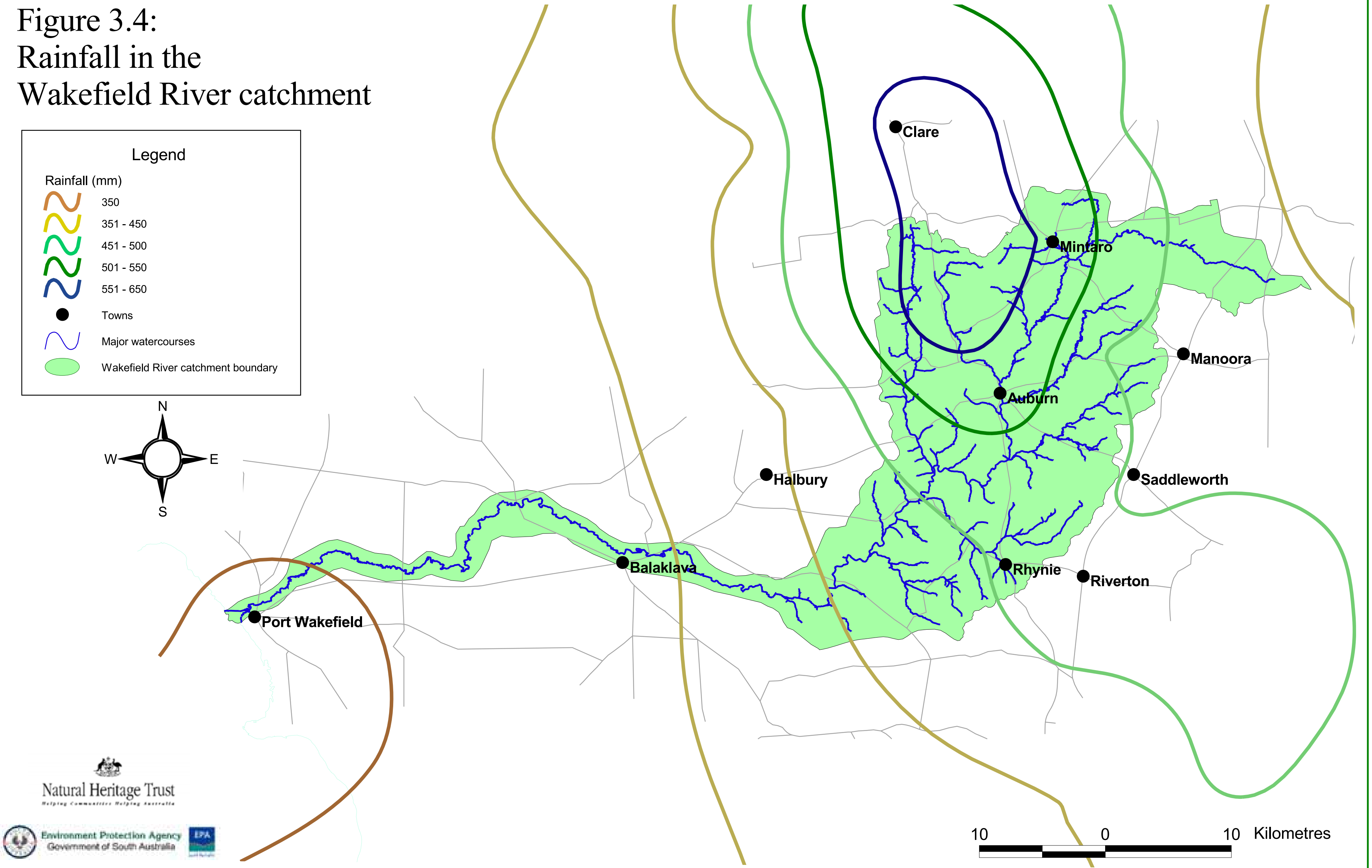

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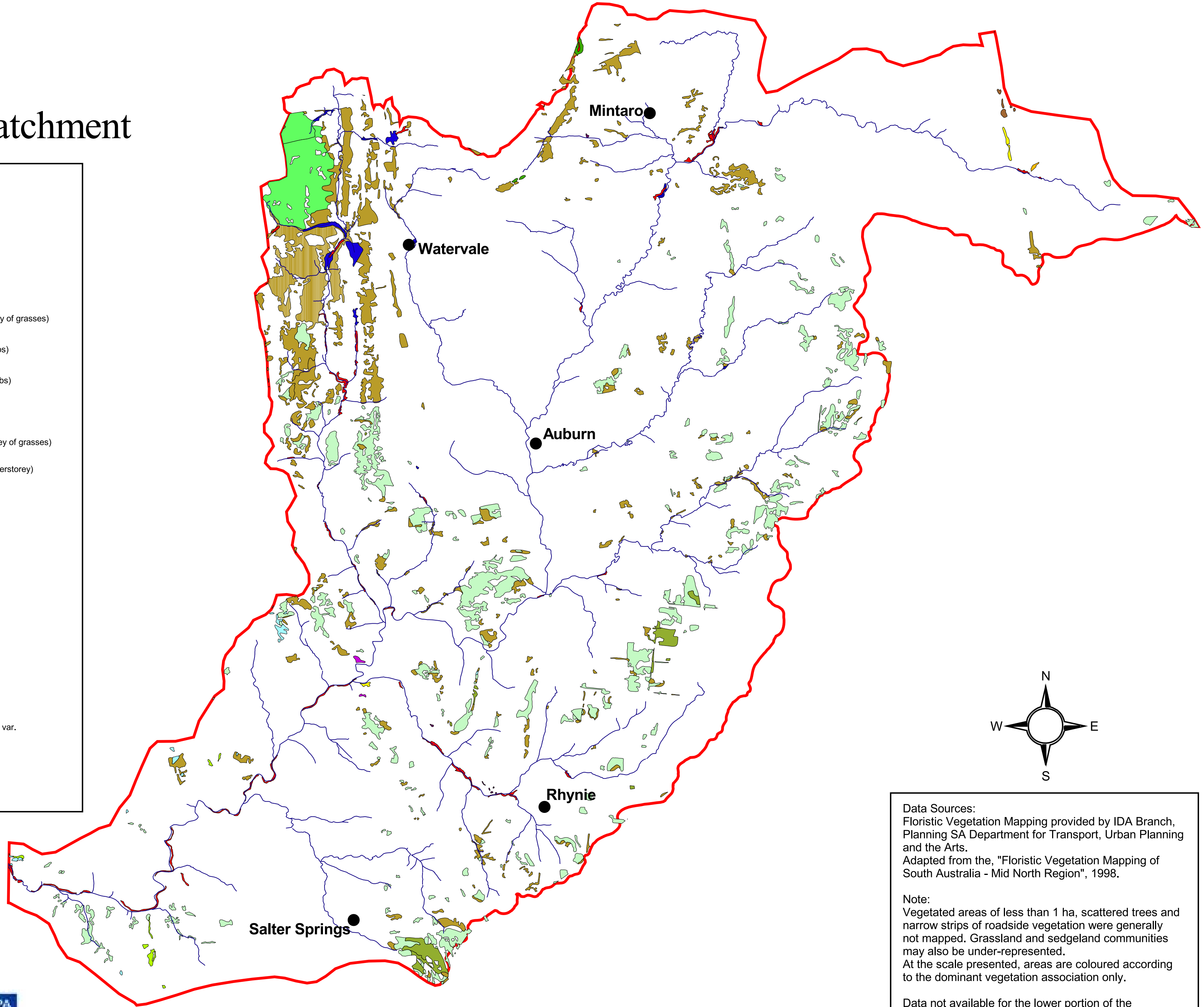
Figure 3.5: Remnant native vegetation in the Wakefield River catchment



Legend

Vegetation Association

Forest
- E. camaldulensis (with understorey of shrubs) Open forest
- C. preissii +/- E. porosa Low open forest

Woodland
- Eucalyptus odoarta, +/- E. leucoxylon ssp. (with understorey of grasses) Low woodland
- E. leucoxylon ssp., +/- E odorata (with understorey of shrubs) Low woodland
- E. odorata, +/- E. leucoxylon ssp. (with understorey of shrubs) Low woodland
- Allocasuarina verticillata, B. spinosa, +/- E. leucoxylon ssp. (with understorey of shrubs &/or grasses) Low woodland
- A. verticillata, Xanthorrhoea quadrangulata (with understorey of grasses) Low woodland
- A. verticillata, Xanthorrhoea quadrangulata (with shrub understorey) Low woodland
- E. macrorhynca (with understorey of grasses or shrubs) Low woodland

Mallee
- E. porosa, +/- Callitris preissii (with understorey of shrubs) Open mallee

Shrubland
- X. quadrangulata &/or A. verticillata Open shrubland to very low woodland
- Acacia paradoxa Shrubland

Grassland / Sedgeland
- Lomandra multiflora ssp. dura Tussock grassland
- Lepidosperma viscidum Sedgeland
- Juncus kraussii Cyperus gymnocaulos +/- E camaldulensis var. Sedgeland

Subcatchment boundary

Streams

Data Sources:
Floristic Vegetation Mapping provided by IDA Branch, Planning SA Department for Transport, Urban Planning and the Arts.
Adapted from the, "Floristic Vegetation Mapping of South Australia - Mid North Region", 1998.

Note:
Vegetated areas of less than 1 ha, scattered trees and narrow strips of roadside vegetation were generally not mapped. Grassland and sedgeland communities may also be under-represented.
At the scale presented, areas are coloured according to the dominant vegetation association only.

Data not available for the lower portion of the Wakefield River catchment.

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Figure 3.5 shows the distribution and type of remnant native vegetation for the Wakefield River catchment west of The Rocks recreation area[4]. Native vegetation is divided into vegetation associations each representing a major change in plant species composition and overstorey structure. Vegetation associations present in the catchment and under-represented in this map include grasslands, sedgelands and samphire/chenopod shrublands (Planning SA, 1998). Refer to Appendix A for details of the vegetation mapping.

Low woodlands of blue gum (*Eucalyptus leucoxylon* ssp.) and peppermint box *(E. odorata*) are widespread in the higher rainfall areas of the catchment. These woodlands typically have understories of sclerophyllous shrubs (eg *Acacia pycnantha, A. paradoxa*) or native grasses such as wallaby grass (*Danthonia* spp.*)* and spear grasses (*Stipa* spp.*)*. Red stringybark woodlands (*E. macrorhynca*) are located in Spring Gully Conservation Park. A few remnant patches of sheoaks (*Allocasuarina verticillata*) and grass trees (*Xanthorrhoea quadrangulata*) are located in the upper catchment (Planning SA, 1998). Early surveyors' notes (c1858) suggest that sheoaks were once more widespread along the Skillogalee and Eyre Creeks.

Areas of open mallee comprising mallee box (*E. porosa*), beaked red mallee (*E. socialis*), peppermint box and native pines (*Callitris* spp.*)* can be found in the lower rainfall zones in the south-west of the catchment. Tussock grasslands dominated by (*Lomandra* spp.*)* can be found in the upper catchment east of Mintaro (Planning SA, 1998).

Remnant native sedgelands of rushes (eg *Juncus kraussii*), sedges (eg *Cyperus gymnocaulos*), reeds (*Typha* spp.*)* and grasses (*Phragmites australis*) are found along the watercourses of the catchment. River red gums (*E. camaldulensis*) can be found along sections of the Skillogalee Creek and the Wakefield River main channel (Planning SA, 1998). Samphire marshes are located along the Wakefield River on the coastal plain. Charophytes and pondweed (*Potamogeton pectinatus*) are typical of submerged aquatic vegetation found in deep pools (Sheldon et al, 1999).

3.5. Water resources

3.5.1 Surface water

The Wakefield River catchment is an ephemeral system, characterised by irregular flows and long dry intermediate periods. The typically low soil moisture levels mean that most rainfall is absorbed into the landscape or riverbed. When flows do occur, they do so as a pulse of water rather than a slow incremental flow (D Cresswell, pers com, 1999).

The Skillogalee Creek subcatchment and the upper section of the Eyre Creek subcatchment receive >600 mm average annual rainfall and have a hydrological characteristic that is closer to the higher rainfall zones of the Mount Lofty Ranges. The major groundwater flows influencing the Wakefield River system are provided by the hydrogeology of these two creek systems. Water has been diverted for intensive agricultural activities in the adjacent Eyre Creek and the Upper Wakefield, so the Skillogalee subcatchment now contributes the most important groundwater flows to the Wakefield system. This flow is of lower quantity and quality than was historically provided by Eyre Creek (D Cresswell, pers com, 1999).

From The Rocks to just downstream of Balaklava, a large proportion of the surface river flow disappears below the sandy riverbed. Historical records suggest two possible explanations.

[4] Data on remnant native vegetation for the lower part of the catchment was not available.

The first is that erosion along the smaller streams following agricultural development, contributed to the deposition of a large sediment load in this section of the river. In response, the river was forced to flow through these sand and gravel beds (Moyle, 1975). The second explanation is that since an earthquake in 1895 along the Owen faultline, a large portion of the surface water flow recharges to groundwater (Moyle, 1975). The Wakefield River downstream of The Rocks to the sea will only flow following significant rainfall events.

The Wakefield River is gauged at one location, just above its confluence with Woolshed Flat Creek. The catchment above this point has an area of 417 km^2. The gauge has been operational since 1953, but siltation and mechanical breakdown meant that early gauging was inaccurate. A continuous, high quality record only exists from 1974. Hydrological data in this report is based on the data recorded from 1974 to 1998.

3.5.2 Surface water quality

Surface water quality in the Wakefield is highly variable and very dependent on flow. This variation makes interpretation of sampling data extremely complex. Data collected from 1974 to 1983 at the gauging station (Glatz, 1985) is compared with ANZECC water quality guidelines for protection of aquatic ecosystems in Table 3.2. The Wakefield River can reach high salinity levels due to the influence of groundwater on baseflows. Median nutrient values (nitrogen and phosphorus) and faecal coliform numbers are within the ANZECC guidelines. Levels of copper and aluminium are relatively high and exceed the ANZECC guidelines. The concentrations of copper and aluminium in water are generally higher in areas of acidic soil and high dissolved organic matter. Copper in particular has a high affinity to dissolved organic matter. Water hardness is likely to reduce the toxicity of copper in this system. Median values tend to be within water quality guidelines, apart from those discussed above, but the range often exceeded guidelines. This is probably due to sampling during high flow events.

Recently surface water quality has been monitored only infrequently and to draw any conclusions on current water quality would require collection of water quality and flow data over a 2-3 year period.

3.5.3 Groundwater

Groundwater within the upper catchment occurs in fractured rock aquifers. Water yield is very irregular due to the random nature of the fractures. Groundwater salinity is also variable ranging from ~500 to >7000 mg/L (Love and Cook, 1998).

A component of stream flow in the Wakefield River originates from groundwater discharge. This baseflow is a critical factor in maintaining permanent pools, some riffle habitats and hyporheic environments during dry periods. It is dependent on the seasonality of groundwater recharge and the impacts of water use.

On the plains the shallow groundwater system is contained within the St Vincent Basin groundwater unit. Groundwater contained within the shallow groundwater system in the Diamond Lake area is very saline. The Wakefield River does not flow all year round and groundwater patterns in this lower section of the catchment are likely to be influenced by the river on a seasonal basis. During periods of high rainfall, river flows will recharge the shallow aquifer. Freshening of the groundwater system is likely to be local.

Table 3.2: Water quality indicators (range and median values, 1974 to 1983) for the Wakefield River.

Indicator	Range	Median	ANZECC Guidelines (Protection of Aquatic Ecosystems)
pH	7.0-8.7	8.3	6.5–9.0
Salinity (conductivity, µS/cm)	390-6450	4230	~ 1500
Turbidity (NTU)	1-260	2	<10% change from seasonal mean
Nitrogen, TKN (µg/L)	200-4450	580	100-750
Phosphorous, total (µg/L)	<10-590	20	10-100
Dissolved oxygen (mg/L)	7.4-12.5	10.6	≥6
Copper (µg/L)	5-142	20	2.0-5.0*
Aluminium (µg/L)	70-25000	2800	<100.0
Chromium (µg/L)	<2-66	14	10
Pesticides (µg/L)	None detected (1980-1981)	-	Pesticide specific
Total coliforms	100-570/100 ml	340/100 ml	1000/100 ml (Agricultural Use)

**Dependent on water hardness*

Adapted from ANZECC, 1992; Glatz, 1985.

The quartzite ridge running north–south from the Wakefield River to Mount Templeton provides a controlling mechanism for groundwater flow. Consequently groundwater flow in the shallow watertable is in a southerly direction towards the Wakefield River near Whitwarta (Land Management and Environment Assessment Services, 1996). This subsurface flow occurs in a historically saline valley basin and since land clearance for agricultural production, the rising of watertables has brought the naturally saline groundwater closer to the surface.

3.6. Water resource development

The heaviest use of groundwater and surface water resources is in the Clare Valley. In recent years the Clare Valley has become a major growth area for viticulture and pressure on local water resources has increased. For example, annual applications for well permits have increased approximately seven-fold from 1996 to 1998 (A Prider, pers com, 1999).

This rapid development sparked community concerns over the sustainability of local water resources. Consequently, on 27 July 1995, a Moratorium under Section 40 of the *Water Resources Act 1990* was placed on any further expansion of the use of surface and groundwater for a one year period. The area under the moratorium was prescribed on 25 July 1996 (see Figure 3.6). This introduced controls over the construction of dams and bores within the Clare Valley Prescribed Water Resources Area[5]. A water allocation plan is currently being

[5] Initially named the Clare Valley Prescribed Wells Area and Watercourses.

prepared for the prescribed area, by the Clare Valley Water Resources Planning Committee, in accordance with the *Water Resources Act 1997*.

Outside the Clare Valley, vineyard development is less intensive and the water resource is diverted primarily for stock and domestic use. The total number and volume of farm dams in the Wakefield catchment has not been accurately quantified. It is known that more dams have been developed for irrigation purposes since 1995 (D Cresswell, pers com, 1999). It is assumed that for the majority of the hydrological record, farm dams would have had a minor affect on recorded flows.

3.7. Impacts of agricultural development and land management practices

Agricultural development and human disturbance have transformed the character and functioning of the Wakefield River. Before European settlement, watercourses would probably have been discontinuous with extensive chains of ponds and swamps in the middle and upper sections of the catchment. Multiple flow channels and a large coastal swamp system would have existed on the lowland plain (Thoms, 1999).

Early accounts of the Wakefield River by Edward John Eyre in 1838 describe '…a chain of ponds of excellent water called the Wakefield' (quoted in Moyle, 1975 **).** James Henderson, a member of an early exploratory expedition bound for the Far North recorded the following comments as the party passed through the Wakefield River area in 1843:

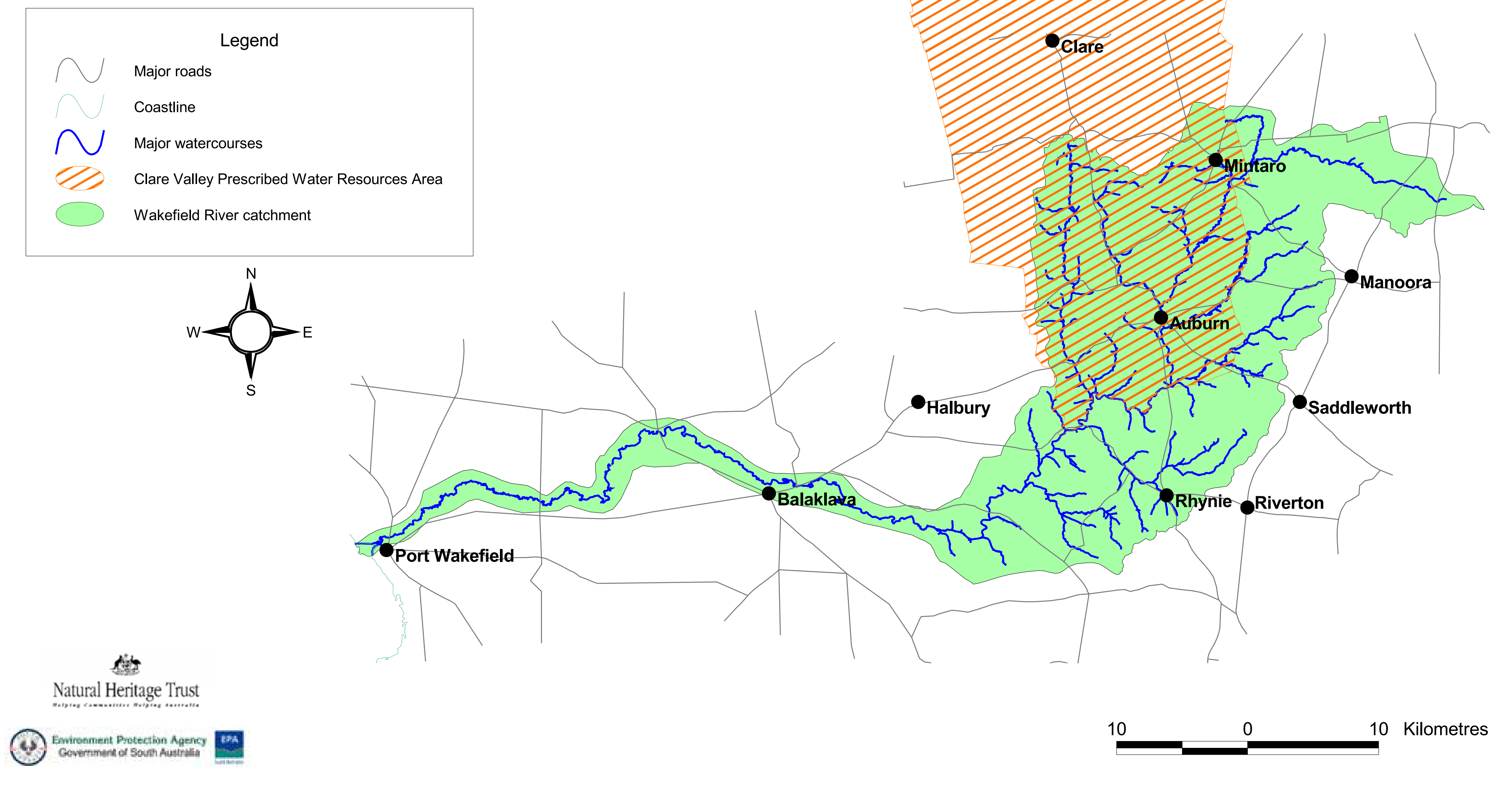
> *All the rivers in the north are very similar in character, consisting of chains of ponds without any trees growing on their banks. The waterholes on the Hutt and the Wakefield are exceedingly deep with perpendicular banks, the water in many instances being level with them…cattle going to drink at these ponds frequently fall in and great numbers unable to get out again have been drowned…*
>
> (quoted in Noye, 1975, p12)

John Horrocks is reported to have planted the first wheat in the Clare district in the early 1840s (Noye, 1975). By the 1860s the land in the north–south ranges from Clare to Gawler was almost fully settled. Most of agricultural ground in the higher rainfall area around the Skillogalee and Eyre Creeks was heavily timbered. The abundant sheoak in the area and the stringybark in the hills west of Penwortham, was cleared and used for tools, in the mines, for fence posts and housing. Reeds from Skillogalee Creek were often used to thatch roofs (Noye, 1975).

The main rail line linking the Mid North with Adelaide was opened in the 1860s and was followed by a line connecting Port Wakefield with Blyth. These rail links provided connections with the Adelaide market, which paved the way for extensive cropping. Around the 1870s, the mallee country around Balaklava was extensively cleared: the wood was sold for railway construction and the land sown for wheat.

Clearance of the mallee was achieved using the 'mullenising' technique of cutting the mallee and burning mallee suckers that arose in the first years of cropping. The invention of the stump jump plough by RB Smith in 1876, accelerated clearing of the mallee lands (Lower North Soil Conservation Board, 1994).

Figure 3.6:
Location of the
Clare Valley Prescribed Water Resources Area
within the Wakefield River catchment



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From 1870 to the 1940s the use of long cultivated fallows of 9-10 months, known as the wheat fallow system, became the common cropping practice to ensure a reliable yield by conserving the winter rainfall for the following year's crop. This practice was carried out over wide areas of the catchment without consideration of the soil type and slope or the need to maintain soil organic matter (Lower North Soil Conservation Board, 1994).

The use of tractors from the 1930s and the subsequent intensive cultivation together with the long periods of soil exposure that accompanied the wheat-fallow system led to considerable land degradation. The principal land degradation problems included severe wind and water erosion, increased surface runoff, breakdown in soil structure and loss of organic matter.

A seal developed on the soil surface, which reduced the ability for rain to infiltrate, exacerbating sheet and gully erosion. This problem was particularly prevalent in the cropping lands on sloping sandy and loamy red-brown soils. In other areas, wind erosion was the dominant erosive force and led major sand movements, which were reported as blocking road access in the Wakefield plains (Lower North Soil Conservation Board, 1994).

From the 1940s, the cropping practice of Ley Farming began to be adopted. This involved rotation of crops with improved pastures such as barrel medic. Soil structure and fertility improved and there was a corresponding decrease in soil erosion. Together with high wool prices, this practice led to an increase in sheep and wool production.

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, which in turn reduces the silt transport into watercourses. The practice of contour banking peaked during the period of 1978-1985 (C Rudd, pers com, 1998). In 1978 the Lower North Soil Conservation Board initiated a subsidised contour banking project, the *Hermitage Creek Group Conservation Project,* in the area around Hermitage Creek. At the end of 1985, approximately one third of all Class III land[6] in the Lower North Soil board area was contour banked.

The use of other land management practices that help manage soil erosion and surface runoff, such as stubble retention and minimum tillage, peaked between 1985 and 1995. Since 1995 there has been a trend back to burning stubble and use of tillage as tools to combat problems such as herbicide resistance in weeds and pest animals, eg white snails and mice. This has reduced the focus on maintaining surface cover (C Rudd, pers com, 1998).

Since the 1970s, irrigated vineyards have become a major land use in the higher rainfall areas in the east of the catchment ie around the Clare Valley region. Most vineyards receive supplementary irrigation from bores, dams and creeks. Vineyards are generally drip irrigated. The wine industry have begun adopting soil and water conservation practices such as reduced tillage, cover cropping and straw mulching.

Today, the major land uses across the Wakefield River catchment are cropping of cereals and grain legumes, grazing of sheep and cattle, and viticulture. Other land uses include dairying, piggeries, production of lucerne, annual pasture seed and hay (Lower North Soil Conservation Board, 1994).

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[6] Class III land is land classed as arable which requires intensive management practices for control of erosion eg contour banks, stubble retention and reduced tillage (Lower North Soil Conservation Board, 1994).

The present character of the watercourses in the Wakefield River catchment is a function of the dramatic land use changes - vegetation clearance and agricultural development - of the mid to late nineteenth century. Within a few decades of European disturbance, river channels became incised and developed a continuous channel network. Incision was accompanied by channel widening which supplied considerable loads of sediments to the lower catchment. These changes have resulted in a loss of habitat diversity and numerous ecological impacts. The current condition of watercourses in the catchment is discussed in Chapters 5 and 6.

4. PROJECT METHODOLOGY

4.1. Overview of the planning process

The planning process adopted by the MNRMPP has two main components - assessing watercourse management priorities and options and determining environmental water requirements. Community and key stakeholder involvement was an essential part of the planning process for both key components. The planning process is illustrated in Figure 4.1.

Work in the Wakefield River catchment began with an airborne video survey in August 1998. Flights over the catchment produced video coverage of the riparian corridor for the Wakefield River and its major tributaries. The EPA project team coded key features of riparian condition to produce Geographic Information System (GIS) maps for discussion at community consultation meetings.

The project focused primarily on larger watercourses, ie third order or greater as defined by the Strahler stream ordering system (Strahler, 1964). In the Strahler 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 +1 is formed.

Key stakeholders played an important role in directing the initial and ongoing phases of the project. The Project Reference group provided a local advisory role to the EPA project staff and facilitated the integration of river management plans into the plans and work programs of their organisations. A Wakefield Catchment Advisory Committee made up of landholders with strong community links and good local knowledge was established with the assistance of the Project Reference group. In addition to promoting community involvement in the MNRMPP, the Advisory Committee advised the EPA project team on local watercourse management issues and appropriate timing for landholder meetings.

Assessment of watercourse condition and environmental water requirements ran more or less concurrently with a process of 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 the Wakefield River
- consider the outcomes of the assessments of river condition undertaken by the project team and prioritise the management issues
- understand the catchment processes at work by viewing the management of the river in a 'big picture context' rather than just at their property level.

Data collection and interpretation for the assessment of watercourse condition was conducted after the first meeting with landholders. This allowed landholders' issues and concerns to be taken into account when interpreting data and identifying watercourse management issues. Feedback on management issues was then provided to landholders at the second meeting and opportunities were provided for landholders to contribute their knowledge of Wakefield River flows.

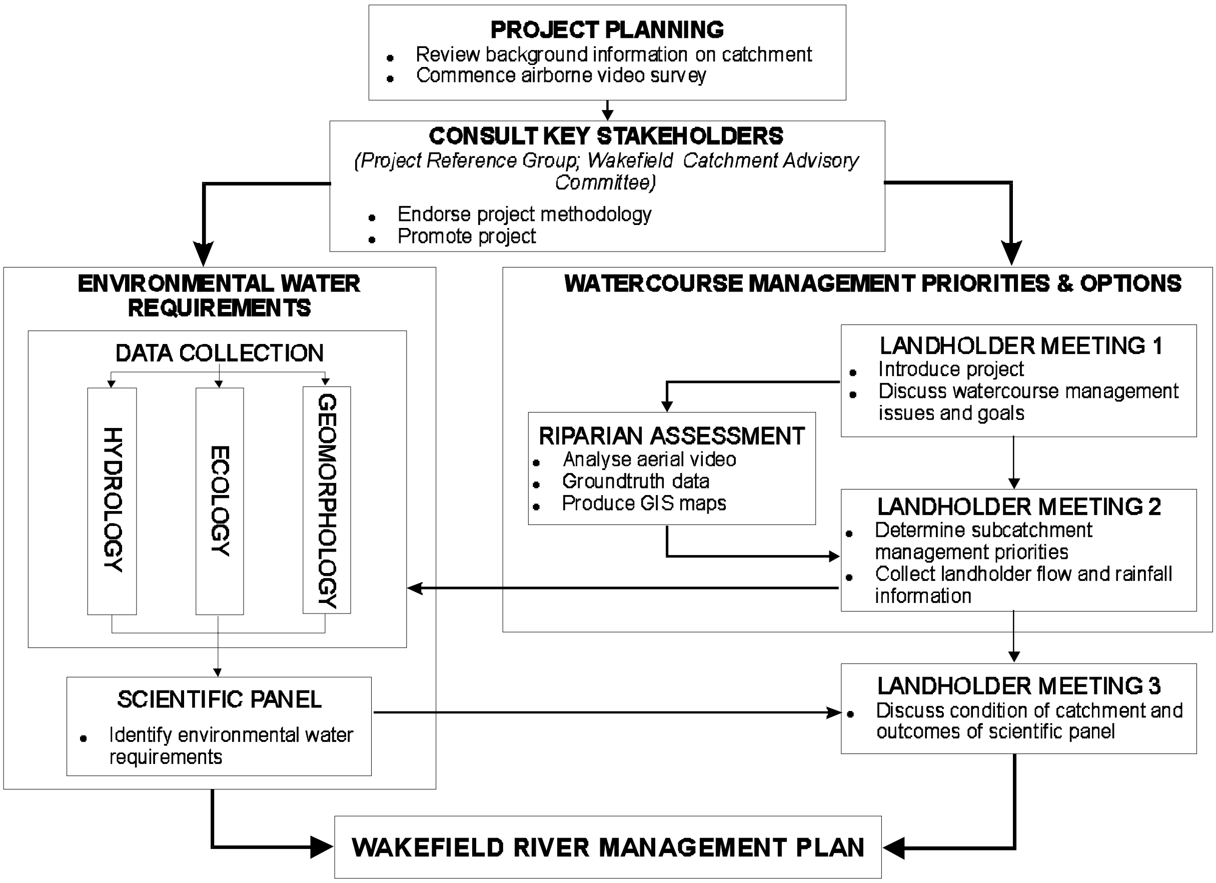

Figure 4.1: Wakefield River Management Planning Process

The project team commissioned studies of macroinvertebrates and fish in the Wakefield River. The team, in consultation with the project ecologist and geomorphologist, collected additional information on vegetation and channel geomorphology. This data was collected after the second landholder meeting. Ecological and geomorphological information, together with hydrological data, was interpreted through a scientific panel approach to determine key flow bands for maintaining/improving the ecological health of the river and its major tributaries. Feedback on catchment condition and the outcomes of the assessment of environmental water requirements was provided at a final landholder meeting.

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 (DENR, 1997b). The Wakefield River catchment was divided into subcatchments on the basis of subcatchment and property boundaries, land use and social networks (Figure 3.2). This subcatchment division had a number of advantages. Landholders within each subcatchment had similar management issues and concerns and consultation at a subcatchment level could focus on local issues and ensure greater landholder involvement because of the small numbers.

4.2.1 Landholder meetings and mail outs

All landholders with property adjacent to a third order or larger watercourse were contacted and invited to be involved in the project. Through meetings and letters, landholders were kept informed about the progress of the project and given the opportunity to identify and prioritise watercourse management issues. Three rounds of community meetings were held, two at a subcatchment level and the final meetings at a catchment level.

The aims of the initial community meeting were to:

- inform landholders about the MNRMPP
- discuss the data collection methods
- identify watercourse management issues of importance to local landholders.

In small group discussions landholders were asked to identify watercourse management issues and barriers and to describe their ideas of a healthy watercourse. Through a simple voting process the landholders were able to identify the watercourse management issues of most importance to them. Feedback from the meeting was provided to all landholders.

Upon completion of the watercourse assessment process in each subcatchment, landholders were invited to attend a second meeting. The management issues identified through the assessment process were presented to landholders. The importance of each issue and options for management were discussed along with general principles for determining priorities for management. Landholders were given the opportunity to vote on their priorities for watercourse management in their subcatchment.

As it was not possible for all landholders to attend this second meeting, a summary of the outcomes of the voting process and the priority list of issues were mailed to every landholder. Landholders were asked to comment on the watercourse management issues identified and the priorities determined at the meetings. These comments and/or suggested changes were taken into account in preparing the final prioritised list of watercourse management issues for each subcatchment.

Two final meetings were held in the catchment after the completion of the environmental flows assessment. The purpose of these meetings was to present landholders with an overview of the 'health' of the Wakefield River catchment, focusing more on environmental water requirements than riparian management issues.

4.2.2 Stakeholder meetings

Feedback to key stakeholder organisations was conducted primarily through the Project Reference group. In addition, meetings and presentations were given for a number of stakeholder groups to inform them about the project and for the project team to gain an understanding of their concerns about river management. These groups included the South Australian Fly Fishing Association, Central Regions Local Government Association, Lower North Soil Conservation Board, Watervale Progress Association and the Regional Development Board.

4.3. Watercourse assessment methods

4.3.1 Watercourse survey

The watercourse survey was designed to provide a rapid assessment of the bio-physical condition of watercourses in the catchment. This assessment was used to locate and identify specific watercourse management issues. The survey method was based on the use of aerial videography to make an initial visual assessment of third order and larger watercourses.

The videography used a Seeker Seabird observation plane with a video camera installed under the passenger side of the plane. Flights were undertaken on fine, sunny days as cloud cover severely reduced clarity and resolution of the video. The plane flew at a height of approximately 1000-1500 feet above ground. This height provided good resolution of watercourse parameters while enabling the pilot to easily track the watercourse. A video recorder recorded the colour image as well as the corresponding Global Positioning System (GPS) data, which was also recorded by an onboard laptop computer.

Watercourse parameters that were assessed from the aerial video include:

- density of riparian vegetation coverage
- location and density of exotic trees and weeds
- large scale bed and bank erosion
- channel aggradation
- pools
- condition of stream works eg bridges, culverts
- adjacent land use.

Data was coded from the aerial video onto 1:15 000 base maps produced using ESRI ArcInfo and ArcView GIS. The coding parameters used to assess the video image were adapted from methods used previously by the Riparian Zone Management Projects (DENR, 1997a; DENR, 1997b). The base maps of the surveyed watercourses included GPS points to aid the location of video image data.

The accuracy of the data taken from the video was ground-truthed by undertaking a 'bridge and road' survey of the catchment and further checked through consultation with landholders. The corrected data were entered into ArcInfo GIS and then converted to ArcView GIS coverages for storage, display and analysis.

Overall, aerial videography provided a rapid and cost effective method for obtaining an overview of watercourse condition and habitat types across the Wakefield River catchment. However, there are limitations to this technique that must be considered. The difficulties associated with flying a meandering watercourse mean that only an estimated 80-85% of the watercourses surveyed was captured on video. In addition, in areas of dense overstorey it was not possible to observe all watercourse parameters. Attempts to assess these areas through ground-truthing could not cover all surveyed watercourses. As a consequence, some data was extrapolated to cover the unobserved sections of the watercourse.

The aerial video flights, analysis of the videos and ground-truthing were undertaken between August 1998 to November 1998 and as such represent a 'snapshot' of the condition of the catchment at this time.

4.3.2 Identifying and prioritising watercourse management issues

GIS coverages created from coding of the aerial videography were used to produce subcatchment maps of watercourse parameters. The information on these maps was used to identify watercourse management issues for each subcatchment. In certain cases, a single stretch of watercourse had more than one management issue, for example poor bank stability plus weed problems and stock access issues. In those cases the most important management issue for that section was selected.

A set of general principles and guidelines, adapted from DENR (1997a), was used to identify and prioritise watercourse management issues (Appendix B). Briefly these guidelines were based on giving priority to areas of conservation value, considering the impact of the issue, the length of watercourse affected and the cost-benefits of undertaking rehabilitation measures.

The watercourse management issues identified for each subcatchment were presented to landholders at the second round of subcatchment meetings. Management issues and management options were discussed and landholders were asked to participate in a simple voting process to determine management priorities for their subcatchment. To assist landholders with their decisions, a number of maps illustrating the extent and location of each watercourse management issue identified by the project team were displayed.

A summary of the outcomes of the voting process and a draft priority list of issues was mailed to each landholder. This gave landholders who were unable to attend the meeting an opportunity to participate in setting priorities. A table of priority management issues and management options was thus produced for each subcatchment (see Chapter 5).

4.4. Assessment of environmental water requirements

4.4.1 Selection of the assessment methods

A range of methods for assessing environmental water requirements is currently used across Australia. The project team and the project's technical consultants reviewed the different approaches in order to select a method that best met the requirements of the project. To fulfil the objectives of the project, the assessment method adopted needed to address the following requirements:

- 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.
- Incorporate community input.

Evaluation of various environmental flow assessment methodologies has highlighted the importance of a multidisciplinary approach that considers the relationships between fluvial geomorphology, ecology and water regime (Arthington, 1998). Methodologies that adopt this approach and have been applied to Australian Rivers include:

- Holistic/Building Block Methodology
- Scientific Panel Assessment Method

- Habitat Analysis Method
- Ecosystems Approach.

The Holistic/Building Block Methodology aims to construct an environmental flow regime from baseflow to flood flows. The approach involves a detailed assessment of the relationships of flow and various attributes of the river ecosystem, including geomorphological characteristics, water quality, biological communities and major ecological processes (Arthington et al, 1996). This approach requires a minimum of two years (Arthington, Brizga and Kennard, 1998) and data requirements are considerable.

The Scientific Panel Assessment Method involves a rapid appraisal of environmental water requirements by a multi-disciplinary team of experts, eg geomorphologist, hydrologist and ecologists. The scientific panel uses field based observations and their experience to make judgements about the geomorphologically and ecologically significant aspects of the flow regime (Arthington et al, 1996; Thoms, 1998). This method has a range of applications and the detail of the findings depends upon the level of information supplied to the panel. It is often incorporated as part of more detailed assessment processes.

The Habitat Analysis Method identifies important riverine habitats and uses flow statistics to describe the flows needed to maintain those habitats (Arthington, Brizga and Kennard, 1998). The method is rapid and cost effective, does not usually involve original field work and incorporates a scientific panel workshop to achieve its outcomes (Arthington, 1998; Burgess and Vanderbyl, 1996).

The Ecosystems Approach is based on the principle that where possible environmental water requirements should mimic the natural flow regime. A scientific panel is used to identify major river process zones and associated ecological processes. Within each of these river process zones, critical flow requirements are determined. An advantage of the methodology is that it involves a more integrated, whole of catchment consideration of how a river functions (Burgess and Thoms, 1998).

4.4.2 The Scientific Panel Habitat Assessment Method

The method developed to achieve the specific requirements of the project incorporates aspects of the Habitat Analysis Method, the Ecosystems Approach and the Scientific Panel Assessment Method and has been labelled the 'Scientific Panel Habitat Assessment Method'.
The method is based on dividing the river system into river process or geomorphic zones. Each of these zones has a unique assemblage of river morphologies or physical habitats. As a result the ecological components and processes for each zone also differ. Data is collected on representative habitats within these zones and fish and macroinvertebrate sampling undertaken at sites across catchment. This information is presented at a scientific panel workshop and the scientific panel uses their professional expertise to determine the critical flow parameters for each river process zone.

The method essentially involves three key phases: an initial data collection or pre-workshop phase, the scientific panel workshop itself and a post-workshop phase. The key steps in the method are outlined in Figure 4.2.

PRE-WORKSHOP PHASE

1. Assemble Scientific Panel
2. Scientific Panel Catchment tour
3. Identify river geomorphic zones
4. Data collection: - Representative site survey
   - Fish survey
   - Macroinvertebrate survey
   - Community knowledge
5. Hydrological modelling

↓

SCIENTIFIC PANEL WORKSHOP

1. Scientific Panel identifies links between fish, invertebrates, vegetation, physical habitat and water regime for each zone.
2. Identify key flow levels
3. For each zone quantify environmental water requirements (flow volumes, duration, frequency, seasonality)
4. Produce a summary of key environmental water requirements for entire river system
5. Identify knowledge gaps and monitoring needs

↓

POST-WORKSHOP

1. Flow modelling to test results and future development scenarios
2. Technical reports on links between geomorphology, ecology and environmental water requirements

Figure 4.2: Process for the determination of environmental water requirements

Assemble Scientific Panel

A multidisciplinary scientific panel was assembled. Members included a geomorphologist, hydrologist, several ecologists, fish biologist and members of the project team (Table 4.1).

Table 4.1: Members of the Scientific Panel.

Participant	Field of Expertise/Role	Organisation
Dr Martin Thoms	Geomorphologist	CRC for Freshwater Ecology, University of Canberra
Dr Fran Sheldon	Lead ecologist	CRC for Freshwater Ecology, The University of Adelaide
Paul McEvoy	Biologist – Macroinvertebrate (Monitoring River Health Initiative)	Australian Water Quality Centre, SA Water
Chris Madden	Biologist – Macroinvertebrate (Monitoring River Health Initiative)	Australian Water Quality Centre, SA Water
Peter Goonan	Aquatic biologist	EPA, DEHAA
Darren Hicks	Ecology – Native fish	Zoology Department, The University of Adelaide
Dave Cresswell	Hydrologist	EPA, DEHAA
Sharon Rixon	Project Team	EPA, DEHAA
Diane Favier	Project Team	EPA, DEHAA
Glen Scholz	Project Team	EPA, DEHAA
Michael Good	Water for Environment Policy	EPA, DEHAA

Scientific Panel field trip

Members of the Scientific Panel were taken on a field inspection of the Wakefield River catchment. The purpose of the field inspection was to provide first hand observations of the river and its tributaries and to provide an opportunity for members of the panel to exchange ideas and observations.

Identification of river geomorphic zones

The river system was divided into different geomorphic zones based on bed slope, channel pattern, sediment character and in-channel morphology. Geology and topographic maps, longitudinal stream profiles, field site visits and aerial video observations were used. Seven key geomorphic zones were identified for the Wakefield River catchment. Each zone has a unique assemblage of river morphologies or physical habitats and differs in terms of its hydrological regime. It was assumed that the primary ecological functions of each zone would also be different.

Data collection

Representative site surveys. Field surveys were conducted at sites representative of the major physical habitats within each zone. These surveys typically included recording riparian and in-stream vegetation, bed sediment sampling, and longitudinal and cross section profiles. Photographs were taken to provide a visual description of each site.

Ecological studies. Ecologists from the Monitoring River Health Initiative (MRHI) analysed macroinvertebrate data from ten MRHI sites in the Wakefield River catchment. This data, collected between 1994 and 1997, was analysed for species richness, the type of species present and their abundance (McEvoy and Madden, 1998).

A survey of fish populations combined with rapid macroinvertebrate sampling was conducted at selected MRHI sites and other sites identified by the fish biologist. This was a one-off survey conducted in August 1998. The data was used to produce an index of the biotic integrity of the river at the survey sites and to determine the environmental water requirements of native fish populations (Hicks and Sheldon, 1998).

Community knowledge. Where possible information such as rainfall records, flood records, general observations related to river flows and historical data was sought from local landholders. This information supplemented the limited rainfall and streamflow information available for the Wakefield River catchment.

Hydrological data and modelling

The Wakefield River is gauged at one location, just above the junction of the Wakefield River and Woolshed Flat Creek. The hydrological data used to estimate environmental water requirements is primarily based on the 25 years of data recorded at this gauging station from 1974 to 1998 inclusive. To overcome a lack of gauging record spatially throughout the catchment and to examine the longer-term variations in streamflow a computer model of the Wakefield catchment was developed.

The hydrological modelling was undertaken by the Senior Hydrologist, EPA, DEHAA. The model used was WaterCress, which is a PC-based water balance model for designing and testing trial layouts of water systems which utilise multiple sources of water. In this case the multiple sources were numerous subcatchments each with differing rainfall inputs. The model was calibrated by comparing the modeled data with actual data (Cresswell, 1999).

Scientific panel workshop

In preparation for the Scientific Panel workshop, all participants were provided with the data collected during the representative site surveys and ecological studies and the outcomes of the hydrological modelling. The Scientific Panel workshop provides a forum for the Scientific Panel to consider this physical and biological data and to collaboratively develop environmental water requirements for each river process zone.

Links between physical habitat, ecology and water regime

The first stage of the workshop involved the identification of the physical habitat and flow requirements of the key ecological components within each river geomorphic zone. As part of this process, important knowledge gaps for each zone were identified. The three parameters identified as influencing ecological components (vegetation, fish and macroinvertebrates) were physical structure, flow regime and the flow event. Descriptors for each of these parameters are outlined in Figure 4.2.

Broad generalisations of the requirements of each ecosystem component for descriptors of physical structure, flow regime and the flow event were identified based on the Scientific Panel’s expertise and knowledge of the literature. For example, in the Mobile zone, bi-annual flows that inundated 10% of the channel were considered important to maintain connectivity between habitats. Data was recorded using matrices adapted from that used for the Scientific Panel assessment of environmental flows for the Barwon-Darling River (Thoms et al, 1996)

Table 4.2: Descriptors for parameters identified as having a significant influence on ecosytem components.

Parameter	Descriptors
Flow Regime	Total Q Flood Frequency Drought Frequency Frequency of Flood Duration Seasonality Sequence of years/ Intervals between good condition Base flow
Physical Structure	Macro Basin - *Reach within basin; Other large scale features* Meso Reach - Channel surface area, complexity, in-channel features, flood runners, deep holes Mini Subreaches - Snags and tree roots, organic debris, aquatic macrophytes, rock outcrops, depth
Flow Event (Hydrograph)	Rate of Rise Rate of Fall Flood Duration Flood Peak Flood Minimum Random Short Term Stage Changes Freshets

(Adapted from Thoms, et al, 1996.)

Identify key flow levels and quantify environmental water requirements

Cross sections taken at representative sites were then used to determine the heights of specific water levels that fulfilled the physical structure and flow requirements of vegetation, fish and macroinvertebrates for each river geomorphic zone. The cross sectional area for each water level and slope value was determined and the Manning Equation used to calculate flow volumes.

Manning Equation: $Q=1/n\ A\ R^{0.66}\ S^{0.5}$

Where:

Q = discharge ($m^3\ s^{-1}$)
n = 'Manning's n'
A = cross sectional area of the flow
R = hydraulic radius
S = slope

Flow volumes were related back to the gauging station to determine flow duration and frequency. The gauging station provided good estimates of relevant flow statistics for sites downstream of the station. For sites upstream of the gauging station flow statistics were weighted proportionally according to area and rainfall values estimated for the subcatchment upstream of the site. All flow statistics are related to gauging station data.

Identify knowledge gaps and monitoring needs

In the final stages of the workshop, key flow principles, core ecological zones, monitoring nodes and knowledge gaps for the Wakefield River system were identified.

Post-workshop processes

As an outcome of the Scientific Panel workshop process, two technical reports were produced which detailed the relationships between environmental water requirements and geomorphology and ecology for the Wakefield River (Thoms, 1999; Sheldon et al, 1999). The reports were used by the EPA project team as key reference documents for producing the river management plan.

Further hydrological modelling was undertaken to refine the environmental water requirements and flow statistics identified by the Scientific Panel workshop. Preliminary modelling of the impacts of future water resource development on environmental water requirements was also undertaken.

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5. WATERCOURSE MANAGEMENT

5.1. Introduction

Land use and land management within a catchment affects the health of a watercourse and its riparian zone. In particular, land management practices can impact on watercourse vegetation, surface runoff and stream flows, bed and bank erosion processes and water quality.

Watercourse management problems in the Wakefield River catchment are diverse and widespread. In addition to their concerns about flows, landholders during the consultation process identified weeds, erosion and sedimentation, the impact of reeds, poor water quality and exotic trees as some of the most important problems along their watercourses. In many cases landholders have inherited problems which were initiated many years ago.

Landholders indicated at the first consultation meetings that the essential elements of a healthy watercourse were healthy vegetation, good water quality, regular flows, no weeds, stable banks and supporting aquatic life such as fish, frogs and yabbies. This chapter provides a framework for improved watercourse management to achieve these visions of a healthy river system.

The first section of this chapter outlines the results of the assessment of the condition of watercourses in the Wakefield River catchment. This is followed by a discussion of the watercourse management issues identified, their significance and potential management options. The final section discusses these issues on a subcatchment basis and outlines the priority watercourse management issues and management options for each subcatchment.

5.2. Watercourse condition

The project team assessed 421.8 km of third order and larger watercourses in the Wakefield River catchment. The survey was conducted during the period, August to November 1998, and the results give a 'snapshot' of the Wakefield River catchment during this time. Parameters assessed include:

- important riparian habitat
- vegetation parameters including riparian and in-stream vegetation coverage, weeds and exotic trees
- channel and bed parameters including erosion heads, bank stability and aggradation; structural works
- stock access.

5.2.1 Areas of important riparian habitat

Certain reaches within the Wakefield River catchment were identified as areas of important riparian habitat (Map 1), for example Long Gully and the main channel of the Wakefield from The Rocks to Undalya (Plate 5.1), Skillogalee Creek below Port Road bridge and sections of the main channel above Mintaro Creek. In general these reaches had a good diversity of native riparian vegetation, a range of in-stream physical habitats such as riffles, channel bars and permanent pools, and good water quality. These areas are key assets giving these reaches of the river a higher recreational, community and ecological value.

Plate 5.1: Important riparian habitat with a diversity of native watercourse vegetation and a range of in-stream physical habitats, Lower Wakefield subcatchment.

5.2.2 Watercourse vegetation

Riparian vegetation

The native riparian vegetation along the surveyed watercourses of the Wakefield River catchment is severely degraded and/or modified. The dominant vegetation type is now annual exotic grasses with or without a very sparse overstorey of native and/or exotic trees (Table 5.1, Plate 5.2). This lack of native vegetation has been caused by a number of land and river management practices, including land clearance, grazing, cropping, altered flow regimes and invasion by exotic trees and weeds. Map 2 shows the types of riparian vegetation along the watercourses of the Wakefield River catchment.

Reaches have been identified in which the condition of the watercourse vegetation is relatively good but has been damaged by human impact (Map 1), for example, sections of the Wakefield River from The Rocks to Whitwarta (Plate 5.3) and in the upper catchment above the river's confluence with Wookie Creek. Two main issues were identified: stretches of watercourse with intact native overstorey but with a highly degraded understorey; and areas with a diverse range of in-stream vegetation but little native bank or floodplain vegetation. In both cases the riparian vegetation has been degraded by grazing and invasion by exotic plant species and weeds. Maintaining and improving these areas of good native watercourse vegetation should be given a high priority.

Table 5.1: Riparian vegetation in the Wakefield River catchment

Riparian Vegetation Type	Length (km)	Percentage of total length
Pasture with or without very sparse overstorey [a]	235.6	55.8
Pasture with sparse native overstorey [b]	51.7	12.3
Pasture with mid-density native overstorey [c]	44.4	10.5
Pasture with dense native overstorey [d]	34.8	8.3
Pasture with medium density mixed native and exotic overstorey	10.8	2.6
Pasture with dense mixed native and exotic overstorey	9.6	2.3
Pasture with sparse mixed native and exotic overstorey [b]	8.7	2.1
Samphire marshland in good condition	3.3	0.8
Revegetation	1.7	0.4
Open forest/woodland with understorey in good condition	0.0	0.0
Unsurveyed	21.4	5.1

[a] <10% coverage; [b] 10-30% coverage; [c] 30-70% coverage; [d] >70% coverage.

Plate 5.2: Section of watercourse showing lack of native riparian vegetation on channel banks and floodplain. The dominant vegetation is pasture grass and woody weeds.

Plate 5.3: Good riparian vegetation along the Wakefield River main channel. A medium density overstorey of river red gums but the understorey is dominated by exotic grasses and herbs.

Emergent in-stream vegetation

Medium density to dense (>80% coverage) stands of in-stream vegetation, ie reeds, sedges and rushes, cover approximately 25% of the total length of watercourses in the catchment. This dense in-stream vegetation is located primarily in the main channel of the Wakefield River from its headwaters to just upstream of The Rocks. Phragmites (*Phragmites australis*) and Typha (*Typha* spp.) dominate the in-stream vegetation below the confluence of the Wakefield River with Wookie Creek (Plate 5.4). These are reaches that have been heavily impacted by past erosion events. The high sediment load from this erosion and a permanent baseflow supports reed growth.

Riparian weeds

The riparian survey was able to distinguish the larger riparian weeds such as wild artichoke, dog rose, boxthorn, hawthorn, blackberry and gorse. The most common riparian weeds in the Wakefield River catchment include wild artichoke, dog rose, boxthorn and hawthorn (Map 3). Weeds, particularly wild artichoke, were a significant watercourse management problem in areas of the Lower Wakefield subcatchment (Plate 5.5) but tended to be well managed in the remainder of the catchment. Woody weeds, such as hawthorn were a particular problem in the upper reaches of the Skillogalee Creek.

Plate 5.4: Dense stands of in-stream vegetation dominated by *Phragmites* and *Typha* along the main channel of the Wakefield River.

Plate 5.5: Section of watercourse heavily infested with wild artichoke, wild fennel and boxthorn, Lower Wakefield subcatchment.

Exotic Trees

Exotic trees were observed in only 6% of the surveyed watercourses throughout the catchment and species recorded include ash (*Fraxinus* spp.), olive (*Olea* spp.), willow (*Salix* spp.), poplar (*Populus* spp.) and pine (*Pinus* spp.). Sparse to dense stands of exotic trees, primarily ash and willow, were observed along the Skillogalee, Eyre, Mintaro and Wookie Creeks and sections of the Wakefield River main channel (Map 4). Exotic trees have adversely affected river ecosystems in these reaches (Plate 5.6).

Plate 5.6: Ash and willow trees now dominate sections of the Eyre Creek.

5.2.3 Channel characteristics

Bank stability

The overall physical stability of watercourses in the Wakefield River catchment was assessed as being moderate to good (Table 5.2). Approximately 40% of surveyed watercourses have banks classified in 'moderate' condition. These areas have the potential to undergo active erosion, if they are not managed, to control grazing and ensure a cover of protective vegetation. Of the surveyed watercourses only 0.9% appeared to be actively eroding areas and were classified as in 'poor' condition. These areas of active erosion were primarily located along the Hermitage and Woolshed Creeks (Map 5, Plate 5.7). 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 5.2: Bank stability along surveyed watercourse in the Wakefield River catchment.

Bank stability class	Percentage of total surveyed length (421.8 km)
Good – good vegetation cover, no significant damage to bank structure or vegetation, usually flat to moderate batter.	54.0
Moderate – discontinuous vegetation, some obvious damage to bank structure and vegetation, generally stable toe, usually moderate to steep batter.	39.8
Poor – evidence of active erosion; little effective vegetation, unstable toe, usually steep to vertical batter.	0.9
No natural bank formation - rocky gorge, incised spurs or dams	0.3
Not observed	5.0

Plate 5.7: Eroding banks along section of watercourse, Lower Wakefield subcatchment.

Erosion heads

An erosion head is a short steep section of stream bed that erodes in an upstream direction (Kapitzke et al, 1998). The presence of an erosion head is indicative of an active phase of bed deepening. Active bed deepening was not a significant issue along surveyed watercourses, despite a number of erosion heads being observed (Map 5). The majority of these erosion heads are reasonably stable but need to be monitored to ensure they do not continue to erode further upstream. There are a some isolated sites of active gully head erosion and bed deepening along the Wakefield River main channel near Undalya and along Hermitage Creek which may require on-ground works to prevent or slow the bed deepening process (Plate 5.8).

Plate 5.8: Erosion head working its way along a side gully entering the main channel of the Wakefield River.

Sedimentation

Past erosion processes, such as channel incision and widening, introduced large volumes of sediment into the river system. In most cases these sediment loads are being retained by in-stream vegetation along the main channel. Disturbance to these areas and/or large flood events has the potential to transport sediment loads downstream resulting in degradation of important habitat areas. The main areas of sedimentation are located along the main channel of the Wakefield River downstream of Undalya to Robins Ford just above The Rocks area.

5.2.4 Stock access

The dominant land uses in the Wakefield River catchment are grazing and cropping. Most grazing properties within the catchment allow livestock unrestricted access to watercourses. A significant proportion of watercourses in the Wakefield River catchment have been impacted and/or are currently being impacted by uncontrolled stock grazing. Stock grazing contributes to bed and bank erosion by removing protective vegetation and destabilising banks through trampling (Plate 5.9).

Plate 5.9: Damage by stock to banks and in-channel vegetation is evident along this section of the Wakefield River main channel. Watercourse vegetation is dominated by exotic grasses and herbs.

5.2.5 Stream works

Bed and bank erosion can result in damage to assets, such as bridges, culverts, and weirs. At the same time, poorly aligned or designed bridges, culverts and weirs can initiate erosion. Structures surveyed included fords, culverts, bridges, weirs, dams and stock crossings, as well as bed and bank stabilisation works. The stability of structures observed during the riparian assessment process is illustrated in Map 6. In general, most structures had a moderate to high stability rating. A number of under capacity and poorly aligned culverts have initiated downstream bank erosion and bed deepening along the Skillogalee Creek (Plate 5.10).

Plate 5.10: Poorly positioned and undercapacity culvert causing bank erosion and scouring downstream, Skillogalee subcatchment.

5.3. Watercourse management issues

The data obtained from the survey of riparian condition was used to identify key watercourse management issues along surveyed watercourses. Highest priority was given to protection and maintenance of areas of high ecological value. Priority was then given to identifying key threatening processes according to the general principles and guidelines outlined in section 5.3.2. No significant watercourse management issue was recorded for stretches of watercourse in good condition and not threatened by degrading processes.

The watercourse management issues identified across the catchment are listed in Table 5.3 and illustrated in Map 1. Watercourse management issues were grouped into three main types: conservation issues, vegetation issues and channel stability issues. The significance of these issues and various management options are discussed in this section.

5.3.1 Conservation issues

Important riparian habitat

Protection of areas of good habitat should be given highest priority. These areas had a range of in-stream physical habitat, such as pools, riffles and channel bars and diverse in-stream and riparian vegetation. Such areas usually have high biodiversity, are important refuges and provide a valuable seed bank. In addition, conservation of remnant vegetation is always preferable to re-establishing new vegetation, as little cost and effort is needed to produce considerable ecological benefit. Management requires not only the identification and control of threats, such as grazing and exotic plants, within the reach but also identification and control of threats that come from other reaches, such as upstream erosion.

Table 5.3: Watercourse management issues in the Wakefield River catchment.

Watercourse management issue	Percentage of total surveyed length (421.8 km)
Conservation issues	
Important riparian habitat	10.5
Vegetation issues	
Lack of native vegetation	34.0
Weeds	15.2
Good watercourse vegetation	12.9
Exotic trees	5.6
Channel stability issues	
Poor bank stability	5.2
Unrestricted stock access	3.4
Single or multiple erosion heads*	0.5
Side gully erosion	0.1
Other	
No significant watercourse management issue	8.6
Watercourse not surveyed	4.5

**On average this issue was assigned a length of 50 m.*

In setting priorities for management, landholders agreed that protection and management of important riparian habitat and native riparian vegetation in good condition should have top priority for action.

5.3.2 Vegetation issues

Good watercourse vegetation

Maintaining and improving areas of good native riparian vegetation should be given a high priority. A number of reaches have been identified where the condition of riparian vegetation is relatively good but has been damaged by human impact (Map 1). These sites have a high recovery potential but require active intervention to revegetate and control threats such as stock grazing and weeds. Typically, these areas fell into two categories: reaches with a healthy native overstorey (>30% coverage) and a degraded understorey; and reaches with diverse in-stream vegetation and with degraded riparian vegetation (overstorey and understorey layers).

Healthy native riparian vegetation is an essential part of a healthy river ecosystem. Well-vegetated banks slow surface runoff, trapping sediments, pollutants and nutrients before they enter the watercourse. Banks are stabilised and protected from the erosive force of water. Leaves and branches are an important food source and provide habitat for aquatic and terrestrial fauna. Riparian vegetation provides shade, lowers water temperatures and regulates algal growth (Davies and Bunn, 1999).

In some areas of the catchment, the increased growth of reeds and other in-stream vegetation due to destocking and other land management changes has caused concern to many landholders. In many cases the presence of large native reed beds, dominated by *Phragmites* and *Typha*, is considered evidence that the system is recovering from past erosion. Reeds, rushes and sedges trap sediment and stabilise the bed and banks of the watercourse. Removal of this vegetation would mobilise the trapped sediment causing further erosion and resulting in sedimentation of downstream habitats. Where no other riparian vegetation exists, in-stream vegetation plays an important role in providing habitat and organic material and in reducing water temperatures. Consequently any attempts to manage reeds should be undertaken with extreme care. It is important to note that reeds, rushes and sedges are native vegetation and their removal may require approval under the *Native Vegetation Act, 1991*.

The *Phragmites* and *Typha* reed beds currently dominating stretches of the river system are evidence of a system in transition. It is likely, over time, these plants will be replaced by other emergent macrophyte and grass species, which will increase habitat diversity. It might be possible to speed up the transition process by revegetating banks and floodplain and/or undertaking river rehabilitation works to increase habitat diversity.

Lack of native watercourse vegetation

The most common watercourse management issue along surveyed watercourses was a lack of native watercourse vegetation (Map 1). The generally degraded condition of native riparian vegetation in the Wakefield River catchment has had and will continue to have significant implications for water quality and river health. Introduced plant species are not able to replace the role of native riparian vegetation. Introduced grasses and weeds are seasonal and do not develop the deep soil-root matrix required to stabilise watercourse banks. Introduced plant species do not provide a full range of habitat requirements for native aquatic and terrestrial fauna (Waterways Commission, 1995). Lack of overstorey vegetation means increased light and higher water temperatures creating unsuitable climate conditions for in-stream flora and fauna and promoting algal growth (Davies and Bunn, 1999).

Revegetation and allowing regeneration of native vegetation are essential steps in rehabilitating degraded watercourses in the Wakefield River catchment. Even in a highly degraded area 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 direct seeded.

Technical advice and a planned approach to revegetation are essential for success. Factors to consider include:

- initial and ongoing grazing management and weed control
- using indigenous plant species
- structural diversity, ie planting a range of species including aquatic plants, reeds, rushes, sedges, grasses, shrubs and trees
- width, ie revegetating a minimum width of 10–15 metres from the top of the stream bank.

When revegetating consideration needs to be given to the original vegetation composition. For example it would not be appropriate to plant tree and shrub species if the original vegetation association was grassland. Locally indigenous plant species [7] should be used because of their intrinsic role in the river ecosystem and because they are better adapted to local conditions and have a higher survival rate. They will also help to preserve plant species which may be locally rare or endangered and provide new seed banks for local species (Carr et al, 1999).

Figure 3.5 (Chapter 3) provides a general indication of the type and distribution of native vegetation across the Wakefield River catchment. Specific information on appropriate locally indigenous plant species should be sought from the local revegetation officer[8].

It is important to select the right plant for the right place across the riparian zone (Figure 5.1). 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.

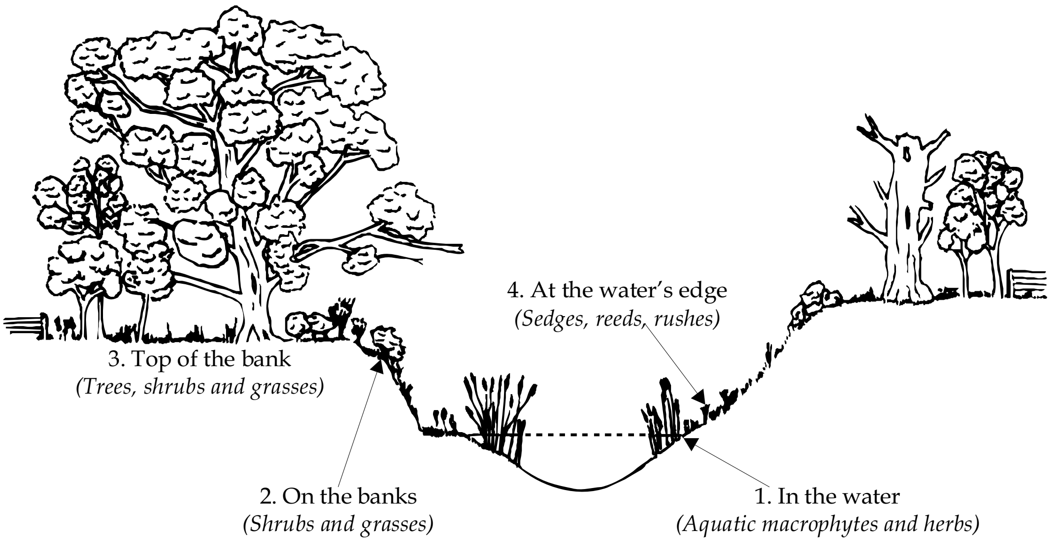

Figure 5.1: Planting zones for riparian vegetation

Riparian weeds

Watercourses act as a conduit for the spread of weed and exotic plant species. Weed species compete with native plant species, do not provide a full range of habitat requirements for native aquatic and terrestrial fauna and do not effectively stabilise watercourse banks. A number of weeds are listed as proclaimed weeds under the *Animal and Plant Control (Agricultural and Other Purposes) Act 1986* and landholders are required by law to control them. Wild artichoke, boxthorn, olive, and bathurst burr are examples of proclaimed weeds in the Lower North Animal and Plant Control Board area which covers the Wakefield River catchment. Advice on weed control can be obtained from local Animal and Plant Control officers.

[7] Indigenous plant species are those which naturally occur in a particular area.
[8] Contact details for local revegetation officers can be obtained from the nearest PIRSA office.

Ongoing weed management is an essential part of protecting and maintaining a healthy riparian zone. When revegetating, thorough weed control is the key to successful plant establishment (Carr et al, 1999). In cases where weed coverage is particularly dense it may be necessary to undertake a 2-3 year program of weed control prior to revegetation.

Watercourses are sensitive ecosystems and care should be taken when controlling weeds. Removal of moderate to dense stands of weeds from a watercourse should be undertaken in conjunction with a program of revegetation using native plant species in order to protect banks and re-establish habitat. Herbicide use should be minimised and only herbicides with least impact on aquatic flora and fauna should be used. Glyphosate biactive is currently the only herbicide registered for use near watercourses.

Exotic trees

Exotic trees growing along watercourses cause a number of problems. Dense stands of trees cast a heavy shade that prevents undergrowth; as a consequence plant and habitat diversity is reduced. Exotic trees do not provide the food and shelter requirements of native aquatic and terrestrial insects and animals. Biological monitoring in South Australia has shown that numbers and diversity of aquatic insects and fish are greatly reduced under ash and willow trees compared with native vegetation. Deciduous leaf drop in late autumn gives a sudden influx of organic material. This material breaks down releasing large quantities of nutrients in a short period of time and deoxygenating the water. Other impacts include flooding and erosion problems, as exotic trees tend to invade the channel of smaller watercourses and obstruct flows.

Exotic tree control requires good long term planning. To maximise the environmental benefits of removing exotic trees, it is important to replace the trees with suitable native riparian vegetation. This replacement vegetation requires time to establish. Where the watercourse is heavily infested, total removal of trees at one time can initiate erosion and result in increased light levels and water temperatures. Staging of removal is important to prevent erosion and allow establishment of replacement vegetation.

Depending on the tree species, two control methods can be used: poisoning by injecting herbicide and then cutting down the tree when dead or cutting down the tree and immediately painting the stump with undiluted herbicide. Timing is important and poisoning is most effective during the growing period, October to April.

5.3.3 Channel stability issues

Bed and bank erosion are natural watercourse processes, for example it is natural for outside bends to sustain some erosion and inside bends to receive deposits. Erosion becomes a problem when it is greatly accelerated by human activities that alter stream flows or directly impact on the channel, for example, vegetation clearance, grazing, in-stream infrastructure and watercourse excavation.

The removal of catchment vegetation and agricultural development following European settlement have increased surface runoff and accelerated erosion. Evidence of past incision and channel widening can be seen in the box-shaped channels and lack of in-stream physical structure characteristic of many reaches of the Wakefield River system.

The processes of bed and bank erosion result in channel deepening and widening, destruction of physical habitat and can threaten in-stream infrastructure such as bridges and culverts. Loss of sediment from bed and banks results in poor water quality and sedimentation of pools, riffle zones and other important aquatic habitats. 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. Well planned revegetation, especially on the toes and mid-section of the bank can greatly assist in stabilising eroding channels.

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. As the erosion event travels upstream it takes the form of a locally high gradient or a 'waterfall', termed an erosion head or nick point (Carter, 1995). As the episode of bed erosion passes a tributary or side gully, these areas will undergo bed deepening as they adjust to the new bed level. Following the passage of an episode of bed deepening, the height of the banks relative to the bed is increased and they become more susceptible to collapse (Department of Land and Water Conservation, 1996).

Erosion heads may sometimes become '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.

Depending on the severity of the erosion, bed erosion can be controlled through the construction of a grade or erosion head control structure and/or revegetation. Control 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 bed erosion can be controlled through revegetation and allowing in-stream vegetation to regenerate.

Poor bank stability

The flow of water within a watercourse is a major factor in causing bank erosion (Department of Land and Water Conservation, 1996). Bank erosion is often accelerated by removal of vegetation, stock grazing, bed lowering, obstructions to stream flow and changes to flow regime.

Poorly aligned or designed bridges, culverts and weirs can initiate bank erosion. Culverts that are under-capacity for the flood discharge of the watercourse result in upstream flooding and damage as water overtops the structure. Poorly aligned structures can redirect stream flow into the bank causing bank erosion. Structures that fail to dissipate the energy of the hydraulic jump can cause scour holes and bank erosion downstream.

It is important that in-stream infrastructure is positioned correctly within the watercourse and constructed at a capacity to handle flood discharges. When repairing or replacing in-stream infrastructure care must be taken to avoid initiating any further erosion to watercourse bed and banks.

Bank erosion can be controlled by first dealing with the cause, for example removing obstructions, 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. These 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 through resistance to flow and strengthens the bank by binding soil with root systems.

Sites of active erosion will require more immediate attention than sites of low level erosion. When determining priorities for on-ground action, consideration should be given to severity, location in the catchment, erodibility of bed or banks and proximity to a high value capital asset. A high value capital asset could be an area of high conservation value or in-stream infrastructure such as bridges and culverts. Site analysis and understanding of geomorphological processes is critical in selecting an appropriate response to the cause of erosion and to avoid treating only the symptoms.

Stock access

Long term, uncontrolled, stock access to the watercourse results in loss of native watercourse vegetation and increased bank erosion (Bell and Priestley, 1998). For example, studies have shown that grazed banks erode three to six times faster than ungrazed banks (Trimble, 1994). 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).

To lessen the impact of stock grazing the timing, duration and intensity of grazing along the watercourse need to be controlled. Fencing and the provision of an alternative water supply is the most obvious means of control. Electric fencing provides a cheap and low maintenance option. Where fencing is not an option it is possible to limit the time stock spend in the riparian zone by other means, for example, providing alternative watering points away from the stream (Bell and Priestley, 1998).

Reducing or totally excluding stock access can have a dramatic effect on riparian recovery. Long term monitoring by landholders has shown evidence of slow recovery within two years and significant recovery to a state approaching the natural state of the stream within 6-8 years (Bell and Priestley, 1998).

When fencing a watercourse it is important to consider locating the fence well back from the stream and parallel to the direction of flow. Where this means large areas are excluded, controlled grazing management of this 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 a number of 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 include:

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

Some of the disadvantages include the cost involved in fencing and providing alternative watering points.

5.4. Watercourse management priorities and options

5.4.1 Purpose and scope

This section outlines the watercourse condition, priority watercourse management issues and management options for each subcatchment in the Wakefield River catchment. The catchment was divided into the following six subcatchments to facilitate the watercourse assessment and the community consultation processes:

- Lower Wakefield
- Hermitage and Woolshed Flat Creeks
- Skillogalee Creek
- Eyre Creek
- Pine and Rices Creeks
- Upper Wakefield.

The watercourse management priorities and options provide a framework for landholders and key stakeholders to deal with watercourse problems and work towards improved watercourse management. The purpose of these is to:

- identify and prioritise watercourse management issues
- recommend management options to deal with these problems
- raise landholders' awareness of watercourse management issues.

Stream flow issues are an important part of total watercourse management, but are addressed with environmental water requirements and river ecosystems in Chapter 6.

The recommended management options do not set out to provide a specific solution for every problem or site. Instead, a range of management options is proposed for each issue. These should be used to set directions for improved management and as a source of ideas from which to choose. Obviously on-ground actions need to be adapted to suit the particular problem and site. Importantly, landholders need to be involved in selecting on-ground actions that are within their means and that suit their property management requirements.

Estimates of the basic costs involved in undertaking riparian rehabilitation works are included in Appendix C. It must be recognised that these costs are approximate only. It is not possible to give precise estimates on rehabilitation, as the most appropriate treatment will vary from site to site. Cost also alters significantly if landholders have the knowledge and skills to undertake some of the required work. Consideration for follow-up and ongoing maintenance of the riparian zone needs to be included when calculating costs.

In implementing the management options outlined it is important to remember the following:

- Social and economic values need to be considered together with ecological values.

- Watercourse management is a long-term process. Noticeable improvements will often be gradual over a 3–7 year period. This is particularly true for revegetation projects in which plants will take a couple of years to grow and become established.

- The Wakefield River catchment is a dynamic system. These priorities and options are based on a 'snapshot' of the condition of watercourses in the catchment in 1999. They do not account for any unforeseen changes that may result from future significant flood events or human induced changes.

5.4.2 Lower Wakefield subcatchment

General description

The Lower Wakefield subcatchment encompasses the Wakefield River from the foothills of the Alma Range to the Port Wakefield estuary. The river channel is dry for most of the year, although substantial hyporeheic flow exists. Along the section of the river from downstream of The Rocks to Balaklava a significant proportion of flow disappears into sand and gravel beds. The dominant land uses along the river in this subcatchment are grazing and cropping.

The Wakefield River is distinguished by the amount of sediment deposited within the main channel. This sediment, from upstream erosional zones, has filled in pools and destroyed in-stream physical structure. The stream channel is incised and has a 'gully-like' appearance. Along the top of the riverbank, continual sand drift from the north has created a slight rise in ground level. This results in a tendency for surface water to flow away from the river.

Downstream from Whitwarta, the river channel actively meanders and has well-developed floodplain features eg flood channels and minor anabranching. This zone is vastly modified and a single channel with no wetland complexes has replaced the original braided channel–wetland–swamp system. This channel is incised and has a 'gully-like' appearance with little in-stream physical habitat (Thoms, 1999). Bed and bank sediments are fine mostly silts and clays. A 6 km section of the river downstream of Whitwarta is influenced by a shallow and highly saline groundwater table. Some hypersaline permanent pools exist.

Community input

Community meetings were held with landholders from the Lower Wakefield subcatchment together with landholders from the Hermitage and Woolshed Flat Creeks subcatchment. At the first community meeting, landholders identified a range of issues of concern for each subcatchment. These concerns have been summarised in Table 5.4. The main landholder concerns across these two subcatchments were impacts on flows, weeds (eg artichoke, onion weed, tomato weed) and erosion issues.

Current riparian condition

Riparian vegetation along the river from the foothills downstream to Whitwarta is relatively healthy. There is dense overstorey of river red gums and evidence of juvenile trees establishing in areas. The understorey is degraded and annual exotic grasses, weeds and agricultural cropping plants are now the dominant form of understorey vegetation. To allow the understorey species to establish, threats such as grazing and weeds will need to be managed. This reach lacks pool habitats and remains dry for most of the time. As a result there is no in-stream vegetation.

Table 5.4: Watercourse management issues in the Lower Wakefield and Hermitage and Woolshed Flat Creeks subcatchments as identified by landholders.

Watercourse Management Issue	Number of Votes
Impacts on river flows*	19
Weeds eg wild artichoke, onion weed, tomato weed, bathurst burr	19
Erosion eg bend erosion and sedimentation at specific sites	14
Reeds	12
Impacts on groundwater quality and quantity	10
Salinity in specific locations	10
Grazing along the riverbank	4
Large flood events	4
Rubbish/debris washed down in floods	1

** Flow issues are addressed in Chapter 6.*

Erosion issues were not a problem in this reach. The river banks typically have a moderate to good stability rating and no evidence of bed deepening was observed.

Riparian vegetation along most of the length of the river downstream from Whitwarta to the estuary is quite degraded. The riparian zone is dominated by exotic vegetation, and riparian weeds are a significant issue. The dominant weed species is wild artichoke with wild fennel and boxthorn also observed. Typically, this reach has a sparse coverage of wild artichoke but there are some areas with medium density to dense coverage.

In the sparse to medium density native overstorey of river red gums along the river just downstream of Whitwarta, dieback of river red gums has occurred along a 6 km section due to the effects of saline groundwater (Land Management and Environment Assessment Services, 1996). Grazing has had significant impacts on understorey species and overstorey tree recruitment. Ephemeral floodplain swamps have been removed from the environment or cut off from the main channel flows.

Ecologically this reach is in a poor condition due to the impacts of exotic vegetation, salinity, grazing and land clearance. It should be noted that some landholders within this area have made considerable effort towards rehabilitation of the riparian zone environment.

Two erosion heads were observed. The first occurs within the Port Wakefield town common approximately 300 m downstream of the highway. When a channel was cut to remove a bend in the river, there was a localised increase in flow velocity that initiated a bed deepening process. This erosion head is located in a heavy clay substrate that has slowed further bed deepening. The second erosion head occurs approximately 5 km upstream and has been caused by a high flow event on a sharp bend. Both erosion heads were considered to be of low priority but will require further monitoring. Banks typically had a good stability rating with some areas of moderate stability (Map 5). These areas have the potential to undergo active erosion if they are not managed to control grazing and ensure a cover of protective vegetation.

Watercourse management priorities and options

The project team, in consultation with landholders, identified watercourse management issues for the Lower Wakefield subcatchment. The location of these issues in the subcatchment is illustrated in Figure 5.2. A final priority list of issues including options for management and length of stream affected is outlined in Table 5.5. Priorities for watercourse management in the Lower Wakefield subcatchment include:

1. **Maintain and/or improve of areas of good vegetation cover**. These are areas with good native overstorey or watercourse vegetation but threatened by degrading processes.

2. **Moderate to dense wild artichoke**. Weeds are an issue due to their impacts on river habitat, poor ability to stabilise banks and their ability to spread rapidly along the watercourse.

3. **Sparse artichoke and lack of native vegetation**.

4. **Sparse artichoke**.

5. **Erosion heads**. Erosion heads are symptoms of bed deepening.

Table 5.5: Lower Wakefield subcatchment watercourse management priorities and options

Priority	Management Issue	Management Options	Length (km)
1	**Maintain and/or improve of areas of good vegetation cover.** These are areas with healthy native overstorey or watercourse vegetation but threatened by degrading processes.	**Stock present:** A: Restrict stock access and control weeds to encourage natural regeneration. B: Restrict stock access, control weeds and revegetate with appropriate native species. **No stock present:** A: Control weeds and revegetate with appropriate native species.	24.7
2	**Moderate to dense wild artichoke.** Weeds are an issue due to their impacts on native vegetation and river habitat, poor ability to stabilise banks and their capacity to spread rapidly along the watercourse.	A: Control weeds B: Control weeds and revegetate with locally native species. *NB: A program of revegetation is needed once weeds are removed to prevent any erosion problems and to re-establish habitat.*	12.2
3	**Sparse wild artichoke and lack of native vegetation.**	A: Control weeds B: Control weeds and revegetate with locally native species. *NB: A program of revegetation is needed once weeds are removed to prevent any erosion problems and to re-establish habitat.*	2.0
4	**Sparse wild artichoke.**	A: Control weeds B: Control weeds and revegetate with locally native species. *NB: A program of revegetation is needed once weeds are removed to prevent any erosion problems and to re-establish habitat.*	25.7
5	**Erosion heads.** Erosion heads are symptoms of bed deepening. Low priority due to the stability of the bed and the dynamic nature of this part of the system.	A: Fence and revegetate, monitor site. B: Construct erosion control works, fence and revegetate. *NB: Consideration needs to be given to severity of erosion, erodibility of bed or banks and location of control features eg rock bars/culverts*	n.a

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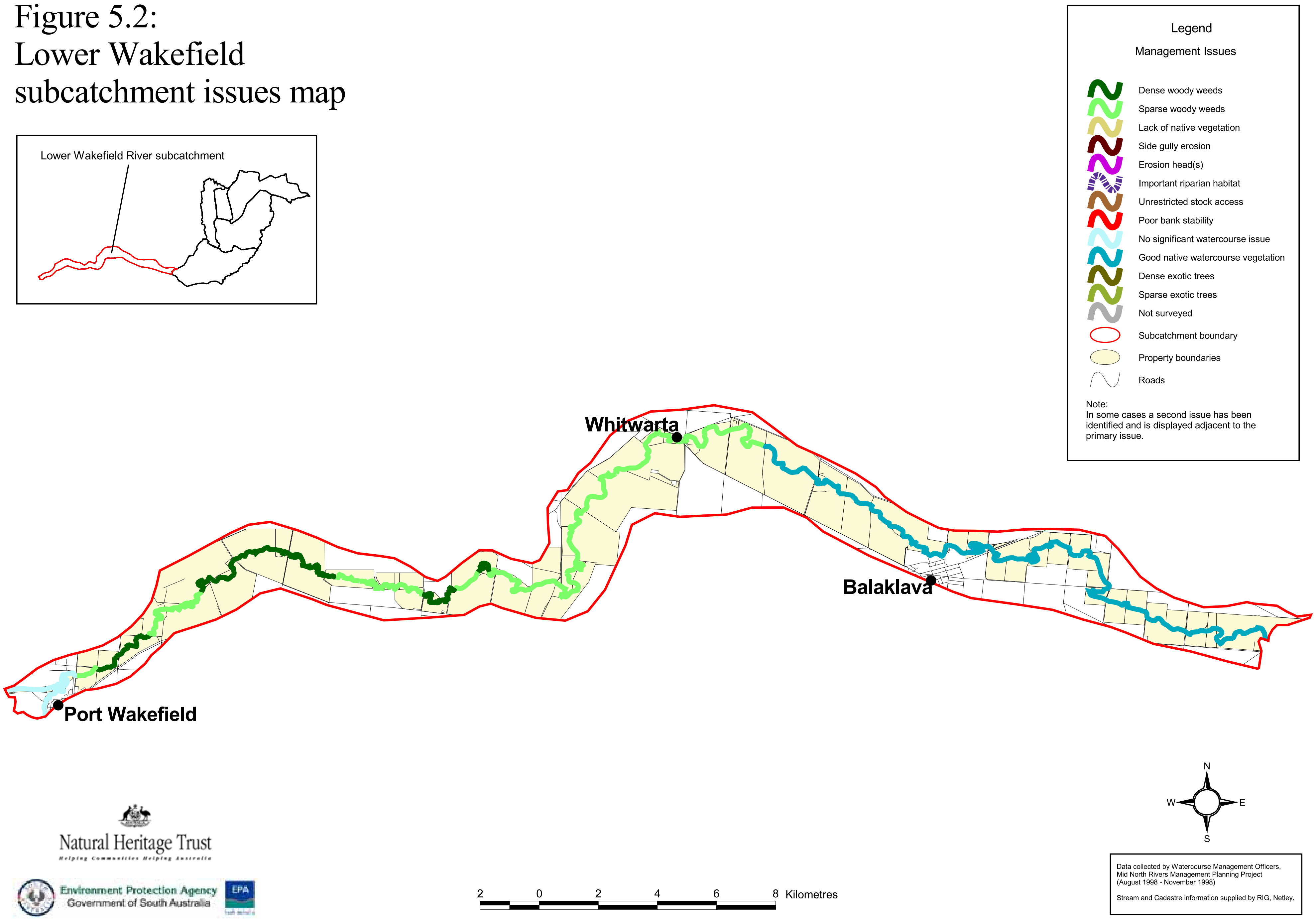
Figure 5.2:
Lower Wakefield subcatchment issues map



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Environment Protection Agency
Government of South Australia
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5.4.3 Hermitage and Woolshed Flat Creeks subcatchment

General description

The Hermitage and Woolshed Flat Creeks subcatchment encompasses Hermitage and Woolshed Flat Creeks and the Wakefield River main channel from the its confluence with Woolshed Flat Creek to the foothills of the Alma Range. Hermitage and Woolshed Creeks are ephemeral streams with no permanent pools. The Wakefield River main channel has significant groundwater fed baseflow and permanent pools. The dominant land use is cropping and there is some grazing of livestock.

The main channel of the Wakefield from its confluence with Woolshed Flat Creek downstream to approximately 2 km upstream of Robins Ford has eroded in the past reducing the physical complexity of the channel. It is characterised by extensive reed beds interspersed with deep pools with a few sections of good pool-riffle habitat. The reed beds are evidence of past erosion and indicate that this area is in a state of recovery.

The Wakefield River from 2 km upstream of Robins Ford to approximately 5 km downstream of The Rocks is characterised by a complex range of physical habitats, eg pool-riffles, in-channel benches, point bars, diverse native watercourse vegetation, permanent pools and good water quality. This zone has high ecological value and requires protection.

Typically, the stream channels of Hermitage and Woolshed Flat Creeks are heavily degraded and have a box shaped appearance with very little in-stream structure and generally steep banks (Thoms, 1999).

Community input

Community meetings were held with landholders from the Hermitage and Woolshed Flat Creeks subcatchment together with landholders from the Lower Wakefield subcatchment. At the first community meeting, landholders identified a range of issues of concern for each subcatchment. The main landholder concerns across these two subcatchments were impacts on flows, weeds (eg artichoke, onion weed, tomato weed) and erosion issues (Table 5.4). Some landholders also observed that over the last 10 years native vegetation and wildlife has increased along this stretch of river. They considered erosion had also reduced due to contour banking, a reduction in grazing and other land management practices eg minimum tillage. For the local community maintaining and improving the important riparian habitat zone along the main channel of the Wakefield River was the major priority in this subcatchment.

Current riparian condition

The main channel of the Wakefield River within this subcatchment was identified as an area of important riparian habitat with high ecological value. Despite being threatened by degrading processes, this reach typically had a range of in-stream physical habitat, such as pools, riffles and channel bars, diverse in-stream and riparian vegetation, and good water quality.

A significant proportion of the main channel is covered by dense stands of in-stream vegetation, predominantly *Phragmites* and *Typha*. Overall, riparian vegetation is degraded with the dominant vegetation comprising annual exotic grasses with little understorey and a very sparse overstorey of natives and/or exotic trees. The effects of cattle grazing are the most likely cause of the limited regeneration of vegetation in these areas.

The erodible nature of the 'Pooraka' soil formation and the high runoff velocities of water along the foot slopes of this subcatchment mean there has been significant bed deepening and bank erosion of streams in this area. The Hermitage Creek system has been particularly affected. Extensive contour banking and modifications in agricultural practice have halted most of the active erosion in these areas. Most of the stream banks are in a process of naturally battering back to a stable grade and were classified as having good stability (Map 5). However there were a number of areas with moderate to poor stability and erosion of these banks will continue during high runoff events especially if stock have access to the riparian zone. The silt load from these areas will have a negative impact on the pools and gravel bars downstream in the main channel.

There has been considerable effort in this subcatchment to reduce surface runoff and rehabilitate eroded streams. For example, in 1976 a major contour banking project, known as the Hermitage Creek Group Conservation Project, was undertaken. Most of the erosion heads in this area have either been stabilised by on-ground works or have eroded back to rock bars and stabilised naturally (eg the large erosion head near Robins ford). Several active erosion heads were identified along tributaries of Hermitage Creek. These need to be monitored to determine their potential to cause accelerated erosion.

Watercourse management priorities and options

The project team, in consultation with landholders, identified watercourse management issues for the Hermitage and Woolshed Flat Creeks subcatchment. The location of these issues in the subcatchment is illustrated in Figure 5.3. A final priority list of issues including options for management and length of stream affected is outlined in Table 5.6. Priorities for watercourse management in the Hermitage and Woolshed Flat Creeks subcatchment include:

1. **Protecting areas of good riparian habitat**. These areas had a diverse range of native riparian and in-stream vegetation, permanent pools of various depths and generally good water quality.

2. **Erosion heads/gully erosion**. Erosion heads are symptoms of bed deepening.

3. **Poor bank stability**. Steep banks caused by severe erosion events will continue to erode until they reach a stable grade. Uncontrolled stock grazing along the creek can exacerbate poor bank stability and accelerate further erosion processes.

4. **Weed control eg wild artichoke**. Weeds are an issue due to their impacts on river habitat, poor ability to stabilise banks and their ability to spread rapidly along the watercourse.

5. **Lack of native riparian vegetation on banks and floodplain**. Two common situations were: presence of in-stream vegetation but no native overstorey or understorey or a native overstorey of river red gums with degraded understorey.

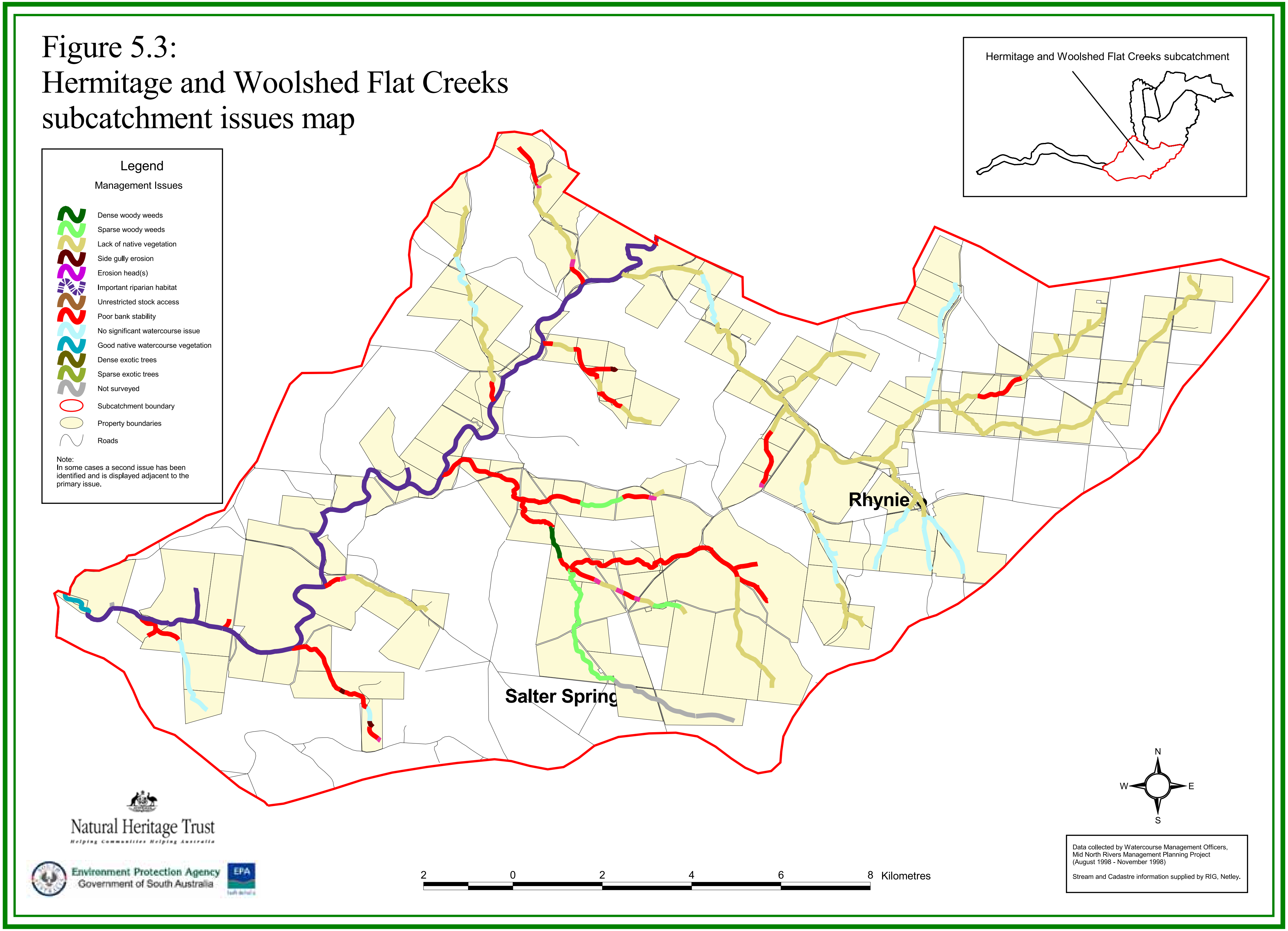
Table 5.6: Hermitage and Woolshed Creeks subcatchment watercourse management priorities and options

Priority	Management Issue	Management Options	Length (km)
1	Protecting areas of good riparian habitat. These areas had a diverse range of native riparian and in-stream vegetation, permanent pools of various depths and generally good water quality.	A: Monitor site to observe any adverse events. B: Control threatening processes eg weeds and stock access C: Control threatening processes and revegetate banks and floodplain with locally indigenous overstorey and understorey species	21.8
2	Erosion heads/gully erosion. Erosion heads are symptoms of bed deepening.	A: Fence and revegetate, monitor site. B: Construct erosion control works, fence and revegetate. *NB: Consideration needs to be given to severity of erosion, erodibility of bed or banks and location of control features eg rock bars/culverts.*	n.a.
3	Poor bank stability. Steep banks caused by severe erosion events will continue to erode until they reach a stable grade. Uncontrolled stock grazing along the creek can exacerbate poor bank stability and accelerate further erosion processes.	Stock present: A: Restrict stock access and control weeds to encourage natural regeneration. B: Restrict stock access, control weeds and revegetate with appropriate native species. No stock present: A: Control weeds and revegetate with appropriate native species.	21.8

Table 5.6 (cont.): Hermitage and Woolshed Creeks subcatchment watercourse management priorities and options

Priority	Management Issue	Management Options	Length (km)
4	Weed control eg wild artichoke. Weeds are an issue due to their impacts on river habitat, poor ability to stabilise banks and their ability to spread rapidly along the watercourse.	A: Control weeds B: Control weeds and revegetate with locally native species. *NB: A program of revegetation is needed once moderate to dense stands of weeds are removed to prevent any erosion problems and to re-establish habitat.*	5.4
5	Lack of native riparian vegetation on banks and floodplain. Two common situations were: • presence of in-stream vegetation but no native overstorey or understorey • native overstorey of river red gums but degraded understorey.	Stock present: A: Restrict stock access and control weeds to encourage natural regeneration. B: Restrict stock access, control weeds and revegetate with appropriate native species. No stock present: A: Control weeds and revegetate with appropriate native species.	40.1

Figure 5.3: Hermitage and Woolshed Flat Creeks subcatchment issues map



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5.4.4 Skillogalee Creek subcatchment

General description

The Skillogalee Creek rises in the eastern foothills of Mount Horrocks and flows west through Penwortham before changing course and flowing in a southerly direction to its confluence with the Wakefield River main channel. The Skillogalee is an ephemeral stream with groundwater fed baseflows downstream of Penwortham and a number of large, permanent pools below Port Road. The dominant land use along the creek is grazing of livestock, cropping and viticulture.

The Skillogalee Creek flows through a valley created by a line of hills. Channel planform is controlled by the valley structure. The creek is a high-energy stream dominated by rock chutes and scour pools. This high-energy environment, together with a lack of major sedimentary deposits suggests that the Skillogalee is an important sediment source for the downstream river system.

Community input

At the first community meeting held with landholders in the Skillogalee subcatchment, landholders identified a range of issues of concern. These concerns have been summarised in Table 5.7. Landholders also considered that the condition of the creek had improved following the ending of winery effluent discharge.

Table 5.7: Watercourse management issues in the Skillogalee subcatchment as identified by landholders.

Watercourse Management Issues	Number of Votes
Rubbish transported down the creek	3
Exotic trees, eg hawthorn and ash, obstructing flows	2
Decreased flows*	1
Decreased water quality	-
Under-capacity culverts	-

** Flow issues are addressed in Chapter 6.*

Current riparian condition

There are a number of sections of the Skillogalee Creek that have native riparian vegetation in good condition. For example, downstream of the Port Road, native in-stream and overstorey vegetation provides important riparian habitat and an important source of organic matter for the downstream river system.

In other reaches, grazing, weeds and exotic trees have seriously damaged the native riparian vegetation. Downstream of the Hoyleton Road bridge, there is a good overstorey of river red gums with an understorey impacted by grazing and weeds eg wild artichoke. East of Penwortham, the riparian vegetation is dominated by dense stands of hawthorn and dog rose with olives occurring on the floodplain (Map 3).

Under-capacity culverts were a problem at a number of low level road crossings between Port Road and Hoyleton Road. The culverts lack the capacity to pass fast flowing flood events, so there is localised bank erosion downstream.

There are several erosion heads (areas of bed deepening), for example, there is an erosion head just upstream of the Port Road bridge. These erosion heads appear to be stable as they have hit rock structures. They still, however, require monitoring to ensure they do not continue to erode further up the watercourse. The majority of the surveyed watercourses in the subcatchment had a moderate bank stability rating (Map 5). These areas have the potential to undergo active erosion if they are not managed to control grazing and ensure a cover of protective vegetation.

Watercourse management priorities and options

The project team, in consultation with landholders, identified watercourse management issues for the Skillogalee Creek subcatchment. The location of these issues in the subcatchment is illustrated in Figure 5.4.

Issues and potential solutions were presented to landholders at a meeting held on Tuesday, 3 November 1998. Landholders present at the meeting did not feel they adequately represented the views of all landholders in the Skillogalee Creek subcatchment. As a consequence, watercourse management priorities for this subcatchment were determined initially by project staff. The priority issue list was sent to landholders for comment before producing the final priority list and management options (Table 5.8).

Watercourse management priorities for the Skillogalee Creek subcatchment include:

1. **Protecting areas of good riparian habitat**. These areas had a diverse range of native riparian and in-stream vegetation, permanent pools of various depths and generally good water quality.

2. **Exotic trees and woody weeds eg willows, olives, dogrose, hawthorn,**. Exotic trees and woody weeds are a priority issue due to their impacts on river habitat, their potential to cause flooding and their ability to spread rapidly along the watercourse.

3. **Erosion heads**. Erosion heads are symptoms of bed deepening.

4. **Poor bank stability caused by under-capacity culverts**.

5. **Unrestricted stock access**. Uncontrolled stock grazing destroys native riparian vegetation, prevents natural regeneration and causes low level, widespread bank erosion.

6. **Lack of native watercourse vegetation**. Two typical situations were:
   - presence of in-stream vegetation but no native riparian overstorey or understorey
   - native overstorey of river red gums but degraded understorey.

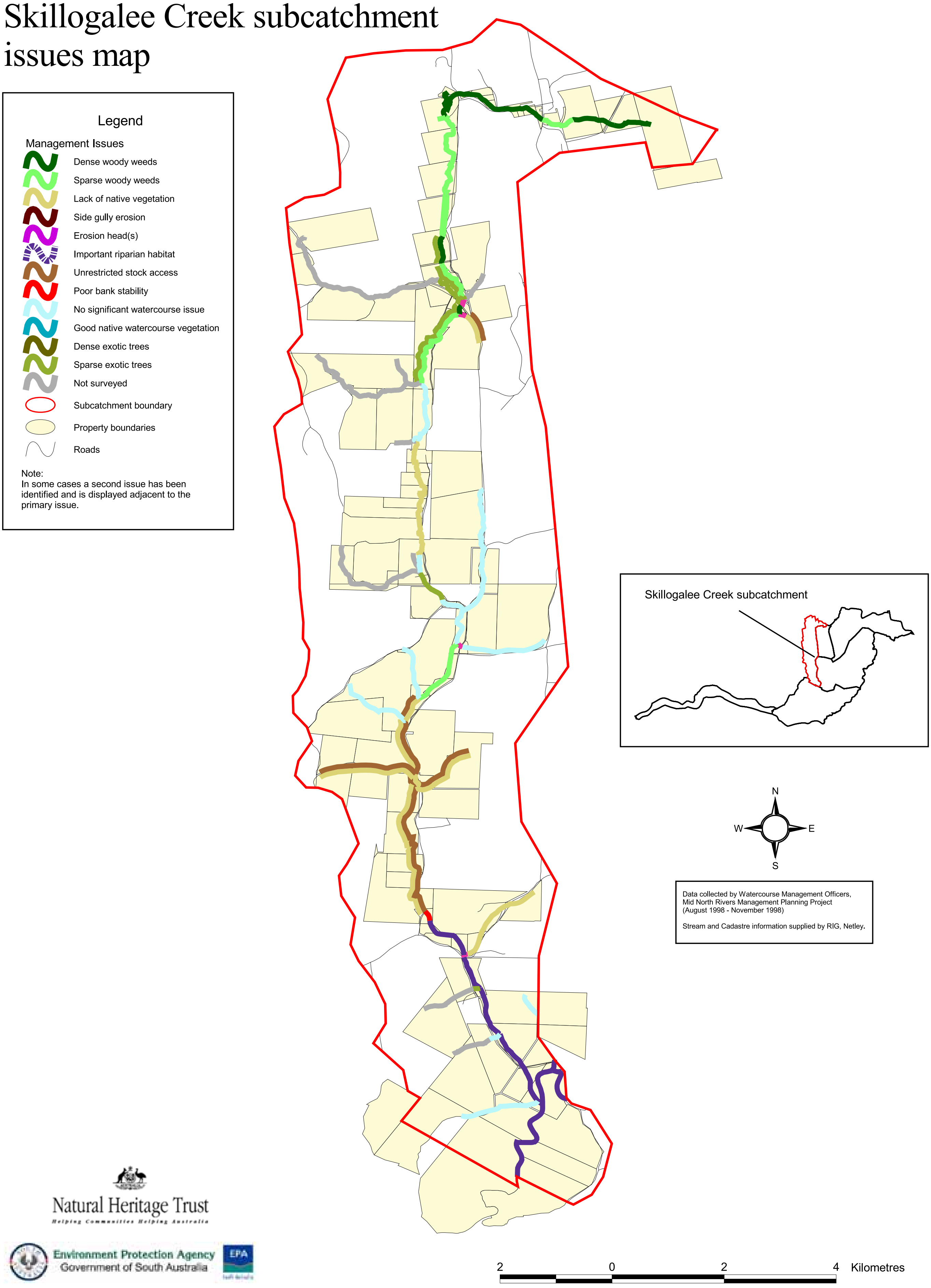
Table 5.8: Skillogalee Creek subcatchment watercourse management priorities and options

Priority	Management Issue	Management Options	Length (km)
1	Protecting areas of good riparian habitat. These areas had a diverse range of native riparian and in-stream vegetation, permanent pools of various depths and generally good water quality.	A: Monitor site to observe any adverse events. B: Control threatening processes eg weeds and stock access C: Control threatening processes and revegetate banks and floodplain with locally indigenous overstorey and understorey species	7.2
2	Exotic trees and woody weeds eg hawthorn, dogrose, willows olives. Exotic trees and woody weeds are a priority issue due to their impacts on river habitat, their potential to cause flooding and their ability to spread rapidly along the watercourse.	A: Remove exotic trees and woody weeds and revegetate with appropriate native species. B: Remove exotic trees and woody weeds, revegetate with appropriate native species and undertake long term exotic tree control. *NB: A program of revegetation is needed once moderate to dense stands of trees and woody weeds are removed to prevent any erosion problems and to re-establish habitat.*	13.1
3	Erosion heads. Erosion heads are symptoms of bed deepening.	A: Fence and revegetate, monitor site. B: Construct erosion control works, fence and revegetate. *NB: Consideration needs to be given to severity of erosion, erodibility of bed or banks and location of control features eg rock bars/culverts.*	n.a.
4	Poor bank stability caused by under-capacity culverts.	A: Construct erosion control works, fence and revegetate. B: Increase capacity of culverts, construct erosion control works, fence and revegetate. *NB: Consideration needs to be given to severity of erosion, erodibility of bed or banks and location of control features eg rock bars/culverts.*	0.2

Table 5.8 (cont.): Skillogalee Creek subcatchment watercourse management priorities and options

Priority	Management Issue	Management Options	Length (km)
5	**Unrestricted stock access.** Uncontrolled stock grazing destroys native riparian vegetation, prevents natural regeneration and causes low level, widespread bank erosion.	**Stock present:** A: Restrict stock access and control weeds to encourage natural regeneration. B: Restrict stock access, control weeds and revegetate with appropriate native species.	5.1
6	**Lack of native watercourse vegetation.** Common situations: • presence of in-stream vegetation but no native overstorey or understorey • native overstorey of river red gums but degraded.understorey.	**No stock present:** A: Control weeds and revegetate with appropriate native species.	6.3

Figure 5.4:
Skillogalee Creek subcatchment issues map



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5.4.5 Eyre Creek subcatchment

General description

The Eyre Creek rises in the foothills of Mount Horrocks and flows in a southerly direction, through the town of Watervale, to join the main channel of the Wakefield River just north of Auburn. Eyre Creek is an ephemeral stream with a number of small groundwater dependent, permanent pools. The dominant land use along Eyre Creek includes grazing of livestock, viticulture and rural-residential blocks.

The Eyre Creek has undergone a significant change from its natural state. The stream channel has been heavily eroded and consequently has a box shaped appearance with very little in-stream physical structure and generally steep banks.

Community input

Community meetings were held with landholders from the Eyre Creek subcatchment together with landholders from the Upper Wakefield subcatchment. At the first community meeting, landholders identified a range of issues of concern across the two subcatchments. These concerns have been summarised in Table 5.9. The main concerns were impacts on stream flows, exotic trees and poor water quality. Landholders also observed that the condition of the Eyre Creek was generally poor: there has been in increase in algal growth and a number of permanent pools have disappeared.

Table 5.9: Watercourse management issues in the Eyre Creek and Upper Wakefield subcatchments as identified by landholders.

Watercourse Management Issue	Number of Votes
Decreased flows*	25
Exotic trees, eg ash and willows	18
Poor water quality eg urban stormwater, agricultural chemicals, town sewage	14
Vegetation and debris transported by floods	9
Management of reeds	9
Weeds eg wild artichoke, wild fennel, cape tulip	4
Siltation	3

** Flow issues are addressed in Chapter 6.*

Current riparian condition

The riparian zone is quite degraded along the entire length of the reach due to invasion by exotic trees and lack of native vegetation. The section of creek that flows through Watervale and just south of the town is heavily infested with ash trees. These trees provide poor habitat for native fauna and shade the watercourse preventing the growth of understorey species and reducing water temperatures. Landholders within the town are concerned about their potential to constrict the watercourse channel and cause flooding.

Little if any remnant vegetation remains. The dominant form of riparian vegetation is annual exotic grasses with little or no overstorey of either native or exotic trees (Map 2). *Phragmites* and *Typha* are the dominant native in-stream vegetation. In some sections, there is a medium density to dense overstorey of river red gums but little native understorey exists. Along the section of watercourse downstream of Leasingham, there is no native overstorey or understorey however a dense coverage of in-stream vegetation is present.

Erosion issues were not significant in this subcatchment and no evidence of bed deepening or active bank erosion was observed. Banks typically had a good stability rating with some areas of moderate stability (Map 5). These areas have the potential to undergo active erosion if they are not managed to control grazing and ensure a cover of protective vegetation.

Watercourse management priorities and options

The project team, in consultation with landholders, identified watercourse management issues for the Eyre Creek subcatchment. The location of these issues in the subcatchment is illustrated in Figure 5.5. A final priority list of issues including options for management and length of stream affected is outlined in Table 5.10. Watercourse management priorities for the Eyre Creek subcatchment include:

1. **Exotic trees, eg ash, willow, olives.** Exotic trees are a priority issue due to their impacts on river habitat, their potential to cause flooding and their ability to spread rapidly along the watercourse.

2. **Lack of native watercourse vegetation.** Two typical situations were:
   - presence of in-stream vegetation but no native riparian overstorey or understorey
   - native overstorey of river red gums but degraded understorey.

Table 5.10: Eyre Creek subcatchment watercourse management priorities and options

Priority	Management Issue	Management Options	Length (km)
1	**Exotic trees, eg ash, willow, olives**. Exotic trees are a priority issue due to their impacts on river habitat, their potential to cause flooding and their ability to spread rapidly along the watercourse.	A: Remove exotic trees and revegetate with appropriate native species. B: Remove exotic trees, revegetate with appropriate native species and undertake long term exotic tree control. *NB: A program of revegetation is needed once trees are removed to prevent any erosion problems and to re-establish habitat.*	20.8
2	**Lack of native watercourse vegetation** was an issue along most of Eyre Creek. Two common situations were: • presence of in-stream vegetation but no native overstorey or understorey • native overstorey of river red gums but degraded understorey.	**Stock present:** A: Restrict stock access and control weeds to encourage natural regeneration. B: Restrict stock access, control weeds and revegetate with appropriate native species. **No stock present:** A: Control weeds and revegetate with appropriate native species.	43.3

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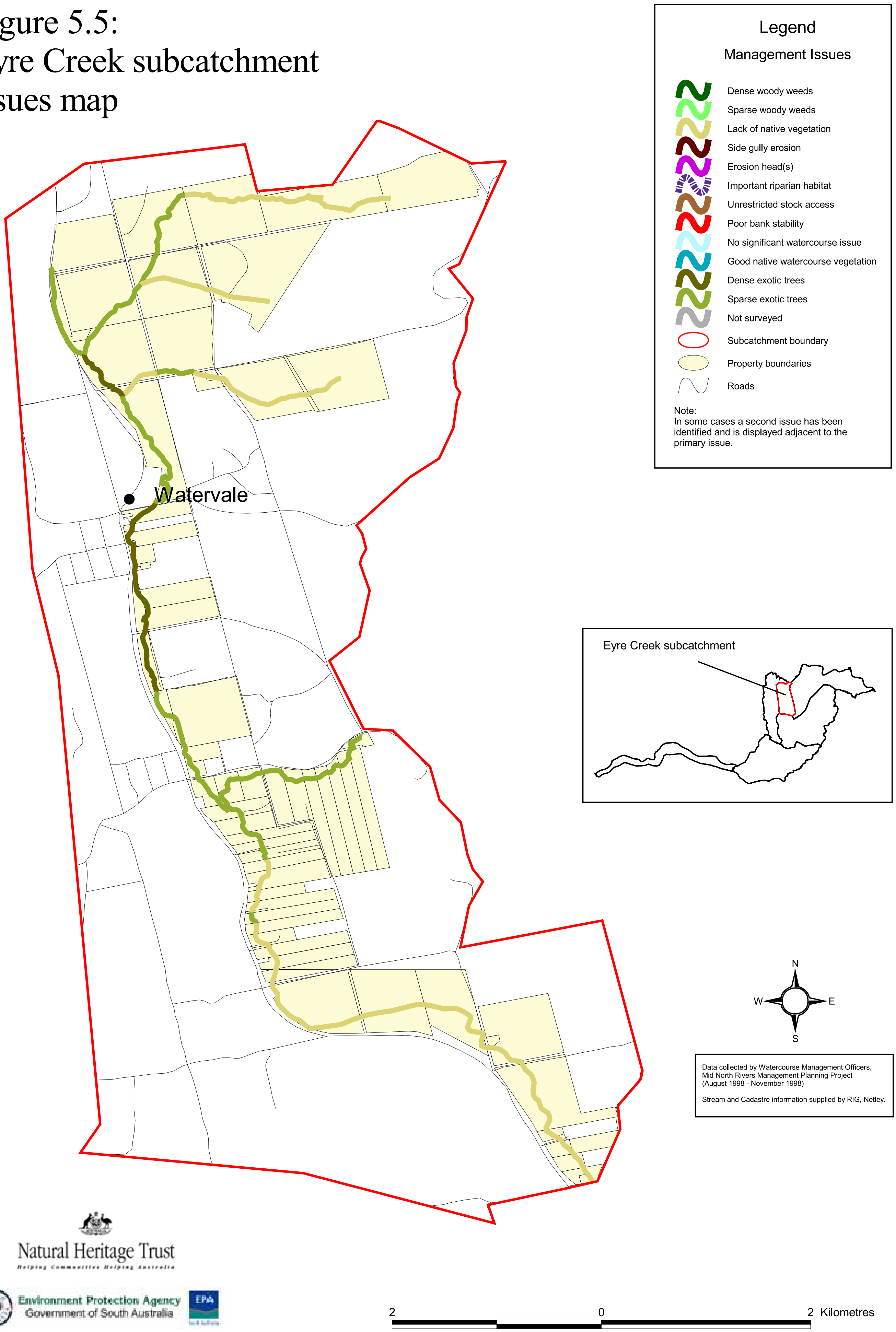
Figure 5.5:
Eyre Creek subcatchment issues map



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5.4.6 Pine and Rices Creek subcatchment

General description

The Pine and Rices Creeks subcatchment encompasses Pine and Rices Creeks, Long Gully and the main channel of the Wakefield River, south of Auburn to 1 km east of the junction with Skillogalee Creek. The dominant land use is grazing of livestock and cropping. Currently, there is little viticulture development in this subcatchment.

Pine and Rices Creeks are ephemeral systems with some small permanent pools of typically saline water quality. These creeks are dry channels for most of the year, flowing only after a period of heavy rain. The Wakefield River main channel is dominated by groundwater fed permanent pools that probably provide important refuges for aquatic animals during summer months.

Watercourses in this subcatchment have degraded stream channels with a 'gully-like' appearance, very little in-stream structure and generally steep banks (Thoms, 1999).

Current condition

Riparian vegetation in this subcatchment is fairly degraded with key threats being uncontrolled stock access, and exotic trees and weeds. The most common issue in this subcatchment was lack of native watercourse vegetation (Map 1). The dominant form of riparian vegetation is now annual exotic grasses or cropping plants with or without a very sparse overstorey of native and/or exotic trees.

This lack of native vegetation highlights the need to maintain and improve areas of good watercourse vegetation. A small patch of degraded remnant riparian vegetation with native shrub and grass species is located along Pine Creek. In some sections of Pine and Rices Creeks there is a good overstorey of river red gums and/or blue gums and peppermint box, however grazing and exotic plant species have impacted on the understorey layer. These areas would respond well to rehabilitation efforts. Pine and Rices Creeks are dry for most of the year and do not support in-stream vegetation. Dense stands of in-stream vegetation dominated by the native reeds, *Phragmites* and *Typha* are found along the main channel of the Wakefield River.

Exotic trees and weeds were not a significant problem in this subcatchment. Where they are present, management is required to ensure they do not spread along the watercourse.

Two large erosion heads upstream of the Main North Road bridge require on-ground stabilisation works. There are two small erosion heads, located on Rices Creek and on a tributary of Pine Creek. These appear to be stable but need to be monitored to ensure they do not continue to erode further upstream. Banks typically had a moderate stability rating (Map 5), indicating that they have the potential to undergo active erosion if they are not managed to control grazing and ensure a cover of protective vegetation.

Community consultation

At the first community meeting held with landholders from the Pine and Rices Creeks subcatchment a range of issues of concern were identified (Table 5.11). The main concerns were impacts on stream flows, weeds and erosion. Landholders also observed that the condition of watercourses had stabilised since the introduction of improved land management practices eg contour banking, minimum tillage and stubble retention, in the mid-1980s.

Table 5.11: Watercourse management issues in the Pine and Rices Creeks subcatchment as identified by landholders.

Watercourse Management Issue	Number of Votes
Impacts on flows* eg dams	32
Weeds eg wild artichoke, tomato weed, bathurst burr, onion weed, horehound	24
Erosion issues eg bend erosion	16
Lack of trees on banks	6

** Flow issues are addressed in Chapter 6.*

Watercourse management priorities and options

The project team, in consultation with landholders, identified watercourse management issues for the Pine and Rices Creeks subcatchment. The locations of these issues in the subcatchment are illustrated in Figure 5.6. A final priority list of issues including options for management and length of stream affected is outlined in Table 5.12. Priorities for watercourse management in the Pine and Rices Creeks subcatchment include:

1. **Protecting areas of good riparian habitat.** This site has a diverse range of native vegetation on banks and floodplain.

2. **Maintaining and/or improving areas of good native vegetation.** These areas have a good native overstorey on banks and floodplain and/or in-stream vegetation but are threatened by degrading processes.

3. **Unrestricted stock access.** Uncontrolled stock grazing destroys native riparian vegetation, prevents natural regeneration and causes low level, widespread bank erosion.

4. **Woody and herbaceous weeds and exotic trees, eg dog rose, wild artichoke, conifers, and peppercorn trees.** Exotic trees and weeds are an issue due to their impacts on river habitat and their ability to spread rapidly along the watercourse. Moderate to dense stands of exotic trees have the potential to cause flooding.

5. **Lack of native riparian vegetation on banks and floodplain.**

6. **Erosion heads.** Erosion heads are symptoms of bed deepening.

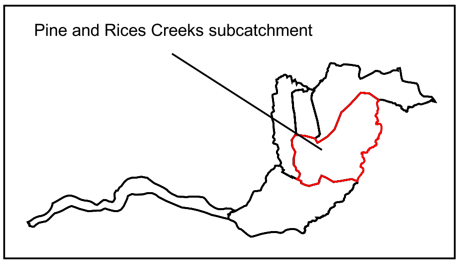
Table 5.12: Pine and Rices Creek subcatchmentwatercourse management priorities and options

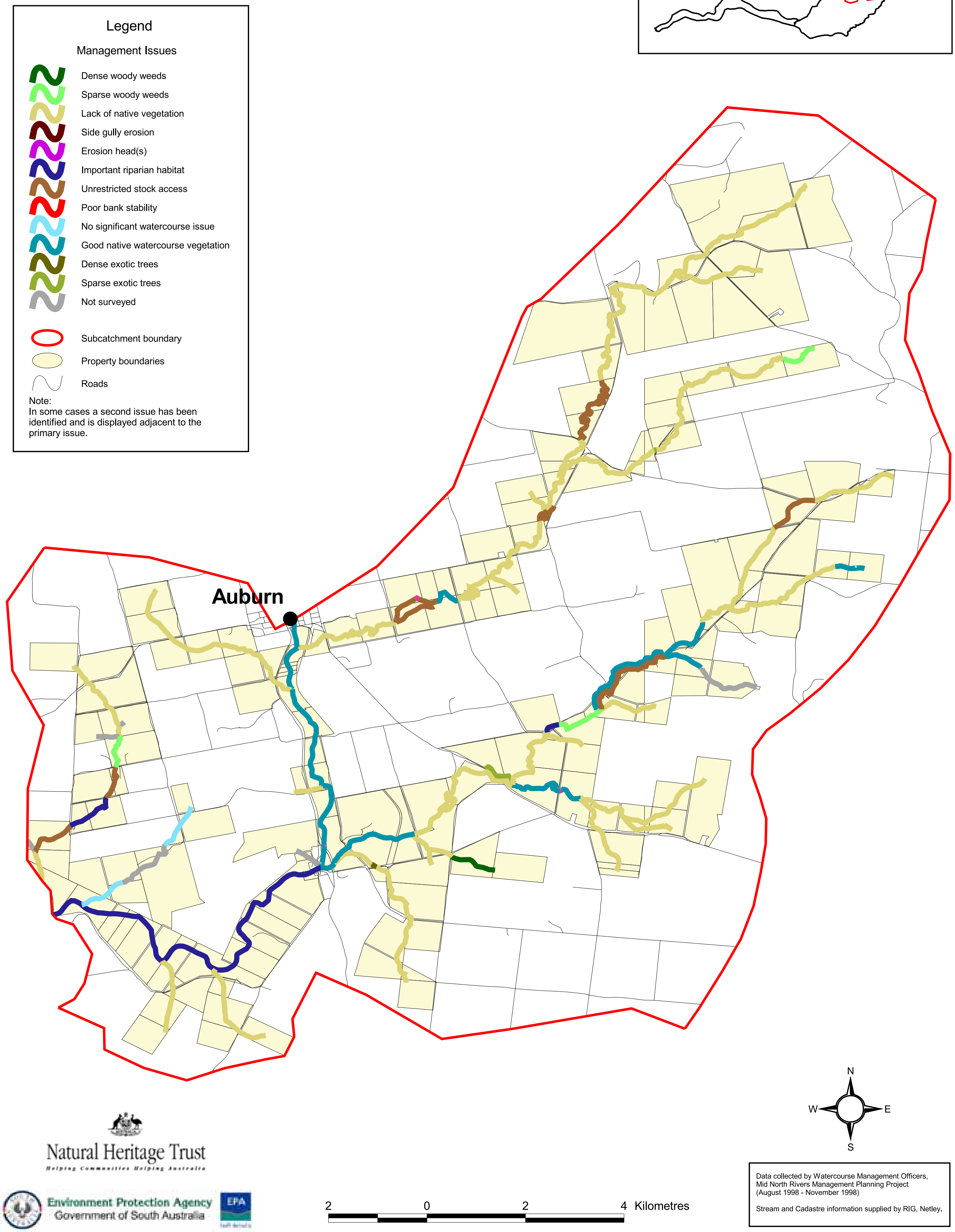
Priority	Management Issue	Management Options	Length (km)
1	**Protecting areas of good riparian habitat.** This site has a diverse range of native vegetation on banks and floodplain.	A: Monitor site to observe any adverse events. B: Control threatening processes eg weeds and stock access C: Control threatening processes and revegetate banks and floodplain with locally indigenous overstorey and understorey species	8.6
2	**Maintaining and/or improving areas of good native vegetation.** These areas have a good native overstorey on banks and floodplain and/or in-stream vegetation but are threatened by degrading processes.	**Stock present:** A: Restrict stock access and control weeds to encourage natural regeneration. B: Restrict stock access, control weeds and revegetate with appropriate native species. **No stock present:** A: Control weeds and revegetate with appropriate native species.	12
3	**Unrestricted stock access.** Uncontrolled stock grazing destroys native riparian vegetation, prevents natural regeneration and causes low level, widespread bank erosion.	A: Restrict stock access and control weeds to encourage natural regeneration. B: Restrict stock access, control weeds and revegetate with appropriate native species.	9.2

Table 5.12 (cont.): Pine and Rices Creek subcatchment watercourse management priorities and options

Priority	Management Issue	Management Options	Length (km)
4	**Woody and herbaceous weeds and exotic trees, eg dog rose, wild artichoke, conifers, peppercorn trees.** Exotic trees and weeds are an issue due to their impacts on river habitat and their ability to spread rapidly along the watercourse. Moderate to dense stands of exotic trees have the potential to cause flooding.	**Exotic trees and woody weeds** A: Remove exotic trees and woody weeds and revegetate with appropriate native species. B: Remove exotic trees and woody weeds, revegetate with appropriate native species and undertake long term exotic tree control. **Herbaceous weeds** A: Control weeds B: Control weeds and revegetate with locally native species. NB: A program of revegetation is needed once moderate to dense stands of trees and woody weeds are removed to prevent any erosion problems and to re-establish habitat.	3.6
5	**Lack of native riparian vegetation on banks and floodplain**.	**Stock present:** A: Restrict stock access and control weeds to encourage natural regeneration. B: Restrict stock access, control weeds and revegetate with appropriate native species. **No stock present:** A: Control weeds and revegetate with appropriate native species.	57.2
6	**Erosion heads.** Erosion heads are symptoms of bed deepening.	A: Fence and revegetate, monitor site. B: Construct erosion control works, fence and revegetate. NB: Consideration needs to be given to severity of erosion, erodibility of bed or banks and location of control features eg rock bars/culverts.	n.a.

Figure 5.6:
Pine and Rices Creeks subcatchment issues map





Data collected by Watercourse Management Officers, Mid North Rivers Management Planning Project (August 1998 - November 1998)

Stream and Cadastre information supplied by RIG, Netley.

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5.4.7 Upper Wakefield subcatchment

General description

The Upper Wakefield subcatchment encompasses the main channel of the Wakefield River above Auburn and the Mintaro, Kadlunga, Wookie and Honey Suckle Creeks. The dominant land use is cropping and grazing of livestock with viticulture occurring along the Wakefield River below its confluence with Honey Suckle Creek.

The reach of the Wakefield River above its confluence with Wookie Creek has a 'chain of ponds' morphology. Typically there is no continuous channel, instead the river comprises a series of a well vegetated, permanent pools connected by small channels. Relatively little morphological change has occurred since European settlement, providing a picture of how the incised watercourses in the Eyre Creek, and Pine and Rices Creeks subcatchments would have once looked.

Despite a lack of native trees and understorey species, there is a good diversity of in-stream vegetation. In areas where stock grazing has been excluded for some time a number of native grass species were observed. It is likely that this reach of the river would respond well to river rehabilitation works. The main threats to this area are uncontrolled stock access to the river.

Typically, the rest of the Wakefield River and the Mintaro, Kadlunga, Wookie and Honey Suckle Creeks have heavily eroded stream channels. Consequently, these watercourses have a box shaped appearance with little in-stream physical structure and generally steep banks.

Community input

Community meetings with landholders from the Upper Wakefield subcatchment were held together with landholders from the Eyre Creek subcatchment. At the first community meeting, landholders identified a range of issues of concern (Table 5.9). The main concerns across the two subcatchments were impacts on stream flows, exotic trees and poor water quality. Landholders felt that the upper reaches of the Wakefield River were generally in good condition and that there was less surface runoff and watercourse erosion because of better land management practices.

Current condition

Several areas of good riparian habitat were identified along the upper section of the Wakefield River. The majority of the Wakefield River main channel is covered by native in-stream vegetation, predominantly *Phragmites* and *Typha*. Overall, however riparian vegetation is quite degraded with a dominant vegetation of annual exotic grasses and a very sparse overstorey of natives and/or exotic trees. In these areas with a lack of native vegetation, the riparian zone offers little to the aquatic environment in terms of shade or organic matter.

A number of areas with a good range of native in-stream vegetation were identified along the Wakefield River main channel upstream of Honey Suckle Creek. As these areas appear to be in a state of recovery, it is likely they would respond well to revegetation and other river rehabilitation works.

Exotic trees and weeds, stock grazing and lack of native vegetation were the main threats along watercourses of this subcatchment. Invasion by exotic trees (predominantly ash trees), olives and woody weeds eg dog rose is a problem along Kadlunga Creek and where the river and its tributaries flow through the township of Mintaro. Landholders have commented that 35-40 years ago, the ash trees and other exotic vegetation were not present along the watercourses.

There are two erosion heads, located on Honey Suckle Creek and a small tributary of the Wakefield. These appear to have stabilised but need to be monitored to ensure they do not continue to erode further upstream. Typically banks had a moderate or good stability rating (Map 5). Banks with moderate stability have the potential to undergo active erosion if they are not managed to control grazing and ensure a cover of protective vegetation. There was an area of poor bank stability along Wookie Creek caused by unrestricted stock access. Stock management and revegetation would help prevent further erosion.

Watercourse management priorities and options

The project team, in consultation with landholders, identified watercourse management issues for the Upper Wakefield subcatchment. Their locations in the subcatchment are illustrated in Figure 5.7.

These issues and potential solutions were presented to landholders at a meeting held on Thursday, 29 October 1998. Because few landholders were able to attend the meeting watercourse management priorities for this subcatchment were determined initially by project staff. This draft priority issue list was sent to landholders for comment before producing the final priority list and management options outlined in Table 5.13. Priorities for watercourse management in the Upper Wakefield River subcatchment include:

1. **Protecting areas of good riparian habitat.** These areas had a diverse range of native riparian and in-stream vegetation, permanent pools of various depths and generally good water quality.

2. **Maintaining and/or improving areas of good native vegetation.** These areas typically had a diverse range of native in-stream vegetation but lacked any native overstorey on banks/floodplain or were threatened by degrading processes eg stock access, weeds.

3. **Unrestricted stock access.** Uncontrolled stock grazing destroys native riparian vegetation, prevents natural regeneration and causes low level, widespread bank erosion.

4. **Exotic trees, woody and herbaceaous weeds eg ash, willows, olives, dog rose, wild artichoke**. Exotic trees and weeds are an issue due to their impacts on river habitat and their ability to spread rapidly along the watercourse. Moderate to dense stands of exotic trees have the potential to cause flooding.

5. **Erosion heads.** Erosion heads are symptoms of bed deepening.

6. **Lack of native riparian vegetation on banks and floodplain.**

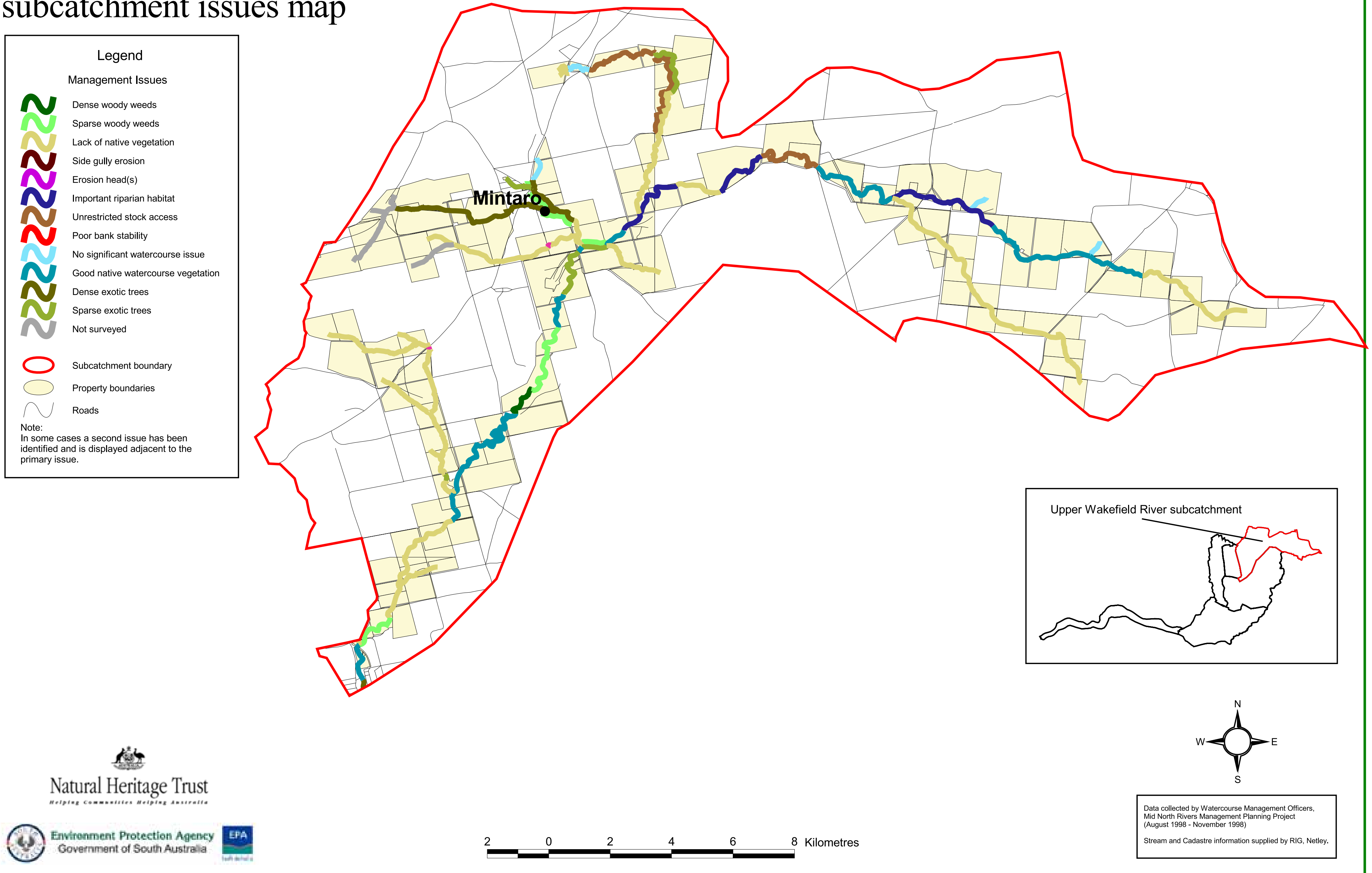
Table 5.13: Upper Wakefield subcatchment watercourse management priorities and options

Priority	Management Issue	Management Options	Length (km)
1	**Protecting areas of good riparian habitat.** These areas had a diverse range of native riparian and in-stream vegetation, permanent pools of various depths and generally good water quality.	A: Monitor site to observe any adverse events. B: Control threatening processes eg weeds and stock access. C: Control threatening processes and revegetate banks and floodplain with locally indigenous overstorey and understorey species.	6.0
2	**Maintaining and/or improving areas of good native vegetation**. These areas typically had a diverse range of native in-stream vegetation but lacked any native overstorey on banks/floodplain or were threatened by degrading processes eg stock access, weeds.	**Stock present:** A: Restrict stock access and control weeds to encourage natural regeneration. B: Restrict stock access, control weeds and revegetate with appropriate native species. **No stock present:** A: Control weeds and revegetate with appropriate native species.	13.5
3	**Unrestricted stock access.** Uncontrolled stock grazing destroys native riparian vegetation, prevents natural regeneration and causes low level, widespread bank erosion.	A: Restrict stock access and control weeds to encourage natural regeneration. B: Restrict stock access, control weeds and revegetate with appropriate native species.	3.7

Table 5.13 (cont.): Upper Wakefield subcatchment watercourse management priorities and options

Priority	Management Issue	Management Options	Length (km)
4	**Exotic trees, woody and herbaceous weeds eg ash, willows, olives, dog rose, wild artichoke**. Exotic trees and weeds are an issue due to their impacts on river habitat and their ability to spread rapidly along the watercourse. Moderate to dense stands of exotic trees have the potential to cause flooding.	**Exotic trees and woody weeds** A: Remove exotic trees and woody weeds and revegetate with appropriate native species. B: Remove exotic trees and woody weeds, revegetate with appropriate native species and undertake long term exotic tree control. **Herbaceous weeds** A: Control weeds B: Control weeds and revegetate with locally native species. *NB: A program of revegetation is needed once moderate to dense stands of trees and woody weeds are removed to prevent any erosion problems and to re-establish habitat.*	13.4
5	**Erosion heads**. Erosion heads are symptoms of bed deepening.	A: Fence and revegetate, monitor site. B: Construct erosion control works, fence and revegetate. *NB: Consideration needs to be given to severity of erosion, erodibility of bed or banks and location of control features eg rock bars/culverts.*	n.a.
6	**Lack of native riparian vegetation on banks and floodplain.**	**Stock present:** A: Restrict stock access and control weeds to encourage natural regeneration. B: Restrict stock access, control weeds and revegetate with appropriate native species. **No stock present:** A: Control weeds and revegetate with appropriate native species.	33.4

Figure 5.7: Upper Wakefield River subcatchment issues map



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6. ENVIRONMENTAL WATER REQUIREMENTS

6.1. Introduction

Environmental water requirements are defined as water regimes needed to sustain the ecological values of water dependent ecosystems. The process and outcomes of the assessment of environmental water requirements for the Wakefield River system is discussed in this chapter. The current hydrology of the Wakefield catchment is outlined in Section 6.2. A general overview of the water requirements of dependent ecosystems, fish and macroinvertebrates found in the Wakefield River system is provided in Section 6.3. Section 6.4 describes the physical and ecological environments in each geomorphic zone of the Wakefield River system. Flow levels important for the physical and ecological functioning of each zone and key management issues are outlined. Section 6.5 summarises the flow bands for the entire system, discusses their function and importance and examines if these flows are currently being met under the current hydrological regime. The chapter concludes (Section 6.6) by identifying five key flow principles to observe in management of the Wakefield River water resource.

6.2. Hydrology

The Wakefield River catchment is an ephemeral system, characterised by irregular flows and long dry intermediate periods. The typically low soil moisture levels mean that most of the rainfall is absorbed into the landscape and riverbed. When flows do occur, they do so as a pulse of water rather than a slow incremental flow (D Cresswell, pers com).

The existing flow regime in the Wakefield River system is modified from pre-European conditions. Clearing and agricultural development following settlement resulted in increased surface flows. These excess surface flows have been somewhat ameliorated in more recent times with improved land management practices such as contour banking, minimum tillage and improved pastures and the impacts of farm dams.

The heaviest use of groundwater and surface water resources is in the Clare Valley. Due to this intensive irrigation development pressure, the Clare Valley region was prescribed as the Clare Valley Prescribed Wells Area and Watercourses in 1996. This introduced controls on dam development and groundwater extraction within the prescribed area.

The Wakefield River has one gauging station which is located near Rhynie at the centre of the catchment (refer to Figure 3.2). The catchment above the gauging station is 417 km^2. While the gauging station has been operational since 1953 the quality of the early record is extremely suspect. Early gauging suffered from silting and the occasional mechanical breakdown, which has left the record disjointed between 1953 and 1973 and not suited to direct calibration. Since 1974 the record is continuous with a high quality rating. Figure 6.1 shows the amount and variability of flow recorded in the Wakefield River over 23 years.

A significant percentage of the water supplied to the Wakefield River is contributed from the areas of higher topography (500-600 m), and higher rainfall, located within the southern Clare Valley. The highest rainfall of 650 mm occurs in the area surrounding Watervale and Sevenhill. Rainfall reduces rapidly toward the south, falling to 500 mm at Auburn and 450 mm at Riverton (see Figure 3.4). Table 6.1 compares flow contributions for major tributaries upstream of the gauging station. The runoff from the Skillogalee and Eyre Creeks greatly exceeds their catchment proportion in comparison to the drier streams such as Pine Creek.

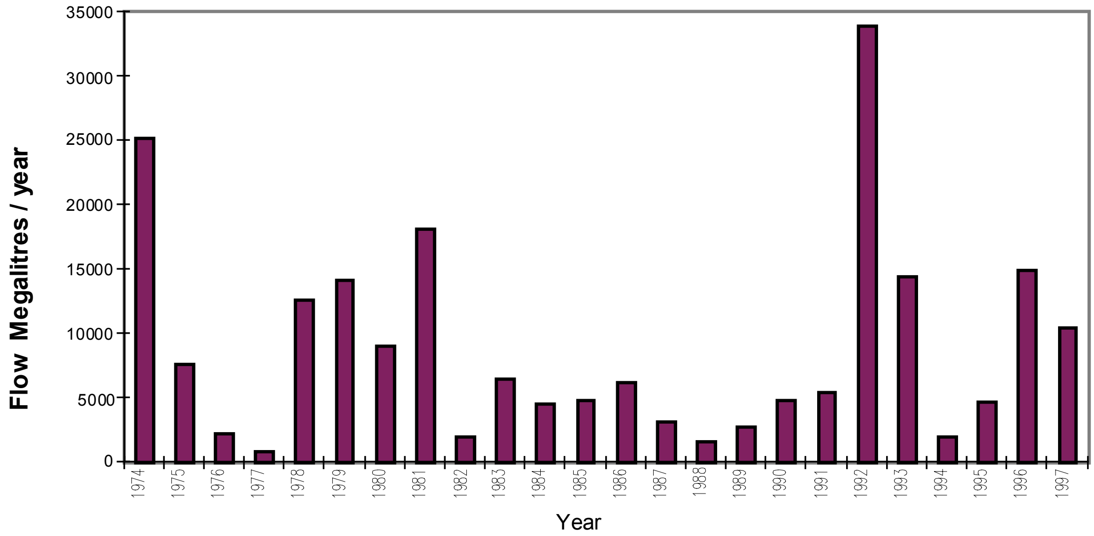


Figure 6.1: Mean annual flow since 1974.

Table 6.1: Flow contribution upstream of the gauging station

River Section	Catchment Area (km²)	Mean runoff (ML/year)	Median runoff (ML/year)	Catchment proportion (%)	Runoff proportion (%)
Skillogalee Ck	81.8	3000	1800	19.6	27
Eyre Ck	27.0	1220	750	6.5	11
Pine Ck	52.0	460	250	12.5	4
Upper Wakefield	18.1	3100	1500	28.0	28
Mid Wakefield	254.9	7600	4000	61.0	69

Below the gauging station the river flows westwards onto the Wakefield plains (30–40 m above sea level) where it receives significantly less rainfall. The mean annual rainfall at Balaklava is 390 mm reducing to 340 mm at Port Wakefield. The lower levels of rainfall and the dispersive nature of the plains topography mean this area contributes little in terms of water resource to the river flow.

The Wakefield River system is dependent on groundwater driven baseflow, which maintains streamflow and permanent pools, primarily along the Wakefield River main channel and sections of the Skillogalee and Eyre Creeks, throughout the driest months. Most of this flow enters the Wakefield River from the Skillogalee and Eyre Creeks with a magnitude related to the previous season. While reasonably constant the baseflow does vary throughout the year increasing as evaporation decreases toward the winter months. Baseflow further increases through winter as a consequence of soil moisture increase and local aquifer discharge.

Downstream of the gauging station to The Rocks, the stream flows most of the year due to groundwater driven baseflow. The stream is slightly gaining and although the change in volume of baseflow appears to be minimal there is a slight increase in salinity recorded over this reach.

From The Rocks to just downstream of Balaklava the reach loses much of its lower surface flows into the sandy stream bed and baseflow passing The Rocks fails to reach Balaklava. The Wakefield River from just downstream of The Rocks to the sea will only flow following significant rainfall events. It is estimated that a flow at the gauging station of at least 1 cumec for 1 day is necessary to overcome the initial and continuous losses and reach the sea.

From downstream of Balaklava to the sea the stream once again becomes a slightly gaining one although no continuous baseflow occurs along its length. High watertables (above the bed of the Wakefield River) occur between Whitwarta and Bowmans and create permanent ponds of water in the stream bed. The extremely high salinity of these ponds (recordings of 12 000 mg/L taken at Whitwarta and 40 000 mg/L at Bowmans) is due to groundwater inflow and significantly reduces the ecological value of these ponds.

Different elements within the catchment will influence the hydrology of the system by differing amounts. Farm dams are most likely to impact on the lower flow ranges, groundwater extraction will impact on baseflows and land clearance will result in an increase in the frequency of high flow events.

6.3 Water requirements of dependent ecosystem components

A wide range of ecosystems are either totally or partially dependent on water to support the ecological processes and the biodiversity of their floral and faunal components. These ecosystems include the in-channel environment of rivers and streams, the riparian zone, floodplains, wetlands, lakes and estuaries. Plants and animals depend upon the various habitats provided within these environments. These include pools, runs, riffles, bars, terraces and floodplains. Some species are tolerant of a wide range of environmental conditions and so are distributed throughout many habitats, others have narrow tolerances of conditions and so are limited to specific habitats. The health, condition and the diversity of habitat within these ecosystems depend upon various hydrological factors. These include the frequency and size of flow events in conjunction with the variability, timing and duration of the flows. The amount and quality of groundwater is also an important component in the maintenance of water dependent ecosystems.

The assessment of environmental water requirements involved identifying key water-dependent ecosystem components of the Wakefield River system. An overview of vegetation, fish and macroinvertebrates is provided in this section. The relationship between these components and river morphology, physical habitat and flow regime is discussed in relation to river geomorphic zones in Section 6.4.

6.3.1 Vegetation

Riparian and floodplain vegetation

Most of the catchment has undergone a significant vegetation change since agricultural development. In general, areas of remnant vegetation are associated with steep slopes and skeletal soils. Nearly all the low lying and floodplain vegetation has been removed for agriculture purposes. The vegetation on the banks and floodplains of streams has been significantly modified and is now reduced to a narrow band (<20 m) on either side of the stream bank. Native understorey vegetation (ie shrubs and/or native grasses) is absent in the majority of riparian zones and has been replaced by annual grasses and weeds.

Clearance and agricultural use has also removed most of the wetland environments on the floodplains, however some lignum (*Muehlenbeckia* spp.) and tea tree (*Melaleuca* spp.) swamps still exist on the coastal floodplain of the Wakefield River. Ephemeral wetlands on floodplains are considered to be one of the most productive of ecological systems (Halse and Jensen, 1993). This is because the large variability in the wetting and drying sequences of the wetland provides a wide range of food sources and habitat diversity.

The composition and abundance of vegetation associations is highly correlated to geomorphic and hydrological variability along the Wakefield River system. The variability, duration and magnitude of flow events are important for maintaining species composition, diversity and abundance. The variability of flow regimes provides some species with a window of opportunity to establish without direct competition from other species, influencing species composition and consequently habitat diversity. For example, recruitment of *Eucalyptus* species is favoured by summer flooding, while grasses are advantaged by winter-spring floods (Bren, 1992). Overbank flows are important for the maintenance and recruitment of riparian and floodplain vegetation, especially river red gums. These flows also help to exchange seed sources and cycle organic matter.

Water quality has a significant effect on the biotic composition of vegetation within the Wakefield River system. Hart et al (1991) stated that riparian vegetation starts to become affected by salinity at levels above >2000 mg/L. In-stream aquatic vegetation (macrophytes) become affected (loss of vigour and reduced species diversity) at levels of 1000–2000 mg/L. This indicates that pools containing very high levels of salinity (ie around Whitwarta) will contain little in-stream vegetation. Certain flows are likely to be important in 'freshening' the system and maintaining water quality. Changes to seasonal salinity levels due to altered flow patterns are likely to affect the germination and health of riparian and aquatic plant species.

Riparian vegetation has the potential to add significant amounts of carbon into the river system. Carbon inputs provide an energy source that maintains ecosystem productivity. Flood events that maintain the river-floodplain connections are therefore important for exchange of nutrients and organic matter required for ecological processes within the river system.

In-stream vegetation

Due to the ephemeral nature of the river system, most in-stream vegetation is associated with significant pools and areas maintained by springs and seeps. In-stream vegetation in the Wakefield is considered to be in poor condition (Sheldon et al, 1999). Submerged and floating plant species are poorly represented in the Wakefield River system, while the emergent macrophytes (reeds) are dominated by *Phragmites* and *Typha* that extend throughout much of the main channel of the Wakefield River. This minimal diversity of in-stream vegetation provides a limited source of food and habitat for aquatic fauna.

Fluctuations in water flow can reduce the dominance of certain aquatic vegetation, increasing habitat diversity and nutrient availability. Periods of no flow resulting in the drying out of a river bed allow terrestrial vegetation to encroach into this environment. Baseflows are important for maintaining pool habitats, aquatic vegetation and emergent macrophytes in dry periods. Low flows are very important for maintaining water quality. The consistent movement of low salinity, oxygenated water through pools prevents the process of eutrophication, which reduces the potential for algal blooms. Higher velocity flows can scour the bed of the stream reducing the extent of reed beds, enlarging the size of pools and increasing habitat diversity. However, intense high velocity flows can cause extensive erosion.

Saltmarsh vegetation

Low-lying saltmarshes are located on the coastal floodplain of the Wakefield River. Saltmarshes are highly productive ecosystems (Woodcock, 1992). They are important habitat for birds and insects and accumulate silt and organic matter, providing the local environment with a rich source of nutrients (Rose and McComb, 1995). They act as a buffer zone between the saline estuarine water and the relatively fresh water flowing in from the hinterland.

The composition of plant species varies with the balance of fresh and salt-water flows. For example, plants of lower salt tolerance tend to encroach into areas of higher salinity after large freshwater flows in winter. Changes to the timing and volume of these flows could alter the distribution and extent of plant communities and the estuarine and aquatic invertebrates that inhabit them (Keally et al, 1995).

Estuarine vegetation

The extensive mangrove environment around Port Wakefield is another highly productive ecosystem. These areas are reliant upon the nutrients, detritus and silt that originate from higher up in the catchment. Regular seasonal flows are required to maintain the productivity of these areas. These flows convey both sediment, which maintains the estuarine beds that support the mangrove swamps, and detritus, which provides a valuable food source for estuarine fauna and flora. These areas also provide important breeding grounds for fish, birds and macroinvertebrates and protect the coastline from the erosive influence of the marine environment.

6.3.2 Macroinvertebrates

More than 240 types of macroinvertebrates were collected from the Wakefield River catchment. Macroinvertebrates collected from the system were composed predominantly of species that are tolerant of a wide range of environmental conditions and are common and widespread in South Australian rivers (McEvoy and Madden, 1998). The most common macroinvertebrates were chironomid and simuliid larvae, nematode and oligochaete worms, springtails and flatworms. Hydrobiid snails, chironomids and caddis fly larvae (*Cheumatopsyche* sp.), which favour flowing water, also occurred in significant numbers. The caddis fly larvae and the less common black fly (*Simulium ornatipes*) are riffle dwelling, filter feeders that play a critical role in making nutrients available to other fauna. Two taxa – a type of mayfly and a type of caddis fly larva – were found only in creeks (McEvoy and Madden, 1998).

Environmental factors that affect macroinvertebrate species composition are flow rates, the timing of flows, substrate type and size, salinity, the temperature of water, oxygen levels and habitat availability.

Macroinvertebrate species have differing life cycles that require varying flow regimes. Those that avoid flow (chironomids, oligochaetes, tipulids, psychodids) are found in areas that contain both high in-stream roughness and refuge areas. Refuges include large stable substratum particles, low flow zones such as pools, nearby tributaries and floodplains (Growns and Davis, 1994). These features occur in areas characterised by low stream gradients. Other species have a requirement for flowing water to fulfil all or at least part of their life cycle (McEvoy and Madden, 1998). Black flies (simuliid) and retreat dwelling caddis flies (Trichoptera) are mostly filterers and so food distribution is aided by turbulence (Growns and Davis, 1994). These features occur in areas characterised by high stream gradients.

Macroinvertebrates that can live in areas of flows but aren't specially adapted, eg mites, scuds and side swimmers (Amphipoda), dragonflies (Anisoptera), stone flies (Plectoptera) and mayflies (Leptophlebiidae) were found at sites with high substrate roughness which provide areas of reduced flow close to the substrate surface (Growns and Davis, 1994). Aquatic bugs (Notonectidae and Corixidae), that live within the water column also accumulate in areas of reduced flow. Specialist species exist where aquatic environments provide relatively consistent conditions that will allow species to both adapt to specific conditions and regularly complete their life cycle. Species diversity is found to be the highest in mid reaches where there is high variability of in-stream surface roughness and flow velocity (Growns and Davis, 1994).

The substrate particle size of in-stream environments also affects species diversity. The smaller the size of the average particle, the less rich the community. This is because areas composed of smaller sediments have a smaller range of habitat types and experience greater flow disturbance than sites with larger substrate size (Townsend et al, 1997). Species richness is higher in communities that feature a balance between low and high hydrological disturbance. These intermediate levels of disturbance create a wider range of habitats that allow both rapid coloniser type species as well as more competitive species to inhabit the same environment (Townsend et all, 1997; Clausen and Biggs, 1989). These sites occur in steeper gradient areas in the Wakefield River such as The Rocks and the Skillogalee Creek. Low flows and drought periods tend to reduce habitat and biotic diversity.

Identification of sensitive insect orders is one method of determining the relative health of various sites. Caddisflies (Trichoptera), mayflies (Ephemeroptera), stoneflies (Plecoptera) contain species that are easily affected by disturbance and poor water quality, are sensitive to environmental change and are characteristically poor colonisers (De Moor, 1992). Dragonflies (Odonata), waterbugs (Hemiptera), fly larvae (Diptera) and beetles (Coleoptera) contain many species which show excellent coloniser and invader qualities and adapt relatively easily to change (De Moor, 1992). Hicks and Sheldon (1998) show that the macroinvertebrate sites assessed within the section of the Wakefield River from The Rocks to and including the Skillogalee Creek contained the highest abundance and range of sensitive taxa (Plecoptera, Ephemeroptera and Trichoptera).

Macroinvertebrates are more sensitive to salinity with some species such as stoneflies (Plecoptera), some mayflies (Ephemeroptera), caddisflies (Trichoptera), dragonflies (Odonata) and some waterbugs (Hemiptera) affected at salinity levels of 1000 mg/L (Hart et al, 1991). These figures are supported by ANZECC water quality guidelines (ANZECC, 1992), which recommended salinity levels of below 960 mg/L for the protection of aquatic ecosystems.

Water quality in the Wakefield River is highly variable and very dependent on flow. The salinity level of this surface water was studied between 1978 and 1983 (Glatz, 1985). The results showed that salinity varied between 250 mg/L and 4128 mg/L. The median value was 2700 mg/L. This could explain why some sensitive macroinvertebrates, such as stoneflies (Plecoptera), were not found in the Wakefield River system and why leptophlebiid mayflies were most abundant in the Skillogalee Creek which has lower levels of salinity (McEvoy and Madden, 1998).

The duration of in-stream flows can also affect some macroinvertebrate species. Stoneflies (Plecoptera) generally require flows that extend for a period of five to six months to develop fully from nymphs to adults. This may be an additional factor as to why stoneflies have not been identified in the Wakefield River system.

Current research (O'Connor, 1993; McKie and Cranston, 1998; Wotton et al, 1998) suggests that some aquatic macroinvertebrates known as 'keystone taxa' play a significant ecological role in river systems by influencing the diversity and organisation of communities. Filter feeders such as black fly (*Simuliidae ornatipes*) and caddis fly (*Cheumatopsyche* sp.) can produce nutrient hot spots by ingesting a wide range of organic matter and processing these nutrients in the form of faecal pellets. This enhances the growth of algae and increases detrital aggregates, therefore increasing food resources for other macroinvertebrates (O'Connor, 1993; Wolton et al, 1998). To maintain a productive habitat for *Cheumatopsyche* sp. and *Simulium ornatipes* reliable flows that also maintain a stable substratum are required.

To achieve a healthy macroinvertebrate ecosystem a range of processes need to be provided: maintenance of good water quality; flows that mimic the natural system; the maintenance of sediment free riffle zones; the enhancement and protection of sufficient habitat; and refuge zones for keystone species.

6.3.3 Fish

The overall results from a fish survey of the Wakefield River by Hicks and Sheldon (1998) show that numbers of native fish in the Wakefield River were very low in terms of frequency and species diversity. The results from the 'index of biotic integrity' suggest that the Wakefield River in terms of native fish ecology is in poor condition (Hicks and Sheldon, 1998).

Native fish found include blue spot goby found upstream and at the estuary, tandanus catfish at The Rocks and hardyhead, yellow-eyed mullet and sea mullet in the estuary. Species, which rely on migration to and from the sea to maintain populations, were notably absent. The discovery of native tandanus catfish at The Rocks (Mobile zone) is indicative of high habitat value of this area. These catfish are believed to have been introduced from the River Murray (Hicks and Sheldon, 1998). Exotic species recorded include goldfish, gambusia (mosquito fish) and brown trout. There appear to be problems with predation and competition from exotic fish species eg trout, mosquito fish. The presence of mosquito fish at most sites studied in the Wakefield except for the estuary suggests habitat degradation – these fish have wide temperature and salinity tolerances (Hicks and Sheldon, 1998).

The Wakefield River estuary (Site 2ES) had the highest biotic integrity with four out of the eight expected species present. From Port Wakefield to The Rocks no fish were observed in pools maintained by surface or groundwater flows. This was probably due to the dry environment of the river channel, the high salinity in the pools and the infrequent flows through this area. There was also little in-stream and riparian vegetation and it was not diverse. This would limit the range and availability of food and shelter for aquatic fauna.

A range of native and exotic fish occur in the river system from The Rocks (Site 200) to the gauging station (Site 202). From the gauging station to Auburn (Site 208) only exotic species were observed. No fish, apart from mosquito fish, were observed at the sites upstream of Auburn. The lack of regular flows, fewer permanent pools and high salinity levels are likely to be limiting factors in the establishment of fish populations in these areas. The environment in the Skillogalee Creek was assessed as habitable, but no fish were observed (Table 6.2). The reasons for this require further assessment.

There was a poor match between the species that were expected at a site and those that were actually observed or captured (Table 6.2). This is essentially due to low and unreliable seasonal flows characteristic of the Wakefield River, poor connectiveness between habitats, poor diversity of in-stream vegetation, and predation and competition from exotic fish.

Table 6.2: Expected (E) native fish species, pre-European disturbance at four sites along the Wakefield River and two of its tributaries and observed (O) fish species.

Scientific name	Common name	Site Number											
		200		202		204		205		208		2ES	
		E	O	E	O	E	O	E	O	E	O	E	O
Native species													
Aldrichetta forsteri	Yellow-eyed mullet											green	red
Amoya bifrenatus	Bridled goby											green	
Atherinosoma microstoma	Small mouth hardyhead											green	red
Galaxias brevipinnis	Climbing galaxias	green		green		green		green		green			
Galaxias maculatus	Common jollytail	green		green				green					
Galaxias olidus	Mountain galaxias					green		green		green			
Geotria australis	Pouched lamprey	green		green				green					
Liza argentea	Flat-tail mullet											green	
Mordacia mordax	Short-headed lamprey	green		green				green					
Mugil cephalus	Sea mullet											green	red
Philypnodon grandiceps	Flat-head gudgeon	green		green		green		green		green			
Philypnodon sp.	Dwarf flathead gudgeon	green		green		green		green		green			
Pseudaphritis urvillii	Congolli	green		green				green				green	
Pseudogobius olorum	Blue spot goby				red							green	red
Retropinna semoni	Australian smelt	green		green								green	
Exotic species													
Carassius auratus	Goldfish		red										
Gambusia holbrooki	Mosquito fish		red		red				red				
Salmo trutta	Brown trout				red								
Tandanus tandanus	Freshwater catfish		red										

***Key to site number** : **200** The Rocks; **202** Near Rhynie; **204** Skillogalee; **205** Auburn; **208** Watervale; **2ES** Port Wakefield near Estuary*

Source: Hicks and Sheldon (1998).

A number of key aspects of the flow regime will influence the distribution, extent and abundance of different native fish species. Migratory fish require connectivity with marine ecosystems for spawning and development in juvenile and adult stages. Most require an adequate flow to the sea once in late autumn/early winter and again in late spring, at least once every three years to complete their life cycles (Hicks and Sheldon, 1998). The rate of fall of a flow event is also important in the migration process, as this can cause stranding of fish in environments inadequate for survival. The species of native fish that rely on migration for completions of their life cycle were noticeably absent from this 'snapshot' survey of fish populations in the Wakefield River system.

Small flows are required to maintain water quality, provide nutrient cycling as well as allowing fish to move between pool habitats. Large flows that cause cobble bed movement, bed scouring and deposition of logs and vegetation are necessary to maintain habitat complexity and provide an influx of food material. Most importantly the timing of natural seasonal flow patterns needs to be maintained to provide for the life cycle processes, such as breeding and migration, required by a wide range of fish species. The Rocks to the gauging station supports a high level of top order native and exotic predators indicating that this reach provides both adequate food resources and good water quality.

6.4. River zone descriptions

6.4.1 River geomorphic zones

The process of determining environmental water requirements for the Wakefield River system involved a number of stages as outlined in Chapter 4. This process involved dividing the river system into distinct geomorphological or process zones. Each zone possesses unique physical and hydrological characteristics that distinguishes it from other parts of the river system and determines the ecological components. Information collected on the biophysical attributes of each zone was used to gain an understanding of habitat types and ecological processes and hence the environmental water requirements for each zone. This section describes the key geomorphic zones and their related environmental attributes. For each zone, important flow levels and their associated functions are identified.

The Wakefield River system was divided into seven key geomorphic zones plus all undefined third order streams were classified as 'ephemeral, undefined' (Figure 6.2). A detailed description of geomorphic zones and the current geomorphological condition of the Wakefield River system is provided in the technical report prepared for the project by Thoms (1999). The seven key zones are:

1. *Lower meandering zone* – Wakefield River main channel from the town of Balaklava to the estuary

2. *Upper meandering zone* – Wakefield River main channel from downstream of The Rocks to Balaklava

3. *Mobile zone* – approximately 2 km downstream of Hermitage Creek to 1 km downstream of The Rocks

4. *Transition zone* – upstream of Robin's Ford to confluence with Skillogalee Creek

5. *Constrained zone* – Skillogalee Creek

6. *Incised zone* – Wakefield River main channel from Skillogalee Creek to Wookie Creek, and Eyre, Pine, Rices, Hermitage and Woolshed Flat Creeks

7. *Chain of ponds zone* – Wakefield River main channel upstream of Wookie Creek.

6.4.2 Lower meandering zone

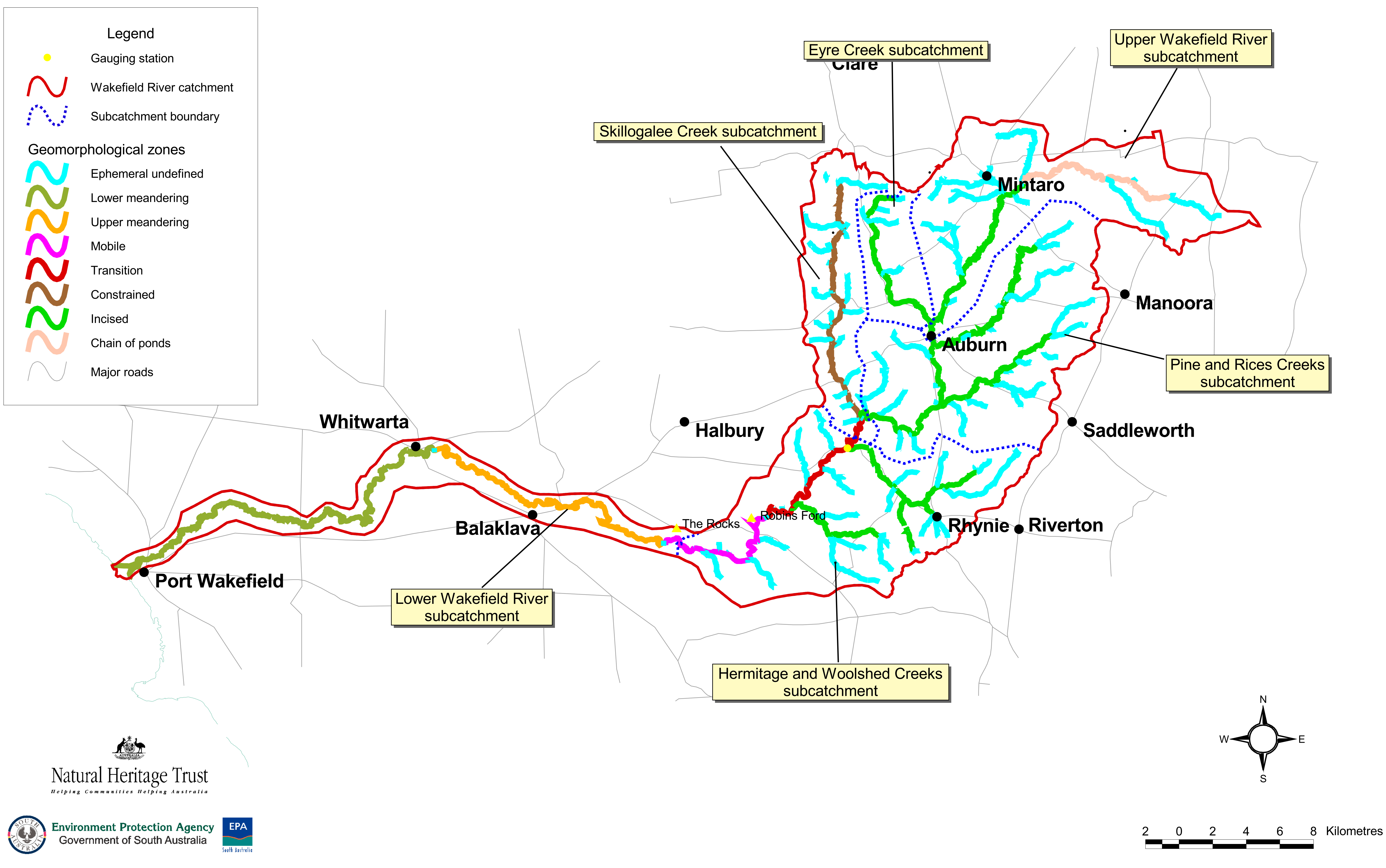
Physical environment

In the Wakefield catchment the meandering zone was subdivided into lower and upper sections (Figure 6.2). This was done for two reasons. First, there was very little evidence of active sediment storage, such as inset benches within the main channel of the Lower meandering zone. Second, the river channel in the Lower meandering zone was 'underfit', being confined to an older palaeo-channel system. An underfit channel is one which is much smaller than expected from the size of its upstream catchment (Thoms, 1999).

The morphology of the in-channel environment of the Lower meandering zone is highly uniform along its length. The dominant physical structure is a 'U' shaped channel with very little internal structure (Plate 6.1; Figure 6.3). River bed sediments are composed of fine sands, silts and clays with a greater silt-clay content than the Upper meandering zone. The cohesive nature of the bank sediment contributes to relatively steeper banks in this zone compared to upstream zones (Thoms, 1999).

Plate 6.1: In-channel profile of the Lower meandering zone, featuring a silt/clay based channel with little in-stream structure.

Figure 6.2:
Geomorphic zones in the Wakefield River catchment



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The ecosystem in this zone has been significantly modified from its original condition. Historically this zone is part of the large distribution system of the lower Wakefield. Multiple flow channels would have dominated the landscape. In the lower areas the river system would have resembled a large coastal swamp with no discernible continuous river channel (Figure 6.3). Recent bed erosion has caused the deepening and subsequent dominance of one flow channel and the resultant loss of connectivity with the floodplain. This channel has very little in-stream physical structure except for three large pools in the vicinity of Whitwarta (Thoms, 1999).

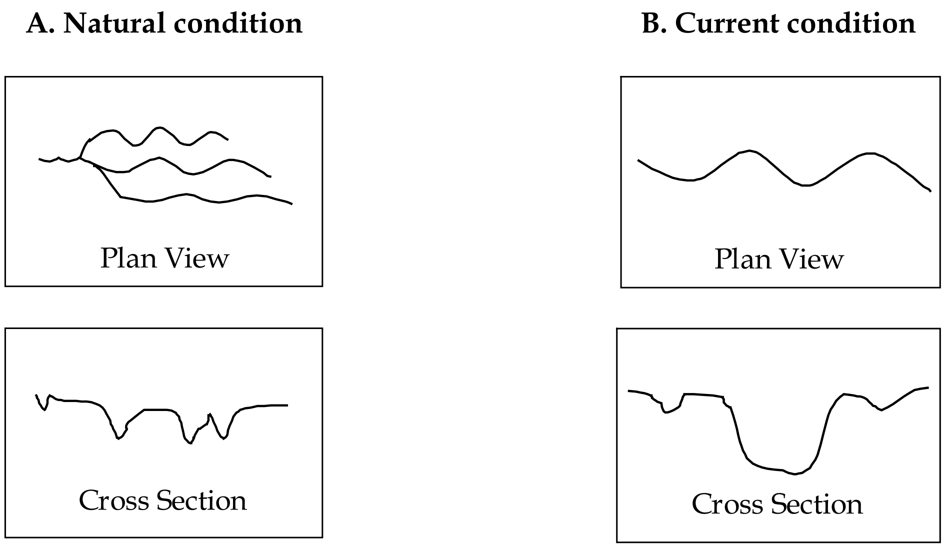


Figure 6.3: Comparison of the natural and current morphological state of the Lower meandering zone (Thoms, 1999).

Ecological environment

The ecology in this zone has been vastly modified from the original distribution channel. There is now very little in-channel habitat and flows concentrated within this section are reduced to episodic events 2–3 times a year (Sheldon et al, 1999). Regular inundation of the floodplain environment has been significantly reduced and most of the ephemeral swamps and fringing vegetation have been cleared and sown to commercial crops. Grazing of domestic animals has also reduced the diversity of vegetation in these areas. The few remaining permanent pools in the zone are maintained by groundwater and remain hypersaline for most of the year; this precludes the establishment of aquatic vegetation within these pools.

The main function of this zone is now as a 'migration' channel between the sea and the permanent freshwater sections in the higher reaches of the catchment. Migration is necessary for the movement of native fish species between the marine and freshwater environment and for the transfer of organic debris from the catchment to the estuary (Sheldon et al, 1999). The highly sporadic nature and short duration of flows in this zone, mean that water is not present long enough to provide an adequate habitat for anything but opportunistic colonisation of generalist macroinvertebrate species.

Important flow levels

The rate of rise and fall of flow events helps to stabilise the channel and prevent stranding of aquatic fauna. Important flow levels to maintain physical and ecological environments in the Lower meandering zone include:

- *Mid flows*: required for fish migration between the freshwater and marine environment
- *High flows*: required for wetting low-lying lignum swamps
- *Floodplain flows*: required for significant riparian inundation and recruitment and maintenance of channel structure and complexity.

Management issues

The ecological health of this region not only involves meeting environmental water requirements but wider land management issues. The riparian zone and floodplain environments of Lower meandering zone have been severely altered and can be considered ecologically degraded. Options to enhance the ecological health of this zone will focus upon reinstating aspects of the original form and function of this zone. These options could include riparian revegetation; protecting and enhancing remnant vegetation associations, eg lignum swamps; reintroducing wetland complexes by increasing floodplain and channel connectiveness and/or creating pools in the lower reaches of the Wakefield River to provide refuge habitat for fish migration between the sea and the upper reaches of the river.

6.4.3 Upper meandering zone

Physical environment

The Upper meandering zone is characterised by a well-defined channel, distinguished by the large amount of alluvial material stored within the channel (Plate 6.2). As a result the morphology of the in-channel environment is variable with the presence of bars (point and lateral) and benches (at various levels). These stores of in-channel sediment reflect the relatively high rates of sediment input to this zone from upstream areas. The river bed sediments contain fine sand, silts and clays. The cohesive nature of the bank sediment contributes to relatively steeper banks in comparison to upstream zones (Thoms, 1999).

The Upper meandering zone was originally characterised by a distributory system with multiple channels (Figure 6.4). One or two of these would have functioned as the main flow channels. There were also many connecting low level flood runners, and an extensive floodplain. Although this is a natural depositional area, excessive sedimentation caused by upstream erosion has resulted in a loss of physical in-stream structure (Thoms, 1999).

Ecological environment

There have been marked changes in the in-channel environment of this zone. Increased sediment supply from upstream erosional zones has resulted in channel contraction with the infilling of pools and the loss of in-channel habitat. Agricultural development has reduced the vegetation within the riparian zone to a width of approximately 20 m from the top bank. The riparian vegetation is dominated by healthy dense stands of river red gums (*Eucalyptus camaldulensis*) but because of unrestricted grazing there is very little understorey vegetation.

Plate 6.2: Typical in-stream environment in the Upper meandering zone, showing organic debris and alluvial material stored within the channel.

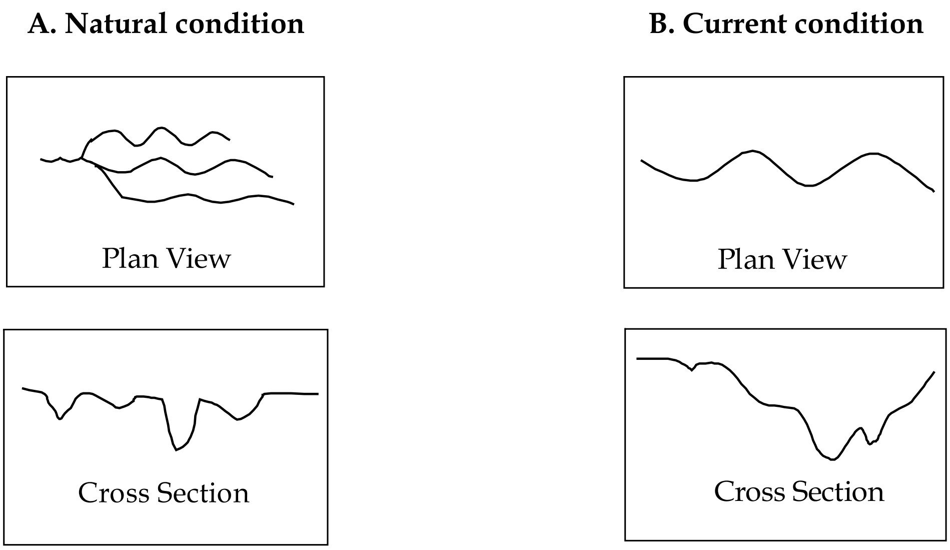


Figure 6.4: Comparison of the natural and current morphological state of the Upper meandering zone (Thoms, 1999).

This section of river exists mostly as a dry channel with flows for only very short periods throughout the year. The predominant function of this section would be the transfer of large amounts of accumulated organic debris through the lower sections of the river to the estuary. This zone contains very little 'in-stream' habitat, providing only a migration pathway for fish between sea and upland freshwater habitats. As there are no permanently viable macroinvertebrate habitats, macroinvertebrates would use this reach opportunistically with

Mobile species colonising temporary pools when water was present. This zone has wide, sandy beds and if subsurface flows were frequent enough would be important for hyporheic habitat (Sheldon et al, 1999).

Important flow zones

The rates of rise and fall of flow events affects channel stability and can prevent stranding of aquatic fauna. Important flow levels to maintain physical and ecological environments in the Upper meandering zone include:

- *Subsurface flows*: maintain the communities in the hyporheic zone
- *Low to mid-flows:* provide flows for fish migration and transport of organic debris between the freshwater and marine environment
- *Floodplain flows*: required for significant riparian inundation and recruitment and for maintenance of channel complexity.

Management issues

Restricted grazing along the riparian zone could establish a greater range of riparian vegetation. This would in turn enhance the habitat diversity of this zone as well as providing increased bank stability.

6.4.4 Mobile zone

Physical environment

The Mobile zone is an area of relatively steep bed slope that is characterised by highly mobile riverbed sediments and a dynamic in-channel environment (Plate 6.3). The river-floodplain environment is relatively active and unrestricted as evidenced by features such as benches, point bar systems and levees (Thoms, 1999). The in-channel environment is extremely variable and has bars (point and lateral), benches (at various levels) and riffle/pool sequences (Figure 6.5). Riverbed sediments typically comprise the larger particle sizes, such as gravel, cobbles and boulders. The in-channel storage features are highly mobile and reflect high rates of sediment transport (Thoms, 1999).

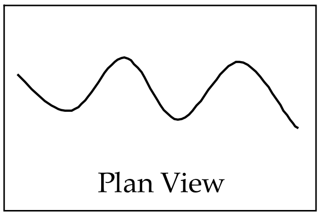
This zone has retained its physical and functional integrity with a diverse range of in-channel physical habitat (Figure 6.5). However, the quality of these habitats has the potential to be reduced by fine sediment deposition from upstream erosion events and compaction due to reduced flushing and remobilising flows.

Ecological environment

This zone contains a wide range of habitats in relatively good condition. This is due to the strong structural integrity of the pool-riffle sequences, the number of permanent pools, the range of sediment sizes in the channel beds, the relatively healthy riparian communities and the presence of emergent and submerged aquatic vegetation.

Plate 6.3: Typical environment in the Mobile zone, featuring pool, bar and riffle characteristics.

A. Natural condition and current condition



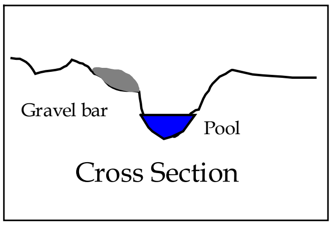


Figure 6.5: The morphological state of the Mobile zone has remained stable over time.

The large deep pools and riffle environments provide significant habitat and refuge for aquatic fauna. The fish survey (Hicks and Sheldon, 1998) showed that The Rocks site in the Mobile zone, had the greatest diversity of fish species and was ranked the highest of all sites in terms of the biotic integrity of the fish assemblage. This zone supports a diverse invertebrate community because there are permanent spring-fed pool-riffle habitats. This area was also rated relatively healthy in comparison to other sites because it supported disturbance sensitive taxa. Results from a rapid invertebrate assessment of the Wakefield River system (Hicks and Sheldon 1998) showed that The Rocks area had, together with the Skillogalee Creek site, equally the highest number of taxa of all sites surveyed. It is likely that the Mobile zone would support healthy hyporheic (subsurface) fauna (Sheldon et al, 1999).

Important flow levels

To maintain ecosystem function this zone requires a diverse flow regime. The range of flows needed to maintain connectivity between the pools and also maintain the substrate heterogeneity of the region, which increases potential habitat diversity. Important flow levels include:

- *Baseflow:* driven by groundwater and important for maintaining significant hyporheic habitat, the water level of permanent pools and maintenance of the health of riparian vegetation
- *Freshet flows*: required for maintenance of water quality
- *Habitat connection flows*: required to maintain water flowing through riffles, the water quality of the permanent pool and connectivity between the permanent pools
- *Mid flows*: provide flows for fish migration and major connections between pool and riffle habitats, and movement of terrestrial organic matter
- *High flows*: important as reset flows within riffles, move gravel/cobbles and scour algae and sediment from rocks
- *Bankfull flows: the* major habitat reset flows responsible for scouring pools, vegetation removal, sediment sorting and habitat modification
- *Floodplain flows*: required for major riparian/floodplain inundation and maintenance of channel complexity.

Management issues

This zone is considered to be relatively intact and of high ecological value. It is characterised by permanent pools and is maintained by a degree of baseflow, most of which is groundwater driven. This zone would be significantly impacted by a reduction in the local watertable.

A major threat to the integrity of this zone is the potential movement of excessive sediment downstream from the Transition and Incised zones. Increased sediment within the Mobile zone would block pool habitats, destroy riffle areas and have the potential to increase the abundance of the reeds *Phragmites* spp. and *Typha* spp. (Sheldon et al, 1999) This should be a consideration for setting management options in both the Transition and Incised zones. The presence of reasonable amounts of sand and gravel within the system and the ecological importance of this zone means it should be protected from sand and gravel extraction.

6.4.5 Transition zone

Physical environment

The Transition zone is characterised by a series of small floodplains presumably of different ages set into remnant high level terraces (Plate 6.4). The river channel is constrained and controlled by the valley, however there are some floodplain formations present. Features of this zone are high bed slopes and high-energy flows that have resulted in heavy erosion of in-stream structures. This zone is a sediment source area evidenced by terrace formations and the active lowering of the modern channel bed. The in-channel environment is variable and has areas dominated by cobble and gravel sized sediments and others dominated by fine silt sediments, which have been extensively armoured and relatively stable (Thoms, 1999). The stability of these bed sediments has resulted through the establishment of dense stands of reed beds. This coarse layer of reeds provides surface roughening which protects the finer materials underneath from mobilisation in high flow events.

Plate 6.4: The Transition zone, featuring characteristic pool and reed beds.

Historically this zone was characterised by a highly variable in-channel environment. The main in-channel features were riffle-pool sequences and mixed sand and gravel beds. Most of the in-stream morphological features such sediment bars and benches have been eroded, and therefore the physical complexity of the channel has now been reduced (Figure 6.6). This zone is currently in a state of physical stabilisation and recovery. This is evident by the stabilisation of sediment in the stream and the re-establishment of in-stream vegetation.

Ecological environment

The Transition zone has some good pool-riffle habitats but it also contains a substantial amount of poorly degraded and incised channel habitat filled with encroaching reeds. Large dense stands of native reeds dominated by *Phragmites* spp. and *Typha* spp. occur along the channel; they provide good stream bed stabilisation but only limited habitat quality and diversity (Sheldon et al, 1999).

Permanent pools in this zone provide some refuge for aquatic fauna. The fish biotic integrity index ranked the site in the Transition zone as poor. Exotic fish species dominate the profile, with few natives recorded or observed (Hicks and Sheldon, 1998). This is mainly due to the deep pools and riffles containing very little diversity of habitat and providing minimal refuge for native fish. In this zone the absence of riffles and the dominance of stands of macrophytes limits the diversity of macroinvertebrate habitat. The hyporheic communities if present would be considered poorly represented.

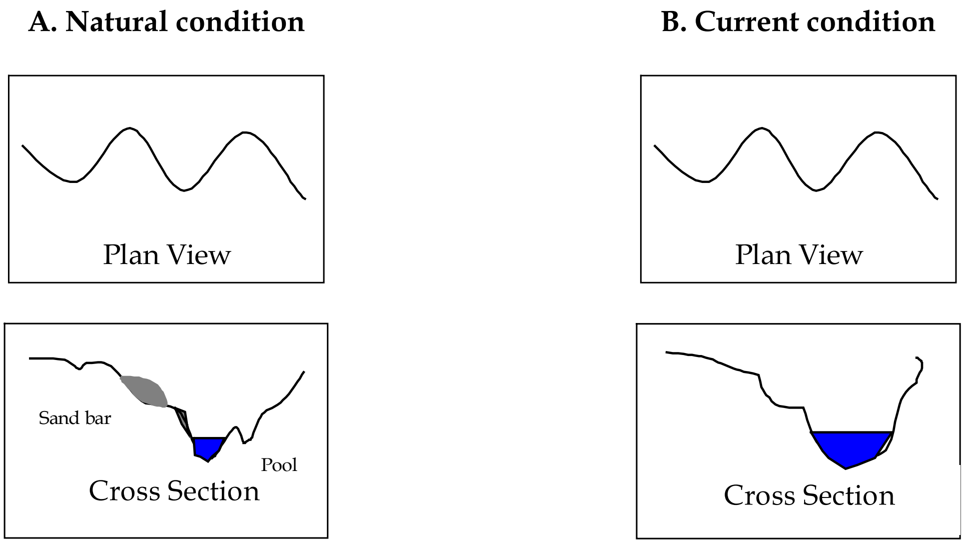


Figure 6.6: Comparison of natural and current morphological states in the Transition zone.

Important flow levels

Important flow levels to maintain physical and ecological environments in the Transition zone include:

- *Baseflow*: maintains the water level of permanent pools and the health of riparian vegetation; is likely to support significant hyporheic habitat
- *Freshet flows*: maintain the water quality of the permanent pools
- *Habitat connection flows*: maintain water flowing through riffles and between pools, migration, water quality and wetting feet of riparian vegetation
- *Mid flows*: provide the major connections between pool and riffle habitats, flows for fish migration between the freshwater and marine environment and for movement of terrestrial organic matter
- *Bankfull flows:* important for riparian zone wetting and fish migration, for substrate resetting and turnover, habitat modification and channel maintenance
- *Floodplain flows:* important for river red gum inundation and channel formation/maintenance.

Management issues

To restore ecosystem function this zone requires a diverse range of flows to be maintained as well as riparian rehabilitation and land management. A critical balance is required to maintain the recovery process in this zone. Further erosion or removal of reeds, either by flows or land management, could remobilise a large amount of fine sediment downstream to the sensitive Mobile zone. However, higher velocity pool scouring flows are required to maintain the balance between pools and the encroaching reed beds. As with the Mobile zone, the ecology in the Transition zone relies upon groundwater flows and a reduction in the local watertable would significantly impact upon this system.

6.4.6 Constrained zone

Physical environment

The Constrained zone runs the length of the Skillogalee Creek (Figure 6.2). It is highly restricted within a narrow valley floor trough and contains limited floodplain formations. Many areas along the river channel are bedrock defined, resulting in large pools forming upstream of these bedrock constrictions (Plate 6.5). This is a high-energy zone dominated by steep bed slopes (Thoms, 1999).

Plate 6.5: Typical environment of the Constrained zone, featuring a pool and bedrock defined channel.

The in-channel structures are dominated by bedrock chutes, large boulder/cobble accumulations and scour pools. Boulder materials are relatively immobile, however cobble accumulations are highly mobile during flood flows and produce well sorted deposits. In this zone sediments are added directly to the channel from adjacent valley slopes. The lack of major sedimentary deposits, together with the high energy flows and unstable river bed, suggests this zone is an important sediment source (Thoms, 1999). The Skillogalee Creek supplies 'good' quality water and contributes a significant proportion of the baseflow to the downstream Wakefield River system.

There has been limited morphological change in this river zone because of the highly constrained nature of the river channel and the influence of bedrock (Figure 6.7). In some areas, erosion has lowered the river bed and the subsequent incision into the sand/gravel sediment has produced permanent channels between the large pools (Thoms, 1999).

A. Natural condition and current condition

Figure 6.7: The morphological state of the Constrained zone has remained stable over time.

Ecological environment

The Constrained zone was considered to be in relatively good condition compared to the other tributaries in the catchment. This zone is an important contributor of organic carbon for the downstream river system. However, the riparian zone is in general decline. There is little re-establishment of river red gums (*E. camaldulensis*) and no understorey vegetation along the majority of the creek. This loss of riparian vegetation could threaten sensitive aquatic fauna. There are areas where grazing has been restricted and the vegetation community remains relatively diverse.

There were no fish found in this zone and there appeared to be no ecological reason for their absence (Hicks and Sheldon, 1998). The Skillogalee Creek displayed the highest level of macroinvertebrate species richness of all the assessed sites in the Wakefield River system. The macroinvertebrate assessment identified a number of uncommon macroinvertebrate taxa (eg *Taschorema* spp. *Koornunga inconspicua*, *Apsilochorema* sp.) from the mayfly and caddisfly groups that were not found in other areas of the Wakefield system (McEvoy and Madden, 1998). This is possibly due to the higher incidence of cool flowing water and a high degree of stream shading characteristic of this zone. Stoneflies (Plecoptera), are a sensitive group of invertebrates and were absent from all surveyed sites (McEvoy and Madden, 1998). This could indicate a lack of reliable flows, as stoneflies generally require good flows for five to six months to complete their life cycles. The presence of permanent water in the lower parts of the Skillogalee raises the possibility of a hyporheic refuge within this zone. This requires further investigation.

Important flow levels

Environmental water requirements within the zone should aim to maintain flows and functioning of the pool-riffle habitat and also the vertical linkages between surface water and hyporheic habitat. Important flow levels are:

- *Baseflow*: important to support potential hyporheic habitat and required to maintain the water level of permanent pools and the health of riparian vegetation

- *Freshets*: maintain water quality in pools

- *Habitat connection flows*: required to maintain water flowing over riffles and between pools, to water macrophytes and maintain the diversity of habitats

- *Mid flows*: provide the major connections between pool and riffle habitats, reset flows within riffles and scour algae and sediment from rocks, allow movement of sediment and organic matter through the system

- *Bankfull flows*: important as major habitat resetting flows, for scouring pools, moving large pulses of organic matter through the system and riparian vegetation watering.

Management issues

The decline in the health of the riparian zone means some sections of Skillogalee Creek are now open and not shaded. Riparian zone management and revegetation is important for the functioning of this region as a cool upland habitat (Sheldon et al, 1999). According to local landholders, groundwater-fed springs in the upper sections of the creek have decreased in flow and in some cases have dried up. This has implications for the downstream pools and the volume and quality of water entering the Wakefield River.

6.4.7 Incised zone

Physical environment

This zone is characterised by a highly degraded channel (Plate 6.6). The channel has a 'gully like' appearance with very little in-channel structure and steep banks. A common feature of this zone is pools separated by short channel constrictions. Pools form upstream of channel constrictions and are the dominant morphological feature in the zones. Channel constrictions are generally associated with major bedrock bars that extend across the channel or at substantial localised gravel deposits that act as riffle areas. Local river bed slopes increase significantly at these constrictions, representing small areas of relatively high energy, in contrast to the relatively low bed slopes and energies of the pool environment. The nature of channel sediment or substratum in these reaches consists of fine silt/clay material overlying a bedrock/cobble base in the pools, with gravel/cobble or bedrock dominating the short constricted riffle areas (Thoms, 1999).

In general, this zone would have once been very similar, in terms of its morphology, to the Chain of ponds zone. Most of the floodplain would have resembled a swamp with large pools and small channels between the pools. There has been a marked change in the morphology of this river zone (Figure 6.8): it has been heavily eroded and gullying of the fine cohesive floodplain deposits and 'chain of ponds' alluvium has produced a 'U' shaped channel. As a consequence there is at present little in-stream physical structure (Thoms, 1999). The dramatic change to the physical environment in this zone is likely to have reduced the diversity of flora and fauna that would have been adapted to the original system with a wider range of habitat.

Ecological environment

The Incised zone includes many different environments so the following statements should be regarded as statements of general river condition. The Incised zone is considered very degraded. There is little in-stream physical habitat with poor connectivity between the remaining pool and riffle sequences and the riparian zone is severely impacted. Riparian vegetation is on the whole, in poor condition and offers limited shade and food source for aquatic fauna. The fish survey identified only exotic fish in the main channel Incised zone and no fish were recorded above the town of Auburn (Hicks and Sheldon, 1998). Areas that have an unstable bed and bank structure offer poor habitat for macroinvertebrates. The pool environments are degraded and this is reflected by the generally poorer diversity of macroinvertebrate species (McEvoy and Madden, 1998). Hyporheos in this zone are absent.

Plate 6.6: Typical in-channel environment in the Incised zone, featuring an eroded 'U' shaped channel.

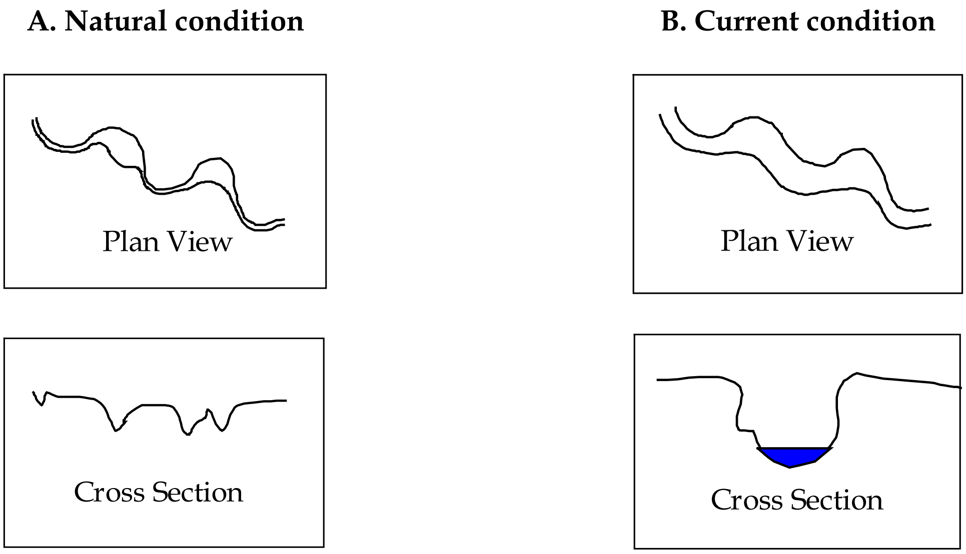


Figure 6.8: Comparison of the natural and current morphological state of the Incised zone.

Similar to the Transition zone, the Incised zone in the main river channel has large sections filled with dense stands of native reeds dominated by *Phragmites* and *Typha*, which are indicative of past disturbance. Although a disadvantage in terms of habitat diversity, reed beds do provide a level of shading and organic matter inputs. The reeds also stabilise much of the sediment within this zone and prevent it from being remobilised further downstream.

Important flow levels

Important flow levels to maintain physical and ecological environments in the Incised zone include:

- *Baseflow*: maintains riffle flows and water levels in permanent pools, important to maintain riparian and in-stream vegetation.
- *Freshets*: maintain water quality
- *Habitat connection flows*: maintain water flowing between pools and water quality in permanent pools, important for wetting of the channel margin and riparian vegetation and sediment movement.
- *Mid flows*: required for transport of coarse sediment, maintaining connections between habitats, fish movement and organic matter pulses through the system.
- *Floodplain flows*: required for resetting the channel structure and wetting of the riparian and floodplain zone

Management issues

This is a zone of severe channel and riparian degradation and the rehabilitation of these areas is more complex than for other zones. Any environmental water management will need to be combined with land and riparian management options. Therefore, a wide range of management options should be considered before rehabilitation is begun. There is a potential for further release of sediment from this area. Management should focus on controlling sediment loss from the Incised zone to protect the ecological and physical functioning of the Mobile zone. This may well be a higher priority than the enhancement of the Incised zone.

The high density of reed species reflects a significant disturbance within the system. More information is required to determine the roles of *Phragmites* and *Typha* in carbon cycling and sediment dynamics (Sheldon et al, 1999). Rehabilitation of reaches in this zone requires bed and bank stabilisation and revegetation of riparian zones. Where appropriate the aim should be to mimic a ‘chain of ponds’ morphology and ecology.

6.4.8 Chain of ponds

Physical environment

The Chain of ponds zone has no strongly discernible continuous channel (Plate 6.7). These systems generally form in very low gradient areas with pools being the dominant physical structure (Thoms, 1999). These pools are connected through high flow events and either dry up or are maintained by groundwater during the summer periods.

Both the valley morphology and the amount of local runoff influence the planform of the Chain of ponds zone. Generally, the river channel has a small flanking floodplain because of a narrow valley floor configuration (Thoms, 1999). The main feature in this zone is the individual pools, which vary in size from less than 2 m to greater than 5 m in diameter.

Plate 6.7: Typical environment of the Chain of ponds zone, featuring a chain of shallow wetland systems.

Little morphological change has occurred in this river zone (Figure 6.9). In areas small incised channels have developed between the pools as a consequence of vegetation clearance and grazing activity. This has resulted in an increase in the frequency of drying of the pools. The Chain of ponds zone could be used a benchmark for what areas of the Incised zone may have been like before hydrologic changes caused massive incision of the channel.

Ecological environment

The ecology of this area is associated with pools and the small connecting swampy channels. There is a diverse macrophyte assemblage. There has been a decrease in the quality of habitat associated with these pool-swamp environments due to grazing and invasion by exotic plant species. The swamp-riffle flora and aquatic vegetation within pools is degraded. Riparian vegetation is generally degraded. However, there are areas with a high diversity of native grasses.

A. Natural condition and current condition

Figure 6.9: The morphological state of the Chain of ponds zone has remained stable over time.

A fish and invertebrate survey was not conducted from reaches this far up in the catchment. The pool and swamp invertebrate assemblages in this zone should be relatively diverse, because of the many in-stream environments. Many of the invertebrates are likely to be opportunistic, as, apart from groundwater-fed permanent pools, the habitat in the zone is essentially ephemeral.

Important flow levels

Important flow levels to maintain physical and ecological environments in the Chain of ponds zone include:

- *Baseflow*: maintains pool water level and supports emergent macrophytes and semi-aquatic vegetation
- *Freshets*: maintain water quality
- *Habitat connection flows*: maintains water flowing between pools, increases available habitat area, maintains water quality and allows wetting of channel margin vegetation
- *Floodplain flows*: required for channel resetting and riparian/floodplain vegetation wetting.

Management issues

Grazing management would be the most effective method of riparian rehabilitation within this region. This area has a high potential for rehabilitation with maximum benefit gained from a minimum of effort. In particular, the Water Reserve at Riley Road has a high diversity of in-stream vegetation and native grasses and should be considered an area of high ecological value. The maintenance of low flows in this system requires an assessment of impacts from water usage in this area. These include the rate and amount of water abstraction from the permanent pools and groundwater and the role of farm dams in intercepting low flows into these environments.

6.5. Environmental water requirements

6.5.1 Quantifying environmental water requirements

Important flow levels that fulfil the physical structure and flow requirements of vegetation, fish and macroinvertebrates for each river geomorphic zone have been outlined in Section 6.4. Cross sections taken at representative sites within each zone were then used to quantify these important flow levels. The cross sectional area for each flow level and slope value was determined and the Manning equation used to calculate flow volumes. The Scientific Panel workshop also identified the seasonality, duration and frequency ideally required for each flow level to fulfil its biophysical function.

A comparison of the flow levels for each zone led to the identification of key flow bands for the entire Wakefield River system. These key flow bands are summarised in Table 6.3. In general, the flow volumes indicated at the gauging station reflect a similar flow level throughout the river system. For example, a floodplain flow at the gauging station will represent a floodplain flow in the Transition, Mobile and Upper and Lower meandering zones. However, there will be some flow volumes that match different levels due to variation in stream channel volume between the different geomorphic zones.

Hydrological data from the gauging station was then modelled and compared with the seasonality, duration and frequency parameters identified by the Scientific Panel (Table 6.3). A more detailed discussion of methods used is provided in Chapter 4.

6.5.2 Baseflow

Baseflow is dependent upon groundwater flow, which maintains the stream flow throughout the driest months. Most of this flow was found to enter the Wakefield River in and directly upstream of the Transition zone with a magnitude related to the previous season. While reasonably constant this baseflow does vary throughout the year peaking through winter as a consequence of soil moisture increase and local aquifer discharge (Figure 6.10).

Baseflow has been recognised by the Scientific Panel workshop as important as it:

- maintains flowing water over riffles
- provides connection between riffles and pools
- maintains the permanent pools over the summer period
- allows re-establishment of in-stream vegetation
- provides significant hyporheic habitat in some regions of the Upper meandering, Mobile, Transition and Constrained zones.

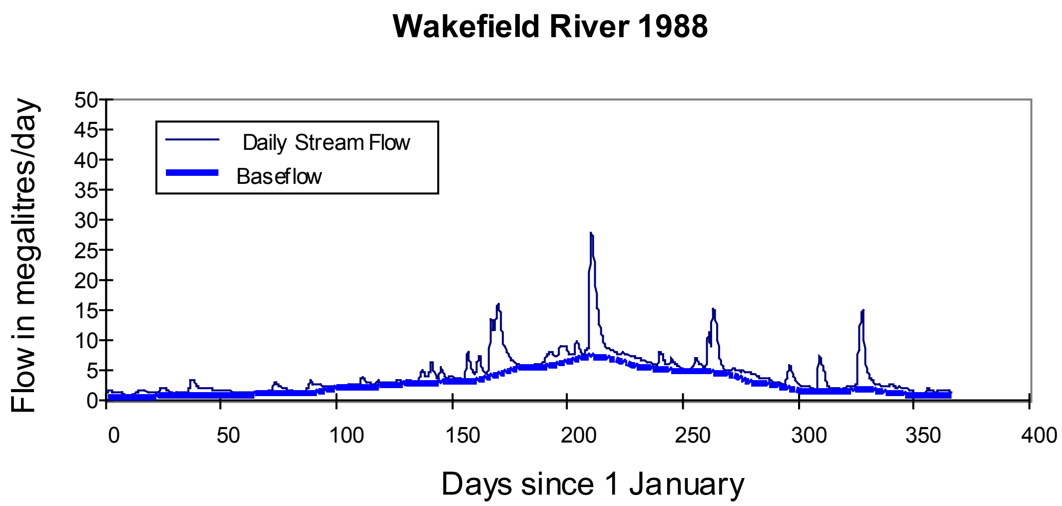


Figure 6.10: River flow in 1988 showing the winter peak in base flow (based on recorded mean daily flows)

Table 6.3: Flow band summary for the Wakefield River.

Flow Band	Peak Flow (cumecs)	Duration Flow (daily max cumecs)	Average Frequency	Duration (time)	Importance
Baseflow	-	current level	current	current	protect at current levels
Freshets	<0.5	current levels	weekly	1 day	less important in winter, more important in spring
Habitat connection	1-3	<1	a few times a year	4+ days	habitat connection and migration between pools/ habitat maintenance - winter to spring
Migration flows	6-10	~3	at least once/year	7 days	fish reproduction/migration flows spring and autumn
Mid flows	15-25	6-10	once every 2 years	-	reset flows/habitat reset
High flows	40	15-25	once every 6 years	-	reset flows/habitat reset
Floodplain	70+	40	once every 20+ years	-	reset flows/habitat reset

Note:

- *All flows (peak and duration) are referenced to the gauging station at the approximate mid-point of the catchment.*
- *In general flow levels indicated at the gauging station reflect the same flow band throughout the river system, eg a floodplain flow at the gauging station will be a floodplain flow in the Mobile and Constrained zone. However there will be anomalies due to variation in stream channel volume between the different geomorphic zones.*

It is likely that since first settlement, groundwater inflow has increased in the area due to past vegetation clearance. Over the past 20 years, however, a significant amount of groundwater has been extracted from both the fractured rock aquifer and streams within the vicinity of Eyre Creek and the Upper Wakefield area. This has had the effect of reducing the quality and quantity of water entering the Wakefield River and its tributaries. The Wakefield is an ephemeral system which relies heavily on baseflows (especially in the summer months) to maintain pool water quantity and quality. It is the consideration of the Scientific Panel that these flows are highly important to the Wakefield system.

It has been recognised by the members of the Scientific Panel that, because of the ephemeral nature of the river, all of the current baseflows are required for the continued ecological maintenance of the river system.

6.5.3 Freshets

Freshets are small to low flow events that occur in two forms. At the top of the catchment these are small surface water pulses caused by a rainfall event. These flows are very important in flushing and maintaining the water in permanent pools. In the bottom section of the catchment freshet flows occur on the recession of higher flood events or are masked by the rise in baseflow over winter. For these reasons freshets are more significant in the upper reaches of the catchment.

Freshets have been identified by the Scientific Panel workshop as important as they:

- freshen up baseflows
- maintain the water quality in the permanent waterholes
- maintain water flowing through riffles.

Cresswell (1999) determined that freshet flows of between 0.035 to 0.14 cumecs occur on average (over the required winter to spring seasons) every 21 days. This is in excess of the weekly flows recommended by the Scientific Panel. However, these freshet flows when combined with the significant baseflows (Figure 6.10) provide the ecological conditions required by freshet flows. Further work is required to determine if freshet flows are significantly impacted by farm dam development in the upper Wakefield area.

Based on assessments of the hydrology in the Wakefield River (Cresswell, 1999) it is likely that freshet events meet the ecological requirements for freshet flows.

6.5.4 Habitat connection flows

Habitat connection flows are most important because they provide the minimum flow to cover the bed of the channel over a reasonable duration of time over the whole length of the Wakefield River. Average flows in the order of 0.5 to 1 cumec, flowing over a 4 day period are required 2–3 times a year to enable fish movement between pools.

These flows were identified as important for:

- maintaining connectivity between pools for fish movement
- riparian vegetation watering and leaching of surface salt accumulation
- enhancing activity in the hyporheic zones.

These flows are the larger 'reliable' flows that occur throughout the wetter months of the year and extend downstream to reach the estuary. These flows are particularly important for fish and macroinvertebrate movement between the rocks area and the confluence of the Wakefield River and Eyre Creek. They are very important for the hyporheic environments in the Mobile and Upper meandering zones; and most important for maintaining the riparian vegetation along the saline areas of the lower Wakefield. Further research is required to determine which activities are impacting on this flow band. Current habitat connection flows are outlined in Table 6.4.

Table 6.4: Habitat connection flows upstream of The Rocks (based on recorded mean daily flows)

Flow of 0.5 cumec exceeded	Number of flow events/year	Median duration of events
24 days per year	3.3	4.0 days
Flow of 1 cumec exceeded	**Number of flow events/year**	**Median duration of events**
12 days per year	3.1	3.0 days

Habitat connection flows are just above the minimum requirements as identified by the Scientific Panel. This flow band has the potential to be impacted upon by further water resource development.

6.5.5 Migration flows

Primarily, these are the flows that allow migratory fish the opportunity to complete their life cycles through movement between the river and the estuary. Migratory fish recruitment is dependent on flows in autumn/early winter (March, April and May) for reproduction and spring (September) for migration.

These flows were identified as important for:

- migration of fish to the estuary to breed in autumn
- fish recruitment and migration inland in spring
- freshening the riparian root zones and flushing areas affected by saline groundwater influence.

Flows that exceed 3 cumecs over a minimum 4-day duration are required to enable fish to move between the estuary and the pools within The Rocks area. These flows need to occur at least once in autumn/early winter and again in late spring at least every three years (Hicks and Sheldon, 1998), because of the three to four year average life span of these fish. The current duration, seasonality and frequency of these flow events are outlined in Table 6.5. This indicates that these flows do not occur frequently enough or for long enough to support the life cycles of migratory fish.

Table 6.5: Fish migration flows (based on recorded mean daily flows).

September flow	No. of 3 day flow events/year	Return period for event
Flow of 3 cumec exceeded 1.4 days per year	0.2	1 in 7 years
March, April and May flow	**No. of 3 day flow events/year**	**Return period for event**
Flow of 3 cumec exceeded 0.3 days per year	not recorded	not recorded

The Wakefield River system has probably always functioned as an opportunistic breeding location and might support populations of migratory fish on a temporally sporadic nature. However, its contribution as a breeding site in a regional gulf context should not be undervalued. Further research needs to be conducted into the life cycle adaptations of fish in ephemeral river systems.

Based on past and present hydrological data, these flows do not occur with enough regularity to consistently support the life cycle of migratory fish.

6.5.6 Mid flows

These flows are required for the in-stream maintenance of structures such as benches, bars and riffle-pool sequences. Mean daily flows of 6 to 10 cumecs are required at least once every two years to maintain the in-stream morphology.

These flows were identified as important for:

- migration
- substrate and other bed load transport
- connectivity with other habitats
- physical habitat generation
- organic matter pulses.

Table 6.6: Mid flows (based on recorded mean daily flows).

Flow of 6 cumec exceeded	Number of flow events/year
2.8 days per year	1.7
Flow of 10 cumec exceeded	**Number of flow events/year**
1.5 days per year	1.2

These flows are currently being achieved at levels greater than required for in-stream maintenance.

6.5.7 High flows

These flows inundate approximately 50% to 100% of the stream channel at various sites and maintain and enhance channel complexity. Mean daily flows of 15-25 cumecs are required approximately once every 6 years. Current occurrence of these high flows is outlined in Table 6.7.

These flows were identified as important for:

- scouring of pools
- cobble and boulder resetting and turnover
- riparian zone wetting
- consistent migration flows
- organic matter throughput.

Table 6.7: High flows (based on recorded mean daily flows).

Flow of 15 cumec exceeded	Number of flow events/year
0.9 days per year	0.7
Flow of 25 cumec exceeded	**Number of flow events/year**
0.45 days per year	0.4

These flows are currently well within the required levels.

6.5.8 Floodplain flows

Floodplain flows modify channel and habitat structure. Mean daily flows of 40-70 cumecs are required with an average frequency once every 20 or more years. In the 25 years of recorded flow events, a greater than 70 cumec flow has occurred only once (Table 6.8).

These flows were identified as important for:

- channel resetting
- habitat resetting
- maintenance of river and floodplain connections
- floodplain and wetland watering.

Table 6.8: Floodplain flows (based on recorded mean daily flows).

Flow volume	Return period for event
Flow of 40 cumec exceeded	1 in 7 years
Flow of 70 cumec exceeded	1 in 40 years

The river system is at present in a recovery phase. High peak flow events could pose a threat to the river bed by scouring out large areas of reed beds and remobilising the sediments, impacting on downstream environments (pools and gravel beds) and reducing in-stream channel complexity. Any river rehabilitation work must take into account the timing, velocity and flooding extent of these flows.

Floodplain flows are currently being achieved.

6.6. Conclusion

The Wakefield Scientific Panel workshop identified five key flow principles to consider when managing water resources in the Wakefield River system:

1) recognition that the Wakefield is a highly erratic pulse system
2) the maintenance of certain important flow bands
3) the maintenance of the natural variability of flows
4) continuity of flows throughout the system
5) protection of the recession limb of the hydrograph to prevent stranding of aquatic fauna.

The results of the hydrological modelling showed that under current conditions all environmental water requirements are being met. However, some flow bands, such as habitat connection flows, are only just currently being met. Maintenance of this flow band is critical and further investigation is required to identify the current impacts on this flow band. A monitoring program is essential to further refine the flow bands identified in this study and to ensure that the water requirements for each key flow band are protected.

7. RIVER MANAGEMENT OPTIONS

7.1. Introduction

The Wakefield River is a semi-arid system characterised by a highly variable flow regime. Many of the native flora and fauna are tolerant of a range of environmental conditions. However, the overall conclusion of the assessment of watercourse condition and environmental water requirements is that the ecology of the Wakefield River is in a poor condition. Much of this is due to changes in hydrology and habitat induced by past land management practices. The ecology of the system can be improved with flow, land and watercourse management combined with rehabilitation of key areas.

This chapter attempts to provide an overview of the condition of the Wakefield River system, summarise the management issues raised by both the assessment of watercourse condition (Chapter 5) and the determination of environmental water requirements (Chapter 6), and discuss management options on a 'whole of river' basis. Recommendations for management are made within an ecological framework based on the following principles.

1. Maintain and enhance the natural variability in connections between habitats.
2. Maintain and enhance the natural variability in carbon/food sources.
3. Maintain/improve the ecological condition of the Wakefield River.
4. Maintain the natural variability of flows.
5. Maintain/enhance the system's biodiversity.
6. Constructed structures/habitats should not take priority over natural habitats.
7. Prioritise areas of higher natural structural and biological diversity (Thoms, 1999).

7.2. Overview of river condition

7.2.1 Hydrology and geomorphology

The hydrological regime in the Wakefield River has undergone dramatic change. Past land clearance and poor land management practices, such as over grazing and wheat fallowing, resulted in increased surface runoff and stream flow that in turn initiated severe erosion events. The outcome has been the destruction of in-stream physical structure and the dominance of a single U shaped channel in many reaches. Linkages between the river and its floodplain have been reduced (Thoms, 1999).

Today, improved land management practices, such as contour banking, minimum tillage and improved pastures and the increasing numbers of farm dams have decreased the volume and velocity of surface runoff and stream flows (Cresswell, 1999). Most large-scale erosion has already occurred and the Wakefield River appears to be in a state of recovery and stabilisation. Little evidence was found of active bed and bank erosion and extensive native reed beds dominated by *Phragmites* spp. and *Typha* spp. act to trap sediment and stabilise the incised main channel.

7.2.2 Ecology

The ecology of the Wakefield River is highly dependent on groundwater fed baseflows and permanent pools. These areas of permanent surface water are of particular importance as refugia in dry periods (Sheldon et al, 1999).

The aquatic vegetation community is not diverse and in many areas absent. Riparian vegetation, such as river red gums and native grasses, is healthy in some reaches but severely impacted in others. Submerged aquatic vegetation is found only in the few 'pristine' deep pools, eg at The Rocks, and includes charophytes and *Potamogeton pectinatus*. The predominant aquatic vegetation present in the system includes the emergent reeds *Phragmites australis* and *Typha* spp. Both taxa form dense and sometimes impenetrable stands along sections of the main river channel (Sheldon et al, 1999).

A snapshot survey of fish populations found only low numbers of native freshwater fish. Species that rely on migration to and from the sea to maintain populations were notably absent. Native fish found include blue spot goby found upstream and at the estuary, tandanus catfish at The Rocks, hardyhead, yellow-eyed mullet and sea mullet in the estuary. The native tandanus catfish at The Rocks (Mobile zone) are indicative of high habitat value of this area. These catfish are believed to have been introduced from the River Murray (Hicks and Sheldon, 1998).

Exotic species recorded include goldfish, gambusia (mosquito fish) and brown trout. There appear to be problems with predation and competition from exotic fish species eg trout, mosquito fish. The presence of mosquito fish in the majority of sites studied in the Wakefield except for the estuary suggests habitat degradation – these fish have wide temperature and salinity tolerances (Hicks and Sheldon, 1998).

More than 240 types of macroinvertebrates were collected from the Wakefield River catchment. Macroinvertebrates collected from the system were composed predominantly of species that are tolerant of a wide range of environmental conditions and are common and widespread in South Australian rivers. The type of fauna found in the reed beds which dominate the main channel, indicate that the reed beds provide habitat for fauna that inhabit both edge and riffle environments (McEvoy and Madden, 1998).

The most common macroinvertebrates were chironomid and simuliid larvae, nematode and oligochaete worms, springtails and flatworms. Hydrobiid snails, chironomids and caddis fly larvae (*Cheumatopsyche* sp.), which favour flowing water, also occurred in significant numbers. The caddis fly larvae and the less common *Simulium ornatipes* are riffle dwelling, filter feeders that play a critical role in making nutrients available to other fauna. Two taxa – a type of mayfly and a type of caddis fly larvae were found only in creeks (McEvoy and Madden, 1998).

7.2.3 Key attributes and threats

Key ecological attributes and threats to the health of the Wakefield River system are outlined below in relation to the different geomorphic zones and subcatchments. Figure 6.2 illustrates how zones and subcatchments relate. Attributes, threats and key management issues are summarised in Table 7.1. Details of subcatchment watercourse management priorities are outlined in Chapter 4.

Table 7.1: Summary of key attributes, threats and management priorities for geomorphic zones of the Wakefield River.

Zone	Attributes	Threats	Management Priorities
Lower meandering	Connection with estuary	Loss of links with floodplain Water use and impacts on migration flows Riparian weeds and grazing Lack of riparian vegetation Lack of in-channel habitat Salinity issues	Protecting migration flows Protecting rate of rise and fall Watercourse management
Upper meandering	Good overstorey vegetation Hyporheic habitat	Loss of links with floodplain Local groundwater extraction Water use and impacts on migration flows Riparian weeds and grazing Lack of in-channel habitat	Management of groundwater extraction Protecting migration flows Protecting rate of rise and fall Watercourse management
Mobile	High ecological value The Rocks area Hyporheic habitat	Local groundwater extraction; pumping from pools Water use and impacts on habitat connection flows; migration flows Riparian weeds and grazing Sediment from Transition and Incised zones.	High priority for conservation Management of groundwater extraction and pumping Protecting habitat connection flows and migration flows Maintaining natural variability of flood and drought Watercourse management Management of upstream threats
Transition	Pool-riffle habitats Reed beds – stabilise sediment	Local groundwater extraction; pumping from pools Water use and impacts on freshets, habitat connection flows and high flows Riparian weeds and grazing Lack of riparian vegetation Reed beds – mono-specific habitat	Management of groundwater extraction and pumping Protecting freshets, habitat connection flows and high flows Watercourse management (especially riparian revegetation) Management needs to consider impacts downstream

Table 7.1 (cont.): Summary of key attributes, threats and management priorities for geomorphic zones of the Wakefield River.

Zone	Attributes	Threats	Management Priorities
Incised	Eyre Creek – baseflow Reed beds – stabilise sediment	Groundwater extraction (Eyre Creek) Loss of links with floodplain Water use and impacts on freshets, migration flows and mid flows Riparian weeds, exotic trees and grazing Lack of riparian vegetation Lack of in-channel habitat Reed beds – mono-specific habitat Potential for future channel erosion	Management of local groundwater extraction Protecting freshets, migration flows and mid flows Watercourse management Management needs to consider impacts downstream River rehabilitation to increase in-channel physical habitat
Constrained	Contributes to baseflow Organic input into system	Groundwater extraction Water use and impacts on freshets, habitat connection flows; migration and high flows Riparian weeds and exotic trees and grazing Lack of riparian vegetation	High priority for management of groundwater extraction. Protecting freshets, habitat connection flows; migration and high flows Watercourse management
Chain of ponds	High diversity of in-stream vegetation Chain of ponds morphology Permanent pools	Local groundwater extraction and pumping from pools Water use and impacts on freshets, migration flows Riparian weeds; grazing Lack of riparian vegetation Potential for future erosion	High priority for riparian rehabilitation efforts Management of groundwater extraction and pumping from pools Protecting freshets, migration flows Watercourse management

Lower and Upper meandering zones

The Lower and Upper meandering zones occur in the Lower Wakefield and Hermitage and Woolshed Flat Creeks subcatchments, respectively. The river here is in a degraded state due to the impacts of exotic vegetation, grazing, salinity and land clearance. These zones are important areas for the transport of organic matter and fish migration to and from the estuary. Hyporheic environments are potentially important.

Key flow issues include maintaining migration flows and mid flows important for the movement of fish and organic matter; flushing of saline areas; and riparian vegetation. Protecting groundwater is potentially important to maintain subsurface flows critical for hyporheic environments. The rate of rise and fall of flow events is important for channel stability and to prevent stranding of aquatic fauna.

Management of environmental water requirements should be combined with rehabilitation of the watercourse. Rehabilitation should focus on revegetation, weed control and restoration of a range of physical habitat types. Dryland salinity issues are important in the Lower meandering zone and intrusion of a highly saline watertable into the floodplain is affecting the health of riparian vegetation.

Mobile zone

The Mobile zone occurs in Hermitage and Woolshed Flat Creeks subcatchment. The zone typically contains diverse pool-riffle habitats, diverse macroinvertebrate and fish communities, and relatively healthy in-stream and riparian vegetation. It is a significant area of high conservation status for the Wakefield River. The Rocks area, in particular, was ranked highest of all sites in terms of fish diversity and biotic integrity and is considered to have high ecological value (Hicks and Sheldon, 1998; Sheldon et al, 1999). The Rocks area is an important reference site.

Maintaining the integrity of this zone through maintenance of environmental flows and grazing and weed management should be a high priority. A major threat to the integrity of this zone is the movement of sediment downstream from the Transition and Incised zones, which would reduce the quality and quantity of pool and riffle habitats.

Key flow issues include protection of groundwater dependent baseflows and permanent pools; maintenance of habitat connection and migration flows for riffle–pool connections; and maintenance of physical habitat diversity and riparian zone watering through floodplain flows. The duration and frequency of flood and drought is important for fish and macroinvertebrates. This zone would be severely impacted by a reduction in the local watertable.

Recommendation	
7.1	The entire Mobile zone should be considered an area of high conservation status and management to protect of its ecological values should be a priority. The Rocks area, in particular, should be considered as an area of high ecological importance and its ecological integrity protected.

Transition zone

The Transition zone occurs in the Hermitage and Woolshed Flat Creeks subcatchment. This zone contains good pool-riffle habitats, potential hyporheic habitat but also has substantial areas of degraded in-channel and riparian habitat (Sheldon et al, 1999). Restoration of ecosystem functioning requires maintenance of environmental water requirements combined with active rehabilitation and watercourse management. Good pool-riffle habitats within this zone should be the focus of management and rehabilitation efforts.

In-stream vegetation is dominated by reed beds, which provide poor habitat diversity. These reed beds serve a function in binding sediment and their removal could have impacts on downstream ecosystems. Management actions need to consider the potential impacts on the Mobile zone downstream.

Baseflows in this zone maintain permanent pools and watercourse vegetation. This zone would be significantly impacted by a reduction in the local watertable. Freshets are important for maintaining water quality in pools. Habitat connection flows are important to maintain flow over riffles and habitat connections. High flows are important to scour pools and reset in-stream habitat.

Incised zone

The watercourses in the Pine and Rices Creek, Eyre Creek and part of the Upper Wakefield subcatchments are classified as part of the Incised zone. Typically, the watercourse channels and riparian areas of this zone are severely degraded. In-stream emergent vegetation along the Wakefield River main channel in this zone is dominated by reed beds, which provide poor habitat diversity. These reed beds serve a function in binding sediment and their removal could have impacts on downstream ecosystems. More information is required on the ecology and role of reed beds.

Maintaining environmental water requirements is insufficient and will need to be combined with active land and watercourse management to bring about improvements in this zone. Management actions need to consider the potential downstream impacts. In particular, protection of the Mobile zone needs to be considered in regard to any rehabilitation works in this zone. The Chain of ponds zone could be used as a benchmark for rehabilitation of reaches within the Incised zone.

Key flow issues include the protection of groundwater fed baseflows and migration and mid flows that maintain pool-riffle connections and water quality in permanent pools. Freshets are important for maintaining water quality in pools. The Eyre Creek is an important contributor of baseflows in the Wakefield River and control of local groundwater extraction is important. The impacts of stormwater discharge from the towns of Watervale and Auburn is a potential threat to the water quality of downstream reaches.

Recommendation	
7.2	Watercourse management in the Transition zone and Incised zones needs to consider potential impacts on the Mobile zone. Disturbance of reed beds, which has the potential to release large amounts of sediment, should be avoided.

Constrained zone

The Skillogalee Creek subcatchment encompasses the entire Constrained zone. The Skillogalee Creek is an area of good ecological integrity and could possibly support an hyporheic habitat. In particular, the area below Port Road has pool-riffle sequences, a diversity of in-stream and riparian vegetation and is an important source of organic matter for the Wakefield River. Other areas however have poor riparian vegetation and erosion caused by stock access. The absence of fish and stoneflies (Plecoptera) from this zone requires further exploration (Sheldon et al, 1999).

The Skillogalee Creek contributes a high proportion of good quality groundwater and surface flow to the Wakefield River (Cresswell, 1999). A range of flows is important including baseflows, habitat connection and migration flows for riffle flow and habitat connections and high flows for pool scouring and habitat modification. Freshets are important for maintaining water quality in pools. Maintenance of the integrity of this area requires land and watercourse management as well as controlling groundwater extractions that could influence baseflows.

Chain of ponds zone

The Chain of ponds zone encompasses the main channel of the river upstream of Wookie Creek in the Upper Wakefield subcatchment. This zone, while impacted by grazing and weeds, was considered a benchmark for what the Incised zone may have been like before land use changes caused massive incision of the river channel. This area has a high potential for rehabilitation with maximum benefit gained from a minimum of effort. In particular the Water Reserve at Riley Road had a high diversity of in-stream vegetation and native grasses and should be considered an area of high ecological value.

Baseflow is important in this zone to maintain permanent pools and emergent and semi-aquatic vegetation. Other key flow issues include freshets and migration flows for habitat connections, diversity and water quality. High flows are important for scouring pools and long term habitat maintenance.

Recommendation	
7.3	The Chain of ponds zone should be considered an area of high priority for riparian rehabilitation efforts by landholders and key stakeholders.

7.3 Management options

7.3.1 Water management

Chapter 6 outlines those features of the flow regime needed to sustain the ecological values of the Wakefield River system at a low level of risk. In particular, the Scientific Panel workshop identified five key aspects of environmental water requirements for the Wakefield River.

- Maintain certain important flow bands.
- Maintain the natural flows variability.
- Maintain the continuity of flows through the system.
- Protect the recession limb of the hydrograph.
- Recognise the Wakefield River is a highly variable, pulse system.

Table 6.3 summarises the key flow bands, frequencies and durations identified by the Scientific Panel as being important to ecosystem function in the Wakefield River system. The seven key flow bands represent an initial assessment of environmental water requirements using best available knowledge. A process of monitoring and further research is strongly recommended to ensure that these flow estimates are revised and adjusted, as new information becomes available. In particular, limited hydrological data and lack of long-term ecological data places limitations on these initial assessments.

The environmental water requirements of the Wakefield River system have been identified. Water resource allocation and management strategies are now needed to implement these requirements. These strategies will need to manage activities such as farm dams, groundwater extraction and pumping from permanent pools to ensure that groundwater and surface water resources are equitably shared with the environment. In particular, the information in this plan will contribute to the Water Allocation Plan for the Clare Valley Prescribed Water Resource Area. This is currently being prepared by the Clare Valley Water Resources Planning Committee in accordance with the *Water Resources Act, 1997*.

It is important to note that water resource management issues are not the only issues which impact on surface flows – land management practices and dryland salinisation also impact on the system. Development of management strategies requires detailed modelling of the natural flow regime and the effects of current development and testing of potential future development and operational rules to determine effects on natural flows.

Abstraction of groundwater and surface water has the potential to have a significant influence on hydrology and ecology in the Wakefield River. Small-scale flow events are ecologically very significant and are likely to be influenced by farm dams. Wells and bores are likely to impact on baseflows and permanent pools. Land management practices will affect the frequency and volume of high flow events. The potential impacts of farm dams and groundwater use on environmental water requirements are summarised in Table 7.2.

Table 7.2: Potential impacts of water abstraction on environmental water requirements.

Flow Bands	Daily Max (cumecs)	On-stream Dam	Off-stream Dam	Ground-water Use
Baseflow	baseflow	✕	✕	✔
Freshets	0.05-0.15	✔	✕	✔
Habitat connection	<1	✔	✕	✕
Migration flows	~3	✔	✔	✕
Mid flows	6-10	✔	✔	✕
High flows	15-25	✔	✕	✕
Floodplain	40+	✕	✕	✕

✔ = potential impact; X = no or little impact

Of the extraction methods, on-stream dams are the most likely to impact on environmental water requirements. There are obvious environmental problems in allowing uncontrolled dam development across the Wakefield River catchment. The most significant is that the river will not flow until the dams spill, changing the rivers natural variability. It seems reasonable that the total volume of water held in this type of storage be limited to ensure that the flow frequencies specified by the Scientific Panel workshop are not exceeded. A management strategy that limits the volume of each type of storage and ensures that they are acceptably distributed about the catchment could ensure an acceptable volume of water is released both in terms of total volume and distribution. As protection of small flow events is paramount, dam construction should consider low flow bypasses in farm dams.

Baseflow will be affected by groundwater use. Groundwater resource development will need to be controlled near important source areas. The location of recharge zones are not well known and could potentially be located a significant distance from where discharge is occurring. Permanent pools and baseflow provide important habitat and refugia during dry periods and should be protected from surface water extraction.

The rate of rise and fall of a flow event is important, particularly in zones where there are no pools or refuges. An increased rate of fall can lead to stranding of fish and macroinvertebrates and slumping of saturated banks. It is likely that pumping during flow events will affect the recession limb of the hydrograph. It is important that this water use does not alter the natural rates of rise and fall of flow events.

Recommendations	
7.4	To protect environmental water requirements, there needs to be management of the type of water storage, volumes of water stored and distribution of storages about the catchment.
7.5	As protection of small flow events is paramount, dam construction should consider low flow bypasses in farm dams or offstream dams.
7.6	Baseflows and permanent pools are essential environmental water requirements and should be protected from local groundwater extraction and the pumping of pools.
7.7	The rates of rise and fall of a flow event should not exceed that of the natural hydrograph.
7.8	Long-term water allocation strategies should be developed based on detailed hydrological modelling aimed at achieving the identified environmental water requirements.
7.9	Water resource management must take an adaptive approach that allows for revision of management strategies based on long term monitoring and improved knowledge.

7.3.2 Watercourse management

Priorities and options for watercourse management at a subcatchment level were discussed in detail in Chapter 5. The primary threats to river health across the catchment are lack of native watercourse vegetation, exotic trees and weeds and grazing of livestock.

The condition of riparian vegetation across the catchment is very degraded. Exotic vegetation, including annual grasses, weeds and trees do not fulfil the same ecological functions as native vegetation and result in a decline in habitat and biodiversity. Improving the ecological health of the system relies on revegetation with locally indigenous species. Rehabilitation of riparian vegetation in the Transition, Incised and Chain of ponds zones is likely to increase the diversity of plant species and encourage competitive exclusion of the relatively homogenous reed beds. High light levels and/or water temperatures could be excluding some macroinvertebrates from streams in the catchment and increasing riparian vegetation, and thus shading could redress this.

Recommendations	
7.10	The proirities and options for watercourse management at a subcatchment level outlined in Chapter 5 should be considered when undertaking river rehabilitation.
7.11	Areas of high value riparian habitat should be considered a high priority for management of grazing, exotic plant control and revegetation.
7.12	Protection and regeneration of native vegetation, overstorey and understorey to improve habitat and protect bed and banks from water erosion should be encouraged.
7.13	Stock management, eg fencing, alternative watering points, which reduces the impacts of stock on river bed and banks and on riparian vegetation should be encouraged.
7.14	Management of exotic trees is a high priority to prevent spreading along watercourses and to improve water quality and habitat value in areas of medium density to dense infestations

7.3.3 Land management

Improved riverine management should not be viewed in isolation from improved land management within the rest of the catchment—the two are inseparable. Past land clearance within the Wakefield River catchment has introduced a number of changes including increased volume and speed of surface runoff which intensifies size and frequency of floods. The most obvious impact has been the incising of watercourse channels and loss of links between river and floodplain.

Significant soil surface management improvements, eg contour banking, stubble retention, minimum tillage and improved pasture management, throughout the Wakefield catchment since the late 1970s have reduced rates of surface runoff and soil loss. However it is likely that highly erosive flood events still occur more regularly than would have been the case prior to European settlement. The regular occurrence of these events represents a potential risk to rehabilitation of the Wakefield River (Cresswell, 1999).

Figure 7.1 shows estimated cumulative sediment transport plotted against time to show potential catastrophic flow events from 1900 to 1996. The figure should be considered as a guide only, but it does indicate that the period 1905 to 1918 (A and B) was the larger of just two major high flow periods in the Wakefield Rivers since 1900. Between these events lies two long low flow periods, the current one has a duration of 35 years (Cresswell, 1999).

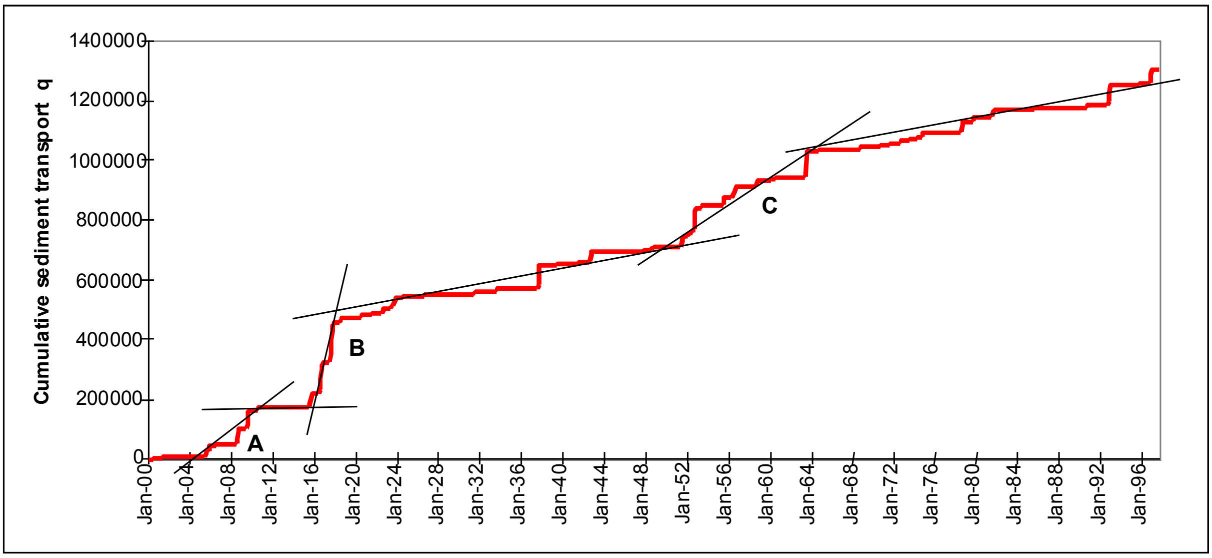


Figure 7.1: Estimated cumulative energy (defined as rate of sediment movement (q)) of river flows plotted against time.

It is likely that these low flow periods represent a period of recovery for the river system. For example, we are currently observing the reclamation of the bed of the channel by reeds that anchor and retain sediment. The permanence of the recovery might depend on the stability of the system during a high flow period. Without the protection offered by in-stream vegetation these reaches of the river could undergo severe erosion and the sediment stored over the past 30 or more years could be re-mobilised.

Land management practices and revegetation of watercourses are important to slow surface flows and protect beds and banks from water erosion. Since 1995 there has been less emphasis on contour banking and more mixing up of control measures with a trend back to the use of burning and tillage as tools to combat weed and pest problems (C Rudd, pers comm). Land management practices that aim to minimise the volume and velocity of surface runoff from a property should continue to be encouraged. Management options include:

- cultivated areas—minimum tillage, direct drilling, deep ripping of hard pans, contour banks, grassed waterways
- pastured areas—maintain good pasture cover at all times, direct drill deep rooted perennial pasture species.

Land clearance can initiate the rising of groundwater tables because less infiltrated water is intercepted. Where the watertable approaches the surface, land will become salt affected causing vegetation decline and, in the worst case, development of saline lakes. Land salinisation upslope of the Diamond Lakes area is introducing a number of environmental problems for the Wakefield River. Death of mature river red gums along the section of river downstream of Whitwarta could be because saline groundwater has migrated to this low point in the river system and a long period of low flow in the Wakefield River from 1983-1989. This low flow period, primarily due to climatic conditions is likely to have prevented salt flushing from the tree roots (Cresswell, 1999). The viability of riparian vegetation in this area will depend on the level of salinisation.

Recommendations	
7.15	Improved land management practices, such as contour banking, minimum tillage and pasture management should continue to be encouraged.
7.16	Protection and regeneration of native vegetation, overstorey and understorey should be encouraged to slow the flow and protect bed and banks from water erosion.
7.17	A permanent observation bore network should be established to assess rising watertables in the Whitwarta area.
7.18	A catchment management plan for the Diamond Lake catchment should be developed and implemented as recommended by the Diamond Lake Dryland Salinity Investigation (Land Management and Environmental Assessment Services, 1996). This would need to involve all landholders in the Diamond Lakes area and the technical support of PIRSA.

7.3.4 Community and stakeholder awareness and support

At the first community meeting, landholders identified a range of issues of concern for each subcatchment. Most landholders were very aware of the management problems, but generally had a poor understanding of 'how watercourses work' and the importance of the riparian zone. Watercourse management issues identified as being of most concern to landholders across the entire catchment are shown in Table 7.3.

During the community consultation process landholders indicated that cost, lack of knowledge of how to identify or deal with problems, bureaucracy and lack of integration between government agencies and lack of time were major barriers to achieving better watercourse management. They also indicated that they often did not know where to seek advice on how to effectively manage their watercourse.

To maintain the momentum of community interest in watercourse management fostered under this project, landholders must be supported in undertaking the recommended works. This support could be in the form of technical advice and funding incentives. For landholders interested in undertaking on-ground works, a more site specific action plan needs to be developed. This plan would include details specific to any on-ground works that need to be addressed, maintenance of the site (eg weed control), who is involved, the timing and the costs.

Table 7.3: Watercourse management issues in the Wakefield River catchment as identified by landholders

Management Issue	Total no of votes
Impacts on flows	77
Weeds	47
Erosion/sedimentation	33
Reeds	21
Water quality	21
Exotic trees	20
Salinity	10
Impacts on groundwater	10
Rubbish/debris	10
Lack of vegetation	6
Floods	4
Grazing	4

Extension advice on land management issues is currently provided through property management planning courses, community landcare officers, revegetation officers and PIRSA land consultants. However, there is an urgent need for an extension program that provides landholders with support and technical advice on watercourse management issues.

It also became apparent that there is a general lack of awareness among landholders and key stakeholder groups regarding their responsibilities under current natural resource management legislation, eg *Native Vegetation Act, 1991*, *Water Resources Act, 1997* and the *Environment Protection Act, 1993*. Consequently, they may undertake activities such as excavation of watercourses or removal of native in-stream vegetation, unaware they may be in breach of one or more of these acts. A program of education and raising awareness is required to improve awareness of legislative rights and responsibilities. The community also needs to be better informed of the appropriate agencies to contact for further information.

Recommendations	
7.19	An ongoing extension program to facilitate better watercourse management in the catchment should be established.
7.20	A watercourse management field guide should be produced which provides high quality, technical advice on managing watercourses in the Mid North region.
7.21	DEHAA should develop and implement a community and stakeholder education program to raise awareness of legislative rights and responsibilities under current natural resource management legislation.

7.3.5 Integrated management

Landholders in the Wakefield River catchment expressed concern with the lack of an integrated approach to water resource and watercourse management within the catchment. These issues are addressed by a range of bodies including soil conservation boards, animal and plant control boards, water resource committees, landcare and catchment groups, government agencies and individual landholders.

One of the major objectives of this project is to integrate watercourse management and environmental water requirement issues into the regional and district planning and implementation strategies of these bodies. This will partially ensure a more integrated approach to river management. However, a co-ordinating body needs to be established to facilitate the implementation of the recommendations outlined in this plan.

Recommendations	
7.22	The river management planning information contained in this document should be integrated into the strategic and operational plans of the following organisations: the Clare and Gilbert Valley Council, Wakefield Regional Council, Clare Valley Water Resources Committee, Lower North Soil Conservation Board, Lower North Animal and Plant Control Board, Mid North Regional Development Board, PIRSA and DEHAA.
7.23	Investigate the feasibility of establishing a regional management body to facilitate the implementation of this plan and other regional natural resource management plans.

7.4. Monitoring and further investigation

7.4.1 Monitoring

Effective river management relies on a sound knowledge of the river system. The management recommendations outlined in this plan are based on a 'snapshot' of the current condition and environmental water requirements of the Wakefield River system. River systems are dynamic and function on a range of time scales. Limited long-term data means that many of these management recommendations need to be reviewed in light of information collected over a longer time scale.

Long term monitoring is an essential part of successful river management. It is important to clearly define what is to be monitored and why and how the information gathered will be fed back into the management process. In ephemeral systems with a high degree of hydrological variability such as the Wakefield River it is also important that the time scale required for monitoring and interpreting change is understood. It is beyond the scope of this project to develop a detailed monitoring strategy but some broad ideas and suggestions are discussed below.

Environmental water requirements identified in this plan were determined on the basis of best available scientific information and experience. It is important to recognise the limitations imposed by a lack of long-term scientific data and comprehensive flow gauging. A process of monitoring and further research with a feedback loop to ensure that the environmental water requirements are revised and adjusted as new data is obtained is essential (Arthington et al, 1998).

Based on cross section profiles taken at sites representative of different geomorphic zones, the Scientific Panel workshop identified important flow bands for the Wakefield River that fulfil certain geomorphological and ecological functions. A key question for monitoring and further investigation is the extent to which these flow bands actually fulfil these functions within each geomorphic zone.

The expected long-term outcomes of this project are improved health and diversity of riverine ecosystems, reduced erosion and sedimentation, improved water quality and reduced stock and weed management problems. We need to assess the impact of watercourse management interventions and environmental water requirements in achieving these outcomes.

One option for monitoring watercourse condition is to measure change to or from natural or reference conditions. The Scientific Panel workshop identified a number of potential reference sites for different geomorphic zones in the Wakefield River catchment (Table 7.4). The Scientific Panel workshop has recommended that monitoring watercourse condition at these sites be considered a high priority. These reference sites could be used as benchmarks against which test-site conditions are compared. Another option for monitoring would be to measure change at sites undergoing active watercourse rehabilitation compared to sites where no action was being undertaken.

Table 7.4: Potential reference sites in the Wakefield River catchment.

Reach/Zone	Site	Reason
Mobile zone	The Rocks	High natural biodiversity
Constrained zone	Monitoring River Health Initiative site, No. 7442.	Healthy riparian vegetation
Incised zone	Monitoring River Health Initiative site, No. 3554.	High abundance of macroinvertebrates
Chain of ponds	Water reserve, Riley's Road	High diversity of in-stream vegetation; chain of ponds morphology

One possible way of measuring change would be to develop an Index of Stream Condition (ISC) based on the Victorian model but suitable for South Australian watercourses. The ISC is an effective management tool for benchmarking the condition of watercourses and for assessing the long-term effectiveness of management intervention. The ISC provides an assessment of changes to hydrology, physical form, riparian zone, water quality and aquatic fauna (Waterway and Floodplain Unit, 1997).

The MNRMPP has collected baseline data that would be important to any monitoring strategy (Table 7.5). In addition, the Monitoring River Health Initiative has undertaken longitudinal studies of macroinvertebrates at reference and test sites throughout the catchment since 1994.

An important initiative by major stakeholders involved in water resource management in South Australia has been the establishment of a State Water Monitoring Co-ordinating Committee and the development of a framework for a co-ordinated Water Monitoring Program. The committee has initiated the State Water Monitoring Review to ascertain water monitoring needs across the state. The information and recommendations contained in this plan should be considered by the State Water Monitoring Review, as part of the review of current monitoring programs, and in the development of future water monitoring programs.

Table 7.5: Baseline data collected by the MNRMPP.

Scale	Data
Catchment	Aerial video of major watercourses*
Site (100 m) – representative of river geomorphic zones	Cross sections Longitudinal profiles Vegetation coverage Sediment sampling Photo points
Site (includes MRHI sites)	Native and exotic fish species – abundance and type

*Third order and larger

Monitoring and assessment of the outcomes and benefits of environmental water requirements and a phase of investigations or research is essential for effective management. However, this effort is wasted unless accompanied by a review of the results and a process for adapting river management processes in accordance with the information gained from monitoring and further investigation.

Recommendations	
7.24	Long term flow monitoring program should be developed for the Wakefield River catchment to assess the Environmental water requirements identified by the Scientific Panel Workshop and to monitor changes in flows.
7.25	A set of environmental indicators for the Wakefield River system should be developed based on the Index of Stream Condition model.
7.26	A long term monitoring program based on the ISC should be established to assess watercourse condition. The program should be based on the use of reference sites and/or comparisons between restored and unrestored sites.
7.27	This plan and its recommendations should be considered as part of the State Water Monitoring Review being conducted under the auspices of the State Water Monitoring Coordinating Committee.

7.4.2 Further research/investigations

In addition to long term monitoring the Scientific Panel workshop identified a number of knowledge gaps and limitations to the currently available data. Special research projects or investigations, which address particular questions and knowledge gaps, are essential to develop a sound information base for river management.

River rehabilitation

An important question about river rehabilitation is what are we aiming for? Studies of relatively unimpacted reaches would provide a benchmark for river restoration, eg the Chain of ponds zone could provide a benchmark for restoration of the Incised zone.

Hydrology

In particular there is a lack on information on the role of groundwater in the Wakefield River system, including the relationships between rainfall, aquifer discharge and baseflow levels. There is a lack of data on the contribution of farm dams and land management within the catchment to reducing surface runoff and river flows. Further studies on the impacts of farm dams, groundwater extraction and land management practices on surface runoff and river flows are required. This is particularly important for the development of water allocation and management strategies. Further investigation of the location of groundwater recharge zones in the catchment is required.

The estimates of flow band volumes and frequencies are based on a limited data set (1974-1996) obtained from a single gauging station. Gauging of flows from the Skillogalee Creek, Eyre Creek and Upper Wakefield River would provide specific hydrological data on flows from these areas and how they relate to gauging station values. This would help refine flow band estimates.

Current data on water quality and salinity data is lacking. Monitoring of water quality over a 2-3 year period needs to be linked with flow gauging. In addition the impacts of stormwater discharge downstream of towns such as Watervale, Auburn and Balaklava is not known.

Geomorphology and ecology

There was a lack of long term and in-depth information on biological and physical attributes of the river system and the relationship with surface and groundwater flows. Suggestions for further studies include:

- long term studies of fish and macroinvertebrates including migration patterns and how they use river flows
- AUSRIVAS modelling of macroinvertebrate data
- in-depth studies of ecology of the Mobile, Chain of ponds and Constrained zones
- in-depth studies of the ecology of pools eg fish, macroinvertebrates and impacts of pumping and groundwater extraction
- studies of rate and nature of geomorphological change in the river system eg persistence of in-channel habitat, sediment sources and storage
- investigation of hyporheic environments, including role as a refuge in dry periods, existence and location of subsurface fauna, their life cycle and environmental water requirements
- further investigation of the role of reed beds and potential management options.

Recommendations	
7.28	Further research studies should be undertaken to investigate knowledge gaps related to specific physical, hydrological and biological attributes of the system.
7.29	Further detailed hydrological modelling should be conducted to assess the impacts of farm dams, groundwater extraction and land management practices on surface runoff and river flows.
7.30	Studies of relatively unimpacted reaches should be undertaken to provide a benchmark for river restoration works.
7.31	A feedback process should be developed for incorporating new information into water allocation and other watercourse and land management strategies.

7.5. Concluding remarks

This plan makes recommendations for watercourse management and outlines the environmental water requirements necessary to maintain or improve watercourse habitats and their ecosystem processes. This understanding of the environmental water requirements of the Wakefield River system will provide valuable information for the development of water management plans (eg Clare Valley Water Allocation Plan). The watercourse management priorities and options will form the basis of planning for on-ground action. These can be used by the community and key stakeholder organisations for both practical and strategic planning and to set priorities for individuals or groups seeking funding for on-ground works.

Inherent 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 current condition of the river system. The field surveys and data analyses were completed within the scope of a one-year timeframe and the project budget. Notwithstanding this, the environmental water requirements that have been identified and quantified have been determined through a scientifically defensible scientific panel habitat assessment approach. The watercourse management priorities and options were developed based on the data collected and in consultation with local landholders and in this sense reflect both ecological and community priorities. Further research and analysis are required to bolster our understanding of the Wakefield River system. In particular, we need to understand better the long-term trends of the system.

The implementation of the recommendations for watercourse management and environmental water requirements will require flexible and adaptive management based on the monitoring of outcomes. In particular it is important to consider that are a number of interacting elements that determine river condition. These include physical character, water quantity and quality, condition of the riparian zone and floodplain and the diversity and population of plants and animals. Improved management of the Wakefield River system therefore requires an integrated approach that combines flow, land and watercourse management.

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APPENDIX A

Floristic vegetation of the Mid North Region

The vegetation map for the Mid North region, shows the distribution and extent of native vegetation in the Mid North Region of South Australia. In this study native vegetation is defined as those areas which appear to be largely unmodified by human activity and where indigenous plant species predominate.

There are various ways to classify vegetation. A modern objective method (PATN) has been used. The vegetation is divided into groups, each representing a major change in plant species composition (floristics) and overstorey structure (height and projective foliage cover). They reflect broad environmental differences and more subtle changes in the environment such as drainage, local topography, microclimate and fire history.

All vegetation and site data, including boundaries between different floristic and structural vegetation types, are held in the Environmental Database of South Australia, maintained by the Information Data and Analysis Branch, Planning SA, South Australia.

The floristic groups briefly summarised in the legend were derived from an analysis of 638 survey sites, from the Biological Survey of SA, and supplemented by literature references and unpublished field notes. The analysis was based on the principle that sites with similar combinations of plant species should group together to form each floristic group. Further subdivision of several floristic groups was made on the basis of various dominant overstorey species. These groups commonly had the same understorey as their parent floristic group.

To differentiate between plant communities, each is described in terms of its overstorey dominants (defined as having a proportion of occurrence >/= 50%, generally a large lifeform size and high abundance) and overstorey structural formation where possible.

The structural formation classes used are according to Forward and Robinson (1996), adapted from Specht (1972) and Muir (1977), and are based on field measurements of overstorey height and projective foliage cover (Table A.1). Identification of plant specimens was greatly assisted by access to the resources and staff of the State Herbarium. The plant names used in the legend conform to *A List of the Vascular Plants of South Australia* (Jessop, 1993).

Mapping

The floristic mapping has resulted from extrapolation of PATN analysis results from the vegetation survey site locations in conjunction with interpretation of predominantly 1987, 1:40,000 colour aerial photography and on-ground inspection.

As native vegetation does not always occur as discrete discernible units that are mappable but could be intergrading or occur in complex mosaic patterns, several groups can occur in a delineated area or block. Where distinct communities can be recognised they have been delineated, however, where the pattern is more complex, then more than one floristic group, in order of dominance, may have been indicated in the original 1:40,000 scale mapping.

Table A: South Australian Vegetation Structural Formations

Life Form/Height Class	Projective Foliage Cover of Tallest Stratum			
	Dense (70-100%)	**Mid-dense (30-0%)**	**Sparse (10-30%)**	**Very sparse (<10%)**
Trees > 30 m	Tall closed forest	Tall open forest	Tall woodland	Tall open woodland
Trees 10-30 m	Closed forest	Open forest	Woodland	Open woodland
Trees 5-10 m	Low closed forest	Low open forest	Low woodland	Low open woodland
Trees <5 m	Very low closed forest	Very low open forest	Very low woodland	Very low open woodland
Mallee (>3 m)	Closed mallee	Mallee	Open mallee	Very open mallee
Low mallee (<3 m)	Closed low mallee	Low mallee	Open low mallee	Very open low mallee
Shrubs > 2 m	Tall closed shrubland	Tall shrubland	Tall open shrubland	Tall very open shrubland
Shrubs 1-2 m	Closed shrubland	Shrubland	Open shrubland	Very open shrubland
Shrubs < 1 m	Low closed shrubland	Low shrubland	Low open shrubland	Low very open shrubland
Mat plants	Closed mat plants	Mat plants	Open mat plants	Very open mat plants
Hummock grasses	Closed hummock grassland	Hummock grassland	Open hummock grassland	Very open hummock grassland
Tussock grasses	Closed (tussock) grassland	(Tussock) grassland	Open (tussock) grassland	Very open (tussock) grassland
Sedges	Closed sedgeland	Sedgeland	Open sedgeland	Very open sedgeland
Herbs	Closed herbland	Herbland	Open herbland	Very open herbland
Ferns	Closed fernland	Fernland	Open fernland	Very open fernland

Adapted from Forward and Robinson (1996); NB: Table originally derived from Specht (1972) and Muir (1977).

Trees - woody; perennial; erect; canopy raised well above the ground. Depth of canopy is usually less than or equal to two thirds of the total tree height. Single stemmed, or if multi-stemmed, fewer than five individual trunks resulting from branching of a single short trunk, that is not a mallee-like lignotuber. Height usually >2 m.
Mallees - genus *Eucalyptus;* multi-stemmed, trunks arising from lignotuber. Low mallee - < 3 m. Mallee - > 3 m
Shrubs - woody; perennial; erect, procumbent or weeping; foliage occupies all or part of total plant height; multiple stems and branches arising from a rootstock or very short common trunk; generally <5 m tall.
Mat plants - herbaceous or woody plants of prostrate habit, with major stems growing along the ground. Rarely exceeds 10 cm in height. Examples of mat plants are *Kunzea pomifera*, *Myoporum parvifolium*, *Carpobrotus rossi* and *Mimulus repens*.
Hummock Grass - Genera *Triodia* or *Plectrachne* only.
Grasses (tussock) - family Poaceae (Graminae); leaf sheath always split.
Sedges - herbaceous, usually perennial, erect, generally tufted; arise from stolons, tubers, bulbs, rhizomes or seeds. Leaf sheath never split. Includes Cyperaceae, Juncaceae, Restionaceae, Typhaceae and Xyridaceae and other sedge-like forms.
Herbs - herbaceous or slightly woody; annual or sometimes perennial; erect or creepers; rarely exceeds 0.5 m height**.**
Ferns - ferns and fern allies, ie non-vascular cryptogams of classes Filicopsida and Lycopsida. This category includes *Ophioglossum* spp., *Lycopodium* spp., *Selaginella* spp. and *Isoetes* spp.

Source: Adapted from Forward and Robinson (1996).

Up to two categories may have been recognised in a mosaic within a given area, however, at any given location some of these may or may not be present. Mosaics have not been depicted on this map. For more detailed mapping, indicating other groups present, finer scale vegetation maps must be used.

Despite extensive sampling, it is possible that some rare community types have been missed. In particular there is considerable under-representation of several floristic communities in this mapping as a result of difficulty in interpreting boundaries from aerial photographs. The most under-represented communities are the grassland/sedgeland communities of which there are many in the Mid North. Others include the samphire/chenopod low shrublands and narrow strips of roadside vegetation.

In addition, the vegetation rarely changes as sharply as the boundary lines suggest. The distinction between some floristic groupings is often blurred by gradual transition from one community type to another.

Vegetated areas < 1 ha and scattered trees were generally not mapped. The techniques used allow this map to be readily updated and further editions are envisaged, as additional information becomes available.

APPENDIX B

Guidelines for identifying key watercourse management issues

Introduction

Within each reach, project officers and landholders identified the key river health issues or threats within that reach using the following general principles and guidelines adapted from DENR (1997a). These guidelines were discussed with landholders to help them determine priorities for voting.

General principles

- **Conservation first.** Protecting or enhancing areas of good quality riparian habitat or remnant vegetation should be given highest priority. In terms of river health and biodiversity the maximum benefit is gained for a minimum of effort.

- **A stable watercourse.** To improve the water quality and the ecological health of a watercourse, it is necessary to first establish a stable watercourse (ie minimise bed and bank erosion).

- **Current management**. All issues were evaluated on the impact (both economic and environmental) of current management practices if they continued unchanged into the future and the consequences of doing nothing.

- **Rehabilitation.** Rehabilitation is conducted on an issue by issue basis, rather than property by property basis. Rehabilitation on a property by property basis would favour those properties with large stream lengths, irrespective of whether they have the most serious management issues. However, some issues will require treatment on a 'reach' basis.

- **Benefit vs Cost.** Rehabilitation of most issues will invariably include a range of potential solutions. Funds for on-ground works are always limited, thus it is important to maximise the net benefits to the landholder and to the wider community. Any rehabilitation work should be guided by the desire to maximise the number and extent of any benefits that may accrue from such work. For example, an erosion head can be controlled by (1) installing a rock chute, or (2) fencing and revegetation. Option 1 is expensive and will only control erosion, whereas Option 2 will cost little and provide a greater range of benefits (eg erosion control, habitat, water quality, and aesthetics).

Specific guidelines

- **Important riparian habitat.** Protection of areas of good habitat should be given highest priority. Such areas usually have high biodiversity, are important refuges and provide a valuable seed bank. Conservation of remnant vegetation is always preferable than re-establishing new vegetation, as little cost and effort is needed to produce considerable ecological benefit. Protection should involve identification of threats from other reaches.

- **Maintaining and improving areas of good native vegetation.** In these areas the condition of riparian vegetation is relatively good but has been damaged by human impact. These sites have a high recovery potential but require intervention, for example, revegetation and control of threats such as stock grazing, weeds.

- **Erosion heads and poor bank stability.** When appropriate, erosion heads and poor bank stability should be treated as a single issue, as poor bank stability is often the consequence of the passing of an episode of bed deepening. If there is a need to delineate between the two issues, priority should be given to erosion heads and then poor bank stability. When determining this priority, consideration should be given to severity, location in the catchment, erodibility of bed or banks and proximity to a high value capital asset. A high value capital asset could be an area of high conservation value or in-stream infrastructure eg bridges or culverts.

- **Unrestricted stock access.** Unrestricted stock access to a watercourse can cause widespread, long-term degradation through removal of native vegetation, physical damage and nutrient pollution. The greater the length of watercourse, the greater the potential to inflict damage.

- **Weeds and exotic trees.** Weeds and exotic trees are detrimental to the ecological health of the watercourse and can cause and/or mask erosion problems. In determining the importance of this issue, consideration should be given to the density of plant coverage, the invasiveness of the plant species, if the weed is a proclaimed plant, the threat to the integrity of native or remnant vegetation and the length of watercourse affected.

- **Lack of native vegetation.** Lack of native vegetation is detrimental to the ecological health of the river resulting in loss of habitat, susceptibility to erosion, higher water temperatures and increased flow velocities. Where lack of native vegetation is caused by unrestricted stock access it should be considered an unrestricted stock access issue. Consideration should be given to the length of watercourse affected.

APPENDIX C

Costings for stream rehabilitation works

It must be recognised that these costs are approximate only. It is not possible to give precise estimates on rehabilitation as the most appropriate treatment varies from site to site. Cost also alters significantly if landholders have the knowledge and skills to undertake some of the required work. Consideration for follow-up and ongoing maintenance of the riparian zone needs to be inclusive when calculating costs. These costs are based on figures obtained from the Torrens Catchment Water Management Board and Wayne Brown, Revegetation Consultant, PIRSA.

Fencing

Electric:	$1100/km for materials (does not include energiser or flood gates) $1000/km for erection – more if in difficult terrain (works undertaken by landholder) $3000/km for contract fencing (includes materials and erection)
Conventional:	$2500/km for materials (does not include energiser or flood gates) $1500/km for erection (works undertaken by landholder) $5500/km for contract fencing (includes materials and erection

If the watercourse is the only stock watering point and fencing will restrict access, then alternative water supplies for stock are required. Basic costs for materials include: $400 for a fibreglass-concrete stock trough, $1000 per km for 19 mm poly pipe, $600 for a pump. If a watering point is required on the watercourse, $100 should be allocated for extra fencing materials. The time taken by a landholder to install a watering point will depend on many factors, however, a general guide is between 3 and 4 days.

Weed control

The cheapest and most cost effective method of woody weed control is to spray and burn infestations. Glyphosate biactive is the recommended herbicide and should be applied by licensed spray contractors. Costs will vary depending on the size of the project and density of the infestation.

Basic Costs:	$40–50/hr for spray contractor (does not include chemicals) $150–$200 for 20 litres of Glyphosate biactive

Controlling weeds prior to revegetation is essential for the success of the project. Care must be taken that increased soil erosion does not occur directly after spraying or that native species are not destroyed at the time of spraying.

Exotic tree removal

Exotic tree removal costs approximately $1300 per day. This cost includes two chainsaw operators and one mechanical 'grab' operator. The 'grab' is specifically designed to handle trees. This tree removal team can manage approximately one kilometre of medium density exotic trees (medium-sized trees) per week, ie an overall cost of $7500 per km. This estimate assumes that there is easy machine access to the site and that tree debris can be piled alongside the creek for burning.

At sites where there is high tree density or access is difficult, hand removal would be required. The cost of hand removal of exotic trees can be as high as $3000–$5000 per 100 metres.

Revegetation

Revegetation can be achieved in many ways. Natural regeneration is by far the most economical, followed by direct seeding and then seedling plantings. Combinations of all of the above may be required for successful river/watercourse restoration.

Revegetation costs approximately $600 per hectare for direct seeding and $1000 to $1500 per hectare for seedling establishment. These costs include the cost of the seed or seedlings, spray treatment prior to establishment for herbaceous weeds (not woody weeds), and the cost of direct seeding machinery or contractors to carry out the work.

Basic costs of materials

Seedlings:	80c–$2 per seedling $1 extra per seedling for planting costs

Maintenance and summer watering may be required in difficult and very dry environments, which will add to the cost of establishment (0.5c to $1.50).

Direct seeding:	Machine seeding — $80–$100/km for ($240–$300 per ha) not including seed. Seed costs of $180–$250 per kg of seed (300–500 grams of seed required per km of seeding) Hand seeding — $4–$8 for every 25 grams of seed

If direct seeding is established at the correct time of the year, no watering is required during summer. Some minor follow-up maintenance may be required in the second year.

Erosion control structures

It is important to note that the cost of constructing structures to manage bed deepening can be highly variable. The following estimates are based on ideal situations where access and design are straightforward.

A recommended treatment for an erosion head 0.3–0.5 metres high is a sleeper weir. Fully installed, a sleeper weir should cost approximately $700.

To construct a rock chute for an erosion head approximately 0.5 metres high, materials, labour and transport would cost around $2500. If the erosion head was 1.0 metre high, then the construction cost would increase to around $7000.

These estimates do not include survey or design. They also assume that rock can be transported from a quarry close by and delivered directly to the site. Large distances from the quarry or difficult access will significantly increase the cost of construction.

GLOSSARY

Adaptive management: an approach often used in situations where there is little information and/or much complexity and there is a need to implement some management changes sooner rather than later. The approach uses the best available information for the first management plan, implements the changes, monitors the outcomes and regularly evaluates and reviews the management plan.

Aerial videography: video footage taken using a video camera mounted on a small aircraft; used to observe and record the condition of major watercourses.

Aggradation: the long-term build up of sediment on a length of stream bed so as to raise its overall surface level.

Anabranch: a distributary stream channel.

ANZECC: Australian and New Zealand Environment and Conservation Council.

Aquatic macrophytes: any non-microscopic plant that requires the presence of water to grow and reproduce.

Aquifer: a subsurface water bearing formation that will yield water to bores, wells or springs.

Bar: a temporary deposit of sediment within a stream channel that may be exposed during low water periods.

Baseflow: streamflow 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; usually lining both banks; formed by lateral accumulation of sands and gravels

Biodiversity: the variety of life forms: the different plants, animals and micro-organisms, the genes they contain and the ecosystems they form. It is usually considered at three levels – genetic, species and ecosystem diversity.

Biota: all of the organisms at a particular locality.

Council of Australian Governments: this consists of the Prime Minister, State Premiers, Territory Chief Ministers and the President of the Australian Local Government Association. It exists to set national policy directions for Australia.

Cumecs: cubic metres per second

Detritus: dead organic material (eg leaf litter) that usually accumulates on the bed of waterbodies.

Ecological processes: all processes whether biological, physical or chemical that maintain the ecosystem.

Ecological values: the natural ecological processes occuring within ecosystems and the biodiversity of these systems.

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. This is what can be provided at this time after consideration of existing users' rights, and social and economic impacts.

Environmental water requirements: the descriptions of the water regimes needed to sustain the ecological values of aquatic ecosystems at a low level of risk. These descriptions are developed through the application of scientific methods and techniques or through the application of local knowledge based on many years of observation.

Ephemeral: a stream that flows for short periods only, in direct response to rainfall and receives little or no water from springs or other sources.

Faecal coliform: a minute intestinal micro-organism.

Flood runners: a wide straight channel across a floodplain that only carries water during floods.

Floodplain: land adjacent to streams that is regularly flooded; often includes seasonal and perennial wetlands.

Flow regime: the character of the timing and amount of flow in a stream.

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: the saturated interstitial zone below streams and rivers. In dry land streams and gravel beds, most water flows through this zone which may act as a 'biological filter' improving water quality and supporting a diverse range of interstitial fauna.

Incised channel: a channel that has eroded its bed to the point where high banks are formed.

Indigenous plant species: plant species that are native to an area, ie 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 that holds back floodwater.

Longitudinal stream profiles: plot of the elevation of the channel bed, banks and water level versus horizontal distance.

Macroinvertebrates: animals without backbones that are typically of a size that is visible to the naked eye. They are a major component of aquatic ecosystem biodiversity and fundamental in food webs.

Macrophyte: any non-microscopic plant.

MRHI: Monitoring River Health Initiative.

Overstorey: woody plants > 5 m tall, usually single stemmed.

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.

Prescribed water resources: water resources declared by regulation that can only be accessed if in possession of a licence to take water issued by the Minister for Environment and Heritage. Prescribed water resources are allocated according to a water allocation plan.

Recruitment: an episode of breeding that leads to adults in the population.

Reeds: semi-aquatic plants of the family Gramineae (grasses).

Riffles: shallow, often stony areas, in streams that have rapid turbulent flow which means these areas are highly oxygenated and important habitat for macroinvertebrates.

Riparian: pertaining to or situated on the banks of a watercourse.

River health: capacity of the river ecosystem to sustain a normal and diverse suite of organisms and ecological processes.

Runs: sections of streams that are channel like with approximately a constant width and depth.

Rushes: aquatic or semi-aquatic plants of the Juncaceae family. Most rushes are 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 Cyperacae. They are mostly perennial grasses or rush-like herbs. Common types include club-rush, bog-rush and sword-sedge.

Sedimentation: the long-term permanent filling of a stream channel, lake or estuary with sediment.

State Water Plan: policy document, which sets the strategic direction for water resource management in the State. The *Water Resources Act 1997* defines the content of this plan and its purpose in setting the policies for the achievement of the object of 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. It is usually the remains of an old floodplain or bed.

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: these are 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. It must be developed through the consultation process specified in the *Water Resources Act 1997.*

Water dependent ecosystems: are those parts of the environment, the species composition and natural ecological processes of which are determined by the permanent or temporary presence of flowing or standing water. The in-stream areas of rivers, riparian vegetation, springs, wetlands, floodplains, and estuaries are all water dependent ecosystems.

Sources: ARMCANZ and ANZECC (1996); Toothill (1984); Boulton (1999), Kapitske et al (1998).

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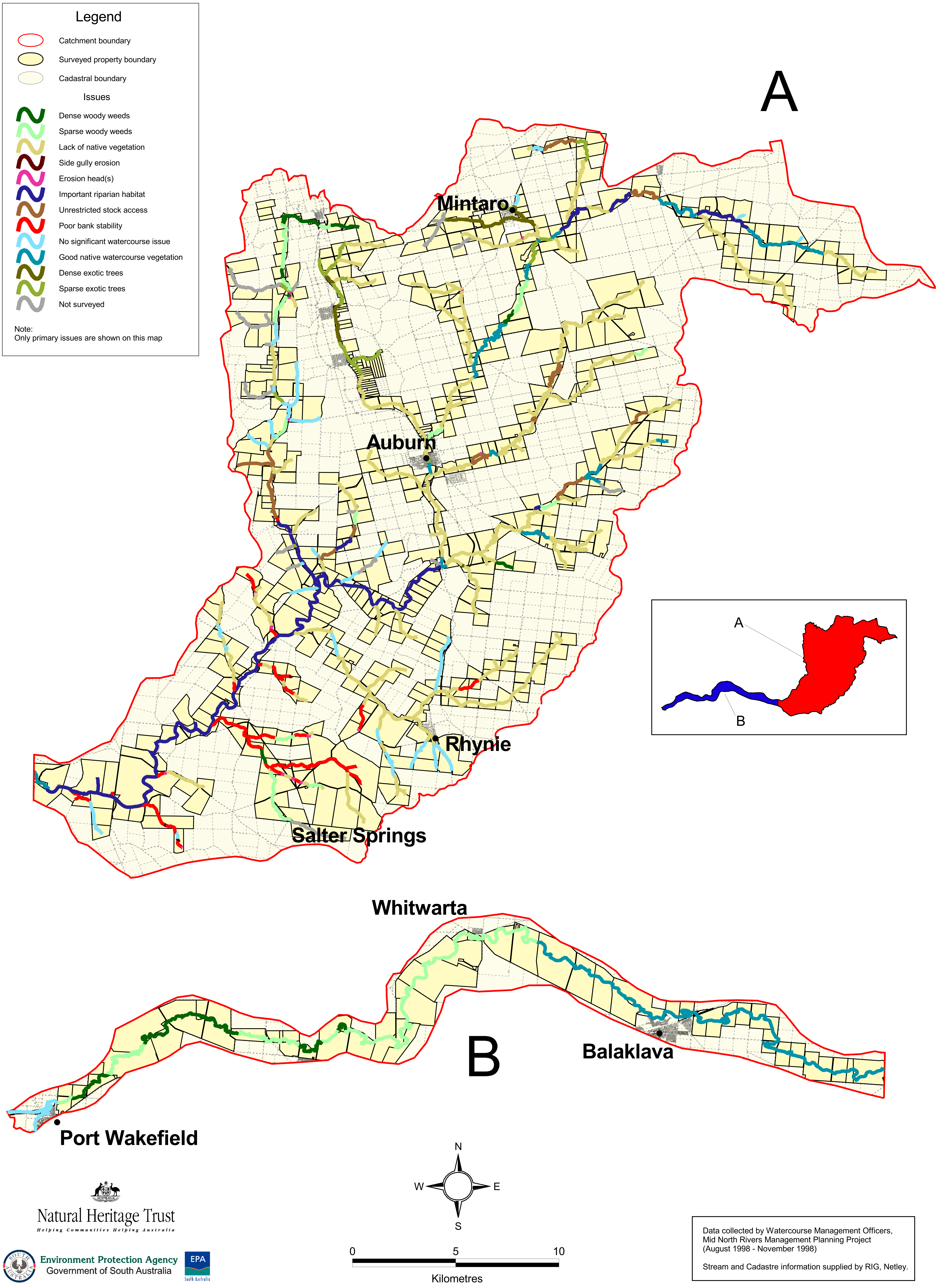
Map 1: Watercourse management issues in the Wakefield River catchment



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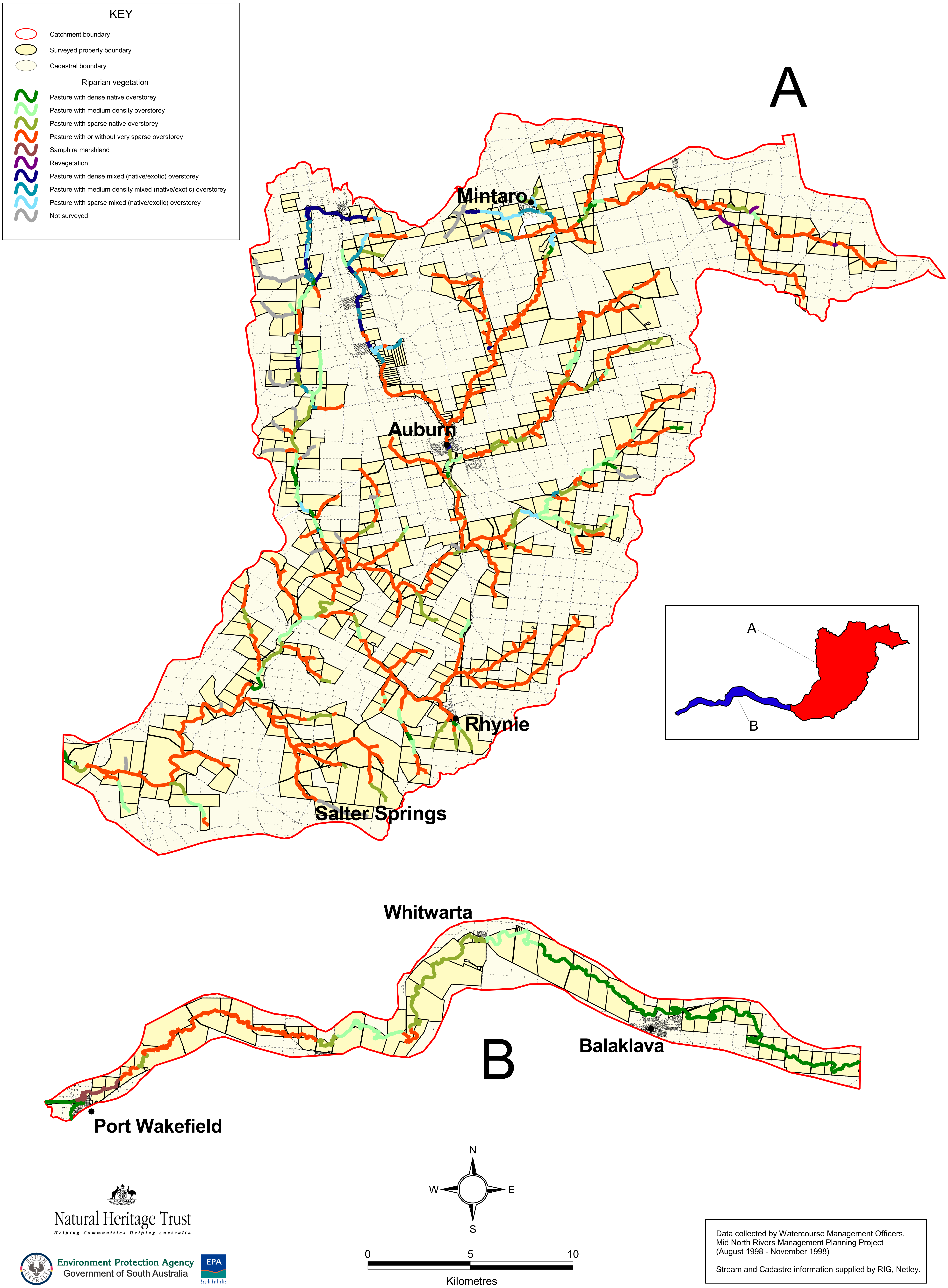
Map 2: Distribution and density of riparian vegetation



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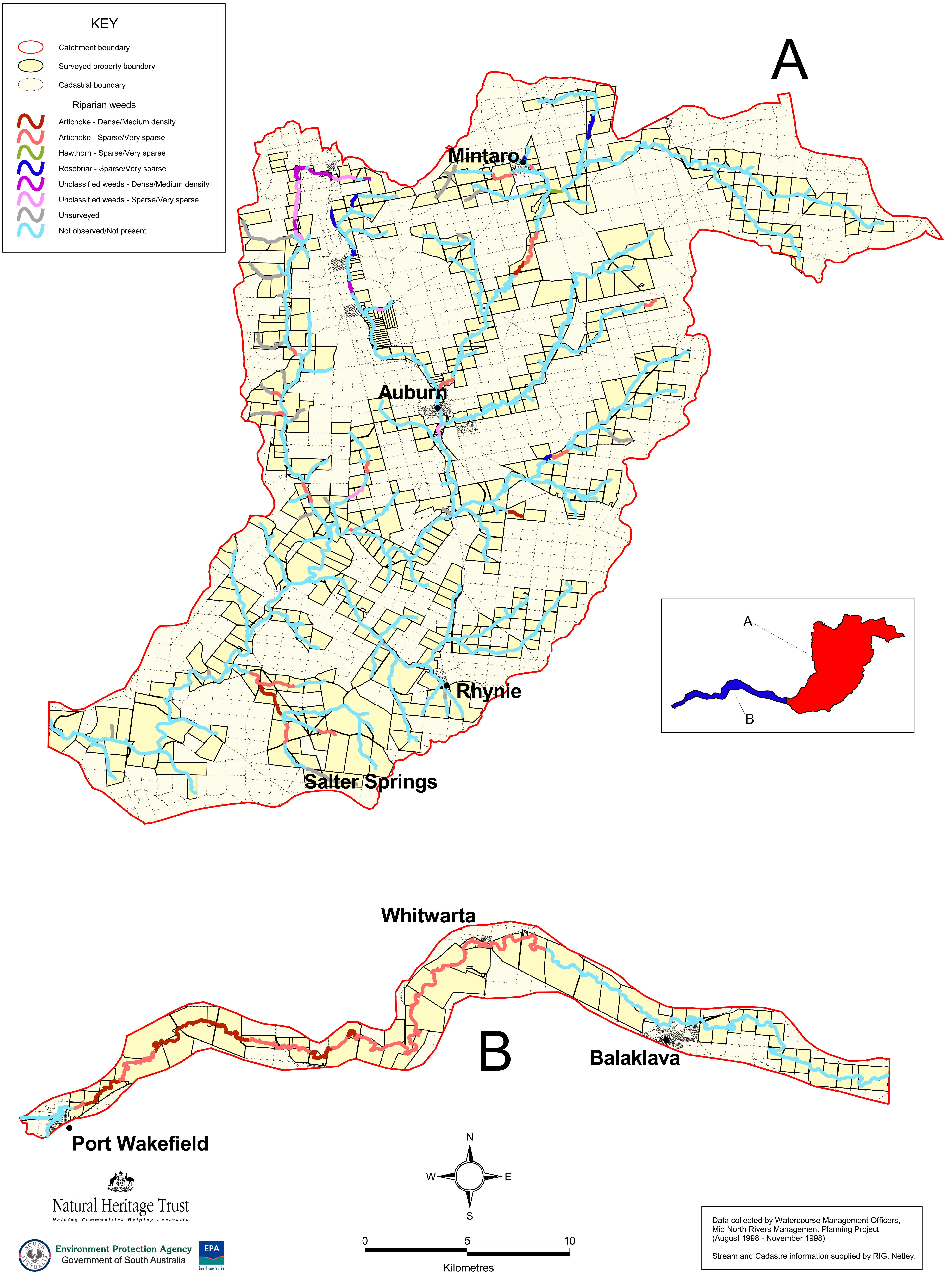
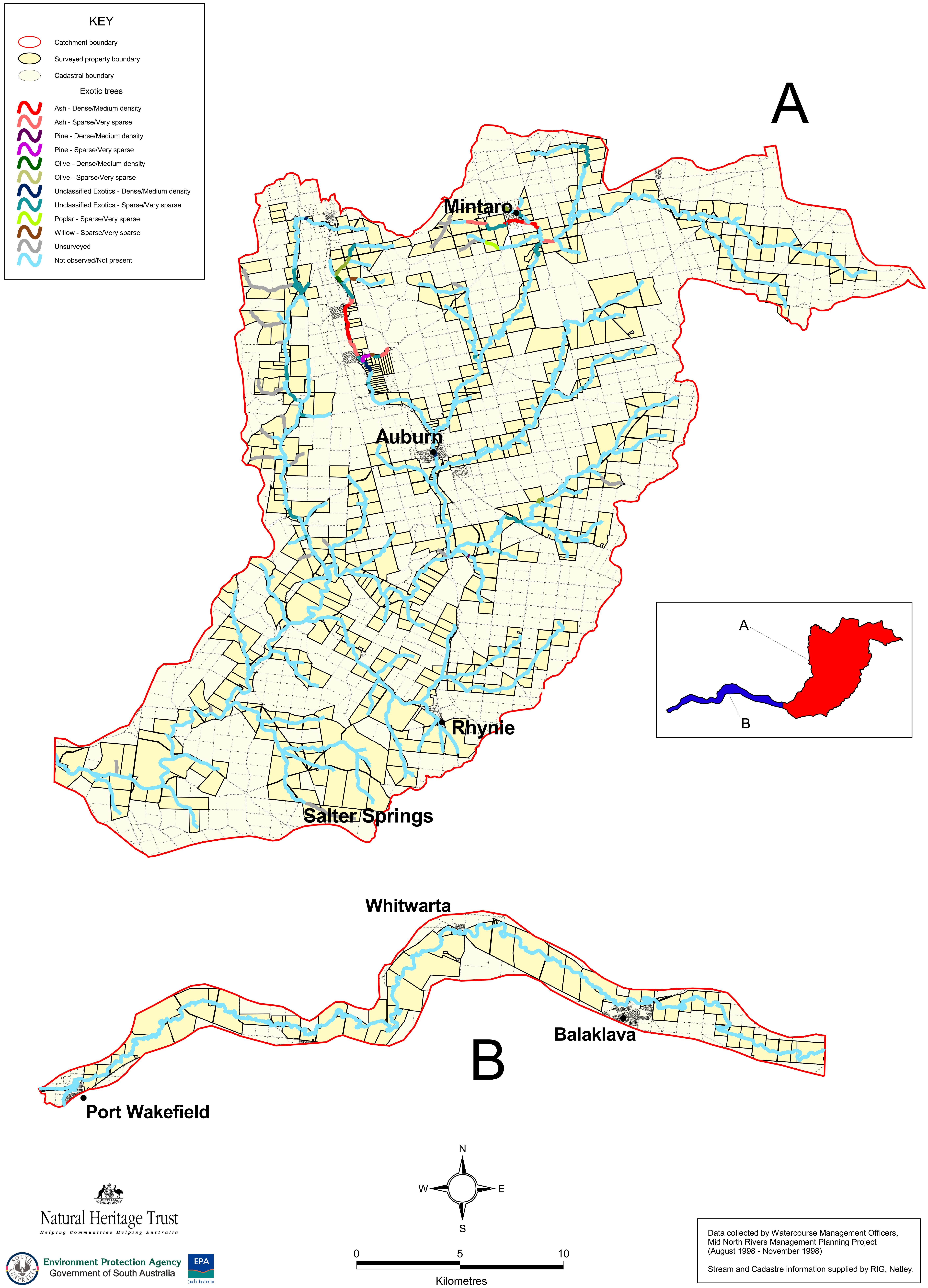
Map 3: Distribution and density of riparian weeds



Map 4: Distribution and density of exotic trees



Data collected by Watercourse Management Officers, Mid North Rivers Management Planning Project (August 1998 - November 1998)

Stream and Cadastre information supplied by RIG, Netley.

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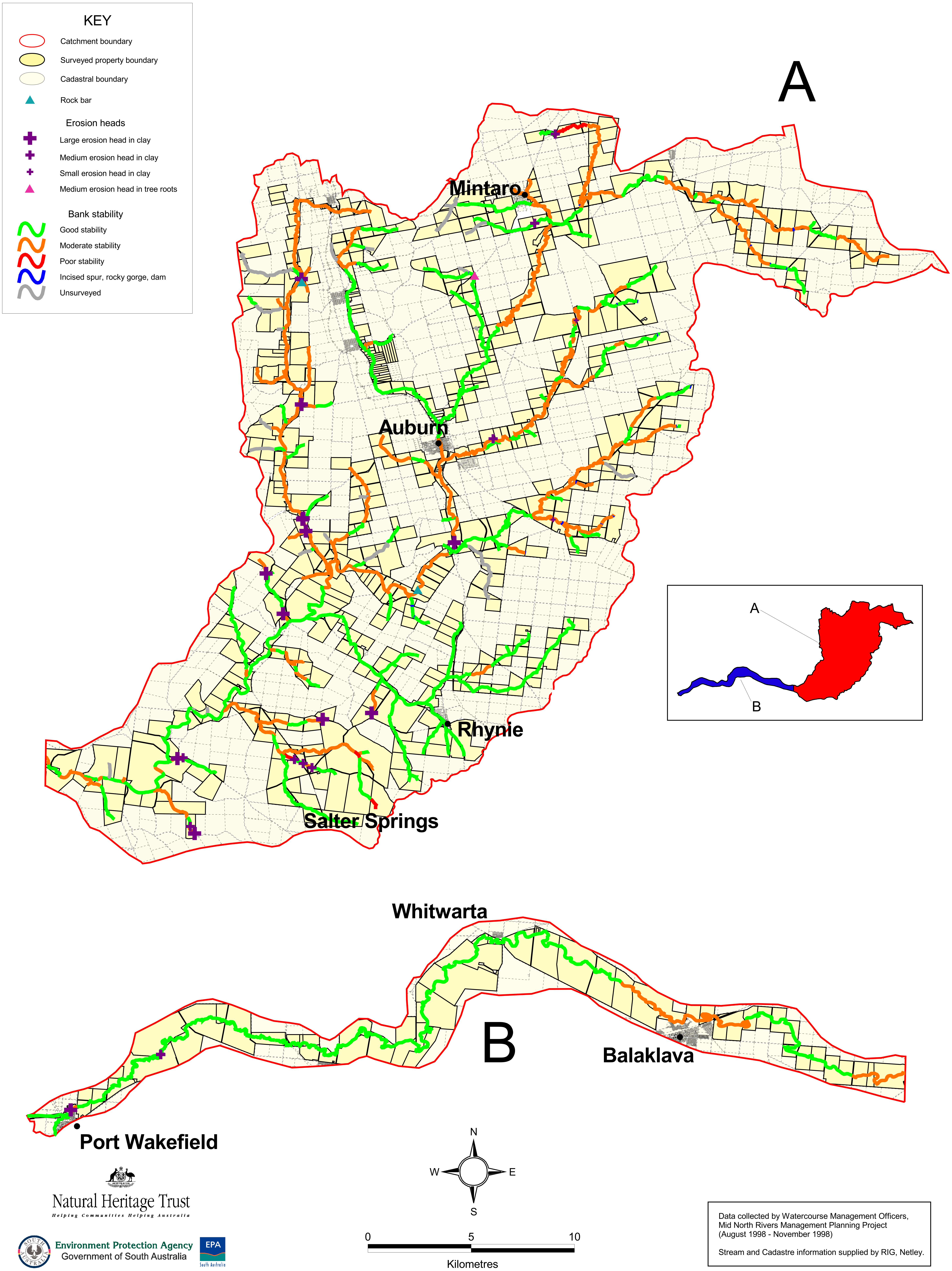
Map 5: Bank stability and location of erosion heads



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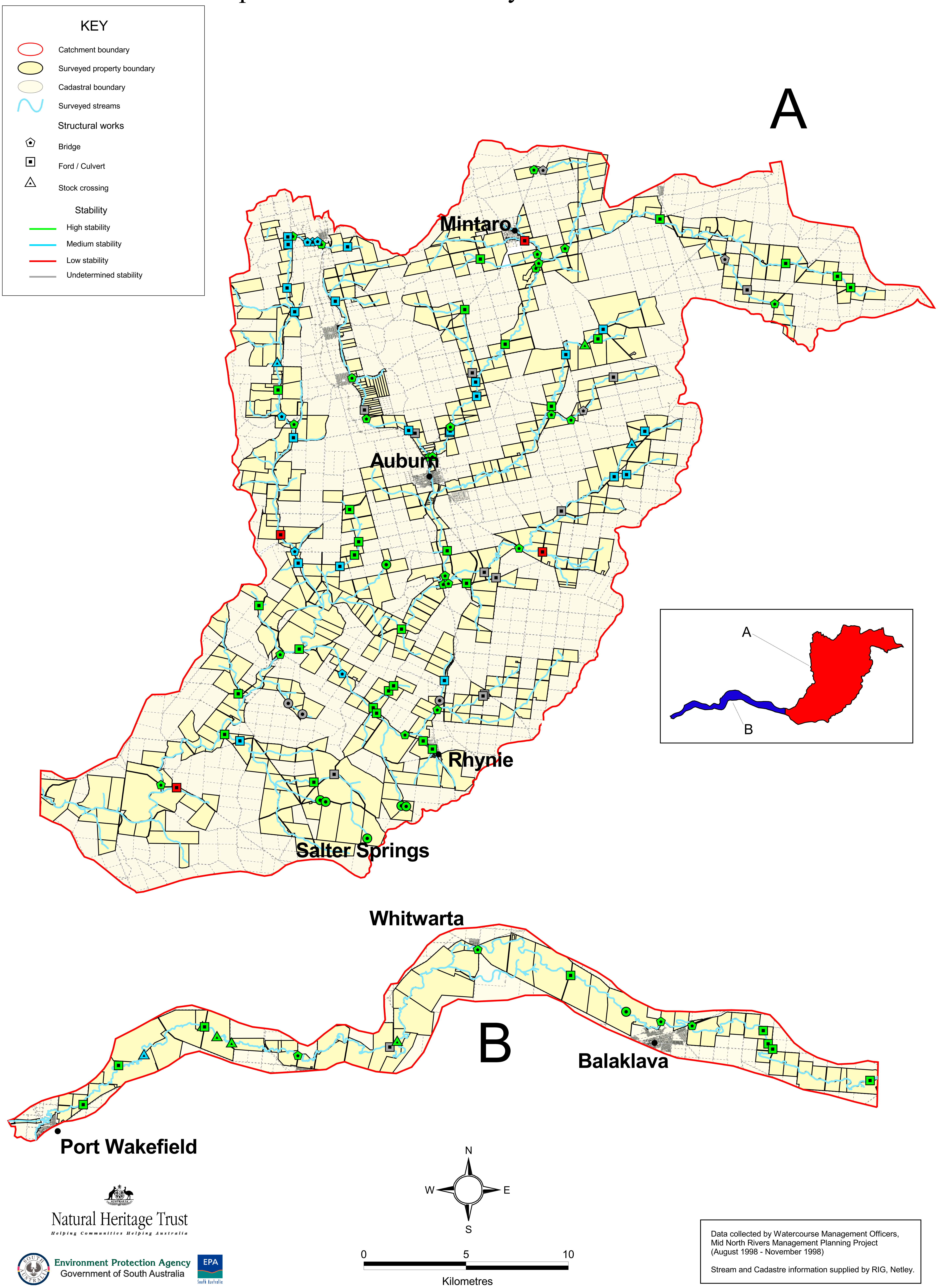
Data collected by Watercourse Management Officers,
Mid North Rivers Management Planning Project
(August 1998 - November 1998)

Stream and Cadastre information supplied by RIG, Netley.

Map 6: Location and stability of structural works



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