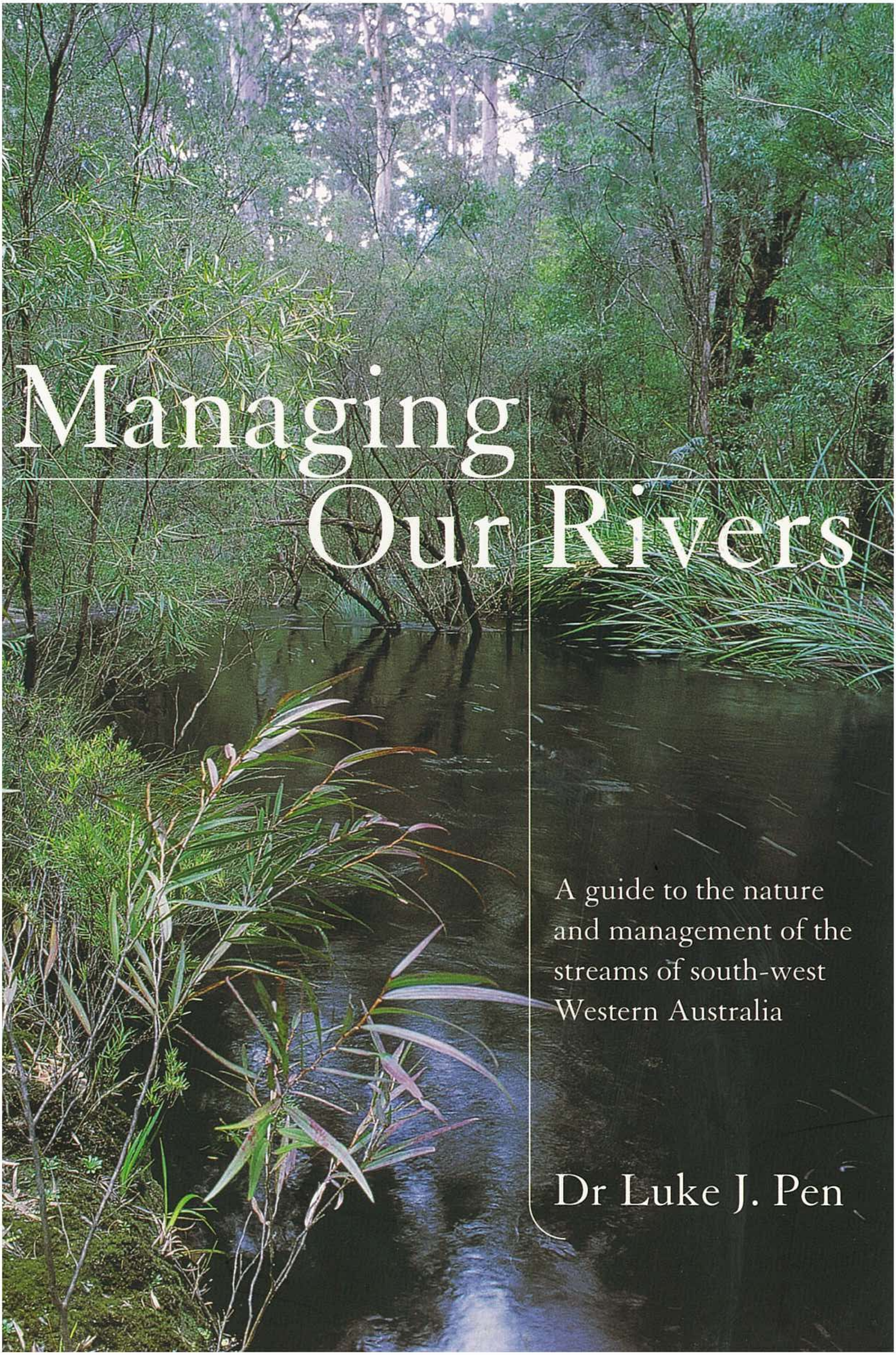

Managing Our Rivers

A guide to the nature and management of the streams of south-west Western Australia

Dr Luke J. Pen

Message from the Minister

This book is a wonderful tribute to the river environment of south-western Western Australia. It is also a tribute to the people who worked on the book's production and to the many others who give their time to help manage and protect our precious rivers and creeks.

This volume is the result of Dr Luke Pen's experience, together with the work of experts in the fields of hydrology, geomorphology, ecology and river management. It clearly reflects Dr Pen's enormous personal commitment to river conservation.

It is undoubtedly a comprehensive review, as well as an inspiring read for anyone who cares about the future of our rivers. It will be an invaluable resource for people such as farmers, landcare officers and community catchment managers, planners, engineers and other management professionals involved in managing catchments and streams.

The book covers an impressive range of topics and contains much useful information on restoration and best practices for stream management.

The book will also be an excellent resource for students preparing for careers in any aspect of planning and environmental management.

I congratulate the author and his support team and commend this book to all West Australians.

Kim Hames.

DR KIM HAMES, MLA
Minister for Water Resources

To Shirley and Ernest.

A short life dedicated to wetlands
and a long one dedicated to estuaries.

Managing Our Rivers

A guide to the nature and management of
the streams of south-west Western Australia

Dr Luke J. Pen

WATER AND RIVERS
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foreword

When I was a boy in the 1960s, living in Queens Park, a rather ordinary swampy suburb of Perth, there were open drains running along the streets. Every year my brothers and I and our friends, waited eagerly for winter, when the drains would run with water and come to life with tadpoles, gilgies and other creatures. We collected tadpoles and kept them in jars, hoping to watch them turn into frogs. To our puzzlement they grew legs and arms, but never did turn into fully fledged frogs. A gilgie was a big catch and the best fun was building dams, which were breached with great ceremony just before our mums called us to dinner. As evening fell we returned wearily to our respective warm homes. Unfortunately, our damp and muddy clothes caused our mothers much consternation, as polio was still a bitter memory in their older minds. Over time most of my friends' parents forbade them to play in the drains, but my parents never did. A few of us continued the tradition up until I was about ten, when sadly the drains were filled in and replaced with pipes.

I don't know how much the wet wintry 'drainy' experience of my childhood has influenced the course of my life. Maybe the menagerie of 100 odd animals my family kept counted also, but when it came to choosing a course at University, I decided upon Environmental Science. When in 1981, I had to choose a subject for my honours year, the suggestion of studying the fringing vegetation of the Swan and Canning rivers struck a chord, which

resonated in my soul. I was back in my drains, wet, cold and loving it. In one sense or another I have never left them. I know and love the rivers of the south-west of Western Australia.

My objective in writing this book is to share the knowledge that I and many other people have gained on the nature of rivers and especially those in the south-west. Equipped with this knowledge, maybe you will come to know and understand the nature of our rivers also, and perhaps feel confident enough to do something to care for them or at least be able to avoid doing them harm. As with the environment generally, most of our rivers are greatly abused and are crying out for attention. Happily, attending to rivers is great fun, as a growing number of Western Australians are finding out. Hopefully, after you have read all or part of this book you'll want to join us.

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preface

The objective of this book is to be a very readable and not too technical review of what we know about south-west rivers and their catchments, as well as a guide to their management. It provides a description of basic stream hydrology and ecology, and describes the use and degradation of south-west rivers and how to restore and manage them in the long term. While not providing the detailed design information needed to repair and manage rivers, it presents the underlying ecological understanding and philosophy on which river management in the south-west should be based. It is also hoped that this book will engender an interest in rivers and awaken a wider ecological sense of the region amongst those who make their home in the south-west.

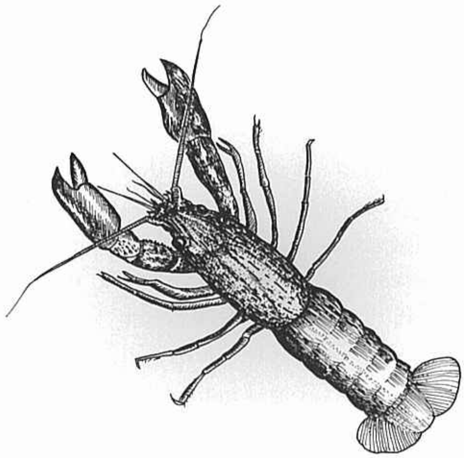
The book is divided into ten chapters. The first introduces the reader to the rivers of the south-west and describes their geological and climatic setting and history. The second chapter provides a basic description of how rivers work physically and how stream channels are formed and why they vary in form. This is done within the context of the unique catchment hydrology of the south-west. A physical understanding of streams forms a foundation for understanding the ecology of south-west streams, which is covered in Chapter 3. Chapter 4 examines the value of fringing vegetation and the role it plays in river form and stabilisation. With an appreciation of river habitats, which comes with an understanding of channel form, climate and stream ecology, the life cycles of the more characteristic animals of south-west river systems are described to illustrate particular niches and life cycle strategies, and thus the contributions that animals make to the nature of south-west stream ecosystems. This is done in Chapter 5, which completes the description of the fundamental nature of south-west streams.

Chapter 6 begins the human part of the story, examining the use of south-west streams, from pre-written history to modern times. Chapter 7 describes the degradation of south-west rivers over the last 170 years, including the effects of salinisation, eutrophication, loss of fringing vegetation and the introduction of exotic plants and animals. Having gained an appreciation of the nature, use and degradation of south-west river systems, the reader is ready for the critical chapter of the book, Chapter 8, which covers management. In this chapter the reader is presented with the latest thinking and technologies on river management relevant to temperate Australia, and especially to the south-west. Essentially this chapter is the knowledge needed for 'river keeping'. Chapter 9 presents the actual 'keepers', describing the activities and administrative arrangements of those agencies, groups and individuals who make the care and protection of rivers part of their life's work. The final chapter explores the not-too-distant future of south-west rivers, in the light of climate change, growing populations and changing catchment hydrology brought on by land clearing.

acknowledgments

The idea for this book came from a talk that I gave at a conference convened by the Blackwood Basin Group (BBG) in November of 1993. That talk, on the nature and management of south-west rivers, was well received and a number of people asked me where the information presented was available. My answer: 'in a thousand places and my head'. So I thought I'd better write a book. This is it and you, the reader, can thank Eric Wright and the BBG for the spark of inspiration.

As for me, I have a number of people I need to thank. Firstly, I must thank Phil Commander and Richard George for assistance in writing the geological section and in understanding the groundwater hydrology of the south-west. John Ruprecht, Peter Muirden and Ian Loh provided considerable advice, helpful suggestions and constructive criticism on the surface water elements of the book. Steve Janicke and Peter Davies commented on sections covering channel form and function. Advice on south-west stream ecology was provided by Kerry Trayler, Peter Davies and Rob Donohue. I must also thank Pierre Horwitz for the many discussions which have helped me to better understand the ecology of the south-west. Kathy Meney, Neville Marchant and Ray Froend gave constructive comment on fringing vegetation and its value to rivers. Thanks also to Ray Froend and Sharon Stratico for suggesting and assisting in the section on environmental water requirements of fringing vegetation. Very useful advice and comment was given on riverine fauna by Mischa Cousins, Rob



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For the chapter on those individuals, groups and communities who are involved in river management I must thank Bev Thurlow, Bruce Hamilton, Kerry Trayler and Susan Worley for some very useful and constructive criticism. I am also grateful to those many people who have shared with me their experience of community based catchment management. Special thanks to Keith Bradby who never hesitated to tell me when I got things wrong and helped me to make this chapter (and others) very much better. The final chapter on the future of south-west rivers could not have been written without the assistance of Peter Williams, Peter Muirden, John Ruprecht, Ian Loh, Richard George and Rick Bretnall.

Throughout the course of the writing of this book I received invaluable guidance and advice from Peter Williams, for whom the rivers of Western Australia have a special place in his heart. I must also thank Jeff Kite, Roy Stone and Ian Loh, who like Peter, have been great mentors to me in the field of water resource management. Similarly, I must thank Bruce Hamilton, Mike Kerr, Bev Thurlow and Rob Atkins for their support and encouragement over the many years I have been involved in waterways management and research.

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Thanks must go to June Hutchison for her wonderful editing of the text. If this book reads well, it is due in no small part to June.

Special thanks must go Karen Majer to whom I am indebted for her editorial work, encouragement and support.

While I worked away in my office on this book, my family endured my absence: on weekends, in the evenings, from net ball and T-ball games, picnics with family and friends and at other times. It was not the first time and it shall not be the last. To Celine my wife and to Susan, Elly and Jenny thank you for the special gift of the time to be creative (and for the many visits).

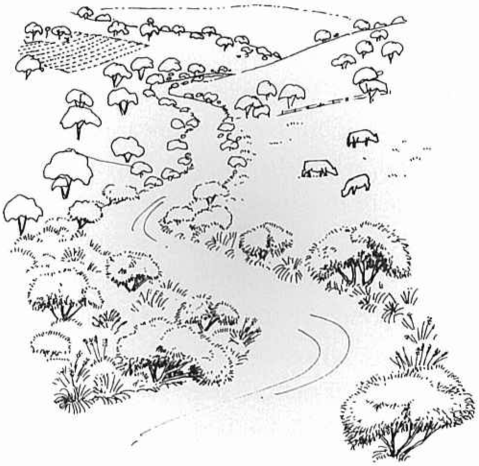
Finally I would like to thank all the scientists who have gained the knowledge of the south-west of our State that is presented in this book. Much of this work was done by students under hard conditions and with little financial reward, but loving every minute of it.

chapter

1

Introduction: the south-west and its rivers

- What is a river?
- Learning about our rivers
- Introducing the south-west
- The rivers



1.1 What is a river?

A river is often defined as a stream of water flowing in a channel. For Australians this is a novel definition as rivers without flowing water, or with no water at all, are commonplace. So in Australia, and in other relatively dry parts of the world, a river or creek must be defined as a channel in which water flows at least occasionally. On a broader scale, a river is part of a drainage system that collects water across a catchment via a myriad of minor channels which combine to concentrate flow into fewer, but larger channels, which successively combine until the last and largest one discharges to a lake, coastal inlet or the ocean. But a river system, whether wet or dry, is much more than a network of channels created by the laws of physics. It is both a physical and biological thing, an ecosystem, whose nature is contingent upon history and governed by geology, changing climates and by living creatures. The rivers of the south-west have a long history and today still support, if only just, a unique, wonderful and abundant life. Knowing something about the nature of our river systems is essential for their wise management and the conservation of the natural resources that they hold. Management in indifference to the nature of rivers is fraught with consequence, as river managers have discovered on the trained and cleared Avon River, where deep permanent river pools, once important habitats and sites for human recreation, are now filling with sediment from an eroding channel. Knowing something about the nature of our rivers is the first step in protecting those rivers which remain in a relatively healthy condition and in restoring those, like the Avon, which were once great natural treasures of the south-west. Therefore, managing our rivers starts with learning something about them.

1.2 LEARNING ABOUT OUR RIVERS

Until we get to know something we generally take it for granted. After reading this book it should be impossible to ignore any stream, no matter how small. You will begin to see meanders, point bars, pools and riffles, paperbarks and flooded gums. You will know why our rivers are often full of vegetation and the water often a dark amber colour. The animals that swim and crawl around in streams will mean much more than whether they are fun to catch and good to eat. The stream ecosystem should come alive and you will know what it is that you, and other people, can do to threaten its existence or ensure its preservation. You will know what to do and what not to do. In other words you will learn about rivers and especially about those in the south-west, between Geraldton and Esperance (Fig. 1.1).

A curious fact about south-west rivers is that a good number of them have two names. The most obvious example is the Swan-Avon, but there is also the Southern-Wungong, the Murray-Hotham and the Blackwood-Arthur (or Blackwood-Beaufort, depending on which branch you consider to be the longest arm of the river system). There is also the Warren-Tone and, perhaps the best example, the Frankland-Gordon. Whatever the reason for the dual naming of these rivers, it is strangely appropriate. The reason for this, as you will read in the next section, is that on the coastal plains and in the Darling Range the rivers are relatively young whereas those beyond the range are of great antiquity, the remnants of river systems that existed over 150 million years ago before Australia was formed. Some young rivers that have formed on the Darling Range have cut back into the land and captured old ones. The best example of this is the Frankland-Gordon, the young Frankland having cut a nicely formed valley back into the land to capture the flat sediment filled valley of the Gordon near the town of Frankland.

Sometimes geologists and river hydrologists will jokingly refer to the backwards form of our larger rivers. They refer to the fact that the older parts of our larger rivers are at the upstream end, while the younger parts lie near the base of the system (see Morrissy 1974). Under an early 19th century view of erosion processes, rivers ran from a steep youthful stage, where they began as minor streams cutting into mountain sides; to a moderately sloped mature stage where they passed through a hilly landscape with deep valleys, that had once been mountainous; and then to an old age stage, where the

FIGURE 1.1 RIVERS OF THE SOUTH-WEST OF WESTERN AUSTRALIA

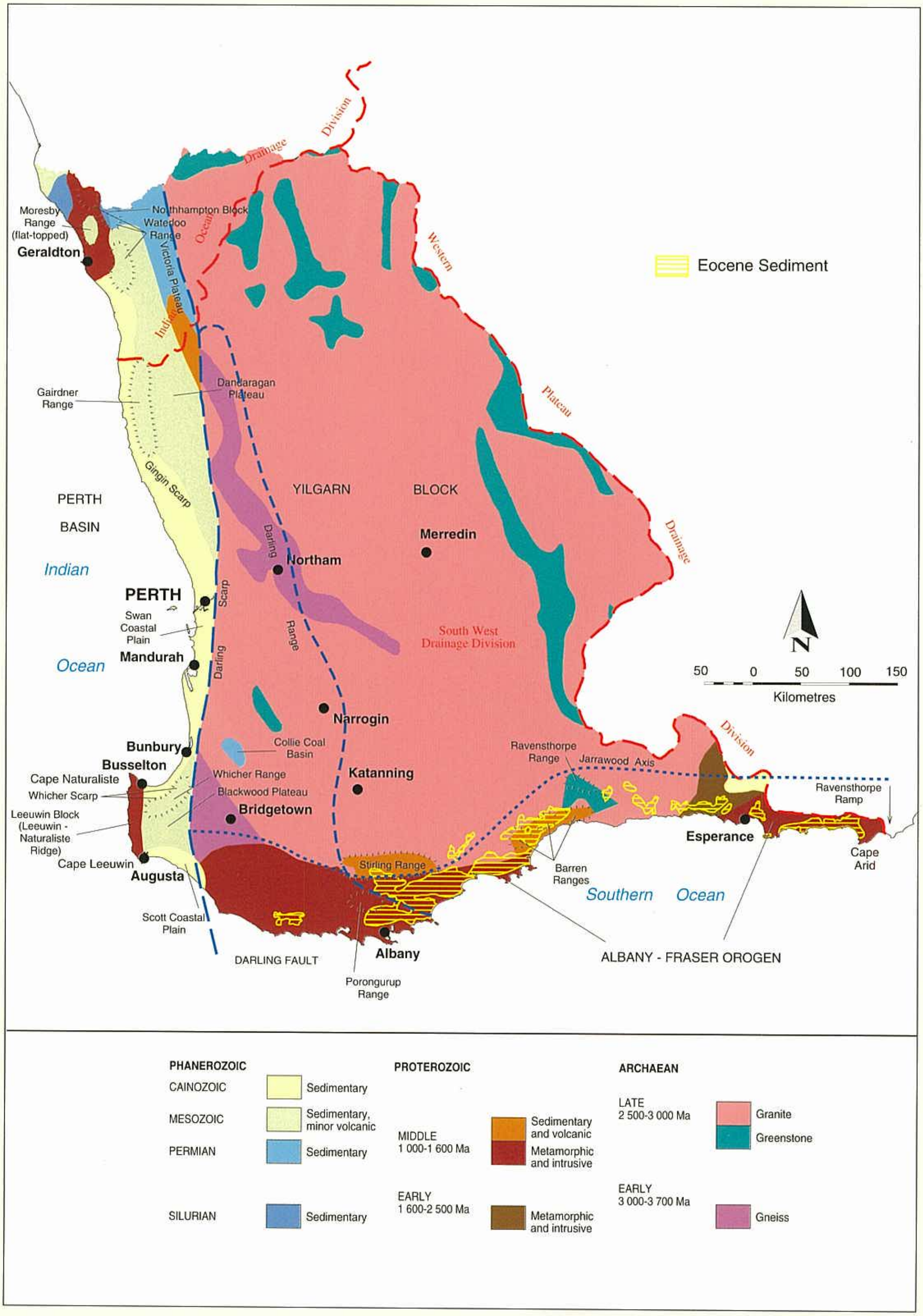


FIGURE 1.2 GEOLOGY OF THE SOUTH-WEST OF WESTERN AUSTRALIA

river passed over a low flat featureless plain of deposited sediment or where the land had long since been eroded down. This plain, known as a peneplain, exists at the opposite end of our rivers; the mature parts are found east of the Darling Range and the youngest parts, cutting into bedrock, are on the steeply sloping Darling Scarp.

These quaint facts actually have a large bearing on the nature of south-west rivers, making them very different from other river systems elsewhere in Australia and the world. Other river systems have their own unique characteristics, but we must learn about ours in order to manage south-west streams properly. A good few geologists, hydrologists, climatologists, geographers, biologists, botanists, ecologists and historians have contributed to our knowledge of the south-west and its rivers. This book summarises what has been learnt so far. Hopefully it will encourage others to continue the good work.

1.3 INTRODUCING THE SOUTH-WEST

1.3.1 Geological history, land forms and the origin of south-west rivers

The Great Western Shield

The land that makes up the vast bulk of Western Australia, from the Pilbara southwards, is known as the Great Western Shield. In the south it consists of the Yilgarn Block or Craton, a giant, ancient, relatively flat and roughly square shaped slab of granite and gneiss, about 2900 to 2500 million years old (Johnstone et al. 1973; GSWA 1990) (Fig 1.2). Not all of the shield is of this age; a mass of younger deformed and reformed rock occurs roughly along the southern edge and slopes gently down to the sea today. It is known as the Albany-Fraser Orogen and dates back to the Proterozoic Era, about 1300 to 1100 million years ago (Johnstone et al. 1973; GSWA 1990). During this era thick layers of sediment collected on much of the shield, but over the long period of time that has elapsed since, most of it has been eroded away (Beard 1981). Remnants of these ancient sedimentary deposits remain today in western and southern parts of the block, with the Stirling and Barren Ranges on or near the south coast being the most conspicuous examples (Beard 1981).

Folded into the granite and gneiss of the Yilgarn Block are large masses of comparably aged volcanic and sedimentary rock. These masses are known as the greenstone belts and are host to much of the valuable mineral resources of the goldfields (GSWA 1990). Rock types of the belts are generally harder and more resistant to erosion than the surrounding granite or gneiss and so often stand above the general landscape, forming low ranges. One example, is the small Ravensthorpe Range near the town of Ravensthorpe.

Gondwana

For much of its geological history the western shield was part of a huge super-continent known as *Gondwana*. Prior to the breakup of Gondwana, about 200 million years ago, the Yilgarn Block was glaciated. In parts of the present day south-west, glaciers gouged small basins in which coal measures subsequently formed from the deposits of swamps that formed after the ice melted. The Collie, Wilga and Irwin Coal Basins are good examples, and date back to the Permian Period, about 230 million years ago. As the glaciers receded melting ice maintained flows in the ancient river valleys.

At about 160 million years ago Gondwana started to break up and to form the present day continents of South America, Africa, India, Antarctica and Australia. At that time, known as the Upper Jurassic Period, Gondwana lay over the South Pole and was generally cool, wet and well vegetated. That part of the continent which was to become the south-west of Western Australia was already relatively flat, its mountain chains long since eroded away to produce a flattish, hilly landscape with river valleys similar to the deep lower Blackwood River valley of today.

Rifting

Continental breakup occurs by a process known as *rifting,* which is the stretching and splitting of the Earth's crust. It is thought to be caused by differential heating beneath large continental land masses, which produces an up-welling of magma from within the earth. The magma presses up on an area of the crust which begins to split along a line, usually in a section of relatively weak crust. At first the crust bulges upwards, and then it stretches, thins, and fractures, forming faults some of which intersect with one another to form separate small blocks of crust. Eventually the crust begins to break apart and separate. On either side of this rift the land rises, leaving a long area of subsiding crustal blocks in the break, known as a *rift valley* or *graben.* Today, such a valley exists in Africa along the western borders of Uganda and Tanzania, where east Africa is slowly breaking away from the rest of the African continent. For a long time the rift valley is a terrestrial environment of forest, swamps and lakes, accumulating sediment carried by the new rivers that form on the raised land on either side. The weight of the sediment, which can be kilometres deep, may further push down the crustal blocks that underlie the valley. Eventually the ocean spills into the valley, creating two pieces of land which continue to move apart until the crust is entirely broken. Into the breach rise sheets of lava or basalt from a long linear volcano known as a mid-ocean ridge. The basalt spreads out from the breach to form new ocean floor and as it does so pushes the new continents across the surface of the earth.

This process created Australia; with two periods of rifting creating the south-west. The first, about 120 million years ago, occurred during the Cretaceous Period, when the south-west separated from what was to become the Indian sub-continent. Then about 45 million years ago, in the Eocene Period, the south-west and the rest of Australia finally severed its connection with what was to become Antarctica (Fairbridge and Finkl 1978). From there the Australian continent, with its company of Gondwanan plants and animals, began its slow continental drift northwards.

The south-west corner of the Yilgarn Block is known as the Darling Plateau or Range, owing to its well dissected and hilly form (Mulcahy et al. 1972). The area of the block beyond the Darling Range and north of the Albany-Fraser Orogen, is referred to as the Yilgarn Plateau (Fig. 1.2).

The Serpentine River where it passes through an area of remnant bush on the Swan Coastal Plain. This, the 'Lowlands' section of the river, is one of the few 'natural' stream sections remaining on the coastal plain between Perth and Bunbury. Photo: L.Pen

A 'rejuvenated' section of the Kalgan River north-east of Albany. Here the river has cut a deep valley and water flows over bed rock. Photo: L.Pen

THE UPPER KENT RIVER EXHIBITING CLASSIC PALAEOCHANNEL FORM: A BROAD FLAT VALLEY WITH SALT-LAKES.
PHOTO: C. CHAPPELLE

GRASSES AND SAMPHIRE COLONISE SEDIMENT DEPOSITS IN THE AVON RIVER AS IT SLOWLY RETURNS TO ITS ORIGINAL BRAIDED FORM FOLLOWING TRAINING IN THE 1960S. PHOTO: D. BENNETT

The Perth and Bremer basins

Below the western and southern margins of the shield, which today rises to about 300 m above sea level, lie the elongate Perth and Bremer basins (Fig.1.2). These basins are the vestiges of the rift valleys that formed during the Jurassic and early Cretaceous periods (160-120 million years ago), and subsequently filled with sediment, now 5-15 kilometres deep (Johnstone et al. 1973; GSWA 1990). It would appear that the rivers of the Yilgarn were particularly active at this time, as large amounts of fluvial quartz sand and clay dating from these periods are to be found in the Perth Basin (Beard 1981). However, conditions changed in the late Cretaceous, when sedimentation in the basin became dominated by marine borne sediment, reflecting the flooding of the then rift valley by the sea (GSWA 1990). The lack of fluvial sediment throughout the late Cretaceous and Tertiary (100 to 2 million years ago) implies that the surface of the Yilgarn was not being heavily eroded at this time.

The Perth Basin and the Yilgarn Block are separated by the Darling Fault (Fig. 1.2), a 1000 km long 'clean' line of fracture that formed on the western margin of the block during rifting and which is apparent today as the Darling Scarp, the crest of which is some 200-300 metres above sea level and well above the general elevation of most of the southern part of the Perth Basin.

To the west of the Darling Fault and underlying the Perth Basin is the Pinjarra Orogen, a mass of broken deformed and reformed rock much younger than that of the Yilgarn Block (GSWA 1990). In places this rock protrudes above the land surface as relatively small blocks bounded by faults. One is conspicuous as the Leeuwin-Naturaliste Ridge (Fig. 1.2). Between it and the Darling Scarp sediment collected, mostly from before the Cretaceous Period (about 130 million years ago), to form the 100 m high 'residual' Blackwood Plateau (once referred to as the Donnybrook Sunklands) (Hodgkin et al. 1979). The northern portion of the Plateau is known as the Whicher Range, and its margin, which rises about 100 m above the coastal plain, is called the Whicher Scarp (Fig. 1.2). Another block, the Northampton, outcrops in the Geraldton Region where part of it is overlain by Triassic and Permian deposits from before rifting (Johnstone et al. 1973; GSWA 1990).

Rivers cut off and stranded

Rifting had a major impact on the rivers of the Yilgarn. Those which once flowed to or from India and Antarctica were cut off and as the giant Yilgarn Block rose from the margins of rift valleys, the land through which they flowed sloped back upon itself, causing major changes in drainage (Fairbridge and Finkl 1978). Along the sides of the great rift valleys new rivers formed, cutting back into the rising plateau, obliterating the old channels and carrying sediment into old defunct river valleys or the basins below. Where these new rivers cut back far enough they captured the old rivers. A good example of this is where a small young river, known today as the Swan, cut back far enough into the Darling Plateau to capture the Avon system. At the same time, the old inland rivers having lost their original gradients and stranded beyond the areas of 'action' where the land was rising most, began to accumulate sediment which accelerated as the landscape began to dry after about 45 million years ago (during the Eocene), and especially after 2.4 million years ago (Waterhouse et al. 1994; Salama 1997). Today the broad deep valleys of these ancient rivers, or *palaeochannels* as they are known, are filled with 50-60 m of sediment, and are host to long chains of shallow salt lakes (Commander et al. 1991). Ancient rivers like the Monger (above the Moore catchment), Ninghan, Yilgarn and the Lochart (Avon) have not flowed regularly since the Miocene Epoch, between 26 and 7 million years ago (White 1997).

Flooding and uplifting

Over the period of this history, sea level varied greatly. During the Jurassic and much of the Cretaceous (about 130-65 million years ago) the sedimentary basins were below sea level and were accumulating terrestrial and then marine sediment (Johnstone et al. 1973; Beard 1976; GSWA 1990). However, at the end of the Cretaceous and during the ensuing Tertiary Era (about 60-7 million years ago), the basins and the Darling Plateau began to be uplifted. The Perth Basin has mostly been at or above the sea level and subject to erosion and denudation ever since (Beard 1976; GSWA 1990).

In the Geraldton region the relative movement of the basin and the Darling Plateau is such that they are today level with one another, becoming less so southwards to about Perth, where the Swan Coastal Plain is well below the Scarp. However, between Perth and Geraldton the terrain is marked by residual sedimentary plateaus, such as the Dandaragan Plateau near Gingin, which rises as the Gingin Scarp on its western side and backs onto the Darling Scarp. The Gingin Scarp[1] extends beyond the Dandaragan Plateau in the vicinity of the Hill River to border a well dissected plateau of Triassic and Jurassic sediments (GSWA 1990). This plateau is called the Gairdner Range and includes a number of peaks that rise as high as the Darling Range itself, the tallest of which is Mt Lesueur. The margins of these plateaus, and also of the Blackwood Plateau to the south, are thought to be old shorelines, from when western parts of the basin were inundated and eroded by the sea during the Tertiary (Seddon 1972; Fairbridge and Finkl 1978). Near Geraldton, uplift has enabled streams, particularly the Greenough River, to erode and dissect the Victoria Plateau, a deposit of sediment lying atop the basin and a northern section of the Northampton Block.

Near Geraldton this has resulted in the formation of the unique flat-topped mesas of the Moresby Range and Chapman Valley area, the flat tops being the surface of the former sedimentary plain (Beard 1976). The broader hilly terrain of the dissected Victoria Plateau near the coast is known as the Waterloo Range.

In the late Eocene (40 million years ago) the sea inundated the south coast as far inland as the Stirling Range and covered the drowned landscape with marine sediment (Fig. 1.2). One of the products was Pallinup Siltstone or Spongolite, a combination of clays, sponge spicules, sand and fossil shells (Hodgkin and Clark 1988a). The resultant plain of sediment was raised and tilted in the Tertiary and was subsequently greatly dissected by south flowing rivers with the formation of the Ravensthorpe Ramp (see

[1] Also once referred to as the Hill River Scarp

below) (Hodgkin and Clark 1990a). In places granite domes and Proterozoic sedimentary peaks protrude above the sedimentary rock, the granitic Porongurup Range, coastal headlands and granite domed hills near Albany and the peaks of the Barren Ranges being the best examples.

During the Tertiary Period (65 to 2 million years ago) the Darling Plateau was further elevated by successive uplifts of the south-western portion of the Yilgarn Block (Beard 1976; Fairbridge and Finkl 1978; Hodgkin and Clark 1990a). As a result of this and where there was sufficient runoff, rivers in the Darling Range deepened their beds and widened their valleys in a process known as rejuvenation (Beard 1976; Fairbridge and Finkl 1978; Pilgram 1979). Along the south coast, the plateau was not so much raised as tilted, with the effect that the belt of land within 40-80 km of the coast slopes gently to the sea in a formation known as the Ravensthorpe Ramp (Cope 1975) (Fig. 1.2). There has also been some recent subsidence of the ramp which has drowned the southern coastline (Fairbridge and Finkl 1978). This inclination of the land created the conditions for new rivers to form and gave rise to the southerly flowing rivers of the south coast (Bettenay and Mulcahy 1972; Fairbridge and Finkl 1978). East of Albany these rivers cut through the sedimentary 'spongolite' rock to create deep V-shaped valleys and sometimes gorges which can be seen today in their natural state in the Fitzgerald River National Park (Hodgkin and Clark 1987, 1988a and 1990b). The new rivers of the south coast obliterated the old drainage lines, but in some cases, notably the Frankland, have captured areas of old drainage beyond the ramp on the edge of the Yilgarn Plateau proper (Bettenay and Mulcahy 1972; Fairbridge and Finkl 1978).

Deep weathering

All the time that the Australian continent was on its long journey northwards and the Darling Plateau and adjacent basins were being reshaped by the effects of oceanic incursions and uplifting, the Yilgarn Block was undergoing deep chemical weathering (Fairbridge and Finkl 1978; GSWA 1990; White 1997). This is the process by which rock breaks down in smaller particles to great depths below the land surface. It requires water and a long period of time. In the Cretaceous and early Tertiary the climate of the south-west was sufficiently wet to provide the water. Another requirement is that the breakdown of material exceeds erosion so that the weathered material collects above the parent rock. The flat landscape of the Yilgarn ensured this and the increasingly sediment filled river valleys helped to ensure that groundwater did not totally drain away, but instead collected in the weathered material. Long after the climate of the south-west began to dry in the Miocene, some 26 million years ago, groundwater remained to maintain the weathering process (White 1997). Today the white clayey weathered material, the 'pallid zone' of the regolith or saprolite[2], can be many tens of metres deep. It has special significance to south-west Australians, because it is this deep poorly drained material that has trapped millions of tonnes of salt brought to the Yilgarn Plateau in rainfall over tens of thousands of years.

[2] Regolith is a layer of fine or coarse loose, broken, rocky material overlying bedrock and mainly formed by the decomposition of that rock. Saprolite is a type of regolith and is basically rotted bedrock.

Recent sea level fluctuations

Towards the end of the Tertiary Era (about 2.6 million years ago) sea level fluctuations became more frequent as the earth began its alternating sequence of glacial and interglacial periods, which settled down in the Pleistocene and subsequent Holocene to a periodicity of about 100,000 years (Williams 1984). Sea level varied repeatedly, falling to low levels during cool glacial periods and rising to their present or slightly higher levels during warm interglacials. It is also about this time that the characteristic Mediterranean climate and mostly dry landscapes of the south-west became established (Williams 1984).

Sea level fluctuations over the last 2.4 million years have had a large effect on coastal areas of the south-west. The most conspicuous formations, probably formed at the very end of the Tertiary Period, in the Pliocene, are the contiguous Gingin, Darling and Whicher Scarps, old shorelines against the Dandaragan, Darling and Blackwood Plateaus, respectively. The relatively flat land below them is the Swan Coastal Plain (Fig. 1.2). South of the Blackwood Plateau is the low lying Scott Coastal Plain (Fig. 1.2). During interglacial periods, when the sea levels were high, sediments were reworked and dunes were thrown up along the coast. On the Swan Coastal Plain a sequence of dunes (e.g. Quindalup, Spearwood and Bassendean) mark different sea level heights (Seddon 1972). The more calcareous dunes hardened into limestone, forming the reefs, rocky headlands, cliffs and hills seen today on the western and southern coasts, again reflecting different sea levels. Limestone has also formed up against the granite domes and headlands of the relatively drowned southern coastline. Along the eastern side of the Swan Coastal Plain, beyond the dune systems, is the Guildford Formation (or Pinjarra Plain), a generally broad band consisting primarily of alluvial sediments washed down from the plateau by numerous creeks and rivers (Seddon 1972). The Greenough River south of Geraldton has similarly built up alluvial soils along an area of floodplain behind coastal dunes, known as the Greenough Flats. A coastal plain formed of old dunes and marine and alluvial deposits extends from 80 km north-west of Geraldton where it is only a few kilometres wide, to Dunsborough on the edge of the Leeuwin Block. The plain, which includes the Swan Coastal Plain, is generally 15-30 km wide (Seddon 1972).

Rivers passing across the coastal plains had to contend with these limestone formations and dunes, sometimes passing along them, as the Greenough River does, until reaching a weak point at which an exit to the sea could be obtained. In some cases streams actually cut or entered caves in the limestone, as the Stockyard Gully does today in the Mt Lesueur region (Beard 1976; Olsen and Skitmore 1991). Indeed the gorge-like Blackwall Reach at the base of the Swan River is thought to be a collapsed cave. In other areas small streams emptied just short of the ocean into small lakes and swamps.

The last sea level rise occurred about 6000 years ago. Once again the previously dry land of the Swan Coastal Plain and the south coast was drowned and the river valleys close to the coast were flooded, creating the coastal inlets that we know today in the Holocene Epoch (Seddon 1972; Hodgkin and Clark 1988b and c, 1990a and b). Sand was mobilised and moved by the ocean onshore and alongshore and was washed up by waves to form beaches, which were blown up as dunes to collect on the old Pleistocene dunes and limestone formations, where they were consolidated by vegetation. Sand bars formed in the mouths of rivers and inlets; where river flows were too meagre to maintain ocean connections (especially east of Albany and north of Perth), many of the inlets and river mouths became progressively closed to the sea, either seasonally or for prolonged periods. In some cases rivers and their inlets became permanently closed from the ocean, the Jerdacuttup Lakes east of Hopetoun being the most notable example. In other areas, small coastal lagoons, swamps and broad floodplains formed behind coastal dunes. The best examples are to be found between Dongara and Jurien on the west coast; in the Busselton area (as the Vasse-Wonnerup System); the wetland systems on the Scott Coastal Plain and the D'Entrecasteaux National Park; the lake systems of the Two Peoples Bay area east of Albany; and the 'little streams' coastline within 40 km north-east of Albany. Sediment is also being deposited by rivers into the broad and shallow inlet and lagoonal systems, and as a result they are dying a geological death as they slowly fill up (Hodgkin and Clark 1988a, 1989, 1990b).

Altered courses

With uplifting of the land and fluctuations in sea level, it is inevitable that some rivers have changed their courses. For example, an ancestral course of the Avon River is known to lie 600 m below Kings Park and the Swan Estuary, its old valley long since filled and covered with sediment (Davidson 1995). On the edge of the continental shelf near Rottnest there appears to be a giant canyon, apparently formed by the same ancient river (von der Borch 1968). Indeed geologists have identified sedimentary deposits and fluvial formations in the Darling Range of at least four ancient drainage systems dating back to between the Permian and the early Tertiary Periods (300 to 50 million years ago) (Fairbridge and Finkl 1978).

During glacial times of the Pleistocene, the sea level was much lower than it is today and the coast many kilometres beyond its present position (Seddon 1972). Rivers which once passed across this dry land and cut valleys, are evident as sub-marine canyons today (von der Borch 1968). The Swan River once passed to the sea north of Rottnest Island (Seddon 1972).

Uplift along the western margin of the Yilgarn Plateau, possibly in the Tertiary, caused a major diversion of the Moore River. Today the ancient part of the Moore terminates in the Yarra Yarra Lakes, but it once flowed southwards along the Coonderoo River, following the line of the Darling Fault, then cutting through the Darling Scarp to form a deep north-south valley now occupied by the Brockman River, which is considered to 'underfit' its valley today. Similarly, Ellen Brook which flows along the base of the Darling Scarp and discharges into the upper Swan River appears 'much too small to have eroded the broad, terraced valley through which it flows' (Seddon 1972). Ellen Brook is possibly an old course of the Swan River. Perhaps a minor stream of the Darling Range cut back and captured the Swan and guided it along its present course (Seddon 1972).

As has been described earlier, river capture has also been a phenomenon of the south-west. Westward flowing drainage systems, such as the Beaufort palaeochannel and the north Stirling internal drainage system, have been captured by the roughly southward flowing Blackwood and Pallinup Rivers, respectively. This has caused some broad valleys of the old systems to become abandoned, filled with sediment and host to salt lakes or freshwater swamps (Waterhouse et al. 1994). The process continues today as the young rivers of the Darling Plateau continue to cut back into the ancient Yilgarn Plateau.

1.3.2 Climate

The climate of the south-west is Mediterranean, with cool, wet winters and hot, dry summers. The weather is determined by an alternating succession of high and low pressure systems steadily moving eastward. In summer, the high pressure systems tend to block the movement of low pressure systems and thus deflect rain bearing frontal systems to the south below the continent. In winter, the highs move further north and their blocking effect weakens, with the effect that low pressure systems can carry rain bearing fronts across the south-west.

Annual average rainfall generally decreases inland in a more or less north-westward direction from the south-west corner, ranging from 900 to 1400 mm on the coast to about 350 mm in the most inland parts of the region (Fig. 1.3). The wettest period of the year is from May to September, and prolonged dry periods are common. In inland areas sporadic thunderstorms may bring isolated heavy falls, while the south coast may receive light local rain during summer and autumn. Occasionally widespread heavy rain may occur during the southward passage of decaying tropical cyclones. One such cyclone, called Errol, produced floods on a number of south-west rivers in January 1982.

The evaporation gradient is in the same general direction as that of rainfall but is reversed, with 800 to 1200 mm average annual evaporation in coastal areas increasing to over 2000 mm in the extreme inland parts of the region.

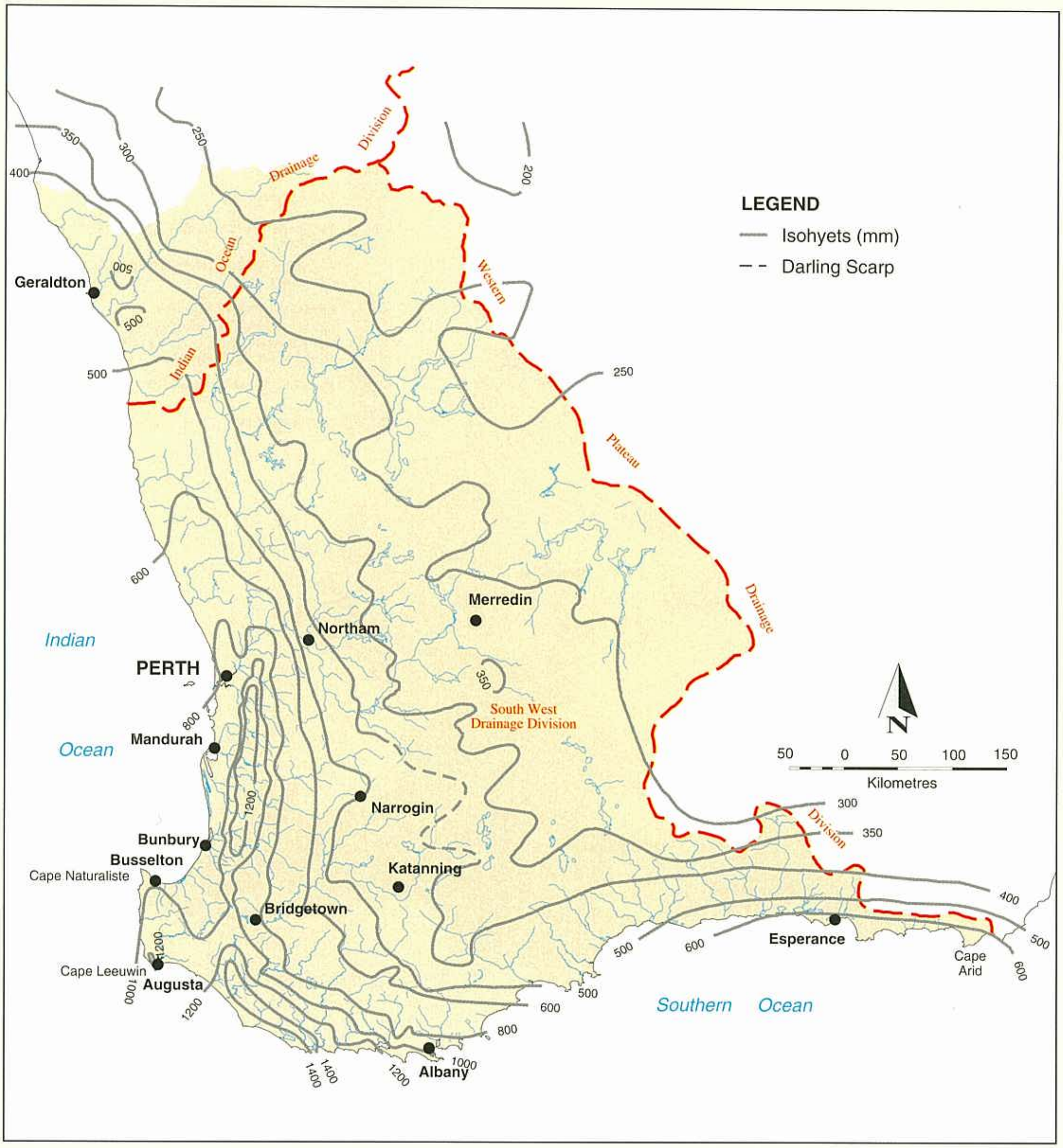


Figure 1.3 Average annual rainfall across the south-west of Western Australia

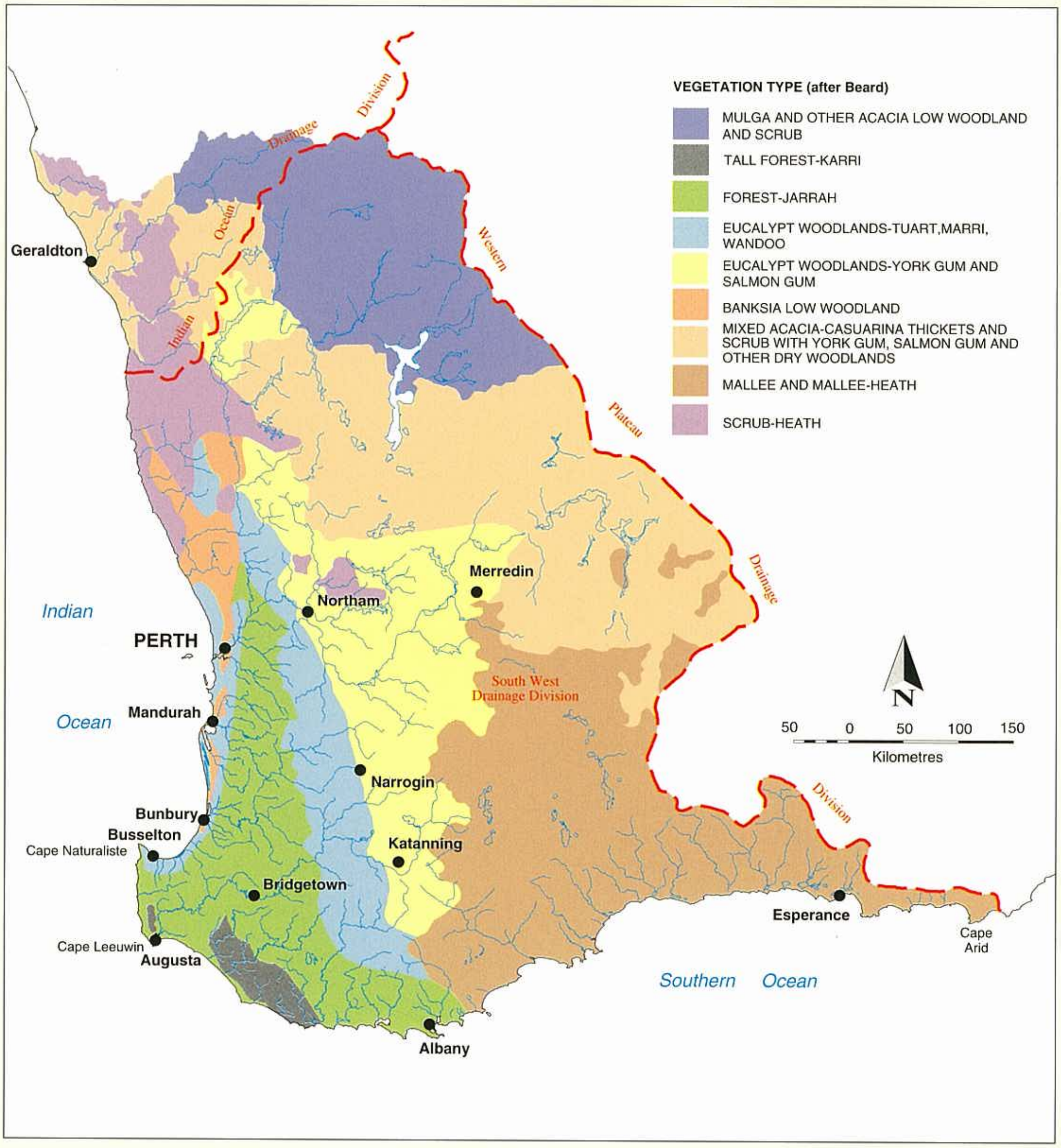


FIGURE 1.4 MAJOR VEGETATION TYPES OF THE SOUTH-WEST OF WESTERN AUSTRALIA

1.3.3 Vegetation

The natural vegetation of the south-west is variable and largely determined by rainfall and soil type (Beard 1981) (Fig. 1.4). In the extreme and very wet south-west corner the deep red loamy soils support tall forest of karri and sometimes also of tall marri and tingle. Medium height forests of jarrah and marri grow on the hard lateritic soils that are more typical of the wetter western parts of the Darling Range. Along the cool, wet south coast west of Albany, sandy soils support a rather scrubby jarrah forest, with pockets of tall karri forest on loamy soils and low shrublands and sedgelands in swampy areas, which are most extensive on low lying areas nearer the coast. Jarrah, tuart and banksia woodlands dominate the deep sandy soils of the Swan Coastal Plain, and there are also small paperbark forests, shrublands and sedgelands in swampy areas. At the northern end of the plain this vegetation gives way mainly to heath and scrub as rainfall drops off to less than 400 mm annually. To the east as rainfall reduces inland, woodlands of marri and wandoo are found on loamy soils where the laterite of the range has been eroded away. Even further east, as rainfall falls below 600 mm annually, these vegetation types give way to woodlands of York gum and salmon gum which in turn at about 400 mm give way to mallee and mallee heath in the southern part of the region and along the south coast east of Albany, and to mulga, scrub and dry woodlands, mainly of acacia, in the north.

Along the rivers the vegetation can be very different from that on the adjacent uplands. It is usually denser and often of species found in higher rainfall areas closer to the coast or which are tolerant of waterlogging and flooding. The characteristic species of south-west rivers are flooded gum, paperbarks and casuarina.

1.3.4 Drainage patterns

In the driest eastern extremity of the south-west region, in the upper reaches of the Moore, Avon and Blackwood catchments, the low rainfall renders the drainage pattern almost indiscernible; there is only a network of broad shallow basins containing salt lakes lying atop the ancient sediment filled river valleys. Only after unusually heavy rainfall do these long basins fill, overflow and join together to flow sluggishly as rivers towards the coast or to large terminating lake systems. Nearer the coast the drainage patterns become better defined as rainfall increases. Westward and south-westward flowing rivers drop down the Darling Scarp from the edge of the Yilgarn Plateau on their way to the sandy coastal plains. River gradients increase and the valleys are deeply incised, often cutting into bedrock. Pools are formed between rocky riffles, with the occasional cascade or waterfall. Once on the coastal plains, gradients are again slight with the rivers draining slowly into the sea, mostly via coastal lagoons and inlets. On the south coast the rivers are relatively short and drain from the edge of the Yilgarn Plateau and then southwards down the Ravensthorpe Ramp producing well dissected valleys all the way to the coast. To the east a number of these rivers flow into coastal lakes and lagoons which seldom or never overflow into the sea.

Drainage zones

The south-west can be divided into three drainage zones (Bettenay and Mulcahy 1972; Mulcahy et al. 1972; Hodgkin et al. 1979)[3] (Fig. 1.5). The largest by far is the zone of *old* or *ancient drainage*, where the climate is semi-arid and average annual rainfall is 450 mm or less. The zone lies on the Yilgarn Plateau where the landscape is remarkably flat and weathered. The drainage system consists of very broad and shallow valleys, often between 3 and 10 km across, containing chains of salt lakes which are connected by very diffuse drainage lines. These valleys often overlie the ancient rivers, which are buried by sediments up to 60 m deep, to form the *palaeochannels*. Where average annual rainfall is less than 350 mm per annum, the flattish watercourses only carry water following local thunder storms which may fill a few lakes, and they only connect up to form long flows of water in years of exceptionally high rainfall. In these years flooding in inland areas would be widespread and the ancient zone may overflow into the younger drainage zones towards the coast, causing major flooding on the main river channels. The western and southern boundary of the zone more or less follows rainfall, being about 40-60 km inland near Geraldton and Esperance and about 200 km from the south-west corner. Generally, only the larger rivers of the south-west, the Avon and Blackwood, and the Moore, tap this area of drainage.

The western and more southern portion of the ancient drainage zone, where annual average rainfall rises to 450 mm, becomes more undulating with definite uplands above broad flat valleys often wider than 5 km. These valleys remain host to large saline to brackish lake systems, but tributary streamlines become discernible by denser fringing vegetation. Flows occur only intermittently in years of above average rainfall or in periods of intense rainfall. This part of the zone occurs about the areas of the Wagin Lakes on the Blackwood and the Yenyenning Lakes on the Avon. Some of the relatively short rivers of the south coast east of Albany may be considered to drain this part of the zone where it comes quite close to the coast.

The zone of *mature drainage* occurs generally in the area where average annual rainfall is between 450 and 650 mm. On the Blackwood River it occurs between the base of the Wagin Lakes and just south of Boyup Brook. Valleys remain broad in this zone, perhaps as much as 5 km across, but the surrounding landscape is undulating. Streamlines are considered rejuvenated and as such are well defined and incised but have a braided often densely vegetated form with occasional pools. Rejuvenation of rivers is thought to have occurred following uplift of the Darling Plateau in the Tertiary Period (about 50 million years ago), causing the rivers to incise more deeply and thus create well defined channels and steep V-shaped river valleys (Mulcahy et al. 1972; Bettenay and Mulcahy 1972). Flows on streams in the mature zone are seasonal, following the winter pattern of the south-west. In addition to the Moore, Avon and Blackwood a number of smaller rivers tap this zone, including the Greenough, Murray, Warren, Frankland, Kent and Pallinup.

[3] The original terms used by Bettenay and Mulcahy (1972) to describe the three drainage zones were old, mature and young. Other authors have since modified them (Hodgkin 1978; Hodgkin et al. 1979) and those used here are in general common usage today (Williams 1992).

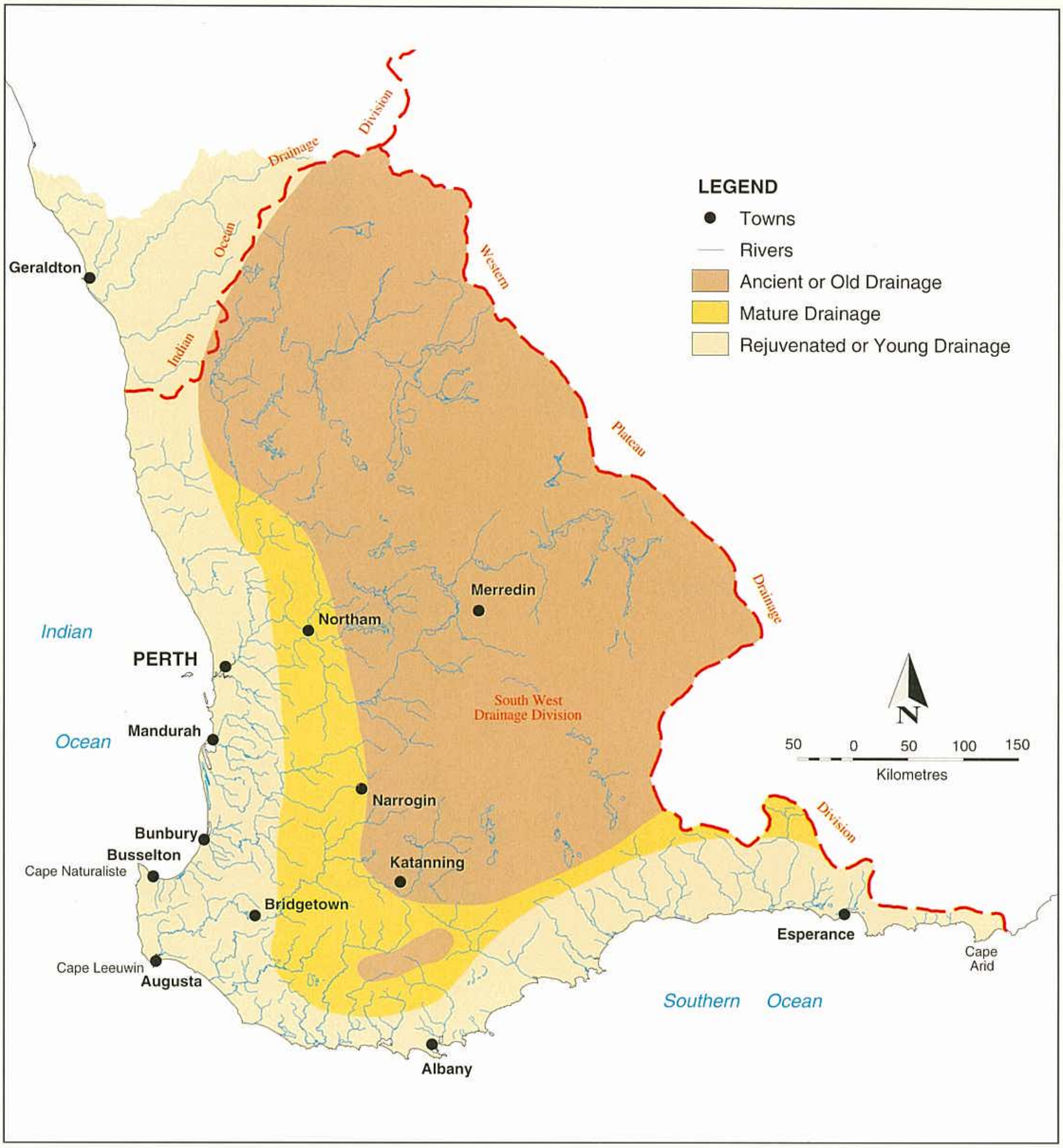


FIGURE 1.5 ANCIENT (OR OLD), MATURE AND REJUVENATED (OR YOUNG) DRAINAGE ZONES OF THE SOUTH-WEST OF WESTERN AUSTRALIA

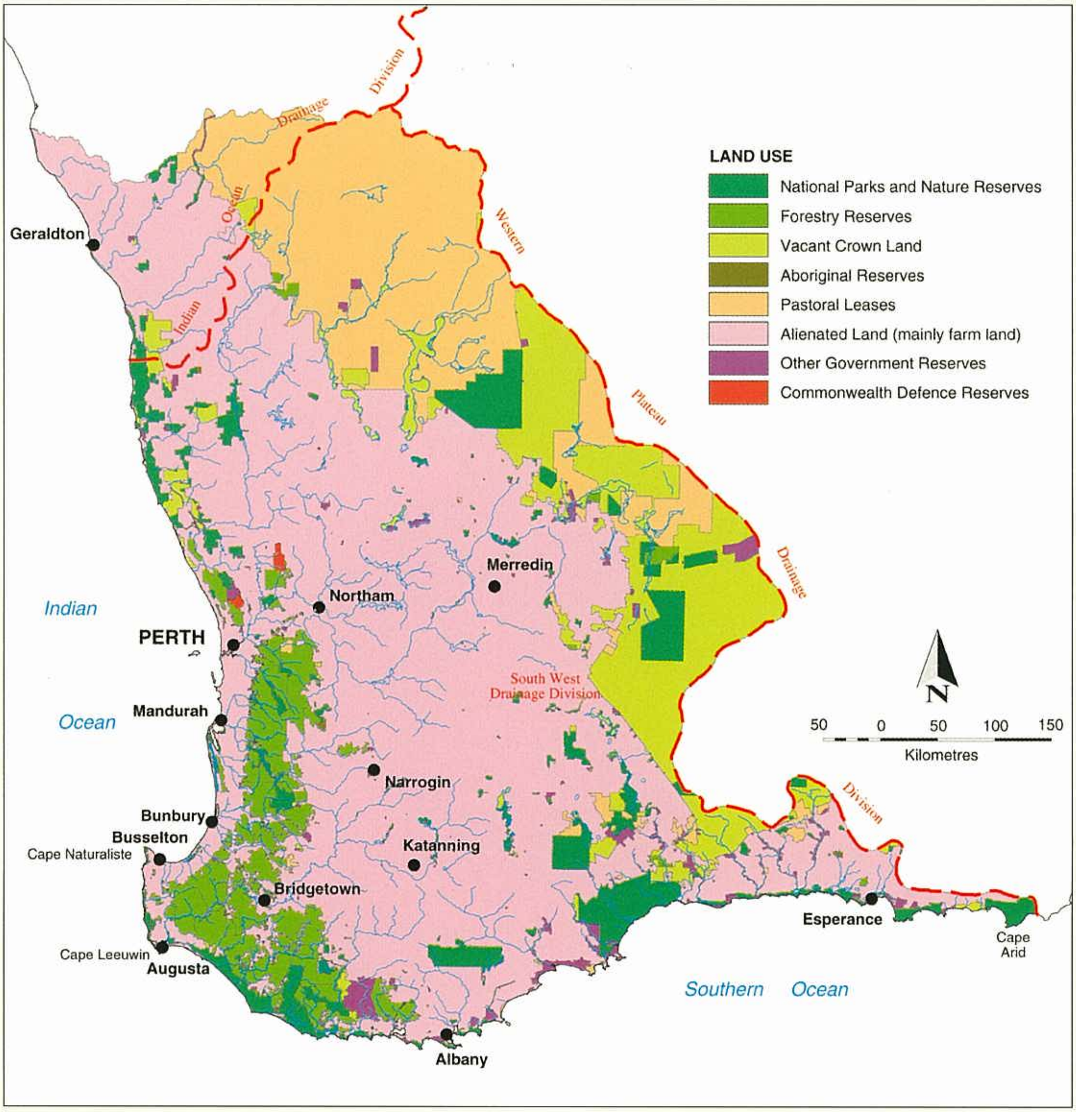


FIGURE 1.6 LAND USE IN THE SOUTH-WEST OF WESTERN AUSTRALIA

Where the larger rivers of the south-west have well defined valleys and channels, they are said to be strongly rejuvenated. This gives rise to the *zone of rejuvenation* (or *young drainage*), which occurs generally where average annual rainfall is usually greater than 600-700 mm. On the Blackwood this zone begins about half way between Boyup Brook and Bridgetown, becoming more pronounced downstream until about Nannup. Other examples are the lower scenic reaches of the Avon, Murray, Collie, Warren, Frankland, Hay and Kalgan Rivers. The surrounding countryside in this zone is typically very hilly and may be 60 to 200 m above the main valley floors (Bettenay and Mulcahy 1972). Flows on rejuvenated sections of the larger rivers are strongly seasonal, becoming perennial as rainfall rises towards the coast. The lower parts of rivers east of Albany, where rainfall is generally much less than 600 mm, are also considered rejuvenated.

The youngest sections of south-west rivers occur on the edge of the Darling Range, where the rivers and creeks passing over the Darling Scarp cut into bedrock, often forming rapids, cascades and waterfalls.

1.3.5 Land use today

European settlement began in the early 19th century with settlements on the Swan River and at Albany. Neither were very successful, but soon the fertile soils of the Avon Valley, the Greenough Flats and other points in the south-west were discovered and land was alienated and cleared for wheat/sheep production. Land clearing and farming also spread along the Swan Coastal Plain. Otherwise the bushland beyond the Darling Range was generally used for grazing sheep. After 1870, alienation and land clearing accelerated and continued through to the 1970s, until the vast majority of the south west was converted to broad acre farming, from north of Geraldton to east of Esperance (Fig. 1.6).

Large naturally vegetated areas remain today on the Darling Range, along the coast north of Perth, on the Blackwood Plateau and the Stirling Ranges, in the Fitzgerald River National Park region and in the eastern part of the South West Drainage Division (Fig. 1.6). Most of these areas are used for conservation and recreation; in the case of the Darling Range forests, also for timber production and water supply. Most of the major freshwater rivers and many of the minor creeks of the Darling Scarp have been dammed to provide water to the city of Perth and irrigated agriculture on the coastal plain, or to supply the country towns of the central wheatbelt and goldfields. A few rivers and minor creeks in the southern Darling Range have been dammed to provide water to country towns in the region. Pine plantations are also present in the range and on the Swan Coastal Plain and Blackwood Plateau.

Most of the wheatbelt is used for wheat/sheep production, with grain production becoming dominant in the eastern low rainfall areas and sheep for wool production dominant in the more southern and south-western areas where the climate is relatively mild. In recent years oil seed production has increased and sheep production for wool has declined. Nearer the coast grazing of cattle for beef production is common and dairying occurs on the irrigated pastures of the southern Swan Coastal Plain and in the cool areas along the eastern edge of the Leeuwin-Naturaliste Ridge and on the south coast.

Horticulture has been a growing industry in recent years. Orchards are to be found in the cool, wet and fertile river valleys of the Darling Range, making use of water supplies from gully dams or from dam releases in the case of the Preston River valley. Market garden horticulture is also to be found in these areas and on the coastal plains north and south of Perth, around Albany and in recent years on the Scott Coastal Plain; in these cases making use of abundant groundwater on soils of mixed suitability. Viticulture is also a growing industry having a long history in the Swan Valley and in more recent times on the Leeuwin-Naturaliste Ridge, in the western and south-eastern Darling Range and along the south coast to Albany. A similar area is increasingly being considered for aquaculture, mostly for marron but also for trout and other fish species. Farm dams of the wheatbelt are often used to raise an eastern species of crayfish, called yabbie.

Pines have been grown on the poor soils of the Swan Coastal Plain since about the middle of the 20th century, but are seldom planted in this region today. However, pines and gum trees are being planted over large areas of the south-west where average annual rainfall is generally greater than 600 mm. Although planted ostensibly for wood and pulp production, they are also planted to combat rising groundwaters and thus address problems of land and stream salinisation. In lower rainfall areas, oil mallees and perennial fodder shrubs are also planted to combat salinity and to diversify farming systems.

There is a substantial mining industry in the south-west. Gold is mined at Boddington on the north-eastern edge of the Darling Range and tin and tantalum at Greenbushes on the south-western edge. Coal is mined in the Collie Coal Basin and has been considered in the Mt Lesueur region. The aluminium rich laterite of the Darling Range is mined as bauxite in a number of areas close to the Darling Scarp. Rare earths or mineral sands, that have been deposited in sediment and sorted by fluctuating sea levels, are mined in the Perth Basin, particularly on the southern and northern Swan Coastal Plain. On the Yilgarn Plateau, within the South West Drainage Division, there is mining for industrial minerals, the products of deep weathering or evaporation. Gold and other metals are mined in eastern areas of the division.

An important industry in the south-west is recreation and tourism which tends to concentrate on the rivers, wetlands, estuaries and coastlines of the region. The south-west draws WA holiday makers at any time and the cool wet karri forest region of the lower south-west, with its diverse landscapes and land uses and associated forms of recreation, is particularly popular.

1.4 The rivers

Putting our rivers in perspective

By world standards the rivers of the south-west of Western Australia are among the smallest and least spectacular[4]. There are two ways to measure the size of rivers, by their actual dimensions and by the amount of water that they deliver to the ocean or to a lake. Take for example, the south-west's largest river, the Blackwood. At its mouth it is about 100-150 m wide and its main channel about 330 km long, as the fish swims. Annually it discharges about 740 gigalitres of water (Appendix 1). Compare the Blackwood with the largest river in the south-east of Australia, the Murray. The Murray, the largest river in Australia and also one of the longest in the world, is 2600 km in length and discharges about 22,000 gigalitres annually (or would if its water was not nearly all diverted for irrigated agriculture). Large as this amount of water is, it places the Murray at only number 87 in the top 200 river discharges of the world (Leopold 1995). The world's largest river, the Amazon, carries 250 times more water.

So the rivers of the south-west are relatively short and carry relatively little water. This should be no surprise given the arid conditions that prevail only a short distance inland from the coast. Put simply, not a lot of water runs off the south-west, and what does mostly flows from within 50 to 150 km of the coast. As you move north or east from the mouth of the Blackwood along the coast, rivers generally get shorter, until they disappear altogether on the south coast east of Cape Arid.

1.4.1 Brief descriptions of the rivers

The South West Drainage Division consists of the catchments that drain into the ocean from just south of Geraldton around the coast to Cape Arid, just east of Esperance (Mulcahy and Bettenay 1972) (Figure 1.1). In this book, however, the south-west region includes the Geraldton region, which extends northwards to just short of the town of Kalbarri. Between Kalbarri and Cape Arid 38 rivers, 50 major creeks and 180 minor streams discharge into the ocean or to a coastal inlet or lake. The largest of the rivers in terms of catchment is the Avon, but the Blackwood River actually carries the larger volume of water and has the longer and deeper river valley. Other large rivers, by south-west standards, include the Moore, Murray, Warren, Frankland and Pallinup. Medium size rivers include the Greenough, Irwin, Collie, Donnelly, Deep, Kent, Denmark, Hay, Kalgan, Gairdner, Fitzgerald, Phillips, Jerdecuttup, Oldfield, Young and Lort. Small rivers include the Chapman, Arrowsmith, Hill, Canning, Serpentine, Harvey, Preston, Margaret, Shannon, Bremer and Hamersley. Smaller stream systems than these do discharge to the ocean or the coast, but they may be considered to be creek size systems by south-west standards. Regardless of size, streams are often named as rivers. Appendix 1 gives details on most of the stream systems that drain to the coast in south-west WA.

[4] The rivers referred to in this section all terminate at the ocean, large inlet or lake system. None are tributary to any other large rivers, unless stated.

the rivers

What follows are brief descriptions of the rivers of the south-west, by region or river basin[5]. The information presented below was obtained from a number of wonderful reviews on south coast estuaries by Hodgkin and Clark (1987, 1988a,b,c,d, 1989, 1990a,b) and from Olsen and Skitmore (1991), Pen (1997) and the Surface Water Hydrology Section of the Water and Rivers Commission.

Rivers around Geraldton - from the Hutt to the Irwin

Strictly speaking, the rivers of the Geraldton area are part of the North West Drainage Division (Mulcahy and Bettenay 1972), but they are included in this book because they are part of the wheatbelt which is a dominant feature of the south-west today.

The small Hutt and Bowes rivers lie within 45-65 km of the city of Geraldton, the Hutt being the most northern river to be included in this book. Both rivers are about 50 km long and drain the farming areas in and around the Waterloo Range. Within about 40 km of the city are four creeks, among them the Oakabella and Oakajee. All are about 7 to 10 km long and rise in the cleared Moresby Flat Topped Range. The rainfall is about 400-500 mm per annum.

The three principal rivers of the Geraldton region are the Chapman, Greenough and Irwin. The Chapman is about 80 km long and drains the farming areas of the very scenic and hilly Waterloo Range and Chapman Valley areas to the north-east of the city, before passing to the sea in the northern suburbs. Here rainfall is generally above 400 mm per annum. The Greenough is a much longer river, about 250 km in length. It rises about 180 km inland close to the zone of ancient drainage on the Yilgarn Plateau where average annual rainfall is less than 250 mm and natural vegetation remains. It then passes through the

[5] A basin is essentially a catchment, but the term is commonly used to describe a large catchment area or a group of smaller catchments contained by a physiographic (landform) unit.

farming areas of the Victoria Plateau to the south of the southern edge of the Waterloo Range (the Kojarena Range). Near the coast it swings to north-west for 18 km passing behind coastal dunes, over an area called the Greenough Flats, which due to the fertility of the alluvial soils has a long history of farming. The river enters the ocean near the present day hamlet of Greenough about 10 km south of Geraldton.

The Irwin River rises on the Yilgarn Plateau in much the same area as the Greenough, but does not extend beyond the wheatbelt about 130 km from the coast. It drains southwards on the plateau in an area of ancient drainage for about 40 km before passing through a wide valley it has cut through ancient Permian deposits (Beard 1976), and then continues through the hilly terrain of the southern part of the Victoria Plateau. About 25 km from the coast it takes a roughly western turn and passes across the coastal plain straight to the sea through coastal limestone at Dongara.

Minor stream systems between Geraldton and Perth

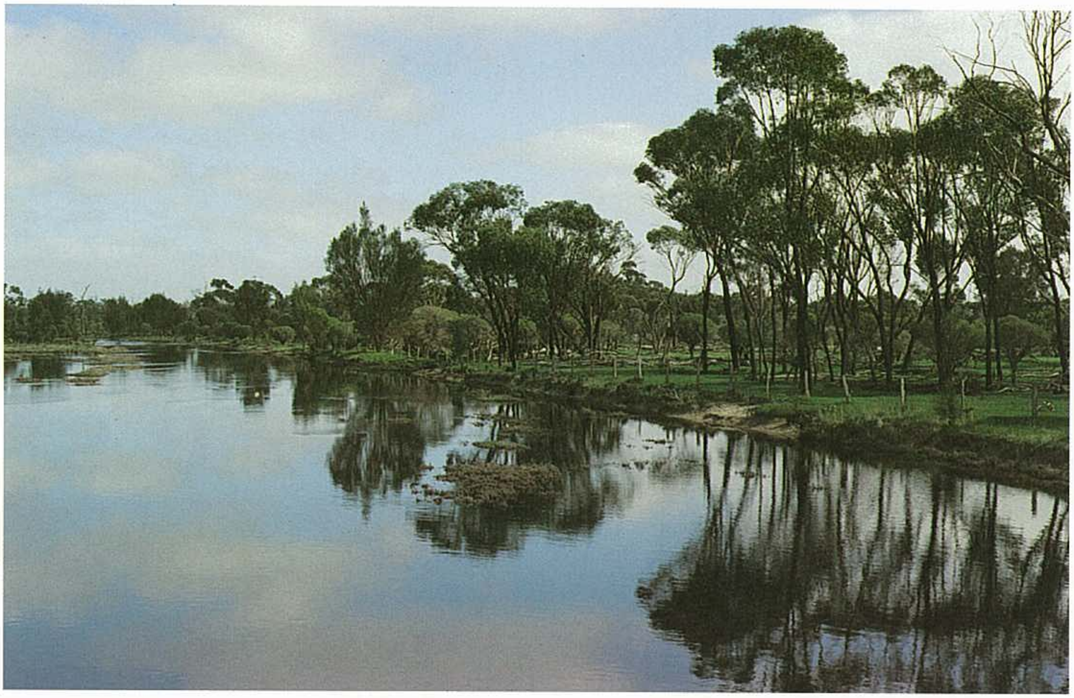
Between Dongara and Guilderton, a distance of about 270 km, only the Hill River enters the ocean. It drains an area of the Gairdner Range south and east of Mt Lesueur and the western margin of Dandaragan Plateau some 50 km inland. Other streams in the region terminate in small fresh or saline lakes and swamps that have formed up against a coastal strip of dunes and limestone and sometimes overflow into caves (Beard 1976). The next most substantial stream, at 80 km in length, is the Arrowsmith River which drains farmland on the southern tip of the Victoria Plateau. The other six streams are all under 30 km long and generally drain the Gingin Scarp. The region as a whole has an average annual rainfall between 400 and 600 mm and retains much of its native vegetation, especially towards the coast. One of the better preserved stream systems is the Cockleshell Gully, which drains the heart of the Gairdner Range including the slopes of the principal peaks, Mt Lesueur and Mt Peron.

The Moore River system and beyond

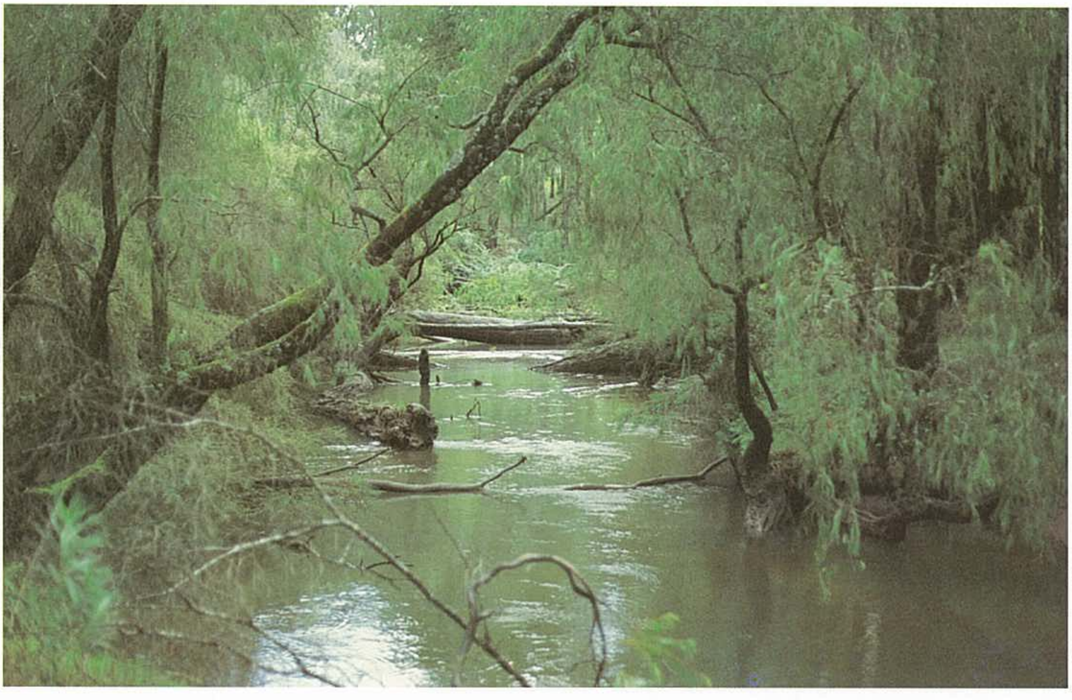
The Moore River catchment lies mostly on the Yilgarn Plateau in an area of mature and ancient drainage with numerous salt lakes stretched out along three broad, almost imperceptible valleys. In periods of unusually high rainfall these lakes flood out and join to flow southwards or westwards. The valleys become more distinct and unite near the foot of the northern Darling Scarp near the town of Moora, whereupon the river flows south for about 40 km before turning west and crossing the southern part of the Dandaragan Plateau. Here the river has no tributaries and passes along a well defined valley for about 30 km before descending the Gingin Scarp at Regans Ford. From here the river turns south and changes form drastically, becoming braided and divided across a broad swampy floodplain between coastal dunes and the higher ground to the east, moving in a roughly southern direction across the Swan Coastal Plain for about 25 km. In this section numerous levees have been constructed to control flooding of farmland on the floodplain. At the southern end of the floodplain the river turns west to flow to the ocean at Guilderton.

A 'RIBBON OF BLUE': THE SHANNON RIVER JUST UPSTREAM OF THE BROKE INLET. PHOTO: S. NEVILLE - ECOTONES

THE ANGOVE RIVER IN THE TWO PEOPLES BAY NATIONAL PARK, JUST TO THE EAST OF ALBANY. PHOTO: L.PEN



The Beaufort River in winter, exhibiting a reflective mood. The Beaufort River is a major tributary of the Blackwood River. Photo: L.Pen



The Harvey River downstream of the Stirling Dam. This part of the river will be drowned by the new Harvey Dam. Photo: L.Pen

Most of the Moore catchment has been cleared and large areas are salt affected. In the upper catchment the average rainfall is as low as 400 mm per annum and the numerous salt lakes discharge into the river giving it quite saline flows. Ordinarily the Moore has brackish or saline flows.

The fresh and permanently flowing Gingin Brook enters the Moore about 10 km from the coast at the head of the estuary. The Gingin rises in the gently incised valleys of the Dandaragan Plateau, passing through the town of Gingin where once it powered a water wheel, before descending the Gingin Scarp and meandering across farmland of the Swan Coastal Plain. The brook is fed by springs on the plateau and general groundwater seepage on the plain, which together create the sort of permanently flowing conditions along the brook that are normally only found in the wet karri forest region of the lower south-west. Perhaps for this reason the brook and the region are known to support a number of disjunct populations of plants and animals more characteristic of fresher and wetter regions of WA (DCE 1983). The fresh permanent flow also puts the brook in great demand for water supply for the adjacent farmland.

Like the Avon and Blackwood Rivers, the Moore can be considered to have a wider catchment lying in the zone of ancient drainage, giving an overall notional catchment of some 55,400 km^2, extending as far as Mt Magnet where average annual rainfall is less than 300 mm. The inland catchment in question is recognised as the Yarra Yarra Basin, and consists of chains of salt lake systems, each with their own internal drainage, along the broad general floodplains of the Monger palaeochannel which terminate in the large Yarra Yarra Lake near the town of Carnamah. Perhaps in the past when the climate of the south-west was much wetter, the Yarra Yarra would fill and overflow via the southward Coonderoo River into Moore River. However, today there appears to be no connection between the lake and the headwaters of the Moore. Wedged in between the Yarra Yarra and the Avon catchments is an area of internal drainage based on the Ninghan palaeochannel. In wetter times it is thought to have discharged into the Avon catchment (Olsen and Skitmore 1991).

Between the Moore and the Swan River, a distance of 85 km, no streams approach the coast.

The Avon Basin

The Avon Basin covers an area of about 115,000 km^2, extending from the eastern Darling Range to about 500 km inland in the western goldfields where rainfall is typically less than 300 mm annually. The basin is about half the size of the State of Victoria and 75% of it is cleared. The vast majority of the basin, about 70%, lies in the zone of ancient drainage where there are numerous salt lakes and systems of internal and irregular drainage, and flows are only produced along the very broad flat valleys during periods of exceptionally intense and widespread rainfall. About 20% of the basin lies in the mature zone. Here in a slightly more undulating landscape with discernible drainage lines, broad flattish but more continuous river valleys, dotted with salt lakes, carry water during years of above average rainfall. Even so only about 10% of the Avon's average annual flow originates from this area, entering the Avon via the Mortlock River at Northam and the

Yenyenning Lakes upstream of Beverley. Nearly all of this part of the catchment is cleared and salt affected and therefore generates saline flows into the Avon. The western or rejuvenated part of the catchment is only 10% of the basin but it generates 90% of the Avon's average annual discharge. The main 'rejuvenated' tributaries, which drain forest and farmland in the 600 to 450 mm rainfall zone, include the Dale River and the Spencer, Wongamine and Toodyay Brooks. Most of these flows are brackish to saline.

The rejuvenated portion of the Avon, which in its natural state had a highly braided form with a broad floodplain, passes along the shallow Avon Valley. Along its length are the towns of Brookton, Beverley, York, Northam and Toodyay, all of which are prone to flooding. Following a particularly troublesome flood in 1955 the Avon was modified or trained to protect these towns. This together with the effects of overgrazing and salinisation has reduced the Avon to a particularly poor state today.

Below Toodyay the Avon River descends to the base of the Darling Scarp, having carved a large valley through the Darling Range. This valley is forested and quite picturesque and can be seen via scenic train rides on the railway line that runs along the Avon Valley. In this area the river receives some fresh inflows from small tributaries in the 900-600 mm rainfall zone. The two largest tributaries in the area, the northern Brockman River and the southern Wooroloo Brook, have mostly cleared and salt-affected catchments and therefore generate brackish flows. As a consequence the Avon remains quite saline as it passes over the scarp. Near the foot of the scarp it becomes the Swan River.

Swan-Canning Coastal Basin

About five years after the beginning of European settlement on the west coast of Australia, the settlers discovered that the Avon and the Swan were indeed the same river, but the names stuck (Shaw 1984). The Avon becomes the Swan at about the Walyunga National Park not far from the base of the Darling Scarp, where important tributaries include the Jane and Susannah Brooks that drain forest, farmland and urban areas in the scarp, and Ellen Brook which drains a large part of the north-eastern coastal plain and western edge of the northern Darling Scarp, most of which is farmland. About 4 km from the scarp the river turns to the south-west and winds its way along the Swan Coastal Plain for about 30 km, firstly through the farmland and vineyards of the Swan Valley and then through the urban areas of Perth, before entering the Swan-Canning estuarine basin at Burswood Island right on the foreshore of the City of Perth. This places Perth in the largest catchment of any major city in Australia.

The Helena River is the largest tributary of the Swan River. It drains an area of the northern jarrah-marri forest in the Darling Range before meandering across the coastal plain through a mixture of farming and urban land. It joins the Swan at Guildford. The Helena supports the large Mundaring Weir which is the northernmost water supply dam and provides water to country towns including Kalgoorlie, via a large pipeline system designed by C.Y. O'Connor in the late 1890s. Because most of the catchment has an average annual rainfall of less than 900 mm, it is prone to salinisation wherever clearing and forest logging takes place. For this reason the catchment, along with other Darling Range water supply catchments, is strictly controlled.

The main channel of the Canning River drains a large part of the northern jarrah-marri forest where rainfall is between 1100 and 700 mm annually, before passing down a small and increasingly urbanised valley to discharge onto the Swan Coastal Plain at Kelmscott. Thereafter it meanders across the Swan Coastal Plain through the southern metropolitan area of Perth. As it does so it gathers water from a number of scarp tributaries, the largest of which is the Southern-Wungong River, which like the Swan-Avon has two names. As with the main channel of the Canning, the Wungong, as well as the Munday and Churchman Brooks, supports water supply dams integral to Perth's water supply. The mouth of the Canning lies at Riverton, and upstream of the old Riverton Bridge it supports the relatively natural Canning River wetlands, which include the original delta islands. In this area Kent Street Weir separates the saline estuary from the upstream freshwater river.

The Murray Basin

There are two river systems of the Murray Basin, having a combined catchment of 8540 km^2, the small Serpentine and the large Murray. The Serpentine River drains State forest east of the Darling Scarp, falling steeply down the scarp through the Serpentine Falls National Park before meandering across the coastal plain where today it enters a long drain before discharging into the Goegrup Lakes wetlands system which connect with the Peel Inlet. The drain is part of a broad drainage system south of Perth which unfortunately delivers large quantities of nutrients as well as water to the eutrophic Peel-Harvey system. Long sections of the Serpentine on the coastal plain have become much wider and deeper through the removal of fringing vegetation and woody debris which once protected the sandy bed and banks. However, in one area of remnant bushland, known as the Lowlands, the river retains its natural form, the only sizeable section of river to do so anywhere on the Swan Coastal Plain south of Perth.

South of the Serpentine system are the short North and South Dandalup Rivers which drain State forest in the western Darling Range, before crossing the coastal plain and joining the lower Murray. Both rivers have incised deeply on the plain for the same reasons as the Serpentine and are today significant sources of nutrients to the Peel-Harvey Estuary. Large storage dams have been built on each of them in the range near where bauxite mining takes place.

The Murray River rises on the Yilgarn Plateau as the Hotham and Williams River systems. Here the rainfall is about 500 mm and because the catchments are highly cleared they discharge large amounts of salt into the rivers. As the rivers flow to the west their valleys deepen and they pass through increasingly hilly and higher rainfall farming country, eventually uniting south of Boddington to form one river and undergo a name change to the Murray. From here the Murray passes through the Darling Range along a deep valley that gathers fresh water from a number of tributaries draining high rainfall forest in National Park and State forest. The valley section of the river is ideal for a large water supply dam, but because the river's water is brackish despite fresh inflows, it remains to provide one of the south-west's most popular holiday destinations. Few people have not heard of the Nanga Bush Camp. Today the Murray Valley is conserved as the Lane-Poole National Park. Below the park the river tumbles down the Darling Scarp, producing 'rapids' suitable for white water canoeing and rafting. On the coastal plain the river has cut a deep valley in the land, which can be seen as one crosses the bridge at Pinjarra. Here a weir has been constructed to prevent the upstream penetration of tidal water coming up from the Peel Inlet.

The Harvey River Basin

This river basin consists of a number of small stream systems draining the forested Darling Scarp and Range between the towns of Harvey and Waroona. The southernmost and largest of these systems is the Harvey River, which penetrates about 20 km into the range. On leaving the scarp the Harvey takes a turn to the north-west, and in its natural state once meandered through a long area of low lying seasonal wetland, gathering water from the smaller northern scarp tributaries along the way before discharging into the southern end of the Harvey Estuary. Today, on the coastal plain, the Harvey has been greatly modified by drainage developments to prevent flooding and enable farming. The biggest alteration is a diversion drain, which was dug to the ocean in the 1930s. The drainage system is responsible for conveying large quantities of nutrients to the eutrophic Peel-Harvey estuarine system.

Two dams lie on the Harvey River in the range, the lower and smaller of which is to be replaced by a new and larger dam to supply Perth's growing population. Between the dams is a 'rapids section' where the river passes over bedrock. It is one of the best canoeing courses in Australia. Five smaller water supply dams lie on the northern tributaries, including the Logue, Samson and Drakes Brooks. Bauxite mining is carried out in the catchment.

The Collie and Preston River Basins

The Collie River system drains forested, wetland and farmland country of the Darling Range and the edge of the Yilgarn Plateau, extending at most 100 km inland to where rainfall is about 600 mm per annum. As the east and south branches of the river cross the Darling Range, they pass over the Collie Coal Basin where coal mining takes place. On the southern branch, the river has had to be diverted around open cut mining. The Collie Basin is an important source of fresh water to the system, especially since the upper cleared catchment contributes significant quantities of salt. By the early 1990s the Wellington Dam, which is the southernmost of the large water supply dams, had been taken off public water supply and replaced by a new dam on the Harris River, a major tributary upstream of the town of Collie draining dense jarrah-marri forest and wetland. Through the town about 13 km of the Collie has been trained to reduce the risk of flooding. Downstream of the Wellington Dam, the Collie drops down through the Darling Scarp through the deep and picturesque Collie Valley, before passing across the Swan Coastal Plain and emptying into the Leschenault Inlet. On the plain the Collie joins the small Brunswick River that drains part of the western Darling Range. It too has a water supply dam.

The 80 km long Preston River system rises in the Darling Range, passing through the Blackwood Plateau and Swan Coastal Plain. While it mostly drains farmland, forest remains on many headwater streams. One of these streams, south of Collie, supports the Glen Mervyn Dam which is used to maintain water supplies over summer and autumn for reticulated horticulture along much of the Preston near Donnybrook and Boyanup. In these areas the river has incised deeply into the land and the sandy river banks are prone to serious erosion. Near Bunbury the river has been trained, straightened and leveed to prevent flooding of urban areas and relocated to the north-east to make way for harbour development.

The Busselton Coastal Basin and Leeuwin-Naturaliste Ridge

The Busselton Basin consists of 26 short river and creek systems that discharge to the coast between Bunbury and Augusta. It covers an area of 2650 km^2 which has a generally high annual average rainfall between 800 and 1200 mm. Between Bunbury and Cape Naturaliste nine short rivers and major creeks drain the edge of the Darling Range, Whicher Range and/or Swan Coastal Plain to discharge into Geographe Bay. The more substantial systems are the Capel, Ludlow, Abba and Sabina which have headwaters mostly in the forested Whicher Range. Many of the creek systems and lower reaches of the rivers have been entirely or partially modified as part of artificial drainage systems to drain the very low lying and now cleared Swan Coastal Plain and thus enable its use for dairy farming and other forms of agricultural use. Five of the rivers and creeks have been leveed and diverted from their estuary, the Vasse-Wonnerup, to discharge directly into the ocean.

Seventeen minor creeks occur along the Leeuwin-Naturaliste Ridge, three of which flow to Geographe Bay on the western side of Cape Naturaliste. Many of these small systems are either partially or wholly contained within remnant coastal vegetation. The only true river system to pass through the ridge is the Margaret River, which drains the north-western corner of the Blackwood Plateau. The upper half of the catchment is heavily forested, with numerous swamps.

The Blackwood River

The Blackwood River system is the second largest in the south-west, having a catchment area of about 20,000 km^2. It reaches some 330 km inland to drain the Yilgarn Plateau about 380 m above mean sea level, but in fact receives little water from this zone where rainfall is on average less than 500 mm per annum. This far inland the landscape is flat and ordinarily receives insufficient rainfall to cause the broad almost indiscernible streamlines to flow, usually only filling the large lake and floodplain systems that stretch along the upper Arthur and Beaufort River systems (Hodgkin 1978; Beard 1981). The largest lake is Lake Dumbleyung, which receives water from the Coblinine and Dongolocking Rivers. Lake Dumbleyung has overflowed into the lower Blackwood system only three times in recorded history, in 1872, 1954 and 1982 (Morrissy 1974; WRC data). Below these lake systems the river system becomes rejuvenated, dropping about 150 m as it passes through the Darling Range and along the deep and picturesque Blackwood Valley. Average annual rainfall also increases to about 900 mm and seasonal flows may occur as far downstream as Nannup, whereupon the river becomes more or less permanently flowing as it winds its way through the high rainfall, densely forested Blackwood Plateau, and receives water from shallow aquifers of the Perth Basin. The lower 55 km of the river is tidal and estuarine water penetrates 42 km up from the river mouth (Hodgkin 1978).

Most of the Blackwood catchment is cleared for agriculture, especially in the upper catchment, and discharges brackish to saline water, more so in recent times because of the altered catchment hydrology of the cleared landscape (see Chapter 7). Only in the lower reaches of the river below Bridgetown, where rainfall is high and evaporation relatively low and large areas of forest and tree plantations occur, do the tributaries of the Blackwood carry fresh water.

The Blackwood Basin includes the Scott River, a lower tributary of the river's estuary which drains the western portion of the highly cleared, low lying, sandy and swampy Scott Coastal Plain.

The Donnelly and Warren Basins

The Donnelly River system drains mostly tall forested hilly country with a rainfall in excess of 1000 mm per annum. The catchment covers an area of 1670 km^2 and is divided mostly between the south-east corner of the Blackwood Plateau and the lower south-west corner of the Darling Plateau. The Warren River catchment covers 4350 km^2 and the river passes across mostly forested parts of the southern hilly Darling Plateau, where rainfall is between 1000 and 1400 mm per annum, to drain woodland and cleared land on the edge of the Yilgarn Plateau. Here rainfall decreases to about 550 mm per annum and salt discharge from cleared land is significant. In this area the Warren has a name change and is called the Tone. The Unicup wetland system of swamps and lakes exists in the upper very flat Tone catchment, but its connection to the river is difficult to discern.

Both the Donnelly and the Warren flow through tall karri forest in their lower reaches before passing through the densely vegetated, sandy and very swampy Scott Coastal Plain, to discharge through coastal dunes directly into the ocean over summertime sand bars at their mouths. This is a unique feature for south coast rivers, which usually discharge into coastal lagoons or inlets, and is shared by the Gardner which lies in the Shannon Basin, except that the Gardner has a rock rather than sand bar, which maintains a permanent opening.

The Shannon Basin

The Shannon Basin consists of twelve creek size systems and three true rivers, although two, the Gardner and the Shannon, are quite small being less than 50 km in length. The basin covers an area of about 2490 km^2 on the southern Darling Plateau or Ravensthorpe Ramp and Scott Coastal Plain. Here the rainfall is at its highest for the south-west, being generally in excess of 1200 mm per annum. For this reason the basin is naturally covered in dense forest and wetland vegetation, most of which remains today. Only the Meerup, Gardner and Walpole River catchments are significantly cleared. A number of creeks and rivers discharge into the Broke and Walpole-Nornalup Inlets. The Broke is mostly closed to the ocean by a sand bar, because the flows of a number of creeks and the Shannon River are generally insufficient to fill the large inlet and cause it to overflow into the ocean for longer than six months. In contrast the Nornalup Inlet is kept permanently open by the high flows generated by the Deep River, the largest river system of the basin, and the adjacent large Frankland system. A feature of the Broke Inlet catchment is that it is entirely contained within conservation estate.

The very large Muir system of wetlands, including some large brackish and freshwater lakes, occurs near the eastern headwaters of the Deep. However, there is no surface connection between them and particularly Lake Muir, the largest and nearest lake, to suggest that the Deep ever receives water from these wetlands in times of flood.

The Frankland, Bow and Kent River

These three river systems vary greatly in size and have a combined catchment area of 6560 km^2. Although all three systems drain high rainfall coastal areas with between 1400 and 1200 mm per annum, only the larger two, the Kent and Frankland, extend inland to the edge of or onto the Yilgarn Plateau, respectively, where the rainfall is less than 600 and 500 mm, respectively. The upper catchments of both rivers are heavily cleared and relatively flat and have ill defined drainage mostly flowing internally to numerous salt lakes which only overflow in years of exceptionally high rainfall. For this reason most of the flow, about 90% in fact, of these rivers is generated in the area south of the Muir Highway, most of which is still forested (Hodgkin and Clark 1988b). Nevertheless, salinisation caused by clearing in the upper catchments has seriously increased the salinity of these rivers to between 1000 and 2000 mg/L and it is still rising, by about 40 mg/L per year in the case of the Frankland. The flow of these rivers is highly variable but mainly seasonal with about 80% of the flow on average occurring during the five months June to October. The Kent discharges into Owingup Swamp which in turn overflows into Irwin Inlet, while the Frankland empties into the Walpole Inlet. The Bow is a small river, only about 20 km long, and it drains the high rainfall karri and tingle forest country to the north of Irwin Inlet.

The Denmark, Hay and Kalgan Rivers and nearby smaller systems

There are three major river systems in the Denmark to Albany region, the Denmark, Hay and Kalgan. The Denmark drains from the edge of the Yilgarn Plateau, about 50 km inland, while the Hay drains from a similar area, about 30 km further inland, but also across to the area just to the east of Mount Barker. Both rivers drain large areas of natural jarrah forest and wetland in their middle reaches and discharge into Wilson Inlet. The largest river system in the region is the Kalgan, with headwaters 70 km inland beginning just south of the township of Cranbrook, north of Mount Barker, and including the north-western corner of the Stirling Range. It discharges into Oyster Harbour north-east of Albany. From Denmark the average annual rainfall drops off eastwards and northwards quite quickly, so that coastal reaches of the rivers run from 1100-800 mm and inland headwaters from 750-500 mm. Flow on the rivers is permanent, but strongest in the five months June to October, mirroring the winter rainfall pattern although cyclonic rainfall in summer can produce exceptionally high flows. All three rivers are marginally fresh to brackish and have elevated salinities caused by clearing in the upper catchments, especially in the Kalgan catchment, although in this case the salinity of the river water was probably always high as indicated by the salt-tolerant fringing vegetation along the upper reaches and the high salinity of tributaries draining the still heavily vegetated Stirling Range.

There are also a number of small river or creek systems between Parry Inlet and Oyster Harbour, draining the high to medium rainfall (1100-800 mm) zone between 15 and 40 km from the coast. They include the Kordabup and the Little and Sleeman Rivers and Lake Saide Drain, the latter three of which drain into Wilson Inlet; tributaries of the Torbay Inlet; and theYakamia Creek and King River which flow into Oyster Harbour near Albany. All these systems have heavily cleared catchments and for the most part are rural and/or urban drains, some of which are responsible for discharging considerable loads of nutrients to their respective inlets. All are fresh.

North-east of Albany along the coast there are about 30 minor drainage lines, rarely extending more than 20 km inland, which discharge to inland lakes, small seasonally closed or intermittent estuaries or coastal dune built lagoons, and very rarely directly to the sea as in the case of the beautiful Waychinicup River. Most drain farmland and a few retain large patches of remnant bushland in their catchments, mostly near the coast. All usually only flow for a few months in winter and spring or after unseasonal heavy rainfall of cyclonic origin, and are fresh to marginally fresh when flowing.

It is also worth highlighting the near-pristine ephemeral drainage lines of the Stirling Range which drain to peripheral lakes or dissipate on the lower slopes.

The Denmark is the easternmost stream system to support a public water supply dam, although in recent years it has been taken off supply because of the raised salinity of the inflowing waters due to upper catchment clearing (see Chapter 7).

Rivers between the Stirling Range and Fitzgerald River National Park

Seven river systems are located between the Stirling Range and the eastern edge of the Fitzgerald River National Park, the Pallinup, Bremer, Gairdner, Fitzgerald, Hamersley, Phillips and Jerdacuttup, all extending between 50 and 100 km inland and flowing roughly parallel to each other in a southerly or south-easterly direction. They all arise directly on the Yilgarn Plateau or on its southern edge. From the plateau they drain coastal plains and/or rugged ranges before passing across the soft Pallinup siltstone plateau where they have generally cut deep gorge-like valleys, sometimes down to granite bedrock, before discharging into coastal lagoons which are occasionally connected to the sea. One exception to this is the Jerdacuttup River on the eastern edge of the National Park, which drains the rugged Ravensthorpe Range and then coastal sandplain before discharging into the Jerdacuttup Lakes, which are now permanently separated from the ocean by a high dune. A second is the Pallinup which also drains sections of the Stirling Range.

There are also a number of short river or creek systems which, though small, give rise to coastal lagoons. They include the

Hunter, Kelly, Boondadup, St Mary and the tributaries of the Dempster Inlet. The short Steere River shares an inlet with the Phillips River that drains the western side of the Ravensthorpe Range.

Rainfall in the catchments is low and erratic, ranging from between 600 and 500 mm at the coast to 400 mm inland annually. The rivers generally only flow strongly following exceptionally heavy or prolonged rainfall which may occur over a few days or weeks each winter. At this time the rivers may swell their inlets, bursting the ocean bars, and discharge to the sea. However, in most years flow is very low and may be negligible in dry years. Despite this, the rivers retain considerable permanent aquatic habitat in the form of deep and often very long permanent river pools which tend to be larger in the lower reaches.

All the longer rivers are saline, which is thought to be a product of either the drainage of salt lakes in the headwater catchments or saline groundwater or both. Many of the rivers also carry large loads of sediment, which are thought to have increased in recent years due to clearing in the catchments and which are slowly or in some cases relatively rapidly filling the coastal lagoons.

A unique feature for rivers of the south-west is the presence of broad, if somewhat broken, vegetated corridors along the rivers as they pass through agricultural land. These corridors are present along the upper reaches of rivers which pass through the Fitzgerald River National Park (Fitzgerald, Hamersley and West) and along the middle and lower reaches of those that pass along the edges or adjacent to the park (Corackerup, Bremer, Gairdner and Jerdacuttup). These corridors make a major contribution to the conservation of the environmental values of the rivers.

Rivers and creeks of the Esperance region

Three large river systems pass through the area west of Esperance known as the Esperance Sandplain, the Oldfield, Young and Lort. All begin about 100 km inland in remnant mallee bushland on the edge of the Yilgarn Plateau, about 300 m above sea level. Here the average annual rainfall is as low as 350 mm per annum, compared to about 550 mm on the coast. The rivers mostly drain gently undulating and often saline farmland country. In their middle reaches they cut shallow valleys to expose granite before dissecting deep valleys in siltstone as they descend to the coastal plain. All three rivers flow to intermittent estuaries, mostly barred from the sea until there is sufficient rainfall to force a breach which may last a few weeks. Between these rivers is a small creek system which flows into the Torradup Inlet which is similarly barred.

Within 40 km either side of Esperance there are a number of major creeks, some of which drain salt lake country north of Esperance. Most flow to lakes and swamps within 20 km of the coast, some of which ultimately overflow to the sea.

East of Esperance average annual rainfall drops off rapidly inland from the 600 mm on the coast, and as a consequence drainage lines are few, with about ten minor creeks only. West of Cape Arid short creeks drain coastal sandplain country, while east of it very minor streams drain coastal dunes or small ranges directly to the sea, often via tiny narrow intermittent estuaries or coastal lagoons which are mostly closed off from the sea by sand bars.

The larger streams flow only for short periods each winter, and only negligibly in dry years. The smaller and very minor systems mainly only flow following heavy rainfall in their catchments. Very occasionally, once or twice a decade, exceptionally wet winters or heavy rainfall of cyclonic or summer storm origin produce strong flows which fill the lagoons and breach ocean bars enabling the streams to discharge to the sea for a few days or weeks.

All the streams on the Esperance Sandplain are naturally brackish to saline, although salinity levels are thought to be elevated through extensive clearing in the catchments, which has also caused an increased amount of sediment to be washed from the highly erosive sandy soils, filling river pools and clogging channels. Eutrophication of river pools, resulting from the heavy application of artificial fertilisers on the poor sandy soils, is also a problem in western parts.

The drainage system of the south-west peters out just to the east of Cape Arid as two or three minor coastal creeks. Further along the coast lies the arid Nullabor Plain and the State of South Australia. The drainage of the plain, which lies atop the Bunda Plateau of the Eucla Basin, is mostly subsurface and there are only a few ephemeral and internal drainage lines. The next stream of any size, lying on the Eyre Peninsula, is over 1400 km away.

1.4.2 State of the rivers of the south-west: a thumbnail sketch

A detailed account of the state of the rivers of the south-west has been given by Olsen and Skitmore (1991) and more recently in the State of the Environment Report for WA (WA Govt 1998) and State of the Northern Rivers report (WRC 1997), which includes the streams of the Geraldton region. It remains here to give a brief description of the state of south-west rivers.

All rivers that drain cleared agricultural areas of the south-west, and that includes most of them, are suffering a number of effects all of which compound one another. The loss of fringing vegetation, principally through overgrazing of riparian zones, has resulted in a loss of habitat and the general erosion of bed and banks, leading to sedimentation of streamlines. Sedimentation is a particular threat to river pools which are needed to maintain valuable summer drought refuges for aquatic fauna. Runoff from farmlands has carried large amounts of farm soil, organic matter and nutrients into waterways, which generally are not buffered by riparian vegetation. This has caused the problem of nutrient enrichment or 'eutrophication', with symptoms such as stagnation and deoxygenation (sometimes causing fish kills) and toxic phyto-plankton blooms. A long section of the Blackwood River suffered a toxic algae bloom in the summer of 1993-94, mirroring the Murray-Darling episode some years earlier. These effects occur also in receiving waterbodies, such as lakes, estuaries, inlets and lagoons. The Swan-Canning, Peel-Harvey, Vasse-Wonnerup, Wilson, Oyster Harbour estuarine systems and also those east of Albany are the most heavily affected.

A major compounding effect of clearing is the salinisation of streams. This is a problem for all south-west streams draining substantially cleared parts of the Yilgarn Block where rainfall is less than 1100 mm per annum on average. Most of the lower reaches of the larger river systems, such as the Avon, Murray, Blackwood, Warren and Frankland, are affected by saline flows from upstream, despite fresh inflows from high rainfall forested areas in their lower catchments. The risk of salinisation to important water supplies led to clearing controls being placed on the Helena, Collie, Warren, Kent and Denmark catchments by 1978 and work is ongoing to protect and revegetate these catchments and thus rehabilitate their water supply potential. In many rivers salinisation is killing fringing vegetation and probably dramatically altering stream ecosystems in other ways yet to be determined.

Where overgrazing and salinisation are not problems, weeds are often taking a stranglehold on riparian zones. This is worst in areas of more intense human development where plant species, commonly garden plants, are allowed to escape into waterways. Generally the same suite of weeds is coming up in all the fresher rivers of the south-west. In addition to weeds are feral fish, including redfin perch and the mosquito fish, now probably the more common fish in most of our fresher rivers. Trout are also stocked in the cooler south-west rivers, but seldom maintain breeding populations.

Large water supply dams, gauging weirs and gully dams have been placed on many south-west streams which carry fresh water. These dams, along with road culverts, have fragmented stream ecosystems and blocked the movement of stream fauna, which need to move in order to respond to the winter flood/summer drought cycle of the south-west. Impounded waters also present a vacant niche for feral fish and several dams in the south-west are known to support large infestations of redfin perch. Water diversions alter downstream flow patterns, possibly creating conditions of drought which can be exacerbated by actual climatic drought. The compounding effects of drought, exotic fish infestations and blockage of movement could lead to extinctions of native fauna.

All rivers in agricultural and urban areas must be receiving considerable inputs of synthetic chemicals from pesticide application, chemical spills, illegal disposal and general runoff, for which the effects on stream ecosystems are unknown. Mine site dewatering into rivers may also be a problem in certain areas.

In many parts of the south-west, drainage systems have been created and natural streams modified to prevent waterlogging and flooding of farmlands and urban areas. On the Swan Coastal Plain between Perth and Dunsborough, and to some extent on the south coast between Albany and Denmark, elaborate drainage systems have been created. These have the effect of transporting nutrients to downstream waterways. Some of these systems have required the channelisation and desnagging of natural streams, as in the case of many Perth metropolitan streams, the Serpentine and Harvey River systems and the rivers in the Busselton and Denmark regions. On the southern Swan Coastal Plain many streams have been diverted to the sea and leveed to prevent flooding, including the Carbanup, Vasse, Capel and Harvey. Levees have been placed on the Preston and the river diverted around harbour developments and the city of Bunbury. Levees have been placed on the lower Moore and Greenough Rivers. Sections of the Preston, Collie and most of the main channel of the Avon have been heavily channelised to improve flood conveyance. In the case of the Avon, this action has compounded the effects of salinisation and overgrazing and led to the loss of most of the river's deep pools through sedimentation. Other smaller sections of rivers in the south-west have also been modified.

In naturally vegetated areas of the south-west, stream systems are comparatively unaffected by human activities. But even here there may be the temporary removal of vegetation to enable mining or logging; and there are the impacts of recreation, including fishing and stream bank trampling by people at play. Areas of natural catchment vegetation may also be affected by disease and altered fire regimes, although the significance of these indirect effects on stream ecosystems, if any, is unknown.

With all of the above activity and the effects on stream ecosystems, the reader would probably not be surprised to learn that there are few pristine stream systems left in the south-west. But there are some. The Cockleshell Gully near Mt Lesueur is mostly in good condition. Most of the streams of the Darling Range behind the dams or which are tributaries of the larger rivers have catchments largely dominated by native vegetation. The smaller streams of the D'Entrecasteaux National Park, including the smaller tributaries of Broke Inlet, are in the national park. The Shannon River can be included, but even this system retains a gauging weir and a dam in the upper reaches. The Deep River and branches of the Frankland, Kent and Hay Rivers lie mostly in State forest or national parks (existing and proposed). The smaller streams of the Fitzgerald River National Park, such as the St Mary, Hunter and Dempster Rivers and Coppermine Creek, may be considered near-pristine. The headwater streams of the Stirling Range National Park and adjacent bushland of the Lake Magenta Nature Reserve and nearby vacant Crown land are also in a near-pristine condition. Many rivers of the south coast east of Albany and especially about the Fitzgerald River National Park lie within broad bushland reserves and, although the water quality of these rivers is compromised by clearing and agriculture in their upper catchments, the riparian zones of the main river channels are in a relatively natural state.

Beginning note

Rivers do not have to be in a completely natural state to have great value. The Kalgan River, while being somewhat degraded, is still a very beautiful river. The Blackwood Valley below Bridgetown, although greatly altered, is still an example of some of the best landscape to be found in the south-west. The southern branch of the Collie River, despite passing through farmland, mining sites and little hamlets, is still the home of many aquatic plants and animals. People can still go marroning in the Collie. The Avon River, despite being salinised and sedimented, still plays host to one of the world's great boat races and many of the people who live in the rural towns along its flanks still cherish the river, despite its current ugliness. And this goes for many people who live near rivers in the south-west, both in urban and rural areas. Many people know what their streams used to be like, some see the beauty that remains and some see the potential that lies within an apparent ditch or drain. Many individuals and groups are active or are becoming active in stream management. This book provides a first step in gaining the knowledge needed to protect and repair the rivers of the south-west of Western Australia.

Chapter 1
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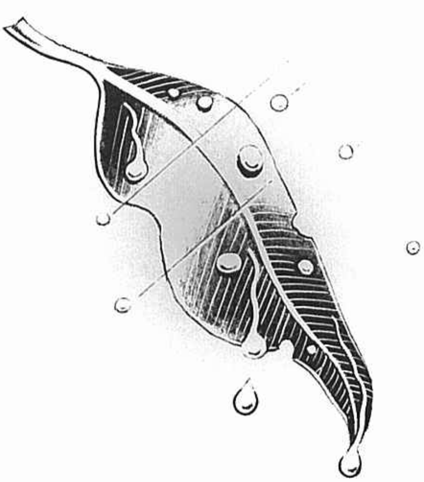
chapter 2

How south-west catchments and river systems work

- Rainfall
- Surface and groundwater movement
- Stream form
- Flooding
- Case study - a comparison of forested and cleared catchments



This chapter deals with the physical nature of streams, which is largely determined by the laws of physics that govern the motion of fluids. Despite the fact that these laws are universal, the behaviour of streams and the formation of channels are highly variable and complex. This is because of changing climatic and geological conditions, over both time and space, and the contribution that living things, mainly vegetation, make to the nature of stream channels. The south-west has its own unique climatic and geological setting, and its own biological response and contribution to this setting. Therefore, to understand south-west river systems, it is necessary to take a catchment wide approach and to look at the land phase of the water cycle as it expresses itself in the south-west. Thus this chapter follows the main pathways of water through and over the land, and along the way explains the formation and behaviour of the river systems. The story begins with rain.

2.1 Rainfall

Falling rain

When raindrops first form and begin to fall they initially gain speed as gravity pulls them towards earth. But soon they reach what is called terminal velocity, where they stop accelerating and fall at a more or less constant speed determined by the frictional effect of the surrounding air. On the way down drops continually break up and coalesce and the drop size distribution takes on a certain characteristic form. Generally, rain contains a range of drop diameters from about 0.25 mm to 7 mm with the larger drops falling further before reaching a terminal velocity (Troeh et al. 1980). Strong winds can further increase velocity and cause the drops to fall at an angle to the ground.

Reaching the ground

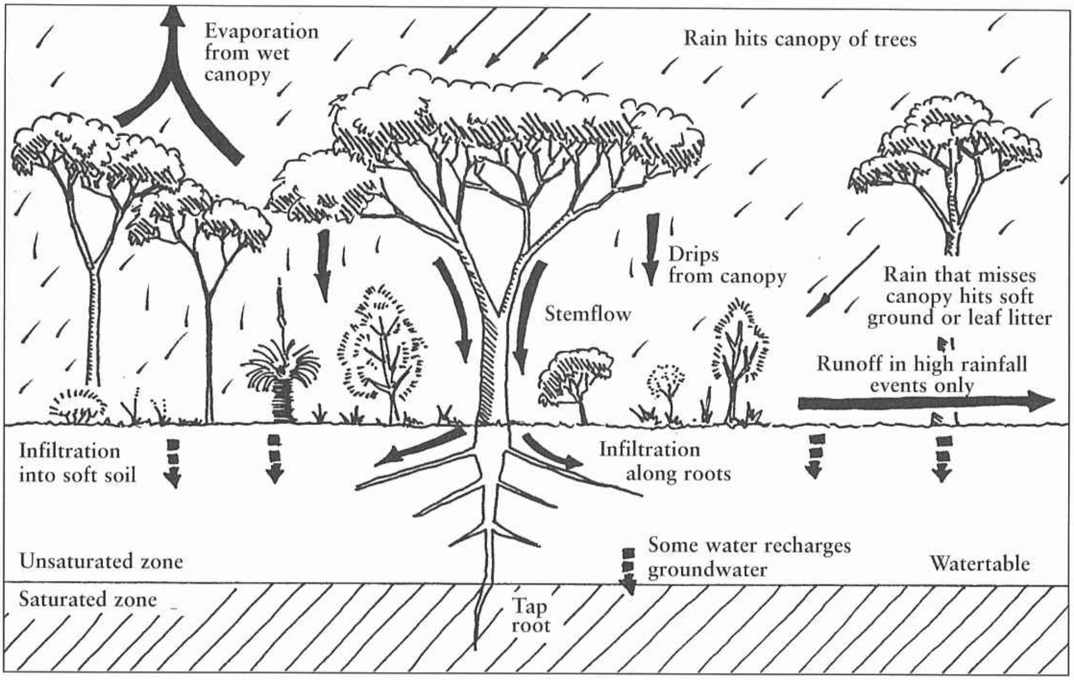
The kinetic energy of the falling droplets is dissipated when the drops complete their atmospheric journey and hit the ground or some object upon it. The magnitude of the impact of each raindrop will be a combination of its size and speed. Large drops have greater momentum and therefore more impact than small ones, and drop size generally increases with storm intensity (Troeh et al. 1980).

While the above explanation may seem obvious, what is not obvious is how significant the energy of falling raindrops is to the erosion of bare soil. Where vegetation is absent, the maximum amount of kinetic energy is delivered to the soil (try tapping your finger on a table and then think of the effect of millions of these little taps on the soil). The pummeling action of the rain breaks up soil aggregates and clods into smaller aggregates or individual particles, moves the soil grains closer together and compacts the soil (Troeh et al. 1980). If rain falls on sloping ground, soil particles tend to be knocked downslope more than upslope and this can lead to downhill soil movement over time.

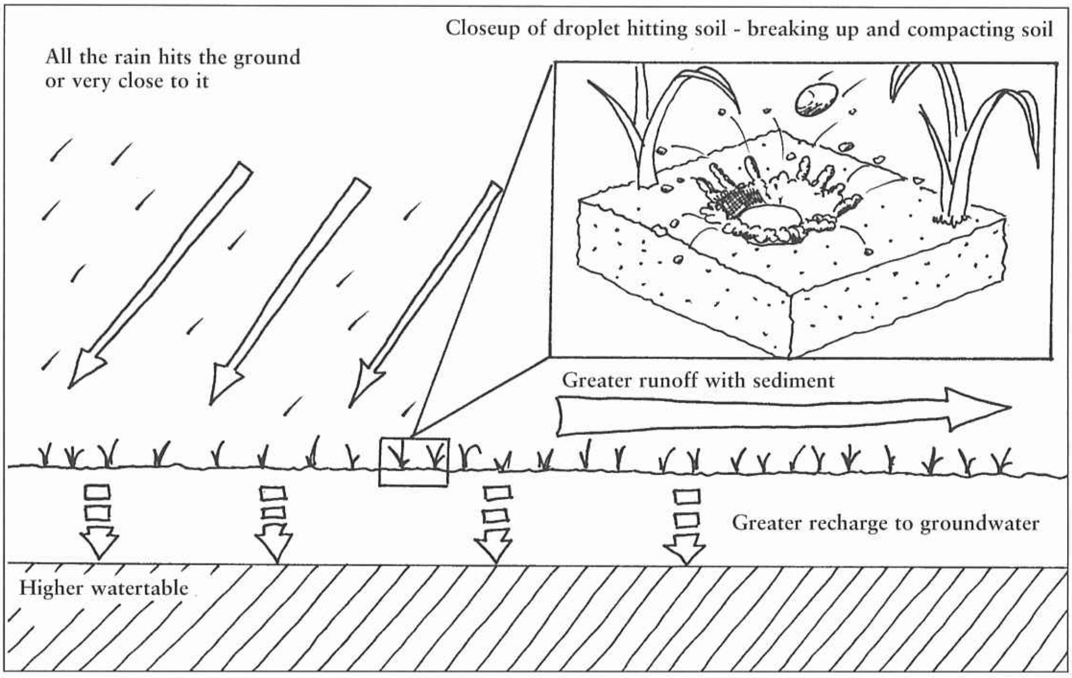
Rain and vegetation

Vegetation therefore has an important role in dissipating the kinetic energy of rainfall. When rain falls over naturally vegetated catchments, much of it does not hit the ground directly but rather is intercepted by the foliage of the vegetation (Moss and Green 1990). Although much of the rain that strikes the vegetation eventually drips through the foliage, the final fall to the ground is mostly short and thus the drops have low kinetic energy. Other droplets are broken up as they hit the vegetation and fall to the ground as smaller, low energy droplets. Furthermore, much of the rainwater actually runs down the branches and stems of the vegetation (DCE 1984). In heavily vegetated areas, rain that misses the vegetation hits mulch and leaf litter on the ground. In most natural areas of the south-west the soil is well defended from the impact of rainfall by its natural vegetation. Of course, exotic vegetation can also defend the soil, but where annual crops and pastures are grown the soil is dangerously exposed over the summer and autumn and often at the beginning of winter. These are periods when thunderstorms and the break of season rain can result in significant erosion.

Tall gum trees can actually produce high energy raindrops. This occurs firstly because the pointed, relatively broad gum



a) Naturally vegetated catchment



b) Cleared catchment at the beginning of winter

Figure 2.1 The general action and movement of rainwater on the land surface of (a) the naturally vegetated catchment and (b) the cleared agricultural catchment in south-west Western Australia

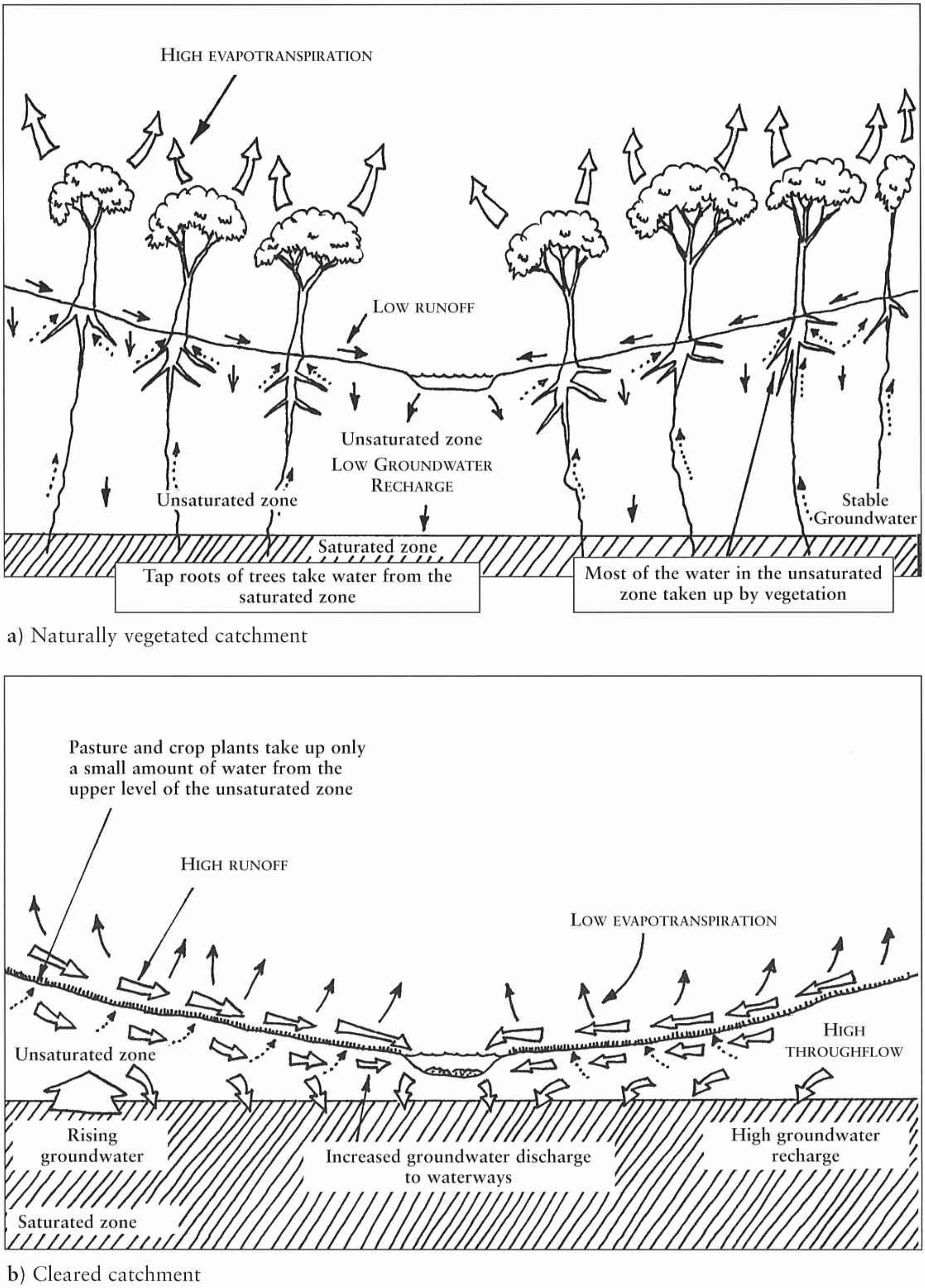


Figure 2.2 A comparison of the general flows of water on the land surface in the ground and through the vegetation of (a) the naturally vegetated catchment and (b) the cleared agricultural catchment in south-west Western Australia

leaves act like microcatchments, gathering water and producing large drops at the tip of the leaves. For tall trees, many of these drops will have uninterrupted falls of many metres, gathering considerable energy on the way and hitting the soil with considerable impact (Moss and Green 1990).

Where the rain goes

Once rainwater has reached the earth's surface it moves in a number of different directions (Fig. 2.1a). Water that remains on the vegetation evaporates. The amount of rainfall which is intercepted and returned to the atmosphere in this way is determined by the surface area of branches and leaves (DCE 1984). In the densely vegetated jarrah forest as much as 28% of rainfall can be intercepted and returned to the atmosphere (DCE 1984), while in the thinner wheatbelt woodlands the amount is about one tenth of this (Nulsen 1992). Rainfall reaching the ground is soaked up by mulch, soaks into the soil or runs across the surface. In natural areas of the south-west virtually all the rainfall that reaches the ground soaks into the soil, with runoff only occurring during intense rainfall events when water cannot infiltrate into the ground fast enough (DCE 1984; WAWRC 1986). Generally, as annual rainfall increases a greater proportion of the rainfall contributes directly to runoff (George et al. 1995; Sadler et al. 1988).

In cleared areas of the south-west, where soils have been compacted by rainfall, livestock and farm machinery, an increased proportion of rainfall contributes to runoff (Schofield 1990) (Fig. 2.1b). Generally speaking, rainfall produces more runoff in cleared areas than in neighbouring naturally vegetated areas. In the south-west, the increase in runoff caused by the clearing of forest and woodlands and their replacement by pastures and annual crops is generally between two and four times (Schofield 1990; Ritson et al. 1995; Muirden unpub. data).

2.2 Surface and Groundwater Movement

2.2.1 Water movement in natural areas

Once rain water reaches the ground it either soaks into the soil or runs across the soil surface. In naturally vegetated areas of forest, woodland and heath, nearly all of the water infiltrates straight into the soil. Only in very high rainfall events when the water cannot penetrate the soil quick enough does water move over the surface (DCE 1984; WAWRC 1986). It is this effect on a large scale that generates flooding. Even then much of the surface runoff will be gathered in depressions or by tiny dams built by washed up leaf litter, to form pools which will slowly soak away. Only a small amount of the water that falls upon naturally vegetated catchments ever reaches creeks by direct runoff (Fig. 2.2a) (DCE 1984).

Nearly all of the rainfall which reaches the ground enters what is known as the unsaturated zone (see Fig. 2.2). This is the zone of the soil between the earth's surface and the watertable. The watertable marks the surface of the saturated zone, where all the space between soil particles is filled with water (DCE 1984). In the Darling Range and on the Yilgarn Plateau proper the saturated zone overlies impervious bedrock.

FOREST, HEATH AND SEDGELAND OF THE DEEP RIVER CATCHMENT NEAR THE WELD RIVER.
PHOTO: J. ALFORD

AN URBAN CATCHMENT OF THE CANNING RIVER, IN THE CITY OF GOSNELLS. THE TWO LAKES ARE IN MARY CARROLL PARK. PHOTO: L. PEN

A rural catchment in the Shire of Manjimup. Photo: S. Neville - Ecotones

The unsaturated zone is where most of the action takes place. Here water is either taken up by plants which eventually return it to the atmosphere via evapotranspiration, or moves laterally slowly downslope to eventually seep into surface streams or lakes or slowly downward to the saturated zone (Fig. 2.2a)[1]. In high rainfall areas of the Darling Range, the water of the saturated zone typically discharges to streams in deep valleys, the base of which is bedrock. A small amount of water also evaporates directly from the upper parts of the soil profile. However, most of the water which enters the unsaturated zone is consumed by plants. In fact, in the wheatbelt, where average annual rainfall is less than 500 mm, about 99% of rainfall was once intercepted and consumed by the indigenous woodland, mallee and heath plant communities (George et al. 1995). In natural catchments very little water escapes the unsaturated zone to flow either to creeks, rivers or lakes or to the saturated groundwater zone. Indeed, some of the water which reaches the streams can actually re-enter the groundwater by percolating through the stream bed (Fig. 2.2a).

Some of the water which does make it to creeks, rivers and lakes will be consumed by fringing vegetation, although some recent research suggests that fringing plant species in certain circumstances make little use of this water (Thorburn et al. 1992, 1994).

In contrast, the large trees, shrubs and mallees of upland dry forest, woodland and mallee communities send their root systems as far down as 40 metres to tap the deep groundwater of the saturated zone and to exploit fully the soil water of the unsaturated zone (DCE 1984; Schofield 1990) (see Fig. 2.2a).

2.2.2 Water movement in cleared agricultural areas

Where the soil has been compacted by rainfall, livestock and vehicles, a greater proportion of rainfall moves from the land as surface runoff (Fig. 2.2b) (DCE 1984; Schofield 1990). Nevertheless, most still enters the unsaturated zone. However, much less is consumed by agricultural plants, especially pastures and annual crops, and therefore more water is left to evaporate from near the soil surface or move through the soil to streams and lakes or to the saturated groundwater zone. As a result, streams carry more water today, relative to rainfall[2], than they did in the past and watertables are rising (Fig 2.2b) (Schofield 1990). The latter effect is compounded by the enormous loss of deep rooted perennial plants which once consumed vast quantities of the soil water and some deep groundwater (Fig. 2.2a).

The broad impact of rising groundwaters and salinisation on the environment is beyond the scope this book, but it should be noted that agricultural clearing is not the only cause. Clearing of native perennial vegetation also occurs for other reasons,

[1] The movement of water in the unsaturated zone depends on the material that comprises the subsoil. For example, duplex soils (e.g. shallow sand over clay) will force water to move in particular ways because of the difference in hydraulic conductivity. Macropores, which form where plant roots rot away, may give the dense clayey soil profile an uncharacteristically high conductivity.

[2] The decline in rainfall over recent years (see Chapters 1, 7 and 10) by 10-20% has reduced river flow by about one third in natural areas in the south-west and would have reduced the increase in river flow brought about by greater runoff and lateral soil water flow in cleared areas.

such as sand and gravel quarrying, residential development and road building. There is also clearing for open-cut mining and clear felling for wood production, but in these cases clearing is often only temporary and groundwater rise is mostly carefully managed (DCE 1984). Poorly executed irrigation is another cause of land salinisation (White 1997). (See Chapter 7 for the impact of rising groundwaters and salinisation on river ecosystems.)

2.2.3 Water movement in urban areas

A large proportion of the land surface of urban areas is rendered impermeable and smooth by roads, parking lots, pathways and buildings. This has the effect of increasing both the volume and speed of runoff, far above that of cleared rural areas (Rhoads 1995). In other words, in an urban catchment for a given rainfall event, there is much more water moving off the land surface than in an equivalent size rural area, and it is moving faster. Furthermore, for a given volume of water, the faster runoff means that peak discharge is greater in the urban area than in rural areas, because the movement of the same amount of water in the urban catchment is compressed into a shorter period of time. To prevent flooding in urban areas, artificial drainage systems are essential. For this reason urban drainage systems are generally constructed to move water quickly and to be large enough to contain the very high peak flows. Compared with rural catchments, the lag time between rainfall and the resultant runoff is very short and even small rainfall events which would produce no runoff in rural areas, can produce considerable flows in urban areas. Thus drainage density, the length of drainage line (including road gutters) per unit area, is much greater in urban than in rural areas (Rutherfurd and Ducatel 1994). Interestingly, runoff from the heaviest of storms is about the same for urban as cleared rural catchments, because the saturated soil conditions that quickly result from the heavy rainfall render the land surface as impenetrable as the impervious land surfaces of urban areas (Rutherfurd and Ducatel 1994).

2.2.4 Surface flow and soil erosion

The actual flow of water over the land surface can take one of two forms. Usually it starts out as a uniform sheet of water which is seldom more than a few millimetres deep (Troeh et al. 1980), but soon becomes channellised to form minor streams along both ill defined and well defined drainage lines. These drainage lines may form small temporary pools or eventually join to form larger streams which are part of a much larger drainage system.

Water flow velocity

Water basically flows under the force of gravity. It either spreads out over a flat surface or runs down a slope. The greater the slope the greater the acceleration. The longer the slope the greater velocity the water will have, until a terminal velocity is achieved as a result of friction with the land surface. A slope may be straight, in which case acceleration is uniform along its length; it may be convex, with water starting out slowly but gaining velocity as it moves downhill; or conversely, the slope may be concave with decreasing acceleration of the water as it moves downhill (Fig. 2.3 a & b). The shape of the contour lines on a hill slope is also important. Convex contours, as you would see with water running down from the top of an inverted bowl, cause the water to diverge (Fig. 2.3c), whereas concave contours, as you would see with water running from the rim to the bottom of the inside of a bowl (Fig. 2.3d), cause it to converge, resulting in the concentration of water and therefore an increase in depth.

In channellised flow, depth in addition to slope is an important factor in determining the velocity of the water (Marsh and Dozier 1981). This is because the channel bed has a large frictional effect, slowing the water and dissipating its energy as heat or as work in the erosion and transport of sediment. In effect the water drags on the channel bottom and carries some of the bottom sediment along with it. Water away from the stream bed is less affected by it and therefore is free to flow faster. A view of the water column in cross section shows that flow velocity increases with distance from the stream bed (Fig. 2.3e). Therefore, as stream depth increases and a smaller proportion of the water is actually in contact with the bed, the overall average flow rate increases. The water just below the surface of the deepest part of the stream moves the fastest of all (Fig. 2.3e). At the water surface, the frictional effect of the air slows the water very slightly (Fig. 2.3e) (Marsh and Dozier 1981).

Often the river bed supports vegetation which is many times rougher than the bed itself. Aquatic and fringing vegetation are very significant elements in the natural channel in slowing the movement of water (Thorne 1990).

The river reach

A section of streamline along which the kinetic energy of the flowing water more or less remains constant is known as a *reach.* Here the flowing water is established in an equilibrium between the forces of acceleration and friction and there is no increase in the volume of water (Marsh and Dozier 1981). A reach would appear as a section of streamline of more or less uniform slope and channel roughness between tributaries.

The action of flowing water

Just as falling raindrops have kinetic energy, so does water as it moves across the land surface. Therefore it can do work. It can detach and lift soil particles, hold them in suspension or at least cause them to jump or tumble (a process called saltation) and carry or push them along. The more kinetic energy water has, that is the faster it flows, the larger and heavier the particles it can detach and carry. If the flow of water becomes turbulent, as for example through the action of falling raindrops on shallow sheet flow, its kinetic energy is increased dramatically and so is its erosive capacity (Troeh et al. 1980). Furthermore, the particles moving around in the water generally have greater density than the water itself, and thus they impart greater energy to the muddy fluid, making the fluid more abrasive and heavier, and therefore more erosive, than clean water (Troeh et al. 1980).

In naturally vegetated areas of the south-west, where surface flow of water is very limited and much of the soil is protected by vegetation, soil erosion and therefore sediment transport is probably insignificant. However, in cleared agricultural areas

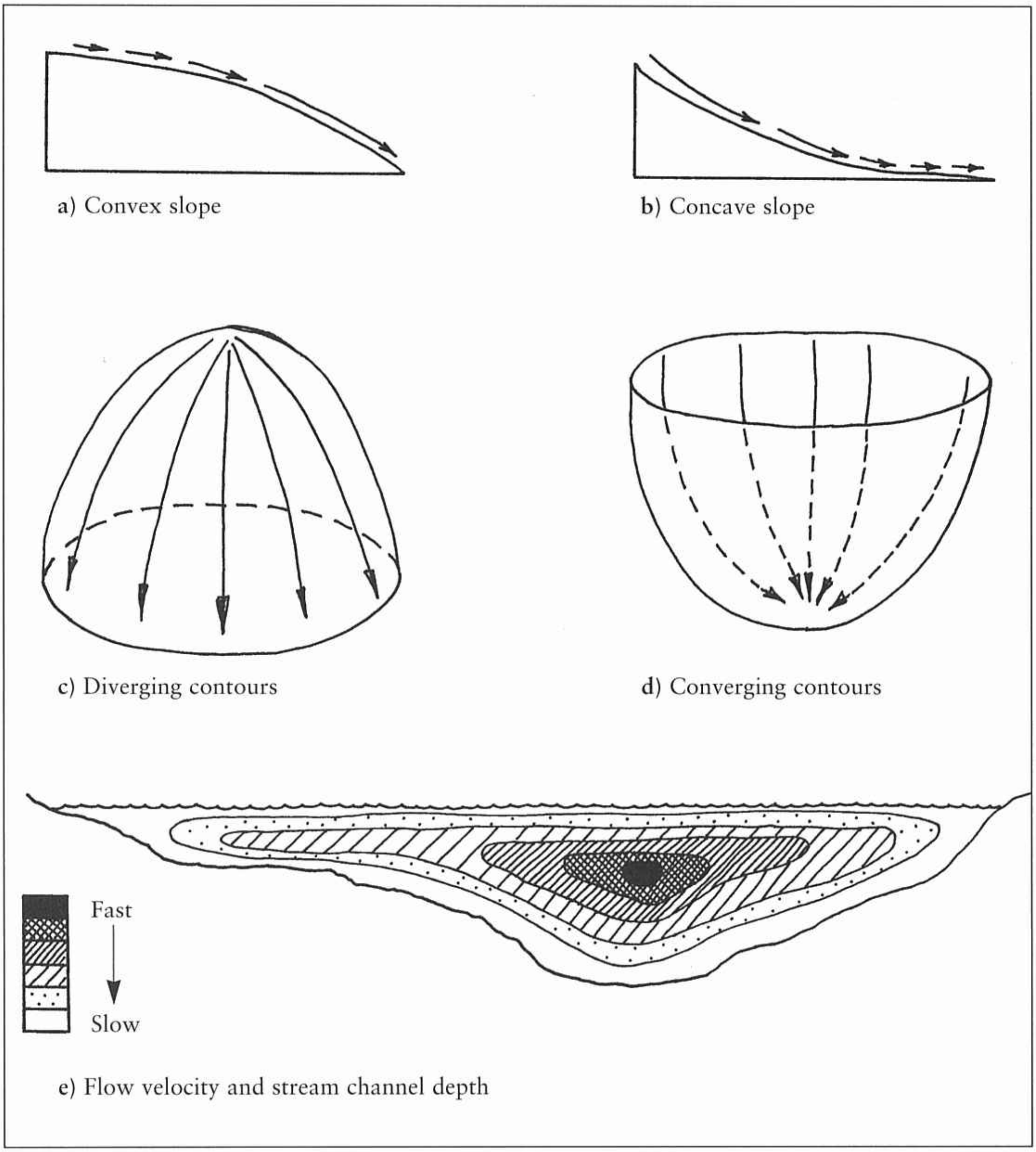


Figure 2.3 The relationships between flow velocity and slope form for (a) convex and (b) concave slopes, for (c) diverging (hill) contours and (d) converging (valley) contours and for (e) stream channel depth (nb. the longer the arrows the faster the flow)

where surface flow is much greater and the soil far more exposed, especially at the end of summer, soil erosion can be considerable (White 1997; SCEP 1991). The turbulent movement of abrasive muddy water over exposed soil can quickly break up soil aggregates and clods and put them into motion. Generally the lighter or smaller the particles the further they are carried (Marsh and Dozier 1981). In this way the soils of our agricultural lands are slowly being sifted of their finer fractions with only the coarse fractions remaining on the farmlands (Troeh et al. 1980). It is the finer fractions that contain most of the nutrients and organic matter needed for highly productive soils.

The nature of the material of the stream bed itself also has a great effect on the work that flowing water can do. For example, silts and clay particles are cohesive and are held in the stream bed principally by molecular attraction, requiring a relatively large amount of energy to detach individual particles. However, once dislodged, their tiny size means that they are easily carried in suspension. In contrast, larger sands and gravels which are held in the stream bed by gravity alone, while being relatively easy to detach, require more energy to transport.

Dissipation of the energy of flowing water

The energy of flowing water is dissipated in a number of ways. Firstly, as explained above, the channel bed itself imparts a large resistance to the flow of water. And when water does work in the channel by eroding and carrying sediment it loses some of its energy and slows down (Marsh and Dozier 1981). Similarly energy is lost when the water is slowed because of increased friction due to aquatic vegetation, or when it is forced to spread out over a large relatively flat area, such as a wide channel or floodplain where the water is in greater contact with the ground. A constriction or barrier may also slow upstream flow. The damming up of water by washed up leaf litter or a log jam along a river, are examples of the latter form of energy dissipation. When this occurs, water loses some of its capacity to erode and to carry sediment, with the result that the coarser fractions, previously held in suspension, will settle out. If the energy of flowing water is not dissipated in some way, gravity ensures that as the water accelerates downstream it gains increasing power to erode and carry sediment.

Vegetation, probably more than any other factor, plays an important role in dissipating the energy of flowing water, especially along creeks and rivers (Thorne 1991). It imparts greater roughness along streamlines, slowing the water and holding it up. In this way vegetation protects the land from erosion and filters out sediment. On floodplains, where floodwaters come to a near halt, even the fine clay and silt fractions have an opportunity to settle out. Unfortunately, the fringing vegetation of streamlines and their floodplains has been lost or thinned in most agricultural catchments, enhancing the capacity for flowing water not only to carry sediment from the farmlands but also to erode exposed beds and banks of creeks and rivers, often leading to severe sedimentation of downstream waterways (Frankenberg 1992).

Incision

The downward cutting action of the stream on the land is called *incision*. The rate of incision is determined by the cohesive strength or the size of the sediment of the stream bed and the amount of energy the stream brings to bear upon it. Where a stream has little energy through flowing along a slight slope or where the stream bed is very cohesive (e.g. clay), incision is very slow. Similarly, where most of the stream's energy is dissipated by vegetation or in the transport of sediment, incision is slow or does not occur. Where a stream bed is covered with sediment too large to be eroded quickly, the stream bed is said to be armoured. But incision can be dramatic on soft sandy channel beds during high flow periods. Interestingly, where incision cuts a deep channel the steep banks often collapse and contribute sediment which armours the bed. For a while net incision of the channel will cease, until the sediment is transported downstream.

Stream power

Stream power is the capacity of a flow of water to do work, to dislodge, lift and carry material. It is also referred to as tractive force. The factors that go into determining stream power are many and interact in complex ways. For the purposes of this book the main factors are slope and depth of flow. Slope has great bearing on the speed at which water moves, and the faster water is moving and the deeper it is, the greater is its stream power.

2.3 Stream form

When rainfall gathers on the land surface and begins to move downslope, it initially flows as a thin sheet. However, flow soon becomes concentrated into streams of faster moving water. This occurs where converging sheet flow creates deep water and where flow naturally moves along paths or lines of least resistance. Channels form along these lines as the stream erodes the ground beneath it. Channellised drainage lines intercept one another and combine successively to form a system of stream channels which grow fewer in number but larger in width and depth as the water progresses downstream and the system gathers more and more water. As drainage lines are low points in the landscape they also receive water via seepage along their banks from the lateral flow of soil water. While groundwater seepage generates the low base flows of creeks and rivers, it is the surface runoff flows, generated by high rainfall events, that excavate and maintain stream channels.

The physical forces which act on the movement of water in channels determine the form of drainage systems. These forces are as much in play on tiny streams as they are on the largest rivers.

2.3.1 Channel width and depth

The width and depth of a channel along a particular reach is determined by the amount of water that flows in an average regular flood, known as the channel forming flow, when heavy rains fall in the catchment and direct runoff is significant (Marsh and Dozier 1981). In south-west

Australia this mostly occurs in mid-winter when the soils are very wet from earlier rains in the season[3]. For most of the time however stream flows are small and in many cases there may be no flow at all for months or even years.

The channel forming flow can be recognised because it fills or more than fills the channel from bank to bank. On average this occurs once every one to two years (Leopold et al. 1964; Leopold 1995; Newbury 1995). The size of this bankfull flow (also known as bankfull flood or discharge), and hence the channel, increases downstream as the river system gathers more and more water via its tributaries from an increasing catchment area. Generally, the width of the channel increases more than the depth as the bankfull flow or channel forming flow increases in magnitude (Leopold et al. 1964; Leopold 1995; Newbury 1995).

2.3.2 Meandering

Water does not flow in a straight line, but rather flows in a wave form. This is due to the water being bent up as it drags on the channel bed and banks. (The effect can be likened to the gathering up of a piece of paper ribbon, standing on one edge, as it is pushed from one end upon a table surface.) Consequently, natural streamlines are seldom straight and for the most part meander across the land. On average the length of a single meander turn is six times the bankfull width of the channel, with a full meander of two bends being twelve times the bankfull width (Fig. 2.4) (Leopold et al. 1964; Leopold 1995). Furthermore, the average radius of curvature of a meander bend is 2.3 times the bankfull width. This is the most energy efficient form of the stream. (Think of this like a stroll through a forest and the path you would take to walk around a tree. You would not wait until you were right up against the tree before you moved around it and you would not begin to walk around it when you first saw the tree, tens of metres away. Also, you would not take a detour that added unnecessarily to the distance you would need to travel. At some point the most energy efficient, or least effort, course would present itself and you would deviate from your straight line course. The least effort course through a forest is a meandering one and one where the meander wave length and amplitude is just right.)[4]

One interesting effect of meandering is that the speed of water increases as it passes around the outside of a bend and decreases on the inside (think of the wheels of a car going around a corner). Erosion occurs at the outside and slightly downstream of the meander bend, while deposition of sediment occurs on the inside, forming what is known as a point bar (see Fig. 2.4) (Newbury 1995). For this reason, the outside of the channel bend usually runs along a steep bank or even a cliff, while the inside of the channel runs along the low lying land formed by the point bar (Fig. 2.4).

[3] An exception to this is the rare occurrence of heavy cyclonic rain during summer. Cyclone Errol caused many rivers to flood throughout the south-west in January 1982 and the exceptional flood levels it produced are often marked at bridges. Look out for them when you are next out and about in the lower south-west.

[4] The analogy can be stretched a little further by considering the desire of the bushwalker to walk at a more or less constant rate and thus minimise unnecessary high effort 'bursts' of energy or the need for rapid changes in course.

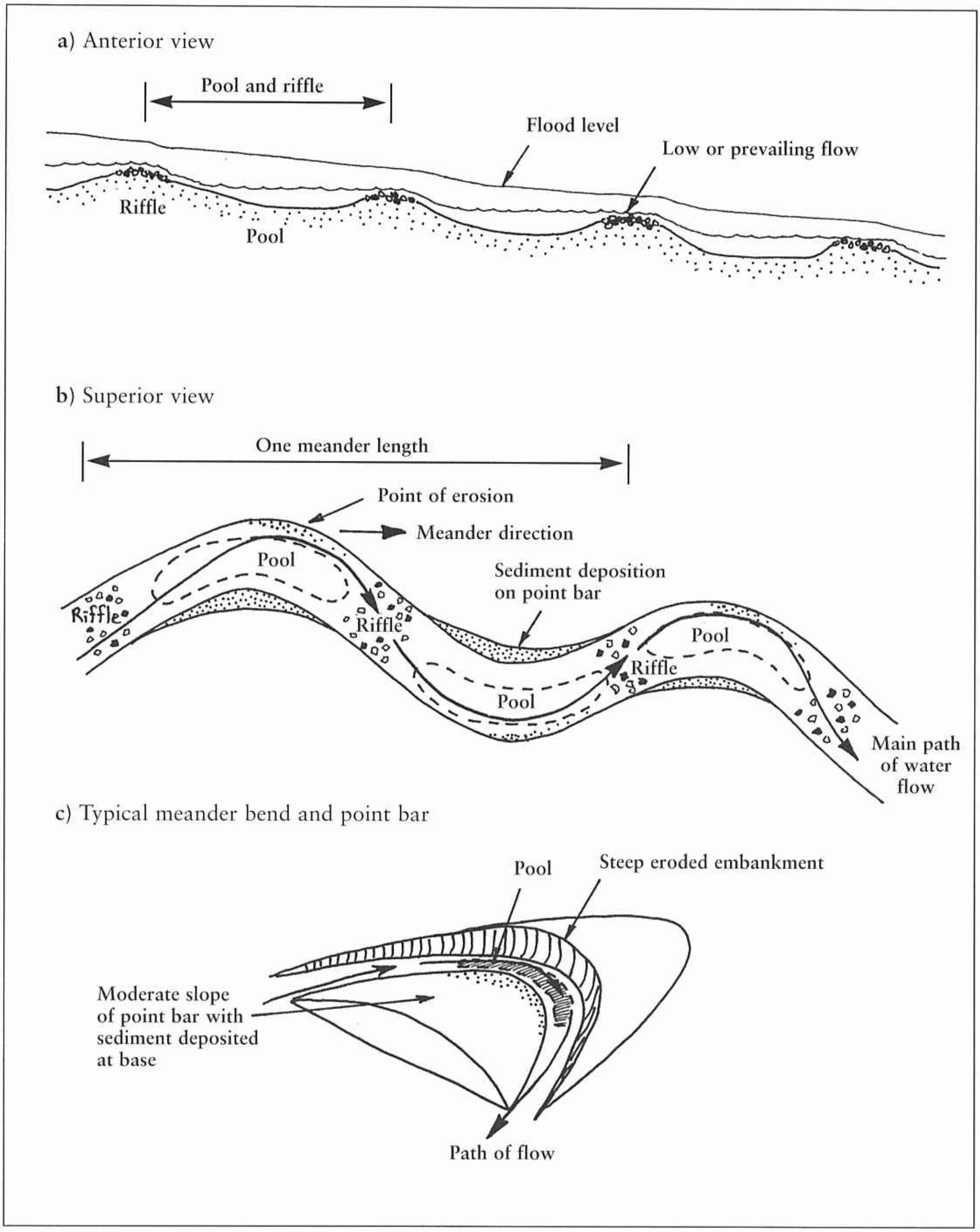


Figure 2.4 Stream channel form: (a and b) pool and riffles and (b and c) meanders and point bars

A second interesting effect of meandering is to increase the length of the stream between two points, thus reducing channel slope and increasing bed area. The result is reduced acceleration due to slope and increased stream bed friction, both of which reduce the velocity and hence kinetic energy of the flowing water. Consequently, water flowing in a meandering channel has a reduced capacity to erode and carry sediment compared to that flowing in the straight channel. Therefore, a meandering channel is more stable and less likely to be eroded than is a straight one between the same two points (Marsh and Dozier 1981).

2.3.3 Pools and riffles

Just as water undulates from side to side it also undulates up and down, forming a stream bed which has alternating deep and shallow zones, known as pools and riffles[5]. Some scientists believe that these zones are formed as a result of the movement of water as it passes round a meander bend (Newbury 1995). As water moves through a bend, centrifugal forces cause it to sweep to the outside edge (think of the lean of a car as it goes around a corner), causing a build-up of water towards the surface of the outside of the bend which displaces the water beneath it. This displaced lower water is forced to move towards the inside of the bend as it moves downstream. The overall effect is that water moves in a spiral form, like a corkscrew, around the bend. Between the bends, where the flow of water straightens up again before the next turn, are shallow areas known as riffles. Because of pool/riffle form, stream beds do not have a constant slope as would be found along a freshly constructed drain, but rather a step form, where water flows from one pool to another as shown in Figure 2.4.

This is one reason why most of the rivers in south-western Australia have large deep pools which retain water over the summer and autumn when river flow is reduced to a trickle or ceases altogether and most of the river channel is dry. During low to moderate flow periods between floods, water appears to flow from one pool to another in a step fashion as each pool overflows into the next pool downstream. At this time, not all the water that can be seen in the channel is actually flowing. Most is impounded within the pools. If not for these pools the river bed would hold much less water and there would be far less habitat for aquatic animals. When the stream channel is in flood, all the water that can be seen is actually flowing, and it is at this time that the deep pools are scoured of sediment that has built up in them during low and moderate flow periods (see Section 2.3.6) (Marsh and Dozier 1981).

As mentioned above, at times of low to moderate flows water is moving only on the riffles, causing them to be scoured of fine sediment which settles out in the pool downstream. In times of flood when water is moving throughout the system, stream power is actually greatest over the pools where the water is deepest. For this reason anything like a decent size rock or log that is washed off a riffle is quickly swept through the pool onto the next riffle where stream power is less than over the pool. Fine sediment which collected in the pools during times of low flow is carried far

[5] Note that a riffle is also the name given to a zone of flowing water where the water surface is uneven due to rocks on the stream bed, but where these rocks do not break the surface.

downstream and swept up onto the point bars.

Studies elsewhere in the world have shown that the length of a single pool riffle sequence is, on average, six times the bankfull width of the stream (Leopold et al. 1964; Gregory et al. 1994; Newbury 1995). A full meander, with two complete riffles (one half at each end and a full riffle in the middle) and two pools, is on average twelve times the width of the channel (Fig. 2.4).

Note that classic pool/riffle form only occurs in streams where channel bed particles are pebble size or larger (Church 1992). Sandy bed creeks and rivers tend to be braided and mainly form pools at constrictions in the river valley, due to scouring by accelerated flow. Pools may also form where dolerite dykes[6] cross rivers creating a riffle/pool sequence for reasons yet to be clearly understood.

2.3.4 Step pools

Along the channels of many upland creeks of the Darling Range, the roots of trees cross the channel and provide for 'steps' which mimic on a small scale the pool/riffle effect seen on larger creeks and rivers (Church 1992; Growns and Davis 1994).

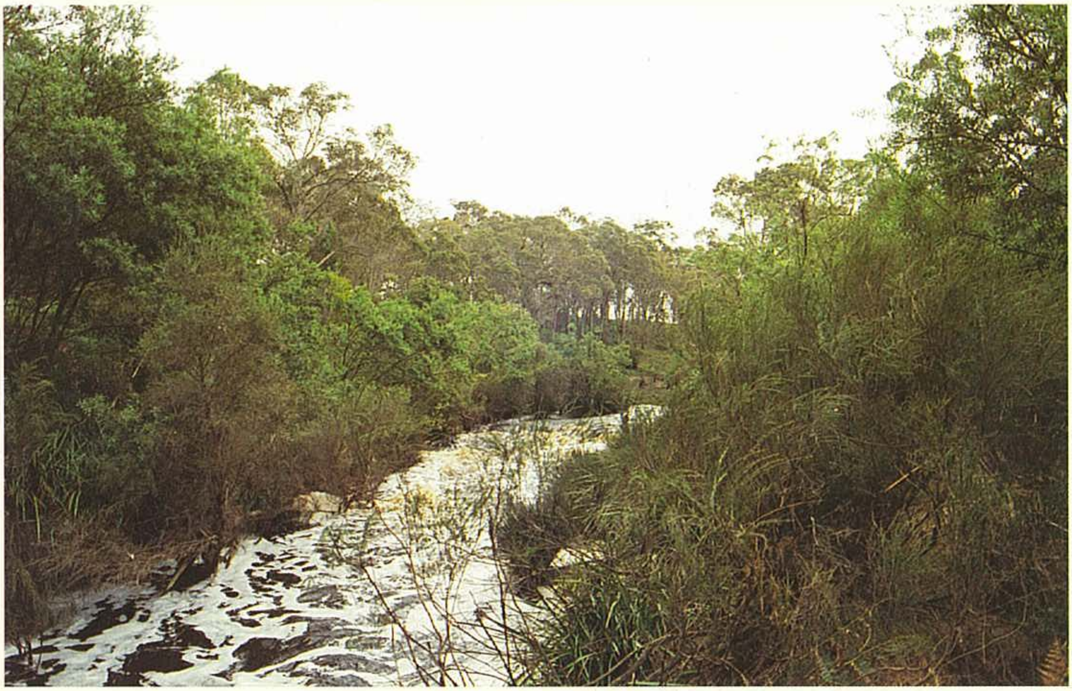
2.3.5 Low flow channel

During moderate to low flows the water in the pools will appear quite still and the water in the riffle zone is often confined to a narrow channel winding from one pool to another. This second stage channel contained within the main channel or floodway of the river is typical of many rivers in south-western Australia. It is formed by the longer lived low to moderate, groundwater fed flows which occur between floods (Myers and Lynes 1994). This second stage channel is often known as the low flow channel, main channel or active channel, and it will also carry water when the flow is reduced to a trickle. The last term applies where the low flow channel mostly does not support vegetation and is actively eroding and transporting sediment, if only slightly. The broad river channel, when well supported by protective fringing vegetation, may be considered inactive.

2.3.6 Changing form: erosion and deposition

The stream channel is a dynamic system; it is constantly changing its form through erosion at certain points and deposition at others (Marsh and Dozier 1981; Dept. Water Resources 1993). In the most stable of rivers, erosion and deposition are virtually limited to meander bends and point bars, respectively. With erosion at the outside and slightly downstream of the meander bend and deposition on the inside and slightly upstream of the bend, each meander is slowly moving laterally downstream (Dept. Water Resources 1993). Thus the wave form of the stream slowly progresses downstream; where the channel once 'zigged' it will eventually 'zag', and so on. Where a stream is well protected by vegetation, changes in channel form may be hardly detectable in hundreds of years, but where vegetation is sparser or has been removed the channel may undergo dramatic change in only a short time.

[6] A dolerite dyke is a long narrow sheet of igneous rock that cuts discordantly through the land. Often the rock is less erosive than the surrounding land through which it cuts.



A well vegetated channel of the lower Kalgan River. The vegetation has been buffeted by recent flood flows. Photo: L. Pen

A meander bend on the middle Kalgan River. Photo: S. Janicke

A river pool on the Collie River South Branch near the hamlet of Collie-Cardiff. Photo: L. Pen

The low flow channel of the Collie River South Branch in the vicinity of 'Hunter's Bridge'.
Photo: S. Janicke

The stream channel will also change form slightly between short periods of low to moderate flow and floods. During low flows, sediment will tend to be stripped from the riffle zones where water is flowing quite rapidly and deposited in the pools where the water is comparatively still. In contrast, during floods the pools are well scoured and sediment is thrown up onto the riffle zones (Marsh and Dozier 1984).

With long term changes in flow magnitude, changes to channel form will be more pronounced. For example, between the 1910s and 1980s, the south-west has experienced a major reduction in rainfall of the order of 20%. This resulted in much lower river discharges in most natural areas, of about 45% for rivers near Perth (Schofield 1990). This means that sediment would have accumulated in most stream channels, reducing their depth and width. In effect, with less water and hence energy the stream channels have contracted in size (Rutherfurd and Ducatel 1994). With a return to average rainfalls or greater, this accumulated sediment will be scoured from the streams and the channels will deepen and widen (Rutherfurd and Ducatel 1994). Clearing and hardening a catchment can also increase discharge significantly, causing dramatic deepening and widening of channels, far in excess of what would occur naturally. This is why severe gullying along minor drainage lines is often seen on farmland and in urban areas.

Erosion and sedimentation in urban areas

Erosion and sedimentation go through two phases in urban areas. In the initial construction phase, vegetation is cleared and the ground is disturbed as buildings and infrastructure are established (Thorne 1990; James 1995; Urbanas and Benik 1995). In this stage the land surface is highly exposed to erosion, with the effect that large quantities of sediment are delivered to streams in surface runoff. Because runoff rates have yet to increase dramatically, sediment collects in the streams and is often colonised by weeds. Accumulated sediment may reduce channel capacity and perhaps cause flooding.

In the post-construction phase the catchment has been rendered relatively hard, smooth and impervious. In this condition catchment erosion is low, but runoff is high. High energy flows can cause channel incision and widening and even channel shift, as the channel grows and alters its meander radius to accommodate the much larger channel forming flows of the urbanised catchment (Leopold 1995; James 1995). This process can be sudden and dramatic and involve damage to drainage infrastructure and adjacent property, especially if protective fringing vegetation has been removed (Rutherfurd and Ducatel 1994; Leopold 1995). After a number of years, sediment which accumulated in the stream during the construction phase may be entirely flushed downstream, and with the decline in new sediment from the consolidated urban catchment, bank and bed erosion may become an ongoing problem (Wolman 1967).

2.3.7 Floodplains, terraces, billabongs and double channels

Floodplains are broad flat low lying areas adjacent to rivers. They are not formed initially by floods, as the name would suggest, but rather by the accumulation of sediment on point bars and the slow lateral movement of the river channel away from the areas of accumulation. Floodplains are so called because they help to contain and to some extent carry floodwaters during major floods when rivers burst their banks and the floodwaters spill over onto the land. By holding water for a time and slowly releasing it to the river channel, floodplains stretch out the flood over time and thereby reduce peak flows. In so doing, floodplains reduce the amount of water the river channel must carry during the height of the flood, and hence the amount of energy it must bear during major flood events. Floodplains can be looked upon as a form of protection against channel incision and widening. Furthermore, because water only moves slowly across floodplains, very fine sediment, which would otherwise be in suspension in the more rapidly flowing water of the channel, is deposited on the plains and thus removed from the floodwaters. In this way floodplains may build up in time through the accumulation of sediment, often creating rich red loamy soils.

A terrace is an old floodplain which is no longer or very seldom inundated by river floods. Terraces form as a result of slow downward movement of the river bed as it cuts deeper into the land over many thousands or millions of years, leaving old floodplains stranded above typical flood levels.

A billabong is an old river pool which has been cut off from the main channel of the river. This occurs where the meandering of the river is highly convoluted and a meander bend progresses downstream faster than the one below it, cutting through to the channel below the next downstream meander. Because this short cut has a greater slope than the old channel, it represents the more energetic route and takes most of the water. As the old section of channel no longer carries much water, it becomes filled with sediment and its pool isolated. True billabongs are uncommon in the south-west, suggesting that river channel change has occurred only very slowly in this region. Some old billabongs remain near the end of the Preston River's natural course near Bunbury. Sometimes secondary channels in braided rivers like the Avon become disused and form long pools which are referred to by local people as billabongs. Backwaters would probably be a more accurate term.

Sometimes rivers in the south-west have two channels for short distances. Usually one channel is dominant, carrying water for most of the time when there is flow, with the second channel only flowing during floods. It is difficult to explain why two channels should form, but one reason may be that vegetation in the main channel slows the water down, causing it to build up upstream and to overflow across the top of a point bar where the more upland vegetation is sparser or across higher ground to a tributary. The process of forming a 'break-out channel' is called an *avulsion* and the resultant channel is known as an anabranche or distributory. Whatever is the cause of an avulsion, during periods of high flow, the secondary channel apparently

A section of the lower Waychinicup River showing the alternating sequence of pools and rocky riffles.
Photo: S. Neville - Ecotones

A small floodplain on the middle Warren River. Photo: L. Pen

A view of the lower Kalgan River, at the site of the Water and Rivers Commission gauging weir. Here the Kalgan River has formed a 'classic' river valley. Photo: L. Pen becomes another efficient route for the water to take, and in some cases a more efficient route. Mostly, double channels occur for only short distances and generally lie close together. However, sometimes they may cover long distances. A good example is the Young River near the Stirling Ranges. Minor double channels may also form as second stage channels within the broader major channel.

2.3.8 Braided streams, levees, bars and deltas

In highly eroding catchments, river systems will carry large quantities of sediment. These will be seen as many small heaps or large plumes of sediment on point bars, behind obstructions or amongst vegetation; as sand bars on the edge of pools; or as levees along the edges of floodplains where floodwaters first slow down and deposition is heaviest. Where the sediment load is not particularly large it will be moved downstream quite efficiently, mostly from point bar to point bar, without compromising the general form of the stream channel. However, if the amount of sediment is excessive it will begin to clog the channel, filling river pools and covering the riffle zones until the stream appears as a long plume of sand known as a slug. In this situation the stream often becomes braided into a series of channels weaving from one to the other through the sand; the stream channel will be seriously compromised and the behaviour of the stream will change dramatically, possibly causing serious erosion of the bank or upstream flooding. Today the Palinup and Moore Rivers are examples of south-west rivers whose lower to middle reaches carry large sediment loads (Olsen and Skitmore 1991; Select Committee on Land Conservation 1990).

When the water of a river or creek enters a lake, estuary or ocean inlet or bay, the water slows abruptly and most of the sediment is deposited, forming islands, spits and bars known as deltas. Deltas mark the end of the creek or river system, although in the wheatbelt some lakes will occasionally overflow into downstream river systems. Heirisson Island on the Swan Estuary marks the end of the Swan-Avon river system. It is not a natural island, but was made from the dredged material of the original deltaic islands, bars, mudflats and salt-marshes.

Bars, levees and deltas provide opportunities for colonisation by vegetation which may in time stabilise them, forming permanent islands and levees. These in turn may affect the behaviour of the water within the channel, leading to further channel alterations to accommodate the new form. Before it was trained the Avon River had a heavily forested braided form. A short section about 300 metres long, between the Balladong Bridge and railway bridge at York, retains its original form.

2.3.9 Waterfalls, cascades, rapids, riffles and runs

Waterfalls are found where water is in free fall or near free fall on a very steep slope. They often form where the flow of water passes from hard ground to relatively soft ground, the softer downstream land eroding away more quickly. In the south-west most waterfalls are found along the Darling Scarp where streams drop from the plateau to the sandy coastal plain, although one of the most spectacular examples, Fernhook Falls, is in the lower south-west on the Deep River.

Seldom, however, do south-west waterfalls actually have one or two true long falls, as in the case of the Mitchell Falls on the Mitchell River in the northern Kimberley. Mostly they are simply the combination of many small short falls and the fast flow of water over steeply sloping rock. They would better be described as steep cascades (Church 1992), where the water falls or flows quickly and with much turbulence over a series of rocky steps along a steep or moderate slope. Gooralong Brook, a scarp tributary of the Serpentine, has a good example of a series of drops, which includes both vertical drops and steep cascades. The Cascades picnic site on the Lefroy Brook near Pemberton is another example. Rapids differ from cascades in that the water is seldom ever in free fall or near free fall, but rather flows rapidly over and between rocks so that the water surface is boiling and broken into froth. Where water flows rapidly over boulders or pebbles and the water surface is uneven but not broken, the stream zone is called a riffle (Church 1992). This is because, in the northern hemisphere where this term comes from, riffle zones between the pools often have flow which resembles this form. Finally, a run or glide is where the flow of water is swift but the water surface is more or less even.

Waterfalls, cascades, rapids and riffles have two very important functions. Firstly, they help to oxygenate the water column. Turbulent flow, often with broken water, increases the surface area of the water in contact with the air which increases the aeration and hence oxygenation of the water, essential for aquatic life. In the south-west this is all the more important because, for reasons outlined in Chapter 3, there are few other opportunities in the natural river ecosystem to oxygenate water. The second function is the creation of sound: the babbling of brooks and the roaring of rapids. Normally the flow of water makes no sound; only when it is accelerated suddenly by an abrupt increase in slope or through having to flow over an obstruction, is noise produced (Newbury 1995). It occurs because of the breaking of bubbles of air which are entrained in the water during initial acceleration. For aquatic animals this noise is important, as it enables some species to find their preferred habitats. For example, in North America it is known that trout find their way to feeding and breeding habitats by moving towards the sound of breaking bubbles (Newbury 1995).

2.3.10 The river valley and riparian zone

The river channel lies within a valley which the stream has dug over many thousands of years. Here we are not talking about the broad valley of the catchment such as the Avon River valley or the Blackwood valley which have been eroded by countless drainage lines over millions of years, but rather the immediate valley of the river which is usually characterised by the presence of wetland plant species such as flooded gums, paperbarks and sedges and rushes. Figure 2.5 illustrates the typical cross sectional form of the river valley and the terms used to describe it.

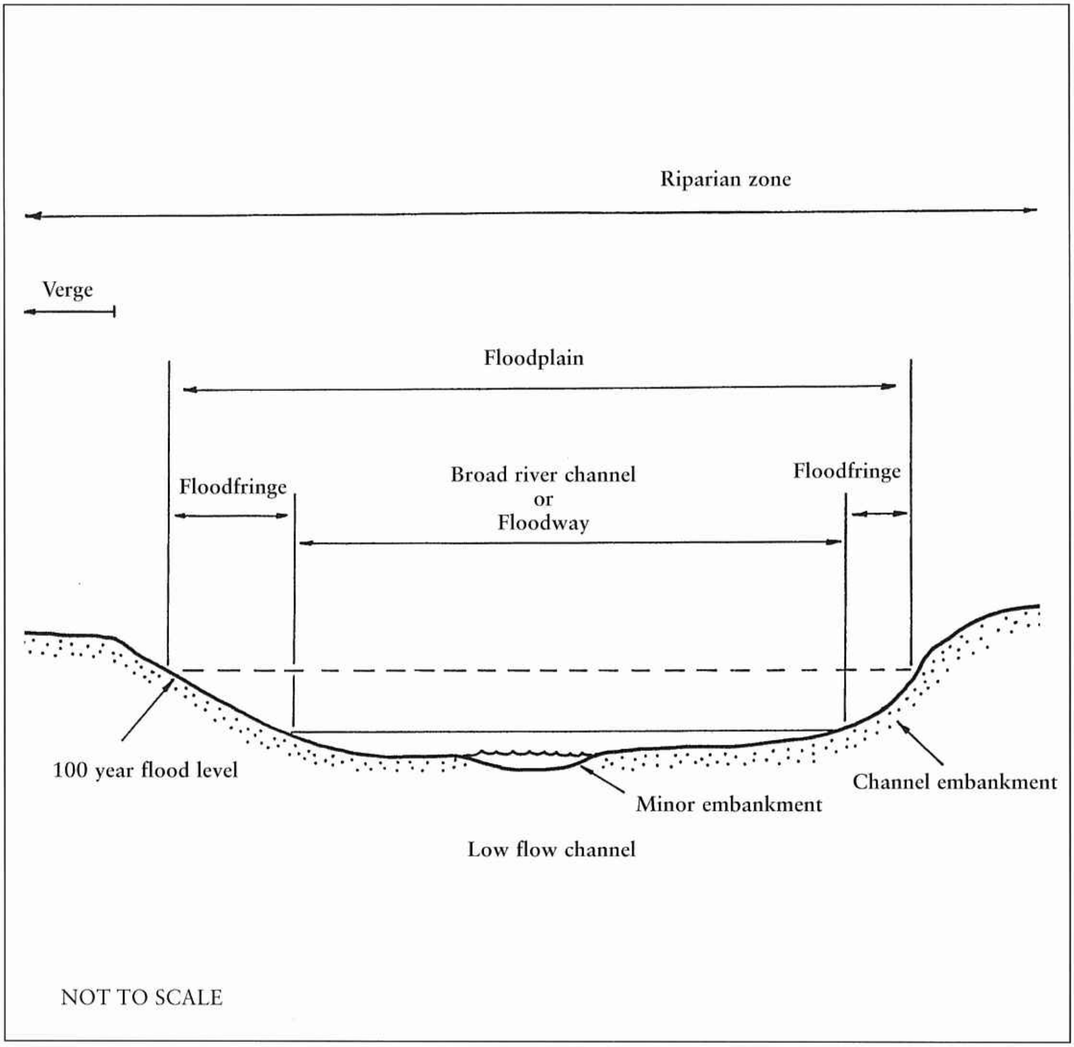


FIGURE 2.5 TYPICAL RIVER VALLEY FORM AND THE RIPARIAN ZONE

In cross section, the river valley consists of a number of zones: the valley embankments, the broad floodplain[7], the broad river channel, also appropriately known in Western Australia as the floodway, and perhaps a central, main or low flow channel. The floodway may be in the form of a riffle (see Fig. 3.2) or a pool (see Fig. 3.2). The actual shape of the valley can vary considerably depending on its location in the landscape. In the Darling Range river valleys are narrow and V-shaped with a small floodplain. In these situations floods are vertical in nature, with water rising to great depths in the narrow river valley. On the other hand, river valleys on coastal plains are relatively shallow with moderate embankments and occasional floodplains (see Fig. 3.2). And at the very extreme, some rivers, such as the Coblinine and the Gordon in very flat areas of the wheatbelt, appear to be all floodplain with no identifiable valley embankments or even floodway.

Another useful zone to recognise, at least for the management of river systems, is the verge. The verge is an area of upland of indefinite width above the crest of the valley embankment on either side of the river (see Fig. 2.5). While this zone is not actually of the river valley itself, it may nonetheless have great influence upon it (see Chapters 3 and 4).

For river management, the entire river valley and the verge areas on either side are known collectively as the riparian zone (see Fig. 2.5). For ecological considerations the verge would not necessarily be included.

2.3.11 Drainage or branching patterns and stream order

In south-western Western Australia most river systems have what is called a dentritic pattern (Marsh and Dozier 1981); where most branches have between two and three tributary branches, with the overall branching form of the stream system resembling that of a gum tree. Figure 2.6 illustrates the branching pattern of the Gardner River on the south coast near Northcliffe. Minor order streams which have no tributaries are called first order streams. Where two or more first order streams come together they form a second order stream; two or more second order streams combine into a third order stream, and so on (see Fig. 2.6) until the branches combine into a single trunk which discharges into a lake, inlet or the ocean, perhaps as a high fifth or sixth order stream.

In headwaters of coastal river systems of the Darling Range the steps of the pool riffle sequence are small and closely spaced within a narrow channel. But further downstream, as the streams combine and drainage area and discharge increase, the steps grow longer and the pools and riffles widen and deepen in a broader channel. Finally, in the lower reaches where all the water of all the tributary branches has gathered, the river is widest and meanders lazily across low gradient broad valleys or coastal plains.

[7] Note that the term broad floodplain, defined and mentioned only in this section, refers to the broad area that is inundated during major floods, which includes the river channel, and is not to be confused with floodplain, as a geomorphic unit or habitat type adjacent to the river channel. The term is introduced here to distinguish floodplain as considered by flood managers.

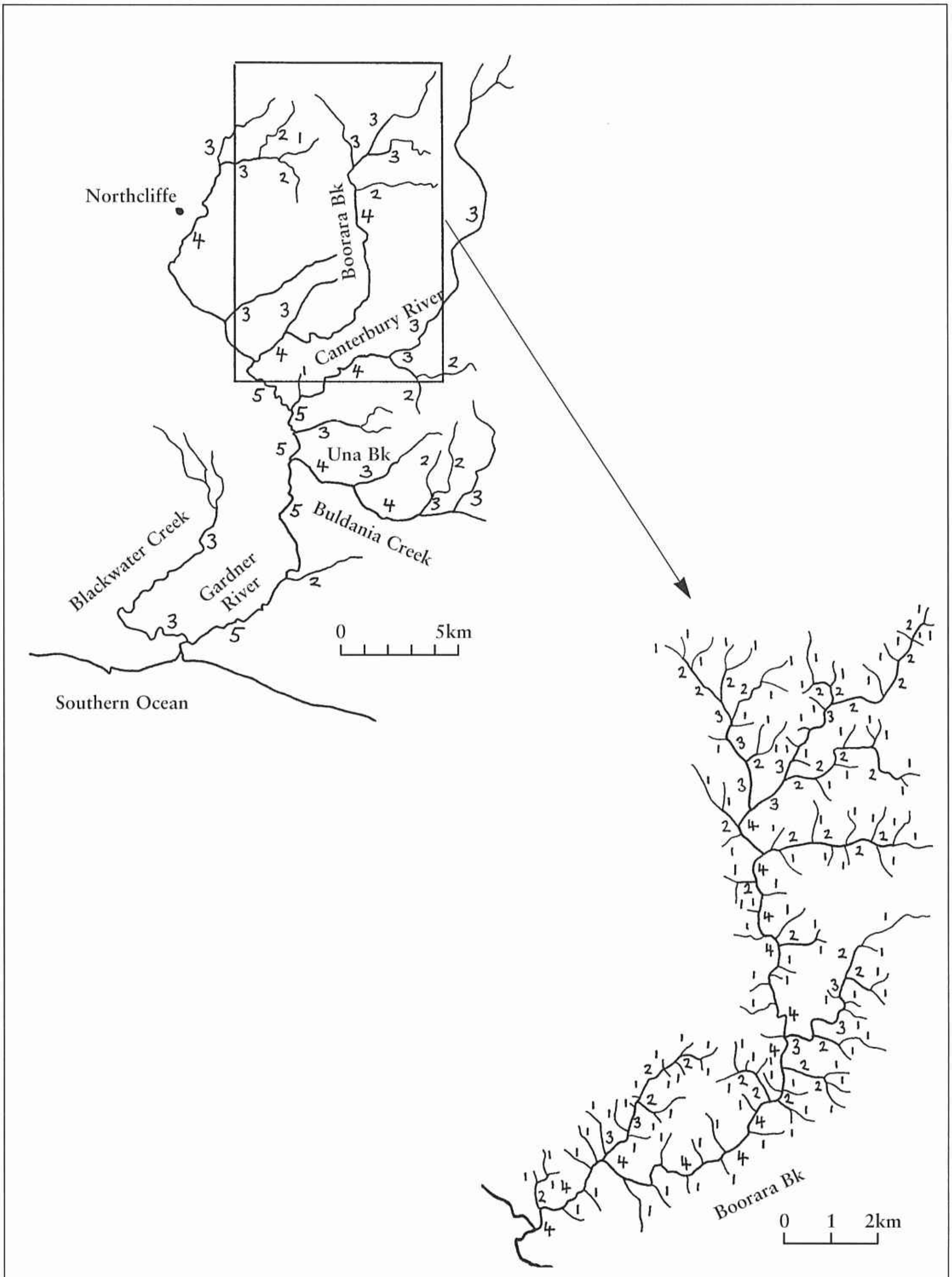


FIGURE 2.6 STREAM SYSTEM BRANCHING PATTERN AND STREAM ORDER

2.3.12 Complications of climate, terrain and vegetation

Having read the above sections the reader could be excused for thinking that stream channels in the south-west will typically have a form which fits the textbook description. But in fact this is rarely the case. If a stream was to have a consistent flow pattern and flow along a uniform slope and over ground with a uniform particle size and weight, then in time it would build a perfect channel which appears to obey all the rules. But natural environments are much more complicated, with great variations in rainfall, catchment discharge, slope, ground cohesiveness and sediment size, weight and quantity, produced by changing weather pattern, land form and land use over both space and time (Church 1992). As a result, natural stream channels represent an 'average' of changing conditions. Scientists have come to understand channel form, as governed by catchment discharge, through the study of natural systems and through experimentation using laboratory models of stream systems (Leopold et al. 1964; Leopold 1995)[8].

Channel form is further complicated by vegetation, especially in areas with periods of aridity. Because south-western Australia has very long dry summers, channels tend not to be inundated with water for much if not most of the year, so vegetation which is tolerant of periodic inundation has colonised river channels in most areas.

The presence of vegetation in river channels is a hugely complicating factor. Vegetation supports the bed and banks and acts to dissipate the energy of flowing water, thereby reducing erosion and increasing sediment deposition. Furthermore, by causing water to back up, it often increases depth with the effect that water can flood adjacent land and flow over higher ground where there may be less obstruction to flow. While the function of vegetation in the stream channel is relatively well understood, and is discussed in Chapter 4, just what is its contribution to overall stream form, other than to further complicate it, is a subject which is only now being investigated (Thorne 1990; Gregory 1992; Masterson and Thorne 1992).

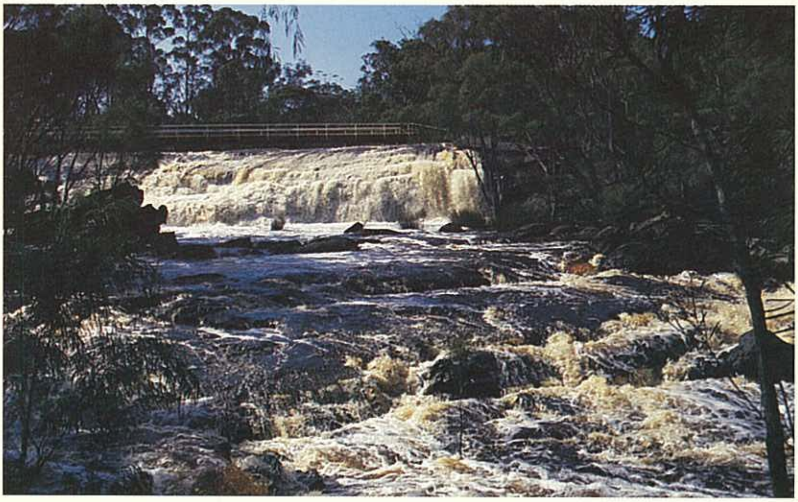
2.3.13 Sediment: the currency of rivers

A river reach is said to be in equilibrium when erosion and sedimentation are in balance. This is reflected by the stable form of the channel. Essentially a balance is struck between the stream's capacity to erode its bed and banks and transport material out of the reach, and the resistance to erosion and transport of new material being washed into the reach (James 1995). As the net movement of sediment is downstream, outgoing sediment must be equalled by incoming sediment from the catchment and from the gradual incision into the landscape of the stream system over time. Some streams may be rich in sediment and others may be poor, but in either case they can still be in equilibrium

[8] One of the greatest of these scientists is the American engineer, Luna B. Leopold. The author recommends his book *A View of the River* for a 'simplified' understanding of the physical nature of rivers.

A SECTION OF THE UPPER BLACKWOOD RIVER EXHIBITING A SOMEWHAT ERODED, BUT STILL BRAIDED CHANNEL FORM.
PHOTO: L. PEN

SMALL RAPID ON THE SOUTHERN BRANCH OF THE MARGARET RIVER. NOTE THE OXYGENATION OF THE WATER AND THE GREEN COLOURATION OF NATURAL ALGAE GROWTH IN THE OPEN CONDITIONS.
PHOTO: L. PEN



FERNHOOK FALLS ON THE LOWER DEEP RIVER.
PHOTO: L. PEN

Wild branching pattern exhibited by rivers in the south-eastern part of the Pilbara region.
Photo: L. Pen

A bankfull flow on Spencer's Brook, a tributary of the Avon River, in the winter of 1996.
Photo: L. Pen

Floodwaters on a floodplain of the middle Moore River during the March 1999 floods that inundated the Town of Moora upstream from this point.
Photo: L. Pen

providing outgoing sediment equals incoming. The stream system can be thrown into disequilibrium when the supply of sediment from the catchment increases, which often occurs with changing land use such as when land is cleared or undergoes urban development (Leopold 1995). Conversely a channel may be starved of sediment, for example when a catchment is effectively sealed through urban development or when sediment is excavated from the channel. In this case the consequences involve channel incision and subsequent widening through bank collapse, mostly where the channel is not well protected by vegetation (Rutherfurd and Ducatel 1994).

2.4 Flooding

2.4.1 What is flooding?

Flooding occurs when a catchment delivers more water to a stream channel system than it can contain. Ordinarily a stream channel system has a great capacity to store water and this capacity generally increases downstream at a greater rate than catchment area (Leopold 1995). For this reason flooding generally declines as the flood pulse moves downstream and more and more of the river valley is available to contain the floodwaters[9].

Flooding generally occurs following unusually heavy rainfall. In the low rainfall wheatbelt region, flooding often occurs from surface runoff following intense summer rainfall of cyclonic origin (WAWRC 1986). This was the cause of flooding on many rivers in the south-west in January 1982 (Bretnall pers. comm.). On the other hand, flooding in high rainfall, typically forested catchments usually only occurs in winter following heavy rainfall on catchments that are already wet from preceding rainfall (WAWRC 1986).

2.4.2 Flooding and floodplains

Floodplains are very important in controlling the power of floods. They provide an area in which to contain floodwaters for a time and thus to draw out the period over which the water moves off the land, reducing peak discharge and peak stream power. In V-shaped river valleys, flooding causes the water depth to rise and rise, and thereby increases stream power. But where floodplains occur, floodwaters can rise only slightly above the active channel and floodway before spreading out over the land. This prevents stream power from rising to a level that could cause serious channel incision and bank erosion. It is important to note that floodplains are often formed by the meandering of rivers themselves and that this means that rivers have an intrinsic capacity to dampen the destructive power of floodwaters over time[10]. We should learn from this and protect floodplains wherever possible.

[9] Some scientists believe the Avon River training program has been effective in reducing flooding, simply because of the increased storage capacity that was brought about by one to two metres of channel incision, an intended consequence of removing the vegetation and ripping the bed (Jim Davies and Ass. 1997).

[10] There is an important exception to this and it is the very broad floodplains of the wheatbelt, which have largely been formed from the filling of ancient deep river valleys with sediment over many millions of years (see Chapter 1).

Often floodplains which are used for farming or urban development are leveed off, raising water level over the channel, and hence stream power, in times of flood.

2.4.3 Flooding and changing catchments

While heavy rainfall is the main cause of flooding, human activities can increase the frequency of flooding by changing the behaviour of catchments. Catchment clearing can increase runoff rates by two to four times that of natural catchments (DCE 1984), and urbanisation by many times greater than this (Rutherfurd and Ducatel 1994). Rising groundwaters will increase the proportion of catchments wetted-up in winter, with a consequent increase in runoff. The result is that rainfall events which once represented no flood risk may in certain catchments, now or in the future, generate problematic flooding. As an example, Watts Creek in the State of Maryland, USA, exhibited nineteen flood flows between 1958 and 1967, when urbanisation in the catchment was not significant, compared with seventy-three between 1978 and 1987, when urbanisation covered much of the catchment (Leopold 1995).

2.4.4 Flood forecasting

On the basis of long term stream flow and rainfall monitoring records, the frequency of floods of various magnitudes can be forecast. Generally the key flood level frequency is that which is only exceeded once in every hundred years on average.

The accuracy of these forecasts depends on the length of record and the degree to which the catchment involved has changed. With catchment clearing, rising groundwaters, drainage, damming and urbanisation the long term record becomes less and less a reflection of the hydrological nature of the present catchment. All this must be taken into account when assessing the risk of flooding and the damage and heartache involved.

case study

2.5 A comparison of forested and cleared catchments

Catchments in south-west Western Australia have been altered dramatically by the clearing of perennial vegetation and its replacement by annual pastures and crops. To illustrate the impact of this change on the behaviour of river systems, two hypothetical catchments will be compared. Their contrasting behaviours are illustrated in Figure 2.7.

These catchments are sub-catchments of a single river system, one naturally vegetated with forest and one cleared for pasture and cropping.

It is late autumn and the winter season is broken by a powerful frontal system sweeping up from the south-west. The first front is only moderate in intensity and drops only a small amount of rain but the second front is strong and drops a large amount of rain.

Forested catchment and the moderate front

Some of the rain is intercepted by the foliage of the vegetation and lost quite quickly from the catchment through evaporation. Still most of the rain either misses the foliage, drips from the leaves or runs down the stems of the plants to reach the ground. Some of it is soaked up in leaf litter or evaporates and the rest percolates into the soft soil where it begins its slow journey towards the groundwater or downhill towards the nearest stream line. But before it can do so, the vegetation, with its deep root systems and thirsty from a long hot dry summer, takes up all of the water and none reaches the groundwater or dry creek beds.

Cleared catchment and the moderate front

Here most of the pastures and annual crops have all but withered away over the long summer and soil has been compacted and roughed up by the trampling of livestock. Thus nearly all of the rainfall hits the ground, delivering a punch of kinetic energy which further breaks up soil aggregates and compacts the soil. The compacted and non-wetting nature of the soil at the beginning of winter causes the

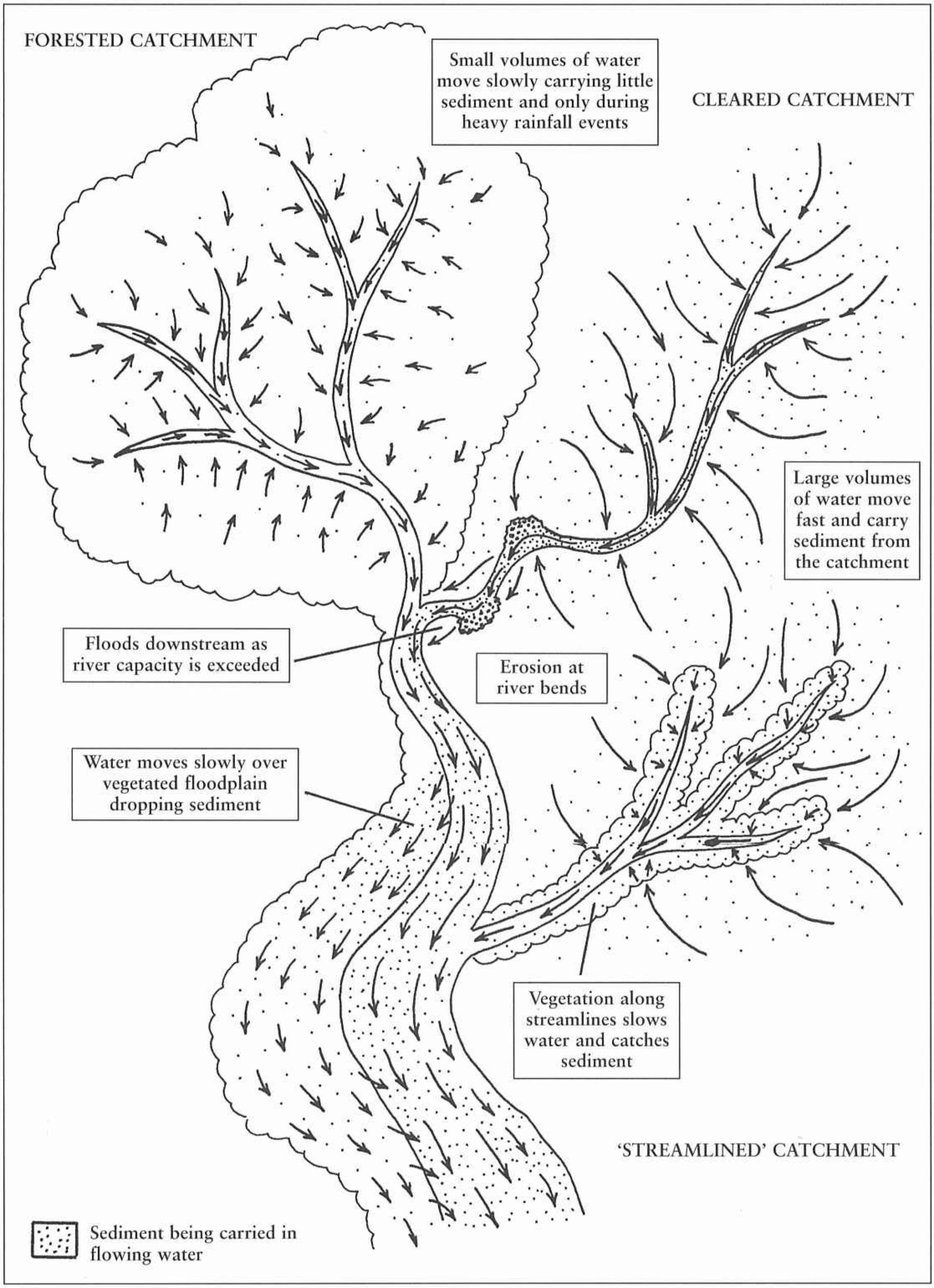


FIGURE 2.7 Comparison of surface water flow on a forested catchment, cleared agricultural catchment and the 'streamlined' catchment (nb. the longer the arrows the faster the flow)

water to lie on the ground for a time, where some evaporates and much begins to flow overland carrying fine soil particles with it. But since the rainfall was only moderate little makes it to the creeks and there is only a cloudy trickle of flow along the creeklines for a short time. Some water gathers in natural sinks, such as depressions, wetlands, dams and soft soils, to evaporate or soak away during the ensuing dry weather. So, as with the forested catchment, most of the water soaks slowly into the ground, but since there is virtually no live vegetation nearly all of this soil water will eventually reach the creeklines or the groundwater, which through years of recharge is close to the surface.

Forested catchment and the strong front

Heavy prolonged showers fall on the catchment. The foliage is quickly soaked with water but only a small proportion of the rain is intercepted and held on the leaves and branches. Although a large volume of water reaches the ground, the foliage continues to absorb much of the kinetic energy of the falling raindrops and the ground is well protected. The soft soils of the forest have a considerable capacity for infiltration of the rainwater, but such is the intensity of rainfall the water cannot soak into the ground fast enough and begins to form pools which slowly drain away. Even so this is only a small proportion of the water which fell, with most of the water still penetrating the ground. Too much water enters the soil to be taken up by the vegetation and so some will eventually discharge to the groundwater or seep laterally into creeklines.

Much of the water that does run off is dammed up by thousands of tiny damlets formed by leaf litter or accumulates in thousands of small depressions, to be held up long enough for the water to soak away once the heavy rains have finished. A small amount of the runoff reaches minor drainage lines, but because they support dense aquatic vegetation the water is once again held up and prevented from flowing quickly downstream. After a number of days the slow drawn-out movement of the water along the creeklines discharges into the main channel of the river, which likewise is densely vegetated. The river will begin to flow, but only slightly. It will only flow strongly after a number of heavy rainfall events have soaked the catchment and seepage is widespread and more or less constant.

The presence of vegetation along the entire route of the surface flowing water dissipates its energy, reducing erosion and promoting the deposition of what small amount of sediment is in transport. The result is that the water leaving the catchment is filtered of its sediment and is very clean, although it may be darkly stained with the tannins which have leached out of the hard dead leaves deposited in the stream beds by the native vegetation.

Cleared catchment and the strong front

The rain falls heavily on the cleared farmland for days. The powerful large fast-falling raindrops pummel the soil, breaking up the soil aggregates further and causing soil particles to fly high in the air. Even though the previous rains dampened the catchment and reduced non-wetting, the soil remains compacted. After some hours the infiltration rate of the soil is exceeded in some areas and water begins to accumulate in shallow pools and then to drain away.

The initial sheet flow is made turbulent by raindrops which increases the capacity of the sheet flow to pick up and carry soil particles. The muddy water soon forms into channels which further erode the soil and carry heavy abrasive water to the exposed creeks. With little vegetation to slow the water the denuded creeks are quickly swollen with rushing muddy water which erodes the banks at meander bends and scours sediment which had accumulated in the channels.

From all over the catchment swollen and bursting minor creeks discharge their loads of muddy water into the river. Because more water has been discharged from the catchment in a shorter period of time than would have occurred under natural conditions, the floodwaters often exceed the natural capacity of the channels. This causes the river to burst its banks in some sections and to dig a larger channel in others, especially where livestock have denuded the bed and banks of their protective vegetation. With further erosion of the banks and scouring of the bed the floodwaters pick up even more sediment. In some downstream sections, where dense riparian vegetation has been protected, the floodwaters are caught up, slowing the water for a time and causing flooding of adjacent land and heavy siltation of the channel and the floodplain. After this the floodwaters proceed downstream, ultimately to discharge their muddy loads into the estuary and the ocean.

Sediment is not all that the river carries. Large amounts of salt, dead plant material, recently applied fertiliser and manure are flushed from the catchment. Soil particles washed from the paddocks are rich in nutrients, and some may be contaminated with pesticides. All of these materials that are washed into the river and estuary place a huge burden on the natural ecosystem's ability to break down the organic material, assimilate the nutrients and tolerate (or not) the rising salt levels and toxic chemicals. Ultimately this burden will become overwhelming.

But this is less than half the story. Much of the water still enters the ground and as there has been little time for pastures and crops to grow, little is taken up by plants. Some water will evaporate in the coming days of dry weather. Most of the water moves slowly towards creeks or to the groundwater where it makes a major contribution to groundwater rise. This in time will bring salt to the land surface and ultimately cause salinisation and contribute to waterlogging over large areas.

The landcare catchment

In the lower part of the river system, a landcare group in a small sub-catchment is leading the way in achieving a hydrological balance by controlling drainage and groundwater recharge. Greater use is made of perennial pastures, fodder crops, minimum tillage, contour cultivation and contour banks. Remnant vegetation has been protected and every available space has been planted to native trees and shrubs and some paddocks or strips of land have been given over to wood and oil crops (e.g. blue gums and oil mallees). To reduce groundwater recharge strategic areas have been planted with deep rooted trees and shrubs. All of the minor drainage lines have been strengthened with perennial pasture or fodder crops and where necessary have been managed or simply fenced-off to protect both planted and native vegetation over the harsh summer period when grazing pressure is greatest. Finally, broad well vegetated and fenced-off riparian zones have been created along the lower reaches of the main creek and along the adjoining part of the river to protect the major drainage lines from erosion.

In this catchment, much of the rain is intercepted by vegetation and the soil is better protected from the impact of raindrops. The softer soils increase infiltration and the perennial vegetation is present to make instant use of the winter-breaking rainfall, and thus reduce groundwater recharge. New and remnant native vegetation is also present to tap the deep groundwater.

Although runoff is greater and swifter in this catchment than the naturally vegetated one, it is slowed significantly by the perennial vegetation of the paddocks and the drainage lines. Consequently, less soil and other material is carried from the paddocks and a greater proportion of it is deposited amongst vegetative buffer strips and the vegetated drainage lines. While slowing the water on the paddocks causes some minor short term local flooding in times of very high rainfall, the slow release of water from the wider catchment reduces the severity of flooding downstream and the damage it can cause to the river and adjoining land. Overall the landcare group has created a catchment which draws out the water of high rainfall events and dissipates its energy, to both reduce erosion and control serious flooding. It also has sufficient vegetation to drink that portion of rainfall which entered the ground.

The quality of water flowing from this catchment does not compare with that from the forested one. It still contains quantities of sediment, organic material and nutrients, sufficient to degrade natural habitats and render the water unsuitable for human domestic use. But it is of adequate quality to support livestock, the irrigation of crops, recreation and many if not most of the elements of the original aquatic ecosystem. In this case the river and its tributaries represent a sophisticated drainage system which can produce a renewable water resource. This sort of catchment is the south-west's future.

Chapter 2
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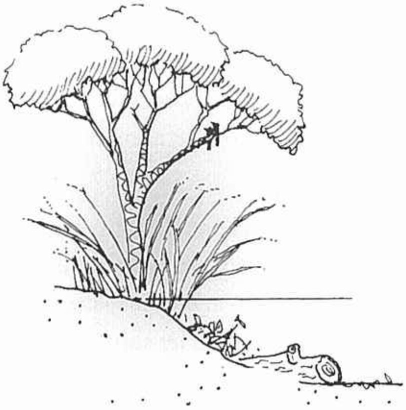
chapter 3

The stream ecosystem

- The annual cycle of drought and flood
- Habitats
- Ecosystem function
- The river continuum



Research into the fundamental ecology of south-west streams did not begin in earnest until the 1980s, when a number of postgraduate students began their studies. Over the years they revealed an ecology that reflected the highly seasonal, nutrient poor and biogeographically isolated environment of the south-west. This chapter explores that understanding in relation to the dramatic and extensive changes that have been wrought on the south-west by human development. Habitats and habitat elements are described and two underlying concepts integral to the science of stream ecology, namely the flood pulse and the river continuum, are introduced. Research into south-west streams continues and hopefully a few young people will be inspired by this chapter to carry on this work and contribute to the worldwide understanding of stream ecology.

3.1 THE ANNUAL CYCLE OF DROUGHT AND FLOOD

River systems in south-west Western Australia generally cease to flow over the long hot dry summer season, which may begin as early as October and finish as late as June. In the drier parts of the south-west, such as the wheatbelt, streams cease to flow altogether, while in the lower south-west, where rainfall is prolonged and evaporation is relatively low, rivers and even some minor streams may have moderate to minor flows in their lower reaches over summer. In the cooler karri forest region a few streams may retain a trickle of flow right along their main channels, but the general situation is one of decreasing flow and increasing dryness as the summer dry season progresses. Although flow is reduced or depleted, deep river pools retain water, providing an essential drought refuge for a wide variety of aquatic fauna. As a result, the general form of rivers in summer, shown in Figure 3.1a, is of a line of disconnected pools along an otherwise dry river bed becoming increasingly connected downstream by a trickle of flow as the rivers pass through higher rainfall country near the coast.

After the first significant rain of the winter season, which usually breaks between April and June, the tributary creeks begin to flow again, filling the low flow channels of the main river courses and connecting the river pools once again. By July the river systems of the south-west are swollen with water and the floodways and even parts of the floodplains may be inundated after a few days of very wet weather. Prolonged and widespread wet weather with heavy rainfall over a number of weeks can produce severe floods which drown the river valley and spill out on to floodplains and even on to the surrounding countryside (see Figure 3.1b).

This annual pattern of summer drought and winter flood is the basic context for south-west river ecosystems. All the plant and animal species that comprise these ecosystems are influenced by it and many are adapted to exploit episodes of drought and flood. The annual cycle not only creates difficulty, it also provides opportunity. Flooding creates a huge area of seasonal habitat ready to be exploited by highly mobile animal species, or plant and animal species which can lie dormant over the dry season to become active during the wet (see Section 5.2). Conversely, the drought enables fringing plant species, tolerant only of periodic inundation, to colonise the floodways of creeks and rivers (see Section 4.1). The populations of plants and animals which we now see in south-west rivers have been able to exploit, or at least tolerate, this environment of seasonal contrasts. They are a community of organisms, an ecosystem which is a biological expression of the annual cycle of drought and flood.

While the annual cycle of drought and flood is necessary to sustain south-west river ecosystems, extremes in either season may create severe hardship. The summer season is harsh enough and made more so by periods of prolonged drought, when winter flooding is weak and summers are long and dry. For example, in 1994 a relatively dry

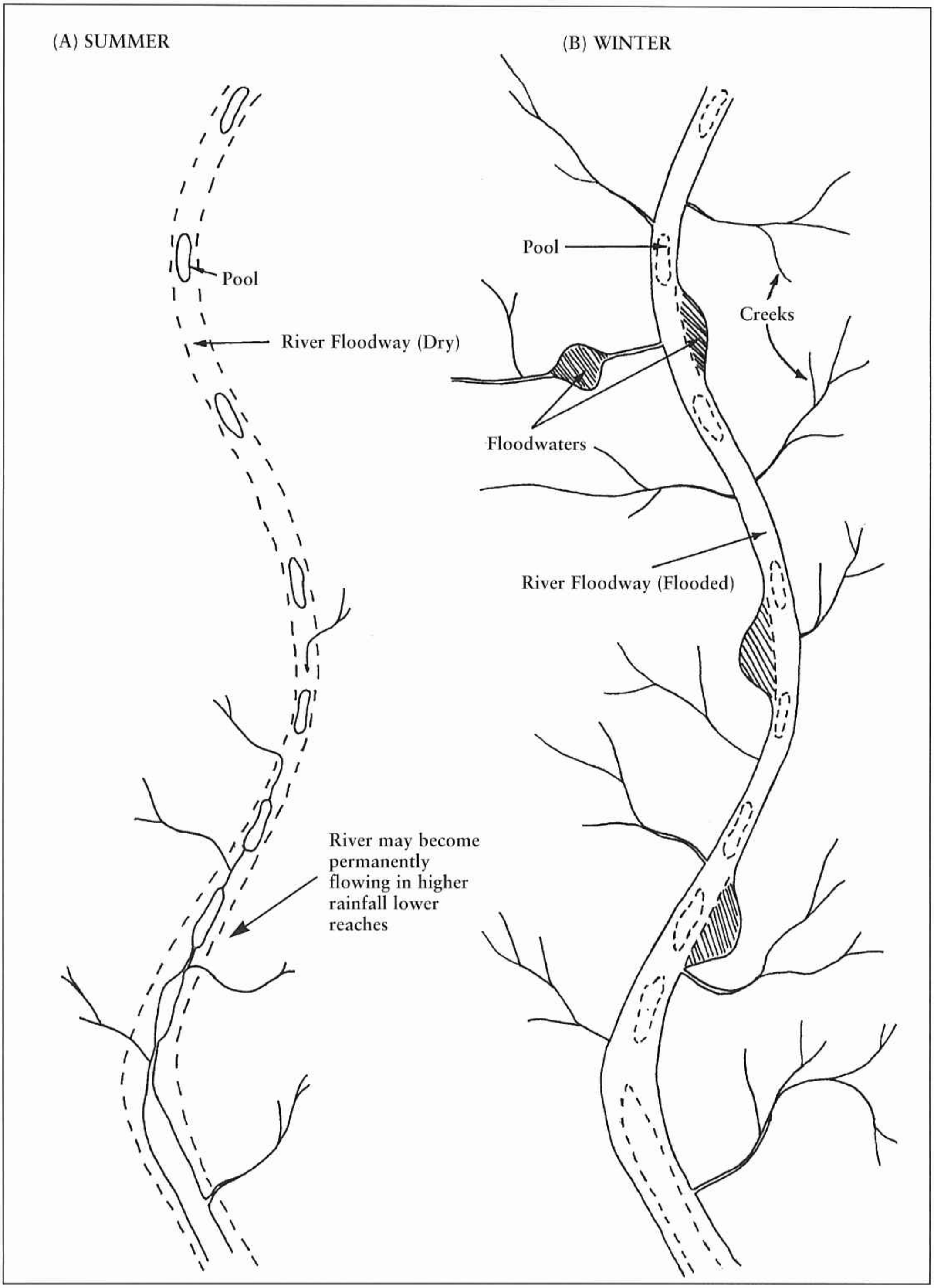


FIGURE 3.1 THE SEASONAL EXTREMES OF SOUTHWEST RIVERS: SUMMER DROUGHT VERSUS WINTER FLOOD

and warm winter was followed by a particularly long and dry summer, lasting nearly eight months. Local people living along the lower Blackwood River commented that they had never before seen the river cease flowing so low down. Near Pemberton, the recorded rainfall in that year was 200 mm below average and minor streams in the karri forest, which normally flowed all year long, were bone dry.

Severe droughts may last for a number of years and even for decades (Ruprecht et al. 1996). Average rainfall near Perth, for example, has declined by 10% since the mid-1970s, reducing stream flow in neighbouring rivers by about one third (Schofield 1990; Ruprecht et al. 1996). Droughts of this magnitude may reduce the extent of riparian habitat by drying out areas of the river valley, affecting the plant and animal populations which depend on the normally moist conditions. On the other hand, prolonged inundation during very wet winters, such as those which occurred in the mid-1940s and 1960s, may stress certain fringing plant species. Over a number of unusually wet years populations of certain plant species may retreat from near the wetter centre of the river, to the drier conditions further up the bank. Fish populations probably contract to the wetter parts of the south-west during prolonged periods of drought and expand in years of high rainfall.

3.2 HABITATS

What is meant by habitat?

The term habitat has meaning only with reference to an organism or to a community of organisms. It is practically impossible to fully describe any particular plant's or animal's habitat, as there are just too many relationships and the boundaries between supposed habitats become more blurred the closer one looks. Organisms experience habitats as a continuum with no real demarcation between zones or even seasons. But from our point of view, it is useful to think of a 'habitat' as a place and time in which a species or community is usually found.

With this definition in mind we can simply treat the more obvious zones within the river as discrete 'habitats' with clear boundaries. Some species, for example, make use of entire river systems while others have evolved to survive in conditions in a particular zone of the river, such as a river pool. At a more detailed level some species may be confined to a particular part of a river zone, such as the bed of a riffle, and maybe only where the sediment is of a certain size composition and organic matter content. Particular habitats may only be present at certain times of the year and some species may make use of different habitats at different times of the year.

THE COLLIE RIVER SOUTH BRANCH AT HUNTER'S BRIDGE IN THE SUMMER OF 1984/85. PHOTO: L.PEN

THE COLLIE RIVER SOUTH BRANCH AT HUNTER'S BRIDGE IN THE WINTER OF 1985. PHOTO: L.PEN

POOL ON THE KALGAN RIVER. A VITAL SUMMER DROUGHT REFUGE FOR AQUATIC FAUNA. NOTE THE NARROW BAND OF STABILISING VEGETATION ALONG THE POOL EDGES. PHOTO: L.PEN

CASCADES ON THE LEFROY BROOK DOWNSTREAM OF THE PEMBERTON WEIR. PHOTO: L.PEN

3.2.1 Broad habitat zones

The natural stream has a great diversity of habitat zones and refuges with differing combinations of light and shade, exposure and cover, flowing and still, and shallow and deep water (Katsantoni 1993). This variety of habitats which support a diverse array of plants and animals, is broadly related to natural stream form (see Section 2.3) and fluctuations in stream flow (Newbury and Gaboury 1993). Thus there are permanent pools, riffles and runs, seasonal floodwaters and areas of terrestrial fringing vegetation on the stream valley embankments. These habitat types are illustrated in Figure 3.2.

The overall river valley. The typical river valley is illustrated in Figure 2.5 and again with vegetation in Figure 3.2. Because much of the broad channel or floodway of the river dries out each year, the fringing plant species, which would otherwise be restricted to the lower river valley embankments, are able to colonise all areas of the floodway except those which are more or less permanently inundated or are often swept by powerful currents. Such areas include the pools and the low flow channels. On the embankments, above the floodway, the riverine fringing vegetation generally gives way to dryland vegetation which dominates the verges. Sometimes vegetation that grows well in wetter conditions can spread into the entire river valley below the verges, possibly because of groundwater seepage along the embankments or simply because the valley is especially moist and humid in some river sections.

River pools. River pools may be 50 to 500 metres long or more, 20 to 50 metres across and 3 to 9 metres deep. It is not uncommon for some small pools only a few tennis courts in area to be 5 to 7 metres deep (Pen unpub. data; Morrissy 1979). Undisturbed river pools are usually surrounded by dense fringing vegetation of paperbarks and sedges and are well shaded and provided with snags and woody debris along their perimeters (Fig. 3.2).

Over the summer season most of the water in the rivers is in these deep river pools, and so, not surprisingly, are most of the river animals, including waterbirds, turtles, water rats, fish, crayfish, shrimp and mussels, all holding out, waiting for winter. The pools provide an essential summer drought refuge, integral to the survival of many aquatic animal populations. However, they may be warm and contain very little dissolved oxygen and so may be harsh environments in summer during the day. Many of the aquatic animal species, especially the fish and crayfish, keep to the shade or stay in their burrows for most of day, venturing out to feed only when conditions are cooler, at night or at dawn and dusk.

Riffles, rapids and cascades. These habitats occur where water flows swiftly over an irregular stream bed, over and between rocks and from one rocky terrace to another, respectively. They are described in Section 2.3.9. Small invertebrates such as blackfly larvae and stonefly nymphs are associated with these habitats, as are introduced trout which feed on these and other animals which live in fast flowing waters. In the south-west, a few paperbarks and sedges manage to maintain a precarious root-hold on sediment trapped amongst the rocky crevices of rapids and cascades.

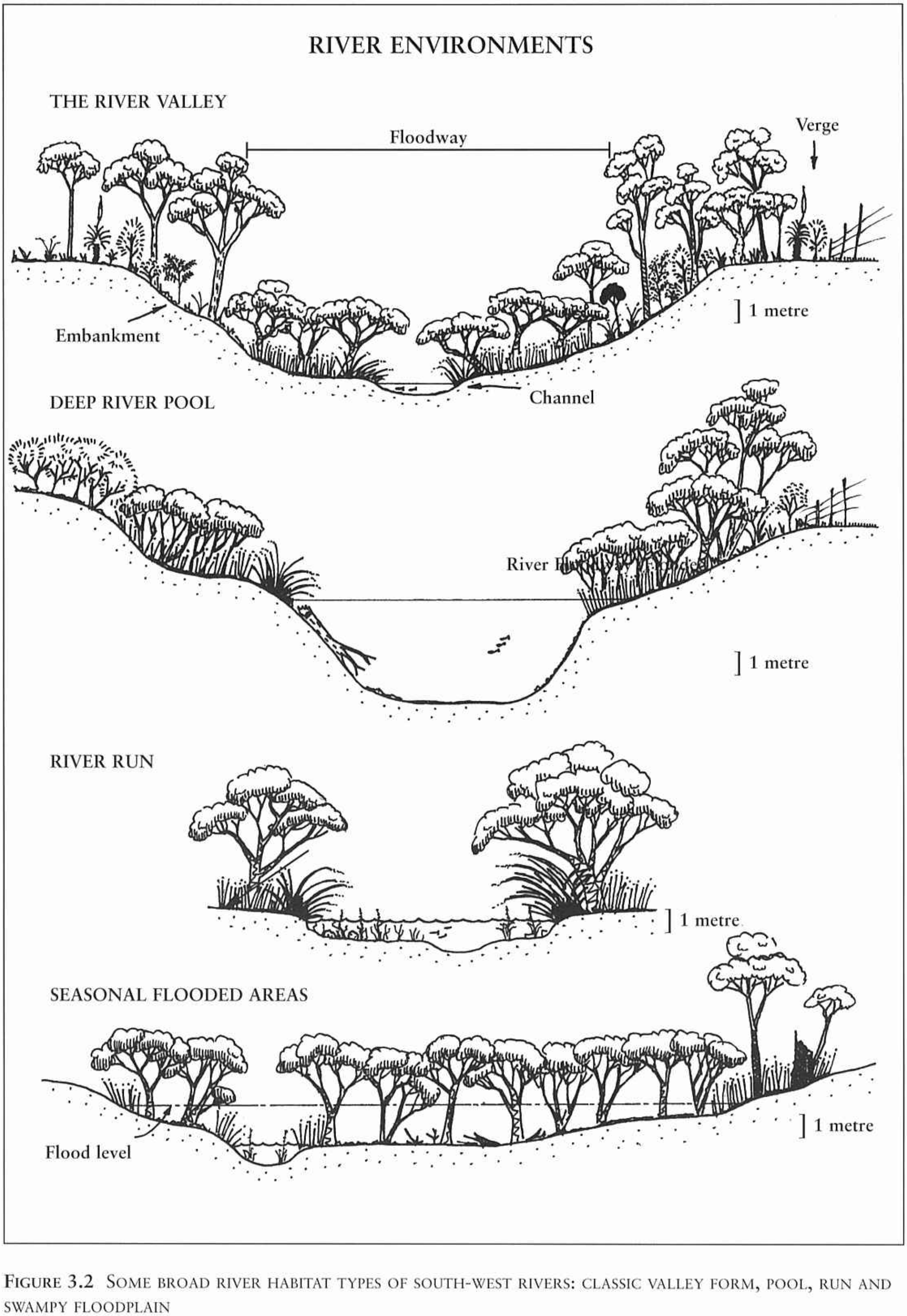


FIGURE 3.2 SOME BROAD RIVER HABITAT TYPES OF SOUTH-WEST RIVERS: CLASSIC VALLEY FORM, POOL, RUN AND SWAMPY FLOODPLAIN

Riffle zones are generally well colonised by flooded gum, paperbarks and a variety of sedges, creating in winter the typical scene of turbulent and frothy flow of shallow water between tree stems, over clumps of sedges and over and under roots and woody debris. The section along the Avon River known as the 'tea-trees', which gives competitors in the Avon Descent so much trouble, is an example of this type of habitat.

Runs and low flow channels. Long reaches of unobstructed stream flow, where the flowing water has a flat surface, are often called runs[1]. In the south-west they are the low flow channels that wind their way across the floodway between pools. In cross section they resemble irrigation canals, typically being a few metres across and about 1 metre deep, but may be larger. As part of the riffle zone between pools, the low flow channels are often well supported and overhung by fringing vegetation, mostly paperbarks and sedges.

The hyporheic zone. Hyporheic means 'under the flow' in Greek. This habitat exists between the surface water of the stream above and the true groundwater below. Its size is determined by stream and groundwater flow as well as the form of the stream. Animals that live in the hyporheic zone are called the hyporheos. They live between the rocks, pebbles and sand grains that make up this zone. There are distinct advantages to living in this habitat including plentiful food and refuge from flow, predators and drought. Some animals use the hyporheic zone as a temporary habitat for all or part of their life cycle.

Floodplains. In terms of habitat, floodplains are generally broad areas of low flat land adjacent to the main floodway of the river. Each year floodplains are inundated to some degree by floodwaters, creating a seasonal habitat which may be used for feeding and breeding by a variety of animals such as tiny crustaceans, burrowing crayfish, birds, frogs and fish. Floodplains may also be part of broader wetland systems which in winter become very swampy through groundwater rise or the build-up of rainwater over a clay layer. Wetlands of this form are usually referred to on maps as 'areas subject to inundation' and are very extensive in the upper reaches of some river systems including the Blackwood, Frankland-Gordon, Donnelly and the Deep.

People often treat floodplains as ancillary to the main river, and as a result there is little consideration for floodplain conservation as part of river management in the south-west. In many areas close to towns or supporting agriculture, flooding of floodplains is even considered unacceptable. But as will be seen later in this chapter and in Chapter 5, floodplains are an integral part of the river ecosystem. There is an exchange of water, nutrients and living creatures between the river and its floodplain, which is essential to the proper functioning of a healthy river ecosystem.

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[1] In the northern hemisphere runs are also known as 'glides'.

3.2.2 Habitat elements

Habitat elements are the building blocks that make up the broad habitat zones and are not necessarily restricted to one type.

Riparian vegetation. Gum trees and paperbarks over sedges and rushes (see Chapter 4) commonly make up the fringing vegetation along rivers in the south-west. These perennial evergreen hard-leaved species dominate the river ecosystem by casting shade throughout the year and by contributing hard, oily, tannin rich leaves and twigs to the water column.

Snags and woody debris. Snags are fallen trees and large branches lying in the river channel. As trees have been falling or dropping branches and twigs into rivers for millions of years it is to be expected that woody debris is important to the ecology of river systems. Apart from generally helping to slow the flow of water, along with the living vegetation, woody debris alters the flow of water, creating eddies and small isolated zones of turbulence or still water which provide 'micro-habitats' for a range of tiny animals and plants. Furthermore, tree trunks and branches add a huge surface area to the river environment, creating a woody habitat for certain species to use for all or part of their life cycles. Tree trunks lying close to or on the river bed provide cover or a sturdy roof for burrowing animals, such as marron and gilgies.

Shade. Over the long summer and autumn period when many aquatic animals are confined to the deep permanent pools, shade cast by the fringing vegetation around the perimeters of the pools is essential to enable the animals to escape from the heat of the sun.

Aquatic vegetation. By definition aquatic vegetation only includes plants which are found submerged in, floating on or emerging from water. Along south-west rivers, truly aquatic vegetation is relatively scarce, as the dense tree canopy 'shades out' many of these plants. Nevertheless, aquatic vegetation is an important component of habitat in areas where the sunlight peeks through gaps in the tree canopy. This occurs mainly around pools and along low flow channels and where riparian and upland vegetation has been cleared for farming and road crossings. Aquatic vegetation provides a specialist habitat for certain animal species, such as fish and hunting spiders, as well as cover for fish, shrimps and crayfish and valuable breeding and nursery habitat for fish during spring. Aquatic vegetation is most abundant in late winter and early spring, dying back in summer, and as such provides a mostly seasonal habitat.

Leaf litter. Leaves and twigs collect in pools or in areas of still or slightly flowing water and form an important micro-habitat for a large range of aquatic organisms, from large crayfish to microscopic bacteria and fungi which break down the organic material and initiate the natural food web. Piles of leaves and twigs can also provide cover for certain fish species, aquatic insect larvae and juvenile crayfish, but only if there is a slight flow of water through the material to maintain well oxygenated conditions.

A tributary creek of the Collie River South Branch. Note the overhanging paperbarks and aquatic vegetation (water ribbons), providing shade and shelter to aquatic fauna. Native fish still spawn in this creek despite the loss of understorey vegetation. Photo: L.Pen

The St Johns Brook downstream of the town of Nannup. Note the overhanging forest, the dark tannin stained water and the highly shaded conditions. Photo: L.Pen

WOODY DEBRIS AT WORK IN THE LOWER DEEP RIVER. NOTE THE BUBBLES ON THE WATER SURFACE, INDICATING THE AERATION EFFECT OF THE PROJECTING LOGS AND BRANCHES. PHOTO: L.PEN

VARIABLE FLOW CONDITIONS ON A SECTION OF THE MIDDLE KALGAN RIVER. PHOTO: L.PEN

Rock and stones. Although vegetation dominates river habitats in the south-west, rock and stone are important habitat elements. The rounded, smooth, hard surfaces of exposed boulders or pebbly patches in the stream bed, provide essential habitat for certain animal species. Where the gradient is steep, rock may dominate the stream channel, creating riffles, rapids or cascades. Here the hard surfaces and often sharply angled edges alter the flow of water, creating a myriad of micro-habitats in which a broad range of animals and plants can find a home. Rock also limits the growth of trees and shrubs over water and creates sunlit habitats. For example, the smooth rocky bed of the rapids area on the northern branch of the Margaret River, supports the growth of algae in the shallow swiftly flowing sunlit waters. Sometimes, in broad rocky areas pools may last over the dry summer, each sustaining a small community of plants and animals. Finally, the irregular and often broken flow of water over rocky stream beds helps to entrain air and therefore oxygen into the water column, improving the quality of habitats downstream. In summer it is not uncommon to find a large number of animals, including fish and crustaceans, collecting below riffles, perhaps enjoying the highly oxygenated conditions.

Sand. This is a common element in south-west streams and typically occurs in low gradient areas. Sandy substrates are generally considered to be poor habitats for invertebrates as they are often unstable under high flow and oxygen may be limited. Invertebrates that live in between or on sand grains are extremely small or are well adapted to coping with shifting environment and low oxygen conditions.

Open water. Many small animals and algae make use of the water column, perhaps moving between the surface and the lower depths at different times of the day. The most common animals to be found in the open water column are the copepods, which are tiny crustaceans generally less than 3 mm in size.

The water surface. A small suite of animals makes use of the water surface, supported by the 'surface tension'. They include springtails, water walkers and some beetles (see Section 5.1.4).

3.3 ECOSYSTEM FUNCTION

The function of stream ecosystems in southern Australia and how they differ from rivers of other temperate regions is poorly understood. But in recent years scientists have opened a few windows on some of the fundamental processes relevant to the management of stream ecosystems in the south-west.

3.3.1 Basic function

In simple terms, for an ecosystem to function it needs energy and raw materials. Energy comes into the system as light and some of it is captured by plants through photosynthesis. Raw materials consist of water, carbon (initially in the form of the gas carbon dioxide) and nutrients, of which nitrogen and phosphorus are particularly important. Plants gather both the energy and the raw materials and make them available to grazing animals which in turn make them available to predatory ones.

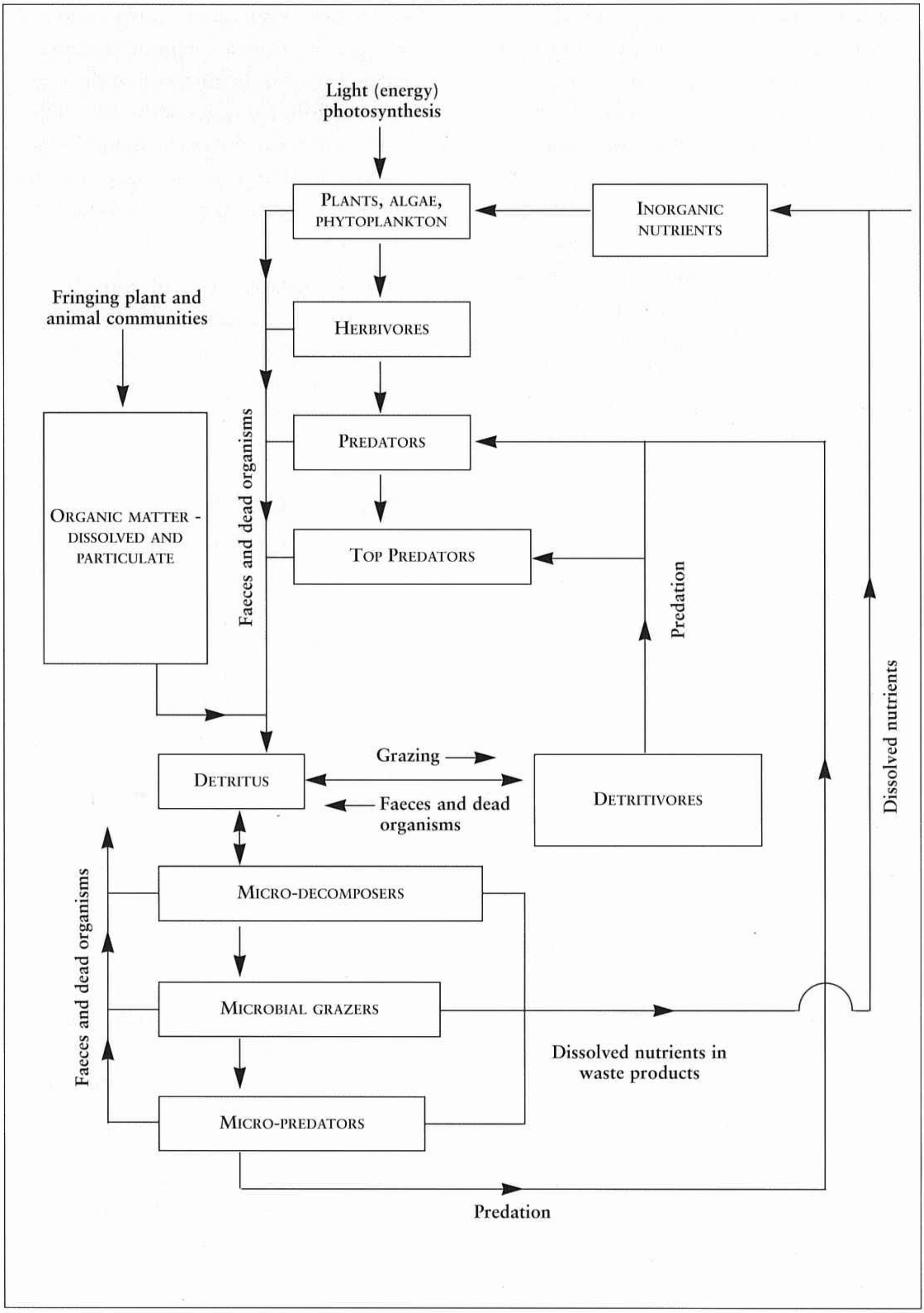


FIGURE 3.3 BASIC STREAM ECOSYSTEM FUNCTION

Dead plant and animal material, including that which has been eaten and excreted, forms detritus and is ingested by animals known as detritivores. Ultimately detritus is broken down into its constituent elements and compounds by tiny microscopic organisms, mostly bacteria and fungi. At this level, much of the raw materials, though none of the energy, is recycled back into the system. The basic system is illustrated in Figure 3.3.

For the most part the energy needed for the growth and activity of plants and animals is made available through respiration. This is the process by which energy is obtained for chemical processes in cells through the breakdown of sugar. Oxygen is necessary for respiration in most cases, but not all zones in a stream have adequate oxygen. Some areas, such as under heavy deposits of leaf litter or at the bottom of deep pools where organic sediments have collected, may become depleted of oxygen through the heavy respiration of aerobic microbes busily decomposing the organic material. In these anaerobic conditions, aerobic microbes can no longer survive and are replaced by anaerobic bacteria which utilise certain chemical compounds to obtain the energy they need to function. Anaerobic respiration often produces sulfur compounds and for this reason stagnant river water sometimes smells of hydrogen sulfide, or 'rotten egg' gas, especially if the sediment is disturbed by wading. Other gases such as ammonia, methane and nitrogen are also produced by microbes and in this way much of the carbon and nitrogen present in the decomposing material within the stream ecosystem is recycled to the atmosphere.

The typical stream ecosystem of the south-west in illustrated in Figure 3.4.

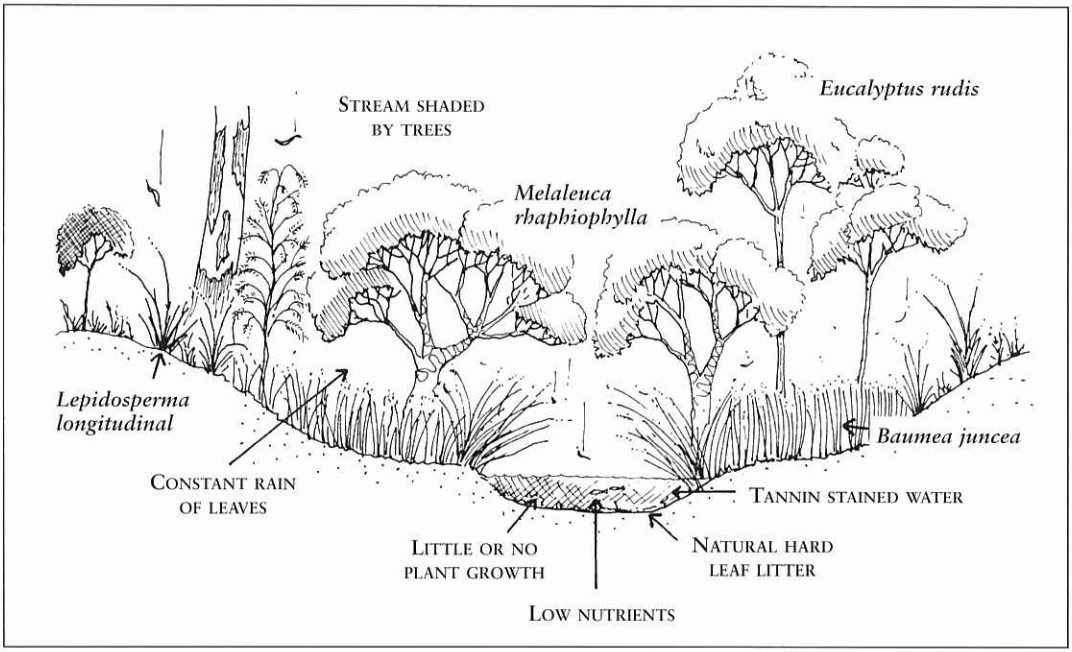
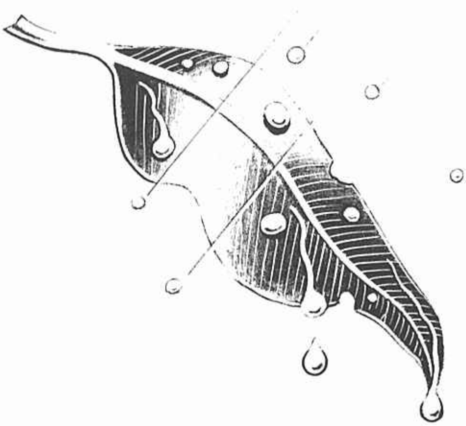


Figure 3.4 The stream ecosystem

3.3.2 The importance of shade and tannin stained water

Most streams in the south-west are well shaded by the dense vegetation which overhangs them. Even where there are broad expanses of water along the lower reaches of the larger rivers or where there are large pools, the shallow margins are well shaded by gum trees and paperbarks reaching far out over the water in an effort to gather as much light as possible. This vegetation drops leaves into the water which are leached of their tannin, a dark brown dissolved organic substance which in part gives south-west waters their characteristic dark tea colour. Eucalypt leaf-fall is heaviest in summer (Bunn 1988b) and so, by early winter, the large deposits of gum leaves make the river water dark brown and some pools and backwaters can become inky black. The shady trees and dark water prevent light penetrating the water column and as a result there is little growth of either algae or aquatic plants in these waters.



3.3.3 Sources of energy, carbon and nutrients

Scientists have shown that the primary source of energy, carbon and nutrients in natural upland streams of the Darling Range is not algae and aquatic plants (Katsantoni 1993; Cummins 1993; Campbell 1993; Davies 1993). The heavily shaded, nutrient poor and darkly coloured water of upland streams supports very little algae or aquatic plant growth. Instead, these streams are fuelled by the slowly rotting hard leaves and woody debris that have fallen from the overhanging fringing vegetation. It is important to note that much of this material falls onto dry stream beds or floodplains and begins to decay within the river valley before being inundated by winter flooding.

The energy, carbon and nutrients contained within the hard leaf, twig and woody material that has been deposited in the stream enters the food web and is used by a wide variety of microbial and invertebrate organisms. Soon after leaves and woody debris have fallen into the stream or have become inundated by flood waters, they begin to leach dissolved organic matter (e.g. tannins). Bacteria living in the water column or bacteria and fungi on the stream bed assimilate much of this material, either in its dissolved form or after it has precipitated out and flocculated to form tiny particles, or when it becomes adsorbed onto certain surfaces (Maltby 1992). Bacteria in the water column may then be eaten by tiny grazers such as protozoans and rotifers, while the organic slimes consisting of bacteria, fungi and algae that form on rocks and leaves become the food of small invertebrates such as mayfly larvae.

As the leaf and woody material is leached of tannins and other chemicals, microbes and invertebrates begin to colonise and help to soften, shred and break up the material into smaller particles, so that in later stages there is an increasing surface area for other bacteria, fungi and invertebrates to work upon. At each stage in the process these detrital feeders take nourishment from the material to grow and multiply. They become food for larger animals which in turn become food also. Waste products produced by animals of all kinds contain organic material for further decomposition and nutrients which can nourish what in-stream plant growth is possible. Often this plant growth is in the form of algae growing as periphyton on the surface of dead leaves, woody debris, rocks or sediment, or algae called phytoplankton that live in the water column. Some invertebrates such as snails and tiny crustaceans, including copepods, graze upon these algae.

Thus the community of detrital feeders that convert the hard dead leaf litter that falls into the stream into the energy, carbon and nutrients needed to sustain in-stream plants, animal grazers and predators, is a key element in the stream ecosystem. However, just what animal species are detritivores and what are nominally grazers is not always clear (Hildrew 1992). An animal may eat detritus but only digest the microbial complement. Another may only digest that part of the detritus which has already been partially decomposed by the microbes, in which case it would be a true detritivore, but one which requires some 'pre-conditioning' of its food. Microbes may indeed survive in the guts of certain animals, doing much of the actual digestion. But whether an animal is a true detritivore or not, by excreting the detrital material in a softer and more fragmented form than when originally eaten it nonetheless contributes to detrital processing and may be considered part of the detrital community.

While dead leaves and twigs make up the vast bulk of organic material entering the stream ecosystem they are probably not the only important source of nourishment. Flower blossoms and pollen, blown or washed by rain into the stream in spring time and summer, may be an important seasonal source of energy and nutrients. Blossoms also attract insects which may be blown or washed into the stream; trapped by surface tension they become food for fish and water walkers, or eventually drown and sink to the bottom. Swarms of insects, such as flying ants, sometimes inadvertently land on river pools, providing an opportunistic meal for native minnows. In winter huge numbers of insects, spiders, mites and other tiny animals are washed from the surrounding countryside into streams, adding to the input of energy, carbon and nutrients.

3.3.4 Sources of oxygen

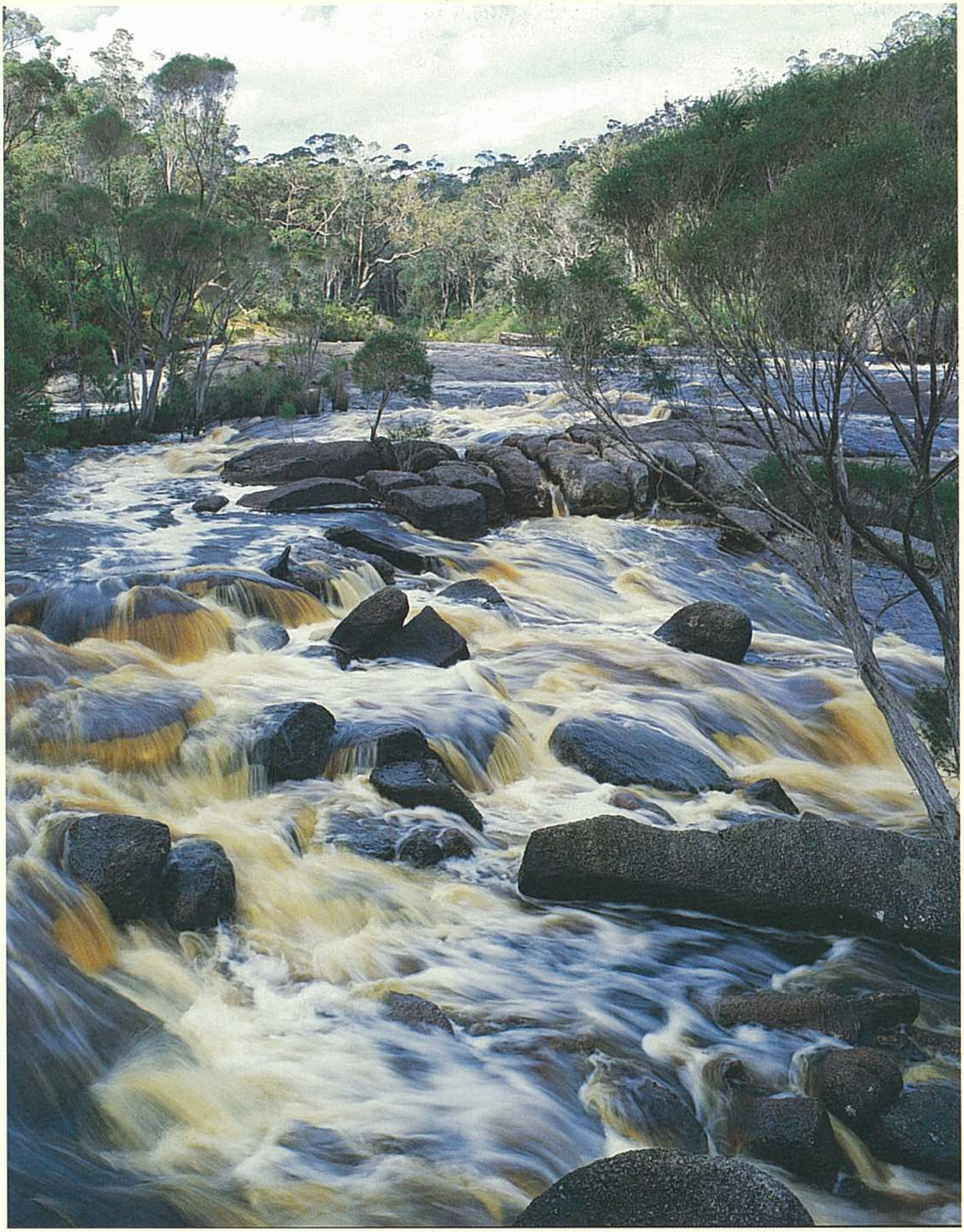
Photosynthesis is the process by which green plants produce sugars necessary for growth. The raw materials are carbon dioxide, water and light. The waste product of this process is oxygen which is released into the atmosphere or water, depending on the location of the plant. In natural south-west streams there is generally little plant or algae growth actually in the water, and therefore photosynthesis cannot be an important source of oxygen. So how do south-west streams become sufficiently oxygenated to support aquatic animals and the high levels of respiration required to decompose dead plant and animal material and thus initiate the food web?

Oxygen and other gases enter and are dissolved in the water at its surface. The immediate top few millimetres of water are always rich in oxygen. In still waters, however, this may be the only part of the water column with high oxygen levels, particularly if the bottom is covered in an oxygen hungry organic ooze. This is because diffusion to lower levels is a slow process. For the water column to become well oxygenated it must be mixed, even if only slightly. Even then, oxygenation of the water column is not very efficient if the water surface is flat and thus offers only a minimal surface area over which gas may be dissolved. But deep still river pools are only part of the river environment. In the winter season the water flows turbulently in the riffle zones. Wavy or broken water flowing over, under and between obstructions, such as snags, plants or rocks, has a much larger surface area to dissolve atmospheric oxygen than does still water.

The most effective sites for oxygenation are waterfalls, cascades and rapids where the bubbling, boiling and frothy turbulent flow creates a vast surface area over which aeration can occur.

The riffle zones are the lungs of our rivers and are most effective in winter when flow is strong. In summer and autumn low flows reduce oxygenation considerably and if flow ceases altogether the pools may quickly become deoxygenated, initially at their lower depths but increasingly towards the water surface as the summer progresses (Morrissy 1979). This not only happens because of the consumption of oxygen by the aerobic breakdown of organic material, but also because warm water holds less oxygen than cool water. Oxygen is a gas and as the water warms up it becomes more volatile and is therefore not so readily dissolved. Whereas oxygen saturation may be as high as 11 mg per litre in winter when water temperatures are less than 10° C, it may be as low as 8 mg per litre in summer when water temperatures approach 25° C. To put this in perspective, oxygen levels below 5 mg per litre are generally lethal to fish and at 20° C, a relatively cool summer water temperature for south-west rivers, marron require oxygen levels in excess of 4 mg per litre to survive (USEPA 1976; Coy 1979; Fisheries 1980). Thus the warm, stagnant and poorly oxygenated pools become a harsh summer refuge for our aquatic fauna.

A typical scene on the lower Warren River amongst karri forest. Here the river exhibits many of the elements of the south-west stream ecosystem: gum leaves, woody debris, shade and tannin stained water. Photo: S. Neville - Ecotones.



RAPIDS ON THE DEEP RIVER. THESE RAPIDLY FLOWING BROKEN WATER SITUATIONS ARE THE LUNGS OF SOUTH-WEST RIVERS.
PHOTO: S. NEVILLE - ECOTONES

case study

3.3.5 Leaf processing in a northern jarrah forest stream

The creeks of the northern jarrah forest are frequently overhung by jarrah and marri trees which drop their leaves most heavily in summer. A study carried out in the early 1980s looked at the processing of jarrah leaves in a shallow pool in Foster Brook in the North Dandalup River system in the northern Darling Range (Bunn 1988a & b).

After about a week in the brook, about 30% of the mass of the leaves was lost through simple leaching. Thereafter nothing much happened for about four months except that a further 10% of the mass was leached away. Although the leaves had been colonised by bacteria and fungi, significant processing of the leaf litter did not begin until winter when a wide range of aquatic invertebrates and microbes went to work. After about 12 months, microbial processing accounted for 13% of the remaining leaf material and invertebrate processing for a further 26%, leaving about 21% of the original litter as leaf skeletons and small fragments.

Among other factors, the lack of processing in summer was probably due to the poor nutritive value of the leaves in their initial 'freshly fallen' state, prior to any microbial colonisation, and the inhibitory effects of a thick heavy waxy cuticle and the toxic chemicals characteristic of gum leaves. The harsh conditions of summer with low flow and oxygen levels were probably also significant. It was not until the leaf material had been pre-conditioned for a short period at the beginning of winter, during which microbes had colonised the material, that the increased nutritive value of the leaves made them more attractive as food for larger stream invertebrates. Only then did leaf breakdown begin in earnest.

It would be interesting to know whether leaves that have been attacked by leaf miners and skeletonisers while still on the tree are broken down faster in the stream than those that have simply died and dried out. This is important because the flooded gum is the most common tree along south-west streams, although uncommon along creeks in the Darling Scarp. The flooded gum probably suffers more from leaf miner and scale attack than any of the other south-west gums. It is common for the foliage of this tree to be entirely browned-off, riddled with holes and covered in scale in spring, just prior to the new season's leaf growth in summer (Powell 1990). So do streams overhung with flooded gums have a more immediate source of nourishment than those overhung by other species? Also, since the leaves have been heavily eaten, do they provide less nourishment to the stream than relatively untouched leaves? Perhaps worthy subjects for research.

3.3.6 The wider system: the riparian zone and beyond

There is a tendency when considering the stream ecosystem to think only of the watery environments, whether seasonal or permanent, and perhaps the immediate adjacent habitats such as the fringing vegetation. But to understand and manage river ecosystems we must take account of the entire riparian zone. For example, as has been mentioned above, certain insects begin to process gum leaves long before they drop from the trees. Furthermore, decaying leaves and twigs on the embankments, which may never be inundated by floodwaters or find their way to the stream, may nonetheless contribute material to it when dissolved organic matter and nutrients are leached by drenching rain into the soil and carried downslope by groundwater (Wetzel and Ward 1992).

If you were to fly over natural areas of the south-west, the river systems would be identified not so much by the water but by the denser vegetation which grows along the streams. The stream ecosystem includes these riparian corridors with their canopy of trees and shrubs and not just the water beneath it. The nature of the broader riparian ecosystem is determined not only by climate and the living creatures within it, but also by the nature of the much larger catchment beyond, as wind and water carry vegetable matter, inorganic sediment, dissolved organic matter, salt and nutrients into the river system. Indeed two of the most serious problems which plague our rivers today, salinisation and eutrophication, are caused by altered catchment processes and not by changes to the riparian zone itself.

3.3.7 The flood pulse concept

While the catchment provides the energy, carbon and nutrients that fuel the stream ecosystem, the streams distribute these materials to the floodplains during times of flood. This effect is known as the flood pulse and it brings inorganic soil particles and often a much needed drink of water to normally dry floodplains. The significance of the flood pulse effect can be seen in the very fertile, iron rich, red alluvial soils of coastal plain rivers, which contrast greatly with the adjacent sandy soils. These floodplain soils once supported magnificent flooded gum forests, some trees of which remain along the middle Swan River today.

The flood pulse concept also refers to the lateral exchange of material from extensive floodplains to the stream channel. It postulates that much of the productivity of the stream ecosystem stems from organic matter and nutrients transported from large floodplains to the stream channel during times of flood. It competes with another concept, known as the river continuum, which postulates that the more important source of these materials is the river itself which, during times of strong flow, transports and distributes organic matter and nutrients along the stream channel.

3.4 The river continuum

Up until now the river or stream ecosystem has been discussed as if one section, with its various habitats, is more or less like any other section. This simplification was accepted to enable an uncomplicated description of basic ecosystem function, but is in fact incorrect. The reason is that a river is a flow of material, from the top of the catchment to its lower reaches near the coast. The lower sections receive water, carbon, energy and nutrients from upstream reaches, at least while the river is flowing. Not all the energy and material, however, is on the move at any one time. Some of it is stored as deposited detritus and inorganic sediment or in living microbes, plants and animals (collectively known as the biota). Also, much of the energy is consumed by living creatures going about their business of life. Nonetheless, a proportion of the energy and material is swept downstream, and new material is washed in from upstream, especially during floods. So the nature of any particular river reach is not only determined by its channel form and riparian zone, but also by the energy and material being eroded, transported and deposited along the river. Thus the river is a continuum, with upstream sections contributing to the nature of downstream sections.

In the final section of this chapter the concept of the river continuum (Vannote et al. 1980) will be explored in relation to our current limited ecological understanding of south-west streams. The concept is illustrated in Figure 3.5.

3.4.1 Functional groups

In order to describe the river continuum, it is necessary to introduce the idea of functional groups within the stream invertebrate fauna. Functional groups are distinguished according to what the animals feed on and how they cope with the physical rigours of living in flowing water. There are two types: functional feeding groups and functional flow groups (Vannote et al. 1980; Cummins and Klug 1979; Cummins 1992). The functional feeding groups are recognised by the configuration of mouth parts and functional flow groups by gripping appendages and general body shape. Together the functional groups describe the animals' methods of acquiring food and the flow environment in which they normally live.

Functional feeding groups

Shredders. Some species of aquatic insects and crustaceans, including marron and gilgies, feed on coarse particulate organic matter (i.e. greater than 1 mm across), like leaves and twigs. In so doing, they break up the coarse material and convert it into fine organic particulate matter, hence the name shredders.

Collectors. These invertebrates feed on the fine organic particulate matter (i.e. less than 1 mm across) produced by slow microbial decay, the action of shredders and physical abrasion as leaves and twigs are dragged along the stream bed. There are two types of collectors: filterers which strain the water column for food particles; and gatherers which browse the sediments. Many shredders and collectors support microbial populations in their guts, which are able to digest resistant plant compounds such as

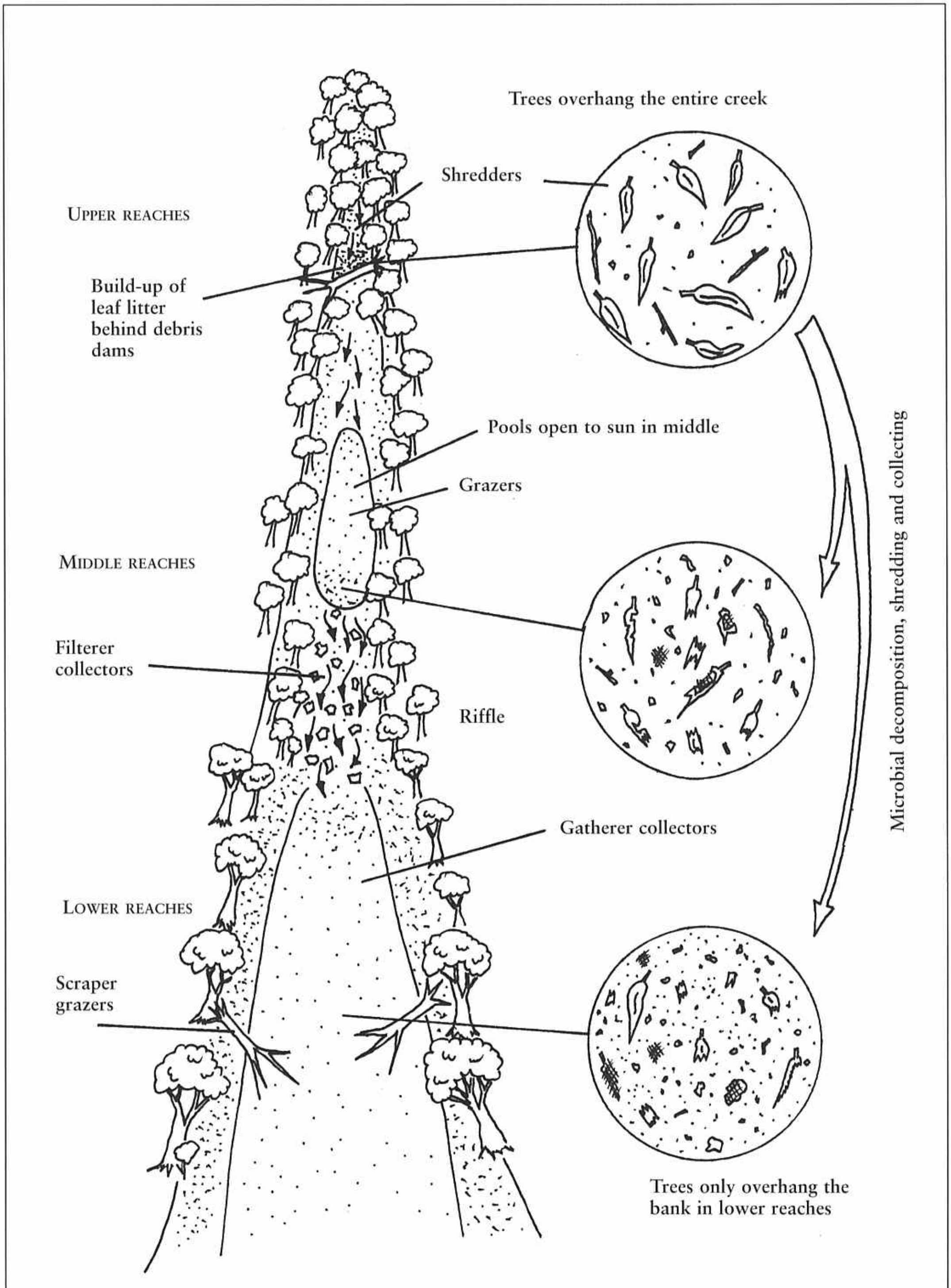


FIGURE 3.5 THE RIVER CONTINUUM

cellulose and lignin. In this way the microbes feed both themselves and their hosts.

Scrapers. Animals which graze upon algae and other organic matter adhered to rocks and plant material are known as scrapers. They feed by shearing their food from the surface to which it clings. Snails and limpets are good examples of scrapers (see Section 5.1.2).

Piercers. Certain small species of aquatic insects are equipped with needle-like mouths which they use to pierce the cells of aquatic plants and animals and suck out their juices.

Predators. Dragonfly and damselfly larvae are examples of relatively large aquatic insects adapted specifically for the capture of live prey. Wherever shredders and collectors congregate to take advantage of accumulations of organic matter, predators will likewise gather to exploit a rich food supply.

Functional flow groups

Unfortunately there are no simple names for functional flow groups. Those given here are the ones used in a recent study of a south-west karri forest stream (Growns and Davis 1994).

Obligates are animals that spend most of their life on the stream bed or on some object upon it and are therefore exposed to flow. They have behavioural or morphological adaptations to cope with exposure to the moving water column, such as sturdy houses from which they gather their food, or suckers, hooks and safety lines to maintain a grip in the swift and turbulent flow conditions.

Facultatives are animals that are able to move around in swift currents or in turbulent conditions, but will still avoid extreme flow conditions. To enable them do so, they have generally evolved a streamlined body shape to reduce drag. Despite their adaptations to flow these creatures will search out more congenial low flow areas when flow is extreme, such as occur in crevices or on the sheltered side of a cobble, boulder or log.

Avoiders. As the name suggests, these animals simply avoid stream flows by remaining buried in the sediments.

3.4.2 Changes along the continuum - over space and time

From creek to river, from pool to riffle

The river continuum begins in the headwater creeks which are nearly always overhung with vegetation and therefore receive a heavy rain of leaf litter (see Figure 3.5). Here shredders go to work on the freshly fallen leaves, producing the fine organic material on which the collectors can feed. When the stream flows strongly, more of the fine particulates will be lifted and carried downstream, and for longer distances, than the coarse particulates. In this way fine organic particulates begin to build up in downstream reaches, producing abundant food for collectors.

There are also two related compounding effects which reduce the input of coarse particulate matter downstream. Firstly, as the headwater creeks join up and the river channel increases in size, the input of coarse leaf litter becomes less significant in proportion to the size of the river, because the riparian vegetation increasingly only overhangs at the banks. Secondly, trees not only drop leaves, they also drop branches and occasionally a whole tree will fall across the stream. In narrow creeks fallen logs form debris dams which catch and accumulate large deposits of coarse leaf litter. These dams are common along narrow creeks but rare along broad rivers. The effect of debris dams is to retard the transport of coarse particulates from headwater creeks to downstream sections.

Because of the preferential collection, accumulation and processing of coarse leaf litter in the headwater creeks, the proportion of coarse particulate organic matter decreases downstream while fine organic matter increases. We would thus expect collectors to increase in abundance downstream compared to shredders. In addition, algae growth, which is retarded in the heavily shaded and deeply tannin stained headwaters, generally increases downstream as the broad waters of the lower reaches become increasingly exposed to sunlight. In these lower reaches, planktonic grazers and benthic scrapers are usually more abundant than upstream.

This, in simple terms, is how the continuum generally works with respect to the transport of organic matter along the length of a river. In detail, the process is not so straightforward. As discussed in Chapter 2, the river channel varies in form and flow conditions. Organic matter will accumulate in still and slow flowing sections and be carried away in fast flowing sections. Collector gatherers would be expected to be most abundant in those very slow flowing or still sections, such as flood waters and isolated pools, where the fine particulate organic matter settles out and accumulates. Shredders would be more important in slow to moderately flowing sections where coarse leaf litter is not carried away. Collector filterers are found preferentially in the riffle sections where they can filter out the particulates suspended in the swiftly flowing and perhaps turbulent water.

Since shredders and collector gatherers feed in slow flowing depositional sites (the latter more so than the former), they are mainly flow avoiders, while collector filterers are mainly obligates (the grippers), able to withstand the swift and turbulent flows on which they depend to bring their food. Predators, which may find prey in both slow and swiftly flowing water, are facultatives (streamlined), as are scrapers which feed on the algae covering the rocks of a riffle or on the bacteria and fungi busily decomposing the leaves on the bottom of a pool.

Seasonal changes

On top of the changes which occur as the river channel grows larger and inherits organic matter from upstream, and those which occur through changing river form, are seasonal changes. In south-west Australia, gum trees mainly drop their leaves in summer. Along river valleys, leaf litter falls mostly on dry river beds, but much falls into the river pools and the waters of permanently flowing sections. Here, summer leaf fall would appear to favour shredders initially and collector gatherers subsequently, once the shredders have gone to work. Along most rivers collector filterers must wait until winter when strong flows stir up and mobilise the bottom sediments and carry the fine particulate organic particles downstream.

THE POOL/RIFFLE SEQUENCE OF THE LOWER WAYCHINICUP RIVER IN ITS NATURALLY VEGETATED CATCHMENT, ILLUSTRATING THE RIVER CONTINUUM IN BALANCE. PHOTO: S. NEVILLE - ECOTONES.

PAPERBARKS AT THE MOUTH OF THE COLLIE RIVER SOUTH BRANCH, ENDURING THE FLOODED CONDITIONS OF WINTER.
PHOTO: L.PEN

SEASONAL FLOODWATER HABITAT WITH AQUATIC PLANTS (VILLARSIA) AMONGST WHICH THE WESTERN PYGMY PERCH SPAWNS IN SPRING (SEE CHAPTER 5). PHOTO: L.PEN

3.4.3 Nutrient spiralling

The reader is no doubt aware of some of the cycles that occur in nature, the water cycle being the most obvious one. There are also the various nutrient cycles, and here we shall include carbon as a nutrient. Carbon is present in the atmosphere as carbon dioxide gas and is fixed by algae and higher plants during photosynthesis to produce sugars. In higher plants some sugars are converted to cellulose or plant fibre. This cellulose and the sugars, as well as other chemicals, are eaten and through oxidation, which occurs with respiration, the carbon is returned to its gaseous form. This cycle is equally relevant to the river, where carbon dioxide is dissolved at the water surface and can be utilised by river algae and aquatic plants. However, in rivers most carbon enters the stream in the form of leaf litter and woody debris. During respiration, mainly of aerobic detrital feeders, large amounts of carbon dioxide may be released into the water column and thence returned, via the water surface, to the atmosphere.

Nitrogen, the most abundant gas of the atmosphere, is also dissolved in river water, and can be fixed by cynobacteria or blue-green algae. Nitrogen is usually present in the water as dissolved nitrite or nitrate ions which were either washed from the catchment or derived from the decay of organic matter. Typically, organic breakdown produces ammonium ions which are oxidised by certain bacteria to form nitrite and nitrate ions. In this form, nitrogen is most readily available to help nourish plant and algae growth.

As we have seen, most nutrients enter the natural stream in the form of fallen leaf litter and woody debris. The decay of this material, and the microbes and animals which are either directly or indirectly nourished by it, releases nitrogen and other nutrients back into the water column. Some bacteria can convert nitrogen and sulfur compounds to dissolved nitrogen gas or ammonia and hydrogen sulfide gases, respectively. If these gases are produced in large enough quantities, the action of these bacteria can result in a net loss of nitrogen and sulfur from the river to the atmosphere.

Phosphorus is another important nutrient but, unlike nitrogen and sulfur, does not have a gaseous phase. Nevertheless, it cycles within the river in much the same way as nitrogen. It can be bound within living or dead organic material or, through decay, released to the water column as phosphate ions, where it too is most available to nourish plant growth. Phosphorus can also be found adhering to the surfaces of tiny inorganic particles, especially those bearing carbonates and iron compounds. In agricultural areas, soil particles are often rich in phosphorus and through erosion can be a very important source of phosphorus, along with the dissolved phosphate ions which are also washed from the farmlands.

In rivers the various nutrient cycles are coupled to the downstream flow of water. This means that when nutrient particles are present in the flowing water column, as dissolved ions or within or adhered to suspended particles, or even as tiny organisms which cannot swim against the current, they are being transported downstream. This downstream displacement turns the cycles into spirals, as particles cycle between the moving water column and relatively stationary sediments and biota (Minshall et al. 1985).

Nutrients in the river are either being stored as deposited sediment or relatively stationary biota, or are being transported downstream. The overall rate of nutrient movement downstream, or the tightness of the spirals, depends on the biological and physical retention mechanisms present within the river to retard the movement of material downstream. For example, filter feeders capture suspended particles in fast flowing zones and thus impede their movement downstream. Also, in those habitats of the river where flow velocity is reduced, such as densely vegetated riffle zones and deep pools, material will settle out and form large deposits until the next big flood. Generally, flow velocity, rather than biological processes, is considered to be the more important factor in determining the tightness of spirals. Furthermore, different nutrients will spiral at different rates. Some are in short supply and are quickly taken up by the biota or are adsorbed onto inorganic particles, while others may be common or in little demand and transported over long distances before being assimilated into the river biota. Nutrients with a gaseous phase, such as carbon, nitrogen and sulfur, may be lost from the river altogether by escaping to the atmosphere.

The concepts of the river continuum and nutrient spiralling show that streams are much more than simple 'highways' for the conveyance of water and other materials. Despite the flow of water, the metabolic processes of the stream ecosystem actually lead to the retention, at least for a while, of much of the material delivered from the catchment and, in some minor cases, from the atmosphere also.

3.4.4 The continuum in balance

Energy, carbon and nutrients are added to the river and are, at varying rates, transported downstream. On the way, some of the energy is used and some of the nutrient material is returned to the atmosphere. But what is not lost from the river continues on its way or is stored for a while as deposited detritus and inorganic sediment or as living fungi, bacteria, plants and animals.

The availability of this material as food, whether living or dead, varies with habitat and season. Leaf litter tends to accumulate in slow flowing or still water conditions, and mostly in summer when leaf fall is heaviest. Fine particles accumulate in those parts of the river where water comes to a halt, in the deep pools and amongst the fringing vegetation of the floodplains. The tiniest of particles and many planktonic creatures remain in suspension always, and are available in many habitats. In contrast, the largest of the particles which can be moved by the flowing water of the river are only transported during floods. But as we have seen, microbes, plants and animals have evolved to exploit the different food resources of the various habitats, from the stillest pool to the most turbulent riffle. In each case, the populations of the species involved breed and multiply to produce numbers and biomass in proportion to the amount of food available. Each population grows to exploit fully the food resources available to it. This is true of populations of detrital feeders, grazers and predators.

The extent to which a food resource is exploited by the community of organisms feeding upon it is determined by an array of limiting factors. If the food resource in question is a deposit of organic matter in a depression of a riffle, a limiting factor may the time available for feeding before the next flood comes along and washes the material downstream. In a deep pool, the limiting factor may be the dissolved oxygen content of the water, which determines the level of activity by aerobic organisms. Other factors include the life cycle, and the behavioural and physiological limitations of the creatures involved. For example, a population of a particular species may be limited in size by the availability of breeding habitat, rather than food; the density of the population may be limited by territorial behaviour; and the rate at which it can process the food resource may be limited by the efficiency of its feeding apparatus and its capacity to digest the material involved. Whatever the reason, no food resource is likely to be entirely exploited.

Since the community of microbes, plants and animals of any section of river cannot be one hundred per cent efficient in consuming all the resources available, much leaks downstream, and this is especially true during floods. But what represents a loss to an upstream section, is income for a downstream section, and so on down the river.

At each point of the natural river, the microbes, plants and animals best suited to maximise the use of resources, whenever, wherever and however they are available, are active to their fullest capacity. For a river system whose catchment is relatively stable, the river continuum reaches a balance or equilibrium whereby material lost from upstream is balanced by consumption downstream, as the river organisms respond to the type and the amount of food available. Thus, according to the river continuum concept, the natural river system, from headwaters to river mouth, can be viewed as a chain of highly 'tuned' parts or ecosystems in which the processes downstream are tightly linked and in balance with those in upstream areas (Minshall et al. 1985).

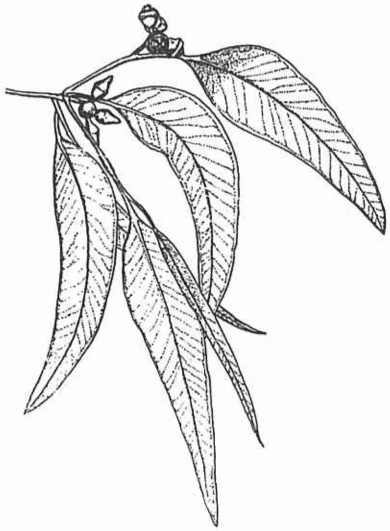
One consequence of a highly efficient river system is that it maximises the consumption of energy, carbon and nutrients delivered into it from the catchment, and thus minimises the amounts that are ultimately delivered to its estuary and to the ocean.

case study

3.4.5 The south-west experience

Little work has been carried out to explore the river continuum concept in south-west Australian streams. So far the only substantial work is that in northern jarrah forest streams and a small stream system in the karri forest (Bunn 1986, 1988a & b; Growns and Davis 1994).

For reasons described above, the former work found that stream invertebrates do not exploit the heavy leaf fall which occurs in summer and significant processing does not begin until winter when the rate of processing was considered low (Bunn 1986, 1988a).



Hence, large amounts of coarse particulate organic matter remain in the northern jarrah forest streams to be transported downstream during the high flow events of winter. In other words, because of a delay in invertebrate processing, these streams leak substantial amounts of carbon, energy and nutrients. However, higher levels of processing may occur in the deeper pools and behind debris dams, where leaf litter collects in large amounts and is not so easily dislodged and washed downstream (Bunn 1988a & b). Indeed south-west stream ecosystems may depend to a large extent on such mechanisms for the retention and subsequent assimilation of much of the carbon, energy and nutrients contained within coarse particulate organic matter (Bunn 1988a & b).

Further studies remain to be carried out on streams fringed with flooded gum and swamp paperbark, the two most common river trees along south-west rivers, and on streams in most major habitat types and stream orders. These studies could examine the contribution of different leaf types and habitats to fuelling the stream ecosystem, and also the effect of terrestrial disintegration and decomposition of leaf litter which accumulates amongst the vegetation of the dry creek and river beds and floodplains, prior to flooding. If it should prove that the leakage of large amounts of coarse organic matter is the rule, studies downstream may reveal a unique faunal composition for broad river reaches, perhaps one uniquely characterised by abundant shredders.

3.4.6 Disturbing the continuum

Over thousands of years the river evolves to reach a balance with its catchment. More or less the same amount of material from the catchment reaches its streams and floodplains each year. The material that is not used in a section of the river ecosystem is quickly pounced upon downstream, as it is upstream, by groups of detrital feeders evolved to exploit the resources available in each habitat type.

Occasionally, major naturally occurring upheavals in the catchment, such as bush fires and extremely heavy rainfall, may result in unusually large amounts of material being washed into the river system. For a while the river continuum may be knocked out of equilibrium, because it cannot cope with the extra material which accumulates in the various habitats along the river. This disequilibrium may express itself as excessive algae growth or the partial deoxygenation of river pools through the heavy microbial decay of leaf litter. The extent of the upheaval will determine the period of recovery, but in time, provided the disturbance is not continuous the continuum should re-establish.

The major changes which early European settlement and modern development have wrought upon catchments are, however, far too great and long lasting for the river to absorb and retain anything like its natural balance. Clearing of natural vegetation has rendered many thousands of kilometres of streamline little more than drains. These drains have little of the natural processing system that would normally break down catchment litter. As a result, huge amounts of organic matter, washed from farmlands and urban areas, are quickly transported downstream to lodge and accumulate in the broader river reaches, especially in the deep river pools. Here the stream invertebrates appear to be overwhelmed by the sheer quantity of organic material and cannot keep pace with the aerobic microbes which soon deplete the pools' oxygen supplies, especially over the warmer, drier times of the year when the river's natural oxygenation capacity is operating at a minimum (Pen unpub. data; Morrissy 1979). The open nature of drains also leads to large growths of algae and aquatic weeds which further increase organic loadings. The result is extensive organic pollution (Morrissy 1978).

This problem is compounded by the fact that the natural vegetation is replaced by pasture grasses, annual crops and deciduous trees (i.e. fruit trees and willows). These new vegetation types have soft leaves which break down more quickly than do the hard leaves of the natural vegetation (Pidgeon and Cairns 1981). Furthermore, late summer storms can flush large amounts of nutrient rich and oxygen hungry manure from bare paddocks into river pools (Morrissy 1978; Kendrick 1976; Olsen and Skitmore 1991).

As the river becomes increasingly polluted with organic matter, many invertebrates and other animals find it increasingly difficult to survive in the degraded conditions. Thus components of the stream ecosystem begin to disappear and the capacity of the stream ecosystem to process organic matter further declines. A few opportunistic species will benefit from the enriched conditions and will be present in large numbers, but these will not fulfill the full range of 'trades' required to keep the continuum in balance. The result is that the river system becomes a large polluted drainage system which delivers an excessive load of nutrient rich and oxygen depleting material to its estuary, which itself becomes polluted.

Ironically, in forested areas where stream ecosystem processes are in a relatively healthy state and water quality is therefore relatively high, the river continuum is often broken by dams. Dams break the continuum by capturing organic material transported from upstream reaches and starving downstream river reaches. At some stage downstream the river continuum may recover to an extent, but only if forested catchments remain below the dam to contribute leaf litter and thus restart natural stream processing (Storey et al. 1991).

Chapter 8 explores ways of buffering streams from heavy loads of catchment material, and thereby shielding the in-stream processes of organic breakdown needed for healthy and rich stream ecosystems.

Chapter 3

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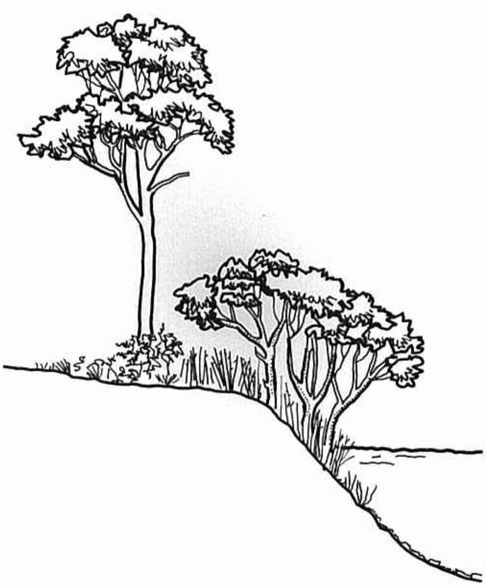
chapter 4

The value of fringing vegetation

- Fringing plant species
- The Role of fringing vegetation
- Landscape



4.1 Fringing plant species

4.1.1 The riparian zone and its vegetation

The riparian zone of south-west river systems is home to a wide variety of native plant species (Fig. 4.1). These include about five types of gum trees, ten paperbark trees, a number of tall shrubs and a few short ones, about twenty common rushes and sedges, a few herbs and at least two grasses. Many of the species are wetland plants which can tolerate waterlogged soils and flooding, at least for a few months each year. The familiar flooded gum and common swamp paperbark are examples, and are more or less synonymous with streamlines, lakes and swamps in the south-west. In the riparian zone they are generally restricted to the bed and banks where flooding and groundwater seepage create seasonal or episodic waterlogging of the soil.

At some point up the slope of the river valley, where periodic flooding and groundwater seepage no longer occur, the

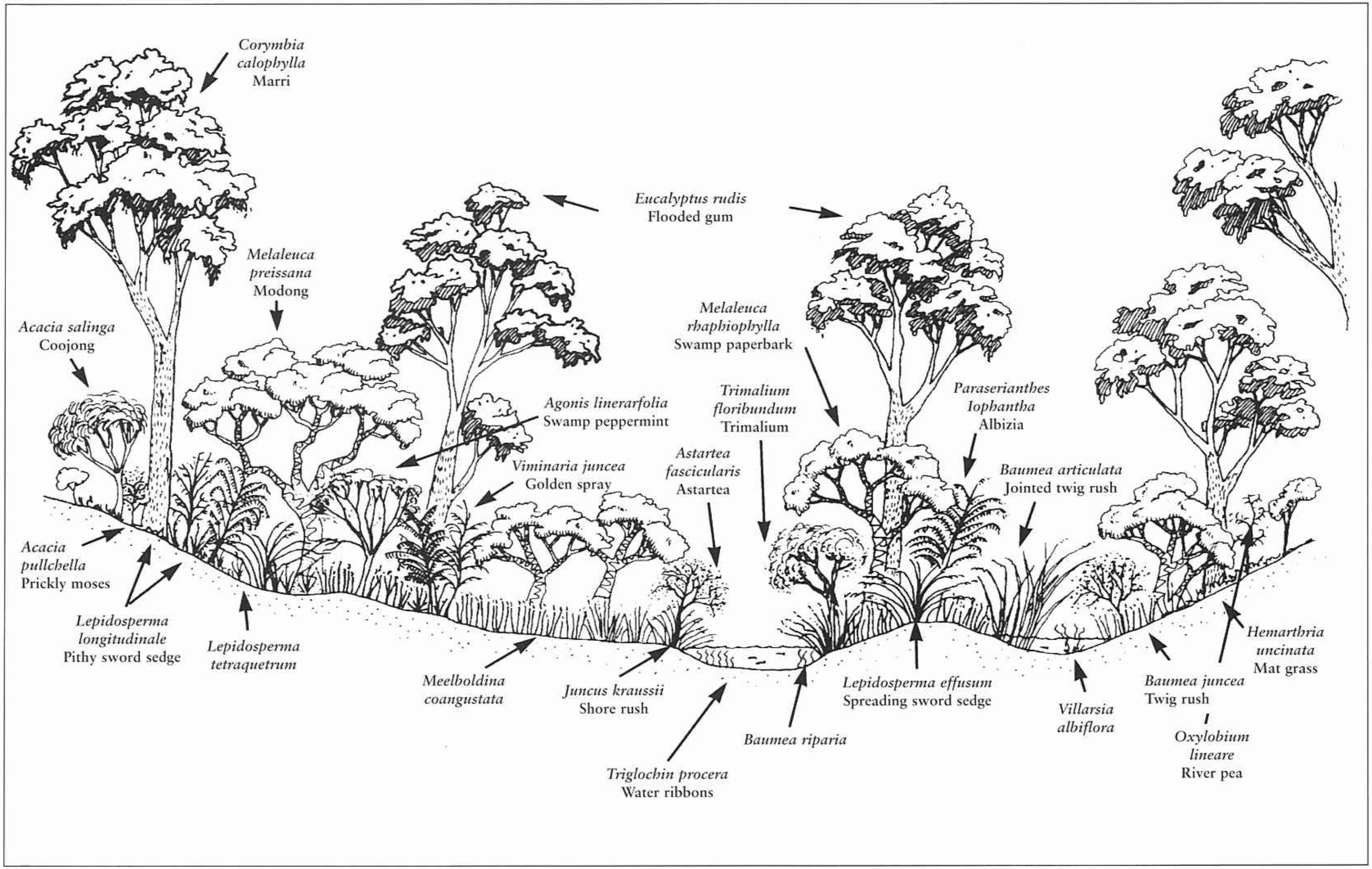


FIGURE 4.1 TYPICAL FRINGING VEGETATION OF SOUTH-WEST RIVERS

riparian species give way to upland or 'dryland' species, like jarrah *(Eucalyptus marginata)*, balga[1] *(Xanthorrhoea preissii)*, banksias and acacias. In low rainfall areas, the point of transition may be very close to the river channel; in very narrow and deep river valleys, it may be several metres upslope. Indeed the transition may occur over several metres, creating a zone known as an *ecotone* where the riparian species mix with the dryland species. The ecotone may be narrow on steeply sloping valley embankments or broad, perhaps many tens of metres wide on flatter valley slopes (Hancock et al. 1996).

Not all riparian plant species are wetland species. Some are more characteristic of the uplands of high rainfall areas, like the karri forest region, but also enjoy the moist conditions of the upper river valley where flooding and waterlogging seldom occur. An example is the tall shrub trymalium *(Trymalium floribundum)*, which is common in the understorey of the karri forest but restricted to river valleys in the jarrah forest (Hancock et al. 1996). Karri *(Eucalyptus diversicolor)* may occur along moist river valleys just outside its main area of distribution. Similarly, marri *(Corymbia callophylla)* is found along rivers in the wandoo woodlands and in turn wandoo is more abundant along streamlines in the wheatbelt, where York gums and salmon gums are the dominant woodland trees.

Some species are more or less restricted to river valleys. The most obvious example is the river banksia *(Banksia seminuda)*. This close relative of the swamp banksia *(B. littoralis)* grows to about 25 m and is the tallest of all the banksias. It can be found along the rivers of the Darling Range and south coast to about Albany (Marchant et al. 1987). The tall yarri[2] *(Eucalyptus patens)* has a similar broad distribution, and grows to 46 m in height on the deep alluvial loams and clays of the larger river valleys (Marchant et al. 1987). Yarri, however, will grow away from rivers in the better soils amongst jarrah and marri.

So how does fringing vegetation define the riparian zone? Basically by creating a corridor of vegetation which is distinct from the adjacent dryland vegetation. Wetland species occur in the centre of the zone, 'relatively high' rainfall species along the flanks, and right on the very edge, a mixture of these species and those of the adjacent dryland vegetation. From the air the riparian zone is often immediately obvious as a ribbon of denser vegetation snaking its way through the more open and widespread upland vegetation.

Biodiversity value of riparian plant communities

Although a relatively small number of species dominate riparian zones in the south-west, the total number of plant species that comprise fringing plant communities of rivers and creeks in the region is quite large. Some groups of plants are quite diverse, including the paperbarks *(Melaleuca* genus) and the southern rushes of the family Restionaceae. Some of the rushes are uncommon, including species of the genera *Meeboldina* and *Hopkinsia* and the species *Platychorda rivalis* and *Lepyrodia riparia,* whose names reflect their typical habitat (Kathy Meney pers. comm.).

[1] Also known as blackboy
[2] Also known as WA blackbutt

4.1.2 Fresh, brackish and saline rivers of the south-west

Within about 50-80 km of the coast, where average annual rainfall exceeds 700 mm, the fringing vegetation of the rivers is similar to that which is characteristic of freshwater lakes and swamps. Here, the deep river valleys and creeklines are very moist, naturally fresh and flow every winter. This zone occurs between Gingin in the north and just east of Albany in the south-east, and more or less coincides with the jarrah-marri and karri forest regions. Inland of this region watercourses begin to flatten out, as does the landscape generally, and the environment becomes drier and increasingly saline. Here, because of the dry and saline conditions, upland vegetation ventures further down into the river valley and species tolerant of saline environments, such as those seen around salt lakes and estuaries, occupy the seasonally wet areas. Between the fresh, relatively wet rivers near the coast, and the saline relatively dry rivers inland, there is a zone of transition where freshwater species give way to salt-tolerant species. Rivers or river sections in this zone will be referred to as brackish.

Depending on the location of a river system in the south-west and how far it extends inland, it may be wholly fresh, such as the Deep; or fresh in its lower reaches but brackish upstream, such as the Warren; or run from fresh to brackish to saline as does the very long Blackwood system which rises some 350 km inland. The much shorter Kalgan River does the same, over an inland distance of only 50 km. The reason for this is that being located near Albany, where rainfall decreases rapidly inland from the coast, the relatively dry saline interior lies only a short distance inland and comes closer to the coast as one moves east. Indeed, near Esperance all but the shortest of streams are brackish to saline all the way to the coast.

It should be noted, however, that due to the rise in saline watertables that followed widespread clearing for agriculture, very few rivers in the south-west that do not drain forested areas are now fresh at any point along their length. Fresh sections have become brackish and brackish sections have become saline along rivers with mainly cleared catchments. Today no portion of the main channel of the Blackwood is fresh (Olsen and Skitmore 1991; WAWRC 1992; Morrissy 1974). Fortunately, freshwater fringing vegetation appears tolerant to moderate increases in salinity, and die-off of fringing vegetation is limited to inland areas. Along some sections of some rivers salt-tolerant vegetation is replacing the dying freshwater vegetation. This subject will be discussed further in Chapter 7.

In this chapter, the natural fringing vegetation of south-west rivers is described under the headings of fresh, brackish and saline. There are too many species to describe in detail and moreover little is known about their biology. The more common fringing plants of south-west rivers, along with their habitats are listed in Tables 4.1 and 4.2, for fresh, and brackish and saline rivers respectively, and Figures 4.2 and 4.3 illustrate the respective plant communities.

4.1.3 The fringing vegetation of freshwater rivers

Fresh water, in a biological sense, has a salinity of less than 3000 mg/L total dissolved salts, or less than one tenth that of seawater (Bayly and Williams 1973; Halse et al. 1993). This is not to be confused with fresh drinking water, which must be less than 500 mg/L.

The south-west generally

On freshwater rivers, the main tree species are the flooded gum *(Eucalyptus rudis)* and the swamp paperbark *(Melaleuca rhaphiophylla)*, together forming a medium to low forest, often with a closed canopy (no open areas between the tree tops). The flooded gum grows to about 20 m and is a close relative (some say the same species) to river red gum *(Eucalyptus camaldulensis)*, which is widely distributed along rivers throughout Australia and tends to be found with flooded gum between Perth and Geraldton (Marchant et al. 1987). The flooded gum has a relatively open canopy, allowing enough light through to support a dense understorey, and can be easily recognised by deciduous smooth bark on the upper branches, greyish bark on the lower branches and base, and typically browned-off foliage resulting from the effects of rampant leaf miners. The flooded gum enjoys situations which range from winter wet to periodically flooded (Boland et al. 1984; Marcar et al. 1995), but appears to avoid permanently waterlogged sites. For this reason the flooded gum mainly occupies the moist river valley bank and raised areas in the river channel, giving way to the swamp paperbark in the middle of the river.

The swamp paperbark is the most common wetland paperbark species in the south-west. It grows to about 5 m tall and has dense bright green foliage, which in contrast to the flooded gum appears to be remarkably free of grazing insects. The species can quite readily grow under the gum but prefers wet sites, including those which may be flooded for much of the year. Typically the paperbark grows along the lower edge of the river valley embankment and across the river channel, perhaps densely fringing the central low flow channel. Viewed from the air the closed canopy of paperbarks, sometimes with a few flooded gums breaking through, forms long ribbons of bright green along many of our larger streams. In some patches the canopy is so dense that nothing grows in the darkness beneath it.

Both the gum and the paperbark fringe the river pools, growing out over the water by as much as 5 and 10 m respectively, giving a soft green and shaded edge to our rivers. In the broad lower reaches of the Capel River large flooded gums grow high over the river, with trees on opposite banks sometimes touching over the middle of the water. Under the gums are tightly packed paperbarks right along the water's edge. Once they stretched back over the very wet grassy floodplains.

There are many understorey species, but the more common include the tall shrub *Astartea fascicularis*, which surprisingly has no common name, and a few sedges. Astartea is found along the water's edge, typically on steep sandy embankments. In the shade under the paperbarks, the small twig rush *(Baumea juncea)* grows abundantly, forming a band to 50 cm in height, often fringing creeks. In the floodway proper, the tall sedges, such as sheath twig rush *(Baumea vaginalis)*, spreading sword sedge

HEALTHY FRINGING FOREST ON THE STEEP BANKS OF THE LOWER KALGAN RIVER. NOTE THAT THERE IS FARMLAND JUST BEYOND THE TREES AND A GOOD FENCE TO PROTECT THE RIVER. PHOTO: L.PEN

THE BEAUTIFUL BARLEE BROOK, A LOWER TRIBUTARY OF THE DONNELLY RIVER, ILLUSTRATING THE CONTRIBUTION OF FRINGING VEGETATION TO THE STREAM ECOSYSTEM. PHOTO: L.PEN

A flooded gum with a rather tenuous grip on the eroding bank of Spencer's Brook, a tributary of the Avon River. Note the exposed extensive root system that once provided structural support to the bank.
Photo: L.Pen

Narrow bands of rushes and sedges form a thin dark green line of protection to the immediate embankment of the middle Kalgan River. Photo: L.Pen

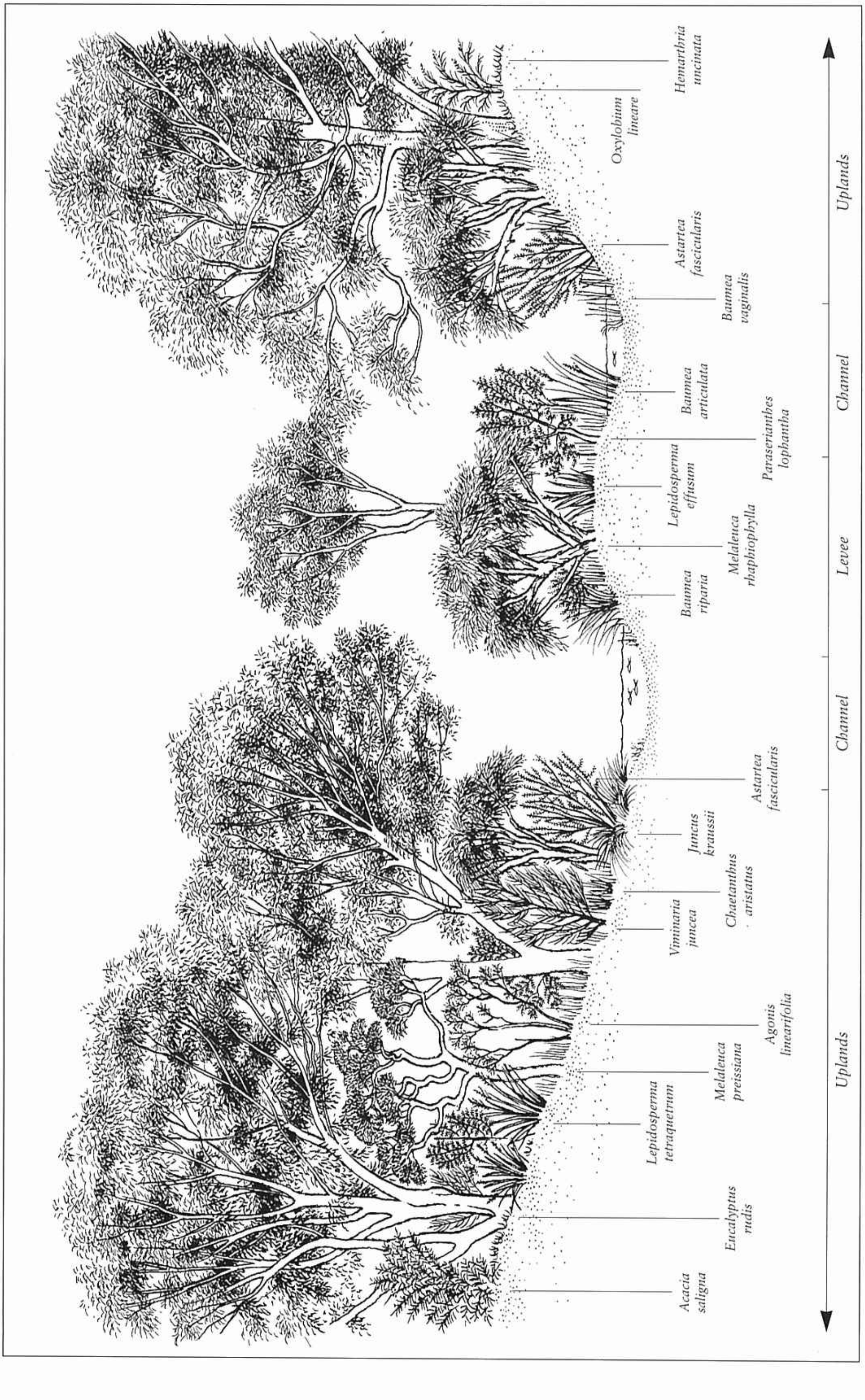


FIGURE 4.2 FRINGING VEGETATION OF FRESHWATER RIVERS OF THE SOUTH-WEST OF WESTERN AUSTRALIA

(Lepidosperma effusum) and angled sword sedge *(Lepidosperma tetraquetrum)*, are common, forming clumps or tussocks around which floodwaters flow.

The full range of typical freshwater river species is illustrated in Figures 4.1 and 4.2 and described in Table 4.1.

The wetter and fresher river valleys

The short rivers of the south coast west of Albany and to some extent the ones further north to Bunbury, are fresh and more permanently flowing than any others in the south-west. The climate is also cool and at least moist all year round. While flooded gum and swamp paperbark are still present, other tree species, such as the beautifully weeping WA peppermint *(Agonis flexuosa)* and Warren River cedar *(Agonis juniperina)*, are quite common, the former found along the upper sandy banks of the coastal stretches of rivers and the latter along streams in swampy areas. The Warren River cedar grows best as closed forest along the lower Warren River and its lower tributaries, reaching heights of up to 30 m, perhaps in an effort to capture some light from the surrounding tall karri trees *(Eucalyptus diversicolor)*. In fact, karri trees themselves can grow well within the river valley and fringe onto floodplains and to the edge of floodways. An exceptional example of this is a stand of tall karri trees in the floodway and on the valley embankments of the lower Kalgan River, well outside the main area of distribution for this species.

Another river valley tree is the tall yarri or WA blackbutt *(Eucalyptus patens)*. It is restricted to relatively rich soils and is found along the deep river valleys of the medium to high rainfall zone (>900 mm annually) of the Darling Range (Marchant et al. 1987). Like the common marri tree *(Corymbia calophylla)*, it will grow close enough to the river to overhang the water.

Dryland vegetation in the river valley

Often 'dryland' vegetation, such as jarrah-marri forest or jarrah-banksia scrub will grow well within the river valley, the wetland species being more or less limited to the water's edge. For example, marri trees rather than flooded gums dominate the valley embankments of the lower Kalgan River, and along the very sandy embankments of the King River, near Albany, jarrah is dominant. This appears to occur where river valleys are very broad and/or valley embankments are well drained.

4.1.4 The fringing vegetation of brackish streams

Brackish water is between 3000 and 10,000 mg/L total dissolved salts, or between one tenth and one third seawater. A section of river or creek which generally carries brackish water, may do so because both incoming groundwater and surface flows are brackish or because saline water from upstream is being diluted by local freshwater inflows.

The tell-tale sign of a brackish stream is the presence of salt-tolerant species typically associated with estuaries and salt lakes, such as shore rush (*Juncus kraussii*) and the swamp or saltwater sheoak (*Casuarina obesa*), amongst the typically freshwater species flooded gum and swamp paperbark (see Table 4.2). Both the flooded gum and the paperbark appear in environments which become seasonally brackish, but in this situation they may survive by making use of fresher groundwater sources, or are

freshwater typical plant species

TABLE 4.1

SCIENTIFIC NAME	COMMON NAME	RIPARIAN LOCATION
Trees		
Corymbia calophylla	Marri	4
Eucalyptus patens	Blackbutt	4
Eucalyptus rudis	Flooded gum	2-4
Melaleuca rhaphiophylla	Swamp paperbark	2-3
Melaleuca viminea	Mohan	3-4 salt tolerant
Melaleuca incana	Grey honeymyrtle	3-4 mildly salt tolerant
Melaleuca preissiana	Modong	4
Acacia saligna	Coojong	4
Agonis flexuosa	WA peppermint	3-4 not in jarrah forest
Agonis juniperina	Warren River cedar	3-4 south coast only
Tall shrubs		
Melaleuca lateritia	Red robin	2-3
Astartea fascicularis		3
Acacia pulchella	Prickly Moses	4
Agonis linearifolia	Swamp peppermint	3
Trymalium floribundum		3-4
Viminaria juncea	Golden spray	3-4 swampy
Paraserianthes lophantha	Albizia	3-4
Callistachys lanceolata	Wonnich	3-4
Oxylobium lineare	River pea	3
Grevillea diversifolia	Variable-leaved grevillea	3-4 near and in Darling Scarp
Grevillea glabrata	Smooth grevillea	4 in Darling Range
Labichea lanceolata	Tall labichea	3-4 near and in Darling Scarp
Dodonaea viscosa	Sticky hop-bush	4
Tall sedges		
Baumea articulata	Jointed twig rush	2
Baumea arthrophylla	Sparse twig rush	2-3
Baumea vaginalis	Sheath twig rush	3
Carex appressa	Tall sedge	2-3
Schoenoplectus validus	Lake club rush	1-2
Lepidosperma tetraquetrum	Angled sword sedge	3
Lepidosperma effusum	Spreading sword sedge	3
Lepidosperma gladiatum	Coastal sword sedge	3 coastal only
Typha domingensis	Cumbungi	3

SCIENTIFIC NAME	COMMON NAME	RIPARIAN LOCATION
Medium sedges and rushes		
Baumea juncea	Twig rush	2
Baumea preissii	Broad twig rush	3
Baumea riparia	River twig rush	3
Bolboshoenus caldwellii	Marsh club rush	2-3
Eleocharis acuta	Common spike rush	2-3
Carex fascicularis	Tassel sedge	2-3
Cyperus gymnocaulos	Spiny flat sedge	2-3
Lepidosperma longitudinale	Pithy sword sedge	3-4
Meeboldina roycei		3-4
Meeboldina coangustata		2-3
Chaetanthus aristatus	Bearded twine rush	2-3
Isolepis nodosa	Club sedge	3-4 sandy sites
Juncus kraussii	Shore rush	2 saline sites
Juncus pauciflorus	Loose flower rush	3-4
Juncus subsecundus	Finger rush	3-4
Juncus pallidus	Pale rush	3
Cyathochaeta avenacea		4
Grass		
Hemarthria uncinata	Mat grass	3 swampy sites
Herbs		
Centella asiatica		3 swampy sites
Emergent aquatic plants		
Triglochin procera	Water ribbons	1

Note: The above list gives only typical species found along rivers and is by no means a comprehensive list of riparian plant species of the south-west. Therefore the lists should not be used as a planting guide. Surveys should be carried out of remnant riparian vegetation along or near the stream that is to be rehabilitated in order to draw up a planting list. Old photographs and species distribution information should be consulted.

KEY		
	1 below low water mark	3 around high water mark
	2 between low and high water mark	4 above high water mark

brackish & saline typical plant species

TABLE 4.2

SCIENTIFIC NAME	COMMON NAME	RIPARIAN LOCATION
Trees		
Eucalyptus rudis	Flooded gum	2-4 brackish streams
Melaleuca rhaphiophylla	Swamp paperbark	2-3 brackish streams
Melaleuca incana	Grey honeymyrtle	3-4 mildly salt tolerant
Eucalyptus occidentalis	Flat-topped yate	4
Eucalyptus wandoo	Wandoo	4 year long well drained soil
Melaleuca cuticularis	Saltwater paperbark	3 very salt tolerant
Melaleuca viminea	Mohan	3
Melaleuca glaberrima		4 somewhat tolerant
Melaleuca uncinata	Broom honeymyrtle	4
Melaleuca lanceolata	Rottnest tea tree	4
Melaleuca aff. halmaturorum		4
Casuarina obesa	Saltwater sheoak	3-4 very salt tolerant
Tall shrubs		
Melaleuca thymoides		3 somewhat salt tolerant
Melaleuca thyoides		4
Melaleuca acuminata		4
Callistemon phoeniceus		3-4 brackish streams
Medium to small shrubs/herbs		
Frankenia pauciflora	Sea heath	3-4
Maireana oppositifolia		3-4
Wilsonia humilis		3
Wilsonia rotundifolia		3
Samolus repens	Creeping brookweed	2-3
Samolus junceus	Brookweed	2-3
Suaeda australis	Seablite	2-3
Sedges and rush		
Carex appressa	Tall sedge	2-3 brackish streams
Carex fascicularis	Tassel sedge	2-3 brackish streams
Carex inversa	Knob sedge	2-3 brackish streams
Juncus kraussii	Shore rush	2-3 inland variety
Gahnia trifida	Common saw sedge	3-4
Schoenus brevifolius		2-3
Cyperus gymnocaulos		2-3 brackish streams

SCIENTIFIC NAME	COMMON NAME	RIPARIAN LOCATION
Grasses		
Austrostipa junceafolia		3
Poa porphyroclados		3
Sporobolus virginicus	Saltwater couch	3-4
Samphires (all very salt tolerant)		
Sarcocornia quinqueflora		3
Sarcocornia blackiana		4
Halosarcia indica subsp. bidens		4
Halosarcia lepidosperma		4
Halosarcia pergranulata		3-4
Halosarcia syncarpa		3-4
Halosarcia halocnemoides		3-4

Note: The above list gives only typical species found along rivers and is by no means a comprehensive list of riparian plant species of the south-west. Therefore the lists should not be used as a planting guide. Surveys should be carried out of remnant riparian vegetation along or near the stream that is to be rehabilitated in order to draw up a planting list. Old photographs and species distribution information should be consulted.

KEY		
	1 below low water mark	3 around high water mark
	2 between low and high water mark	4 above high water mark

sufficiently high on the bank to avoid the elevated salinities of winter flows that originate in saline parts of the catchment. Other species which are known to colonise brackish sections include flat-topped yate (*Eucalyptus occidentalis*), the small paperbark mohan (*Melaleuca viminea*), and the succulent salt bush (*Halosarcia lepidosperma*).

4.1.5 The fringing vegetation of saline environments

Water in excess of 10,000 mg/L total dissolved salts is saline. Saline rivers can be easily recognised in summer by the presence of salt crystals on the river bed. The vegetation is similar to that seen on estuaries and consists of samphires (Sarcocornia and Halosarcia species mostly), the shore rush (*J. kraussii*) and the common saw sedge (*Gahnia trifida*), and the small trees saltwater sheoak and saltwater paperbark (*Melaleuca cuticularis*). Other more typically inland salt-tolerant paperbarks may also be present (see Table 4.2). An 'average brackish to saline plant community' is illustrated in Figure 4.3.

4.1.6 Aquatic vegetation

True aquatic plants can only survive in water. Some grow only within water and are called submergents; some have floating leaves, such as water lilies; and some have parts which emerge above the water surface, and are called emergents. In the south-west, all the aquatics are attached to the stream bed by roots and are generally emergents. The most common species in fresh waters is water ribbons (*Triglochin procera*), with green ribbon-like leaves and fleshy flower heads which protrude above the water surface. In knee deep water, the plant grows to about half a metre in height and may form dense stands, much favoured by fish and gilgies, in sunlit stretches where water flow is mostly moderate to slow. Otherwise water ribbons is sparse in the shade of paperbarks. In relatively sunlit creeks or low flow channels of river floodways, which may flood to a metre's depth or more, the leaves can grow many metres in length, waving and undulating downstream in the flow of water.

Other emergent species include waterlily-like plants of the genus Villarsia, with round sometimes floating leaves about 10 cm across and small white or yellow flowers, and species of Myriophyllum which have leaves that often resemble a bottlebrush.

A number of large attached algae species of the family Characeae are conspicuous in sunlit sites, particularly on rocks in shallow fast flowing water. A common one is *Chara coralina*, which has thread-like leaves. It will also grow in shallow water over a muddy bed, providing cover for fish, gilgies and shrimp.

Superficially similar to Chara are the submergent flowering plants of the family Potamogetonaceae. Annual species of this genus form dense grass-like beds in ephemeral brackish to hypersaline pools that form in the upper reaches of inland rivers (Brock and Lane 1983). These short-lived habitats are particularly productive and support relatively heavy waterbird feeding. A good example is the abundant growth of *Coleogeton pectinatus* in the Northam town pool which supports quite a few waterbirds (Appelhans and Walker 1998).

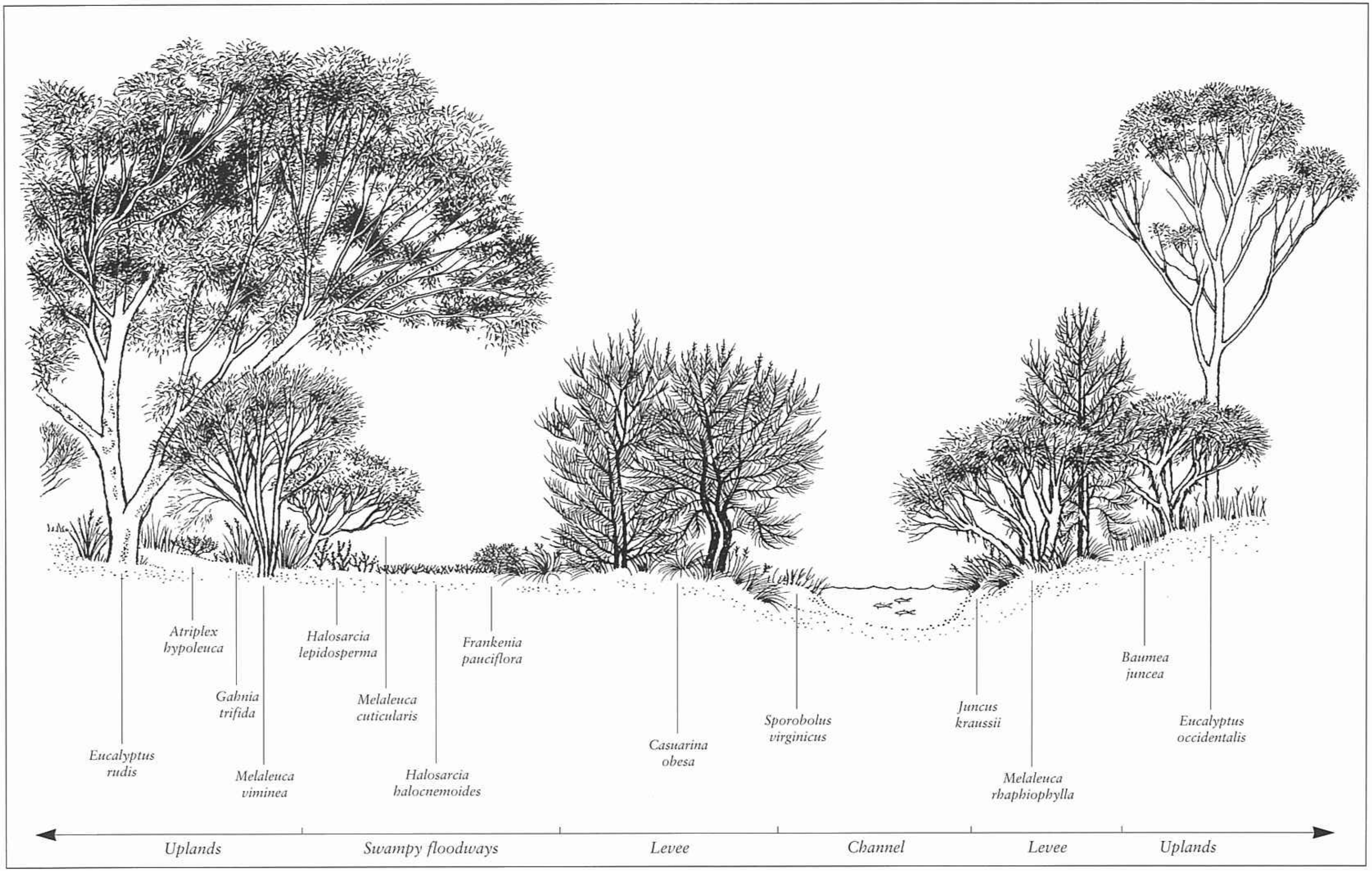


Figure 4.3 Fringing vegetation of brackish and saline rivers of the south-west of Western Australia

4.1.7 Notes on salinity and waterlogging

All plant species have varying levels of tolerance to salinity and waterlogging. Those that have a relatively high tolerance have a competitive edge, in wet and/or saline environments. Salt and waterlogging-tolerant species are mostly restricted to wetland sites where their tolerances are advantageous, but some species may also be found in upland sites where salinity or waterlogging pose no problem. Some species are tolerant of both salinity and waterlogging, while others are relatively tolerant of one or the other only. Furthermore, tolerances vary with life cycle stages, with juveniles perhaps being much less tolerant than adult plants (Hart et al. 1991).

Species that are tolerant of salinity and waterlogging have developed the physiological and/or biochemical means to exclude or exude salt, or deal with low oxygen conditions of saturated soils, respectively (Hart et al 1991; Marcar et al. 1995). But they can only make use of these adaptations up to a point. If salinity rises above normal levels or waterlogging is particularly prolonged, plants will become stressed and exhibit reduced vigour, and after a time, without respite, will eventually die (Froend et al. 1987; Bell and Froend 1990; Froend and van der Moezel 1994). In species such as flooded gum, swamp paperbark, saltwater paperbark and flat-topped yate, germination of seed is particularly strong following flooding, which paradoxically may have stressed or even killed parent trees (Freond et al. 1993; Froend and van der Moezel 1994). However, recruitment of new plants can only occur if seed is set and subsequent conditions are suitable for germination and early growth. In some cases, adult plants may be healthy but regeneration is not occurring because soil conditions are outside the tolerance range of juvenile stages. It is also worth remembering that plants stressed by salt and/or waterlogging will cope less well with other forms of stress, such as insect and fungal attack.

A small amount of work on salt and waterlogging tolerance has been done on south-west riparian species, albeit with respect to trees and to wetland environments other than rivers. While not conclusive, this work suggests that paperbarks (Melaleuca species) and the saltwater sheoak are tolerant of prolonged inundation, while the flooded gum is less so (Froend et al. 1987). As a general observation, species which appear to be tolerant of fresh waterlogging appear to be relatively tolerant of saline waterlogging also, that is, of the combined effect of salinisation and waterlogging (van der Moezel et al. 1991). The saltwater sheoak is an example of a species that is very tolerant of the combined effect (van der Moezel et al. 1988).

4.1.8 Environmental water requirements

The environmental water requirements (EWRs) of fringing vegetation are the conditions necessary to maintain the health and vigour of plant species and enable them to regenerate. They include soil moisture levels, the proximity of the watertable in relation to plant root systems and the duration of waterlogging and inundation.

There are two aspects of EWRs: firstly water needed by the plants to maintain proper metabolism, that is water they need to drink, and secondly the soil moisture regime needed to maintain the sort of conditions that favour them. Some species are very tolerant of prolonged inundation or waterlogging, while others are more tolerant of winter wetness, followed by summer dry conditions. Each species has its own particular 'wetland' regime under which it flourishes. Without these 'requisite' conditions a species will lose its competitive advantage and be replaced by species that are favoured by the new conditions, and these days these species are often weeds. EWRs are particularly important to the management of wetland plant species and have been the subject of research on the management of wetland systems on the Swan Coastal Plain (Froend et al. 1993; WRC 1997).

This research has made a number of findings which are relevant to the management of riverine fringing vegetation. The wetland trees, flooded gum (*Eucalyptus rudis*), swamp paperbark (*Melaleuca rhaphiophylla*) and modong (*Melaleuca priessiana*), respond slowly to changes in water regime, mainly through episodic seedling recruitment events. These events, which increase germination and seedling survival, occur periodically. For example, they occur under drawdown conditions on open areas of moist sediment; after fire when the cover is reduced and a nutrient rich ash bed is present; when water levels are high enough to carry fallen seed to open areas with full sunlight; or during a combination or sequence of these events (Froend et al. 1993). Once seeds have germinated, the small relatively slow growing seedlings will only survive if they are not totally submerged in the following year (Froend et al. 1993). Along rivers of the south-west it is quite common to see patches of flooded gum seedlings or saplings whose germination can be traced to the period immediately following a significant flood event.

Work on sedges and rushes has shown that the larger species, such as lake club rush (*Schoenoplectus validus*), are more tolerant of deep, prolonged inundation (Froend et al. 1993). This is thought to be because the taller species have a more extensive rhizome and root structure and their tall stature allows them to maintain a large leaf area above the water. Medium size species, including small twig rush (*Baumea juncea*), pale rush (*Juncus pallidus*) and pithy sword sedge (*Lepidosperma longitudinale*), all found along rivers, are less tolerant of inundation, occurring in areas where inundation, when it occurs, is generally less than half a metre in depth. Likewise the smaller species occur in areas where inundation is only shallow (Froend et al. 1993). Rhizome growth and extension is the main form of reproduction in sedge and rush species, but recruitment via seed will be successful under moist conditions in which flooding does not occur until the plants are large enough to maintain leaf area above water level (Froend et al. 1993).

Changes to the seasonal and long term regime of water flow and level can significantly alter the nature of riparian plant communities. The mix of species near and in a river can change and become dominated by weeds. The most devastating change is the loss of riparian trees when prolonged flooding or drought prevents successful seedling recruitment. Dams and artificial surface drains can have a significant impact on the EWRs of riparian plants, changing the amount and timing of available water. Research to identify the EWRs of riparian ecosystems and management plans to provide sufficient water to meet those requirements are recognised as a basic requirement of wetland management today.

4.2 The role of fringing vegetation

4.2.1 Ecosystem functions

Shade, shelter and tannin

Overhanging fringing vegetation casts shade and drops branches, twigs and leaves in the water. Shade is important for a number of reasons. It provides an essential refuge for aquatic animals from the hot summer sun and makes many open water species, such as the small freshwater fish, the western minnow, much less conspicuous to predators, especially cormorants. Shade also reduces the growth of aquatic plants and algae, which has important implications for the natural ecology of south-west streams (see Section 3.3). Submerged branches and leaf litter provide shelter and micro-habitats for a large range of aquatic animals, and the tannin (or more correctly gilvin) which leaches from the leaves and twigs gives south-west waters their characteristic tea or amber colour, which further serves to cut down light penetration and to hide aquatic animals.

Fuelling the stream ecosystem

Because heavy shading and the dark colour of the water inhibits plant growth in south-west streams, the leaves, twigs and woody debris that fall from the overhanging vegetation are the main source of energy, carbon and nutrients needed to fuel stream ecosystems. This means that healthy south-west stream ecosystems are inextricably linked to the fringing vegetation of the riparian zone. And not just any vegetation will do. The natural ecology of south-west streams is dependent on the hard, waxy and often toxic leaves of the gum, paperbark and tea trees that line the streams. The leaves of these species are highly resistant to breakdown and can take as long as 18 months to decompose in water (Bunn 1988), providing ample time for invertebrates to capitalise on this abundant food source before it rots away through the action of microbes. Furthermore, the slow decay of native leaves reduces the microbial oxygen demand and helps to keep river pools adequately oxygenated over the summer (see Sections 3.3.5 and 7.9.1).

The role of woody debris - snags, debris dams and habitat diversity

What you and I would call logs, branches and twigs, stream ecologists and hydrologists term 'coarse woody debris'. In years past, logs and branches were collectively called snags and were considered to be unsightly and obstructions to flow. Snags were (and often still are) removed in what were euphemistically described as river improvement schemes. Often many thousands of tonnes of logs and branches were removed from tens or hundreds of kilometres of rivers (Bradby 1997).

The importance of coarse woody debris lies in its overall role of greatly increasing the extent and diversity of habitat. Some habitat values are relatively obvious. For example, large logs and branches significantly increase the surface area of the stream and provide habitat and shelter for aquatic animals, and are in themselves a source of food for wood feeding microbes and invertebrates. Dead logs and branches projecting from the water are loafing sites for birds and turtles. Cormorants need dead branches, free of foliage, on which to perch and stretch out their wings, to dry their feathers and warm up after long hours fishing. Water flowing over snags also helps to oxygenate the water column.

But the contribution of woody debris to the stream ecosystem is more far reaching than these simple functions and has to do with altering the flow of water. When water approaches a snag it must flow around it, under it and/or over it. When it does, it accelerates and may scour the bed and banks, thus widening or deepening the stream channel. Along creeks, fallen logs may reach right across the channel, catching woody debris washed down during floods, to form what are known as debris dams. Such dams create ponds upstream and plunge pools just downstream where the fall of water passing over the dam scours a hole. In this way a small creek with a series of debris dams or even just woody accumulations may gain a pool riffle sequence of sorts, with alternating fast and slow flowing sections, and large volumes of impounded water (Gurnell et al. 1995). Above dams, ponding may increase the wetted area of the stream valley, such that wetland plants may extend further up the embankment and floodplains may be more extensively inundated during floods (Gurnell et al. 1995). Since water is held back, the creek is not only wetter over a larger area, but also for a longer period of time. Also, accumulations of woody debris and debris dams capture non-woody organic material and prevent it from being washed downstream, thereby reducing the loss of organic matter from headwater creeks and increasing its in-stream utilisation by microbes and benthic invertebrates (Gregory 1992; Gurnell et al. 1995).

By increasing the range of depths and velocities that water may take within the stream valley, woody debris greatly increases the extent and diversity of habitat. This is reflected in an increased abundance and diversity of plant and animal species within the stream environment (Gregory 1992; Gurnell et al. 1995). While the removal of snags may be viewed by those ignorant of stream ecology as an action of little ecological consequence, it is in fact one of the main steps in reducing a natural stream to a mere drain.

Ecological corridors

A well vegetated streamline provides a corridor of land and water along which many animals can move (Hussey et al. 1989; Saunders and Hobbs 1991). Some animals will move up and down the corridor looking for food, while others may use it to get from one area of habitat to another. Still others migrate as part of their life cycle (see Section 5.2.2). In cleared areas riparian corridors provide an avenue of movement for many species that will not or cannot cross open terrain, including fish which keep to the shadows cast by vegetation to avoid becoming conspicuous to predators.

Even in naturally vegetated areas the moist riparian corridors enable the overland movement of aquatic species, such as frogs, turtles and crayfish.

4.2.2 River valley and channel support

As we have seen, the soils of the natural stream valley support a varied flora of trees, shrubs, sedges, rushes and herbs. In turn, the vegetation maintains the stream bank and protects it from erosion and subsidence. The vegetation does this in a number of ways. Firstly, fringing vegetation increases streambank roughness which acts to dissipate the energy of running water and reduce the erosive capacity of stream flow (Troeh et al. 1980; Thorne 1990). This phenomenon is discussed in greater detail below. Secondly, roots and rhizomes bind and reinforce the soil of the embankments. The large roots of trees anchor the embankment in place and the smaller roots and rhizomes of shrubs, sedges, rushes and herbs hold the surface soil firmly in place above and between the large tree roots. This soil-root matrix can add extra cohesion of the order of ten times that of the unvegetated embankment (Thorne 1990). It is rather like steel reinforcing in concrete. Like concrete, soil has great compaction strength but limited tensile strength, in that it is easily pulled apart. The roots, with their great tensile strength, act like steel reinforcing, greatly increasing the structural integrity of the stream embankment and bed.

The roots and rhizomes also act to loosen and break up soil, with the result that a well vegetated bank enables rapid infiltration and passage of rain water (Riding and Carter 1992; Thorne 1990). Together with the drawing of water by the plants themselves, greater hydrological conductivity causes the bank to be drier than a similar unvegetated bank. In wet weather, this means that the vegetated embankment is less likely to become saturated with water for long periods, and thus less prone to mass failure, such as subsidence and toppling caused by the added bulk weight of the water (Thorne 1990).

Lastly, riparian vegetation is generally highly resilient, exhibiting relatively quick regeneration and recolonisation following the damaging effects of severe floods. In this way the vegetation helps stabilise the river system against the effects of severe erosion and sedimentation (DeBano and Smidt 1990; Wissmar and Swanson 1990).

So, the next time you view a length of river, try to imagine the skeleton of roots beneath the soil of the embankments and bed, each tree enmeshed with the trees next to it, along the entire length of the river and along the tributaries. Human ingenuity could not build a better structural support system for the river valley, and this natural systems maintains itself indefinitely, at no cost to the human community.

4.2.3 Energy dissipation and channel form

Water passing through or over vegetation is slowed down by friction, with the kinetic energy of the flowing water converted to heat. Vegetation, including dead woody debris, greatly increases stream channel roughness, contributing very significantly to the slowing of water movement (Thorne 1990; Gregory 1992). Because the natural floodways of south-west rivers are often heavily colonised by fringing vegetation, the velocity and hence power of floodwaters is greatly reduced. Even in channels which are inundated most of the time and may be free of fringing vegetation, emergent aquatic species such as water ribbons can significantly slow the flow of water (Watts and Watts 1990).

This reduction in flow velocity caused by the frictional effect of streamline vegetation has a number of consequences. Firstly, slowing the flow of water causes it to bank up and spill over onto the floodplains which further reduces the power of floodwaters. Even in low flows the banking up of water by vegetation helps to maintain water depth upstream and thus maintain aquatic habitat for longer periods than if the water was allowed to simply flow away (Watts and Watts 1990; Hearne and Armitage 1993; Gurnell et al. 1995). Secondly, a reduction in stream power and hence erosive capacity prevents floodwaters from widening and deepening stream channels.

4.2.4 Vegetation and flooding

Dense vegetation along stream channels is often implicated in flooding. By holding up the water, fringing vegetation and the woody debris that it produces can increase the duration and peak height of flooding, as a flood is stretched out along the floodway and floodplains of the river (Gurnell et al. 1995).

This relationship led to the Avon River training program in the 1960s and early seventies, following severe flooding of Northam in 1955 (Hansen 1986). Between Beverley and Toodyay, a portion of the floodway of the Avon was cleared of its vegetation, then mostly swamp paperbarks and flooded gums, and heavy deposits of woody debris were removed to increase the conveyance of water. It was also realised that the removal of the vegetation and debris would increase stream power with the effect of incising the channel and mobilising large amounts of sediment. This has indeed occurred and today the channel is about 1-2 metres deeper and most of the Avon's pools are filled or are filling with sediment (Hansen 1986). In addition, the increased depth of the channel has further increased the Avon's stream power. So, the Avon in flood today, while being less able to cause flooding on adjacent lands, is theoretically a more powerful river than it was in its former heavily vegetated state[3].

[3] As a matter of interest, sediment in the Avon river is being stabilised by colonising saltwater sheoaks and a variety of native and exotic shrubs, herbs and grasses. Maybe the river channel is once again becoming vegetated and through accretion of sediment from upstream and local tributaries the bed may be slowly stabilising and building itself back up to its original elevation. Who knows? The effects of salinisation and livestock grazing make the process far from clear and monitoring is required to ascertain the the overall impact of colonising plants.

4.2.5 Sediment and nutrient retention

Research being carried out in Europe, North America and New Zealand increasingly highlights the important function that riparian zone vegetation has in filtering out sediment and nutrients carried in flowing waters. Work on vegetated buffer strips along waterways or between waterways and agricultural land has shown that vegetation of many forms, including grasslands, sedgelands, woodlands and forests, can filter out and retain substantial amounts of sediment and nutrients (Peterjohn and Correll 1984; Cooper et al. 1987; Dillaha et al. 1988, 1989; Heede 1988; Knauer and Mander 1989; Margette et al. 1989). Dissolved nutrients, especially nitrate, are readily taken up and assimilated by plants (Yates and Sheridan 1983; Peterjohn and Correll 1984; Howard-Williams and Downes 1984; Howard-Williams et al. 1986; Pinay et al. 1990).

By reducing stream flow, riparian vegetation promotes sediment deposition (Thorne, 1990). Sand can be deposited even when water is fast moving and silt will settle out where vegetation causes a marked reduction in flow. However, near-still water, such as that caught in densely vegetated floodplains, is required for the deposition of the very fine clay fractions (Troeh et al. 1980). Over time, substantial streambank and floodplain accretion can occur in certain areas as a result of sediment deposition, and this can alter hydrological processes (Thorne 1990). The removal of suspended sediment by vegetation is especially important, as water carrying sediment has a greater momentum and is more abrasive than clean water, and thus has an enhanced capacity to cause erosion (Troeh et al. 1980).

Much of the nutrients trapped in the vegetation of waterways or in buffer strips is assimilated by the vegetation (Odum 1990). Generally, the longer the water is held by the vegetation, the greater the uptake of nutrients (Howard-Williams et al. 1986). Of course, the nutrients are eventually released back into the water column when plant material decays, but much of this will once again be assimilated, maintaining the balance of a natural system. In this way the riparian system retards the rate of transfer of nutrient particles downstream, in a process known as nutrient spiralling (Pinay et al. 1990; Pieczynska 1990) (See Section 3.4.3).

Nitrogen can be removed from riparian systems completely via the biochemical process of denitrification, which causes nitrate to be converted to gaseous nitrogen. This process can be the major form of nitrogen removal in certain riparian zones and during particular environmental conditions such as those which occur during and after flooding (Jacob and Gilliam 1985; Pinay et al. 1990).

4.3 Landscape

The value of landscape lies in its consistency and in the gradual merging variation from place to place. Variation creates contrast and enables the recognition of differences and similarities. Regional differences in landscape are often quite sharp, whereas differences within a region are more often variations on a theme. Regions can differ as sharply as red and white wine, while different types of red wine, a red burgundy or a claret, are like local variations. For some, there may be a world of difference between two local landscapes, while for a non-drinker, red wine is just red wine. The point of these comparisons is that to a wine buff, the colour, bouquet and taste of a particular wine, taken together, mean so much more than the mere label, and so it should be for the place in which you live. To truly appreciate your country or region you need to savour its odours, colours, sounds and hues. Often you do without knowing it. Taken together these sensations and your memory of them constitute your sense of place.

Rivers contribute significantly to the landscape and hence identity of Australia. Tall gum and paperbark trees, lazily overhanging broad expanses of amber coloured water on a hot day create a typical scene. Exposed snags projecting from deep dark waters, the grey wood perhaps dappled white in places by cormorant droppings, a mosaic of light and shade on foliage and water, all add to a sense of mystery that draws the viewer into the depth of image before them. In farming areas split post and wire fences may separate the riparian vegetation from yellowing pastures or fruit trees, and the mooing of cattle and the bleating of sheep may be heard in the distance. There may be the cheerful sound of gurgling water and calling crows, a slight just detectable cool breeze and the smell of eucalyptus and stale dry gum leaves; the splash of a duck feigning injury to protect her unseen young and the crazy chaotic whirlings of whirligig beetles on the water's surface near the shore. These sensations say 'water' and are what draw people to rivers, for mystery and adventure.

To a large extent riverine landscape, and the sensations which it generates within us, are dependent on native vegetation. It is the native plant species that contribute to the form, colours, patterns and odours of the river, and through the provision of habitat, the sights and sounds of its native fauna.

Chapter 4
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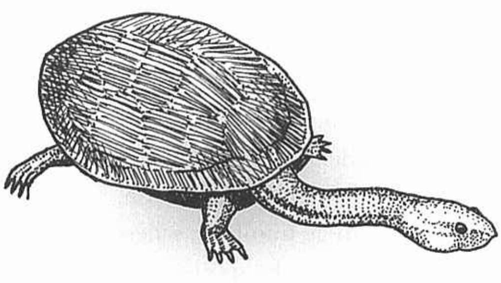
chapter 5

River animals and their habitats

- Aquatic Fauna
- Habitat needs and life cycle strategies
- An impoverished and ancient fauna



This chapter introduces the more common types of aquatic animals found in south-west rivers and gives an overview of their ecosystem roles, habitat needs and life cycles as they are presently understood. The objective is to show how the habits and habitats of the riverine animals reflect, and are part of, the nature of south-west river systems.

Before proceeding it may be useful to explain a few simple scientific terms. The plants and animals of the water column are known as the plankton, the animal component as zooplankton and the algal component as phytoplankton. The bacteria, fungi, animals and plants that inhabit the stream bottom are known collectively as the benthos, and such creatures are referred to as benthic.

5.1 Aquatic fauna

5.1.1 Tiny animals of the plankton and benthos

Protozoans *(Protozoa)*

Protozoans are microscopic single celled organisms, less than 0.5 mm in size. They are usually symmetrical, but can be irregular in shape. They may be free floating, with or without some form of locomotion, or may be attached to a surface. Some forms ingest particulate organic detritus, bacteria, small algae, other protozoans and tiny multicellular creatures, while others are also photosynthetic (obtaining energy from sunlight) or, alternatively, saprophytic like fungi[1]. Protozoans in some river environments may make a significant contribution to detrital breakdown and to fuelling the food web as they become food for larger animals.

Sponges *(Porifera)*

Freshwater sponges are occasionally found in shallow flowing water encrusting submerged logs, stones and rock. An encrustation is a dull light brown colour, about 1 cm thick, and may cover an area as large as two square metres. Sponges feed by straining the water that passes through them and filtering out bacteria and small particles of organic matter, including detritus.

Hydras *(Cnidaria: Hydrozoa)*

The student of biology would be familiar with hydras, as Hydra species are often used in teaching as an example of a simple polyp-form multicellular animal (Fig. 5.1). He or she may, however, be surprised to know that they are quite common in south-west streams, though seldom seen because of their small size, less than 10 mm in length. Hydras are cylindrical in shape, with a disc at the bottom end, for attachment, and a mouth at the upper end. The mouth is surrounded by about six tentacles, armed with stinging cells, which gather the hydra's food of tiny planktonic animals and bring it to the mouth for ingestion.

Primitive worms

A large range of animals are known collectively as flatworms or primitive worms. Another group are known as roundworms or nematodes. The most common flatworms are the free living turbellarians. Other types, and some nematodes, are parasitic or commensal[2] and are discussed in Section 5.1.11.

Turbellarians are generally under 3 cm in length, elongate, flattened and dark in colour. They move along the stream bottom gathering food which is thought to consist of living or decaying organic matter (Williams 1981).

Free living nematodes are among the most abundant and widespread of all the animal groups. They are elongate and cylindrical in shape and generally only a few millimetres in length. They inhabit the benthic environment of the stream, sometimes in huge numbers, where they feed, depending on the species, on all types of organic matter, dead or living.

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[1] In saprophytic organisms food is obtained in solution form from decaying plant and animal tissue.

[2] Commensal animals live on or in another creature without harming it.

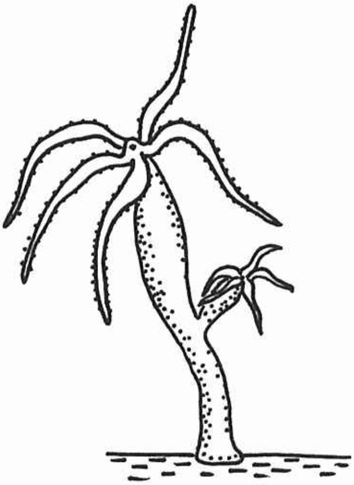


FIGURE 5.1 A TYPICAL HYDRA WITH A BUDDING INDIVIDUAL WHICH WILL FORM A NEW SEPARATE HYDRA. HYDRAS ARE USUALLY LESS THAM 10 MM IN LENGTH.

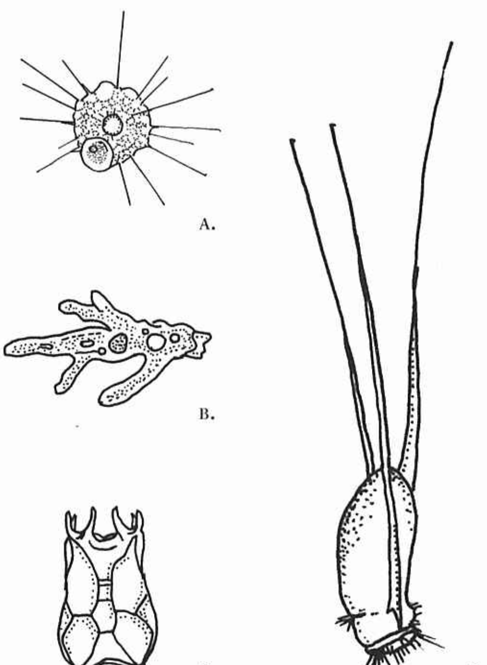


FIGURE 5.2 A SELECTION OF MICROSCOPIC ORGANISMS FOUND IN RIVERS: PROTOZOANS (A AND B) AND ROTIFERS (C AND D). NOTE THAT ORGANISMS OF THESE GROUPS ARE HIGHLY VARIABLE.

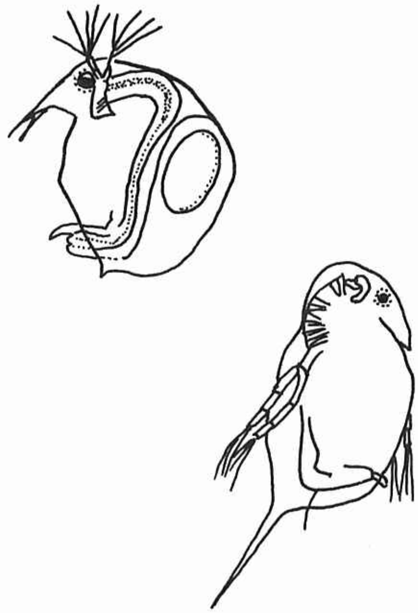


FIGURE 5.3 TWO EXAMPLES OF CLADOCERANS. THESE TINY CRUSTACEANS ARE MOSTLY LESS THAN 3 MM IN LENGTH AND MANY FORMS LESS THAN 1 MM.

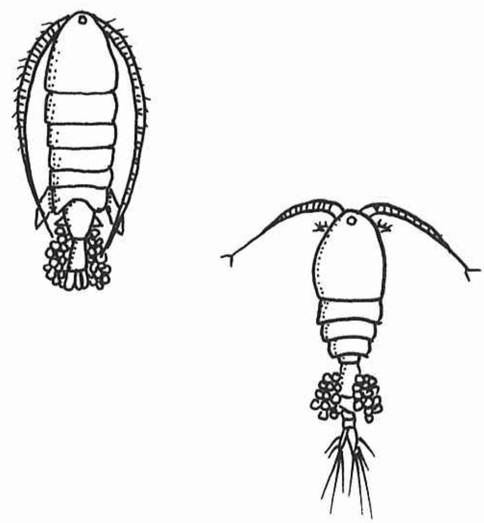


FIGURE 5.4 TWO EXAMPLES OF COPEPOD CRUSTACEANS. THESE ANIMALS ARE USUALLY LESS THAN 5 MM IN LENGTH.

Rotifers *(Rotifera)*

Rotifers are a highly variable group of mostly microscopic multicellular animals. Basically they consist of a head, trunk and in some species a foot which is used to adhere to a submerged surface (Fig. 5.2). Rotifers are mainly free living and planktonic. Most planktonic rotifers are filter feeders, feeding on bacteria, tiny algae and particulate organic matter (Shiel and Koste 1986). They are often an important part of the diet of fish larvae[3].

Water fleas *(Crustacea: Cladocera)*

These tiny crustaceans are characterised by a bivalve carapace, like a cockle shell, which encloses the body but not the head of the animal (Fig. 5.3). Some species have large antennae which assist in swimming. Cladocerans vary in size from 0.25 mm to 10 mm. Some species are benthic and feed on fine particulate matter, while others are free living and are an important component of the plankton. From time to time the river pools of south-west rivers give rise to large populations of the giant cladoceran, *Daphnia carinata*, which is the best known species of the Cladocera.

Shell shrimps *(Crustacea: Ostracoda)*

Unlike cladocerans, ostracods are tiny crustaceans that have a bivalve carapace that encloses the entire animal. When active, the valves open slightly to enable the appendages to protrude for swimming and food collection. Ostracods come in a variety of shapes and sizes, between 0.25 and 6 mm in length, but mostly they superficially resemble bivalve molluscs or seeds, hence the names shell or seed shrimps. The texture and coloration of the carapace are also quite variable amongst the species, and quite interesting when seen under the microscope. Depending on the species, the carapace may be smooth, hairy, pitted or grooved and may be transparent, pearly white, with or without coloured patches, which are often turquoise blue, or even black and brown on a translucent background. Most ostracods are free living and benthic, but some species occasionally move into the water column.

Copepods *(Crustacea: Copepoda)*

Copepods are tiny elongate bullet shaped crustaceans, up to 5 mm in length, with conspicuous antennules which in some species are as long as the animal itself (Fig. 5.4). An interesting characteristic is that the females carry their eggs on their tail segments. Copepods have no common name, which is surprising given their high abundance in the plankton of most aquatic habitats. In the waters of the more nutrient rich rivers of the south-west, copepod numbers may reach several hundred thousands per cubic metre. This abundance must make copepods important phytoplankton grazers, and in turn, food for fish and other animals.

5.1.2 Small benthic invertebrates

Segmented or true worms *(Annelida: Oligochaeta)*

The segmented worms found in the organic sediments of south-west streams are not very different from those present in the typical well watered suburban garden.

[3] Just after fish hatch from an egg they are still developing their adult 'fish' form and are therefore referred to as larvae.

They are cylindrical in shape, anywhere from half a millimetre to 50 mm in length and dull pink, red or brown in colour. Essentially, worms are roving tube-like digestive systems, crawling through the sediment ingesting both organic and inorganic matter and probably digesting a mixture of diatoms and other algae, plant material, bacteria and detritus. Worms are often present in the sediment in large numbers and in some instances would make a significant contribution to detrital processing.

Snails and limpets *(Mollusca: Gastropoda)*

Gastropod molluscs have a single cone shaped shell, which is coiled in the case of snails and indiscernibly coiled and somewhat flattened in limpets. Both move using a large muscular foot and feed using a rasping tongue or radula which grinds and rasps algae and bacterial slimes from the surfaces of rock and plant material.

The streams of the south-west are the homes of a modest number of snails (*Glacidorbis* sp. and *Physastra* sp. being among the more common) and perhaps only one species of limpet (*Ferrissia pettardi*). The snails are mostly less than 2 cm in length and are black in colour, while limpets are transparent and less than 6 mm in length, making them very difficult to find. Nevertheless both snails and limpets can be found feeding on the surface of relatively freshly fallen leaf litter, woody debris and the stems and leaves of submerged aquatic plants. An interesting feature of freshwater gastropods is that they are often intermediate hosts to parasitic trematode worms, some of which are known, in their latter stages, to infect freshwater fish (see Section 5.1.11).

Watermites *(Arachnida)*

In these small animals, the head, thorax and abdomen have become fused to produce a single body mass (Fig. 5.5). Watermites vary in size from less than a millimetre to 10 millimetres across and come in a variety of bright colours, red, green and blue being typical. While the bodies of these animals are mostly soft, there are a number of armoured plates, usually on the underside but in some species covering most of the animal. Watermites have four pairs of legs which are fringed with hair to enable swimming, and large mandibles which they use to pierce the bodies of their prey and suck out the juices. In south-west streams, watermites can best be seen in shallow still water as tiny little coloured balls moving in a somewhat haphazard manner between the benthos and the water column.

Amphipods *(Crustacea: Amphipoda)*

South-west streams support a few species of amphipod, mostly of the genera Austrochiltonia and Perthia (Fig. 5.6). A typical amphipod has a distinct head, a thorax with seven pairs of long walking legs and a six-segmented abdomen. Species in south-west streams grow up to 10 mm in length, though most are much smaller, and may be pinkish or grey in colour. Female amphipods carry their eggs about in a brood pouch between the legs. Amphipods are amongst the most common of benthic animals and can be present in muddy sediments in thousands of individuals per square metre.

Stonefly larvae *(Insecta: Plecoptera)*

South-west stonefly larvae are dull coloured insects, mostly less than 15 mm long, which are found on rocks and vegetation, usually in fast flowing water. They have long antennae, two pairs of wing buds in the older nymph stage, stout thoracic legs and usually two long thin tails (Fig. 5.7). They are thought to eat detritus. The life of a stonefly nymph typically lasts from a few months to several years, while the winged adult life is very short.

Mayfly larvae *(Insecta: Ephemeroptera)*

The mayfly larvae of south-west streams are generally quite small, less than 10 mm in length, and are found in a wide range of habitats. They are characterised by short antennae, prominent abdominal gills and three tail filaments (Fig. 5.7). While larval life may last several months, the winged adult lives for only a few days.

Dragonfly and damselfly larvae *(Insecta: Odonata)*

Dragonfly and damselfly larvae are among the more fascinating of aquatic insects, not the least because they are relatively large, common and moderately variable, and there are good keys for the identification of south-west species (Watson 1962; Davis and Christidis 1997). Dragonfly larvae are relatively squat insects, under 20 mm in length, with large heads, small thoraxes and bulbous abdomens (Fig. 5.8a). Damselfly larvae are more slender (Fig. 5.8b), up to 50 mm in length, and have three tail 'fins', which are in fact gills, at the end of their abdomens.

All odonatan larvae are carnivorous and hunt along the stream bottom using a mouth part that has become modified to form a grasping pincer-like organ that is hinged in the middle. The organ is kept folded below the head and is shot out at great speed to seize small animals. When collecting aquatic animals, care should be taken to place the more aggressive dragon fly larvae in a separate container to prevent them from 'throttling' their fellow captives.

When dragonfly larvae reach their final stage, after one to several years of larval life, they leave the water to take on the winged adult form. Discarded larval exoskeletons are commonly seen attached to fringing vegetation.

Corixids, water boatmen and water scorpions *(Insecta: Hemiptera)*

Common south-west hemipterans include corixids, water boatmen, water scorpions and water walkers. The last group is discussed in Section 5.1.4. Most hemipterans are carnivorous and have mouth parts in the form of piercing rostrums or beaks, which they use to suck the body fluids from their prey, such as small aquatic animals and terrestrial insects and spiders that land or fall onto the water surface. All hemipterans need atmospheric oxygen for respiration and for this purpose they carry a supply of air when submerged, in the form of bubbles that cling to the body surface, and which is replenished with periodic visits to the water surface.

Corixids, also known as lesser water boatmen, have large black legs which they use to swim (Fig. 5.9a). They are nearly always present along the water's edge, on muddy bottoms or among vegetation. Since corixids are negatively buoyant, they need to rest upon the stream bottom or submerged objects when not swimming.

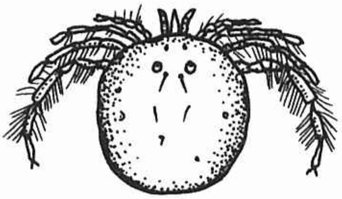


FIGURE 5.5 A TYPICAL WATERMITE, USUALLY 1-10 MM IN LENGTH.

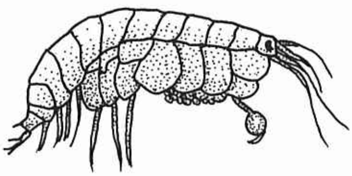
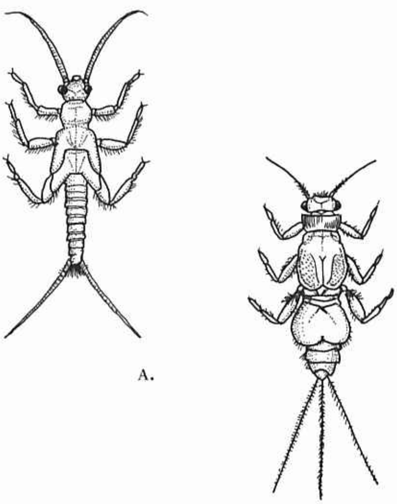


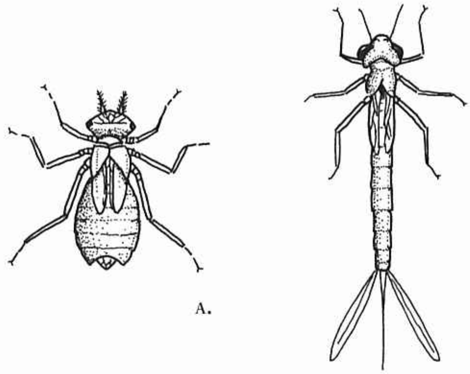
FIGURE 5.6 AN EXAMPLE OF AN AMPHIPOD. FRESHWATER AMPHIPODS ARE GENERALLY LESS THAN 10 MM IN LENGTH.



A.

B.

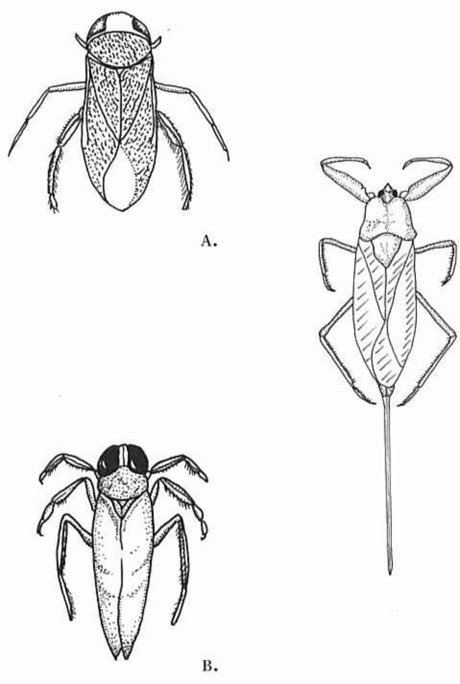
FIGURE 5.7 EXAMPLE OF A STONEFLY LARVA (A) AND MAYFLY LARVA (B). BOTH TYPES ARE USUALLY LESS THAN 15 MM IN LENGTH.



A.

B.

FIGURE 5.8 EXAMPLE OF A DRAGON FLY LARVA (A) AND DAMSELFLY LARVA (B). USUALLY LESS THAN 20 AND 50 MM IN LENGTH RESPECTIVELY.



A.

C.

B.

FIGURE 5.9 EXAMPLE OF A CORIXA (A), WATER BOATMAN (B) AND WATER SCORPION (C). CORIXA AND WATER BOATMAN ARE USUALLY 5-20 MM IN LENGTH AND WATER SCORPIONS UP TO 50 MM.

They feed on particulate organic matter which they scoop up with their front legs. One of the most common species is the small corixid *Micronecta robusta*, which is particularly abundant in nutrient enriched waters. Usually the flatter and slightly smaller nymphal stages are also present in large numbers.

Water boatmen are elongate insects, under 12 mm in length, with long back legs that are used for swimming and resemble long oars, hence the name water boatman (Fig. 5.9b). Unlike corixids, which are mainly seen on the bottom, water boatman are carnivores of the open water, sometimes aggregating in large numbers. They prey upon small aquatic animals, including small tadpoles and fish, and can even inflict a painful bite to humans.

Water scorpions are large voracious predatory insects approaching 5 cm in length (Fig. 5.9c). They are dull coloured, stick-like or flat and broad in form and have very long legs. The first pair are prehensile, with backward facing claw-like forelegs which are used to capture prey and then hold it during feeding. A characteristic feature of water scorpions is a long respiratory tube at the end of the body. This tube is pushed through the water surface and into the atmosphere to collect a long bubble of air for breathing.

Blackfly larvae *(Insecta: Simulidae)*

Blackfly larvae are black or grey coloured grub-like animals no more than 10 mm in length (Fig. 5.10). They are mostly found in rapidly flowing waters, clinging to rocks and logs with the aid of a posterior sucker equipped with hooks. They feed by sieving the water of tiny animals, dead particulate organic matter and algae, using comb-like structures on their heads. If the larvae wish to move or are dislodged they make use of a silky thread which is attached to the stream bed or log and acts as a safety line. Larval life is very short and may last only a few weeks (Williams 1981). There is also a short pupal stage in which the animal develops within a fixed cocoon. Blackfly larvae are not limited to permanent waters and apparently are tolerant to periods of dryness (Williams 1981).

Midge and biting midge larvae
(Insecta: Diptera)

Large swarms of little black flies are often encountered among the fringing vegetation of the stream. These are adult midges of the family Chironomidae, and their aquatic larval stages are among the most common and abundant of aquatic fauna, being found in the sediments of nearly all stream environments. Midge larvae are segmented, worm-like, with a distinct head, a pair of tiny prolegs and finger-like gills on the last segment (Fig. 5.11a). They are generally under 15 mm in length, but some of the larger species may approach 20 mm in length. Their colours vary and include white, green and red. The large red larvae of the genus Chironomus are easily sorted from sediment, the red colour being produced by the high content of larval blood, which is advantageous in the low oxygen conditions of the more putrid sediments (Williams 1981). Depending on the species, midge larvae are herbivorous, carnivorous or detrital feeders. The pupal stage, in which the developing adult can be discerned, is inactive and rises to the surface when the adult is ready to emerge. Interestingly, midge pupae are an important component of the diet of native fishes (Pen and Potter 1991a), suggesting that the stage is particularly prone to predation.

Adult biting midges, of the family Ceratopogonidae, can inflict a bite which is totally out of proportion to their tiny size. Their larvae are elongate and mostly featureless worm-like animals less than 12 mm in length and usually light green in colour (Fig. 5.11b). The larvae are common in wet sand, organic sediments along the stream margins, rock pools and amongst algae.

Caddisfly larvae *(Insecta: Trichoptera)*

Caddisfly larvae build a larval case of sand grains, twigs or pieces of plant material, depending on the species (Fig. 5.12). The case protects the soft abdomen, while the hard head, thorax and thoracic legs protrude from the case when the larvae are active. Larval cases of the various species may be conical or coiled, and round, square or triangular in cross section. The larvae are mostly less than 10 mm in length and inhabit a wide range of stream environments. Depending on the species, they may be carnivorous, herbivorous or omnivorous. Caddisfly larvae remain in the case and spin a cocoon about themselves for final development into their adult form.

Waterbeetles and their larvae *(Insecta: Coleoptera)*

Waterbeetles are, as beetles are in general, a very diverse group of animals and the streams of the south-west support a great many species. They vary in size from only 2 mm across to up to 40 mm in length and in coloration from jet black to multicoloured, mostly with mottled or striped patterns of dark browns and yellows (Fig. 5.13). Most have mouth parts for biting, but while many species have features which reflect an aquatic life, such as a streamlined form and legs modified for swimming, others show no apparent structural difference from terrestrial beetles. As people who have freshwater pools will know, waterbeetles can fly, a useful ability as it permits adult beetles to quit sites which are no longer favourable and fly in search of better habitats.

Waterbeetle larvae are also aquatic and vary greatly in structure (Fig. 5.14). They may be hard skinned predators with well developed mandibles or they may be soft bodied and grub-like plant eaters. Pupae are almost always terrestrial (Williams 1981). Most adults and some larvae require atmospheric oxygen for respiration and must renew supplies by coming to the water surface. The adults of many species store air in bubbles about the body surface.

The adults and larvae of some species are voracious predators, attacking small aquatic animals and even tadpoles and small fish. However, some species may be carnivorous as larvae and herbivorous as adults, while in other species this situation may be reversed. Probably the most impressive of waterbeetles in south-west streams is the giant *Homoeodytes scutellaris*, which grows to about 25 mm in length and resembles a typical waterbeetle. Its larvae grow to 4 cm in length and have large mandibles.

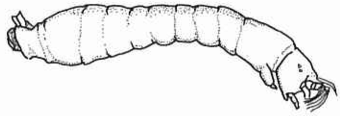


FIGURE 5.10 EXAMPLE OF A BLACKFLY LARVA, LESS THAN 10 MM IN LENGTH.

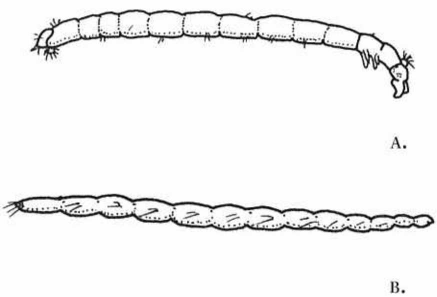


FIGURE 5.11 EXAMPLE OF A MIDGE LARVA (A) AND BITING MIDGE LARVA (B). GENERALLY LESS THAN 15 MM IN LENGTH

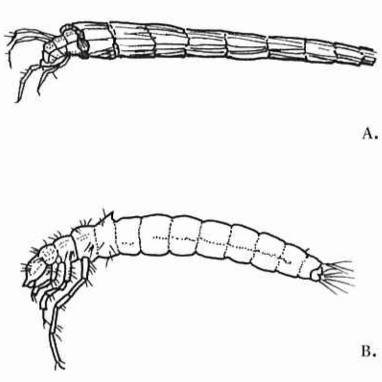


FIGURE 5.12 EXAMPLE OF CADDISFLY LARVAE, ONE WITH PROTECTIVE CASE (A) AND ONE WITH CASE REMOVED (B). LARVAE ARE MOSTLY LESS THAN 10 MM IN LENGTH

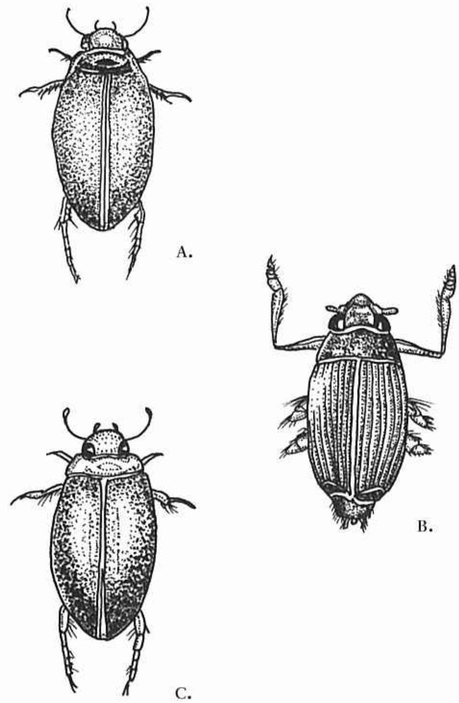


FIGURE 5.13 EXAMPLES OF ADULT WATERBEETLES. MOST SPECIES ARE LESS THAN 20 MM IN LENGTH. EXAMPLE (B) IS A WHIRLYGIG BEETLE WITH SHORT BACK LEGS TO SKATE ACROSS THE WATER SURFACE (SEE SECTION 5.1.4)

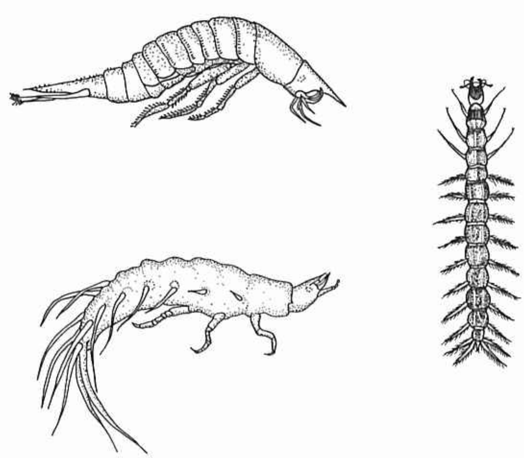


FIGURE 5.14 EXAMPLES OF WATERBEETLE LARVAE

5.1.3 Large benthic invertebrates

Freshwater mussel and other shellfish *(Mollusca: Bivalva)*

Bivalve molluscs have two shells or valves which are hinged dorsally and which enclose the body of the animal. The freshwater mussel, *Westralunio carteri*, is the only bivalve mollusc present in freshwater streams of the south-west. Large numbers are often found in shallow moderately flowing water amongst leaves and woody debris. The species is brown in colour, grows to about 6 cm across (Wells 1984) and, like all mussels, is a filter feeder, sucking water in via its inhalent siphon and expelling it via its exhalent siphon. Food particles, consisting of tiny planktonic creatures, are filtered out across the gills, with inedible inorganic particles separated out prior to ingestion. Mussels have a large muscular foot which can be protruded beyond the partly open valves to enable them to move around.

With the increasing salinisation of our south-west rivers, one estuarine bivalve mollusc has moved upstream to exploit the saline conditions. Along the Avon River, the small false mussel, *Fluviolanatus subtorta* (less than 2 cm), is very common today (Kendrick 1976; Wells 1984). The shells of long dead animals litter the river bed in some places.

Shrimp *(Crustacea: Decapoda)*

The south-west of Western Australia has one species of freshwater shrimp, *Palaemonetes australis*. This small species, growing to about 3 cm in length, is quite common and sometimes superabundant in permanent and temporary waters. Palaemonetes has very long legs and is transparent and dull olive green in colour, though large females may have brown diagonal markings on the flanks of their exoskeleton. Breeding is in spring and, as with crayfish (see below), females carry their eggs and subsequently their young on the pleopods of their abdomen. Individual females may carry between 20 and 60 young (Bray 1978). Observations suggest that the species is omnivorous (Hodgkin 1978).

Crayfish *(Crustacea: Decapoda)*

Marron, gilgies and koonacs are collectively known as freshwater crayfish (Riek 1967). All have a typical lobster form with large well developed claws, all burrow to some extent and breed in winter and early spring, and females of all species carry their eggs and young on the pleopods of their abdomens. They differ, however, in their size and habitat associations.

The marron (*Cherax tenuimanus*) was naturally found in deeper perennial waters of the southern jarrah forest and karri forest, but through artificial introductions to extend a regulated recreational activity known as 'marroning', the species is now found in all river systems between the Moore River (north of Perth) and the Waychinicup River (just east of Albany) (Morrissy 1978). Marron have also been introduced into many farm dams throughout the wheatbelt (Morrissy 1978).

The marron is known to be an 'opportunistic scavenger', foraging at night and eating practically anything organic, living or dead (Coy 1979; Fisheries 1980). Its dietary breadth is no doubt enhanced by its large size; reaching nearly 400 mm in total length and 2 kilograms in weight (Coy 1979). In fact it is the third largest freshwater crayfish in Australia and the world. However, these days, because of heavy marroning and poaching, few individuals reach more than 300 mm in length or a kilogram in weight. Nevertheless marron are still present in large numbers in the larger of the south-west rivers and creeks, and remain by far the largest and most dominant of the benthic invertebrates in south-west streams. Although the stream ecology of marron has never been studied comprehensively, the large size of the animal and the scope of its diet must render it one of the most crucial components of the south-west stream ecosystem. Indeed its diet, involving all levels of the food chain, is probably why the species is capable of reaching a size and level of abundance sufficient to support a recreational fishery.

Gilgies (*Cherax quinquecarinatus* and *C. preissii*) are superficially similar to marron but grow generally to only 80 mm in body length, although specimens as large as 120 mm have been collected. Whereas marron are generally black in colour, and sometimes even deep blue, gilgies are mostly olive green or tawny brown. In proportion to their size gilgies have larger claws. The distribution of gilgies is similar to that of present day marron, except that they can occupy shallower waters. Gilgies appear to have a similar diet to marron.

Koonacs (*Cherax plebejus* and *C. glaber*) occupy seasonally inundated habitats including seasonal streams. They are intermediate in size between marron and gilgies, reaching body lengths of between 60 and 160 mm. They exhibit a great variety of colorations, including black, red, blue and green, with or without coloured spots, patches or dorsal stripes. A single stretch of creek can have koonacs of various colorations. Koonacs survive dry periods in long vertical burrows that reach down to the groundwater (Horwitz and Richardson 1986). These burrows are evident in winter and spring by mud chimneys at their entrance, but disappear completely from the land surface in summer. In a study along a Dunsborough creek, koonac burrows were found to contain about one animal per burrow, but some had two, a male and female, and some had gravid females (Horwitz and Knott 1983). Just what koonacs eat is unknown.

5.1.4 Animals of the water surface

Springtails *(Insecta: Collembola)*

Collembolans are tiny little wingless insects, no longer than 4 mm in length, that often inhabit the surface film of fresh waters, including those of streams (Fig. 5.15). They are usually pink, grey or purple in colour and have a silvery sheen. Their posterior segment is in the form of a fork shaped springing organ which enables collembolans to leap into the air, hence the common name springtails. Collembolans are most common in winter and can be found in huge aggregations, especially when washed up against a piece of debris lying across the water surface of a creek.

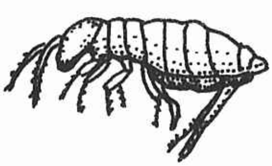


FIGURE 5.15 A TYPICAL SPRINGTAIL OR COLLEMBOLAN, LESS THAN 4 MM IN LENGTH.

Water walkers *(Insecta: Hemiptera)*

Water walkers are long legged active insects that skate across the water surface in search of prey, usually other insects which have landed or fallen onto the water surface. They are generally under 12 mm in length and occur in groups (Williams 1981).

Water spiders *(Arachnida)*

Large green hunting spiders, about the size of a twenty to fifty cent piece, are found among the fringing vegetation of still and slowly flowing waters. They are of the family Pisaridae and genus Dolomodes. They can walk on water and even break the surface film to grapple with insects, tadpoles and tiny fish that venture near the surface. These days, when our rivers are infested with large numbers of the small introduced mosquito fish (see below), that spend most of their time near the water surface, hunting by these fish-eating spiders must be very profitable.

Whirligig beetles *(Insecta: Coleoptera)*

Whirligig beetles, of the family Gyrinidae, can often be seen whirling around in large numbers on the still water surface of the edges of river pools or where the water is only slowly flowing. They are oval in shape and jet black in colour and are about 10-15 mm long (Fig. 5.13b). Their back two pairs of legs are greatly shortened and help them to skate along the water surface in search of prey. When disturbed they submerge and swim to the bottom or scatter into fringing vegetation. The most common species are of the genus Macrogyrus, whose larvae are entirely aquatic.

5.1.5 The pouched lamprey

The pouched lamprey (*Geotria australis*) belongs to a group of primitive eel-like and jawless fish. Unlike true bony fishes, lampreys have no paired fins and have a cartilagenous skeleton. Their mouths consist of a suctorial disc, lined with tiny teeth, and a toothed tongue, which they use to extract muscle tissue and blood from their prey. Fossil evidence suggests that lampreys have been in existence for over 280 million years and have changed little in form in that time (Potter et al. 1986b).

The pouched lamprey occurs in the temperate regions of the southern hemisphere, being found in the rivers of southern South America, southern Australia and New Zealand. In south-west Australia it is most common in the river systems of the cool moist karri forest region, including the Donnelly, Warren, Gardner, Shannon and Deep Rivers, but is also found in some other streams south of the Swan River (Morgan et al. 1998).

As with most lamprey species, the pouched lamprey spends most of its adult life at sea, re-entering rivers and embarking upon an arduous migration to permanent headwater creeks where it spawns and dies. Small larval lampreys, known as ammocoetes (pronounced am-mo-seats) spend about four years filter feeding from burrows in soft sediments before metamorphosing into miniature adults and moving to the ocean. (Section 5.2.3 describes the life cycle of the pouched lamprey in greater detail).

The adult pouched lamprey is about 650 mm long, has two dorsal fins and one tail fin, seven small round gill slits on each side, one nostril and a primitive pineal eye on the back of its head[4]. Marine adults are a brilliant cobalt blue and silver in colour with bright greenish dorso-lateral stripes. On entering fresh water, adults become greyish blue initially and finally brown, with males developing a large sac or pouch, hence the name, which hangs down just behind the mouth. The function of the pouch is unknown. Ammocoetes range in length from 10-80 mm, have no eyes and are dull brown or black in colour, while recently metamorphosed young adults, known as 'downstream migrants' are beautiful miniature versions of their parents.

5.1.6 Fish

The fish of south-west rivers can be divided into four groups: native riverine species, introduced species, estuarine spillovers and marine visitors. There are six riverine species: the western minnow, western mud minnow, nightfish, western pygmy perch, Balston's perchlet and freshwater cobbler. Only the cobbler commonly grows longer than 15 cm. All of these species are found only in the south-west of Western Australia, between Moore River and Albany (Allen 1982). The western mud minnow and Balston's perchlet are mainly found in the area between Margaret River and Denmark.

Another two native minnows are found in the lower south-west in lakes, streams and coastal lagoons between Walpole and Esperance. They are the spotted mountain minnow (*Galaxias truttaceus*) and the common jollytail (*Galaxias maculatus*). Both species grow commonly to about 10 cm in length and occur in the south-east and south-west of Australia, in landlocked and 'ocean run' populations. The extent to which these species are landlocked or make use of river environments in the south-west is under investigation (Morgan et al. 1998).

Two introduced freshwater fish are now common in the south-west, the redfin perch and the mosquito fish, also known by its scientific name, Gambusia. Two trout species, the rainbow and the brown, are stocked in some rivers and creeks of the south-west for recreational fishing. Crucian carp and goldfish, both introduced, have been recorded in some rivers (Allen 1982).

Some of the most common fish species in south-west rivers are essentially estuarine, but also live and breed in river waters. None grow larger than 12 cm. The Swan River hardyhead and the Swan River or blue-spot goby are very abundant in some south-west rivers, perhaps the saline ones, and can be found considerable distances inland (Allen 1982). The big-headed goby is common in west coast rivers and is present in small numbers in south coast rivers between Augusta and Albany (Morgan et al. 1998). The relatively large sea mullet, a marine species, is known to move up large rivers in large numbers in many parts of the world, and south-west rivers are no exception (Merrick and Schmida 1984). Finally the estuarine black bream lives in the lower tidal reaches of rivers.

[4] The pineal eye is a primitive eye-like structure present in some primitive animals. Its function is thought to be related to the regulation of diurnal (day-night) rhythms of the body.

Freshwater fish

Western minnow *(Galaxias occidentalis)*

The western minnow is a highly muscular torpedo shaped fish, commonly growing to 10-12 cm in length. Larger animals from 13 to 20 cm are sometimes present within a school of smaller fish. The upper parts and flanks of the minnow are light olive green in colour and are dotted in a myriad of tiny black spots, which may be arranged in a more or less even pattern or in vertical 'tiger' stripes. The belly is silvery white, fins amber and the eye golden. Characteristic features of galaxiids are a single soft dorsal fin and the absence of scales.

The western minnow is entirely carnivorous and will eat a wide variety of aquatic organisms from tiny planktonic crustaceans to large water beetles. While smaller fish mainly eat planktonic invertebrates, it appears that as they grow bigger they increasingly feed from the water's surface, taking insects and spiders which land on, or fall onto, the surface film (Pen and Potter 1991a). In fact the western minnow will leap out of the water to take insects flying just above the water surface. A telltale sign of minnows is ringlets of water moving along the edge of the river in the early evening as the school forages for food.

Unlike the other native species which hug the bottom, are nocturnal or seldom stray from cover, the western minnow is an open water and daylight-active species, except when migrating. It prefers to swim in schools in moderately flowing water, especially circling eddies of water, often feeding on animals drifting in the water column.

Ageing studies in the Collie River have shown that the western minnow can live beyond five years of age, but few fish reach their second year (Pen and Potter 1991a). Fortunately, both males and females breed near the end of their first year of life. Spawning takes place in headwater creeks in winter and spring, with the female western minnow producing between 200 and 2500 eggs, the number of eggs per female generally increasing with fish size (Pen and Potter 1991b).

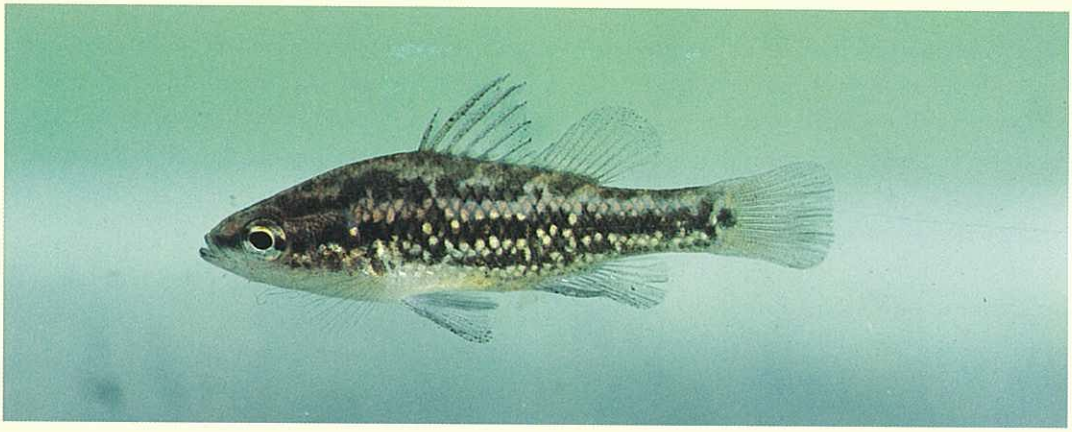
The western minnow is sometimes infected with parasitic nematode and trematode worms (Pen and Potter unpub. data). The nematode worm, which can be as much as 60 mm long and 1 mm in diameter, can usually be seen coiled in a cyst beneath the skin of the belly. Infected fish mostly carry between one and three nematodes. Trematode worms are microscopic and don't actually resemble true worms at all. They are sometimes present in fish within small black cysts, about 1-2 mm across, within the skin, flesh or even fins of the fish. Usually only one cyst is present in an infected fish, but some fish can carry thirty or more (see below).

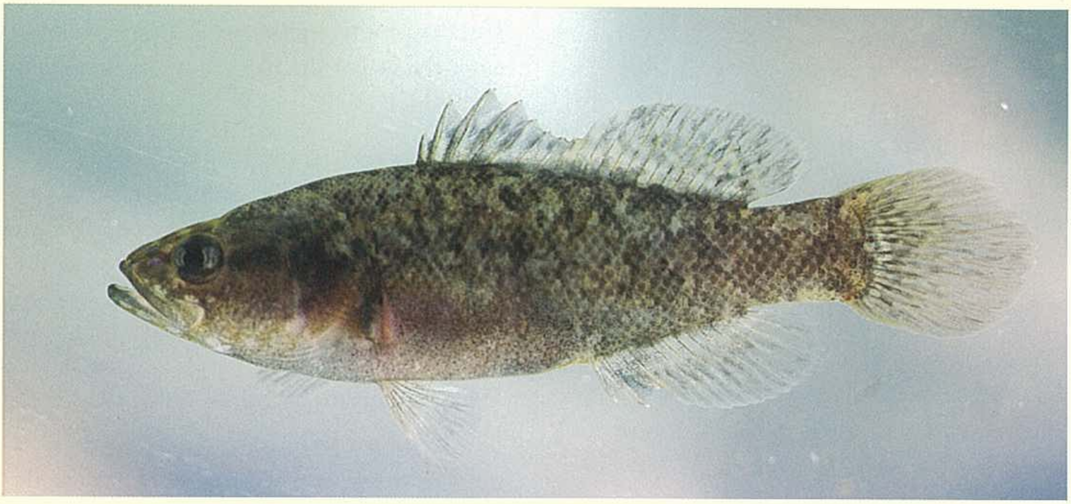
The western minnow is a very fast swimmer and would be a difficult prey for many fish-eating predators such as turtles, water rats, herons and the large introduced redfin perch. Probably the most important predators are the little pied and little black cormorants.

Western mud minnow *(Galaxiella munda)*

The western mud minnow is a galaxiid similar in basic form to the western minnow, except that it is generally much smaller; with adults mainly between 3 and 5 cm in length. The back and sides of this scaleless fish are brown to olive green with a longitudinal silver and gold stripe, while the belly is silvery white. As its name suggests, it can be found in the mud, mostly of minor order streams of the karri forest between the Donnelly and Denmark Rivers (Morgan et al. 1998).

A rare sight. A lamprey out in the open in daylight. Seen here on the Lefroy Brook near Pemberton just at the base of the Rainbow Trail gauging weir. Photo: L.Pen





The three most common and widespread native fish in the south-west of Western Australia: western pygmy perch, nightfish and western minnow. The pygmy perch grows no larger than 70 mm in length and the other two are seldom longer than 120 mm. Photo: L. Pen

The mud minnow lives for only slightly more than a year, dying shortly after spawning in the winter/spring period (Pen et al. 1991). Spawning appears to take place amongst the flooded fringing vegetation and woody debris of the same stretch of creek in which they live. Unlike the western minnow which produces one large clutch of eggs which is shed and spawned all at once, the mud minnow produces a number of small clutches of eggs over the breeding season. Each clutch varies between 30 and 100 mature eggs.

The diet of the mud minnow is a combination of terrestrial fauna, presumably taken from the water surface, tiny planktonic animals and small midge larvae from the stream bottom (Pen et al. 1991).

Nightfish *(Bostockia porosa)*

The nightfish is closely related to the giant Murray cod of the eastern states. But while the latter species grows to nearly 2 m in length and over 110 kg in weight, the nightfish seldom grows larger than 16 cm and 20 g. Nevertheless the nightfish is a beautiful and very interesting fish. Typical specimens are between 60 and 100 mm in length. The backs and sides are mottled olive brown to dark purplish brown and the breast and belly pinkish white. The fins are lightly to moderately pigmented in a mottled pattern. A characteristic feature of the nightfish is a series of large pores beneath the eyes and along the snout.

Nightfish spend the daylight hours hiding amongst aquatic vegetation, rocks or woody debris, coming out in the early evening to forage for food, which mostly consists of small crustaceans and midge larvae (Pen and Potter 1990). Larger fish may take larger prey, such as dragonfly larvae, shrimp and snails. Recent observations have shown that juvenile nightfish, which are present in the shallow floodwaters of late spring, feed during the day (Morgan et al. 1998).

Studies of the nightfish in the Collie River have shown that fish can reach more than six years of age, but that few survive for more than three years. Males mature in their first year of life and females not until their second. Spawning occurs in headwater creeks during winter and spring, with females producing between 200 and 1200 eggs, the larger the fish the more eggs (Pen and Potter 1990).

The main natural predators of the nightfish are probably water rats, turtles and cormorants, but in some areas the introduced redfin perch, a very abundant and common large fish, probably accounts for most of the predation (Pen and Potter 1992).

Western pygmy perch *(Edelia vittata)*

The small western pygmy perch is one of the most common and abundant of fishes in the fresh waters of the south-west. It grows no larger than 7 cm in length and most adults are between 3 and 5 cm. It is brownish in colour, being generally darker on the back and with some whitish yellow or golden bands either side of a dark brown irregular lateral stripe. The belly can be lighter in colour and the fins are lightly to moderately pigmented. During the breeding season, the male pygmy perch take on brilliant breeding colours. They become much darker, their lateral bands and stripes become more prominent and the belly turns a bright orange. The only change to the females is perhaps a bluish tinge to the back.

During the day pygmy perch keep close to cover such as that provided by rocks, aquatic vegetation and woody debris, but they still move around in a loose aggregation. In the evenings they will move further from cover and even into shallow waters a few centimetres deep to forage for food. Due to the size limitation imposed by their small mouth, they eat a wide range of small aquatic animals, mainly from the stream bottom (Pen et al. 1993).

The population of the pygmy perch in the Collie River was found to be mainly under two years of age, with less than one per cent in their third, fourth or fifth year of life. Both males and females mature in their first year and spawning takes place in seasonal creeks and well vegetated floodwaters (Pen and Potter 1991c).

Balston's perchlet
(Nannatherina balstoni)

Balston's perchlet is closely related to the western pygmy perch, but grows considerably larger, reaching lengths of up to 90 mm. It has a similar coloration, being brown to dark brown and grading to yellowish white on the breast and belly. It often has a darker brown mid-lateral stripe with yellowish white diamond shape blotches or stripes either side. Balston's perchlet can be distinguished from the pygmy perch by its large mouth, which extends below the eye.

Today the main area of distribution of Balston's perchlet lies between the Warren and Shannon Rivers, but individuals have been collected in tributaries of the lower Blackwood and Scott Rivers, as well as in the Margaret River and streams of the Two Peoples Bay area, east of Albany. In fact a single fish was caught in the Collie River Southern Branch in 1985, close to the northern headwaters of the middle Blackwood, and there is a record from an area 80 km north of Perth (Morgan et al. 1998). Both these records suggest that the species was more widely distributed in the past, prior to loss of much suitable habitat through urban and rural development (Morgan et al. 1998).

In its natural streamline habitat, Balston's perchlet has never been found to be abundant. It is typically found among fringing vegetation where it presumably feeds and breeds. Studies carried out on the south coast show that small perchlets consume tiny crustaceans, while the larger fish mainly feed upon terrestrial insects and spiders (Gill and Morgan 1998). Breeding occurs in winter and early spring, at the end of the first year of life when fish are about 60 mm in length (Morgan et al. 1995). Females carry between 550 and 1600 eggs.

Freshwater cobbler *(Tandanus bostocki)*

The freshwater cobbler is an eel-tail catfish which grows to about 60 cm in length and 2 kg in weight. It ranges in colour from black to mottled brown and black; the breast is usually whitish in colour. There are eight barbels or whiskers projecting from behind the mouth and the skin is tough and scaleless. The dorsal fin and pectoral fins have venomous spines.

Little is known about the life cycle of the freshwater cobbler in the natural riverine habitat. However, studies of populations in Wungong Dam near Perth have found that the species breeds from late spring to early summer and feeds upon insect larvae, shrimps, crayfish, molluscs and small fish (Morrison 1988; Hewitt 1992).

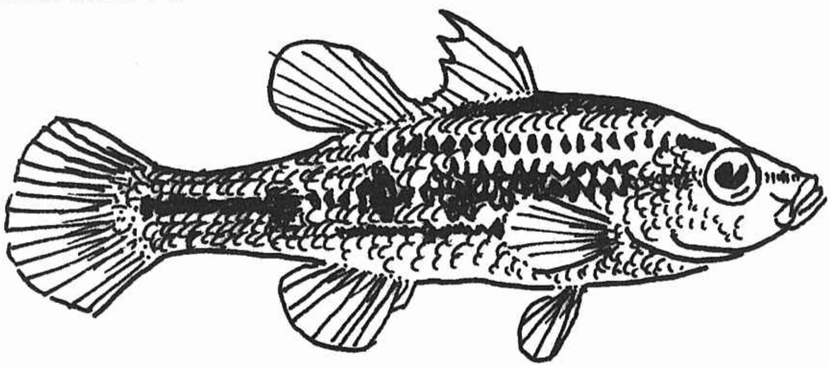
case study

Pygmy perch spawning

The late Bruce Shipway, once the manager of the Pemberton trout hatchery, made some observations of pygmy perch spawning in the late 1940s (Shipway 1949). It remains the only work to date to have documented the spawning of a native south-west fish species.

Like the mud minnow, the pygmy perch produces a number of clutches of eggs over the breeding period. A single clutch appears to be shed more or less continuously over a period of a week or so, after which spawning is not resumed for 6 to 8 weeks. Shipway observed that over a period of a week a large female produced about 60 eggs while a number of smaller ones produced fewer than 20 each. The eggs were observed to fall amongst aquatic vegetation where one or more males would fertilise them. He noted that a number of males would concentrate upon a single spawning female and a larger one would try to chase off the smaller males. While this was going on, non-spawning females would dart in to eat the eggs if they could. Fertilised eggs were observed to hatch after 60-72 hours and the subsequent fish larvae to develop into adult form in 2-3 weeks.

Given that the pygmy perch can live for a good few years, will breed in captivity, is not shy of people (in fact will come to the glass to see what's going on) and has brilliant breeding colours, it is hard to understand why the aquarium industry has not made more use of this little indigenous species.



Introduced fish

Redfin perch *(Perca fluviatilis)*

Redfin perch is a deep robust fish, with a large head and mouth, reaching 250-430 mm in length and over 2 kg in weight. As it grows the head becomes proportionately smaller and the fish develops a characteristic humped back. In colour it is olive to brassy green and has six to nine wide vertical dark bars down each flank; the fins are characteristically red, pink or orange. The dorsal fin is very pronounced with pungent fin rays which need to be avoided when handling the fish. The gill covers also have a backwards facing spine.

Redfin prefer still waters and slow moving sections of rivers and are very tough, able to survive high temperatures and low dissolved oxygen levels. They breed in the quieter waters among aquatic vegetation in spring, producing hundreds of thousands of eggs. Studies in New Zealand have shown that redfin reach 100-150 mm by the end of their first year of life and can live for five or more years, maturing generally in their first or second year (Jellyman 1980).

The natural distribution of redfin is centred on the temperate regions of Europe and northern and eastern Asia. Today redfin is one of the most widely translocated of freshwater fishes, arriving in Western Australia in 1892 to fill a gap in the 'table-fish' resource of the inland south-west[5]. It was introduced to a lake near Albany, and in one way or another has found its way to almost every freshwater river and lake in the south-west. Due to a lack of natural enemies, and probably also fishing pressure (as the fish is considered by all but die-hard redfin fishers to have poor sporting qualities, though excellent eating qualities), it has produced large populations of mostly small fish, which must take a terrible toll of our native aquatic fauna. Studies have shown that the fish will eat pygmy perch and nightfish, but mainly feeds on freshwater crayfish (Pen and Potter 1992). On the lower Murray River redfin perch have been linked circumstantially to a major decline of the pygmy perch population (Hutchison 1991). The impact of redfin perch on the recreational marron fishery is unknown. Ironically there is today a demand from some inland fishers to make further introductions of large sporting and table fishes.

Mosquito fish *(Gambusia holbrooki)*

The mosquito fish is small, less than 60 mm in length, has a flattened upper surface, upward facing small mouth and a large rounded belly. Back coloration is greenish blue, sides are grey and belly white. Females develop a large bluish black spot on each side of the body in front of the anal fin when they mature. Males only grow to 35 mm in length and are different in form to females, being slimmer and having an elongate anal fin, known as a gonopodium, used to fertilise females. The females give birth to live young.

Gambusia prefer warm shallow sunlit waters which are still or only slowly flowing. Breeding occurs from spring to autumn in the south-west, with females producing from 10 to 250 young, following about four weeks of pregnancy. Females

[5] Although most people then and now live near the coast where there is more than ample opportunity for table and sporting fishing, inland people perceived the need for a table fish to supplement their sources of food. Remember this was at the time before motor cars.

can produce more than one brood per season and their young are ready to produce their own in about two months. In this way gambusia numbers can explode and if the summer is a particularly long one, as in 1994-95, they can produce super populations right along the lengths of rivers, so that wherever you look you will see gambusia. Fortunately, gambusia live only short lives, from a few months to just over a year, generally dying in or at the end of the breeding season in which they mature (Krumholz 1948). Young which fail to mature in the current summer, over-winter in cold unfavourable winter waters, to give rise to the next summer's explosive population (Pen and Potter 1991d).

The mosquito fish is native to the rivers that drain into the Gulf of Mexico. The fish's capacity to breed up into huge populations in a short time and to feed voraciously on aquatic insects and crustaceans has lead to its translocation throughout the world to combat mosquito breeding. Its introduction to Australia in the 1920s and then Western Australia in the 1930s was, as with the redfin perch, thought to be a good idea at the time. Today gambusia are easily the most abundant aquatic vertebrate in the freshwater rivers of the south-west. The presence of such an abundant and carnivorous fish species has probably had a severe impact on the food webs of near-natural stream ecosystems (Horwitz 1994). Although the mosquito fish has been shown to have little effect on native fish of the Collie River, it has been observed to attack native fish in some lake environments, tearing the fish apart, and to clip the fins of native fish in these wetlands and also along the Blackwood River during the long summer of 1994-95 (Pen and Potter 1991d; Morgan et al. 1998; Hambleton 1996). The impact of the mosquito fish on mosquito populations is unknown. The value of mosquito fish as food to other animals is also unknown, but it is certainly not important to the diet of redfin perch in the Collie River (Pen and Potter 1992).

Rainbow trout *(Oncorhynchus mykiss)* and brown trout *(Salmo trutta)*

In south-west rivers rainbow trout typically grow to about 600 mm in length and 2 kg in weight. An adult rainbow has an olive green back, light green sides and silvery white belly. The head and body are profusely marked with small black spots which are denser on the upper part of the body. Often there is a pink flush to the sides which gives the rainbow effect. Juvenile rainbows are bluish grey with many spots on the body and dorsal and tail fins. Fingerlings have a number of distinct blotches along their flanks and black spots along their backs. Their fins are orange.

Brown trout also grow to about 600 mm but have a deeper body and thus reach larger weights than rainbow trout. The adult fish is darkly coloured, with a dark brown or olive green back. The upper part of the body has dark spots while the more lightly coloured lower part has red spots. The fins are yellowish and golden. Juveniles are greyish with a brown tinge and distinct dark blotches, known as parr marks, along the flanks. These parr marks become darker in the fingerling stage and there are large brown spots along the flanks.

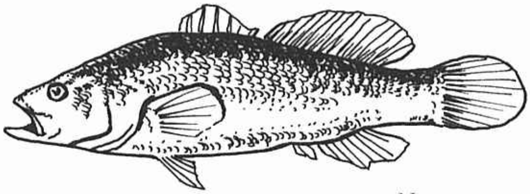
Rainbow trout are native to the coastal river systems of western North America, while brown trout are native to Europe and western Asia. Both species have been widely translocated throughout the world to provide a western style of freshwater fishing. Brown trout were introduced to the south-west of Western Australia as early as 1874 and rainbow trout not until 1902.

In Australia, rainbow trout can live for about five years, with both males and females breeding for the first time in their second or third year of life, sometime in early winter or spring (Merrick and Schmida 1984). It is at this time that rainbows can be seen attempting to leap over weirs and waterfalls as they undertake their annual pre-spawning upstream migration. Brown trout generally do not mature until their third year and live for nine years or more. They spawn in autumn to late winter. Both species require stream sections with gravel beds for spawning, but as these are few and far between in the south-west, reproductive success is low and trout numbers can only be maintained by artificial stocking from the Pemberton trout hatchery. Hopefully this means that trout have little potential to infest south-west rivers, as redfin perch have done. The diets of the trouts include small fish, aquatic insects, molluscs and crustaceans, and terrestrial insects taken from the water surface.

Carp *(Carassius species)*

Two carp species have been reported from south-west streams, Crucian carp *(Carassius carassius)* and goldfish *(Carassius auratus)* (Allen 1982). Both can be recognised by their similarity to the goldfish kept in household aquaria, except that they grow to 2 kg or more, and are more dull in colour in keeping with the tannin stained water. The two species are closely related and are difficult to distinguish, growing to about 30 cm in length. Goldfish are native to Asia and Crucian carp to Europe (Merrick and Schmida 1984).

Both species breed in spring and are omnivorous, feeding on a wide range of aquatic animals and algae. Carp are known to be bottom feeders and in the eastern states have a bad reputation for stirring up the bottom sediments and muddying the habitats of native aquatic fauna.



Nightfish

Estuarine and marine species

Swan River hardyhead *(Leptatherina wallacei)*

From a distance it is easy to mistake this species for the western minnow as it is similar in form, being elongate and growing to about 80 mm in length. But close up its different coloration of olive upper parts and silvery sides with prominent copper bands, as well as the presence of scales and two dorsal fins, enables it to be distinguished easily. The hardyhead is mainly an estuarine species but has penetrated well inland along the more saline rivers, such as the Blackwood, Avon and Moore, where it can be found in huge schools (Allen 1982). In the Blackwood large numbers can be seen as far upstream as Duranillan (Morgan et al. 1998).

The Swan River hardyhead lives for just over a year, breeding in spring, and subsequently dying. Estuarine fish are known to eat planktonic crustaceans, flying insects, worms and unicellular algae (Prince et al. 1982; Prince and Potter 1983; Potter et al. 1986a).

Swan River goby *(Pseudogobius olorum)* and big-headed goby *(Afurcagobious suppositus)*

Gobies are tiny bottom dwelling fish whose pectoral fins (the bottom ones just behind the head) are fused to form a single sucker-like disc. This disc probably helps them cling to submerged objects and to the bottom. The Swan River goby is mostly light brown, becoming paler on its lower parts, and has dark blotches along its sides. It grows no larger than 60 mm in length and has a small mouth which extends to the front of the eyes. The big-headed goby can grow as long as 110 mm and can be distinguished by its large mouth, which extends beneath the eyes. It is light brown, becoming darker above and paler below, and as with the other species has a number of dark blotches along its sides.

Both gobies are most abundant in south-west estuaries, but they are also found in nearby coastal lakes and associated rivers. In estuaries, both species live for at least a year and spawn in spring, with the Swan River goby also spawning in autumn (Gill et al. 1996). Estuarine populations of the Swan River goby have been found to eat algae and mats of bacteria and fungi, as well as tiny aquatic animals, whereas lake populations of the big-headed goby eat aquatic insects, molluscs, terrestrial and aquatic insects and tiny fish (Fairhurst 1993).

The big-headed goby has only been found in small numbers in some south-west streams. The Swan River goby is very abundant in a number of south-west river systems, especially, it would seem, in the more saline ones like the Murray and Blackwood. Despite their abundance, however, they are difficult to spot due to their small size, almost perfect camouflage and habit of sitting very still on the stream bed until disturbed, whereupon they quickly move to another spot where they again sit perfectly still.

Sea mullet *(Mugil cephalus)*

Sea mullet is a marine species, reaching 90 cm in length, which happens to spend long periods of time in deep river waters. It can be recognised by its elongate body, flat head and small mouth and two separate dorsal fins. In rivers its coloration is blue, green or brown, being darker on the back than on the sides, and lighter again on the belly.

The species is a bottom feeding omnivore, taking a wide variety of plant, animal and detrital material in rivers and estuaries. Spawning occurs at sea, sometime between autumn and spring, and occurs for the first time when the fish are about three years of age (Merrick and Schmida 1984).

Black bream *(Acanthopagrus butcheri)*

This robust and moderately compressed silvery coloured fish, growing to about 500 mm long, is mainly an estuarine species, but will make considerable use of lower non-estuarine reaches of rivers to feed on small aquatic animals and plant material (Fisheries 1993).

5.1.7 Frogs

The south-west of Western Australia is home to at least twenty-six frog species, with three new species being discovered only recently (Tyler et al. 1994; Roberts et al. 1997). Of the twenty-six, about twenty spend a substantial part of their life cycle along streams, the others being frogs of the forest floor or granite outcrops. Most are ground dwelling and burrowing species, but two (of the Litoria genus) are capable of climbing vegetation and are known as tree frogs; however even these probably spend as much or more time on the ground (Main 1965). Although frogs are not conspicuous along streams, their abundance in winter is indicated by the clamour of the mating calls of advertising males.

Frogs are 'unspecialised opportunistic feeders', mainly eating insects (Williams 1983). Tadpoles mainly eat algae. Their main predators are water spiders, water scorpions, dragonfly larvae, large water beetles and their larvae, the turtle, tiger snake and waterbirds.

The quacking frog *(Crinia georgiana)*

This small (20-40 mm long) light to dark grey, brown or black frog is found throughout the jarrah and karri forests and along the coast to Esperance. It inhabits swampy areas along streams which become inundated with shallow water in winter. Breeding takes place in mid-winter and early spring, with eggs laid freely in shallow water or on wet ground which will soon be flooded.

Lea's frog *(Geocrinia leai)*

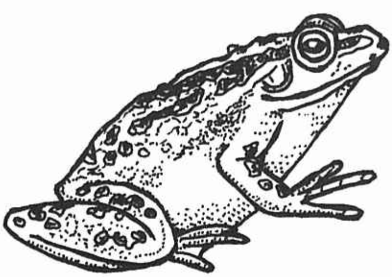
This small (18-26 mm long) brown or yellowish species, with greenish underparts, inhabits the cool shady swamps and swampy streams between Dandaragan and Two Peoples Bay. In the southern part of its distribution, it is especially common along the streams. Breeding occurs from mid-autumn to early spring. Eggs are laid in a mass attached to sedges or rushes overhanging the water. Tadpoles wriggle free and fall into the water.

The south-west corner Geocrinias

The high rainfall area between Margaret River and Walpole supports four closely related species of the genus Geocrinia: the roseate frog (*Geocrinia rosea*), yellow-bellied frog (*Geocrinia vitellina*), white-bellied frog (*Geocrinia alba*) and Nornalup frog (*Geocrinia lutea*). All are quite small, being no more than 25 mm in length, and are generally black, grey or brown in colour, with the first three species having bright or lightly coloured under surfaces, as indicated in their names.

Within the high rainfall area, the roseate frog has the widest distribution, being found in the Warren River valley and westwards to Margaret River. The white-bellied frog is limited to vegetated creeklines over a 101 km^2 farming area around Karridale and Witchcliffe and the Nornalup frog is restricted to a small area around and within the Nornalup National Park. Neither of these species was discovered until 1989 (Roberts et al. 1990). Small as their ranges are, they are huge in comparison to the 6.3 km^2 known range of the yellow-bellied frog. This species is known only from the Spearwood Creek system and adjacent riparian corridors on the northern side of the lower Blackwood (Wardell-Johnson and Roberts 1991, 1993).

All four species are mainly found along well vegetated riparian corridors with leafy, peaty soils that stay moist for long periods over summer (Wardell-Johnson and Roberts 1991, 1993). Breeding is mainly in spring, with that of the yellow-bellied frog extending into summer. Eggs are deposited in small depressions on the moist soil under leaf litter or dense vegetation or at the end of tunnels dug into the creek banks (Wardell-Johnson and Roberts 1994). The young develop in the jelly mass surrounding the eggs and do not enter water until they have attained their adult form (Wardell-Johnson and Roberts 1994).



Frogs of the genus *Heleioporus*

The western spotted frog (*Heleioporus albopunctatus*) and the western marsh frog (*Heleioporus barycragus*) are large robust frogs reaching nearly 90 mm in length, and are chocolate coloured with white to yellow spots and blotches which are more or less restricted to the sides of the body and limbs in the latter species. The moaning frog (*Heleioporus eyrei*), plain frog (*Heleioporus inornatus*) and sand frog (*Heleioporus psammophilus*) are somewhat smaller, reaching 60-65 mm in length. Their colorations are generally brown, variously mottled with grey, yellow and white.

All the species of this genus in the south-west breed in winter and eggs are laid in burrows which they excavate and then use as calling sites. The tadpoles undergo their early development within the burrows and are flushed into the streams or swamps with rising water levels through the winter months. Outside the breeding season, the adult frogs probably move up to several kilometres from the breeding sites, sheltering during the day in moist litter or soil. During the hot dry summer and autumn period and prolonged droughts the animals survive by burrowing deeper into the ground, including the moist sediments of creeklines, a process known as aestivation.

The moaning frog is widespread throughout coastal parts of the south-west. It generally congregates for breeding around wetlands, but can also be found along smaller watercourses. The sand frog has a patchy distribution, linked to the occurrence of low lying sandy habitats. Its breeding sites are generally away from streams but may be found on raised river terraces (old high floodplains) and perched swamps. The plain frog is found in the Darling Range and inland of Walpole and Mt Barker on the south coast. This species and the western marsh frog are both commonly associated with the smaller seasonal creeks that are common in the rugged terrain of the Darling Range. The western spotted frog is found in the drier wheatbelt region where it breeds along winter and spring flowing streams and endures hot dry summers.

The bull frog *(Limnodynastes dorsalis)*

The bull frog is found throughout the south-west corner. It is a robust animal between 60 and 73 mm in length, with short legs. In colour it varies from pale brown to deep chocolate, with large patches of green and a narrow cream or pale yellow mid-dorsal stripe. The groin area is crimson. In winter and spring, the bull frog is found amongst vegetation along streams and in swamps, while it holds out in burrows over the dry period of summer and autumn. Breeding is in winter and spring, with eggs laid in foam 'rafts', often hidden beneath overhanging vegetation, on the surface of still or slowly flowing water. The call is a loud 'bonk' which is audible over considerable distances.

Tree frogs of the genus *Litoria*

The bell frog (*Litoria moorei*) is the large frog, reaching about 75 mm in length, commonly seen seated upon a large leaf or hanging basket in the moister parts of many suburban gardens. It is robust and very muscular in form, having powerful and well developed hind legs. In colour, it varies from uniform pale brown to green, or pale brown with many dark green or brown patches. The range of the bell frog extends from the Murchison River all the way round the south-west corner to the Pallinup River, where it inhabits swamps, lakes and well vegetated streamlines, including grassy creek lines in paddocks (Tyler et al. 1994). Breeding occurs in spring to summer and eggs are laid in a floating jelly mass attached to vegetation. Tadpoles can be found throughout the summer in the wetter parts of the south-west. The closely related spotted-thighed frog (*L. cyclorhynchus*) replaces the bell frog in the east from Albany to Israelite Bay. Little is known about its biology (Tyler et al. 1994).

The slender tree frog (*Litoria adelaidensis*) is much smaller than the bell frog, reaching only about 50 mm in length. It is distributed from Port Gregory to Bremer Bay. The slender tree frog, as the name suggests, is an elongate frog with a narrow, tapering head and slender body. The upper surfaces of the animal vary in colour from plain brown or green, or brown with large green patches. There is usually a dark brown stripe along the sides of the body and head, the underparts are white. The natural habitat of the slender tree frog includes the well vegetated margins of streams. Breeding is similar to that of the bell frog (Tyler et al. 1994). Males call from early winter but most breeding occurs later in spring when eggs are deposited in a jelly mass which is attached to vegetation just below the surface of the water.

The froglets

Four small species of froglet, generally less than 30 mm in length, are found in various parts of the south-west. All are highly variable in colour, with varying combinations of grey, brown, black and white arranged in patterns of stripes and patches. All inhabit both permanent and seasonal wetlands and streamlines, and all breed in autumn and spring. In all but one species eggs are laid in shallow water where they are deposited at the bottom of small depressions. Glauert's froglet (*Ranidella glauerti*) differs in that it deposits its eggs in shallow puddles or moist litter alongside ponds or streams (Aplin pers. comm.; Tyler et al. 1994).

The squelching froglet (*Ranidella insignifera*) is restricted to the Swan Coastal Plain where it inhabits temporary wetland areas. The closely related bleating froglet (*Ranidella pseudinsignifera*) occupies similar habitats but over much of the south-west. The south coast frog (*Ranidella subinsignifera*), as the name suggests, is found along the south coast between Manjimup and Cape Arid, again in seasonally wet areas. Glauert's froglet inhabits permanently wet situations, including swampy streamlines, between Moore River and the Pallinup River.

5.1.8 Reptiles: the tiger snake and long-necked turtle

Many reptiles make their home among riparian vegetation, including a number of geckos, skinks and lizards, the bearded dragon and the dugite. The species described below are more characteristic of wetland habitats.

Western glossy swamp egernia (*Egernia luctuosa*)

This medium size skink, which is about 13 cm in length not including tail, is found in dense vegetation adjacent to wetlands and streams in the wetter parts of the south-west. Coloration varies from greenish yellow, yellowish brown to dark brown, with paler underparts. Although a highly secretive animal, it can be found basking on logs and flattened vegetation. When disturbed it will take to water and can swim with ease. It feeds on invertebrates and gives birth to live young (Storr et al. 1981; Cogger 1992; Bush et al. 1995).

The western tiger snake (*Notechis scutatus*)

The tiger snake cannot be considered an aquatic animal but it is included here because it is often encountered along rivers, especially along the swampier sections where it hunts for frogs. It will readily take to the water in warm weather and can swim strongly[6]. Tiger snakes are stout in form, have large heads and can grow to 1.5-1.8 m in length. They are often recognised by their 'tiger stripes', but can in fact exhibit a range of colorations, from dark steel blue to black, with or without orange or yellow cross bands. The undersides are usually pale orange or yellow (Glauert 1967). The species is quite aggressive and has very potent venom, making it the most dangerous snake in the south-west (Underhill 1988).

[6] Once, when taking environmental measurements in the middle of the Collie River from a small one man inflatable boat, the author had a visit from a large tiger snake who swam out to the boat, had a look round to check out the action and then swam to shore and went about its business.

The long-necked or oblong turtle[7]

(Chelodina oblonga)

The oblong turtle is common along south-west rivers, including some of those which are considerably degraded or brackish. It is quite a large animal with a long neck and a shell length of up to 40 cm. It is thought to feed on a variety of aquatic organisms, including crayfish, shrimps, aquatic insects, molluscs and fish (Williams 1983; Bush et al. 1995)[8]. In colour, it is dark brown to black above and whitish below. Turtles mainly inhabit river pools and the long permanent stretches of the larger more perennial rivers. They are air breathers and can leave the water for short periods, which females must do in spring and summer in order to lay their eggs on land (see section 5.2.3). It is also quite common to see turtles resting lazily on snags which protrude from the water.

5.1.9 Waterbirds

Waterbirds generally congregate in large numbers in shallow highly productive waters where food is plentiful. For this reason, shallow lakes, the margins of estuaries and seasonal wetlands tend to be the most important waterbird habitats, at least in terms of bird numbers. When rivers support highly productive waterbird habitat on their floodplains in winter and spring, wetlands everywhere are doing the same. Not surprisingly, therefore, classic river habitats, in comparison to lake systems, are not especially important in the overall wetland habitat complex that supports most south-west waterbirds.

In summer, when waterbirds are in a desperate search for aquatic habitat, the best that can be provided on rivers is generally the deep river pools, which support only very limited shallow waters. Maybe one or two white-faced heron, a large egret or a few ducks and hens will be seen searching for food along the pool margins. For diving birds, such as cormorants and grebes, the concentration of fish, crustaceans and other animals in the pools is a boon. But for most birds, which feed by wading, dabbling or up-ending, the larger lakes and estuaries are the more important summer/autumn refuges. Exceptions to this are the shallow partially sediment filled and nutrient rich pools of the larger and more degraded rivers, such as the Avon and Blackwood. On these pools large numbers of ducks and hens congregate over summer and autumn (Hansen 1986).

True river habitats are of only marginal value to most of the region's waterbirds. However, a small suite of species are nonetheless important components of riverine ecosystems and for some of them rivers must make a significant contribution to the support of their populations (Jaensch et al. 1988). These species are described below. Furthermore, although not dealt with here, many bushland birds will make use of riverine habitats, for drinking, feeding and/or nesting. Given that riparian corridors are often among the most

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[7] No doubt you are now thinking 'tortoise'. In this book the term turtle is preferred because of the aquatic nature of the oblong turtle. True tortoises are land based (see Bush et al. 1995)

[8] During scientific sampling for marron with drop nets in the Collie River, the long-necked turtle was found to eat the Perth herring, sea mullet and old 'BBQ' packs which were being used for bait. This suggests that the turtle is a scavenger. It was noted that the turtles were especially fond of uncooked sausages!

substantial areas of natural vegetation remaining in some localities, many bushland bird populations may depend on rivers for their survival, even if only as corridors linking their more important habitats.

Grebes

Australasian grebe *(Tachybaptus novaehollandiae)*

This small bird, reaching no more than 250 mm in length, is one of the more common waterbirds on south-west rivers, but is seldom present on river pools in numbers greater than two or four (Luke Pen pers. obs.). Its trill or titter can often be heard from some distance and individuals can be seen running across the water with the aid of their wings, although diving is the characteristic response to disturbance. The Australasian grebe is generally grayish black or brown with white underparts. It has a dark head with a characteristic yellow spot between each eye and beak. Breeding occurs in spring, with pairs constructing floating nests in which they deposit four to six eggs. Up to four broods can be produced in a single season. Australasian grebes feed on aquatic insects and probably small crustaceans and fish, by diving and swimming long distances under water (Frith 1976).

Hoary-headed grebe *(Poliocephalus poliocephalus)*

This grebe is slightly larger than the Australasian grebe and is easily distinguished by the narrow white plumes that overlay the black feathers of the head. The body is grey above and white below. When breeding, the top of the head darkens while the sides and throat become white. Young immature adults have black and white heads. Hoary-headed grebes are less often seen than little grebes but can be present on large pools of the larger rivers in small to large flocks (Frith 1976; Pen pers. obs.). Breeding occurs after substantial rain but generally in late spring to mid-summer. A floating nest of water plants is built amongst fringing vegetation.

Cormorants and darter

Little pied cormorant *(Phalacrocorax melanoleucos)*

This small black and white cormorant, which grows to a length of 610 mm, is one of the most common waterbirds along south-west rivers. It can be seen, singly or in small groups of two to four, swimming on the surface, diving after prey, flying along the river or out in the sun perched on a dead branch drying its permeable plumage and probably warming up after a long time spent in cool or cold water. The species is thought to feed on fish, crustaceans and the larger of the aquatic insects (Frith 1976). Sometimes it can be seen hunting with the little black cormorant. Breeding can occur throughout the year, depending on the supply of food, with nests of sticks and debris built in trees, large shrubs or even on the ground. Along rivers small groups of cormorants nest in trees overhanging water. If the young are reasonably well developed they will leap into the water if frightened and climb back to their nests when all is safe.

The little black cormorant *(Phalacrocorax sulcirostris)*

As the name suggests the plumage of this bird is entirely black. Apart from this the little black cormorant is very similar in form and life cycle to the little pied. Hunting behaviour is different however, with groups of little blacks working together in the water to round up fish. In fact, fish are thought to be the main food of the little black cormorant, and the species is known to feed heavily on exotic fish species in lakes in the eastern states (Williams 1983). The large numbers of gambusia and redfin perch present in south-west rivers may therefore represent a major food source for little blacks.

Darter *(Anhinga melanogaster)*

The darter, which grows to a length of 900 mm, is similar in form to cormorants except for the S-shaped neck and stiletto-like beak. Males are glossy black with a white stripe below the eye extending along the side of the head and neck. Females are grey brown above and pale below and the head stripe has dark edges. When swimming, only the head is kept above water and it is easy to mistake a darter for the raised head of a swimming snake. Darters also swim well under water and like cormorants must stand in the sun to dry their wings and warm up. Food consists of fish, small turtles and large aquatic insects which are caught in ambush by darting the head out and spearing prey (Frith 1976).

Heron and egret

White-faced heron *(Egretta novaehollandiae)*

This tall (to 670 mm long) grey heron with its characteristic white face is one of the most common waterbirds in the south-west. Along rivers it hunts for crayfish, shrimp, fish and frogs on wet ground or in shallow water by searching around and shooting out its long G-shaped neck to catch prey in its long beak. Breeding occurs throughout the year depending on the availability of food. The nest consists of a loose platform of sticks in a tree, which may or may not be near water.

Great egret *(Ardea alba)*

This long white bird, reaching a length of 830 mm, is uncommon but conspicuous along rivers and can be seen feeding in much the same way as white-faced heron. Sometimes individual birds will spend many days just below weirs hunting fish that are trying to move upstream. Breeding and nesting is as for the white-faced heron, except that nests are often at ground level amongst sedge stands (Frith 1976; Pizzey 1980).

Hens, coot and rail

Purple swamphen *(Porphyrio porphyrio)*

The swampy sections of rivers will almost certainly have at least one or two swamphens, shyly roaming about in search of frogs, snails and other small animals and chewing at soft rushy stems. The swamphen is the largest of the hens likely to be encountered along rivers, reaching lengths of up to 480 mm. The upper parts of the body are black brown, while the face, neck, breast, shoulder and upper body are dark blue. The rump is white and the large bill and frontal shield is bright red, as are the legs. Breeding occurs in winter or spring when large platform nests of trampled down rushes are built.

Eurasian coot *(Fulica atra)*

This small black bird (up to about 400 mm long) with white beak and frontal shield, is very common along south-west rivers. Coots are often present in groups of twenty birds or more, on water or on land, feeding mostly on plant material. Breeding is in spring and summer, with nests of leaves, twigs and water plants placed on or near water. Males and females share the duties of raising the young.

Dusky moorhen *(Gallinula tenebrosa)*

The moorhen is very similar in form to the coot, but can be distinguished by its red beak and frontal shield and white vertical stripe on each side of the tail which is held up and often flicked nervously. Moorhens are not as common on rivers as coots and are more likely to be seen on the land, though when frightened they will scurry to the water. Breeding is in winter and spring, with pairs building dish shaped nests of aquatic vegetation amongst rushes. Food consists of aquatic plants and small invertebrates.

Black-tailed native-hen *(Gallinula ventralis)*

This hen is similar in form and general coloration to the moorhen and is similar in size (to 350 mm long). Upper parts are black and underparts are grey with a blue tinge. Like the moorhen it cocks its tail, but unlike the moorhen it has bright red legs and white patches on the lower middle sides of the body and a grey green beak. Native-hens are thought to be common along rivers (Frith 1976; Pizzey 1980), but it is difficult to catch sight of them. Usually they are only seen dashing from one bush to another. Breeding occurs when conditions are favourable. Cup shaped nests are made of plant material on or near the ground.

Buff-banded rail *(Gallirallus philippensis)*

The buff-banded rail, which grows to about 310 mm in length, is occasionally seen along rivers, mostly in the early morning or evening when it is more active and will venture from dense vegetation where it spends most of the day. The coloration of the species is complex, but is mainly chestnut brown above and mottled black and white below, with a white stripe above each eye, a greyish throat and a chestnut band on the chest. The legs are long and red. Like the moorhen, it flicks its tail when nervous. Breeding is in spring and summer or when conditions are favourable (Frith 1976; Pizzey 1980). The nest is cup shaped and made of pulled down and woven grass or rushes. Food consists of small invertebrates and plant material.

Ducks and swans

Black swan *(Cygnus atratus)*

Black swans are only occasionally found on rivers. Breeding occurs from May to September, with nests consisting of large mounds of sticks, rushes and leaves amongst rushes or near the water's edge. Swans use their long necks to graze on water plants below the water surface.

Australian shelduck
(Tardorna tadornoides)

Also known as the mountain duck, this regal bird is often seen in nesting pairs along rivers in winter and spring. Males grow to a length of 720 mm, and females slightly less to about 680 mm (Frith 1976; Pizzey 1980). Both sexes are mainly black with white, green and brown wings and a chestnut breast. Males have a white ring at the base of the neck. Females are easily distinguishable from males by the absence of this ring and by a white patch around each eye and the base of the bill. Breeding occurs in winter, with nests mainly built in trees. Australian shelducks mainly graze on green plants on land and in water, but will also eat insects and molluscs.

Pacific black duck *(Anas superciliosa)*

Just about any stretch of inundated river will have at least one black duck. This mottled black, brown and light brown duck is one of the most abundant and common waterbirds to occur on inland waterbodies. The species is easily recognisable by the horizontal black stripe, with white stripes either side, that runs along each side of the head. Both sexes are the same in coloration, but females are slightly smaller than males, which can reach about 600 mm in length. Pairs begin nesting at some time between July and September when water levels are at their maximum. Nests consist of woven cups in tree holes, on the ground or amongst sedges. Males leave the partnership soon after the eggs are laid and the females are left to raise the ducklings. Feeding is by dabbling and up-ending for small aquatic animals or the seeds of aquatic plants or by stripping the seeds from fringing plants.

Grey teal *(Anas gracilis)*

This small teal (to about 460 mm long), with its mottled coloration, looks quite similar to the black duck. It is distinguishable by its smaller size, soft brown body plumage and different coloration of the head: dark brown on top and on the back of the neck and light brown to almost white along the sides and on the throat. Females are slightly smaller than males. Grey teals nest at any time of year, providing water levels are up and food is available. Nests are located in a wide variety of locations. Feeding is as for the black duck.

Australian wood duck *(Chenonetta jubata)*

Both males and females of this handsome duck, of upright posture, grow to about 480 mm in length but are very different in coloration. Males are mainly grey, with a dark brown head and neck which has a mane of black feathers. Females are mainly grey brown, with a pale brown head and neck and white horizontal stripes above and below each eye. Both sexes have mottled grey brown chests, darker on males. The name 'wood duck', may be derived from the fact that the species is known to nest in the hollows of living trees (Frith 1976; Pizzey 1980). Breeding is in spring and both sexes raise the young. In fact a number of pairs appear to pool their young and raise them together, leading to the formation of flocks which camp by river pools over the long summer. Sometimes many birds come together and flocks may number nearly 200 birds. Wood ducks feed mainly on grass and herbs on land adjacent to or far from water. Each year about 150 wood ducks camp by the ornamental ponds of the Canning City Council offices which are immediately adjacent to the Canning River. Here they enjoy a peaceful protected environment with lush green reticulated lawns providing a secure food supply.

Musk duck *(Biziura lobata)*

Both male and female musk ducks are black brown overall, with feathers tipped with white. Males grow to 720 mm in length, much larger than the females at about 600 mm, and can be easily distinguished from females by a large black leathery lobe under the bill (Frith 1976; Pizzey 1980). In spring males advertise by expanding this lobe, throwing their tail feathers forward in a fan shape, raising their heads and swimming around in circles, kicking out water and making a loud 'k-plonk' sound. Females may respond, and after mating build flimsy cup shaped nests amongst fringing vegetation and raise their young by themselves.

The musk duck is almost completely aquatic, feeding by diving for small aquatic animals and plant seeds. While nearly helpless on land, it is a powerful swimmer on the surface and below water, and will escape detection by sinking below the water with only its nostrils exposed to permit breathing.

5.1.10 Water rat

The water rat (*Hydromys chrysogaster*) is one of only three inland aquatic mammals in Australia (the other two being the platypus and the small false water rat of northern Australia) and the only one in south-western Australia (Strahan 1983; Williams 1983). It grows to about 30 cm in length, not including the tail which is as long again, and can weigh as much as 750 g. Males grow slightly larger than females, about 5 % longer and 20-30 % heavier (Strahan 1983). Its aquatic lifestyle is reflected in its broad, slightly webbed, hind feet and waterproof fur, which is black to brown on the back and upper sides and white to orange on the lower sides and tummy (Strahan 1983). The tail is also black, but with a characteristic white tip (Fig. 5.16).

The water rat is a placental mammal not a marsupial, and breeds in spring or summer. About three to four young are raised in a nest at the end of a long burrow in the river bank. The opening to the burrow is located

FIGURE 5.16 THE WATER RAT, *HYDROMYS CHRYSOGASTER*. IT GROWS TO 30 CM IN LENGTH, NOT INCLUDING THE TAIL.

beneath the water surface. For this reason water rats are seldom seen despite their relative abundance. However, a telltale sign of their presence is chewed crayfish exoskeletons and small scats (faeces) on rocks, logs or old fence posts where the animals regularly go to consume their meals. Apart from crayfish, the water rat also eats shrimps, aquatic insects, mussels and fish (Strahan 1983). Along with cormorants, large fish and humans, the water rat is probably one of the main animals at the top of the river food chain, although its young, once they emerge from the burrow, may be prone to predation by snakes, large predatory birds and foxes and cats.

5.1.11 Parasites and commensals

A parasite is an organism which obtains its food from another organism in or on which it lives, even if only for a very short time. A parasite may or may not be harmful to its host. A commensal is an organism which lives in close association with another organism without affecting it, either negatively or positively.

Leeches *(Annelida: Hirudinea)*

These black or grey, elongate and partially flattened worm-like animals, which vary in length from between 10 and 100 mm when extended, have two suckers, one at the posterior end which is used for gripping only, and one at the front of the animal which contains the mouth and is used for gripping and feeding. Probably no animal strikes more fear into people spending time by south-west streams, including stream ecologists, than do parasitic leeches. The larger more conspicuous leeches of the south-west feed by sucking blood and other body fluids from fish, frogs, turtles, birds and mammals, including humans. They can swim by a vertical undulating motion or crawl by using their suckers, either in a grub-like fashion or by pivoting from one sucker to the other. Not all leeches can swim and not all are parasitic; some are carnivorous (Williams 1981).

Trematode and nematode worms

Adult nematodes and trematodes (known as flukes) infect some species of birds and other vertebrates that frequent rivers (Johnson and Mawson 1947 and 1951 cited in Pollard 1974; Williams 1981; Mawson et al. 1986). The intermediate larval stages of these parasites, which reach rivers in the droppings or urine of the parental hosts, also parasitise crustaceans, molluscs and fish (Beumer et al. 1982) and are particularly conspicuous on the smaller fishes.

Nematodes as long 60 mm can be seen coiled within freshwater minnows (Galaxiids) and the introduced mosquito fish (*Gambusia holbrooki*). Infected fish mostly carry between one and three nematodes. One western minnow (*Galaxias occidentalis*) from the Collie River was found to have thirteen nematodes, comprising 18% of the fish's total weight (Pen and Potter unpub. data).

The western minnow is also occasionally infected with trematode worms. These are microscopic and don't actually resemble true worms at all. They are sometimes present in fish within small black cysts, about 1-2 mm across, located in the skin, flesh or even fins of the fish. Usually only one to three cysts are present in an infected fish, but some fish carry thirty or more. On one particular minnow, caught in a tributary of the Collie River, no less than 133 cysts were counted (Pen and Potter unpub. data).

The life cycles of typical nematode and trematode worms are described in Section 5.2.3.

Temnocephalid worms
(Temnocephalidae)

Temnocephalid worms are black leech-like animals up to 12 mm in length. They are generally oval in form and have a number of short tentacles. They are commensal on crustaceans and, in Australia, particularly on freshwater crayfish (Williams 1981). It is quite common to see many temnocephalids on marron, possibly more so in nutrient enriched conditions (Morrissy pers. comm.). Just what temnocephalids do on marron and what they eat is unknown, but marron farmers consider them to be a nuisance. Interestingly, pygmy perch and small native minnows found along the south coast eat these worms, suggesting that they may provide a clean-up service to freshwater crayfish.

5.2 Habitat needs and life cycle strategies

It is tempting to look at a river and think that if it were fringed with healthy native vegetation and perhaps fenced off, and the water quality was as it should be, that its habitat value for riverine animals would be well secured. Unfortunately, while this would be true for some species, such a perception is based on a limited understanding of the broad habitat needs of riverine animals in general. Many riverine species make use of the broader river system, such as its seasonal creeks, and floodwaters and adjacent riparian lands, at some stage in their life cycles (Fig. 5.17). For other species, such as the lamprey and waterbirds, river systems represent only part of their broad habitat needs which may include the ocean, estuaries, lakes and swamp systems or even dryland ecosystems such as the jarrah forest.

Our limited understanding of the habitat needs of those animals which make at least some use of rivers and creeks, precludes a classification of life cycles and habitat use relevant to rivers. But there are two crucial elements which can be discussed: the need for aquatic refuges during drought and the need to move in order to fulfill life cycle stages and make use of the full river ecosystem. For many animal species these two elements, refuge and movement, enable them to survive the summer drought and flourish during the winter flood. In a broader sense, the use of refuges tied to the subsequent dispersal of animals enables populations to fully exploit available habitat as it varies from year to year. Populations which shrink after several years of drought may expand their distribution and replenish their numbers during wetter years.

To provide some detailed insight into the use of rivers by animals, twelve examples of river habitat use and life cycle strategies are given.

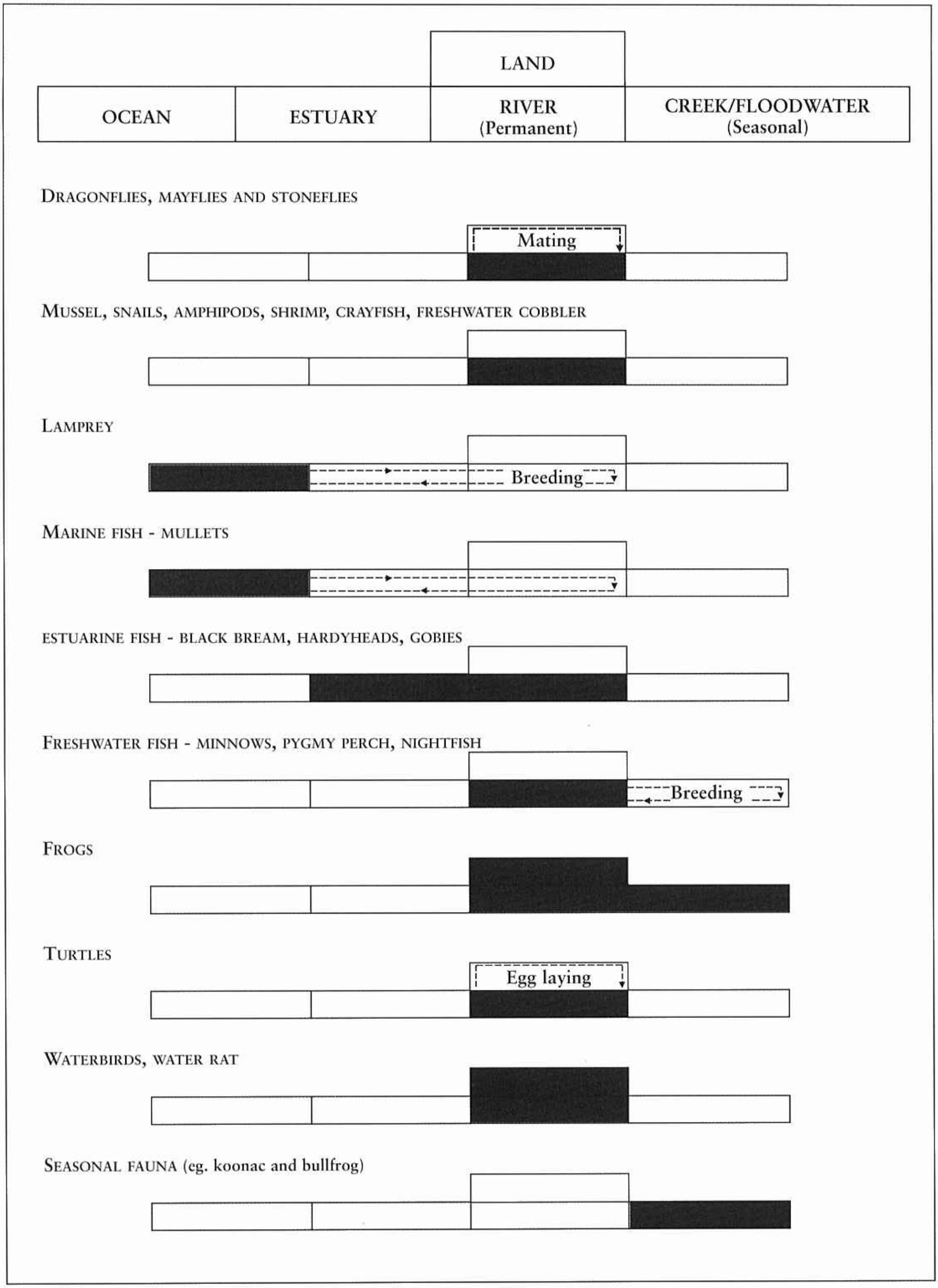


Figure 5.17 Examples of different life cycle strategies of the fauna of the rivers of the south-west of Western Australia

5.2.1 Coping with drought and exploiting the flood

The warm to hot dry summers and cool wet winters of our Mediterranean climate place considerable demands on freshwater fish fauna. River animals must survive the dry summer/autumn drought period, which may last as long as eight months, in order to enjoy the wet winter and spring period. In fact winter and spring is when most of our freshwater fish species breed.

During the long summer season south-west rivers gradually dry out and their fauna must retreat to permanent waters, which for the most part are the deep river pools, or to burrows. As early as October any fish which had moved into the seasonal creeks and floodwaters over the winter must move quickly downstream to avoid becoming stranded or trapped in small pools which will ultimately dry up. Native fish appear to be very adept at 'knowing' when to move, as it is rare to find them trapped in seasonal pools. Introduced species, on the other hand, such as redfin perch and the mosquito fish, appear to be less 'tuned-in' to the seasonal conditions and many thousands are killed each year because they fail to make the move. Unfortunately more than enough survive in permanent waters to ensure the survival of their populations.

Essential as the river pools are to the survival of our freshwater fauna, they provide at best a harsh summer refuge. Water temperatures are high and oxygen levels are low. Also the animals are present in relatively high densities and predation by cormorants, water rats and introduced fish, such as the large redfin perch, must take a heavy toll each summer.

For the naturalist the summer pools offer a good opportunity to observe the behaviour of native aquatic animals. The western minnow can be seen cruising the shaded areas during the day, and feeding from the water surface in the evening and early morning before the summer heat forces them to return to the shade. Telltale signs of the western minnow are ringlets of water in early evening. Pygmy perch keep close to cover, such as rocks, woody debris or vegetation, during the day, but in the early evening will move out along the shore to dabble amongst the sediment in search of tiny benthic invertebrates to eat. The nightfish is hidden amongst debris during the day and only comes out at night to feed, which it does in the same manner as pygmy perch. Marron hide amongst rocks and woody debris during the day but come out at night in large numbers.

When winter breaks and the river system starts to flow strongly again, the native fish move out of the permanent waters and into the seasonal waters where they, and for some species their offspring, can exploit the rich food resources of the seasonal habitats. For some species this requires the arduous task of migrating to particular habitat zones where they spawn, which is the subject of the next section.

5.2.2 Migration

A migration of an animal species is not to be mistaken for a simple movement. For example, streams nearly always only flow in one direction and if animals are not ultimately to be washed down to the sea they must tend to move upstream rather than downstream. This sort of preferential direction of movement is clearly not a migratory one. Similarly, the dispersal of aquatic animals from the pools when the rivers flood-out in winter is also not a migratory movement. Rather a migration, in relation to animal populations, is a movement from one habitat to another, to fulfill one or more life cycle stages.

From studies carried out in the Collie River system and from short observations made elsewhere in the south-west that are consistent with the findings of these studies, it is known that at least three of the native freshwater species, the western minnow, nightfish and western pygmy perch, undergo arduous migrations in the winter and spring, for breeding (Pen and Potter 1990, 1991a,b,c). All three of these species disperse from the summer pools and make their way upstream and from the main trunk of the river into small seasonal tributary creeks. Sometimes their passage is obstructed by steep stream gradients, dense fringing vegetation or obstructions such a log jams, road culverts, dams and weirs. It is at these points that the fish are observed in large numbers waiting for the opportunity to negotiate the obstruction. This may come with a flood, in which water overtops the obstruction, or a very wet night, in which case the fish may swim overland in the few millimetres of water that gather and flow across the land surface. It is an inspiring sight to see several hundred small fish leave the deep water and slop and wiggle their way through sedges or over pasture in an attempt to find the main channel of the creek and get upstream.

The western pygmy perch not only moves into seasonal creeks but also seasonal floodwaters along the main arm of the river and the seasonal creeks, especially those floodwaters which support dense growth of ephemeral aquatic plants.

At the time of migration and when the three fish species are present in the seasonal habitat, it is obvious that they are in breeding mode. Apart from male pygmy perch, the bodies of the other three species swell with roe (eggs) or milt (sperm). Even though the testes of male pygmy perch undergo no major increase in size, they show a more obvious sign of breeding, brilliant breeding colours of orange, black and gold.

By the time breeding is complete in late spring, the seasonal waters begin to contract and become stagnant as flow drops off. At this time fish that have survived spawning slowly retreat, along with their offspring, to the perennial waters of the main river channel. Interestingly, the young of the year are seldom found in the seasonal creeks. It is thought that the eggs or fish larvae, soon after being fertilised or after hatching, are washed downstream into the main channel of the river where, as juveniles, they are known to gather in the shallows in large numbers. As the summer approaches they make their way to the deeper perennial waters with their parents.

case study

Migration of the pouched lamprey

The most spectacular migration that occurs in south-west rivers goes on largely unseen each spring. It is that of the marine pouched lamprey. As mentioned earlier, the pouched lamprey must migrate from the ocean into the permanent headwater streams of the lower south-west to breed.

They first approach the south-west coast in mid-winter and enter the rivers just when river flows are at their maximum, no easy feat considering the velocities involved. Then they must negotiate rapids and climb waterfalls, and these days also dams and weirs, in order to get upstream and find their breeding habitat. Fortunately, lampreys are good climbers, using their suctorial mouths to gain a grip on wet surfaces and whipping their bodies upwards to inch their way up and over obstructions. In very wet weather, lampreys will leave the water and snake their way cross-country to get around the most challenging of obstructions, such as the Pemberton Weir and the Rainbow Trail gauging weir, which are found a short distance upstream from the town of Pemberton on the Lefroy Brook.

Most of the lampreys' migratory movements occur on dark nights when water levels are rising and rain is falling. For this reason, few people have witnessed the migration of pouched lampreys, although occasionally some animals can be seen attempting to get over waterfalls and weirs during daylight. Most lampreys, however, spend their daylight hours hiding under rocks and logs and amongst fringing vegetation.

The movement of lampreys from the ocean into fresh waters and over obstructions is not without its price. During the early stages of the run, lampreys are susceptible to blood poisoning and internal bleeding, and dead blood-stained animals are a common site along karri forest streams in winter. Many more die from injuries and exhaustion incurred while attempting to climb or get around the more hazardous obstructions. Sometimes lampreys get lost in wet weather by following the flow of water from roads and paddocks, so they become stranded the next day and quickly die in the sun.

The great annual upstream migration of the pouched lamprey has its sequel in the downstream migration of the recently metamorphosed, cobalt blue 'downstream migrants', which occurs over a few weeks in winter.

5.2.3 Examples of life cycle strategies and river habitat use

Estuarine encroachers: fish and shrimp

Many inland fish species are considered to be derived from marine ancestors (Allen 1982). That is, at some times in the past, parts of marine or estuarine fish populations moved into rivers and subsequently evolved into new inland fish species. Today a number of small fish species, known to be abundant in estuaries, are also present in south-west river systems, particularly the more brackish or saline ones. The more successful species are the Swan River goby and the Swan River hardyhead (see Section 5.1.6). For example, the goby is very common along the brackish Murray River and the hardyhead produces huge populations along the saline Avon River, as far upstream as Beverley. Both species are present right along the main trunks of the Blackwood and Pallinup Rivers. The goby also appears to be present in many freshwater streams, more so than the hardyhead (Morgan et al. 1998).

The freshwater shrimp, like these fish species, is abundant in estuaries. But unlike these species it is widely distributed in fresh, brackish and saline streams. The shrimp may be considered both an estuarine and a freshwater species.

Both these fish species and the shrimp can live their entire life cycle in either estuarine waters or inland waters. The goby and particularly the shrimp appear to be able to exploit fresh waters to a greater degree than the hardyhead. For these species, their presence in rivers is more than mere 'spillover' from the estuaries.

The fresh-salt interface: the black bream

The black bream lives on the estuarine freshwater interface that occurs over several kilometres on all the larger river systems of the south-west. While spawning is apparently restricted to the upper estuarine reaches of rivers (Fisheries 1993), bream will move into estuarine and riverine waters proper to feed.

Marine visitor: the sea mullet

The sea mullet is a marine species that makes use of estuaries and rivers. It is known to venture well inland on eastern and northern Australian rivers (Merrick and Schmida 1984). In the south-west the more open, permanent and continuous sections of the lower reaches of rivers are probably the more important riverine habitat for mullet, given the region's generally small and less perennial rivers. Indeed mullet can often be seen moving upstream, leaping and feeding in the lower reaches of the Moore, Avon and Blackwood Rivers. In the eastern states, studies have shown that juvenile fish spend about three years in estuaries and coastal sections of rivers before returning to the sea, where as adults they breed (Cadwallader and Backhouse 1983). Work in south-west Western Australia is more or less consistent with this view and suggests that rivers, along with estuaries, provide very important habitat for the early growth of sea mullet (Chubb et al. 1981; Lenanton et al. 1984).

Marine adult and freshwater larva: the pouched lamprey

The life cycle of the lamprey spans headwater streams to the deep ocean (Potter et al. 1986b). In the ocean adults feed on a high protein diet of fish flesh and blood. For this reason they are thought to spend from only a few months to a couple of years in the ocean growing to their full adult size of about 650 mm in length. At the end of their adult marine life they approach the coast of the south-west and during June and July, when river flows are at a maximum, they enter the rivers and move upstream. Once in fresh waters they cease feeding and live off bodily reserves. Adults are thought to spend about 16 months in south-west streams, spawning in the spring of the year following their migration. After spawning they die.

Following spawning by the adults, larval lampreys first appear in December, when they begin their life as blind filter feeders, burrowed in the soft sediments of permanently flowing and cool freshwater creeks and rivers of the lower south-west. Since their food consists of nutrient poor organic matter, larval life takes on average four and a half years to complete, at which point the lampreys are about 80-95 mm length. Animals at this size cease feeding in January or February and undergo metamorphosis into young adults, a process which takes about three months. In July and August the young adults move quickly to the sea during high flow events (Potter et al. 1986b).

The full life cycle of the pouched lamprey is only supported on a regular basis in the karri forest region of the south-west where the cool moist conditions maintain a large number of permanently flowing streams. Although lampreys have been observed in rivers as far north as the Moore River and as far east as the Waychinicup River (east of Albany) their migration into systems outside the karri forest region is mainly a sad waste of effort, as there is seldom any suitable habitat to sustain their larval stages. Some exceptions to this may be the perennial streams of the high rainfall zone of the western Darling Range.

Terrestrial adults and aquatic larvae

Many of the aquatic insect species of streams, such as dragonflies, mayflies, stoneflies and caddisflies, have terrestrial winged adults and aquatic larvae. The adults mate on or over land and lay eggs on or over water. Most adults live for only a few days to a few months, while larval stages may last a few months to two or three years, depending on the species.

In studies of the life histories of eleven aquatic insects in northern jarrah forest streams, three basic life cycle patterns were found (Bunn 1988). The first consists of a one-year life cycle, where breeding occurs at one time of the year and the larvae more or less develop at the same time and emerge into the atmosphere as adults over a relatively short period of the year. The second involves a two-year life cycle where different cohorts breed only once a year. The effect is that cohorts of young from different years overlap each other. In other words larvae of different ages and sizes can be found together. In this life cycle strategy adult emergence is extended over long periods. The third pattern is marked by breeding more than once in the year, resulting in slow and fast growing cohorts of larvae, depending on the time of year in which they were born. Animals born in late summer grow slowly over the long winter and are not ready to emerge by the following summer, but pass through a second winter to emerge and breed early in the summer of the following year. Their offspring, however, have the whole warm summer period to grow and grow fast, passing through only one winter to emerge and breed late in the following summer, ironically giving rise to another slow growing cohort. In this way three generations are produced every two years.

The three life cycle patterns described above are idealised. The actual rate of growth of aquatic insects and other animals varies from year to year and site to site, depending on more or less favourable conditions. For example, short warm winters and nutrient enrichment may increase growth rates, while long cool winters and summer stagnation may reduce them. The success of recruitment of new animals through breeding, which determines population densities, will also affect growth rates.

Animals that need permanent water

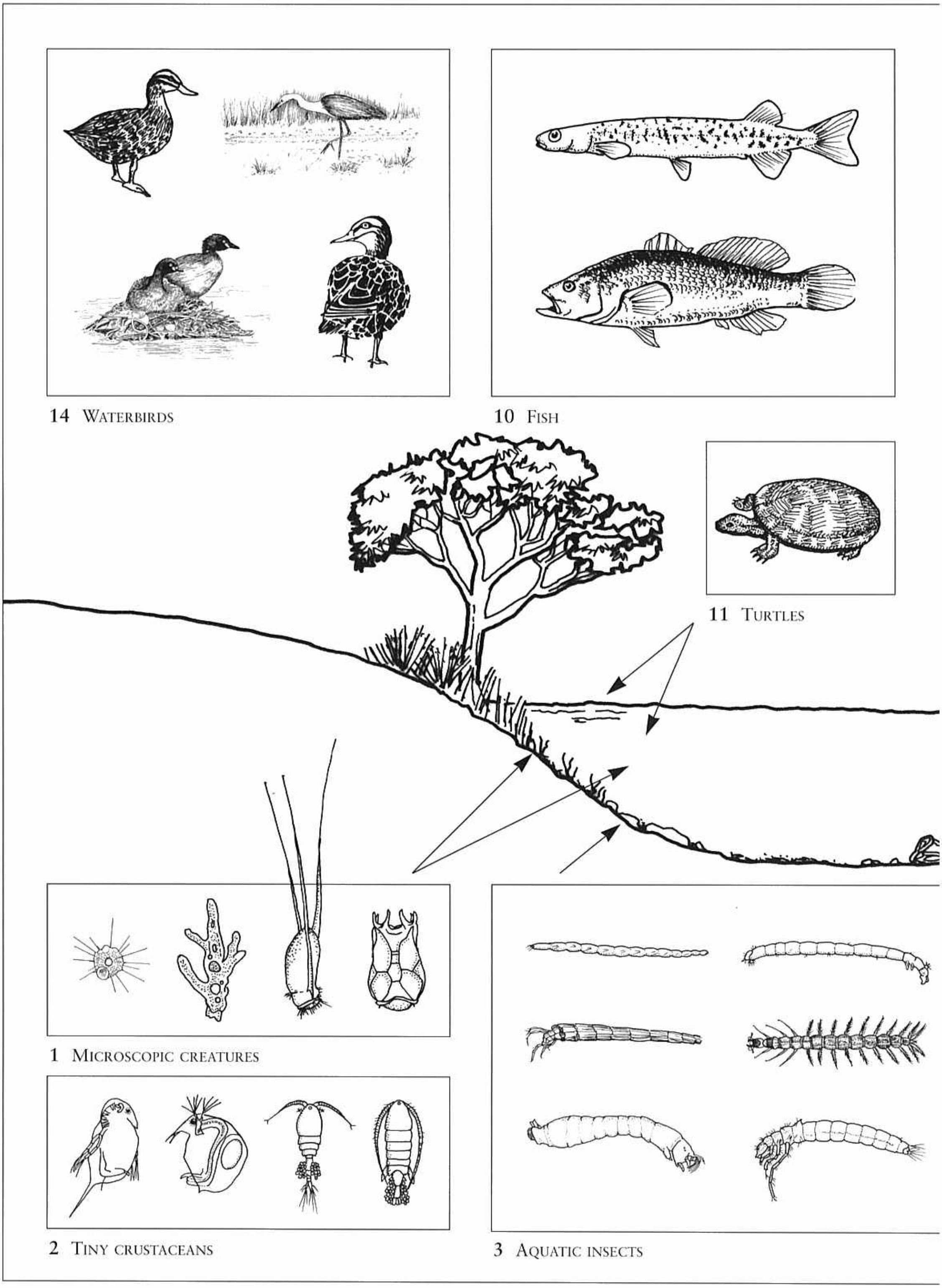
Many riverine animals need permanently inundated habitat to survive. Examples include the water rat, all the fishes, the turtle, the mussel, the marron, freshwater shrimp and many aquatic insects. Even some highly mobile waterbirds that are almost helpless on land, such as the little grebe and musk duck, require open water all year round. While such habitat is plentiful along the lower coastal reaches of rivers, permanent water along rivers in inland areas is often limited to deep river pools. For many species of longer lived animals, which cannot burrow to groundwater or survive long out of water, the river pools are an essential requirement for their survival in inland areas.

Permanent water but terrestrial egg incubation: the long-necked turtle

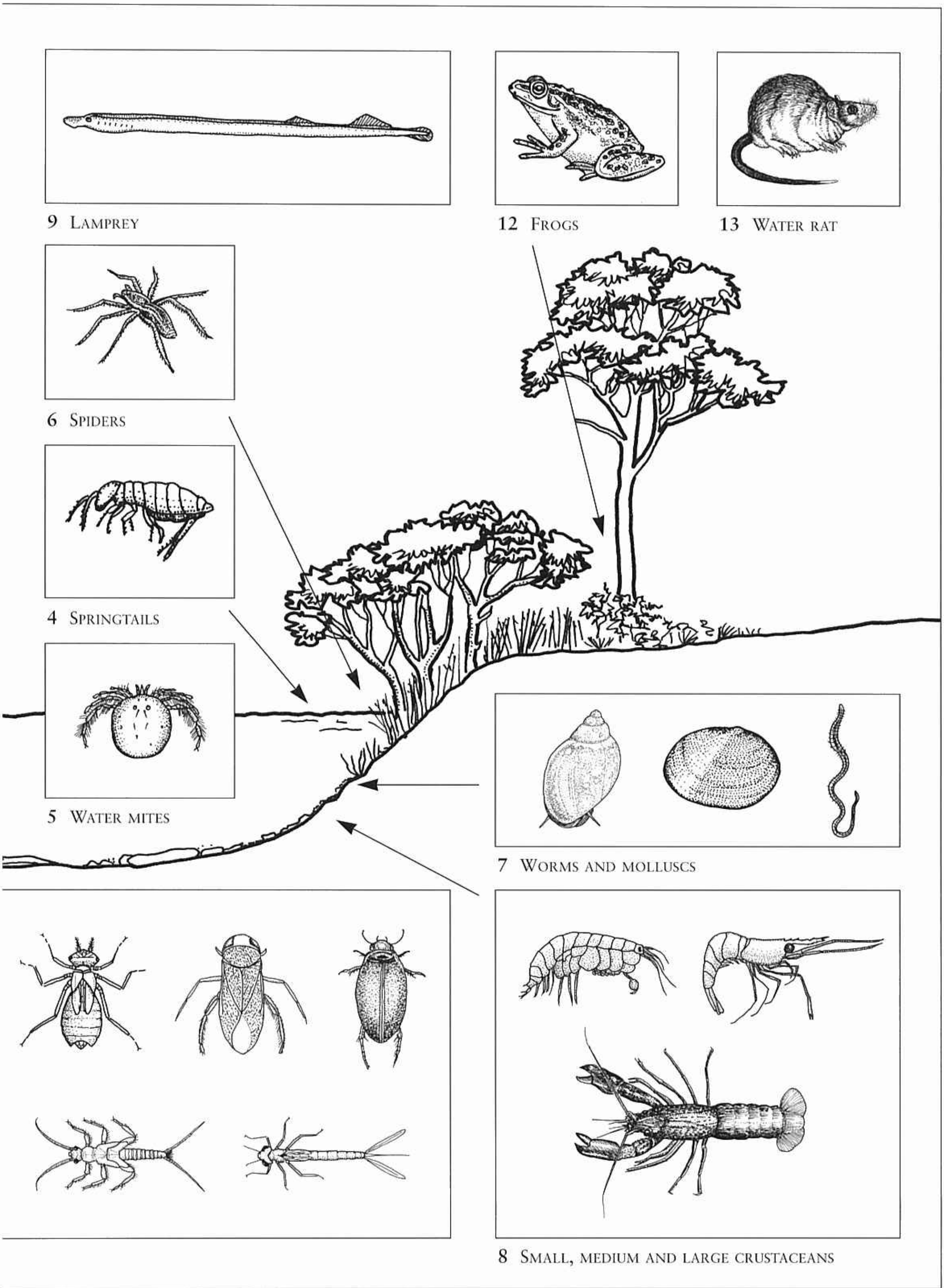
The long-necked or oblong turtle is an example of an animal that needs permanent water but lays its eggs on land. For most of the year the turtle occupies the more permanent waters of the river. On rare occasions, groups and individuals may be forced to leave the water and search for new habitat. This may occur when normally permanent pools dry out or when turtles have inadvertently found their way into ephemeral waters, or if conditions in a pool are no longer favourable, such as when food runs out. But for the most part, male and female turtles spend their time in the river. However, each spring and summer breeding females must leave the water for a short period, in order to lay their eggs on land (Williams 1983).

Observations of turtles at Thomsons Lake Nature Reserve near Perth, have revealed that a female turtle may move as far as 100 m across country in search of a site with soft soil (Clay 1981). Once found she digs a vertical shaft where she lays about twelve eggs. She then replaces the excavated material over the eggs and promptly returns to the water. The eggs are left undefended to incubate in the soil until about mid-winter, when the young dig their way out and move to the water.

The survival of turtle populations therefore depends on the presence not only of permanent water but also of adjacent areas of soft soil. Today, many of these areas have been lost through development and soil compaction and turtles are increasingly forced to lay their eggs in unsafe localities such as sandy ridges, open paddocks, vacant lots and household gardens, where their



River fauna of south-western Western Australia


9 Lamprey
12 Frogs
13 Water rat
6 Spiders
4 Springtails
5 Water mites
7 Worms and molluscs
8 Small, medium and large crustaceans

nests are prone to inadvertent destruction, vandalism and predation by foxes. Furthermore, turtles need to be able to make their way to and from nesting areas in relative safety. But with land clearing and development, the journeys of the females and young are fraught with hazard, having to cross open ground where they are greatly exposed to the harsh sun and to predators, and in some areas having to cross busy roads (Bush et al. 1995).

From summer pools to winter floodwaters and back: native freshwater fishes

Three species of freshwater fish, the western minnow, western pygmy perch and nightfish hold out in river pools in inland areas over the long dry summer. When the winter season breaks and river systems flood out, these fish move out of the pools and into seasonal creeks and floodwaters, where they spawn in late winter and spring. As the seasonal waters contract over late spring and early summer, the surviving adults and juveniles make their way back to the permanent river pools.

This annual spawning migration is an adaptation to the highly seasonal river environment of the south-west. Just what the advantages are in making the arduous migration is not yet known. Maybe the warm, oxygen rich and food rich shallows of seasonal floodwaters increase the survival of young fish, or perhaps the waters support a lower density of predators than in the main channel. Whatever the reasons these annual spawning migrations would not have evolved unless there had been a selective advantage to the survival of the fishes' offspring.

From summer burrows to winter floodwaters: the koonac and bull frog

Some animals never leave the seasonally dry habitats of seasonal creeks and floodplains. Instead of moving to refuges located elsewhere, as the fishes do, they create their own refuge on site in the form of burrows. Koonacs dig burrows down to the groundwater where they sit waiting for winter flooding (Horwitz and Richardson 1986). Bull frogs also take refuge from dry conditions in burrows (Main 1965). When winter comes both koonacs and bull frogs come to the surface to enjoy the favourable conditions, replenish fat reserves and get on with breeding.

Summer aestivation: the western spotted frog

The western spotted frog inhabits the seasonally sandy watercourses of the wheatbelt region. It survives the hot dry summer, not by taking refuge in burrows like the bull frog, but by aestivating in the mud of stream beds. Specimens have been found buried over 75 cm down in moist sand (Main 1965). The rare salamander fish (*Lepidogalaxias salamandroides*) found in peat swamps along the lower south-west coast is also known to aestivate over summer, but this species is seldom found along streams (Morgan et al. 1998).

Piggyback on a fish: the freshwater mussel

The life cycle of the freshwater mussel, *Westralunio carteri*, remains largely unresearched and therefore unknown. But we can infer a great deal from other members of its family, Hyriidae (Atkins 1979; Williams 1981). In this mussel family, fertilisation occurs when sperm, released into the water column by the male, are drawn into the ripe female via the inhalent siphon to the gills where the eggs are located. Following fertilisation, the eggs develop into what are known as glochidium larvae, which on leaving the mother become temporarily parasitic on freshwater fish. The larvae are less than 1 mm across and attach themselves to the gills, fins or body surface of the fish, where they encyst, become covered by tissue and begin to develop into their adult form. After some days or months, the larvae leave their hosts and sink to the bottom where they complete their development into miniature adults.

The freshwater mussel, like other river animals, must be able to disperse in order to fully exploit available habitat. The availability of habitat will vary from year to year, more in the wetter years and less in the drier years. Given that mussels are slow moving and relatively sedentary animals, larval encystment on fish may be a very efficient means of dispersal (Williams 1981). This is especially the case because, as we have seen, native freshwater fish migrate upstream each year. By hitching a ride on fish to make their annual move upstream, the freshwater mussel may be able to exploit newly available habitat and thereby replenish upstream populations which had become extinct as a result of drought.

From animal to animal: fish parasites

The western minnows of the Collie River have been found to be infected with nematode and trematode parasites. Nematode worms were present in the body cavity, while trematodes were present as black cysts, mostly in the flesh of the fish.

Nematodes and trematodes have very complex life histories. In their adult stages they are parasitic within vertebrates, usually birds or mammals. Eggs are conveyed to the river in droppings. In the case of nematodes the eggs are eaten by tiny animals which are in turn eaten by fish, which as a result become infected. The nematode parasitises and develops within the fish and waits to be eaten by the final host. In the trematode life cycle there is an intermediate host, usually a mollusc species. Where the infected minnows were found in the Collie River, only two molluscs were present, a snail (*Physastra* sp.) and limpet (*Ferrisia* sp.). Whichever is the intermediate host, the parasitic stage within the mollusc gives rise to a tadpole-like larva, known as a cercaria, which escapes the mollusc and searches for its required fish host. When it finds one, it burrows into the flesh and encysts. There it waits to be eaten by the final host.

The best candidate for the final host for the two parasites that infect the western minnow along the Collie River is the little pied cormorant. This waterbird, one of the most common fish-eating birds along the river, is one of the few native predators capable of catching the fast swimming, open water minnows. It is also known to be heavily infested with parasites (Johnston and Mawson 1947 and 1951 cited in Pollard 1974). It is interesting to consider whether the annual summer drought favours parasites, in that the infection of molluscs, minnows and cormorants would be enhanced by the high concentration of these animals in river pools over summer.

The land-water interface

Some river animals live mostly between the land and the stream. For example, the shellduck will feed on and nest near water, but will also feed on land. Similarly, the wood duck which feeds mostly on land, camps near water over summer, even by pools in dry farmland where green feed may be some distance away. The water rat obtains its food from the water, but will consume it on land. It also builds nesting burrows in the river bank which can only be entered from below the water surface. Four frogs of the Geocrinia genus live almost exclusively by streams but only occasionally enter the water. For all of these animals and many others, the stream environment is no less important, even though they make little direct use of the actual aquatic environment. For them the stream may provide the necessary humidity and soil moisture required for breeding or provide protection and refuge from predators. Whatever the case, the land-water interface of the stream supports all or part of the life cycles of a wide range of animals.

5.3 An impoverished and ancient fauna

Scientists have concluded that the stream fauna of the south-west is relatively impoverished; that there are not many species in south-west streams compared to south-eastern Australia (Bunn and Davies 1990). They noted the relative absence of invertebrates with long life cycles, of algae grazers and groups associated with northern Australia. Possible reasons for the impoverishment include the insular nature of the south-west, isolated over millions of years by ocean and desert, which largely prevents immigration to replace species which had become extinct, possibly during periods of aridity. In addition to aridity, periodic saline flushes of water from inland saline areas have been suggested as a possible cause for extinction of fauna intolerant of increased salinity (Horwitz 1996). Also, the low levels of algae growth and the poor nutrient value of detrital food resources may limit not only the abundance, but also the diversity of stream invertebrate life (Bunn and Davies 1990). Whatever the causes, south-west streams today are marked by invertebrate species with short life cycles and tolerance to seasonal or intermittent flows.

The relative impoverishment of the fauna of south-west streams in no way devalues the richness of the broader aquatic fauna of the south-west region. Many species of invertebrates, fish and frogs, including many which are found in stream systems, are unique to this region. Where stream systems may have lost species due to isolation, aridity and salinity, the wetlands of the south-west, especially those which have the capacity to stay wet in periods of drought or prolonged aridity (such as peat swamps), have retained many unique and rare species, often of ancient faunal groups, relics of wetter times of the deep past when Australia was part of the super continent known as Gondwana (Horwitz 1996).

Chapter 5
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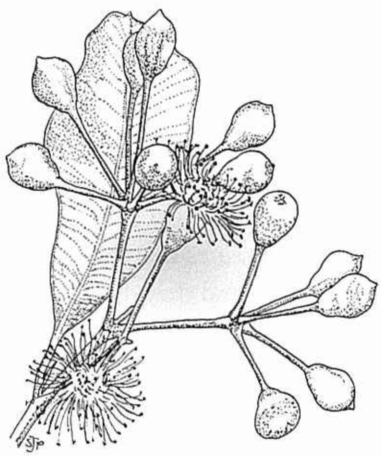
chapter 6

Human use of the south-west river systems

- EARLY HUMAN USE
- MODERN RIVER WATER USE
- DRAINAGE
- FLOOD PROTECTION
- RECREATION AND SPORT
- FISHING AND AQUACULTURE
- SCIENTIFIC AND EDUCATIONAL USE



6.1 EARLY HUMAN USE

Humans probably began to use rivers not long after the first few persons stepped upon the continent, at least 40,000 years ago (Shaw 1984). One of the earliest known sites of Aboriginal occupation in the south-west is along the upper Swan River and dates back 38,000 years (O'Connor et al. 1989). Just what use these first Australians made of rivers has been pieced together from various sources, including archaeological evidence, the observations of later day Aboriginal culture by the early European settlers and the memories of Aboriginal descendants.

In the south-west during summer, Noongar people would congregate around the lake systems, many of which were and still are connected to river systems, to take advantage of large concentrations of animals, especially waterfowl, taking refuge from drought. In winter these wetland areas would become relatively unpleasant and Aboriginal people would disperse to drier areas along with their game. The lower estuarine reaches of streams such as the Serpentine River and Bennett Brook on the Swan River were popular 'supermarkets' where frogs, birds, turtles and fish could be caught and root stocks harvested (Hallam 1975; Hallam 1987; O'Connor et al. 1989). On both these streams, weir-like fish traps were constructed of brush. Fish would be driven towards a trap where they could easily be speared as they swam over the weir crest and along a raised chute (O'Connor et al. 1989). It is thought that similar fish traps were used near Albany (O'Connor et al. 1995). Fish were also caught in pools by sweeping them towards the shore using brush as a simple form of net (Armstrong 1836).

In addition to offering food, river systems were also the major pathways for Noongar people travelling through the region and especially across the Darling Range. Not only did the rivers form permanent routes between major feeding areas, such as lake systems and the estuaries, they provided pleasant camping sites on the river pools and supplies of fresh water from the many springs that are found along the flanks of the rivers (O'Connor et al. 1995; Horwitz and Wardell-Johnson 1996). Even the naturally saline rivers, such as the Pallinup, had freshwater springs along them. A freshwater pool near the junction of the Pallinup River and Warperup Creek was a regular camping spot (O'Connor et al. 1995).

For the Noongar peoples, rivers were literally rivers of life, and it is not surprising that they did and still do figure greatly in their mythology and spiritual life. Of special significance is their dreaming ancestor, the serpentine Waugal. The Waugal belief relates to a profound respect for water in a dry land which, given the spiritual dimension in human life, has become expressed as a creative force, deity or spirit in animalised form (O'Connor et al. 1989), perhaps because the river meanders and pools and riffles evoke the form and movement of a snake-like creature.

Just over two hundred years ago the long custodianship of the Australian continent by the Aboriginal peoples was interrupted. In the south-west, this began with the arrival of Europeans by boat about 170 years ago, first at Albany and then on the Swan River estuary. Not surprisingly, both sites were selected because of the availability of nearby fresh water. For the Europeans to expand their colony and begin farming, they also had to find inland sources of fresh water. Perhaps because of their curiosity and a natural propensity to share, and because the Europeans appeared to offer some advantages, some local Aborigines cooperated with the settlers and led them inland along their well worn river routes, pointing out sources of fresh water (O'Connor et al. 1995). Some even shepherded flocks of sheep along traditional pathways. Inevitably, however, cultural differences, particularly an unwillingness to share on the part of most Europeans and the displacement of Aboriginal communities by the growing settlements, led to conflict which took a heavy toll of Aboriginal people. But disease took a heavier one. After tens of thousands of years of isolation from the continent of Asia, Aboriginal people had a low natural immunity to the diseases that the settlers brought with them and they died in large numbers (O'Connor et al. 1995). On the Beaufort River there is an important Aboriginal site known as 'Measles Bridge', where measles first broke out amongst Aboriginal people living on that river (O'Connor et al. 1995).

6.2 Modern river water use

6.2.1 Early settlement

The early European settlers moved out of the centres of Albany and Perth to impose on Australia an agrarian way of life developed around the Mediterranean over thousands of years. The tools of the trade were horses, cattle, sheep, goats and pigs, cereal crops, fruit trees and a wide variety of vegetables, all exotic and all to be grown in neatly arranged paddocks. This intense use of the land required clearing of the native vegetation and large quantities of fresh water: for livestock watering, sheep washing (to clean the wool prior to shearing) and dipping (for disease control), household uses and irrigation; and later, reticulation of market gardens, orchards and pastures. All this was at a density of human occupation far in excess of that of the Aboriginal peoples. Furthermore, stock routes with reliable watering points were needed to shepherd sheep and take them to market.

With the development of rail transport after 1880, fresh water was required to provision the steam engines (Horwitz and Wardell-Johnson 1996). Flour mills and timber mills, some constructed as early as the 1850s (Lund and Martin 1996; Horwitz and Wardell-Johnson 1996), also needed water for their steam engines. So settlers searched for water along the old Aboriginal pathways, the rivers, and often established settlements along them (Horwitz and Wardell-Johnson 1996). For example, Toodyay, Northam, York and Beverley are located on the Avon, and Augusta, Nannup, Bridgetown and Boyup Brook on the Blackwood. Most of these towns were major steam rail transport centres and/or mill towns in their day. The flour mill at York still stands as does the flax mill at Boyup Brook, built during the Second World War and now a tourist and conference centre on the banks of the Blackwood (Horwitz and Wardell-Johnson 1996).

To show how rivers played a role in establishing settlement, it is worth mentioning one very ordinary example. In 1858, George Stedman Watts and his two sons were camping in the Darling Range south-east of Perth when their horses strayed into the bush. Whilst the party tracked them along the later named Bannister and Wandering Brooks for about 30 km, they came upon a freshwater spring on the banks of the Wandering Brook, about 8 km upstream of the Hotham River. Encouraged by the quality of the country Stedman Watts sought and was given freehold title to the land in 1861. He coined the name 'Wandering' which was later given to the town of the same name (Schorer 1974). Incidentally, the town of Pingelly derives its name from an Aboriginal word meaning 'small gully of water', and the town of Boyup Brook from an Aboriginal name for a local pool, 'Boyup' (Horwitz and Wardell-Johnson 1996; Lund and Martin 1996).

Fresh water was not the only resource that rivers provided. In the very early days of the Swan settlement, it was the relatively rich red alluvial soils of the Swan and Canning river floodplains that were found to be the most useful for agriculture (Seddon 1972; Jarvis 1979; Appleyard and Manford 1979). The Canning River was also an important transport route, particularly for timber which was loaded at Mason's Landing at

Cannington for transport down to Fremantle (Carden 1968). In the days of the horse and buggy the local river pools were important recreational and social amenities. For example, Burlong Pool on the Avon River was a popular picnic site for local farming families during the early part of the 20th century, as was Perry's Pool on the Hotham, (WAWRC 1992a; Lund and Martin 1996). Gibbs Pool on the Harvey River was a popular 'swimming hole' at about the same time. The early introduction of the redfin perch, a fine table fish, along with the existing native freshwater cobbler and marron and the many waterfowl that took refuge from drought on the river pools, enabled fishing and duck shooting, and provided an important source of food for settlers in the early days before their farms could supply all their needs.

But life is full of irony, and so it was for the settlers and their descendants. It was not long after the establishment of towns and farm houses on the major rivers, that frequent flooding called into question the wisdom of their locations. For example, the Swan-Avon system flooded twenty-seven times between 1830 and 1955, the last one having such serious consequences on human settlements that it led to a major river training program (Harris 1996). The town of Williams was moved to a better location soon after flooding in 1905 and many other towns in the south-west have been affected by flooding over the years, leading to a range of flood protection works (Lund and Martin 1996). If not for the decline in rainfall since the 1960s flooding would be a continuing problem, made worse in some areas no doubt by widespread clearing which increases flood intensity.

Furthermore, with the changing surface and groundwater hydrology of the south-west, brought about by widespread clearing, salinisation became a problem and many settlers or their children soon found their once fresh rivers turning salty. Also, increasing soil erosion and the use of fertilisers led to sedimentation and nutrient pollution. In time many rivers, especially in inland areas, became less useful for watering and less attractive for recreation. Marron, perch and cobbler began to disappear by the 1960s (Horwitz and Wardell-Johnson 1996; Lund and Martin 1996). Today many river pools in farming areas are foul and saline in summer when they are most needed, and often shrouded in dead trees. Fortunately, the success and experience of south-west farmers gave them sufficient wealth to take advantage of new technologies and develop innovations to collect water from elsewhere, and also to afford vehicles fuelled by fossil energy to move further afield in search of recreational opportunities. For most rivers the only use remaining was the basic one of drainage, and even this has become compromised in recent years by erosion and sedimentation.

But today's rural people have not turned their back on the rivers. Years of living in a dry land have developed a yearning for the things of life that spring from water and have kindled a growing movement of farmers and rural townspeople to manage rivers and bring back some if not most of the values that were so cherished by the country's first human inhabitants.

6.2.2 Scheme water supply: the dams and weirs

The long hot dry summers of the south-west necessitate the storage of water in order to maintain a year round supply. Some coastal areas have ready made storages of water, in the form of groundwater or more specifically, extensive shallow freshwater aquifers. Today much of Perth and the towns of Bunbury, Albany and Esperance get their water from coastal aquifers. Large dams also provide a form of water storage, but these can only be built where the shape of the land is suitable. With Perth's rapidly growing population of the late 1800s and the need for irrigation on the coastal plain, it was only a matter of time before water supply engineers looked constructively at the fresh rivers of the Darling Range with their deep valleys. The first dam, the Victoria, was completed in 1891 and was constructed on Munday Brook, a tributary of the Canning River (Le Page 1986). It was a comparatively small structure by today's standards with a 15 m high wall, capable of impounding only 0.9 million cubic metres (MCM) and capturing about 86% of the stream's average flow (PWDWA 1985).

Water was also needed for the goldfields region and the growing number of wheatbelt towns. However, the relatively flat and ancient wheatbelt and goldfields areas have neither freshwater rivers or fresh groundwater, nor the hilly terrain needed to build large dams. The solution was a major country water supply scheme designed by C.Y. O'Connor and completed in 1902 (Le Page 1986). For this scheme the large Mundaring Weir was built on the Helena River, a tributary of the Swan. It had a 30 m high wall, impounded 21 MCM of water and was capable of capturing 50% of the average stream flow (PWDWA 1985).

Since those early pioneering years, twenty-three dams have been built on the hills' rivers, with reservoirs ranging in size from 0.3 MCM to over 200 MCM, and capturing a full 32% of the total freshwater flow from the scarp between Perth and Bunbury (Williams pers. comm.). Only the large brackish or saline rivers, the Avon and the Murray, have not been dammed. About twenty scarp streams also flow freely to the Swan Coastal Plain or into the Murray.

South of Bunbury, there are few public water supply dams and all are small (under 0.8 MCM), mostly on the tributaries of the major rivers (PWDWA 1985). For example, a small dam was built on the Lefroy Brook early in the century to supply the town of Pemberton and its trout hatchery, and later in 1985 a larger dam was built upstream on Big Brook to supplement this supply. The larger of the lower south-west dams are located near Nannup, Manjimup and Denmark. Only the last is located on the main channel of a river, the Denmark. One of the smallest dams lies on the upper Gardner River near Northcliffe, a fine example of a small attractive and relative unobtrusive facility which blends in with the scenic beauty of the surrounding forest.

Not all dams in the south-west have the same function. Storage dams store water, capturing a proportion, if not most, of the water that flows into them. Pipehead dams do not store water, but hold a portion of the 'run of the river' flow for immediate transfer by pipeline to a large storage dam, upstream on the same river system or in an adjacent catchment. The South Dandalup Dam is a large storage dam which can hold far more water than its small catchment can produce in all but the wettest years. It was constructed to store water from adjacent streams and from dams that are known to overflow regularly and thus lose water. Unfortunately, because of the run of recent relatively dry years the South Dandalup has mostly been empty since it was completed in 1974 (PWDWA 1985).

Two dams in the south-west, the Wellington and Denmark, on the Collie and Denmark Rivers, have had to be taken off town water supply owing to increasing water salinity caused by salinisation in their partially cleared catchments (WAWA 1989). Both catchments are being rehabilitated and have strict controls on clearing to prevent further increases in salinity. Similar controls have been placed on the Warren and Kent catchments which are earmarked for future water supply and the Helena catchment which provides water to the Mundaring Dam (WAWA 1989).

6.2.3 Country town and farm water supply

Country people collect and store water in various ways, often without depending on river systems. For domestic use, water collected on roof tops is stored in tanks. Stock are often watered from excavated soaks or from dams placed below springs and seepage areas. Earth dams are placed on a slope or in a depression with or without a contour bank or drain to intercept rainfall runoff and bring water to the dam. For many wheatbelt country towns, which are not connected to water supply schemes supplied by the large Mundaring and Harris River Dams, small dams placed at the base of small bushland, rock or bitumised catchments, with very high runoff rates, are the main means of water collection and storage.

Farm water supplies that make direct use of river systems are to be found closer to the coast where the more dissected terrain enables the construction of gully dams and the underlying clayey soils reduce percolation of water into the ground. These dams are usually small, inundating only a few hectares of land at most, and have walls constructed of earth. Their small size and the high runoff rates of their mostly pastured catchments mean that most of them can only collect a few per cent of the average annual streamflow. For this reason it is not unusual to see a series of dams along a watercourse, forming a step-like pattern down a valley. Gully dams are most common in the middle Blackwood, Donnelly and Warren catchments where they are essential to the growing horticultural industry.

Gully dams made of earth are not much different in function from the large concrete and stone public dams; both serve to capture and store a portion of the water leaving the catchment. But whereas a great deal of research and planning goes into the construction of public dams to ensure their safety in times of flood when large flows overtop the dam, the same cannot be said for many private gully dams. Yet their construction from earth and their location in high rainfall and largely cleared areas renders them far more prone to collapse during flash floods. Although these dams may comply with sound engineering principles, their construction was not based on the rigorous investigations into catchment discharge required for public supply dams, and thus their stability during high rainfall events is not assured. Indeed, public dams are required to meet ever more stringent international safety standards and old dams occasionally have to be upgraded.

6.2.4 Irrigation

Irrigated agriculture from surface water resources is a major land use on the southern Swan Coastal Plain, covering about 12,000 ha and consuming about 200 MCM of Darling Range water annually (Stone pers comm.; WAWA 1990). This water is supplied by seven dams with reservoirs ranging in size from 9 to 185 MCM (WRC data). The dams and most of the channel systems which bring water to the farms were built between the 1910s and 1970s (WRC data). Nearly all of the irrigated land in the Waroona, Harvey and Wellington Irrigation Districts is simple pasture, mainly supporting cattle.

In the late 1980s about 60% of the irrigated area and 65% of the water was used by about 170 dairy farms to produce nearly half of the State's supply of milk (WAWA 1990). The rest of the land and water was mainly used for beef production, but a small proportion was used for horticulture. Today, viticulture and other forms of horticulture are becoming more important, mainly replacing beef production. A trend towards higher value products is expected to continue as land users are required to meet the real costs of irrigation in the near future (WRC 1998).

While irrigation enables high agricultural production to continue over the long dry summer, it is not without its environmental problems. About 33% of the irrigated land is suffering depressed yields caused by salinisation and waterlogging (WAWA 1990). The problem is caused by rising groundwater, due to leakage from the channel system and over-watering, and the build-up of salt through evapotranspiration in poorly drained areas. It is made worse in some areas by the high salt content of the water from the Wellington Dam, which in some years reaches 1000 mg/L, too high for long-term sustainable agriculture in the absence of good drainage which permits the efficient through-flow of salts (WAWA 1990). Studies done in the Dardanup area have shown that about three times as much salt is applied to the land in the irrigated water as runs off in drains, leaving large amounts of salt to pass into groundwater (WAWA 1990). In many areas, brackish groundwater underlies farmland, often rising to the surface and affecting crops in winter.

The solution to this problem is lower water use and better drainage, but drainage also has impacts. Irrigated farmland is fertilised, and water passing from the land to the drains carries nutrients that pollute downstream waterways. About 58% of the irrigated area of the coastal plain drains to the Leschenault Inlet and 34% to the Peel-Harvey Estuary (WAWA 1990).

6.3 DRAINAGE

The most basic use which humans derive from river systems is drainage. This section deals with drainage not only in relation to natural streams but also to modified ones and entirely artificial waterways.

Drainage whether natural or otherwise is needed for two basic reasons, to remove large amounts of water deposited in storms (stormwater) and to lower the watertable to enable some form of land use. In the southern suburbs of Perth, large seasonally swampy areas have had to be drained to permit residential development, and with the spread of hard rooftops and roads, drains were needed again to remove stormwater. There is an irony here, in that most swampy areas are low lying and flat and do not allow rapid stormwater drainage once urban development is established. Such areas are prone to flooding during heavy rainfall.

In other low-lying areas of the Swan Coastal Plain and along the south coast to Albany, land has had to be drained to permit agriculture. In the early days, the new settlers did not have the resources and expertise to carry out the broad scale drainage that was needed. So in 1894 requests were made to government for drainage improvements. With the passing of the first Drainage Act in 1900, extensive drainage works were initiated over the following 30 years, involving the modification of existing natural streams (mostly the removal of woody debris or channel enlargement) and construction of new drains (WAWRC 1992b). In the irrigation districts, drainage was also needed to carry irrigation water away, to prevent waterlogging and to allow an efficient throughput of water to prevent the build-up of salts.

All of this work took place on the southern Swan Coastal Plain and along the coast between Denmark and Albany, and today there are six drainage districts: Mundijong, Waroona, Harvey, Roelands, Busselton and Albany, which together drain about 320,000 ha of land (WAWRC 1992b). There are also large areas of private drainage on the Scott Coastal Plain, about Walpole-Nornalup and east of Albany. Also, in the wheatbelt, where widespread clearing has led to groundwater rise and salinisation, drainage is increasingly considered necessary to prevent waterlogging by intercepting and carrying away salty groundwater before it rises to the land surface.

Artificial drains are usually trapezoidal in cross section, being wider at the top than the bottom, with steep sloping sides. The drain is designed to carry a larger than typical flood when bankfull and to minimise upstream flooding, typically to no more than three days in rural areas (WAWRC 1992b; Jim Davies et al. 1994). Most drains are straight and have a slope sufficient to generate a flow of no more than 1 m per second, which is not too energetic to cause erosion. Drains of this design have a number of advantages: they require the excavation of a minimum amount of earth, minimise bed area and thus drag and require smaller bridges and culverts to span them (WAWRC 1992b). Many landowners prefer wider drains because of the perception that they can carry more water. But actually, while wide drains hold more water, actual conveyance may be reduced by increasing drag caused by the greater area of contact between the water and the bed.

While drains open up areas to development and may increase economic income, they are not without their problems. Their steep sides are prone to collapse and damage by livestock, which is worsened in times of flood, resulting in serious erosion and sedimentation. If drains are not grazed by livestock, they quickly become infested with weeds and may need to be periodically cleaned out. This is usually done by spraying and where necessary a back-hoe is used to dig out accumulations of sediment and plant material and to scrape bare the sides of the drains (Jim Davies et al. 1994). Spoil is usually dumped beside the drain, creating levee banks. In this way drains increase in width and depth over the years (Jim Davies et al. 1994). Some old suburban drains have already reached backyard fences.

Drains are expensive to build and maintain. The operating cost of the drainage districts was estimated at over $2.5 million in 1992-93 (English 1994). More striking is the replacement cost for the 2510 km of drains in the six drainage districts, which was estimated at $93.7 million for the same period (English 1994). This figure allows us to estimate drainage value of river systems. For example, the Kalgan River system has been estimated as having about 4000 km of streamline (Weaver et al. 1994), giving it a notional asset value of $150 million. And the Kalgan, being a river ecosystem albeit moderately degraded, is far more than a mere drain.

6.4 FLOOD PROTECTION

Drainage systems, natural or otherwise, by their very nature reduce flooding but they can also cause it by transferring large quantities of water downstream to low-lying areas and by allowing water upstream from the ocean during storm surges. The Geographe Bay catchment about the town of Busselton, has both problems. For these and other reasons, the Buayanup, Vasse and Capel Rivers were diverted from their estuaries to discharge directly to the sea, and floodgates were placed at the mouths of the Vasse and Wonnerup Estuaries (Olsen and Skitmore 1991). The nearby Five Mile Brook was similarly diverted to protect Bunbury. Further to the north, the Harvey River was diverted for 21 km to discharge to the sea rather than occasionally flood a large low-lying area of land between the town of Harvey and the Harvey Estuary (Olsen and Skitmore 1991). This large community employment project was carried out by 2500 men using shovels and wheel barrows during the great depression of the 1930s (Le Page 1986).

As was discussed in Chapter 2, serious flooding can also occur when floodwaters burst river banks and inundate extensive floodplains, on which may be valuable farming land or settlements. In this case the obvious course of action has always been to increase the conveyance capacity of the river. This can be done in two ways. The first is called 'river training' which involves channel straightening and the removal of vegetation and debris to reduce drag and thus increase the flow velocity. A secondary effect is incision which increases channel depth and in turn further increases velocity (as stated in Section 2.2.4, velocity is mainly a function of depth). Thus the river not only flows faster, it can also hold more water, which in itself is a form of flood mitigation. In the south-west, 187 km of the Avon River between Toodyay and Brookton was 'trained' (though not straightened) between 1958 and 1970 (Harris 1996). This action is perceived to have had a major deleterious impact on the river, largely involving the mobilisation and transportation of huge quantities of sediment and the subsequent sedimentation of river pools. While the flood mitigation function of the trained Avon River is considered to be limited (Binnie and Partners 1985), similar but smaller scale works carried out in the 1960s along 13 km of the Collie River, near Collie, have been successful in preventing flooding of the town of Collie, and with no serious sedimentation problems (Olsen and Skitmore 1991).

An alternative approach to flood mitigation is to raise the river with levee banks. Such works have been carried out on the Greenough River, south of Geraldton, on the Avon River at Northam, and on the Preston River at Bunbury (WAWA 1994). Levee banks are also located on 3 km of the Harvey River diversion. Landowners with substantial pasture land on the floodplain of the lower Moore River have also erected levees to reduce flooding. Although levees are effective means of containing floodwaters, they do so at the price of increasing effective channel depth and thus stream power. Leveed rivers are powerful rivers and should the levees ever break the extra power is available to do much damage. Furthermore, if the levee is only located on one side of the river, the raised water level may erode the upper level of the opposing high natural bank, a situation which appears to exist on parts of the west bank of the lower Moore River as it flows along the eastern edge of a high sand dune.

As an extreme example of flood protection, consider the lower Preston River. It has been straightened, streamlined, widened and constrained within levees 4.4 km long, in a series of works carried out between the 1950s and 1980s (Olsen and Skitmore 1991). The levees were raised and strengthened following floods in 1964. In addition the river has been relocated to make way for harbour developments, and will be moved again as the harbour grows.

A curious fact about flood protection works is that they are generally only supported by the local communities whilst past floods are still fresh in their memories. As time goes by, and the recollections of past floods slowly dim, the cost burden of maintaining drains, training schemes and levee banks becomes intolerable; landowners refuse to pay drainage rates, local governments drop channel maintenance programs and no one, as it turns out, appears to have responsibility for particular levee banks (Olsen and Skitmore 1991; Jim Davies et al. 1994; WAWA 1994). That is, until the next big flood.

Lastly, the large water supply dams are also a form of flood protection. The inhabitants of the lower Collie may one day be thankful for the presence of two large dams, the Wellington and the Harris, on the Collie system.

6.5 Recreation and sport

Rivers of the south-west provide a wide range of recreational opportunities, including swimming, boating, fishing and shore based activities, such as walking, picnicking and camping (Feilman 1987; Madden 1995). In the early days of European settlement, people from the Perth urban areas would take rail and later bus excursions to John Forrest National Park (Jane Brook), Mundaring Weir, Lake Leschenaultia (on Cookes Brook), Araluen (Stinton Creek) and Serpentine Falls (Olsen and Skitmore 1991). Today, these sites are still important to the Perth community.

With growing affluence, increasing leisure time and the advent of the motor car, people now have access to recreational sites on rivers from Geraldton to Albany, and there is a wide range to choose from. Along the Darling Scarp the irrigation dams, which do not have to provide drinking quality water, are available for recreation, as is the small Big Brook Dam nestled amongst regenerating karri forest near Pemberton. Because the dams close to Perth are not available for recreation in order to protect water quality, recreational facilities are provided at the base of the dam walls, sometimes around a natural river pool or a previously existing small dam. Some famous old swimming sites like Lake Leschenaultia and Fonty's Pool near Manjimup are actually old disused gully dams.

A number of rivers in the south-west still provide recreational opportunities amongst natural surroundings or the aspect of a free flowing wild river. One of the best examples is the Murray River where it flows through the dense jarrah-marri forest of the Darling Range. Now part of the Lane-Poole National Park, it provides a major recreational area for thousands of people, especially over the long weekends of the early part of the year when the weather is usually fine. The Warren River National Park provides similar opportunities, but with the added feature of overhanging tall karri forest.

The larger powerful rivers are popular for boating. Some, like the Donnelly, Warren and Frankland, are probably canoed more for their scenic values than for the 'wild' river experience, but rivers like the Murray and the Deep provide both wild, turbulent waters and scenic qualities. The Avon and Blackwood, although highly altered along much of their canoeable lengths, provide the longest continuously canoeable sections. For this reason, these rivers can support major sporting events, involving both powered and unpowered boats, like the Avon Descent from Northam to Perth which takes place in August, and the Blackwood Classic from Bridgetown to Augusta on the Queen's Birthday holiday weekend. The canoeing and swimming legs of the Blackwood Marathon take place between the Winnijup and Jayes Bridges on the Blackwood River between Boyup Brook and Bridgetown.

A more subdued experience is provided by lonely river pools. Some of these, like the Ellendale Pool on Greenough River near Geraldton, are amongst farmland, while others are deep within forest, such as the Barrabup Pool on the St Johns Brook near Nannup. In fact there are hundreds of river pools throughout the south-west that would do for an afternoon's swim, family

THE WELLINGTON DAM ON THE COLLIE RIVER. IT WAS COMPLETED IN 1933 AND TWICE RAISED, IN 1944 AND 1960. IT CAN STORE 170 MILLION CUBIC METRES OF WATER. PHOTO: D. MOSS

FLOOD CONTROL LEVEES ON THE TRAINED LOWER PRESTON RIVER. THE LEVEES ARE TO PROTECT THE CITY OF BUNBURY FROM FLOODING. PHOTO: J. GARBUTT

Trout fishing on the Lefroy Brook near Pemberton. Photo: S. Neville - Ecotones

Canoeing on the Avon River. Photo: Unknown picnic or a lonely night's camp, under black, leafy and starry skies.

Scenic drives are also available along some rivers. One of the best is the drive from Balingup to Nannup that winds its way along the deep Blackwood valley. The best time is morning in late winter, when the hillsides of deep green paddocks, pines, jarrah and marri are shrouded in mist and the Blackwood flows in flood through the dense fringing vegetation of flooded gums, paperbarks and tall sedges. Many rivers, which are too densely vegetated to canoe and are not flanked by road, can be walked and it is strange that more is not made of river walking as a form of recreation - a stroll in the footsteps of the Aboriginal people.

Finally there are river parks, where one can enjoy a community atmosphere down by the river. A long park winds its way along the Canning and Southern-Wungong Rivers and includes an amphitheatre at Gosnells. Balingup has a small park and football field on the floodplain of the Balingup Brook. There are river parks in the towns along the Avon River and the one at York has helped the town play host to an annual jazz festival. The town of Margaret River has a small heavily used little park with a grand view up the river, and a river walk along foreshores of tall karri forest. But the best is on the Denmark River opposite the town of Denmark. Here a small park under tall karri and paperbark trees is host to village fairs, concerts and plays. Nowhere is there a better example of what a south-west river has to offer to community life.

6.6 FISHING AND AQUACULTURE

6.6.1 Fishing

Humans are hunter gatherers by nature and it is therefore not surprising that, in spite of a bounteous supply of food, fishing is one of the most popular amateur pursuits in Australia. Unfortunately, inland fishing is very limited as the rivers of the south-west do not support a broad assemblage of native fish species suitable for fishing. The only large fish is the freshwater cobbler and it is not rated highly for its table or sporting qualities, at least not from a European cultural perspective. For this reason, the early settlers were very interested in introducing fish species which could offer the sort of 'rod-and-line' fishing to which they were accustomed. Chief among the fish most sought after were the ultimate in freshwater fishing species, the trouts. Rainbow trout and brown trout are held in high esteem by freshwater fishers, especially fly fishers, for their beauty, strength and not least (or perhaps least) for their eating qualities.

Interest in introducing trout to the south-west grew after locals heard of successful introductions in Tasmania in the 1860s (Coy 1979). Following an early crude attempt to place a small batch of brown trout ova in the cool waters near Albany in 1877, a trout hatchery was constructed on the Preston River in the early 1890s (Coy 1979). From there a number of south-west streams were stocked. However, serious introductions did not begin until the 1930s when the Pemberton Trout Hatchery on the banks of the Lefroy Brook began operation. This facility has operated for over 60 years providing millions of ova, fry and fingerlings for stocking streams and farm dams throughout the south-west. In 1971 it was taken over by the government and is now operated by Fisheries Western Australia, which concentrates stocking in irrigation dams, farm dams and waterways that already support trout (Fisheries Dept. 1995a).

A second trout hatchery was opened on the Collie River South Branch in 1939, just upstream of the present day Schultz's Weir. It was short lived however, burning down in 1945 and never rebuilt (Coy 1979); the concrete remnants can be found among regenerating forest at the upper end of the weir pool.

The success of trout in south-west streams is greatly limited by high summer water temperatures, as neither species can tolerate temperatures much above 20° C, and by a lack of gravelly stream beds needed for spawning (Fisheries Dept. 1995a; undated a). Some successful breeding does take place however, in some south-west streams and presumably the tributaries of some of the major Darling Range rivers, as there are long lived populations in these waters. Even though hatchery breeding has given rise to trout which can tolerate temperatures up to 23° C (Morrissy 1973), the best waters for trout are the cool waters of the south coast streams and the dams of the northern jarrah forest. In the case of the latter, only the irrigation dams, where water quality is not of paramount concern, may be legally fished (Fisheries Dept. 1995a).

Because the trout fishery is limited in size, it is tightly regulated by Fisheries Western Australia. A south-west freshwater angling licence is required (for all fish species) and the relevant literature should be consulted as to open/closed waters and seasons and legal sizes, bag limits and fishing gear. In the early 1990s about 8000 licences were taken out annually (Fisheries Dept. 1995a).

Other fish species have been introduced over the years, among them redfin perch, carp, tench, eels and large eastern state species, such as Murray cod, silver perch and golden perch. Of these only redfin perch has been widely successful; some would say too successful. Introduced in 1892, large catches were reported from a number of rivers by 1910 (Coy 1979), and since then the species has spread to virtually all south-west fresh waters. Today it is considered feral, producing large stunted populations of poor sporting and eating quality. Nevertheless, diehard seasoned redfin fishers continue to pursue the larger fish in the larger rivers, such as the Murray, Collie, Blackwood and Warren, while the smaller fish amuse young anglers and holiday makers.

6.6.2 Marroning

The most important inland amateur fishery in the south-west is not based on a fish species, but on the large nocturnal freshwater crayfish, marron. Since the early days of settlement, marron has been prized for its fine eating qualities and relative ease of capture using any one of a variety of methods, including baited drop nets, scoop nets and snares. Through the translocation of marron beyond its original range of the streams of the jarrah and karri forests, both to extend the fishery and for aquaculture, it can now be found in river pools and farm dams from Geraldton to Esperance (Morrissy 1978; Fisheries Dept. 1995b).

Despite the abundance and broad distribution of marron, there are major concerns over the ability of stocks to withstand current levels of fishing pressure from a growing human population. To protect the fishery, controls have been put in place similar to those for trout, only more severe. For example, marron can not be caught from a boat and many waters are declared 'snare only'. In 1995, 18,630 licences were issued for a short, less than two month season over January and February (Fisheries Dept. 1995b). Again, the relevant Fisheries literature should be consulted for current season's regulations.

Marron may have an important ecological role to play in the health of river ecosystems and regulation of the fishery in the future may need to account for this role as well as the sustainability of the fishery.

6.6.3 Aquaculture

Aquaculture, or the farming of fish and crustaceans, is a growing industry in the south-west. The principal species involved are rainbow trout, brown trout, marron and the introduced crayfish, the yabbie (*Cherax albidus*). To achieve reasonable growth rates and marketable quantities, specially designed grow-out ponds are required for trout and marron (Fisheries Dept. undated a,b,c). Consequently, rivers are mostly only used in trout and marron aquaculture as sources of water and in some cases for the disposal of wastewater following treatment (Morrissy pers. comm). Often trout farms, such as the one on Treen Brook, offer pay fishing to tourists and thus make a useful contribution to recreational fishing (Fisheries Dept. 1995a). Similarly, some farmers in the cooler parts of the south-west stock their dams with fingerlings from the trout hatchery to offer pay fishing, creating what is called a 'put and take' fishery.

The yabbie was introduced into WA from the eastern states as early as 1932. It does not grow as large as marron, but still reaches a size considered reasonable for consumption and farming. Because the species is tolerant of higher water temperatures than marron, it is suitable for rearing in the larger farm dams of the wheatbelt (Morrissy 1995; Fisheries Dept. undated c). Over the years yabbie farming has become lucrative for farmers with the right kind of dams. To develop the industry Fisheries Western Australia maintains a small research facility at Beverley. In an effort to protect forest stream ecosystems from invasion by the yabbie, farming of the species is limited to the agricultural area east of a boundary drawn from Perth to Albany and which runs along the inland margin of the State forest (Fisheries Dept. undated c).

6.7 SCIENTIFIC AND EDUCATIONAL USE

River systems are of considerable scientific and education interest because they are 'focal points for concentration of indigenous flora and fauna, vivid representation of geomorphic and geological forms, indicators of regional and local water quality and important media for reproductive processes in the biota' (Patrick Coffey 1990). The very nature of rivers, together with their catchments, brings their ecological, physical and hydrological processes into collision with human activities, the results of which inevitably attract researchers. Drake (1995) noted that streams (and wetlands) which were the subject of scientific investigations or had the potential to be so, had significant unique features such as a rare species (e.g. the pouched lamprey); were near-pristine and thus offered the unique opportunity to study natural processes; presented the opportunity to study long-term climatic or catchment changes; had been previously studied and provided a good basis for further work; or by chance were related to the specific interests of scientists and funding bodies.

It follows that, because rivers provide a wide range of uses and services, they become water resources that need to be managed. Management requires that the community knows a great deal about the nature of rivers and knowing about rivers, like anything else, requires that knowledge gained through research is passed on to other people through education.

Research and monitoring

Not all scientists are agreed on what constitutes research. Some believe that only the testing of hypotheses with rigorous statistically valid experiments is research and that the rest is mere descriptive science or natural history which does little more than develop the models which need to be 'researched', to prove whether or not the models are valid, and thus can be applied in management (Underwood and Chapman 1995). Whatever the opinion, research in south-west rivers can be divided into short-term investigations which may last a few weeks to as long as five years, and long-term monitoring which may last many decades.

The most important research carried out on south-west stream ecosystems is the largely descriptive work carried in the 1980s and 1990s at the School of Zoology, University of WA, and led by Drs Stuart Bunn and Peter Davies. The results of this pioneering work are described in Chapter 3. As an example of experimental research, Drs Ivor Growns, Kerry Traylor and Jenny Davis, from Murdoch University's School of Biological and Environmental Sciences, investigated the impact of logging on karri forest streams over the late 1980s and 1990s. Their work involved descriptive studies, hypothesis generation and properly replicated sampling of stream invertebrates from streams in logged areas and unlogged areas (see Chapters 3 and 7). Since the mid-1970s, a fish research group, under the supervision of Professor Ian Potter from the same School has been conducting research on the primitive pouched lamprey. This work has been both ecological and physiological in nature, as the study of the primitive physiological and biochemistry of the lamprey helps in the understanding of the biology of more advanced animals, including humans. In the 1980s, the fish group moved on to study the natural history of the south-west's small suite of endemic freshwater fishes (see Section 5.1.6).

The Water and Rivers Commission, in conjunction with CALM, Agriculture WA, CSIRO and some landowners, maintains a number of research catchments throughout the south-west looking at the effect of short and long-term clearing and subsequent revegetation on groundwater movements and saline discharge. This work has contributed significantly to our understanding of catchment hydrology, as outlined in Section 2.2.

The Water and Rivers Commission also maintains 585 streamflow gauging and water quality monitoring stations throughout the State (Muirden pers. comm.). These stations usually take the form of a small concrete weir and raised metal or concrete shelter in which the measuring equipment is housed. Presently about 240-365 stations are in operation. The research which utilises these facilities is an example of long-term monitoring, in this case needed to gain an understanding of streamflow variation in relation to climate and catchment changes. Armed with this information the Commission can direct water supply development; and water suppliers, such as the Water Corporation, can be confident that they have sufficient supplies of suitable quality water to meet projected demands, especially in times of prolonged drought. Main Roads Western Australia also uses the information to calculate the necessary size of road culverts and bridges so that flooding seldom damages roads.

Stream monitoring is also done to determine nutrient and sediment loads, providing essential information for catchment management and planning. By monitoring a number of streams over a long period of time, sub-catchments and particular catchment activities which yield high loads can be identified and targeted for management. For example, stream monitoring identified the Ellen Brook catchment, on the outskirts of the Perth metropolitan area, as a major source of nutrients for the lower Swan River (SRT 1998). Over the years, monitoring will show whether or not catchment management in this rapidly developing part of greater Perth is effective in reducing nutrient and sediment loss from catchments.

Research and development

A second phase of research involves taking the results and developing technologies which can be applied to solve particular problems; hence the phrase 'research and development' or 'R & D'. To promote R & D on environmental technologies the Federal Government has set up the Land and Water Resources Research and Development Corporation (LWRRDC) to sponsor R & D programs in conjunction with government agencies, community groups and private businesses. In the 1990s, LWRRDC ran two programs of relevance to river management: the Rehabilitation and Management of Riparian Lands Program and the National Eutrophication Management Program, both in partnership with State government agencies and community groups. Environment Australia is implementing two nationwide programs: the Monitoring River Health Initiative whereby a range of streams, both near-pristine and degraded, are sampled for invertebrates by local universities and State government agencies in a search for regional biological indicators which can be used to monitor stream ecosystem condition; and the National River Health Program to sponsor research into environmental water requirements.

Education

Many schools, TAFE colleges and universities make use of rivers and creeks (and wetlands) in their teaching courses. Since teaching sessions in schools and TAFE colleges may last an hour or less, access is an important factor in determining whether or not a local stream is regularly used, as is the permanency of the creek's flow of water (Drake 1995). For example, the Barlee Road Footbridge on the Capel River is within walking distance of the Capel Primary School which makes regular use of the river for its biological programs. Even better, Winter Creek near Narrogin, runs through the Agricultural College and is used as part of College's land use and landcare studies (Drake 1995). More distant streams tend to be used for day long course work or extended camping trips. For example, Geenyulgup Brook, near Yallingup, has been used by the Margaret River Senior High School for its annual geography studies for over ten years.

Since 1989, the link between school studies and river systems has been broadened and deepened by a WA program known as Ribbons of Blue, which is part of the Commonwealth Government's nationwide Water Watch Program (see Section 9.4). Ribbons of Blue operates out of the Water and Rivers Commission and assists many schools and community groups to carry out water quality and macro-invertebrate monitoring of local streams in various catchments around the south-west. In this way education embraces research and develops a keener understanding by local school students and older community members of scientific methods, stream processes and land use impacts. This program, described in greater detail in Chapter 9, involved 185 groups in 1997 and is invaluable in raising local community awareness of the need to protect and manage river systems.

Future use

As the human population of the south-west grows over the coming decades, the demands placed on rivers will increase. More water will be needed to support human activities, the demand for rivers to provide for recreation and lifestyles will rise and river systems will be called upon to drain more and more water from the land, much of it containing sediments, nutrients, salt and other pollutants. The use of rivers, and of the catchments that sustain them, is taking its toll on river health, and of wetlands generally. As a result, the capacity of the rivers of the south-west to provide for existing needs, let alone those of the future, is declining. The degradation of south-west rivers and their catchments is the subject of the next chapter.

Chapter 6
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chapter 7

River system degradation

- Salinisation and waterlogging
- Erosion and sedimentation
- Riparian zone degradation
- Eutrophication and deoxygenation
- Introduced fish
- River diversion, drowning and blockage: dams, weirs and culverts
- Weed invasions
- Toxic chemical pollution
- Stream ecosystem degradation
- An hypothesis: organic pollution of south-west rivers?

To manage river systems it is necessary to understand what is wrong with them, and to distinguish between cause and symptom. Both must be attended to by managers, but the final reckoning is always with cause. The ultimate cause is us, the people of the south-west of Western Australia. We must understand that the changes made to our catchments, the materials we add to them, the plants and animals we have introduced, the structures we build and activities we undertake have consequences far beyond our good intentions for ourselves and our community. Those consequences extend to most elements of our natural world and indeed ultimately upon ourselves. This chapter describes those we see in our rivers.

7.1 Salinisation and waterlogging

7.1.1 The cause of salinisation

Moisture laden winds coming off the ocean from the west or south-west in winter cool over the south-west land mass and drop rain. These winds also carry ocean salt which was whipped up by waves and wind and carried high into the atmosphere. So when rain falls, a small amount of salt is also deposited on the land, about 100-170 kg per hectare annually near the coast, gradually decreasing inland beyond the wheatbelt to about 20 kg per hectare (estimated from WAWA 1989, see Hingston and Gailitis 1976).

As was described in Chapter 2, most of the water which falls as rain soaks into the soil and is taken up by the vegetation, whereupon it is transpired back to the atmosphere. The effect is that the vegetation takes up the water and leaves the salt behind in the soil. In the Darling Range near the coast, where rainfall is heavy, as much as 30 % of the water eludes the vegetation, passing through the soil to generate strong streamflow. Here there is sufficient water movement to flush much of the salt from the soil and carry it back to the ocean, more or less as quickly as it is deposited. But further inland less and less water escapes the vegetation and with poorer drainage there is less water to flush salt from the land.

Over the thousands of years in which the current climatic regime has been in existence, salt has gradually accumulated in the soils of the south-west where rainfall has been insufficient (generally less than 1100 mm annually) to produce strong groundwater movement and hence stream flows. As a result, most of the soils of the south-west have high salt storage levels, anywhere from 5-120 tonnes per hectare in the 1000-600 mm rainfall band (Stokes et al. 1980). In the lower rainfall areas of the wheatbelt, salt storage can be in the thousands of tonnes per hectare (McFarlane and George 1992; WA Govt. 1996). With widespread clearing of the native vegetation of the south-west and its subsequent replacement with lower water using annual crops and pastures, more water is passing into the groundwater, raising the watertable and carrying 'fossil' salt to the surface. Where salt is carried to a normally dry ground the effect is known as dryland salinisation. Where salt is carried to wetlands and causes an increase in the salinity of flowing surface water it is known as stream salinisation.

7.1.2 Stream salinisation

The early European explorers, scientists and settlers noted that inland waters of the south-west and those along the south coast east of Albany were naturally brackish or saline[1] (Bennett and McPherson 1983, cited in George et al. 1997). With the high soil salt content of the inland areas, the limited groundwater flow to streams produced brackish and sometimes saline river pools in summer and in some situations brackish to saline base flows (Hodgkin et al. 1979). For example, the Boonawarrup Creek which flows out of the southern side of the heavily vegetated Stirling Range is naturally saline (Pen pers. obs.). During flooding rains, however, the mostly surface flows were fresh and the many lakes of the wheatbelt would have received inflows of fresh water in winter. In the case of shallow lakes,

[1] Generally, engineers and agricultural scientists define fresh water as having less that 500 mg/L of total dissolved solids; marginally fresh 500-1500 mg/L: brackish 1500-5000 mg/L and saline more than 5000 mg/L (George et al. 1996). Ecologists consider fresh water to be less than 3000 mg/L; brackish 3000-10,000 mg/L; saline 10,000-35,000 mg/L (see Bayly and Williams 1973 and Halse et al. 1993 in Chapter 4 Sources of Information).

many of which were (and still are) surface expressions of brackish or saline groundwater, their water was made increasingly saline through evaporation until all the water had evaporated leaving a white salt encrusted lake bed in dry periods. These salt lakes can be viewed as 'windows to the groundwater' where the groundwater reached the surface and evaporated or drained away. Some lake systems, especially those in the very low rainfall areas of the eastern wheatbelt and beyond, accumulated such high salt loads that when they overflowed in exceptionally wet years they produced brackish flows on their associated downstream rivers. The Avon is an example of a large river system which is connected to salt lakes in its eastern catchment. All of this explains why many of the rivers of the south-west, where annual average rainfall drops below 600 mm, supported a wide variety of salt-tolerant plants (see Chapter 4).

Today, the process of salinisation is increasing the salinity of streams. This happens in two ways. Firstly, increasing groundwater flows carry larger quantities of salt directly to streams. Officers of Agriculture WA have noted a steady increase in base flow of the Kalgan River over the last 20 years (see Section 10.3 and Fig. 10.2). This suggests that with rising watertables groundwater seepage into the Kalgan is steadily increasing, and in the case of the low rainfall part of the upper catchment greater quantities of salt are probably being discharged and carried downstream into the normally fresh parts of the river. The second process involves dryland salinisation, in which rising groundwater carries salt to the land surface where it can be washed away by surface flows and carried into lakes and streams. Both processes account for steady increases in salinity of most south-west rivers. For example, salinity in the Warren River, whose catchment is about 40% cleared, has gone from less than 300 mg/L in 1940 to about 800 mg/L in 1985, representing a steady increase of about 15 mg/L per year (Schofield et al. 1988). Salinity in the longer Blackwood River, with an 85% cleared catchment, has gone from about 500 mg/L in the mid-1950s to nearly 2000 mg/L in the mid-1980s, a yearly increase of about 50 mg/L per year (Schofield and Ruprecht 1989).

7.1.3 Temporary stream salinisation: the effects of logging and mining

Significant groundwater rise can occur when logging or mining operations temporarily thin or clear an area of forest (Schofield 1990). In the intermediate rainfall zone (1100-900 mm annually), groundwater rise under thinned or cleared forest is rapid and can lead to increased saline flushes of stream systems. These abnormal events cease when the forest regenerates and once again draws heavily on groundwater. In the past it is likely that certain salt-sensitive fauna were displaced and perhaps eliminated from streams by unusually high salinity. Today, logging operations in the intermediate rainfall zone are careful not to cause saline flushes (CALM 1994).

7.1.4 Streamline waterlogging

Another effect which has received little attention but which must certainly be as important as salinisation, is increased inundation and waterlogging of streamlines. With rising watertables and greater groundwater discharge, not only are seepage areas along stream embankments likely to be larger, but prevailing flows are probably at higher levels and of greater duration, as with the Kalgan River above. Many streams which would have ordinarily dried out each summer, probably now flow all year round or at least have beds and banks which remain waterlogged for longer periods. The effect of greater inundation and waterlogging, together with salinisation, probably explains the extensive stands of dead and dying trees along many inland watercourses of the south-west.

7.1.5 Conspicuous effects of stream salinisation and waterlogging

Salinised streams are usually evident by dead and dying native fringing vegetation. It is usually replaced by more salt-tolerant native species or by exotic species, such as grasses, whose life cycles are short and which exploit only the fresher winter and spring period. Sometimes the effects of salinity are difficult to detect but may be seen, at closer inspection, by the absence of regeneration of native trees and shrubs. It is also difficult to distinguish the effects of salinisation and excessive waterlogging. Indeed prolonged waterlogging alone may be responsible for the death of native fringing plant species along some rivers. On others, the effects of waterlogging and salinisation compound one another and make life increasingly difficult for fringing plant species, already contending with leaf miners, borers and disease. Flooded gums stressed by waterlogging and salt may be finally killed by a heavy burden of leaf miners. In many areas, where fringing vegetation is not protected behind fences, grazing by livestock is an added pressure.

7.1.6 Specific effects on wetland life

While the symptoms of salinisation in inland areas are obvious, there has been very little research into the effects of salinisation on wetland life in Western Australia. Most of what has been done concentrates on aquatic vegetation and wetland trees and then mostly on or around lakes (see the work of Brock and Lane 1983 and Brock and Shiel 1983; Froend et al. 1987; van der Moezel and Bell 1987a and b; van der Moezel et al. 1988. A small amount of information is available on the impact of increased salinity in lake systems on waterbird breeding (Halse 1981, 1987). A number of scientists (Hart et al.1991) have completed a review of the effects of salinisation on freshwater biota across Australia. The major findings of these studies are outlined below.

Effect on plants

Many aquatic plants and algae species are salt sensitive, with abnormal salinity variations and peak levels of the order of 1000 - 2000 mg/L likely to be lethal. Below this range plants and microalgae may exhibit what are called sub-lethal effects.

Adverse effects on fringing vegetation are often apparent at salinities greater than 2000 mg/L. However, considerable variation between species and populations of the same species has been found. Not surprisingly, specimens from existing saline situations exhibit a greater tolerance to salinity than those from fresher sites. Salinity and waterlogging may act synergistically (together) to cause greater stress to plants than either factor acting alone. Species tolerant of waterlogging appear to be better able to cope with the joint effect than do species tolerant of salinity alone. For a more detailed discussion of the effects of salinity on fringing vegetation see Section 4.1.7.

Effect on the microbial community

Small changes in salinity may have little effect on microbial processes, but significant impacts upon the microbial community in or adjacent to waterbodies may occur if salt inputs interact with other environmental factors to create harsh conditions, such as stagnation, stratification, waterlogging and deoxygenation.

Effect on animals

Very little work has been done on the effects of salinisation on wholly aquatic animals anywhere in Australia, let alone in south-western Australia. But a number of scientists have pieced together a basic understanding from what limited work does exist (see Hart et al. 1991). Most species of freshwater fish are relatively recently evolved from marine ancestors and appear tolerant of salinities up to or greater than one third sea water (10,000 mg/L). Although larval fish are more sensitive than either adults or eggs, those born in spring would not be exposed to the most saline conditions of the year, which typically occur in late summer or with early winter flushing flows.

Frogs are most sensitive to changes in salinity, although some species are associated with moderately saline environments. Tadpoles and egg masses may be very sensitive indicators of salinity changes along streamlines. The long-necked turtle would also appear to be at risk from salinisation.

Tolerance to saline conditions varies greatly among waterbird species. Many species of water fowl, such as ducks, swans and teals, are able to feed in saline wetlands but require a nearby source of fresh water from which to drink (Halse 1987). In south-west wetlands low breeding success for some waterfowl species has been recorded for salinities above 3000 mg/L, possibly due to the poor ability of ducklings to osmoregulate[2] (Halse 1987).

Aquatic microbes and invertebrates seem to be amongst the freshwater animals most obviously sensitive to increases in salinity, with adverse effects being shown at salinities above 1000 mg/L. The most sensitive groups appear to be multicellular microbial organisms and certain groups of insects and molluscs. Stoneflies, some mayflies, caddisflies, dragonflies and certain hemipterans (corixids and water scorpions) are very sensitive. Pulmonate gastropods[3] are the most sensitive molluscs.

Work carried out on marron by the Fisheries Department (Morrissy 1978) has

[2] Osmoregulation in this sense refers to the capacity of an organism to maintain internal salt levels, by absorbing water rather than salt.

[3] A pulmonate gastropod is a snail with a lung rather than a gill.

shown that the lethal salinity for adult and juvenile marron appears to be in the vicinity of half that of sea water (17,000 mg/L). Salinities of this magnitude and greater are only attained in the very headwaters of inland rivers during summer. It is possible that the embryos and larval young carried by spawning mothers are less tolerant to salinity, but salinities in the upper reaches of major rivers are at a minimum in spring time when spawning occurs. Present day distribution of marron includes waters having salinities above that of freshwater, but well below the above lethal level (i.e. 500-5000 mg/L).

Just what the impact of salinisation has been upon the fauna of south-west rivers is largely unknown, but there are a few hints from observations and surveys along the Avon, Hotham and Blackwood Rivers. Anecdotal and museum collection evidence has been used to document the disappearance and decline of some animals in the Avon River in the vicinity of the Avon Valley (Kendrick 1976). The freshwater mussel, freshwater cobbler, black bittern, two small snails, a welk and a limpet appear to have undergone major declines in abundance since the 1940s. A small estuarine (false) mussel (*Fluviolanatus subtorta*), on the other hand, appears to have increased in abundance in response to the more saline conditions. A planktonic copepod (*Sulcanus conflictus*) typical of estuaries has also been found in large numbers in Avon River pools (Rippingale 1981). Work on a section of the Hotham River and a small tributary, Thirty-four Mile Brook, found that this brackish part of the river system (about 10% sea water), while having similar densities of benthic invertebrates to jarrah forest and Swan Coastal Plain streams, was very poor in insect fauna, particularly mayflies, stoneflies and caddisflies (Bunn and Davies 1992). Crustaceans, particularly a species of amphipod (*Austrochiltonia subtenuis*), were the most abundant animals and as a group are known to be the most salt-tolerant of macroinvertebrates (Hart et al. 1991). A study of the macro-invertebrate fauna of points along the Blackwood River, which becomes increasingly saline upstream, observed no particular relationships between faunal composition and salinity other than to note a relatively low number of species (Williams et al. 1991). In all three surveys, disentangling the effects of raised salinity from those of nutrient enrichment, organic pollution, sedimentation and stagnation was not possible and firm conclusions about the effects of salinity could not be made.

Studies of the effect of logging on streams in the karri forest suggest that small changes in salinity may have some role in altering the composition of macroinvertebrate communities (Growns and Davis 1991; Trayler and Davis 1998).

7.2 Erosion and sedimentation

Another consequence of land clearing is increasing runoff (see Chapter 2). In other words, a rainfall event can produce a larger flood flow or pulse on a cleared catchment than on a heavily vegetated one. Hydrologists say the catchment has become 'flashier', from the term 'flash flood'. Urban catchments with their hard surfaces are the flashiest of all. For the river channel, increased runoff means that the average size flood has increased and the process of building a bigger channel may begin (see Section 2.3.6). If the stream channel remains well vegetated this appears to be a slow process, but if it has lost its protective vegetation, erosion can begin and the stream may build itself a deeper and wider channel (Rutherfurd and Ducatel 1994).

7.2.1 Bed incision and bank collapse

Many streams in the south-west appear to be dominated by fringing vegetation and have wide shallow channels or floodways with a number of interchanging shallow low flow channels. When the vegetation is lost the increasing velocity along the deeper of the low flow channels, where stream power is greatest, causes incision. As this channel deepens the banks become steeper and increasingly prone to collapse or mass failure. This may occur in two ways: scouring, especially on meander bends, may undercut the bank causing the soil above, now unsupported, to collapse downwards; or flood flows may saturate the bank, which subsequently collapses or subsides under the added bulk weight of the water. This is a common problem on steep banked sandy drains. Tree and shrub roots will do a great deal to prevent bank collapse but only if the root zone itself is not undercut. If so, they are undermined and eventually fall into the widening channel. Scouring around fallen tree trunks can cause further erosion.

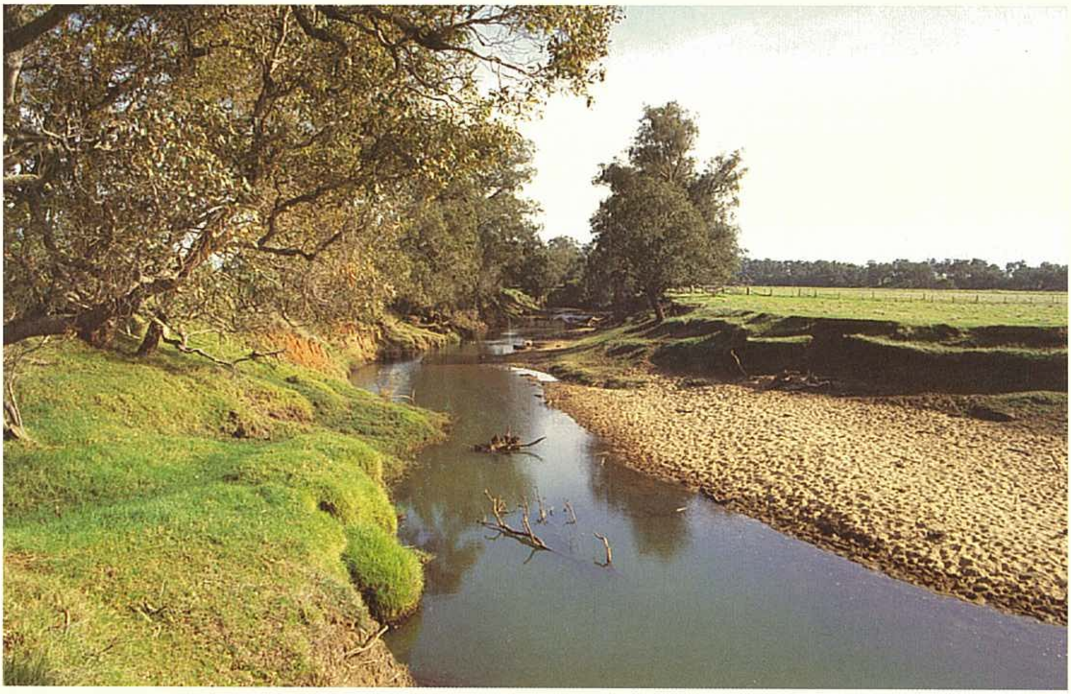
An insidious feedback effect occurs as the incising channel grows, for as it deepens and widens it captures more and more of the flood flow and thus gains greater stream power and hence capacity to incise. However, by this stage the coarse material dislodged from the bed and banks may begin to accumulate in the channel and the process slows down; that is until the sediment has been mostly washed away. A further effect of incised channels is to drain and thus dry out the floodplain, which may prevent the regeneration of wetland plant species. Incision can occur on natural streams whose upstream catchments have been cleared, resulting in increased runoff and hence greater and more powerful flows along downstream sections.

7.2.2 Washouts and floodplain stripping

Washouts, or off-channel scours, occur where sandy soil of the floodway is exposed, usually along tracks and ploughed firebreaks. During floods the soil is scoured from the exposed area, forming a shallow ditch or bathtub shaped hole which grows in size with each successive flood. The largest are many metres deep, perhaps 10 metres across and hundreds of metres long. The worst occur where the native fringing vegetation of the main river channel or low flow channel is intact, but the adjacent floodway vegetation has been cleared. Here the flood flows shoot around the fringing vegetation and race along the cleared part of the floodway, washing away the loose soil wherever it is exposed.

A similar process can occur on floodplains where the vegetation has been cleared and the soil exposed, and the main channel has become obstructed by debris or clogged with sediment. In this situation flood flows, unable to move along the main channel, race across the floodplain, stripping the soil and creating washouts.

THE RAVAGES OF SALINISATION, WHERE THE YENYENNING LAKES ENTER THE AVON RIVER. PHOTO: L. PEN



AN ERODED SECTION OF THE BRUNSWICK RIVER. NOTE THE LARGE SEDIMENT PLUME AND THAT THE RIVER IS WIDENING AND ERODING BACK INTO THE FARMLAND. PHOTO: L. PEN

A minor tributary creek has become incised, the banks have collapsed and the trees have fallen into the growing cavern. This was probably a result of larger and more frequent flood flows from a cleared catchment.
Photo: L. Pen

A gully formed on a steep bank where a small dam on adjacent land overflowed into the river.
Photo: L. Pen

7.2.3 Gullying and headcuts

Gullying generally refers to the rapid formation of a deep channel or branching network of channels, where there was once only a minor stream or only a shallow depression. This process is to be expected wherever the clearing of vegetation results in increased runoff and therefore drainage density (i.e. the length of streamline per ha). Gullying is particularly likely on exposed non-cohesive soils and where this type of soil is shallow and overlies clay. In heavy downpours in late summer large areas may be gullied in an afternoon.

Headcutting is one way in which a gully may be formed. It refers to a backwards moving point of incision upstream along a streamline. Headcutting occurs where the slope of the channel suddenly increases and the flow of water consequently speeds up. At this sudden point of increasing stream power erosion is greatest, removing the soil over the face of the slope and thereby cutting backwards into the channel in the upstream direction. In this way the headcut gradually moves upstream, drastically deepening the channel as it proceeds. Where a tributary stream finds itself falling into a deeper incised channel below a fresh headcut or section of incision, the extra drop at its mouth creates the conditions for a new headcut. In this way a chain reaction of headcuts may proceed upslope from an initial point of erosion. Classic gullying is just this process.

7.2.4 Lateral erosion

This refers to the spread of erosion outwards from the streamline. It can occur in two ways. The first is the lateral shift of the stream channel as the complementary processes of erosion and sedimentation cause the channel meanders to change location and progress downstream. The second is the lateral spread of 'gullies', 'herring bone' channels or 'rills' and sheet erosion along the channel as water flowing directly from the land accelerates over the convex slope of the denuded riparian zone and into the growing channel. Lateral erosion is destructive to property, undermining fencelines, roads and houses and ruining agricultural land. It is usually at this stage that land managers are forced to act to stem the loss of valuable agricultural land. This means fencing off and rehabilitating much larger areas than would have been needed to prevent the problem in the first place.

7.2.5 Sedimentation

Sediment is the product of erosion and sediment transport is largely a factor of particle size. While the finer sediments can be carried quickly downstream in suspension, the coarser sediments are typically rolled along the bed. As a result coarse sediment can build up in the stream channel forming long plumes or bars. Where these plumes catch up with one another, they form a long slug which smothers aquatic habitat. Even worse, sediment slugs may fill river pools. Along the Avon nearly all of the original twenty-two river pools are filled with sediment. Much of this sediment was mobilised by incision induced by the Avon River Training Program, which involved the removal of stabilising vegetation.

Interestingly the typical floods of the Avon do not seem to be able to scour this coarse sediment from the pools in the way rivers are normally known to do (see Section 2.3.3). By comparison floods on the Fortescue River in the Pilbara appear quite capable of scouring the large pools at Millstream, despite the huge loads of sediment carried by that river (Pen pers. obs.). This suggests that the Avon pools were formed in the past when rainfall was heavier and the Avon was more powerfully flooded. Subsequently, less impressive floods have been capable of maintaining the pools by scouring the finer particles, but not, it appears, powerful enough to remove the coarse sediments that have collected in them in recent times.

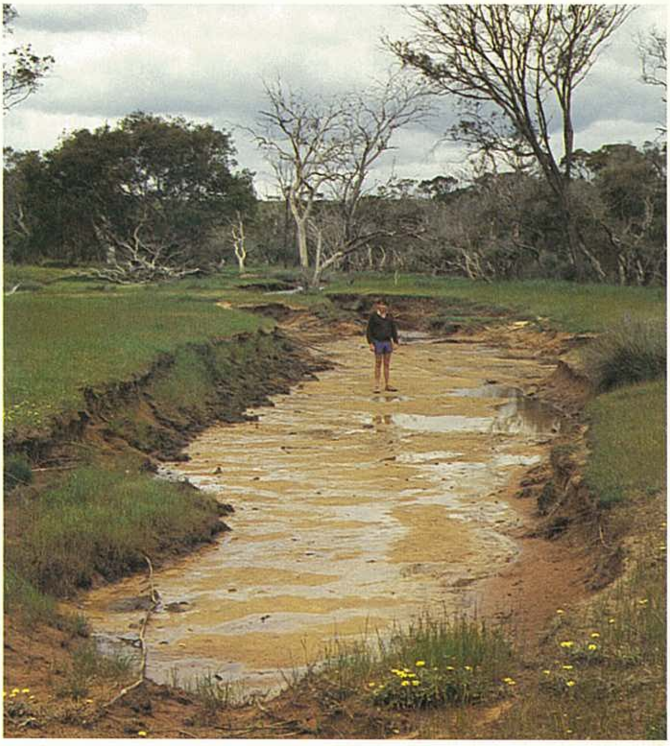
River pools elsewhere in the south-west are filling with sediment, notably in the powerful Blackwood River, suggesting that many river pools in the south-west are no longer subject to the scouring flows that formed them and thus are prone to sedimentation. River pools provide essential habitat for many aquatic fauna during the summer/autumn months when flow is absent on many streams. The loss of the faunal drought refuges would have a catastrophic impact on the river ecosystems of the south-west.

While sediment slugs may be a short-term remedy for troublesome incision by covering the natural bed, high sediment loads can also have two negative effects: large sediment accumulations can retard streamflow and cause upstream flooding; or conversely, can deflect flow into the adjacent streambank or even onto adjacent land, causing further erosion (Schmidt and DeBano 1990; Thorne 1990). Large sediment slugs, while preventing incision, may cause lateral erosion of the channel, producing a broad shallow channel.

Sediment also has a direct effect on plants and animals and on microbial processes (Waters 1995; Wood and Armitage 1997). Large amounts of suspended sediment can reduce light penetration, which reduces photosynthesis, which in turn affects the growth of plants and algae. This effect may be particularly problematic on rivers and broad creeks where an open canopy permits light to reach the stream bed. In these sunlit areas water plants and algae form an important component of the stream ecosystem. Aquatic macroinvertebrates are particularly vulnerable to deposited sediment as the particulate composition of the stream bed is a major factor in the formation of their respective microhabitats. Typically streams subject to increased sedimentation have a less diverse invertebrate fauna, with caddisflies, stoneflies and mayflies that prefer coarse sediments becoming less abundant, and worms and midge larvae that prefer fine sediments becoming more abundant. Suspended sediment can be abrasive and may damage the fine gills and mouth parts of invertebrates and the gills of fish. Sediment deposition may also slow the breakdown of organic material by smothering the stream bed and thereby reducing the availability of oxygen to microbes and macroinvertebrates involved in detrital processing.

7.2.6 Log jams and flood debris

Where erosion is extensive, large numbers of trees and shrubs are undermined and fall into the channel, to be washed downstream during the next big flood. Usually this debris becomes jammed in the channel at some point, typically up against a fallen log,



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A CREEK ENTIRELY DENUDED OF VEGETATION IS NOW ERODING BACK INTO FARMLAND AS A RESULT OF SHEET EROSION CAUSED BY RUNOFF FROM THE ADJACENT PADDOCKS.
PHOTO: L. PEN

◀

A FIREBREAK WASHOUT. THIS IS A PROBLEM ON MANY RIVERS WHERE FIREBREAKS OR TRACKS ARE LOCATED WITHIN THE FLOODWAY OF THE RIVER. WASHOUTS, OR OFF-CHANNEL SCOURS AS THEY ARE ALSO KNOWN, CAN BECOME MUCH BIGGER OVER TIME.
PHOTO: L. PEN

Box culverts nearly filled with sediment on a creek in the Pallinup River catchment. The next flood will go over the road. Photo: L. Pen

This small log jam on a tributary of the Collie River is of little consequence, but larger ones on the larger rivers can cause major channel breakouts (avulsions) which can erode large areas of farmland. Photo: L.Pen patch of intact fringing vegetation, bridge pylons or a fence placed across the channel. A log jam can cause upstream flooding or even lead to an avulsion, where the flow of floodwater deflects off the debris to carve a new channel through the adjacent land. In south-eastern Australia, bank erosion and avulsions are serious problems and they are often caused by log jams, and in some cases by the dense growth of willow trees (EGRMB 1995; Rutherfurd and Hardie 1996; Water Resources 1994).

Large quantities of woody debris can also be produced by salinisation and waterlogging as dead trees eventually break up and fall over. On the upper Frankland-Gordon River, a huge quantity of dead timber is accumulating in the floodway, waiting for the next big flood to move it downstream. Woody debris add considerably to the damaging effects of floods by pushing over vegetation, tearing out fencelines and damaging bridges.

7.3 RIPARIAN ZONE DEGRADATION

Riparian zones of the main channels of most south-west rivers outside conservation reserves were initially left intact when the adjacent land was cleared to make way for agricultural and urban development. These zones are becoming increasingly degraded through a combination of salinisation, livestock grazing, frequent burning and weed invasion, which is preventing the regeneration of native plant species. It is the native plants that cast shade and thereby provide relief for aquatic animals on hot summer days, that drop branches and leaves into rivers providing shelter and initiating the natural food web, and that protect the bed and banks from erosion during floods. In the absence of fringing vegetation, rivers become little more than eroding and sedimented ditches, open to the sun, muddy and weed infested. Devoid of the habitat needed to support the rivers' native and diverse animal life they are home only to a few of the more common native species, or feral animals such as rabbits and mosquitofish (gambusia).

The author has observed in the rivers of the south-west a pattern of degradation similar to that described for remnant vegetation generally (Pen 1994a; Pettit and Freond 1994), with the added complication of erosion as the supporting vegetation is lost. The pattern is illustrated in Figure 7.1.

The healthy river valley

In a healthy river valley, native vegetation is dominant. Not only does it provide habitat for a huge range of animals, it also supports the soil that sustains it (Thorne 1990). The large root systems of trees, which may extend laterally as far as 50 metres, become interlaced and tangled to form a mesh or soil-root matrix to a depth of several metres. This matrix, of trees tied together and supporting one another, is found along each side of the river and holds the river valley embankments securely in place. The smaller root systems and rhizomes of shrubs, sedges, herbs and grasses hold the soil firmly between the large tree roots and, most importantly, form dense masses of roots and rhizomes along the bed of the river channel.

In the well vegetated river valley, flood flows rarely dislodge the soil in any section along the length of the river. Only rarely does the action of flowing water gain the

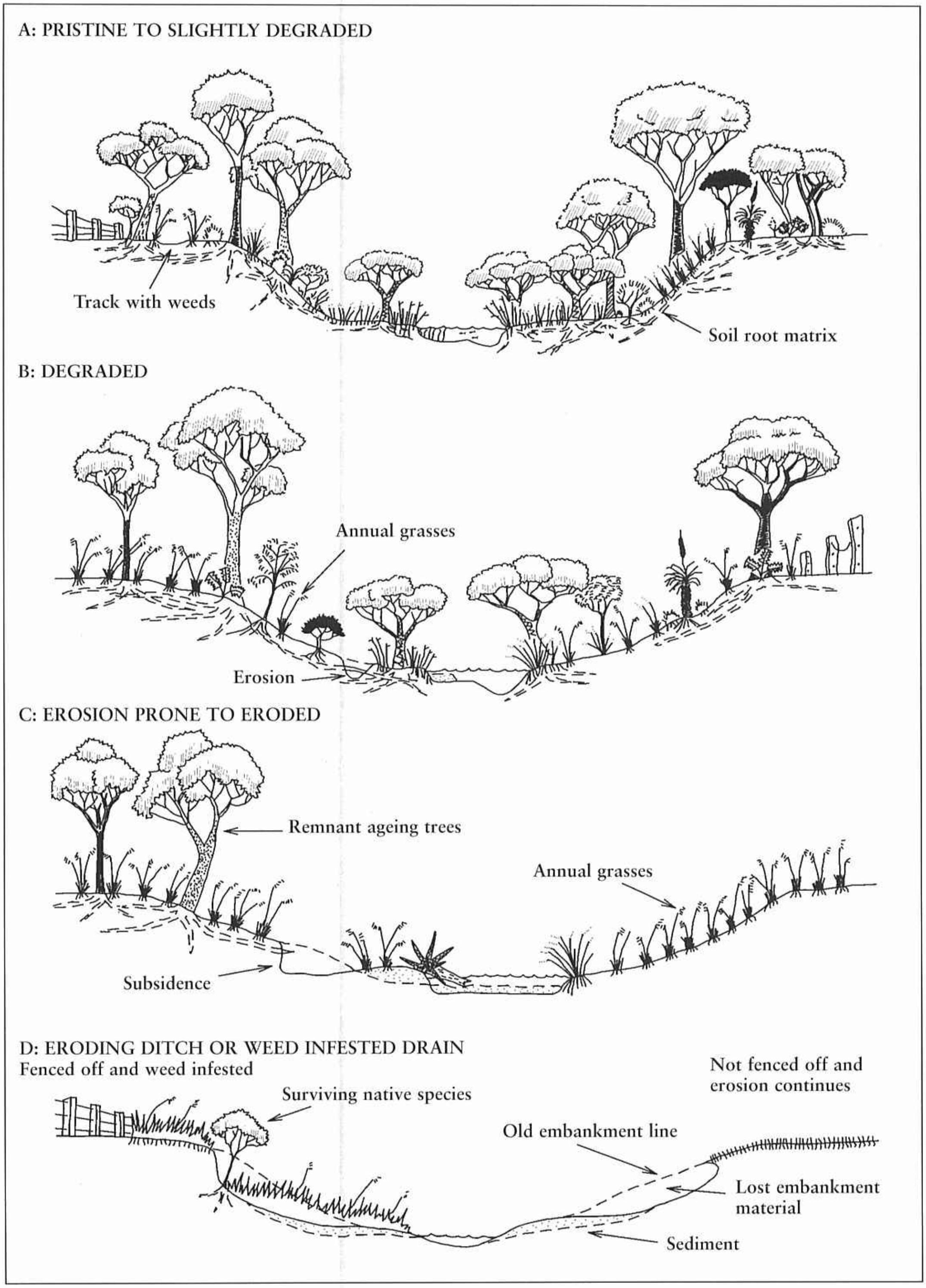


Figure 7.1 The process of riparian zone degradation in an agricultural landscape: pristine to slightly degraded bushland (a); degraded (moderately weed infested) bushland (b); erosion prone to eroded (c); and eroding ditch or weed infested drain (d).

upper hand and erosion occur. This usually happens during major floods and at powerful meander bends or points of flow constriction or deflection about fallen trees, and would appear in most cases to be arrested by the growth of vegetation between floods.

Dense riparian vegetation also serves to retard the rate of flow of floodwaters and to filter out or cause the settling of suspended solids (Thorne 1990). This action is enhanced by fallen trees and branches which trap leaf litter and form obstructions which reduce water velocity and hence the stream's capacity to erode and carry sediment.

The degrading river valley

The earliest stage of degradation is the occasional presence of weeds. In near-pristine vegetation, weeds are probably brought in by the wind or animals. This type of degradation is merely floristic and poses no threat to the integrity of the river valley, as the native vegetation remains dominant. However, where there are points of physical disturbance, such as along walking and vehicular tracks or where feral pigs or rabbits have turned over the soil, localised exposures of soil and infestations of weeds may occur. In this situation there is a small risk of severe erosion.

Typically, severe degradation does not begin until livestock regularly enter the river valley to graze. Here they trample the native vegetation, eat out the more palatable species, compact the soil and bring in weed seed. This encourages the establishment of weeds and retards the regeneration of native species (Pettit and Froend 1994; Pettit et al. 1995; Hussey and Wallace 1993). The rate of weed invasion is accelerated by the increased frequency of fire, which favours species with short life cycles which are mostly introduced grasses, over species with long life cycles which are mostly native (Hussey and Wallace 1993). In many areas the effects of grazing are compounded by salinisation, and in some areas salinisation and waterlogging alone are responsible for the loss of vegetation and subsequent weed invasion.

Eventually, the native understorey species are replaced entirely by weeds, and native trees begin to die out as the level of regeneration can no longer keep pace with mortality.

The eroding river valley

As the weed invasion progresses, with continued livestock grazing and trampling, frequent fires and/or salinisation and waterlogging, the deep root systems of native shrubs, sedges, grasses and herbs, which once had a firm hold on the soil between the large tree roots, are largely replaced by the shallow root systems of introduced, mostly annual grasses and herbs. These new species do not bind the surface soil as well as the former native species, especially over the late summer/autumn period when most have senesced, and are quite easily dislodged by livestock trampling and surface water flow. When this happens, the river valley is prone to severe erosion.

If the thin protection afforded by annual weeds is lost, the soil between the large roots of trees and tall shrubs may be washed away. Up on the valley embankment surface flow from adjacent pastured areas, or high flood waters can dig long furrows, exposing tree roots and undermining trees and tall shrubs. In the river channel proper, sections of embankment may be undercut beneath the root zone, causing it to collapse. Where this occurs the remaining parts of the embankment may be held in place by tree roots until further undercut. If trees are not present parts of the embankment can subside into the river. An unsupported valley embankment may become particularly vulnerable to subsidence when the soil profile becomes saturated (Thorne 1990), or perhaps where rising groundwater levels have rendered the bank waterlogged over long periods each year.

Initially only the most vulnerable stream sections exhibit severe erosion. But gradually more and more areas become eroded until the stream resembles a wide ditch. With erosion and sedimentation on the ascendancy, channel movement which was once imperceptible becomes apparent, as the unconstrained stream exercises its newly found power. Add to this the eroding effect of lateral flows from the adjacent land and the stream floodway may begin to cut back into the land. It is usually at this very late stage that land managers recognise a problem and fence off and replant the stream in an effort to bring it under control. Unfortunately, if grazing is removed from the riparian zone at this late stage weeds generally dominate, often supporting vermin and producing a fire hazard in summer.

While livestock, mainly cattle, sheep and horses, contribute most to riparian zone degradation, feral animals such as rabbits, and even kangaroos make a significant contribution in some localities. People also add to the degradation through trampling, damage by vehicles, vandalism and arson. Many recreational sites on rivers throughout the south-west exhibit damage caused by people at play.

7.4 EUTROPHICATION AND DEOXYGENATION

7.4.1 The simple story

In the summer of 1993-94 there was a heavy bloom of blue-green algae along the main channel of the Blackwood River. The extensive growth of microscopic algae is a classic symptom of nutrient enrichment, a process known as eutrophication. With broad scale agriculture in most catchments in the south-west, it is inevitable that rivers will receive large quantities of nutrients, either dissolved in water, adhering to small soil particles eroded from the land or contained within dead plant and animal material, including manure washed from paddocks. Large quantities of nutrients and organic matter are also washed from the hard surfaced and heavily drained urban areas during high rainfall events. Point sources of pollution such as dairies, animal feedlots, sale yards and abattoirs can also make a significant contribution of organic material and nutrients to waterways.

Although much of this material is flushed down to the estuary or out to sea in winter, much also accumulates in the deep river pools. Scientists working on the Swan River believe that when the organic portion decays and consumes all the oxygen in the water, chemical processes occur which increase the release of nutrients from the sediments into the water column, thus fuelling an algal bloom (SRT 1998). While abundant algae, through photosynthesis, add oxygen to the water, they also remove it through respiration at night, and especially when the bloom collapses and decays.

Eutrophication and deoxygenation radically change the river environment. The depletion of oxygen alone is enough to kill off much of the river's animal and microbial life. Indeed, many of these creatures, including bacteria, fungi and crayfish, are needed to consume the very material that chokes the river. If they are lost a vicious circle of oxygen depletion and ever increasing organic build-up can occur. As the process worsens algal blooms will increase in frequency often involving toxic species that may render the river unsuitable for stock watering and recreation.

7.4.2 Degradation of river pools

In the mid-1970s, Dr G. W. Kendrick of the WA Museum first raised the problem of oxygen depletion of river pools by decaying organic matter in the bottom sediments (Kendrick 1976; Morrissy 1978). He referred to the problem as 'organic pollution', and especially noted the effect of late summer downpours in which large quantities of manure and dead grass were washed from dry season farmlands into river pools, apparently causing 'anoxic' (oxygen depleted) events that killed fish and crayfish. One such event on the Collie River during the summer of 1995-96 was widely reported in the popular media. Morrissy (1978), in a study of marron habitat in the south-west, noted 'the more insidious potential for greatly increased organic input to inland waters following clearing of the land and the cultivation of cereal crops and stock pasture'. He found that pools on the upper Murray, Blackwood, Warren and Frankland-Gordon systems contained large accumulations of organic matter (Morrissy 1978). He also observed the compounding effect that pool stratification had on oxygen depletion, caused by warm, marginally fresh water from late winter season flows or adjacent fresh tributaries, overlying residual cool, brackish or saline water (Morrissy 1979). Stratification reduces mixing and accelerates oxygen depletion. In these circumstances few marron were found (Morrissy 1978).

River pools are essential drought refuges for many aquatic animals, but are of little use if they become anoxic over summer. This is particularly true for marron, which forms the basis of an important recreational fishery and is an obvious indicator species of decline in the health of river pools. The documentation of marron catches and sightings from the recollections and writings of rural people have revealed a widespread decline in the inland extent of marron populations (Morrissy 1978 and references cited in Chapter 6). Indeed, Morrissy (1978) concluded that for inland areas there was little evidence that salinisation or overfishing alone was responsible for declining inland marron stocks, and suggested that organic pollution and eutrophication were more likely causes. Along with the marron, many other pool-dependent aquatic species must have declined from inland areas.

Foreshore disturbance on a river pool caused by cattle trampling. Livestock watering points should be located where the foreshore is naturally hard or has been specially hardened-up. Photo: L. Pen

Blue-green bloom on the upper Collie River in the summer of 1985/86. Photo: L. Pen

Sediment and organic matter (including manure) washed into a river pool following a late summer thunderstorm.
Photo: L. Pen

The redfin perch *above* and the small mosquito fish (Gambusia) *left* are now probably more abundant in south-west rivers than the native fish. Note that the larger of the two mosquito fish is the female.
Photo: L. Pen

7.5 Introduced fish

A number of freshwater fish have been introduced to the south-west. Fortunately only two have formed broadly distributed breeding populations, the tiny mosquito fish (*Gambusia holbrooki*, to 50 mm long) and the large redfin perch (*Perca fluviatilis*, to 450 mm long). Both species are prolific breeders and are known to prey heavily on native fauna.

The mosquito fish forms huge populations over the summer, which must have a major impact on the abundance, structure and composition of planktonic and benthic invertebrate communities (Lloyd et al. 1986). The species has also been linked circumstantially to the decline in native species where it has been introduced in other parts of the world (Lloyd et al. 1986). In the south-west it has been observed to attack and clip the fins of native fishes in certain habitats (Morgan et al. 1998; Gill et al. 1998; Pen pers. obs.) while apparently living in harmony with native species in others (Pen and Potter 1991). Certainly the species is more tolerant of poor water quality than native fish and apparently replaces them in degraded environments (Lloyd et al. 1986).

Mosquito fish are presently absent or in low abundance in the very important fish habitats of the south coast and this situation needs to be maintained to ensure the survival of several of the south-west's endemic fish species (Morgan et al. 1998).

The redfin perch is known to prey heavily upon freshwater crayfish and on some native fish species (Morrissy 1978; Pen and Potter 1992). It has been circumstantially linked to the loss of the western pygmy perch (*Edelia vittata*) on the Murray River (Hutchison 1991). Both the mosquito fish and the redfin perch infest river pools and presumably impoundments, placing them in close proximity to native fauna as they contract to permanent waters over the summer. At these times predation of native fauna by these abundant introduced species must be high. The effect on the food webs and ecosystem structure (i.e. the interrelationships of the various native species) is unknown, but must be significant. Of serious concern is the impact on marron and gilgie populations which, as the largest and most abundant (by weight) of benthic invertebrates, must play an integral role in detrital processing (see Sections 3.3 and 5.1.3).

Although the redfin perch and two trout species were introduced as sporting and table fish, both species are considered to provide only limited recreational fisheries. In the case of redfin, this is due to perceived poor sporting qualities and a propensity to 'runt' at high population densities, and in the case of trout to limited cool water habitats suitable for stocking (see Sections 5.1.6 and 6.6). As a consequence there is a growing demand to introduce eastern state fish species for recreational fishing (Prokop 1995). New species are also demanded for aquaculture, for which the high quality waters of the south-west appear to have much potential (WAPC 1997), and for fish for ornamental ponds, particularly Koi carp.

In the past, fish species native to eastern Australia were introduced into Western Australia to stock inland rural dams on the condition that the fish involved were certified disease free and were to be placed in impounded waters only (Fisheries Dept. WA 1997a). Today, we recognise the need to protect aquatic ecosystems from inadvertent and intentional introductions. Therefore, the translocation of fish species into WA is subject to regulation by Fisheries Western Australia (Fisheries Dept. WA 1997a). Given the impact of mosquitofish and redfin perch on natural aquatic systems, any consideration of further introductions of exotic fish species must take into account the possibility for escape and subsequent infestation, and any likely consequent impacts on natural water resource values. To this end, Fisheries Western Australia has produced guidelines for the assessment of proposed translocations (Lawrence 1993; Fisheries Dept. WA 1997b). To be approved, proposed introductions must show minimal risk to WA aquatic ecosystems.

7.6 RIVER DIVERSION, DROWNING AND BLOCKAGE: DAMS, WEIRS AND CULVERTS

7.6.1 River diversion

Dams are used to divert water away from a stream for use elsewhere and/or for use at another time of the year. One consequence is less water flowing downstream, relative to upstream of the dam, at certain times of the year. Some dams which function as storage dams may not actually divert water away from the system but rather hold it up, to be released downstream during the dry period of the year. In this case there may be more water flowing downstream, relative to upstream, possibly rendering permanent what was once a seasonal stream. For many streams however, a considerable draw will be placed on the meagre summer and autumn flows, so that insufficient water may be available to ensure downstream flows much beyond the base of the dam in the drier times of the year. This may well be a problem for some private gully dams in the south-west, located on what were once permanent streams. Even though these dams may only take a small percentage of the winter flood flows, they take a much greater proportion of the summer/autumn prevailing flows.

In some situations dams may not be needed to facilitate water diversion. For example, the permanently flowing Gingin Brook north of Perth provides water via direct pumping from the stream. The cumulative effect of many pumps can significantly reduce the Brook's flow over summer and autumn.

Altered flow regimes

The general effect of dams or direct pumping is to change the downstream flow regime. Stream order may decrease with a consequent shrinkage in the stream environment. For example, upland vegetation may move closer to the watercourse and replace fringing vegetation which occupied ground no longer inundated or waterlogged at times during the year. Below the larger dams, flood frequency decreases and flooding only occurs in very wet years when the dams overtop. For example, the Mundaring Weir overflowed for the first time in twenty-two years in 1996[4]. By contrast the Wellington

[4] Even in this case the dam receives water via a pipeline from a downstream pipehead dam.

Dam supplies water for irrigation over the summer months and is scoured in summer to remove salty water, so that it produces moderately high flows at times when they would ordinarily not occur. The water is also very cold, coming as it does from near the bottom of the dam, producing low temperatures at a time of the year when water is ordinarily warm.

All of these effects disrupt the stream ecosystem in ways that would be hard to explain, even if they were known. For example, how do the native fish respond when winter floods do not arrive to aid them in their upstream migrations or form their much needed spawning habitat? How does vegetation on the floodplains cope when the annual flood pulse fails to replenish nutrients, year after year? What happens to channel form in the absence of regular channel forming flows? How do animals handle a sudden pulse of cold water in summer? These questions and many others are currently under investigation across Australia as water resource managers attempt to compensate for the downstream effects of dams and direct pumping on stream ecosystems (see Chapters 6, 8 and 9).

7.6.2 River drowning

The most obvious effect of a dam is the complete drowning of a section of stream ecosytem and its replacement by a large impoundment, which in the case of storage dams slowly shrinks over the summer, exposing a muddy bottom. This new environment is alien to the south-west where deep lakes do not occur naturally, but some native animals nonetheless make use of them. Marron and freshwater cobbler are very common in the public water supply dams of the Darling Scarp, and pygmy perch and nightfish can be found along the water's edge. Rainbow trout maintain small populations in some dams and redfin perch are known to infest others. Cormorants can often be seen foraging in some dams, indicating the presence of fish. Fringing vegetation will grow about the edges of dam impoundments where water level is kept more or less constant, as for example on the Big Brook Dam near Pemberton. However, dams can only go a small way towards compensating for the loss of highly complex stream ecosystems and, as described earlier, any infestations by alien species may only lead to further disruption of upstream ecosystems.

7.6.3 Barriers to faunal movement

Many long lived aquatic faunal species in south-west rivers withdraw to permanent waters over the summer period and disperse to seasonal waters in winter. At least three species of native fish go on annual spawning migrations in winter and spring and the pouched lamprey migrates from the ocean to spawn in fresh, permanent, low order streams of the karri forest region (see Section 5.2.2). Although some aquatic fauna such as the marron and the turtle can leave the water to negotiate obstructions, most species are severely limited in their capacity for cross-country movement. Therefore the many dams and weirs of the south-west present additional obstructions to faunal passage, in some circumstances causing the complete blockage of movement and injury and exhaustion of animals. For example, lampreys can climb small dams, but are often injured in the process and many dead animals can be seen below obstructions each spring.

Sometimes an obstruction presents a barrier to movement, not by its size but by its design. For example, the Rainbow gauging weir on Lefroy Brook near Pemberton has a metal plate fixed at a right angle to the lip of the crest (to prevent damaging cavitation), which prevents lampreys from moving across the wall of the weir. Road culverts are often raised above the level of the stream bed. In both cases animals can only move upstream if they can leave the water, which can be very hazardous, or when the weir or culvert floods out. Prior to these opportunities animals expend much needed energy maintaining position below the obstruction, which may render them prone to predation, injury or exhaustion.

Dams and weirs present obstructions to movement in both directions. They prevent animals from moving upstream to reach seasonal breeding habitat or from recolonising habitat formerly dried out during a period of drought. Dams also prevent animals from moving downstream, when for example juveniles and eggs are washed downstream into the dam impoundments or when animals retreat downstream to avoid drought.

The impoundments of dams and weirs represent a new form of habitat which may provide a vacant niche for some exotic species, like trout and redfin perch. These fish may prey upon native fish, possibly even eliminating some populations, especially when drought forces the native fish to withdraw downstream into permanent waters of the infested impoundment (see below). Indeed the introduced species may also move from the impoundments into tributaries, possibly leading to heavy predation of tributary fauna.

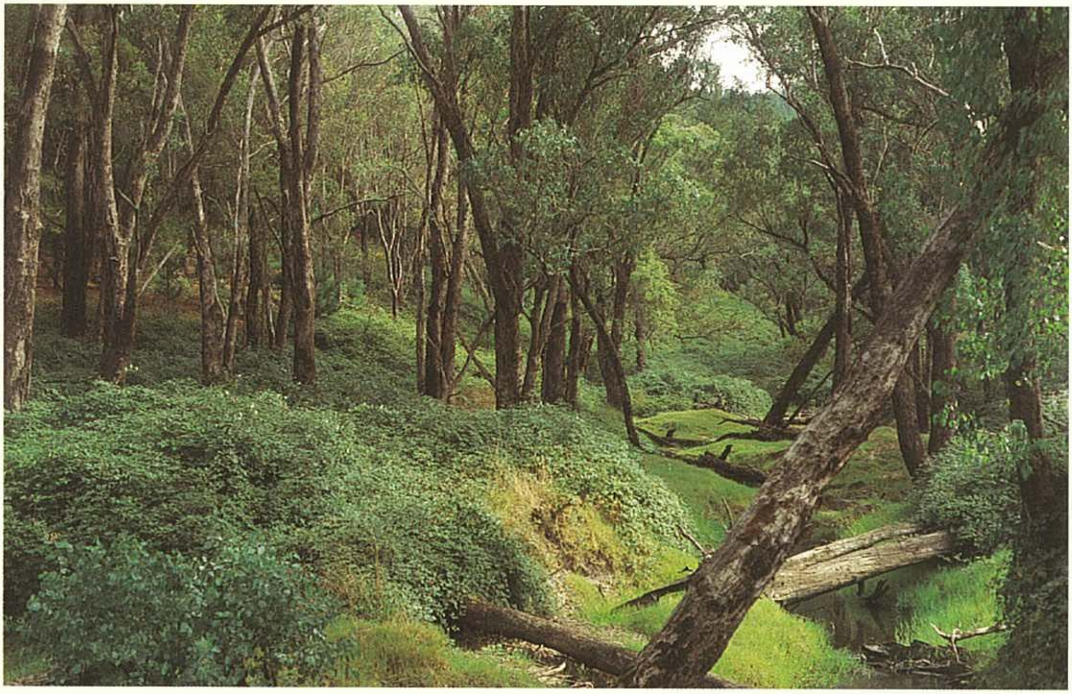
The Big Brook Dam on the Lefroy system is an excellent case study. This dam is known to block the upstream movements of the western pygmy perch and the annual migration of the pouched lamprey (Pen et al. 1988, 1991). The upstream creeks which once supported larval lampreys became devoid of them in the years following the construction of the dam (Pen et al. 1988, 1991). Furthermore, the impoundment is known to support a serious infestation of redfin perch. The western mud minnow (*Galaxiella munda*), a species virtually restricted to south coast streams and which was formerly abundant in the headwaters above the dam, all but disappeared following the severe drought of 1994-95 in which all of the system except the impoundment dried out for several months (Morgan et al. 1998; Morgan unpublished data).

7.6.4 Breaking the river continuum

The most fundamental change to the stream ecosystem brought about by dams is the breaking of the river continuum. Material being washed downstream is captured by the dam impoundment, like a huge river pool but one that is only ever very slightly scoured. Plants, animals and microbes of the downstream ecosystem, which take their nourishment from the steady flow and large episodic pulses of energy, nutrients and carbon, must accommodate to the much reduced inputs from upstream. As the stream ecosystem begins afresh below the dam, like a headwater stream, these members of the continuum are displaced downstream.

Every winter and spring thousands of native fish, attempting to move upstream, gather below this weir and others like it throughout the south-west. Occasionally weirs like this flood-out and the fish can move upstream. Large dams, culverts and fences jammed with debris also block fish movement. Photo: L.Pen

Road culverts somewhere in the Moore River catchment. Note how the pipes are raised above the bed level. It is impossible for small fish to move upstream through these culverts. Photo: P. Muirden



SERIOUS BLACKBERRY INFESTATION ON THE BALINGUP BROOK. BLACKBERRY IS PERHAPS THE WORST RIVER WEED IN THE LOWER SOUTH-WEST. PHOTO: L.PEN

SPINEY RUSH *(JUNCUS ACUTUS)* COLONISING A SALINISED RIVER FLAT IN THE UPPER BLACKWOOD CATCHMENT. THE NATIVE SHORE RUSH *(JUNCUS KRAUSSII)* SHOULD BE PLANTED IN SUCH AREAS TO PRE-EMPT THE ESTABLISHMENT OF THE SPINEY RUSH. PHOTO: L.PEN

7.7 WEED INVASIONS

Exotic plants are becoming an increasing problem along rivers in the south-west. In the absence of predators and pathogens, but having the requisite conditions for regeneration, many exotic plants have established very successful populations, which are in many cases displacing native plant species. Some weed species (e.g. veldt grass) are favoured by changes in environmental conditions, such as an increase in fire frequency. Others, such as tall grasses, everlastings and woody shrubs, have exploited cleared upland sites adjacent to rivers. Many species of vines and creepers, deciduous trees, tall herbs and mat grasses have exploited the moist environment of the disturbed river valley (Pen 1994b). On the middle Blackwood River, pines and fruit trees are coming up amongst the native plant community of the upper river embankments, a by-product of adjacent pine plantations and orchards. Furthermore, weed invasions along rivers are particularly intense near towns like Donnybrook, Nannup, Bridgetown, Balingup and Albany where a wide range of garden plants is available to 'escape' into river valleys.

Possibly the worst case of weed invasion on a waterway is along the Canning River near Kelmscott (Pen 1993). Nowhere else in the south-west do vines, tall grasses and woody weeds dominate the river valley to the extent and intensity they do on this river. A number of vine species, such as bridal creeper, Japanese honeysuckle, dolichos pea and morning glory are smothering the largest of trees; a variety of giant grasses including bamboo, giant reed and elephant grass pack the water's edge; and a number of trees, among them coral tree, Cape lilac, castor oil bush, poplar, willow and edible fig are slowly replacing the native flooded gum and swamp paperbark. Elsewhere blackberry brambles, buffalo grass, watsonia, arum lily, canna lily and blue periwinkle choke the understorey, and the list goes on.

The typical assemblage of weeds in the freshwater river valley is illustrated in Figure 7.2. These are the most common invaders along the moister and fresher rivers of the south-west, but each town has its own particular suite of garden escapees. For example, the pretty rest area on Harvey River, where it passes under the South West Highway, hosts a very serious infestation of buckthorn *(Rhamnus alaternus)*. And many of the streamlines of Albany are choked with a taylorina[5] *(Psoralea pinnata)*, a fast growing, early flowering shrub from southern Africa.

The reader may wonder what is so bad about garden escapees. Don't their roots support the bed and banks? Don't they slow the water down? True, but they don't represent a stable plant community on which we can depend and which we can manage with a minimum of effort. In the absence of exhaustive management (such as that carried out in the typical garden), garden escapees are just a chaotic assemblage of weeds, ever changing in a dog-eat-dog war with one another.

Furthermore garden escapees and other weeds seldom provide habitat for native animals; their leaves and bark are barren wastes, devoid of the invertebrate

[5] The story around Albany is that the plant escaped from Constable Taylor's garden, hence the name

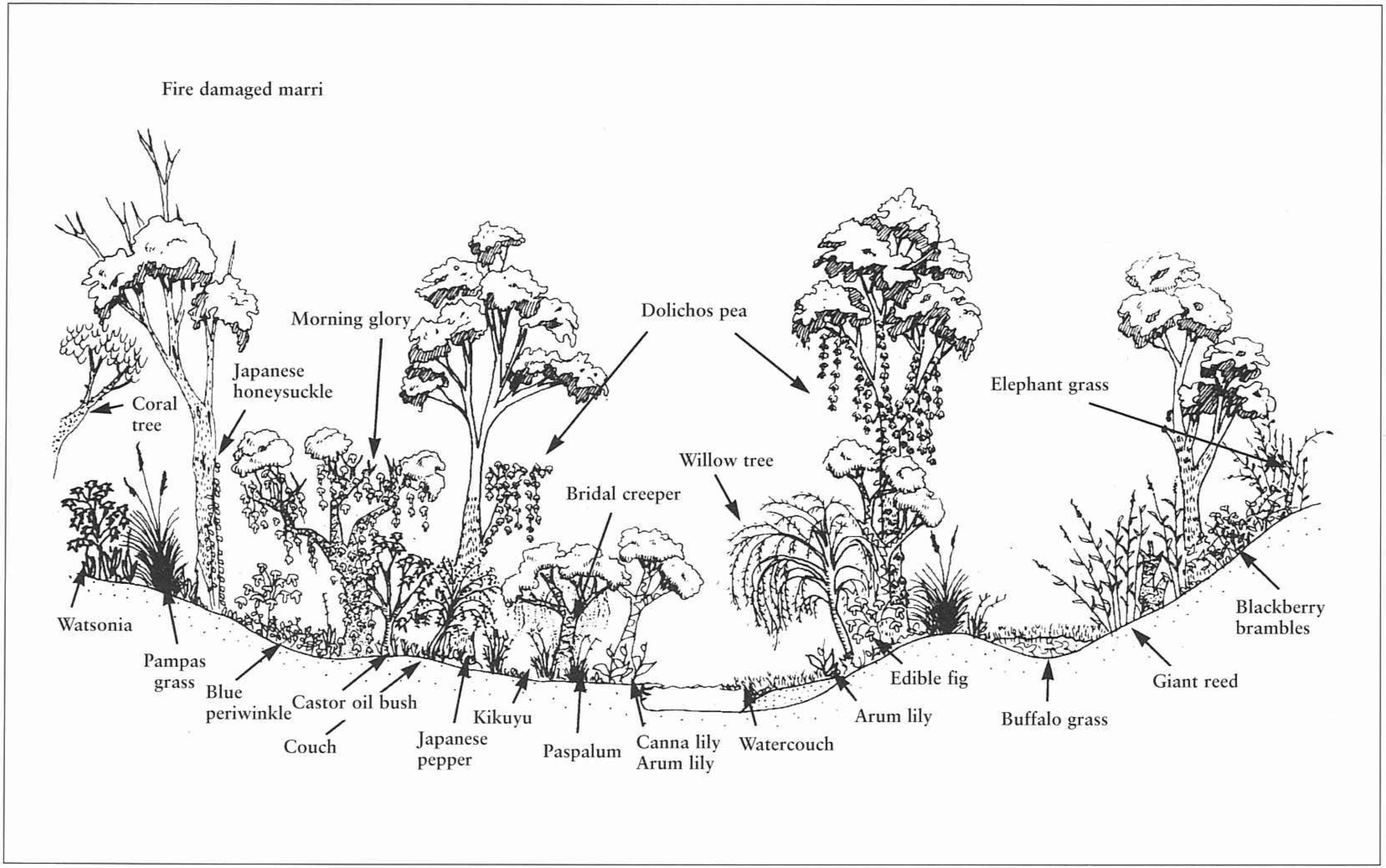


FIGURE 7.2 MAJOR WEEDS INVADING THE FRESHWATER RIVER VALLEYS OF THE SOUTH-WEST OF WESTERN AUSTRALIA

communities needed to support birds, lizards and other animals (E&NR undated). Most of them have soft leaves which decay quickly in the stream, often depleting much needed oxygen (Pidgeon and Cairns 1981; E&NR undated); and many species are deciduous, dropping their leaves all at once in autumn, producing a form of organic pollution (as well as leaving a winter skeleton of branches of no use to our native animals) (Frankenberg 1985; Carter 1993). Every winter the dead leaves of London plane trees clog the gutters of Perth's city centre drains, which discharge to the Swan River estuary; and deciduous trees are becoming increasingly common in Perth's newer residential areas! Of course, not all garden species have to escape to find themselves along rivers, some are cultivated right there, such as the grassy lawns with deciduous trees on riverside parks.

Weeds can also build up in streams, especially in open sunlit urban conditions or abandoned farmland. The dense growth of weeds can slow flow rates and cause sedimentation. Many exotic grasses are far more vigorous than native sedges and in the absence of grazing can quickly consolidate sediment deposits. In this way the stream bed is raised and this can subsequently lead to avulsions and problematic flooding.

7.8 Toxic chemical pollution

Toxic chemical pollution involves contamination of stream ecosystems with toxic synthetic chemicals and heavy metals. Synthetic chemicals are usually herbicides and pesticides, applied to cropping areas, crops (including tree crops) and animals to control weeds or invertebrate pests, respectively. Large quantities are sprayed throughout the south-west each year. For example, herbicides are applied to the ground to kill annual weeds prior to seeding for annual crops or planting trees. Pesticides are applied to horticultural crops to improve production and prevent spoiling of fruit and vegetables. Sheep are sprayed to control lice and ticks. Even landcare plantings and direct seeding require a preparatory application of herbicides to control weeds. It is these chemicals that find their way into streams through spray drift, surface runoff or in groundwater. Their effects on aquatic organisms can go largely undetected, but since they are designed to interfere with the normal metabolic processes of plants and invertebrates, it is reasonable to assume that they could be quite serious. For this reason, many modern biocides are designed to break down quickly once released into the environment. However, certain additives that improve the effectiveness of these chemicals may still be troublesome. For example, surfactants, added to herbicides to improve leaf penetration, can be harmful to frogs (Bidwell and Gorrie 1995).

Even with the use of modern short lived biocides, the legacy of the longer lived ones or their residues and metabolites remain with us. In some cases long lived chemicals are still used or have only just recently been withdrawn, such as heptachlor to combat termites. It is these chemicals that collect in stream sediments and enter the food chain. And through the process of biomagnification, which occurs because animals must eat many times their own weight to survive, the chemicals gradually increase in concentration within aquatic animals as they move from animal to animal up the food chain. This is a particular problem for higher order predators that inherit the contamination of many thousands of lower order animals. In one of the few studies to address this phenomenon in the south-west, rainbow trout in Gooralong Brook (Serpentine system) were found to contain measurable amounts of heptachlor, barely acceptable levels dieldrin and DDT levels up to six times of that considered acceptable (Davis et al. 1988). It should be noted however, that toxic effects may be expressed at different levels of concentration, and in different ways depending on the organism involved and its health and life cycle stage.

Heavy metals also find their way into rivers. Some heavy metals are broadcast over large areas of the south-west as trace elements and contaminants in fertiliser. For example, large quantities of copper and zinc are known to be transported by the Avon River each year (Atkins and Klemm 1987). Other heavy metals were present in once widely used metal based fungicides and sheep dips. Certain mining activities may also cause the release of heavy metals, and in the case of coal mining may also generate, through mine 'dewatering', acid waters which exacerbate the effects of certain heavy metals on stream biota.

In 1987 the Environmental Protection Authority commissioned a study of biocide contamination in a number of south-west rivers (Rutherford 1989). This and other smaller studies found unacceptable levels of only the more persistent organochlorines and their residues in the water of many of the rivers, and seldom detected contamination of the sediments (Olsen and Skitmore 1991). However, there is no reason to be complacent, as some biocide residues, heavy metals and other toxic substances, especially the highly toxic PCBs (the polychlorinated biphenols that escape from industrial processes or products), have low solubility in water and may be difficult to detect in water samples, and even moderate levels of sediment contamination are difficult to detect (Mackay 1989; Rutherford 1989). Furthermore, the complexities of aquatic food webs make it difficult to determine the extent of ecosystem contamination, although the concentrations in certain long lived filter feeders, such as the freshwater mussel, may provide a rough guide (Aquatic Research Laboratories 1988).

7.9 STREAM ECOSYSTEM DEGRADATION

7.9.1 Loss of native fringing vegetation: from stream ecosystem to weed infested drain

The loss of native fringing vegetation and its subsequent replacement by weeds increases exposure of the stream channel to strong sunlight and reduces the input of hard woody debris and native leaves (Fig. 7.3). These effects are more or less true regardless of the cause of the loss of native fringing vegetation, whether it be active clearing, passive clearing by livestock, salinisation, undermining by erosion or frequent fire. Where once a stream ecosystem was well shaded and relied upon an input of slowly decaying hard wood and gum leaves to fuel its food web, it is now

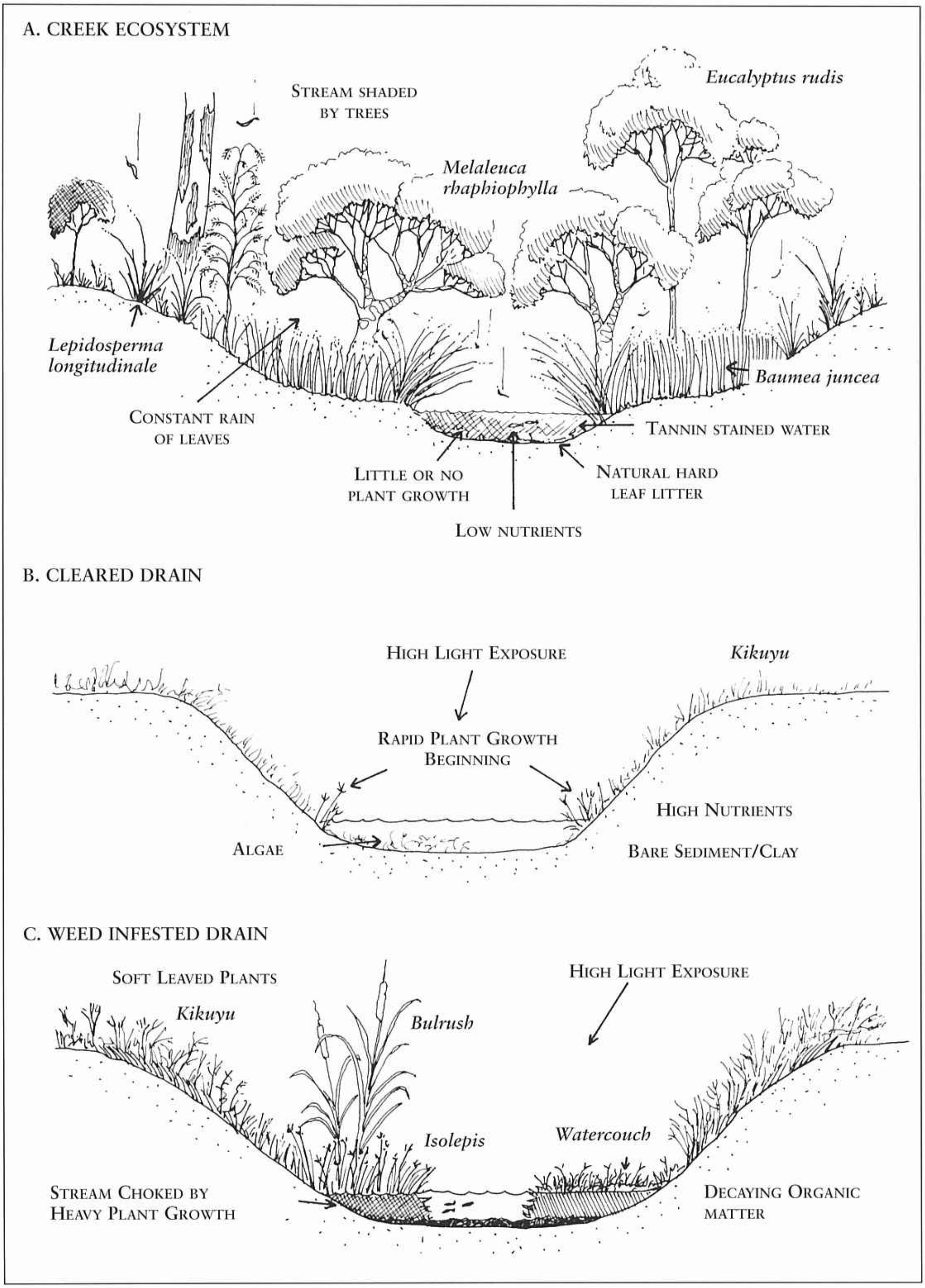


Figure 7.3 The environment of the natural creek ecosystem (A) compared to a cleared drain (B) and a weed infested drain (C)

open to the sun and receives a deluge of swiftly rotting soft leaves, not only from the new weedy fringing vegetation, but also from the broader cleared catchment (Fig. 7.3). Here, soft leaved material from pastures, annual crops and horticultural plants is easily washed downslope into unbuffered streamlines.

More light reaching the stream ecosystem warms it up, increasing stream metabolism and at the same time reducing the dissolved oxygen needed for organic breakdown by aerobic microbes and the hard pressed native animals that need shade and plenty of oxygen to survive the hot summers (Reynolds 1986; Campbell and Doeg 1989; Quinn et al. 1992; Davies and Nelson 1994; Harris 1996). In the river pools and beneath the surface of large sediment deposits, the oxygen supply is quickly exhausted by the swiftly rotting soft leafed material (Reynolds 1986; Townsend et al. 1992; Bunn et al. 1997). Once the oxygen is used up, anaerobic microbes take over and the decay of this material may slow dramatically.

With the extra light and especially the addition of nutrients, either washed in or eroded from urban and agricultural catchments or released from rotting oozes at the bottom of pools, aquatic weeds and algae can grow rapidly and abundantly. For a time algae and/or submergent aquatic weed growth may add substantial quantities of oxygen to the stream water through photosynthesis, but eventually the plants and algae die and add to the problem of organic build-up and pollution. In the case of streams that are ungrazed by livestock, aquatic weeds can grow to fill the entire stream channel. Such clogged streams, or rather weed infested drains, are very effective at catching sediment, which ironically reduces channel capacity and leads to flooding. For this reason, clogged streams must be periodically cleaned out so that flooding does not damage property or reduce agricultural yields. A second irony is that once the supporting and flow retarding vegetation is removed, erosion can occur.

7.9.2 Habitat loss and fragmentation

Few stream systems of the south-west retain most of their natural habitat, as the majority occur within catchments that are either mostly or at least partially cleared. Fewer still have catchments which are entirely dominated by natural vegetation. Coppermine Creek in the Fitzgerald River National Park is an example of one such river system. Some river sections pass through broad blocks of forest and heath. Long sections of some rivers, especially those to the east of Albany, pass through broad corridors of native vegetation, but even here the immediate tributaries of these rivers pass through cleared catchments. Many rivers retain only their immediate fringing vegetation and then often only in patches and of diminishing native species. The great majority of stream sections are little more than drains lined with remnant trees over pasture. Thus stream habitats within blocks, corridors or patches of natural vegetation are by definition part of degraded and fragmented stream ecosystems with water qualities greatly compromised by upstream land use.

Fragmentation of streamline habitat is also brought about by dams, weirs and road culverts and the development of new alien habitats. In the case of dams, large impoundments are inserted along the streamline where once there were none. Such environments are alien to the south-west and represent a vacant niche to some introduced animals. In fact several dams in the south-west are known to support breeding populations of trout and redfin perch. Open drains and weed infested streamlines, which often interrupt natural streamlines, may similarly offer vacant niches. For example, sunlit streams are often infested with the mosquito fish which can tolerate very warm water (Lloyd et al. 1986), and the weed infested Canning River is known to support carp.

The effect of streamline habitat fragmentation on the survival of native stream faunal populations is largely unknown. But it is obvious that most remaining populations must now negotiate more obstructions than in the past, and pass through exposed and alien situations in order to move between their increasingly depleted and isolated habitats. On top of the added levels of endurance and recuperation needed to make the arduous and hazardous journeys between distant habitats, these populations must often run a gauntlet of fish-eating introduced fish species now present in many river systems.

Failure to maintain connection between remnant habitat results in the fragmentation of the original more broadly distributed populations of plants and animals. Small isolated populations are prone to extinction through catastrophe, which in south-west streams is normally drought but may now also be predation by introduced fish or fire in the case of riparian zone species. Small isolated populations are also subject to inbreeding which may decrease population fitness in the long term, resulting eventually in extinction, especially in the rapidly changing environment of the south-west.

7.9.3 Removal of woody debris - desnagging

As discussed in Section 3.2.2, woody debris is an essential component of stream ecosystems. Unfortunately few people are aware of its significance and there is often strong pressure to remove woody debris to increase flood conveyance, improve navigation, introduce snag free fishing and remove swimming hazards. No doubt desnagging is sometimes necessary, but it is done with little knowledge of the consequent impact on stream habitat and channel form. From 1900 to 1939 the streams of the Swan Coastal Plain south of Perth were desnagged and trained in a huge human effort to reduce flooding (Bradby 1997). In some incidences rock bars were also removed and a section of the Serpentine River was trained. Today coastal plain people lament the loss of fish and birds and recreational amenity, and many landowners are forced to manage streams which have become greatly incised and widened owing to highly energetic flood flows. In other areas channels are laden with sediment. Following the floods of 1982, there was a call to desnag long sections of the Blackwood, and again on the Moore River following the floods of early 1999. Fortunately this was not done, as the removal of woody debris from rivers has been shown to have little effect on flooding (Gippel et al. 1998).

7.9.4 River diversion

A number of rivers in the south-west have been diverted from their original estuaries, mainly to alleviate flooding on the Swan Coastal Plain. A notable example is the

20 km long Harvey Diversion Drain which was dug by hand during the great depression to relieve flooding and to create employment for about 2500 men (Olsen and Skitmore 1991; Bradby 1997). Most of the small rivers that once discharged into Vasse-Wonnerup Estuary near Busselton are now diverted directly to the ocean, including the Vasse and the Capel Rivers. Because the river/estuary connection has been severed, river diversion no doubt removes valuable habitat for a variety of estuarine species, but new habitat is created along the lower reaches of the diversions.

7.9.5 Living stream vs drain

A natural living stream system consumes energy, nutrients and carbon and dissipates the power of flood flows, while conveying water to a lake or estuary. It works most effectively when it is in equilibrium with its catchment and contains all of its component parts. Human activities disturb the equilibrium through catchment clearing and alter the component parts through the removal of riparian vegetation.

The result is a rather inefficient drain, which is either eroding, clogged with sediment or choked with weeds. It provides few environmental services, such as clean water and sites for recreation, seldom provides for drainage without assistance from humans, and then only at the price of eroding the land and delivering large quantities of sediment and pollutants into downstream waterways. The next chapter explores ways and means of protecting and restoring living streams and how we can learn to live in equilibrium with them.

7.10 An hypothesis: organic pollution of south-west rivers?

In reading some of the previous sections and Chapter 3, it may be dawning upon the reader that organic pollution from accumulated leaf material may be a serious problem for south-west rivers. This possibility has received little attention by scientists, despite being suggested by Kendrick and Morrissy in the 1970s. The build-up of oxygen depleting black oozes in river pools, which is becoming increasingly apparent today (Reynolds 1986; Barmuta et al. 1992; Bunn et al. 1997), and the foul (rotten egg) smell of anaerobic decay along many of our inland rivers in summer and autumn, suggest that the subject is worthy of research. The widespread clearing of hard-leaved forests and woodlands and the establishment of pastures, annual crops and deciduous horticultural species, together with weed infestations along streams, have certainly produced a massive source of swiftly decaying, soft-leaved material. With the clearing of streamlines, this material is easily washed into and along streams, collecting in pools and building up amongst or beneath inorganic sediment deposits. In naturally vegetated streams, this material would ordinarily collect amongst the vegetation, much of it never entering the stream channel, and would break down in the humid open air of the riparian zone where oxygen is never in short supply. The problem is probably strongly related to low river flows when natural oxygenation is minimal, and is at its worst during prolonged drought periods as have been occurring in the south-west since the mid-1970s.

The 'trained' Avon River in summer. The fringing forest of the central part of the river has been removed and the bed has deepened over time. Note the green grasses colonising sediment deposits.
Photo: L.Pen

The Avon River in flood during the winter of 1996. This is a bankfull flow for the present day channel of the Avon River. Photo: L.Pen

THE GWAMBYGINE POOL ON THE AVON RIVER FILLING WITH SEDIMENT. SEEN HERE IN LATE 1993, MOST OF THIS SEDIMENT HAS SINCE BEEN REMOVED BY THE AVON RIVER MANAGEMENT AUTHORITY AND THE WATER AND RIVERS COMMISSION. PHOTO: L.PEN

THE SAD STATE OF MANY RIVERS IN THE SOUTH-WEST OF WESTERN AUSTRALIA. PHOTO: L.PEN

Chapter 7
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chapter 8

Managing our rivers

- CATCHMENT MANAGEMENT IN RURAL AREAS
- CATCHMENT MANAGEMENT IN URBAN AREAS
- RIPARIAN ZONE MANAGEMENT
- STREAM CHANNEL MANAGEMENT: EROSION CONTROL AND REPAIR
- STREAM ECOSYSTEM PROTECTION AND MANAGEMENT
- POINT SOURCE POLLUTION CONTROL
- MANAGING SALINISATION AND WATERLOGGING
- FLOOD MANAGEMENT
- WHO DOES THE MANAGING?

This chapter outlines the challenges and opportunities of river management in south-west Western Australia and describes the procedures and technologies available to meet them. It does not provide the detailed technical information needed to design and construct specific works. For this information see the technical references listed in Appendix 2.

A note on approvals and communication

Since this chapter may inspire the reader to action, it must also draw attention to the need for approval from (or at least communication with) relevant responsible authorities. Some catchments and river systems in Western Australia are subject to legislation, and approvals may be needed before any river management works are initiated. In some cases, river management is coordinated by statutory management authorities, while in others non-statutory catchment management groups are on hand to guide action (see Section 9.2). There are laws covering management of certain rivers for potable water supply, irrigation and flood management, and for the protection of wildlife and heritage, including Aboriginal heritage. For clarification of legal matters and the need for coordination in a particular area, contact the local office of the Water and Rivers Commission. Needless to say, for any work on private or public land, permission is required from the landowner or vesting authority, respectively.

8.1 CATCHMENT MANAGEMENT IN RURAL AREAS

8.1.1 Reducing surface erosion and sediment transport

Preventing surface soil erosion basically involves controlling the rate at which water, having fallen as rain, moves across the land and into streams. This conflicts with the objective of past rural and urban drainage, which is to get excess water off the land and into a drain or river system as quickly as possible, mainly to prevent nuisance or destructive flooding. Unfortunately, the quicker water moves, the more of the catchment it takes with it as the energy of swiftly flowing water does its work, lifting particles and transporting them downstream. Once water begins to flow in a fast moving stream severe soil erosion, such as gullying, can be expected. Along with the soil particles eroded from the land are their quota of nutrients, either adhering to the surface of particles or contained within them. Any action that reduces soil erosion also reduces nutrient loss and the discharge of oxygen depleting organic substances. It should also be mentioned that retaining precious topsoil on farmland is a worthy objective in itself.

CONTOUR CULTIVATION AND CONTOUR BANKS

Cultivation along contours, rather than perpendicular to them, will slow the rate at which water flows across the land, reducing soil loss by as much as 50% (SCEP 1992). Slightly raised banks running along the contour will also help to intercept water, along with its load of sediment and dead plant material, causing the water to form a shallow temporary pond and soak into the soil. These constructed 'level sills' also ensure that runoff is distributed evenly across the slopes. Contour or grade banks can be used to direct runoff into dams, onto areas of greater absorptive capacity or onto areas with high water use such as perennial pastures, fodder crops or tree plantations (SCEP 1992).

VEGETATIVE BUFFERS

Vegetated strips along waterways can be used to form lateral buffers which intercept and slow runoff and thereby trap suspended sediment, including much organic material. The effectiveness of the buffers depends on their width and the form of the vegetation, as well as the slope of the land (SCEP 1992). The wider the buffer the better. A vegetative buffer need not be of native vegetation and can be a simple grassy strip which is fenced off to control grazing and is occasionally crash grazed or harvested for hay. Vegetation within the waterway itself forms a longitudinal buffer which similarly slows the flow rate, prevents erosion and traps soil, sediment and organic matter.

Minimum tillage and stubble retention

By not ploughing and instead drilling seed into soil which is partially protected by the stubble from a previous season's crop, soil disturbance and exposure of bare loose soil to late summer storms or early winter rains, which can cause serious soil erosion, is minimised (SCEP 1992). It must be remembered however, that by retaining stubble instead of burning it off or ploughing it in, more soft leafed material is left on the paddocks to be washed into waterways where its subsequent decay can lead to oxygen depletion. For this reason, buffers are required to intercept this material before it can enter waterways.

8.1.2 Reducing nutrient loss

Any activity that reduces soil erosion also reduces nutrient loss. But no matter how hard we may try to prevent soil erosion, the necessary use of fertilisers on the poor agricultural soils of the south-west will always ensure that nutrients will be present in the environment in significant quantities and thus available to be washed into waterways. However, it is possible to minimise the amounts of nutrients delivered onto the land, their subsequent availability for transport by water and the possibility of them reaching waterways.

Soil testing and fertiliser use

Fertiliser is generally applied according to traditional practice, usually some time before the winter/spring growing season. Today, we know that after a number of years of fertiliser application, many soils are rich in nutrients but may be deficient in a few trace elements (Weaver and Prout 1993; Weaver and Reed 1998). Soil should be tested to determine fertiliser requirements and avoid excess application of nutrients, a portion of which will find their way into waterways.

Soil amendment

It is sometimes possible to artificially increase the ability of soils to retain nutrients. Referred to as 'soil amendment', this practice commonly involves top dressing the native soil with a product like Alkaloam (bauxite residue), fly ash or even common clay. This can dramatically reduce the amount of nutrients lost from the soil and improve farm productivity (Summers et al. 1992).

Perennial pastures

In the cooler and wetter parts of the south-west, where average annual rainfall is about 700 mm or greater, perennial pastures can be grown. They have a number of advantages over annual pastures. Apart from providing green feed all year long, they can increase soil organic matter content, enhance soil structure and, because they draw water all year long, maximise water use and thus reduce recharge to groundwater (SCEP 1992). For stream management, perennial pastures have the advantage of reducing nutrient loss. Their extensive and persistent root systems are able to take up nutrients at any time of the year, especially at times of unseasonable or early winter downpours when paddocks supporting annual pastures are relatively bare and dusty and therefore prone to erosion. Also, because there is no critical germination period at the beginning of winter, fertiliser can be applied in spring when growing conditions are best (SCEP 1992). In this way fertiliser need not be applied before the break of the winter season when the risk of soil erosion from heavy rainfall is greatest[1]. Of course, for farmers who rotate their paddocks between cropping and pasture growth, perennial pastures are less of an option since they take some time to become established. However, for beef and wool production, other grazing activities and for hobby farming in the 700 mm plus rainfall belt, perennial pastures are worth considering (SCEP 1992).

Perennial pastures are particularly suited to floodplains. These areas are generally more fertile and remain moist for longer periods of the year than upland areas, and so can provide valuable summer grazing. In return perennial pastures provide added protection from erosion that can occur when the floodplains carry or contain floodwaters.

VEGETATIVE BUFFERS

These not only provide a physical barrier for trapping soil sediment and organic matter, they also filter out and assimilate nutrients. Research has shown that grassy strips and other vegetative buffers 10-50 m wide can achieve phosphorus and nitrogen filtration rates of the order of 50-100% (Groffman et al. 1991; Barling and Moore 1994; Herson-Jones et al. 1995; Daniel and Gilliam 1996; Haycock et al. 1996). The nutrients assimilated by the vegetation can be utilised by crash grazing or preferably in hay production since this latter use does not involve livestock returning nutrients to the grassy border as urine and manure. It should be noted that buffers may need to be wider where surface flows converge.

8.1.3 Drain management – 'streamlining'

Rising groundwaters are causing waterlogging and salinisation across much of the south-west. This is occurring as a result of widespread clearing and the lower water uptake of mostly annual crops and pastures, compared with the original deep rooted perennial native vegetation. To manage the problems of rising groundwaters, drainage can be used as part of broader catchment management to maintain productive farmland. In some coastal wetland areas, farming is only possible because artificial drainage is used to lower the natural near-surface watertables. Without drainage, excessive waterlogging and flooding would occur in these areas.

Necessary as drainage is in some areas, its use must be combined with proper drain management to prevent bank erosion and to reduce the transport of sediment, organic matter and nutrients to downstream lakes and waterways. On the Swan Coastal Plain, a program known as 'Streamlining' (Heady and Guise 1994) promotes drain management to deal with this problem.

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1 On the other hand, a paddock may be too boggy in early spring to take the vehicle required to distribute fertiliser.

Cultivation on the contours, stubble retention, alley farming, corridors and well vegetated riparian zones, all hallmarks of good rural land management. Photo: S. Neville - Ecotones.

A vegetative buffer of native plant species maintained on a small creek in the Hay River catchment. Photo: L.Pen

Classic streamlining on a drain with natural stream channel form on a park in a new suburb of Perth.
Photo: Unknown

A stormwater retention basin made into an ornamental pond and wetland in an urban parkland.
Photo: Unknown

Fencing and revegetation of drains

Streamlining involves the fencing off and revegetation of a strip of land along the drain (which may be considered a riparian zone akin to that of a river or creek), and in some cases the revegetation of the drain banks. Fencing is used to exclude or control livestock grazing and thus protect the banks and vegetation. Where necessary an access track is left on one side of the drain to permit regular maintenance. The fenced-off and revegetated drain is well supported against erosion and serves as both a lateral and longitudinal biofilter. In most cases where this work has been carried out, drainage efficiency has not been significantly impaired.

As a rule, revegetated drains will slow the flow of water (as does, it might be added, the accumulated sediment from 'unstreamlined' eroding drains). Indeed this is partially the aim of streamlining work, which seeks to reduce erosion and promote filtration. As a result, some increase in flooding might have to be tolerated in some situations. Most drainage systems were notionally designed to prevent flooding of more than three days duration, but it is worth noting that a recent study highlighted the fact that six days flooding could be tolerated without undue damage to pastures (Jim Davies & Assoc. 1994).

Controlling aquatic weeds with shade

Another aspect of drain management is controlling aquatic weeds. In the absence of livestock grazing, weeds can become a problem, especially if the drain remains open to sunlight. Unlike the native sedges favoured for streamlining, many aquatic weeds will grow to clog the entire channel unless controlled (Sainty and Jacobs 1981, 1994). For this reason, shade from overhanging trees is needed to discourage heavy weed growth. Native sedges and rushes have evolved in shady conditions of natural streamlines and should grow in balance with the artificial drain channels that are lined with trees. Where revegetation is to be on only one side of the drain, it should be on the northernmost side to maximise shading of the stream.

8.1.4 Water harvesting

Rural areas are dotted with dams. Some are gully dams on creek lines and many are square hillside dams or round 'turkey nest' dams, some of which, in low rainfall areas, are linked to drains or contour banks to increase the interception of runoff. These dams perform a very useful function of harvesting excess runoff and thereby reducing downstream erosion and sediment and nutrient transport to downstream waterways.

VEGETATIVE FILTERS ON FARM DAMS

In late summer and autumn when paddocks are dry and dusty and prone to losing large quantities of soil during heavy downpours, these dams can intercept large quantities of inorganic sediment, organic matter and nutrients before they enter river systems. In this way water harvesting can contribute to river management. Unfortunately, the water coming off the paddocks at this time is not of a high quality for farm use, being muddy, polluted with animal wastes and dead plant material and rich in nutrients, all of which in due course can foul the water held in the dam. For this reason it is a good idea to maintain a vegetative buffer of sedges or grasses just above the dam to filter out this material, which will subsequently break down in the open air. Vegetative filters are especially important on dams used for marron or yabbie growing where maintaining high water quality is essential.

SUMPS

On market gardens and orchards where fertiliser application is heavy, excess water can be drained to a sump and partially reused. This should help to reduce nutrient loss, both by reducing the amount of water leaving the growing area and by re-application of nutrients that escaped assimilation by the plants in previous applications.

8.2 CATCHMENT MANAGEMENT IN URBAN AREAS

Urban catchments are hard, with large areas of roofing, concrete paving and asphalt. So there is relatively little opportunity for infiltration of rainfall and, if it were not for highly efficient drainage systems that quickly convey water to groundwater sumps, lakes and waterways, flooding would be a major problem. Unfortunately the speed at which the water runs off the land and flows down the drains causes large amounts of sediment, organic matter, nutrients and other polluting substances, known collectively as 'slugs', to be washed into creeks and rivers (Weeks 1982). For example, water reaches the Swan River in hours from urban drains after heavy rainfall, compared to days from natural streams (WRC data). The worst time of year is late summer or autumn when, after many months of dry weather, large amounts of potentially polluting substances have accumulated on the land surface. Also, in late autumn large quantities of leaf material are produced by exotic deciduous trees and it is common to see roadside drain inlets blocked with dead autumn leaves.

8.2.1 Increasing infiltration

River and wetland pollution caused by urban drainage was recognised as a serious problem in the late 1980s (WSUDRG 1990; Mouritz et al. 1994). Since then there has been a steady development of 'best management practices' to reduce runoff and filter out polluting substances, culminating in an approach known as *water sensitive urban design* (WSUD) (Whelans et al. 1993; Evangelisti & Assoc. et al. 1998). Through better stormwater management WSUD exploits the opportunity for infiltration into the ground and for pond retention between rainfall events. In the south-west there is considerable time between rainfall events, even in winter, and although rain may not soak into the ground where it falls, because the land is covered by some form of hard impervious material, there is plenty of opportunity to direct water to where it can percolate into the soil or initially form a pond, to soak away in the following days. These infiltration and retention sites remain connected to drains via overflow mechanisms, so that in periods of prolonged heavy rainfall the drains can once again function to prevent storm flooding. The crucial reasoning here is that stormwater need not be directed straight to wetlands and rivers, but is conveyed to the groundwater. In this way vegetation and soil can be used to filter stormwater of organic matter and sediment and soil microbes are given the opportunity to decompose a portion of the organic matter, while vegetation can assimilate a portion of the nutrients. Where this approach is applied over a wide enough area, 'slugs' of pollution will no longer be a normal occurrence after each rainfall event.

Some of the technologies for increasing infiltration are described below.

Porous paving and asphalt

The first opportunity for infiltration is where the rain falls. Ordinarily, paving and asphalt do not permit the percolation of water, as the gaps or interconnected spaces and voids necessary to enable infiltration would render these surfaces too weak to sustain heavy traffic. However, in lightly trafficked areas such as walkways, bike paths, driveways and car parks, strong sealed surfaces are not necessary. In these situations a simple course of stones, cemented together with concrete or asphalt, can be used to create a highly porous but still comparatively hard surface which permits the percolation of rain water straight into the ground. Alternatively, preformed modular concrete or brick paving can be used. There are a number of different types available, some with holes and others creating gaps between the slabs or bricks. Sand or pebbles can be placed in the openings or soil can be used to grow grass.

Swales

A swale is simply a long depression with moderately sloping sides. It can support grasses or sedges and rushes. Water flowing off roofs, car parks, sporting fields, park lands and garden lawns can be directed to swales. A long swale could be used as an open drain to permit a considerable amount of infiltration prior to discharge to a drainage system. The aim would be to have the water drain away in a day or two, to prevent any breeding by mosquitoes.

Infiltration basins and trenches

These are simple impoundments or trenches dug into permeable soil or created by the formation of embankments, and in the latter case back-filled with stones.

Urban forestry

Small areas of bush, strategically located, can be used to intercept and retard runoff and facilitate infiltration, thereby reducing peak flows. The vegetation will also subsequently transpire a portion of the groundwater.

8.2.2 Increasing filtration and sedimentation

Other aspects of water sensitive urban design (Whelans et al. 1993) are filtration and sedimentation. Here the aim is to filter out a portion of the sediment and organic matter being carried in stormwater, either before entering a drain or while flowing within a drainage system. Just as in rural areas, filter strips of vegetation can be used along drains to intercept a portion of the sediment being carried in runoff. The vegetation will also assimilate a portion of the nutrients. Once in the drainage system, detention basins can be used to slow or halt the water for a time and sedimentation allowed to take place, as it does in river pools. Where flooding is not a problem wetland vegetation can be added to the drain to create a biofiltration system and this can be done to varying degrees, depending on the situation. As a logical extension of this approach, artificial wetlands can be created to strip nutrients and sediment, a practice which is becoming increasingly common around the world and is being trialled in the south-west, not only for stormwater control but also for pollution control at wastewater treatment plants. These methods are discussed in more detail below.

Filter strips

These consist of belts of grass, sedges or a mixture of fringing plant species densely planted to slow runoff and achieve an immediate improvement in water quality by trapping suspended sediment. Filter strips are generally feasible on slopes of less than 5% (Whelans et al. 1993). An added function is the breakdown of organic matter by microbial activity and subsequent assimilation of nutrients by the vegetation. Grassy strips can be mowed and the clippings composted.

Detention basins

In many cases detention basins are intended simply to provide temporary storage in order to reduce peak flows to within the discharge limitations of the drainage system, but these days they are also used to achieve an improvement in water quality through sedimentation. The longer the period of detention, the more smaller and lighter particles are given the opportunity to settle out, and the better the quality of water that passes out of the basin either through a gravel filter bed or a raised overflow pipe or riser. From time to time the basin needs to be cleaned out and inlets and outlets unclogged to avoid problems of mosquito breeding, stagnation and offensive odours and unsightliness.

Artificial wetlands

Where a detention basin can be made to retain water for long periods or where groundwater levels are naturally high, it is possible to construct artificial wetlands. The addition of wetland vegetation, and in time a simple wetland ecosystem, to a drainage system can further improve water quality through the processes of biofiltration, microbial decomposition and bio-assimilation. Artificial or 'constructed' wetlands, as they are increasingly referred to, can offer real water quality improvements, as well as supplementary wetland habitat, but their use and development is complex and good results are dependent on good design and maintenance (Evangelisti 1994; Evangelisti & Assoc. et al. 1998).

8.3 Riparian zone management

8.3.1 Identifying the riparian zone

The first step in managing a river or creek is to identify the riparian zone, that is, the corridor of land in which the stream 'lives'. Because south-west streams are asleep or dozing most of the year, the best way to do this is to look at the stream when it is in flood. At this time it is pretty obvious where the water is flowing strongly and where it is spilling over onto floodplain or moving slowly over adjacent land. The zone in which the main flood flow is occurring is the floodway and it is the target of most attention, for this is where the flooded river or creek has the energy to erode and transport material. The broad floodplain is usually a quieter zone, but a careful eye should be kept for any action which may be occurring due to an alteration in the behaviour of the stream brought on by channel obstructions or the clearing of vegetation. The floodway and the floodplain comprise the riparian zone. To this should be added a buffer of upland, also known as the verge.

As a general rule, high-gradient streams, which are usually narrow and have obvious and often steep embankments, need to have their narrow riparian zones set aside for management. This is because the high energy potential of the stream and the fragile embankments require careful management. At the other end of the spectrum, broad, low-gradient streams, which have little stream power and only moderately sloping banks (if any discernible banks at all), need not be managed so sensitively. For example, river paddocks, in which landowners are careful not to overgraze perennial vegetation and thus expose the soil, are a management option for the future?

8.3.2 Protecting and rehabilitating fringing vegetation

Fringing vegetation must cope with physical disturbance, fire, grazing, weeds and disease, all of which are a natural part of south-west ecosystems. They help establish the balance between mortality and regeneration that characterises a healthy ecosystem. Unfortunately, past land management practices have paid little attention to maintaining this balance on rivers or elsewhere. Thus we have seen an increase in the magnitude and frequency of such disturbance, resulting in an increased rate of mortality and a lack of regeneration of native plant species, and in turn, of all the other creatures that depend on them.

Reducing disturbance

Protecting fringing vegetation consists of restoring the balance between mortality and regeneration. This can be done by reducing the amount of physical disturbance or by concentrating it in certain areas; by reducing fire frequency where needed and creating conditions that do not represent a serious fire hazard; by limiting grazing to levels that do not preclude the regeneration of dominant native species; by eradicating invasive weeds; and through all of these activities achieving an increase in the health and vigour of the native vegetation and of the many animals it supports.

Fencing

Without doubt the most effective means of managing the riparian zone is fencing. Fences can be used to exclude or control livestock grazing and to guide human activities into areas that are appropriate to them. Fences also serve to delineate land uses and to prevent them from spilling over into the riparian zone. Simple logs or rocks spaced out along a line could be used to delineate the riparian zone where actual exclusion is not required; for example where back yards or parks and gardens back onto rivers.

8.3.3 Replacing and managing fringing vegetation

Planning and plant selection

Aerial photographs can be used to mark out areas to be planted. If these are unavailable or too expensive, simple sketch maps (using a compass, reference points and pacing out distances) are probably just as effective. If the intention is to work along a sizable river section or creek system a survey should be conducted to gain an idea of the job at hand and to identify priority areas. A number of standardised survey techniques are available (see Appendix 2).

Plants for a particular area should be selected from local provenance[2] stock wherever possible. Some local nurseries, often run by schools, landcare groups or the Wildflower Society, specialise in propagating local varieties of native plant species. However, changes in local conditions may warrant the consideration of species and varieties which may not have been characteristic of the subject area in the past. The best example of this is along salinised waterways where salt-tolerant species are required. In all cases species native to the south-west should be planted in preference to eastern state species, because local native species are adapted to local conditions, support local fauna and will most likely regenerate, all factors essential to the reconstruction of natural ecosystems. Advice on suitable riparian plant species for particular areas and situations can be obtained from a number of agencies and groups, such as CALM, Water and Rivers Commission, Agriculture WA, Greening Australia (WA) and the Wildflower Society.

When the riparian zone is to be used for grazing, non-native pasture and fodder shrub species may be acceptable. For example, Puccinellia grass can be used on broad flat waterways as an understorey to native trees and shrubs. Grazing however should be light or appropriately timed to prevent the exposure of large patches of the watercourse.

Site stabilisation

There is no point planting out foreshore areas which are eroding and unstable. Before planting it will be necessary to use appropriate bed or bank stabilisation techniques, as described in Section 8.4. Similarly, if the river channel appears to be widening or shifting its location, replanting

[2] Serious seed collectors use the term provenance to refer to the area in which the seed is collected. To maintain local plant species varieties, local provenance seed should be used. The Main Roads Department has defined local provenance seed as that collected within 15-50 km of the site to be revegetated (Hussey and Wallace 1993).

to stabilise it would be futile. Rather, stable channel form must be determined first and measures taken to secure it before attempting revegetation.

Controlling disturbance, weeds and pests

Physical disturbance by vehicles, heavy human traffic and large animals must be controlled before any planting is undertaken. In many circumstances livestock should be fenced out, especially where a full fringing plant community is to be re-established. In areas where trees only are to be replaced, fencing out of livestock will be required until the plants are large enough to withstand grazing and trampling. People using foreshores in residential and recreational areas should be directed away from planted areas. Simple wire fences or logs are effective. Signs explaining the aims of the project will help to gain community support.

Weeds are a major threat to successful plant growth. To give plantings and seedlings a competitive edge in the first year, physical removal of weeds or careful spraying with herbicides is often essential. Particular attention should be paid to the more dominant and aggressive weeds, such as blackberries and bridal creeper. Remnant small native shrubs and sedges should be protected from the herbicide, by for example placing a bucket over them when spraying is being carried out. Choose only herbicides with a low toxicity to aquatic life and a short residual life. Take care to prevent spray drift onto the stream by spraying on windless days.

Plantings will be grazed or damaged by a range of insects and some birds and mammals. The dominant grazer in rural areas is likely to be the rabbit, and kangaroos can also be a problem. In these situations, small plantings can be protected by re-usable wire cages which are held in the ground by pegs. Placing old tyres around plants is known to discourage rabbit grazing. In rural areas preliminary baiting with 1080 poison is an option for rabbit control, but permission is required from Agriculture Western Australia, Industry Resource Protection.

Soil preparation

Ripping of the soil to a depth of 30-60 cm can improve water infiltration and drainage, particularly for compacted soils. It makes planting much easier and promotes rapid root growth. However, ripping should only be done on the upper embankment and verge areas of the riparian zone, as loosening the soil of the floodway will almost certainly lead to serious erosion. Care should also be taken not to uproot any remnant trees and shrubs. In salinised and waterlogged areas, mounding is needed for establishment of seedlings, and the valleys between the mounds should lead down to a waterway for the disposal of excess water.

Planting trees and shrubs

Where frosts are not a problem and summers are hot and dry, trees and shrubs should be planted in autumn. In areas where frosts commonly occur and summers are mild (the south coast), spring plantings are an option. Seedlings should be ordered at least six months in advance. Planting at densities of 1000 to 1300 seedlings per hectare is typical where no native vegetation remains. For example, 1000 seedlings would revegetate a bank one kilometre long and 10 m wide. In areas of sparse remnant vegetation, a density of 500-600 per hectare may suffice. As many as 3000 seedlings per hectare may be necessary where a dense vegetative corridor is required to connect valuable bushland habitats.

Transplanting sedges and rushes

Obtaining sedges and rushes from nurseries may be difficult and expensive, depending on the species needed[3]. A number of suppliers are listed in the Yellow Pages. The high cost is often due to the fact that many sedge and rush species produce little or no viable seed and need to be propagated by tissue culture. The twig rush (*Baumea juncea*) is a notable example. The alternative is to transplant sedges and rushes from sites where they are abundant or where they are about to be destroyed by development. The best time of year is early winter when growth is minimal, just before the maximum growth period of late winter to early summer. To reduce the shock of transplanting, the leaves should be cut off about 10 cm above the root stock, higher for the larger species (i.e. 30 cm for species that grow taller than 1.5 m). As a general rule the upper two thirds should be removed prior to planting.

Direct seeding

Direct seeding is the broad scale sowing of native tree and shrub seed onto a prepared site. It enables the establishment of a range of native species with little labour and at a relatively low cost. To be effective however, a very high degree of weed and pest control is necessary. Even so, results can be highly variable. One means of achieving weed control is to remove the upper 5 cm of topsoil, an operation known as scalping, which removes most of the weed seed and bulbs. Main Roads Western Australia uses direct seeding to great effect in re-establishing native bush on roadsides. It is also used successfully on streamlines in the Mount Lofty Ranges catchments in South Australia (Burston and Brown 1996). Combined with a program of collecting local native seed, direct seeding can be a most effective means of restoring local varieties of native plant species.

Encouraging natural regeneration

In many areas native species are already present along a streamline but are not successfully regenerating. There can be a number of reasons for this, including competition with weeds, grazing by rabbits or frequent fires that kill native plant 'offspring' while encouraging introduced annual grasses. Keeping these added pressures under control will encourage successful regeneration of the native flora. For example, weeds can be cleared away from seedlings to enable successful early growth, fences can be constructed to keep rabbits at bay and the frequency of fires can be reduced. Shallow ripping, or 'scarification' as it is known, can be carried out near flooded gum (*Eucalyptus rudis*) trees to encourage regeneration. Often the problem then becomes one of thinning the seedlings as flooded gum regenerates readily in the absence of grazing, providing also that soils are not too saline. Swamp paperbark (*Melaleuca rhaphiophylla*) can be

[3] In 1999 most of the more common south-west sedges and rushes could be purchased for 80 cents to $1.20 per planting tube or small pot

encouraged by placing branches with ripe fruit along the water's edge. In salinised and waterlogged sites swamp sheoak (*Casuarina obesa*) regenerates rapidly in the absence of grazing and readily under light grazing. It is likely that many other native species will show similar responses once protected from weeds and grazing.

Fire management

The vegetation along streamlines can present a fire hazard and will require management. Simple firebreaks (e.g. livestock crossings), fuel reduction exercises and, if necessary, periodic controlled fires (about once every ten years is preferable[4]) should suffice. On the Avon River, the Avon River Management Authority is aiming at tree canopy closure to shade out annual 'fire-prone' weeds along most of the river, using regular control burning mainly to protect settlements and valuable assets. It should be noted that the perennial trees and shrubs of the typical streamline are far less ignitable than the annual grasses which often grow abundantly along the upper embankments and verges.

8.3.4 Livestock management

The control of livestock grazing is the single most important management activity in the riparian zones of rural areas, and there is no better way of achieving this than by fencing. Pressure to fence off streams generally elicits a negative response from many rural landowners. There are a number of reasons for this. Firstly, the riparian zone may provide good grazing and water that the landowner is reluctant to close off behind fences. Secondly, fencing is expensive and finding the funds to fence kilometres of streamline, both sides, may be difficult. Lastly, there is the matter of managing the riparian zone once it is fenced and no longer generating income for the landowner. These are reasonable concerns and for those who have stable streams at the moment, fencing seems unnecessary or of low priority. On the other hand, there are also many landowners who are now fencing and replanting eroding streams because they must; to prevent the loss of valuable farmland through erosion. So fencing off streams can be a preventative action that will save money in the long term.

Fencing

Fencing is not necessarily used to exclude stock totally from the riparian zone. Only in the case of steep, poorly to moderately cohesive embankments of deep river valleys where stream power is high, is it necessary to exclude large animals like cattle and horses permanently. If the aim is to protect high quality bush in the riparian zone to maintain habitat, landscape and an ecological corridor all livestock should be excluded. However, where the riparian zone has a history of grazing and the exclusion of stock would lead to an explosion of weeds and a serious fire hazard, maintenance of the zone by grazing is beneficial. The key here is to use fences to control the level of grazing so that the dominant native vegetation is able to

[4] Vegetation with heavy annual weed growth is often burnt more frequently (legally and illegally). Frequent fires (i.e. every 1-5 years) favour annual weeds and thus maintain the risk of fire and reinforce the need for controlled burns. This is a vicious circle that is not compatible with the management of healthy bushland plant communities.

regenerate, and the bed and banks are not so denuded of vegetation as to become prone to erosion. The landowner need only keep a watchful eye on the riparian zone to see that it has adequate cover of a mixture of native and pasture plant species and erosion is not significant. Troublesome major weeds would be identified at an early stage of establishment and eradicated immediately.

Watering and crossing points

Certain sections of rivers are amenable to heavy stock presence and are therefore preferred sites for stock watering and crossing points. Such sections include the inside of meander bends, where sediment deposition rather than erosion occurs, and hard stony areas. If they are not available, then small areas of foreshore can be hardened up with field stone. Vehicle and livestock crossing points should be located in straight sections of the river where stream power is low (i.e. below a dense stand of paperbarks) or where the river bed is hard. Of course such points can also be hardened up with field stone to create rocky riffles which are valuable habitat in their own right. Indeed this is already a common practice. Care should be taken to direct paddock runoff away from stock or vehicle access points to prevent gullying of the valley embankment.

Placement of fences

Considering the expense of fences it makes sense to locate them away from the floodway of the river where they won't be torn out or damaged by high velocity flood flows (Fig. 8.1). In the absence of a good knowledge of flood levels and frequency, landowners have tended to maximise paddock area and locate fences up against the low flow channel of the river, but this has proven to be a poor economy in the long term. On some rivers as many as four old 'wrecked' fencelines can be seen along the river, the landowner progressively locating new fences a little further, but not far enough, up the embankment. Fences located in floodplains should ordinarily be safe from serious flood damage as 'spill-over' flood flow velocities are generally low.

Managing broad low gradient streams

The low gradient rivers of the wheatbelt, like the upper Moore, Beaufort, Coblinine and Gordon, are often hundreds of metres across and in some cases kilometres across. In these situations it is impossible to identify a definite riparian zone so fencing off a neat narrow corridor of riparian bushland is impractical. The solution to managing these rivers lies in the creation of river paddocks of grazed 'B grade' bushland. Just how this can be done commercially remains to be developed, and further difficulty arises in the quick removal of stock prior to flooding. Also, many of the broad low flat rivers are very saline and need to be revegetated with salt-tolerant species which may not be so palatable to stock or able to withstand useful grazing.

8.3.5 Weed control

Weeds can be divided into three groups for management: annual pasture species, garden escapees and true aquatic weeds. The management of annual weeds is probably limited to preliminary spraying and soil scalping to give native plantings a head start. Hopefully, in the long term,

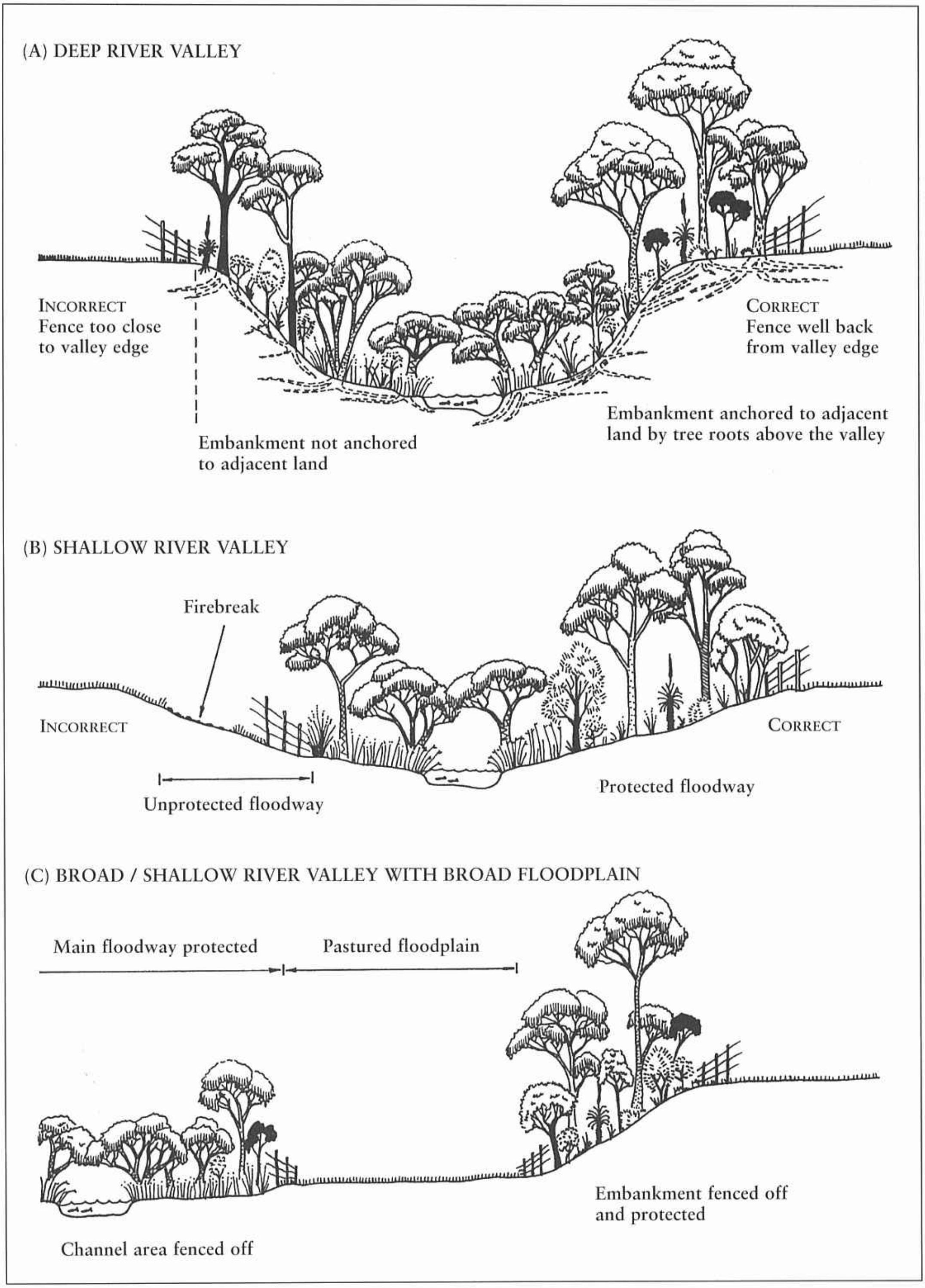


Figure 8.1 The correct and incorrect placement of fences in relation to the river valley: the deep river valley (a), the shallow river valley (b), and the broad shallow river valley with broad floodplain (c).

A WELL VEGETATED RIPARIAN ZONE HAS BEEN MAINTAINED ALONG A CREEK ADJACENT TO FARMLAND NOW PLANTED UP WITH BLUEGUMS. PHOTO: S. NEVILLE - ECOTONES.

A PARTIALLY REHABILITATED SALINISED CREEKLINE IN THE UPPER BLACKWOOD CATCHMENT. PHOTO: L. PEN

SMALL FENCED AREA LEADING DOWN TO THE KALGAN RIVER, AFFORDING ONLY LIMITED ACCESS BY LIVESTOCK TO THE WATER'S EDGE. PHOTO: L. PEN

THE WISE USE OF FLOODPLAIN. THIS FLOODED PARKLAND LIES ON THE SWAN RIVER. PHOTO: R. BRETNALL native species will be able to hold their own against most weeds, particularly in the shaded conditions of the riparian forests of the wetter coastal areas.

The major tree, shrub, vine, ground creeper, bulbous, herb and tall grass weeds, the 'garden escapees', can only be controlled in the riparian zone by removal or poisoning. In other words sheer hard work. Management must be preventative rather than curative. Constant vigilance is required to 'nip these weeds in the bud' before major infestations occur. The planting of these species in parks and gardens along streams should be discouraged and the disposal of garden clippings into riparian zones considered an offence worse than littering.

In some situations, weed trees and other large weeds may be effectively securing the river bed and banks from erosion. If so, care must be taken with their removal, through a staged program of native tree and sedge replacement as the weeds are removed.

Although infestations of true aquatic weeds are uncommon the consequences are severe, as the *Hydrocotyle* infestation of the middle Canning River in the early 1990s showed, and cannot be left uncontrolled. Removal of the infestation is necessary and can cost hundreds of thousands of dollars (Klemm et al. 1993). Costly follow-up control may be required for many years after. Once again prevention is the key. As the introduction of aquatic plants is thought to occur when people dispose of unwanted pet fish into streams or when aquatic plants escape from ornamental ponds located on streamlines, prevention must involve responsible forms of aquarium disposal and the use of aquatic plant species which are slow growing and non-invasive, respectively.

Information on weeds and their control is available from organisations such as the Agriculture Protection Board, Agriculture Western Australia, CALM and Greening Australia (WA) (see also Appendix 2).

8.3.6 Recreational use of the riparian zone

Foreshore activities and amenities

The selection of foreshore sites suitable for human activities, such as camping, picnicking, fishing and swimming, requires as much care as the selection of sites for livestock access. Sites should be hard or at least not prone to erosion and have ample potential to be hardened or protected with good vegetative cover, such as gardens and lawn. The water's edge is most prone to erosion and must be protected with rock, logs or even old tyres where stable beach fails to form. Small patches of fringing vegetation, well delineated with logs, should be maintained on the foreshore and especially along the water's edge to provide tree root support of the bank, shade, landscape and some habitat. Runoff from park areas should be carefully managed to prevent gullying and nutrient loss.

Boating, boat races and other sporting events

Canoes and other non-powered boats are the best ways to appreciate a river but problem bank damage may occur where canoes are launched and retrieved from the water. Launching sites need to be hard or at least not prone to erosion (i.e. placed on the inside of a meander bend where sediment is typically deposited). Another problem is that the removal of boating hazards, mainly snags, may be necessary to protect human life, but is nonetheless a form of river degradation. Also noisy boating parties may disturb waterbird breeding in spring.

Much has been made of wave action from power boats causing foreshore erosion. This is certainly true where protective fringing vegetation has been lost and power boating is common. Perhaps activities such as water skiing should be limited to river sections with rocky foreshores or where fringing vegetation is intact or at least is being rehabilitated.

Some individuals and groups are concerned about the impact of once-a-year power boat races and associated practice days. In their direct effect on foreshores, they are far less damaging than typical river floods. However, spectators and support crews can cause serious damage to foreshores, and this is true for other sporting events on rivers. Vantage points for spectators should be chosen with care and be well signposted.

For all of the above activities fringing vegetation has one indispensable role. It provides a ready refuge from humans for those animals, especially waterbirds, for whom the river is home.

Floodplains

Floodplains are needed to disperse floodwaters but they need not remain in their natural state to do this. They can be used for parklands and sporting fields, with judicious planting of native trees, shrubs and sedges to protect sensitive areas from erosion and to maintain landscape and habitat elements. There should be minimal use of fertiliser on lawns and sporting fields, and certainly with very low phosphorus applications.

8.4 STREAM CHANNEL MANAGEMENT: EROSION CONTROL AND REPAIR

8.4.1 Stream bank protection and repair

An eroding stream embankment can be protected and repaired in a number of ways. It can be hardened up with stone or some other material, so that it is not so easily eroded; the surface of the bank can be covered in some well bonded sheeting or matting to prevent the water from dislodging soil particles; the erosive flows can be deflected away or dissipated so that sedimentation rather than erosion occurs in the previously eroding area; and finally steep banks prone to collapse can be reformed to improve their structural integrity. Various technologies to protect, repair and stabilise stream banks are available and are described below. They can be used singularly or in combination, but it is now acknowledged that the re-establishment of fringing vegetation is the key to long-term stabilisation, and all of these technologies should be looked upon as interim steps in the restoration of a stable stream form with supporting riparian vegetation (expanded in Section 8.4.5).

Bank hardening

REVETMENTS consist of rock or other material and objects that cannot be washed away, placed at the base ('toe') of an eroding or erosion prone bank, thus protecting and holding the bank material in place. Rocky revetments are also known as **rock rip-rap** and can be very pleasing to the eye if arranged by hand along minor watercourses. The Blackwood River has a natural rock rip-rap between Bridgetown and Nannup, which has done a great deal to protect that river from severe bank erosion. However, stone need not be the only material used if revegetation of the bank is to be carried out subsequently. In this case unsightly materials such as **old car bodies**, filled with stone and soil, can be used, providing, of course, that all potentially polluting substances, such as heavy metals, battery acid and oil, are removed first. **Old tyres** can be used by laying them flat at the base of an eroding bank or up against a moderately sloping bank or by stacking them against a steep slope. Wired together and secured in place by posts driven into the ground, they are appropriate in low to medium energy conditions where they cannot be swept away and sediment can collect in them and ultimately support vegetation. Geotextile mats, cellular concrete blocks and asphalt, in combination with vegetation, can also be used to create revetments. The use of these materials is described in more detail below.

LOG WALLING is an alternative to rock rip-rap along low embankments, where rock may not be easily available. Log walls are constructed by placing logs along the eroding bank, which are secured in place by logs driven into the bed. Trees and shrubs or just pasture grasses can be planted behind the logs. Log walling is aesthetically pleasing and contributes to stream ecology in much the same way as snags.

ROCK GABIONS are wire mesh cages loaded with small rocks. Gabions are generally in the shape of a bed mattress and can be laid down and wired together to cover an embankment. The open nature of the rocks enables sediment to collect in the spaces, ultimately giving rise to vegetation growth which secures the rocks in place, hopefully long before the plastic coated wire deteriorates.

GEOTEXTILE TUBING is a recent innovation used to support and protect the lower embankment of the river channel. The material for the tube is made of high-strength polyester fabric. The tube is first laid out as needed and then a sandy slurry is pumped into it. The water escapes from the tube via the tiny gaps between the strands of the fabric, allowing sand to form a solid mass capable of resisting erosive forces.

Surface protection

MATTING, ASPHALT AND PAVING

On moderately sloping banks, erosion can be prevented by placing a sheet of well bound or solid material over loose soil. Flat or 'three-dimensional' mats made of cellulose, plastic or **geotextile** can be laid and fastened down over preseeded soil to secure the emerging seedlings, which will ultimately provide the long-term bank protection. **Pocket fabrics** containing preseeded soil can be used in the same way. Alternatively **asphaltic** material can be applied to the surface of the soil. As the material decomposes or deteriorates, it is replaced by vegetation, generally grasses and sedges. **Cellular concrete blocks**, similar to the porous paving described above, are used where flow velocities can be very high and some regrowth of vegetation is desired. All of these technologies are expensive and are generally only used in urban areas, and then only when cost effective, such as when bank erosion threatens property or threatens to become much worse if left uncontrolled.

Flow velocity reduction

Revegetation is often all that may be required to protect an eroding embankment. The above ground vegetation will reduce near-surface flow velocities and roots and rhizomes hold the soil of the embankment firmly in place. The means to restore native vegetation are described above and few lessons are required to bring back grasses and weeds, if that is all that is required for bank stabilisation. However, in areas which are actively eroding, revegetation is no simple matter as plantings and seedlings are easily dislodged. In this situation near-surface flow velocities must be reduced. The following bank stabilisation methods are designed to do just that.

Deflectors

These are structures built to project at right angles, or slightly angled downstream, from the eroding bank to deflect and guide the flow away from the bank. In this way the flow velocities adjacent to the eroded bank are reduced and sediment can deposit behind each deflector. This sediment helps support the toe of the bank and enables revegetation of the eroded area, ultimately rendering the deflectors redundant. Deflectors may be made of rocks, logs or secured brush or may take the form of open log or closed picket fences. Short high deflectors, generally as high as the bank, are known as **groynes** and low long deflectors are known as **retards**. A number of old fence-like deflectors can be seen on the Brunswick River below the town of Brunswick Junction and along the Collie just upstream of the South Western Highway. Sometimes short extensions, known as **vane dykes**, are added to the end of the deflectors roughly in alignment with the direction of flow, to redirect flow more precisely. Free standing vane dykes may be secured in line to guide flow direction.

In areas of severe erosion where quick revegetation is required within the channel area, a number of technologies are available and are here referred to collectively as **dissipaters**, since flow dissipation rather than deflection is the main objective. **Heavy duty wire mesh fencing**, strung out along the low flow channel edge of the eroded area and with attached fences equally spaced apart and leading back towards the bank at right angles, is used to dissipate flood flows, and bring about sedimentation and possibly protect plantings. The fencing is usually held in place by star pickets and pieces of old railway line, which are used to take the very severe strains placed on the fencing during high flows. A variation on this method is to use a band of folded wire mesh to enclose gravel in a sort of long 'gravel mesh sausage' arranged as described above. Here the weight and form of the tubular rock fence helps to secure it in place and to guide flows above the channel bed to protect plantings. Both these methods have been used in the eastern states where channel shift is a major problem, threatening to destroy hundreds of hectares of valuable farming land or other property. A less expensive but not as effective alternative is the use of 'jacks', which are simple cross shaped structures made of logs secured in the eroded area. They provide no immediate protection to plantings but, by encouraging sedimentation, will ultimately foster revegetation. Brush of cut trees and shrubs is an even cheaper option and can be secured with rope, wire or cable tied to buried logs ('dead men') or driven posts.

Preventing bank failure

The erosion of steep banks often occurs as a form of mass failure when the bank is left unsupported but saturated with water immediately following a bankfull flood or heavy rainfall. In these situations a number of actions can be taken to prevent or reduce bank collapse. **Battering** to an angle of about 45 degrees or less restores a stable form which should not so easily collapse and thus provide the opportunity for revegetation which affords long-term stability. Through the addition of roots by the vegetation, the structural strength of the bank should increase in time. However, it should be noted that trees also add considerable weight to a bank and at some points on steep banks the judicious removal of very large and heavy trees, especially those which lean ominously, may be warranted. Similarly any heavy objects located at the top of steep eroding banks should be removed to reduce the chances of collapse, through what is called bank surcharge.

8.4.2 Stream bed protection and repair

Channel bed erosion, or incision, is usually caused by an increase in flow velocity. This can be caused by increasing the slope of the channel, which happens for example when a meander bend is cut off thus shortening the length of the channel over the same drop in elevation, or by reducing bed roughness which can happen when vegetation and debris are removed. Incision can also occur when bed armouring is removed to expose a more erosive underlying layer of material; such as when removing pebbles over sand.

The solution to bed incision is to reinstate those features of the stream which formerly controlled erosion of the bed, such as channel vegetation or the pre-existing slope, or to incorporate new features which cannot be eroded and which dissipate the energy of flowing water. These latter features are usually placed along relatively short sections of streamline where a considerable drop in elevation is to be managed.

GRADE REDUCTION

Shortening the length of a channel will increase flood conveyance, not only by reducing the distance over which the water must flow but also by increasing its velocity over the greater slope. Unless the channel is well armoured by stones, rock or concrete or protected by vegetation and woody debris, it will incise. Conversely lengthening a stream, thus reducing grade, slows the flow of water and allows its energy to be dissipated over a longer reach. Previously mobile sediment now collects on the bed or is carried downstream more slowly. Even where incision is occurring as a result of vegetation loss, grade reduction can be considered as a control method, but only where space is available. For example, an incising creek running through parkland could be lengthened and made into a feature. Lengthening would involve the introduction of meanders and riffle zones to create a more natural and stable form.

CHANNEL ARMOURING

This simply consists of placing a layer of coarse particulate material along an incising bed. The size of the individual particles, whether pebbles, cobbles or boulders, would be keyed to the maximum stream power of the channel, the particles being too large and heavy to be mobilised by the stream power produced at the highest of flood levels. For example, rock bedding is sometimes used to stop incision along road gutters in country areas. Placing suitably sized rocks in an eroding stream or drain also creates riffles zones and high-flow microhabitats which improves habitat diversity and hence biodiversity.

WEIRS AND DROP STRUCTURES

These are essentially waterfalls, used to transfer water from one elevation to another at a single point that has been hardened so that headcutting is not possible. This offers an immediate solution to any headcut: simply build a weir or drop structure on top of it. But for a channel which is incising right along its length, a number of weirs and drop structures need to be placed at predetermined intervals along the channel to obtain intervening grade reductions sufficient to reduce stream velocity to below the erosion threshold. Usually the crest of one weir is placed at or just above the elevation of the toe of the immediate upstream weir. In this way water is impounded back to the base of the upstream weir. Where water is impounded above each structure, sedimentation occurs, resulting in an upstream grade reduction, which produces the desired effect of reducing flow velocity. This suggests the alternative erosion control method of placing a weir below the headcut rather than on it, which may be necessary if the site of the headcut presents certain problems.

To create or retain natural features of the Darling Scarp, weirs should be constructed of rocks with the length at least five and preferably ten times the weir height. These 'natural' weirs become rapids or riffles zones, which improve habitat and water quality (see below).

A stilling basin or splash pool is usually incorporated into the design of a weir or drop structure. It can be constructed or allowed to form by itself. Alternatively, where a stilling basin is not desired or a splash pool may undermine the structure, rocks or concrete blocks can be used to dissipate the energy of the falling water. Where revegetation of the stream channel is contemplated as the ultimate erosion control measure, a weir can be made of logs. Permanent weirs are also excellent sites for vehicle and livestock crossings and foot bridges.

CHUTES AND RIFFLES

One major disadvantage of weirs and drop structures is that they create barriers to upstream faunal movements. An ecologically friendly (and more easily constructed) alternative is rock chutes. Their size depends on the channel size but for typical creeks and rivers they are usually 0.5-5 m high and 5-50 m long. Constructed with a one in twenty grade on the downstream face (down to 1:10 grade for the shortest of chutes) and with a shallow V-shaped cross section, so that water is always directed to form a rough central stream, rock chutes do not present a serious barrier to aquatic faunal movements. They function, not as waterfalls, but more or less as cascades, rapids or riffles, dissipating the energy of flowing water over short, moderately sloping sections and allowing the formation of longer, low grade quiescent sections between them. In this way rock chutes can be used to create a section of stream that mimics a pool/riffle sequence. This type of channel is promoted widely in North America and Europe to maintain fish breeding migrations necessary to sustain important recreational and commercial fisheries (Newbury and Gaboury 1993a and see below). In south-western Australia rock chutes have the added value of oxygenating stream water.

GRASSY CHUTES

Where perennial grass cover is sufficient to prevent incision, these have a great deal of potential in agricultural situations and along roadsides. Grass cover would be controlled to allow reasonable stormwater conveyance by limited grazing or mowing for hay. This solution could have widespread application in wheatbelt areas where grades are low and streams generally follow a wide shallow channel. In this case salt-tolerant tufted grasses would be used.

VEGETATION will prevent channel incision by increasing flow resistance and supporting the bed with roots and rhizomes. However, establishing vegetation in an eroding channel is almost impossible without the control structures described above to prevent incision and encourage sediment deposition. Temporary structures can be created with logs or brush. These can be allowed to deteriorate as the vegetation spreads and grows and takes over the role of defending the channel. In some situations the spoil (sediment plume) thrown up by incision might well form a natural downstream control structure if stabilised by vegetation. In some cases vegetation cannot take hold because the sediment plume is too mobile to be colonised. In others it may well be prevented because of heavy livestock grazing. In this case, controlled grazing with fencing may be sufficient to encourage sediment plume colonisation by vegetation, which by raising channel elevation may well arrest upstream erosion in the long term. A number of sections of the greatly incised Avon River have been stabilised by vigorous introduced grasses which have colonised sediment deposits. One example is the section immediately above Gwambygine Pool on the Avon River upstream of York.

You might wonder why bother with revegetation of the channel? Why not just leave erosion control to permanent structures? Well, permanent weirs, drop structures and rock chutes can be very expensive depending on the order of the stream and the availability of materials. Furthermore, since these structures bring about sedimentation in the intervening areas, vegetation will grow between the structures whether the land manager wants it or not, especially where the stream is seasonal. This vegetation will have to be managed, so why not put it to work as part of the erosion control response? Where channel embankments are not steep, controlled grazing can be used to maintain vegetation at a density that optimises between flood conveyance and erosion control.

8.4.3 Sedimentation control and repair

Wherever there is erosion, usually somewhere downstream there will be a plume of coarse sediment slowly making its way down to the estuary or lake or collecting in quieter parts of the river or on the floodplain. When sediment plumes or slugs reach considerable size they can cause serious problems, such as obstructing flow and raising the stream bed (reducing conveyance and causing flooding), blocking road culverts, filling pools or overlying valuable habitat or farmland. Unfortunately, short of excavation, there is little that can be done to manage sedimentation except wait for the material to pass through the river system. If the sediment is stabilised by vegetation, it may remain in the system indefinitely.

Well, what can be done? Basically look for opportunities to remove sediment, get it moving or allow it to collect where it does not cause trouble. For example, if a slug is passing by a town the material can be used for land development and construction (e.g. house pads). River sediment is usually well sorted and of high quality and in the eastern states rivers are a major source of building and road aggregate. On the Avon River near Northam, sand is excavated where it collects in the Burlong Pool. Unfortunately, in south-west rural areas the demand for sand rarely compares with the amount collecting in local river beds.

Where sediment is causing local problems, it may be possible to mobilise it and move it downstream. For example, where sediment plumes have been stabilised by introduced grasses and the elevated stream bed is causing problematic flooding, simple grazing may be sufficient to expose the sediment and get it mobile again. Devices such as deflectors can also be used to concentrate flow towards those parts of the channel where sediment is collecting.

In certain areas it may be acceptable or even desirable to have sediment collect in the floodway or floodplain. The various means of getting sediment to collect in previously eroded areas are described above. For broad river floodways, low rocky or fence-like retards can be extended right across the river to bring about shallow sedimentation. Sediment collects as a sheet upstream of the retard and is subsequently consolidated by vegetation. This action may be necessary to protect river pools, and has actually been contemplated for a number of reaches of the Avon River (ARMA 1999). Such retards, known as **silt-traps**, need to be very strong and are usually constructed from wire mesh attached to cable strung out along sturdy fence posts driven into the river bed at a 60 degree angle facing downstream. In fact, many typical farm property fences located in floodways become effective silt-traps, once entangled by debris.

Sediment is very much the currency of the river channel. A stable river reach, like a stable economy, is a balance between the 'incoming' and the 'outgoing'. Extracting too much sediment may very well lead to serious incision of the river bed, and retaining too much may cause serious flooding and the permanent loss of river pools. Ironically, on the Avon, while most of the pools are filling with sediment, many sections are protected from incision by overlying sediment plumes.

8.4.4 Snag management

Snags, or coarse woody debris, are a nuisance: they obstruct flow, interfere with boating and fishing, are considered unsightly and can cause localised erosion. For these reasons there is often pressure to remove them, an operation known as **snagging** or **desnagging**. But snags are also essential to the ecology of south-west streams (see Section 3.2.2). Good stream management emphasises moving rather than removing snags, and then only up to a point. Snags contribute to energy dissipation and their complete removal along a reach may lead to erosion. Similarly, debris dams trap organic material which fuels the food chain and their removal may reduce the abundance of animals along a reach (including marron and fish). The very fishers who curse snags often fail to realise that their good fishing may well depend on the sort of environment created by the troublesome debris. And negotiating fallen logs must certainly be part of the challenge of boating wild rivers.

For those people who live by rivers, the human compulsion to 'tidy up the place' should be resisted for the sake of those creatures for which the river is home.

Nevertheless, snags may cause real problems such as scouring of the bank and channel blockage. The latter effect usually occurs through the formation of debris dams, which may cause damaging upstream flooding and possibly very serious channel avulsions . In these situations snags may have to be reoriented, moved or pruned and debris dams broken up.

Rather than removing the timber from the stream, it could be allowed to settle somewhere downstream or taken to a nearby site where it cannot cause any trouble. It may also perhaps be used in the construction of the erosion control devices described above. In this way the woody material can continue to play its part in the stream ecosystem.

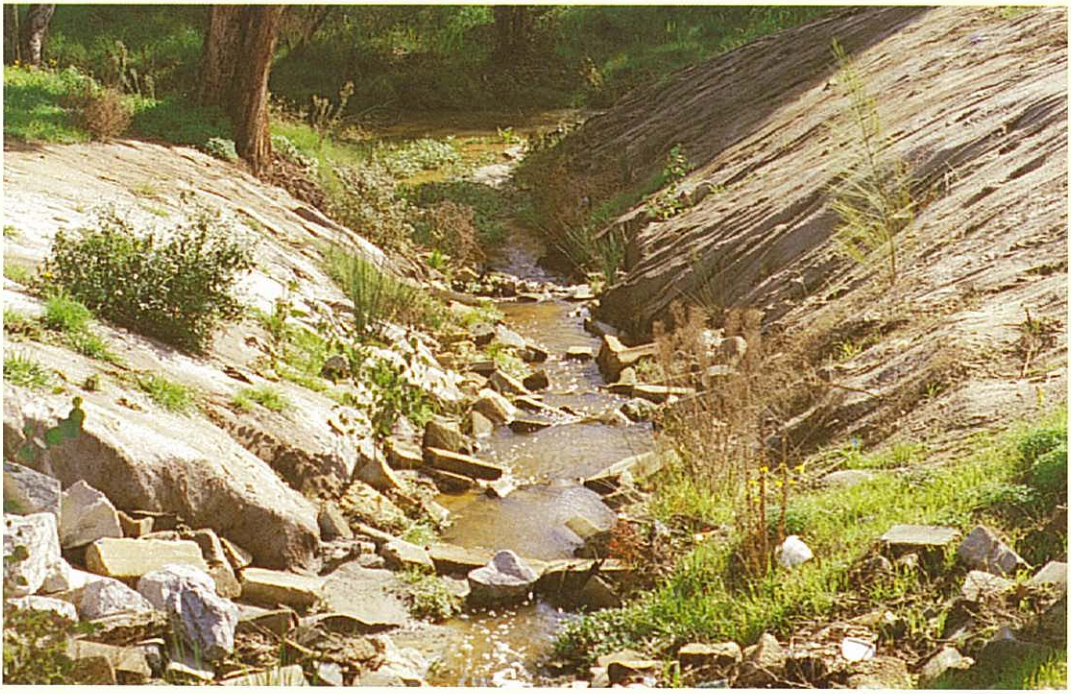
8.4.5 Recognising stable stream form

Any works in a channel must conform to stable stream form. As a guide, the depth and width of a channel are strongly related to the flood discharge equalled or exceeded on average once every one to two years (see Section 2.3). This is usually the bankfull discharge, or channel forming flow, and relates in turn to the wavelength of the meander, which is usually 10-14 times the width of the channel (Church 1992). By knowing the discharge characteristics of a catchment (i.e. frequency of different size floods), a rough estimate can be made of the dimensions that represent stable stream form for the pertinent stream reach; and it is to these dimensions that channel stabilisation works must be tailored. For example, deflectors could be positioned to leave the recognised stable stream width unobstructed. Failure to recognise stable stream form may render channel works prone to undermining and collapse.

Difficulties arise when discharge characteristics of a catchment change with changing land use. Generally runoff increases dramatically with clearing and then again with urban development. In these situations care must be taken to account for the enlarged channel that may result from the increased size and power of the channel forming flows (i.e. those that occur about once every one to two years). In contrast, eroded sections of a stream in a catchment undergoing a change in land use from livestock grazing to forestry plantations may be left to stabilise without human intervention. This will take the form of sediment accumulation, channel contraction and subsequent colonisation by vegetation, providing grazing is not heavy.

Once stable stream channel dimensions have been determined, account needs to be taken of channel shift which is a normal part of a stream's meandering behaviour. This can be done by reserving land along the meander belt. Alternatively, channel shift can be controlled by preventing erosion with fringing vegetation. Unfortunately this can be done only at the cost of reducing conveyance through the increased roughness that vegetation imparts to the bed and banks. Here again an optimum must to be reached whereby the vegetation is pruned or thinned sufficiently to achieve the desired level of conveyance, while at the same time not exposing the floodway to excessive erosion. In other words the presence of vegetation in the floodway, imparting a known level of roughness, can be built into a stable stream design (Miller and Quick 1996; Ribi undated).

BRUSHING OF AN EXPOSED SANDY BANK ON THE LOWER MOORE RIVER. PHOTO: L. PEN



ROCKS AND BROKEN CONCRETE ARRANGED AT THE BASE OF THE SOUTHERN WOOD CREEK (CITY OF GOSNELLS IN PERTH) TO ARREST HEADCUTTING AND CREATE A CASCADE EFFECT. MESH HAS ALSO BEEN ARRANGED ON THE BANKS PRIOR TO REVEGETATION. PHOTO: L. PEN

STREAM CHANNEL ANALYSIS ON THE GREATLY WIDENED AND DEEPENED LOWER SERPENTINE RIVER. DONE DURING THE MAY 1998 RIVER RESTORATION WORKSHOP HELD AT FAIRBRIDGE. PHOTO: L. PEN

PARTICIPANTS AT THE FIRST RIVER RESTORATION WORKSHOP, HELD AT MURESK IN MAY 1996, OBSERVE THE CONSTRUCTION OF A ROCKY RIFFLE TO ARREST SERIOUS INCISION ALONG SPENCERS BROOK, A TRIBUTARY OF THE AVON RIVER. PHOTO: L. PEN

8.5 STREAM ECOSYSTEM PROTECTION AND MANAGEMENT

This section describes the approaches and technologies available to protect and maintain stream ecosystems. It is a step on from the simple stabilisation of stream sections and offers opportunities for individuals and community groups to replace or keep native plants and animals and certain landscape features, such as babbling brooks and pools, that are ordinarily incompatible with modern land use practices.

8.5.1 Channel form restoration and stabilisation

The foundation of a natural stream ecosystem is natural stream form, which is described in Chapter 2. Natural stream form, with its riffles and pools, together with regional underlying geology, climate, stream flow pattern, fringing vegetation and coarse woody debris, provides the large variety of habitats over space and time needed to support the various life cycle stages of the microbes, plants and animals that comprise the stream ecosystem. The closer a restored stream approaches its natural form, the richer and more stable will be its ecology.

Stream analysis and design

A procedure for determining natural stream form has been developed in Canada by Newbury and Gaboury (1993a). The reader is referred to this text for a detailed description of the method. Here the underlying basis and the procedure itself are briefly described.

The underlying philosophy of the Newbury method is that restoration works along a section of stream or reach should conform to and be reinforced by the natural geomorphological processes at work in the reach (see Section 2.3 and Newbury 1993, 1995). These processes are determined by local geology and the pattern of stream flow, the latter of which is determined by climate and the size and nature (i.e. runoff rates) of the catchment draining into the reach. A particularly important factor is the frequency of flood flows that fill the active channel and are known as channel forming flows. Generally, flows of this magnitude occur once every one to two years (Leopold 1995). As outlined in Chapter 2, channel forming flows are the predominant factor determining the channel size, meander radius and pool/riffle frequency. The Newbury approach aims to recognise and restore the natural form that is appropriate to the reach in question.

10 basic steps
for stream analysis and design

1. Catchment analysis

A topographic map is used to delineate the catchment area and to identify the stream order of the section to be restored. Depending on the size of the catchment and the stream order of the section, 1:250,000 to 1:25,000 scale maps could be used. A transparent grid or a planimeter is used to determine catchment area. A traced stream system diagram should be overlaid upon a geological map to identify the nature of land through which the river section is passing and any anomalies in drainage density (length of stream per km). It may be that the section in question is very different from the wider system or that it may present certain problems, such as highly erosive soils or a propensity for flooding. At this stage it is useful to identify other similar stream sections (i.e. of the same order) upstream or downstream or in the wider system, especially sections remaining in a relatively natural state and with similar underlying geology. These sections can be used as 'sample' reaches for the identification of natural channel form and habitat elements that can be incorporated into the restored section.

2. Profiles

A profile of the central or longest stem of the stream system should be sketched on a graph (elevation vs distance) by using the points of interception of the contour lines and the stream line. This enables the recognition of any discontinuities in the profile of the stream which may cause abrupt changes in stream character, and where the subject section lies in relation to them. For example, the subject section may lie in a region of sudden increasing slope, which may relate to a local change in geology. It may be worth looking for similar sample reaches in the wider system which cross the same geological unit.

3. Flood flows

Records of flow should be obtained from the nearest or most relevant stream gauging station (similar catchment and rainfall). The record is then adjusted upwards or downwards to account for the difference in catchment size between that of the station and the stream section to be restored (i.e. multiplied by the ratio of the two catchment areas). This data can be used to determine the frequency and magnitude of channel forming flows, which can then be compared with that estimated from channel geometry measurements (see below). The frequency of flood flows may be significantly underestimated if the reach to be restored is of a much lower stream order than the one supplying the flow data. This is because minor streams flood more readily than do major ones.

4. Channel geometry surveys and measurements

A longitudinal survey using a surveyor's level, staff and tape measure is done along the centre line (lowest line of the channel or thalweg) of the stream section to be restored. Where evident the elevation of the bankfull level on both sides of the active channel is also recorded. A number of cross sections are also done over different zones of the channel, i.e. pools and riffles, where the channel is well defined. A random selection of bed material (pebbles, cobbles, boulders and logs) is measured (mean diameter) to gain a estimate of particle size distribution. These data are then plotted up to determine bankfull width and depth and average channel slope, and used in conjunction with standard formulas, tables and/or charts to estimate bankfull roughness (or Manning's n). This information is then used to predict bankfull velocity, stream power (given as tractive force on the channel bed) and finally bankfull discharge. These measurements can also be done for the selected sample reaches.

Estimates of bankfull discharge, or channel forming flow, calculated from the channel geometry measurements are then checked against the flood flows determined in Step 3.

Stream power estimates are used in conjunction with standard formulas and tables and the particle size data to estimate what fraction of the bed material is mobile under bankfull flows for different zones of the stream. Obviously a sandy bed would be very mobile and any restorative works would have to take this into consideration.

5. Rehabilitation reach survey

Further detailed longitudinal and cross sectional surveys are carried out to provide the necessary ground level profiles needed for planning the restorative works.

6. Preferred habitats

Detailed sketch maps are made of the sample reaches, showing the size and location of habitat elements such as woody debris, shade and leafy deposits, and especially the form and dimensions of pools and riffles as they relate to the motion of water. This information is used as a template for the rehabilitation of habitat and is very important where an objective is to provide for the particular habitat needs of an animal species; for example, to create pools for marron, or for a rare fish species threatened by a dam development.

7. Selection and sizing of rehabilitation works

Riffle structures are designed and located to comply with the natural form of the stream and are built from cobbles and boulders of a size too large to be moved by the stream power exerted at bankfull flow. Similarly, other objects such as logs and stones are placed in the stream where they will remain stable. The number and location of riffles may be more frequent than the natural form would indicate if the object is to create stilling ponds below each riffle, so that fine bed sediments are not so easily mobilised at bankfull flows. The riffle structures may be designed to provide the habitat elements identified in Step 6. For example, boulders may be located to create small chutes, standing waves and waterfalls, and the downstream face of the riffle may have a narrow or broad V-shaped cross section and 1:20 slope to facilitate fish passage.

8. Instream flow requirements

This step is only necessary for regulated streams where water is required to be released from a dam at a sufficient rate and in an appropriate pattern over time to maintain preferred aquatic habitat. This subject is discussed in more detail below.

9. Supervise construction

It is essential that those who planned the restorative works are on hand to supervise the construction of riffles and the placement of habitat elements (e.g. boulders and logs).

10. Monitor and adjust design

After a few bankfull flows the rocks that comprise the riffle may settle or roll to a lower level and it is even possible that the adjacent earthy bank may scour out. It may be necessary to relocate some of the boulders, add more stone to bring the crest of the riffle back up to the design level and place more rock up the face of the bank to correct for scouring. Also, monitoring of stream fauna is recommended to assess any improvement in habitat.

Note of caution

The above stream restoration method was developed for North America where the geology of the land is relatively young and the land is littered with rocks yet to be whittled to sand. South-west streams on the other hand pass through an ancient landscape and are mostly sandy or clay based with riffle zones mostly dominated by vegetation and woody debris rather than rocks. Furthermore, our catchments are in a state of flux, with changing land use, a significant declining rainfall trend and rising groundwaters. All of these factors mean that the changing runoff rates of catchments make determining natural stream form problematic in many areas. Nevertheless, the Newbury method offers the south-west community a procedure which, through trial and error, we can adapt to our own circumstances and learn more about the geomorphology of our streams in the process.

8.5.2 The need for biofilters

Healthy fringing and aquatic vegetation acts as a biological filter (Peterjohn and Correll 1984; Howard-Williams et al. 1986; Riding and Carter 1992). It sieves out both organic and inorganic material carried in floodwaters and will assimilate a portion of the nutrients flushed from the catchment. Certain aquatic plants can be used to filter out pollutants (Sainty and Jacobs 1994).

South-west streams are naturally fringed with vegetation and in most areas, except for the pools and rocky riffles, the channel bed is also lined with vegetation. This vegetation acts like a sieve, trapping organic matter and for most of the year holding it out in the open air where it composts away. In the absence of vegetation much of this organic matter can find its way into river pools, where over summer and autumn it decays and sorely taxes the river's capacity to replenish dissolved oxygen, in the meagre to nil flow conditions of these seasons. The result of this 'organic pollution' can be stagnation and oxygen depletion that kills aquatic life and promotes toxic algae blooms (see Section 7.4).

The natural fringing vegetation is needed to form natural biofilters. The vegetation growing on the flanks of the river can be looked upon as lateral biofilters which trap material washed off adjacent farmlands, parklands or urban land. The vegetation that lines the channel bed can be viewed as a longitudinal filter that progressively catches the material that has already found its way to the stream or is generated within it. Replacing the native fringing vegetation where it has been cleared helps to restore the 'river continuum' and close up the 'nutrient spirals' of the stream ecosystem (see Section 3.4.3).

8.5.3 Building and restoring stream ecosystems

Drainage lines, whether they be of natural or artificial origin, represent a very common form of wetland. Unfortunately they are primarily valued for their drainage function. In urban and many farmland areas drainage lines are typically eroded, weed infested or polluted, with little or no consideration given to other potential values, such as wildlife habitat, ecological corridors, erosion control, biofiltering of pollutants, landscape, recreational amenity and opportunities for education and scientific research. However, in recent years the biofiltering or nutrient stripping function of well vegetated streams has received some attention as part of an effort to reduce the amount of pollutants being carried to downstream waterways (WAWA 1993). In some areas of the south-west, this has led to the establishment of fringing vegetation along some old and new drainage lines in a process known as 'streamlining' (Heady and Guise 1994) and the promotion of water sensitive urban design (Whelans et al. 1993; Klemm and Switzer 1994).

Putting the native vegetation back along streamlines or incorporating it into new drains not only achieves the narrow objective of creating biofilters, it also creates a more attractive landscape as well as wildlife habitats and corridors (Land Systems EBC 1993; Whelans et al. 1993). The realisation of this has fostered the broader objective of creating 'living streams' of native plant and animal communities, which have some if not all of the stream values mentioned above (Pen and Majer 1993). In this way drains and degraded streams may become a living feature of the environment, rather than just an essential, and often unattractive, part of the human infrastructure of urban and rural lands.

The natural creek versus the drain

The differences between a stream ecosystem and a drain may seem obvious but are actually little appreciated in an ecological sense. But this fundamental appreciation is essential to the creation of living streams. Work at the Zoology Department at the University of WA and elsewhere has shown that the primary source of energy, carbon and nutrients in the natural creek line is not from within the stream itself (Katsantoni 1993; Cummins 1993; Campbell 1993; Davies 1993; Davies 1995). This is because the heavily shaded, nutrient poor and dark tannin stained water supports very little algae or aquatic plant growth. Instead, the instream part of the creek ecosystem is fuelled by the slowly rotting hard leaves and woody debris that have fallen from the overhanging fringing vegetation (Cummins 1993; Campbell 1993; Davies 1993).

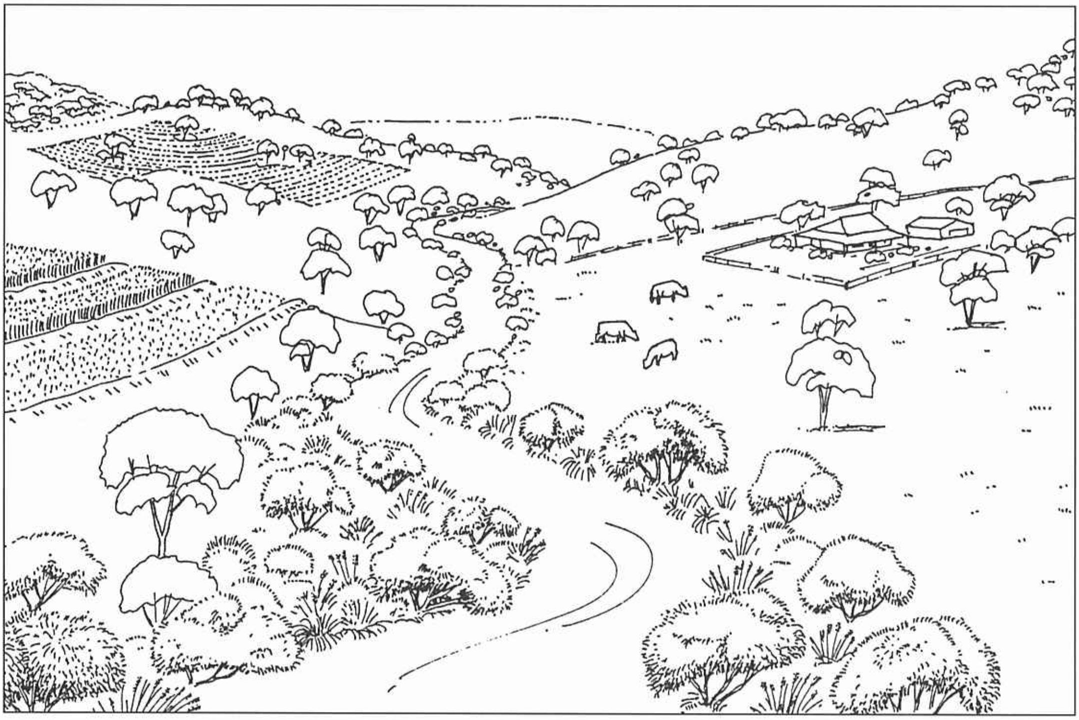
Dead plant material accumulates and decays on the stream bed, as a range of invertebrate and microdecomposers initiate the food chain. This process releases nutrients into the water column which support some algae growth, which in turn supports herbivorous molluscs, crustaceans, insects and tadpoles. Both detrital and herbivorous invertebrates are food for predatory insects and crustaceans, which in turn are eaten by larger insects, crustaceans, fish and amphibians. Finally these animals provide a rich food supply for large animals such as turtles and birds. Fringing vegetation can also provide food directly, in the form of fallen insects and spiders which have been blown from leaves and blossoms onto the water's surface. This provides a rich harvest for water walkers, water spiders and fish.

Contrast this situation with that of the typical drain or rural creek which is open to the light and nutrient rich (Weeks 1982). Here, relatively free of grazing, introduced aquatic weeds are able to grow in abundance in the stream channel itself, block the flow of water and encourage the abundant growth of troublesome animal species, such as mosquitoes, midges and the prolific mosquito fish (Sainty and Jacobs 1981).

The natural stream has a great diversity of relatively undisturbed habitats and refuges with differing combinations of light and shade, exposure and cover, fast flowing and still, and shallow and deep water (Katsantoni 1993). This variety of habitats can support a large variety of plants and animals, whereas the drain has little more than one highly disturbed and often polluted habitat (Katsantoni 1993; Newbury 1993).

If living streams are to be created in southern Australia, they must be stable and have a diversity of habitats with the essential elements of shade, hard leaves and tannin stained water. These 'ingredients' can be used to develop, as far as possible, a natural stream ecosystem and to keep the stream channel free of choking aquatic vegetation and algae. They can be added simply by establishing fringing native vegetation along streamlines as described above.

Opportunities
for streamline restoration



The various types of degraded streams include the following:

The town drain

A typical urban or town drain is a straight deep open ditch. The banks are usually steep and support a dense growth of introduced grasses and other weeds, as does the adjoining land of the drain reserve. The drain bed itself is usually white sand or clay obscured by the abundant growth of introduced aquatic weeds and slimy algae. Animals are often present, but these are usually the commonplace ones such as the introduced mosquito fish. Few native species are present.

From time to time the drain becomes clogged with plant material and accumulated sediment and litter that obstruct flow. The drain must be cleaned out and this is usually done by spraying weeds and digging away the grasses from the embankments. In this way many drains have become both deeper and wider over time, as material has been removed from the banks and placed on the adjoining land. The disturbance involved in drain cleaning means that only the most resilient of plants and animals can find a home along the drain. Unfortunately, nearly all of these are introduced weeds and pest animal species.

The farmland drain

In farming areas, drains are usually old natural creek lines which have been cleared of their natural vegetation or proper drains which have been excavated to prevent winter flooding and waterlogging of farmland. The abundant growth of grasses and other weeds along the drainage line, so typical of urban drains, is prevented by livestock grazing. Unfortunately, the livestock also damage the embankments, dislodging soil and exposing areas to water erosion. This means that farm drains carry heavy sediment loads and are marked by severe disturbance. As with urban drains, they support only the most resilient of species.

Degraded creek lines

Many natural creeks and small river systems are now part of urban or country drainage systems and, although never cleared of their natural fringing vegetation, have become eroded or infested with weeds (Rutherfurd and Ducatel 1994).

Soft versus hard leaves

Drains and many degraded streams mainly support introduced plant species with soft leaves which decay relatively quickly in the water (see Sections 7.7 and 7.9.1). Many of these plants, including a number of large trees, are also deciduous, dropping their leaves at one time of the year. A relatively large quantity of leaves dropped into the stream represents a form of organic pollution which can deplete the water of dissolved oxygen. Furthermore, the lighting conditions of the stream range between full shade to suddenly full light, a regime which is alien to most southern Australian streams. This situation contrasts greatly with that of the natural stream described above, where the hard leaves of most native plant species fall at a relatively constant rate (mainly summer) and break down only slowly in the stream and shade remains more or less constant (Frankenberg 1985; Riding and Carter 1992). Also, unlike the drain, the natural streamline does not have to be completely cleaned out periodically.

Degrees of streamline restoration

For a full description of how to go about creating a living stream the reader is referred to Hemphill and Bramley (1989), Petersen et al. (1992), Katsantoni (1993), Land Systems EBC (1993), Newbury and Gaboury (1993a and b), Pen and Majer (1993), Whelans et al. (1993), Heady and Guise (1994) and guidelines and manuals listed in Appendix 2.

Not all streamlines can be restored or developed into something similar to fully functioning creek ecosystems. Many will have to be left as they are, to serve in their primary role as totally unimpeded drainage lines. For example, some drains have been made of stone or concrete, while others will simply carry too great a volume of water at certain times of the year for successful plantings. However, most streams will permit some degree of living stream development. It may only be a line of trees or shrubs along one side of a drain reserve, but even this small plantation will provide food and shelter for invertebrates and birds (see Fig. 8.2).

Some drains or old creek lines, with or without modification, may easily handle the volume of water discharged to them and could support bands of fringing vegetation without impeding flow and causing upstream flooding. In this case, a partial or completely vegetated zone could be developed along the entire stream or sections of it, with trees and shrubs at the upper level of the embankment and above it, and sedges and rushes along the immediate periphery of the stream itself. Maintenance of the channel would consist of clearing the actual channel of the drain of any obstructions to flow, such as fallen branches and aquatic weed growth (Fig. 8.2).

In areas where flooding may not be a problem, such as on farmland or near parkland, fully functioning creek ecosystems may be appropriate. In this case a dense band of fringing vegetation, sometimes growing right across the stream, could be developed and other habitat elements which would obstruct flow, such as logs and stones and aquatic plants like water ribbons, could also be added to the main channel.

Adding form, habitats and introducing animals

To further broaden the range of habitats, a natural stream form could be re-established with riffles, pools and meanders and incorporating small islands, lagoons and floodplains, as outlined in Chapter 3. Essentially, the natural streamline of south-west Western Australia is an ephemeral drainage line, for the most part dry over the summer and autumn period. In the winter, previously dry creeks, floodways and floodplains become inundated and create a diverse range of habitats for aquatic life. In most river systems, only the river pools retain water over the entire year.

Some streamline habitats are illustrated in Figure 8.3.

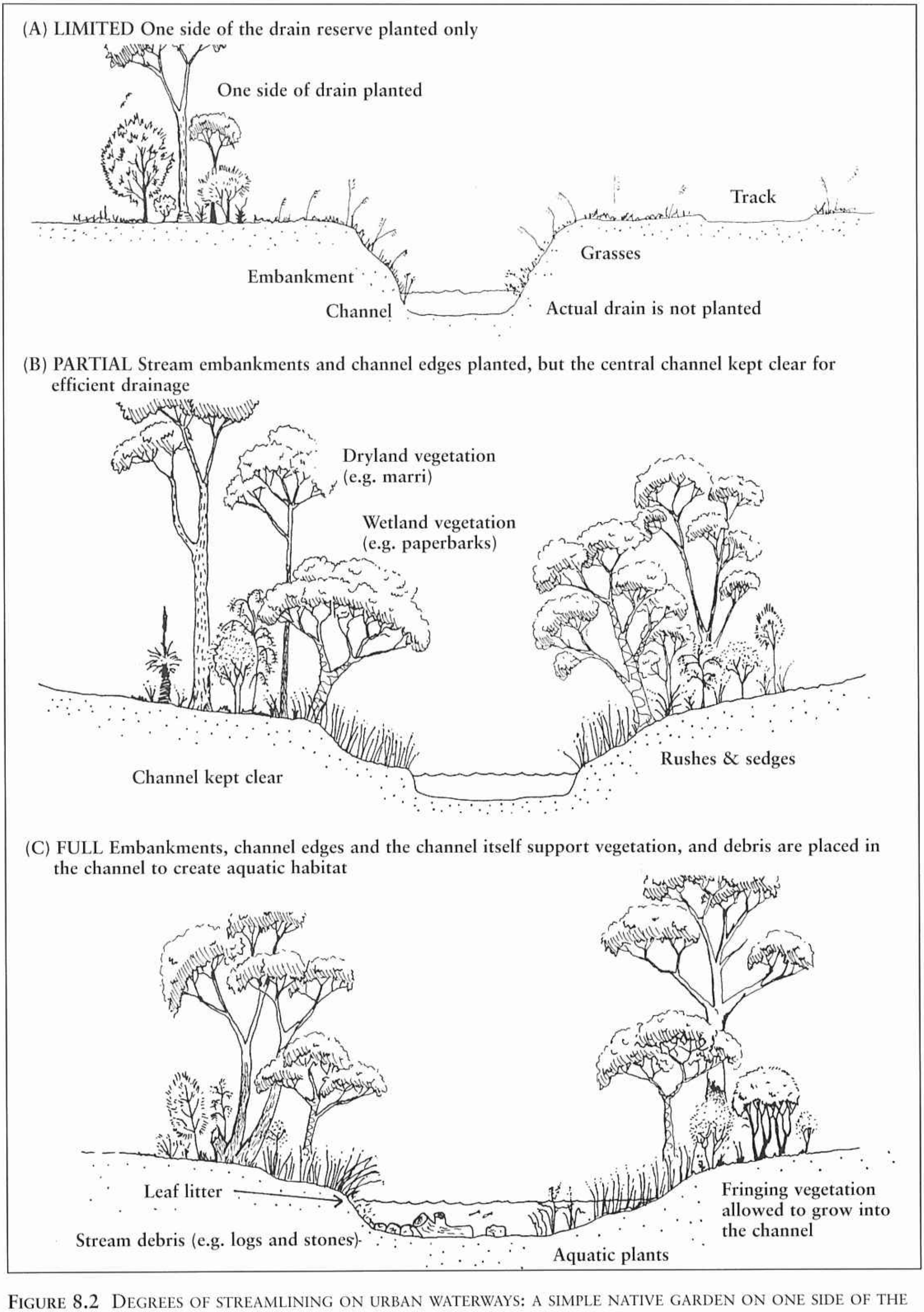


FIGURE 8.2 DEGREES OF STREAMLINING ON URBAN WATERWAYS: A SIMPLE NATIVE GARDEN ON ONE SIDE OF THE DRAIN (A); THE RIPARIAN ZONE PLANTED OUT WITH NATIVE SPECIES, BUT MAIN CHANNEL LEFT UNOBSTRUCTED (B); AND NATIVE PLANTS ALLOWED TO ENCROACH ON THE MAIN CHANNEL, AQUATIC PLANTS INTRODUCED TO THE MAIN CHANNEL ALONG WITH WOODY DEBRIS AND ROCKS TO CREATE HABITAT (C).

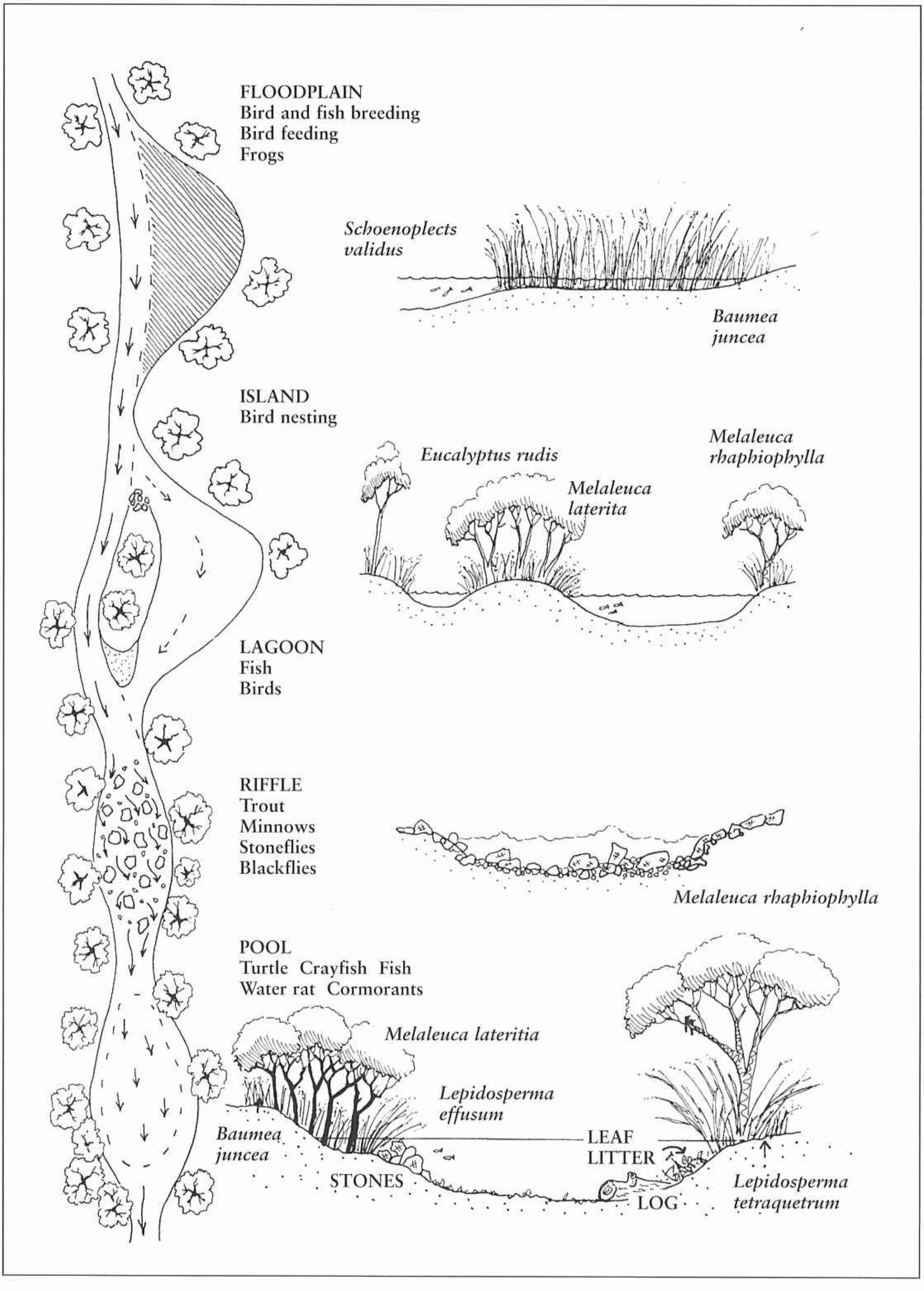


FIGURE 8.3 EXAMPLES OF TYPES OF STREAMLINE HABITATS THAT COULD BE INCORPORATED INTO 'LIVING STREAM' PROJECTS ON DRAINS AND OLD CREEKLINES

Pools

These provide an area of permanent water essential to many species of aquatic fauna, including fish, crayfish, the long-necked turtle, the shrimp, the mussel and some waterbirds. There may be an opportunity to create pool habitats in retention and infiltration basins, but they must include the habitat elements typical of pool environments. These include overhanging vegetation, shade, leaf litter, logs and stones. Fringing emergent vegetation is optional but recommended, especially if fish and bird breeding is to be encouraged.

Riffles

Pebbles, rocks and logs can be placed in fast flowing zones to create riffles. Blackflies, stoneflies, native minnows and trout enjoy this type of habitat. However, in nutrient rich waters, algae fouling may become a problem, so shading with trees is recommended.

Runs

Long reaches of unobstructed streamline are often called runs. They may be wide or narrow. In the south-west they are usually well vegetated with trees and so can be easily created along drains by planting trees in the appropriate location to maximise shade and the fall of leaf litter over water. Most drains should offer the opportunity to create this type of habitat.

Floodplain

In areas where occasional flooding is not a serious problem, such as parklands and sporting grounds, the creation of seasonal floodplains along drains may be possible. Seasonal floodwaters amongst native vegetation would provide breeding habitat for a range of animals such as fish and frogs, and feeding habitat for birds.

Sedge and rush stands

Filter beds consisting of dense stands of sedges or rushes will also provide very useful feeding and breeding habitat for waterbirds and other animals. In areas frequented by people, such dense stands of vegetation provide a ready refuge for waterbirds seeking shelter from annoying humans and domestic animals.

Re-introducing fauna

When, finally, the stream has matured into a creek ecosystem, the introduction of local native animals which had become extinct in the former drain can be carried out. Freshwater fish, frogs, crayfish and shrimps can be taken from nearby creeks and placed in the new living stream. However, this can only be done with the approval of Fisheries Western Australia and CALM.

Maintaining drainage function

The important function of drainage cannot be forgotten, especially in urban areas where drains must be allowed to flow unimpeded. The main channel of the drainage line will have to be cleared every so often. Vegetation may have to be cut back and fallen branches removed. Most of all, any obstruction which is likely to catch debris, and cause a dam to form, must be broken up and the pieces relocated or removed at the earliest opportunity. Where serious flooding and damage to property could occur, the streamline should be checked for fallen logs prior to the break of winter.

8.5.4 Environmental flows

The term environmental flows refers to an amount of water allowed to flow down a stream to maintain habitat and allow faunal movement. It also refers to a pattern of flow and water levels which should mimic as far as possible the natural flow pattern and include at least one channel (bankful) flood every year or two. In other words an environmental flow would consist of sufficient flow to maintain 'wetted habitat', an occasional winter flood and, if the stream in question is permanent, summer base flows. It is likely that environmental flows will be set for all regulated streams in the south-west in the coming years. Currently, changes to the relevant Act (Rights in Water and Irrigation Act) are being considered that will formalise the administrative process, which will involve local Water Resource Committees and wide community input. Wherever appropriate, dams will have to be constructed with the means to release water. 'Run of the river' pumping will continue to be managed to ensure that sufficient water remains in the stream to maintain the essential elements of stream habitat. A method for determining environmental flows has been developed by the Water and Rivers Commission (Davies et al. in prep.) and a method for determining channel forming flows and natural stream form is described above.

Maintaining carbon and nutrient flows

As was seen in Section 3.4, in describing the river continuum, the stream ecosystem is somewhat dependent on the flow of carbon and nutrients carried along the channel by the flowing water. Dams block this flow of material but there is a way of maintaining a proportion of the original flow and thus enabling the stream ecosystem to recover its normal function a short distance downstream of the obstruction. It can be done by placing a dam just above a junction with a tributary creek having good riparian vegetation, or better still a largely naturally vegetated catchment. Studies on the Canning River have shown that Stinton Creek, which drains native forest just below the Canning Dam, maintains a good supply of carbon, nutrients and also water to downstream reaches of the river, supporting a relatively typical invertebrate fauna (Storey et al. 1991). For this reason, in planning for water extraction in the Harvey River catchment, it was recommended that most of the streams draining forest downstream of the proposed new dam site remain undammed (WRC 1998).

Floodplains also provide material for stream ecosystems in a process known as the flood pulse. It is therefore also important to maintain connection with portions of floodplains, preferably the parts that retain natural vegetation. This requires the careful placement of dams and weirs, and of levee banks used to control flooding.

8.5.5 Fishways and lamprey guides

As described in Section 5.2 the native fishes and the pouched lamprey of the south-west undertake upstream migrations in the winter/spring period. It is likely that other stream fauna make similar movements. It makes sense for them to do so, in order to make full use of stream habitats offered by the summer drought/winter flood climate of the south-west. However, migrations of stream fauna are increasingly obstructed by dams and weirs and there is a need to develop basic fishways around these obstructions to maintain viable native fish populations.

In the eastern states, where large native fishes represent important recreational and commercial fisheries, a variety of fishways, such as ladders and lifts, have been trialled on dams, weirs and locks to maintain fish passage along rivers. The facilities have been expensive to build and their effectiveness in permitting fish passage has been difficult to determine (Harris 1984; Mallen-Cooper 1993). Sadly, in the south-west fishways are simply too expensive an option for fish that have little commercial or recreational value. However, there is one technology that is probably affordable for small dams and weirs: fish bypass streams (Jungwirth 1996; Gaboury et al. undated). These small pool/riffle form streams are constructed to skirt around the dam wall and to have no more than a 1:20 grade on the riffles. They would flow only in winter and spring when small dams ordinarily overflow anyway and exactly at the time when fish and lampreys are on the move. Such fishways need only be constructed where valuable stream habitat lies either side of a dam.

For lampreys which will leave the water and snake their way across country on very wet, dark nights to negotiate obstructions, fishways may not be necessary. Instead small fences (40-60 cm high) can be constructed to guide lampreys around an obstruction. Lamprey guides can be seen on the Lefroy Brook at the Pemberton town weir and the Rainbow gauging weir. They should be built of non-abrasive materials (i.e. plastic coated wire), as indeed should the ground surface on which the animals move. Foreshore sites warranting lamprey guides would be evident by the presence of dead lampreys in spring.

8.5.6 Discouraging invasive pests and weeds using shade

This section is about discouraging rather than controlling. This is for good reason. The control of many introduced pests and weeds that plague rivers, like the mosquito fish and kikuyu grass, is almost impossible at the present time. But we can discourage them and help native plants and animals hold their own. For example, the mosquito fish prefers warm shallow sunlit waters whereas native fish stick to the cool shade in summer and autumn. Where there is no shade about a river pool in summer, mosquito fish can often be seen clipping the fins of the native fish who have no shade in which to take refuge. In this case discouraging the exotic fish and encouraging the natives would consist of planting trees to shade the shallow parts of the pool. Shade would very likely discourage a whole range of weeds, like kikuyu, that prefer open sunlit conditions. Unfortunately the often heavily leaf-eaten foliage of the flooded gum probably doesn't create much shade, but the dense fine leaf foliage of the paperbark does. So the key is to plant paperbarks under native gum trees, which conforms with the natural structure of riverine forests and woodlands on most rivers. Paperbarks will also lean out over river pools, casting shade over the shallow peripheral areas that native fish and crayfish prefer.

8.6 POINT SOURCE POLLUTION CONTROL

Point sources of pollution include sewage treatment plants, piggeries, dairies, feedlots, livestock saleyards and abattoirs, among other industries. Strictly speaking the control of polluting substances from such facilities is an in-house management responsibility subject to environmental protection legislation administered by the Department of Environmental Protection (DEP), and therefore does not constitute actual on-the-ground river management. Nevertheless point sources are a significant contributor of pollutants to some rivers and are included here for completeness.

Despite laws for controlling pollution, many point sources of river pollution continue to exist. This is generally because the facilities involved existed long before the community's attitude towards the protection of the environment hardened into demands for action. In this situation environmental protection runs up against entrenched cultural practices, not dissimilar to the situation that exists with broad acre catchment management. But, slowly, point sources of pollution are being licensed and controlled. Today a series of policy documents and technical guidelines for pollution control, relevant to water resource protection, are available from the DEP and the Water and Rivers Commission.

Another type of point source of pollution is accidental spills, for example from trucks carrying chemicals or fertilisers, or when factories, depots or warehouses burn down. It is essential that emergency procedures are in place to intercept spilled pollutants before they can escape into waterways.

8.7 MANAGING SALINISATION AND WATERLOGGING

In the battle against salinisation there is a call to treat the cause not the symptom. In other words to plant trees and other high water using plants high in the landscape where they can intercept water before it recharges the groundwater. Planting out the low valley bottoms which are already salinised and waterlogged, the discharge sites, is looked upon as treating the symptom. While this is true with respect to treating salinisation in itself, there is a need to replace the dead and dying vegetation of streamlines to prevent erosion. Plant species more tolerant of salt and waterlogging should be introduced right now to replace the former less tolerant vegetation. Otherwise this secondary impact of salinisation, namely the erosion of salt-affected land, may become as serious a problem in the long term, as eroding waterways eat into valuable farmland and destroy habitat.

8.8 FLOOD MANAGEMENT

Every now and then rivers burst their banks and flood the adjacent land. Although this is a normal part of the behaviour of river systems it is generally found unacceptable by those who have suffered from flooding, and there is a demand for flood mitigation works such as channel clearing and levees. But every time these works are put in place more of the energy of floodwaters is transferred to the river channel. This means there is more energy available for the river to dig a deeper and wider channel, move sediment and damage property. Flood management must therefore be a combination of conveyance and containment to control both the volume of water on the move and the energy contained within it. In other words, some flooding should be tolerated and some floodplains devoted to land uses for which flooding is a minor problem and accepted occurrence.

Flood management is therefore an important part of land use planning. To assist in this, the Water and Rivers Commission produces 1 in 100 year floodplain maps which show the level to which flooding will occur, on average, at least once in every hundred years. More importantly the maps show the main floodway of the river, where the main flow of floodwaters is contained and where under no circumstances should there be any development. These maps have been produced for parts of a number of south-west rivers, including the Swan-Canning, Murray, Serpentine, Brunswick, Collie, Preston, Vasse and Blackwood, in areas where development is particularly intense and flood prone (i.e. townsites). The Ministry for Planning and local governments use these maps to guide development and land use planning.

For areas where floodplain mapping has not been done, local flood history and common sense should guide planning. Floodplains are generally obvious by their low lying nature and there are often people who remember the last big flood, such as the one of January 1982 in which many of the rivers of the south-west carried major flows, produced by heavy rainfall from Cyclone Errol. In some places, such as Schultz's Weir on the Collie River South Branch, signs have been erected indicating the peak flood level for this event. Unfortunately, since this time, houses have been built on obviously flood prone land on a number of rivers in the south-west. Hopefully, the owners of these homes accept that a flood will come through the house once in a lifetime (on average), in much the same way as people living near volcanoes accept the hazards of the occasional eruption. Flood level signs have been erected on the Blackwood River (1982 flood), at bridges and townsites, and for the Avon River in the town of Northam. One hundred year flood level marks have been placed on power poles in the town of Bassendean (Bretnall pers. comm.).

In the future, flood frequency and intensity is likely to increase. There are a number of reasons for this, which are discussed in more detail in Chapter 10. Firstly, there is the effect of higher runoff rates for cleared catchments and even higher rates for waterlogged land which is increasing in area every year as a result of rising watertables. Secondly, these effects would be compounded by a return to a period of average winter rainfall and more so by a period of above average winters. Under this scenario larger floods are likely to occur. The magnitude of these floods could be calculated by appropriate catchment modelling, and this information should be used now to guide planning and avoid widespread flood damage in the future.

8.9 WHO DOES THE MANAGING?

River systems are the means by which the land is drained. They collect water and carry it through a landscape that has been predominantly shaped by water. As such, rivers can be looked upon as natural drainage 'infrastructure', just as important as artificial drainage systems and other human made infrastructural systems such as roads, railways, pipelines and powerlines. Unfortunately, because rivers and creeks are natural and were not built by human hand, they are taken for granted and not perceived as having asset value or as being in need of maintenance. This is surprising since Western Australians are well aware of the value of artificial drainage and, like people everywhere, are attracted to rivers, to live by and for recreation. In this sense rivers have real asset value, often reflected in crowds of people at leisure, water supply potential and property values. Nevertheless rivers are still mostly taken for granted, that is until they become flooded, eroded, clogged with sediment, polluted or infested with weeds and feral animals. Then rivers become a liability.

Given that rivers need management, who should assume responsibility? Basically, everybody. This is because river systems are simply too large and extensive and the land uses and the tenure of land within the catchment too variable to enable on-the-ground management by any one group. Because rivers are a continuous system they must be managed in an informal cooperative way by all individuals, businesses, agencies and groups that live and work in a catchment.

Who does what depends very much on the size of the stream. Tiny streams can easily be managed by individuals and small groups. But many small streams soon join up to become major creeks and these in turn join to become large powerful rivers that require considerable effort, resources and expertise to manage effectively and safely. At the middle and upper levels, management must be well supported by State and local government expertise and material. The situation can be likened to the management of roads. Individual landowners have the responsibility of managing driveways and roads and tracks on their property. Longer and more frequently used service roads between properties are managed by communities, through their local government, and major roads are managed by the government. The entire system is planned and coordinated to ensure that the capacity of the main roads is sufficient to service all the minor ones. A model similar to this is needed to manage river systems, with those in the community deriving the most benefit from a stream contributing most to management.

The benefits of river management can be perceived in two ways: by the direct values that rivers provide, such as drainage, water supply, recreation, landscape and enhanced property values; and by the prevention of the very negative outcomes of a lack of proper management, such as erosion, sedimentation, eutrophication, stagnation and even flooding. It is an irony that the benefits of management are often only appreciated and considered cost effective when a river begins to erode valuable farmland or to threaten structures. By this time, river stabilisation and restoration can be very expensive propositions.

Mostly however, rivers should need little management. Once the riparian zone each side of the stream is managed sustainably, so that supporting vegetation can regenerate, streams will mostly look after themselves. Management will then mostly take the form of intermittent erosion repair, sediment clearing, channel maintenance (to improve flows) and weed removal (before a major infestation forms), as well as occasional controlled burning. However, a well-managed river system will require constant vigilance and preventative maintenance to pre-empt major problems from developing. Those that keep watch and act to manage rivers may be called 'river keepers' and they are the subject of the next chapter.

Chapter 8
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chapter 9

River keeping and river keepers

- How to start keeping a river
- River groups, statutory bodies and Integrated Catchment Management
- River management in south-west Australia
- Ribbons of Blue and the art of stream monitoring
- Listening and learning
- Wider integration with landcare
- Passing on our river heritage

More and more people are becoming involved in stream management as part of a wider landcare movement. Although not yet nearly enough, given the size of the task, the growing effort and resources going into river management is very encouraging. In farming areas, individual landowners and catchment groups are fencing off and replanting creek lines. Where streams are sluggish and flow along relatively broad flat and flood prone valleys, some farmers are carefully regulating grazing to achieve sustainable management. In urban and semi-rural areas small groups of people are volunteering their time to protect and restore degraded creeks and drains on publicly owned land. These days it is not unusual to see community groups working steadily to manage all the creeks in their sub-catchment or to protect the main channel and major tributaries of a river. The results of this work should become apparent as community and school groups monitor the health of waterways.

Assistance to community groups involved in river restoration and monitoring comes from local governments, State government agencies and private enterprise and through

State and Federal government funding. Coordinating groups, Land Conservation District Commitees (LCDCs), large and small catchment groups and Waterways Management Authorities (in proclaimed management areas) promote, assist and plan these works. On the south coast, Green Skills, a non-profit environmental training and employment group, has been busy planning and executing river management works, among many other activities.

Local communities are taking much of the responsibility for river keeping and local people are becoming river keepers. This chapter explores what is involved in river keeping and introduces a selection of river keepers and their achievements.

9.1 How to start keeping a river

9.1.1 Adopting a river section

When something goes wrong with a river there are always plenty of people calling for something to be done about it. Rarer are individuals and groups putting their hands up to assume responsibility or to take action. But this can and is being done. For example, at Bridgetown, the Blackwood Environment Society has weeded and partially revegetated a section of the Blackwood River valley either side of the town. On the King River near Albany, people from a rural residential estate have teamed up to assist the local government to manage an adjacent section of the river, which was very scenic and abounded in grand marri trees and wildflowers. In Mundaring, the Bugle Tree Creek Group and the Jane Brook Protection Society have weeded and replanted native understorey in sections of the Jane Brook to maintain important habitat and a key landscape feature of the area.

There are other circumstances in which a community group or business can adopt a section of river. Sporting clubs who make regular use of a river section could give something back, in the form of occasional rubbish removal, foreshore restoration, weeding and revegetation. Water skiers, white water canoeists, power boat enthusiasts and angling clubs are examples of the groups that could make such a contribution. Progress Associations seeking to promote their area through a particularly scenic section of waterway could contribute to river management. Tourism businesses offering scenic boat rides, canoe hiring or waterside chalet accommodation which depend on scenic waterways, should invest in river management to ensure the viability of their businesses in the long term. Although river sections used by these groups are limited, this type of contribution to management is sorely needed, both because of the intensive nature of the uses involved and the unique river values which are usually associated with these forms of river use.

Another opportunity for river management occurs where neighbouring landowners make significant use of a stream for water supply, such as direct stock watering or by pumping to gardens or horticultural developments. In this case, neighbours could team up to manage that section of the river that is crucial to them. One way to achieve a group approach would be to develop a management plan to guide or govern stream management by individuals.

For streams that provide very important water supplies, such as Gingin Brook, the Serpentine River and the Warren River, users are licensed under the Rights in Water and Irrigation Act. In these areas the licence conditions will require the users to comply with a management plan that has been developed by the Water and Rivers Commission and a local water resource management group.

Management of any streamline on public land needs permission from the relevant vesting authority (e.g. local government, Water Corporation, Department of Land Administration, CALM) and where the stream involved has been declared under an Act of Parliament for some form of management (e.g. flood control or water supply) approval is also needed from the Water and Rivers Commission. Advice on the particular activities involved should be obtained from the Commission or leading catchment management groups, as stream management must be appropriate to the region, consistent in the methods used and sustainable in the long term.

Groups who are prepared to do work of benefit to the public, earn the right to be heard and taken seriously and to work in partnership with statutory authorities, not only on matters pertaining to the interests of the river, but also on matters of specific interest to themselves. For those who have the environment at heart, action speaks much louder than words and will build 'mountains' of credibility with authorities and the public. For those who have their own 'river use' interests at heart, becoming a responsible river manager is both an investment and payment 'in-kind' for the services rendered by the river.

9.1.2 Setting up a river group and becoming involved

Cooperative work as a group is basic to human nature. This is well illustrated by the number of community groups involved in landcare, environmental protection and community service. Most river management by the community is being done and will be done by groups with objectives and ranges of activities that far exceed the narrow scope of rivers. To name a few: branches of the Wildflower Society and Naturalists' Club, bushland 'friends groups', LCDCs[1] and the many small sub-catchment groups whose broad sustainable land use and catchment management includes streams. Given the large number of community groups that exist, the reader may find help on setting up a river group from the people already 'on the ground'.

Nevertheless, if you have just built a house in a new riverside estate, moved to an area by a river or creek or just seen the potential for a 'living stream' lying within a rather shabby drain for the first time, you may be wondering how to become involved in stream management. The first step is to get some literature from the Water and Rivers Commission and contact your local council for a list of community groups with similar interests in your neighbourhood. Even if these groups are far from your area, ask to sit in on one of their meetings to get an idea of what they do and how. There are many such groups in the Perth area and larger country towns. For example, on the Canning River, the Litoria Creek and Bannister Creek groups have been active near the estuary and the Friends of the Canning River have worked in the upper

[1] Land Conservation District Committees, under the *Soil and Land Conservation Act 1945*

PARTICIPANTS AT THE VERY WET MAY 1999 DUNSBOROUGH RIVER RESTORATION WORKSHOP SHOW OFF THEIR RESTORATION PLAN. PHOTO: J. OATES

MEMBERS OF THE MURRAY DISTRICTS ABORIGINAL ASSOCIATION AND FAIRBRIDGE ECOTRACK STUDENTS HELP TO RESTORE A SECTION OF THE SOUTH DANDALUP RIVER. LOGS WERE PLACED TO PROTECT THE FORESHORE AND CREATE SMALL POOLS AND WETLANDS TO ENHANCE STREAM HABITAT. PHOTO: G. HEADY

Rush and sedge planting on Hedley Creek, Avon Catchment. Photo: B. Kelly

Elizabeth Andrew on the banks of Noneyup Creek at Donnybrook. All the weeds have been removed by Elizabeth and the students of St mary's Primary School to uncover and encourage remnant native plants.
Photo: L. Pen

catchment, with assistance from the Canning and Gosnells local governments. Gosnells Senior High School has collected seed and propagated native plants for planting about wetlands and streams in the area. There is a wealth of experience in many of these groups that can help you.

The next step might be to act as an individual. With permission from your local council you could remove some of the more conspicuous weeds along parkland streams, always leaving enough vegetation (including the less serious understorey weeds) to protect the stream from erosion. Like-minded people seeing you in action will ask what you are doing and before long a group may form. Alternatively, talk to your neighbours and suggest activities like litter collecting and weeding around native seedlings, and maybe even an autumn planting of native trees and shrubs. When a number of people are willing to act, contact your local council or existing catchment groups for technical and material support and inquire into community grant schemes for financial support (the local catchment centre is a good start). As the group grows in size and range of skills, it is worth considering becoming incorporated. This protects members from personal litigation arising from stream works and qualifies the group for substantial State and Commonwealth government funding grants. As well as practical on-the-ground work, every group can take a strategic coordinating role, linking with others to form a network of groups that work more effectively together than alone. Networks are useful for mobilising groups to lobby governments for action and support and obtaining funds.

9.1.3 Surveying and sampling your river

In order to manage a stream system or even just a section of stream, it is necessary to get to know it. A simple walk taking notes is a start. For rigorous surveys, standardised survey methods are available from the Water and Rivers Commission and have already been used on a number of rivers in the south-west (see Section 9.3.1). Survey methods are available for rural and urban areas, and cover the assessment of riparian habitat, foreshore condition and channel form. They are useful to create an overall picture of the form and condition of a section of stream or stream system, so that protection and restoration works can be prioritised and planned. A key aspect of river management is the prioritisation of stream sections, regardless of condition, which appear to be degrading rapidly or are at most risk of suddenly becoming degraded. Furthermore, a knowledge of the river and its behaviour enables river managers to avoid unwise decisions that lead to the fruitless expenditure of time, resources and effort, and may make problems even worse.

The results of river surveying can be used to promote and galvanise community action in river management. Maps of river condition can be used to show individual landowners their place on the river, where they lie in relation to the wider drainage system and what the implications are to them and their neighbours of poor river management. A useful adjunct exercise is a photographic survey. There is nothing like a few pictures to stimulate people to go and have a look for themselves. Later these photos can be used to make a 'before and after' comparison following stream restoration works.

Another valuable source of river knowledge is the memories of those who have lived along them for many years. Jim Masters, who lives on the Avon River near Toodyay, is an invaluable source of knowledge on the past condition and flood behaviour of the Avon. There are many others and such people are often very happy to be interviewed and to share their experiences. The wisdom of such people is a resource that can be recorded in 'oral histories'.

9.1.4 Writing a management plan

There may be some scepticism about management plans[2] because they are seldom formally implemented and end up on shelves collecting dust. Sometimes a failure to implement lies within the plan itself, perhaps because the approach taken was too expensive. On other occasions failure is simply due to a lack of resources or of will on the part of those who are required to act, and who, often as not, did not produce the plan and have more pressing problems to attend to. Nonetheless planning is essential and a written management plan is a very useful document.

A good management plan is a clear unambiguous statement of intention. It should contain background information, a description of the problem, why there is a need for action, what needs to be done, where, how, by whom and how soon. The production of a management plan should be steered by a group representative of the various views of all those with a stake in that section of river or catchment in question. In draft form the management plan should be circulated to relevant community members for comment and criticism. The final plan must be well supported, or 'owned', by those individuals and groups who are most active in the catchment and must stand as a 'manifesto' of those who put their name to it. A plan that is workable and owned by the community has the best chance of being implemented, although probably not as envisaged or according to the desired timetable. At the very least action will happen as a result of the greater community awareness and education that goes with good catchment planning. A measure of good planning is how much it generates interest and the will to act.

9.1.5 Changing land use and checking vesting and control

Circumstances change, and as cities and towns expand, rural and semi-rural lands come under pressure for subdivision. This has advantages and disadvantages. The main advantage is that foreshore areas can be vested in the Crown (public ownership) as a condition of subdivision. This enables State and local government or community groups to take responsibility for management of foreshores, giving foreshore land a permanent level of protection from inappropriate development. One disadvantage is that the foreshore areas vested as reserves may be quite narrow and

[2] Here management plans include any plan for action, including recovery plans, action plans and management programs

therefore difficult to maintain in a natural state. Clearing or filling of adjacent areas may occur in order to maximise development potential. This reduces the ecological and amenity value of the reserved area and makes it difficult to manage.

It is important when groups are planning to manage a river foreshore to check who controls the land and what the future plans are for the area. There is nothing more disheartening than to find months of rehabilitation work demolished by a bulldozer undertaking maintenance or redevelopment works. For this reason small catchment groups should consult with catchment coordinating groups and other community groups, who can often influence State and local government policy and land use planning and management, and coordinate on-the-ground activities. Wherever possible community groups should work in partnership with the authority in which the reserved land is vested. They are the legal managers and are often 'eager keepers'. when help is offered.

9.1.6 Support programs

While river keepers can find the time and energy to act, it is not so easy for them to find the materials and expertise. Finance and technical guidance are essential for success and a number of support programs are in place at the State and Federal levels (including financial support from State Landcare, Gordon Reid Foundation and the Natural Heritage Trust). For information on these programs you can contact any regional office of the Water and Rivers Commission. It is important to note that just as river management is only one aspect of catchment management, there are other programs, led by Agriculture WA and CALM, which support other catchment activities, such as remnant vegetation protection and degraded land rehabilitation. To achieve the best results, river management should be done as part of wider catchment management.

Technical support

A full range of technical guidelines and manuals for stream management is being produced or obtained by the Water and Rivers Commission and will be available through local government, catchment centres and catchment coordinating groups (see Appendix 2). For technically difficult river management problems or for problems on large powerful rivers, where great care is required, the Water and Rivers Commission has a River Action Team (known as the 'River Rats') to assist local government and community groups.

River restoration courses

The Water and Rivers Commission currently runs restoration courses in different parts of the State. These courses are intensive and comprehensive, covering all aspects of channel and riparian zone restoration, protection and long-term management. Each course is centred on a particular stream system in the State where management by community groups has been initiated. In the not too distant future the Commission hopes to develop short courses and fully accredited courses in stream restoration and management, offered through the TAFE college system or at University summer schools.

Demonstration sites

It is planned that over time a number of river restoration demonstration sites will be constructed in accessible sites dotted around Western Australia. Each site will show how the various components of stream restoration, including revegetation, fencing, rocky chutes, woody debris replacement and weed control, combine to alleviate particular stream management problems. Not all demonstration sites would be constructed by the Commission. In fact a number already exist in the Blackwood and Wilson Inlet catchments, the product of individual and community group efforts supported by State and Federal Government (LWRRDC and NLP[3]) funding.

R&D program and partnerships

The Commonwealth Government sponsors research projects on rivers in the south-west through three major research and development (R&D) programs. The Rehabilitation and Management of Riparian Lands Program aims to develop specific management responses by identifying the role that rehabilitated riparian zones play in stream ecology and in nutrient and sediment buffering of streams in agricultural areas. This work is taking place on the Kalgan, Hay, Blackwood, Serpentine and Dandalup Rivers and involves the joint efforts of the CSIRO, University of WA, Edith Cowan University, Agriculture WA and the respective catchment coordinating groups. The management techniques stemming from the research will be disseminated to the community via State government agencies.

The National River Health Program sponsors research into environmental flows for regulated[4] rivers.

Living Streams Award

To promote stream management the Water and Rivers Commission sponsors an award for excellence in stream protection and restoration as part of the State component of the National Landcare Awards. Applications are invited every two years and information can be obtained from regional branches of the Water and Rivers Commission. In 1999 the Landcare Awards also included a Rivercare Award, for the Rivercare component of the Natural Heritage Trust.

The Water's Edge Program

Since the mid-1990s the South West Development Commission has run a program for local government and community groups in its region, providing financial support for the rehabilitation and enhancement of townscapes located near water. The program aims to assist country towns by promoting the development of tourism, recreational and cultural activities through environmental repair and amenity improvement focused on waterways and wetlands. This program is particularly relevant to the lower south-west where many towns are located on rivers. Towns which have benefited from the program include Augusta, Balingup, Busselton, Boyup Brook, Bridgetown, Collie, Donnybrook, Harvey, Pemberton, Nannup and Northcliffe.

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[3] Land and Water Resources Research and Development Corporation and the National Landcare Program.

[4] A regulated river is one used for water supply, via a dam or off -stream water abstraction

9.1.7 Heartbreak and losing battles

Stream ecosystem restoration and management is a new and evolving field of human endeavour. Mistakes will be made and failures will happen. Months and years of work may be lost because of flooding, inadequate weed control, vandalism and carelessness. For example, many groups have been frustrated by people removing plantings to maintain river views, by rabbit grazing of seedlings and by accidental spraying of plantings with herbicides meant for adjacent weeds. Even when projects go well, there is always, as river keepers know all too well, the perpetual war against weeds. It is important not to lose heart and remember that all of us involved in the art of stream restoration and management are learning and refining ecological and management skills.

Over time stream management will become more effective and rewarding. In the meantime the risk of failure can be reduced by not 'biting off more than can be chewed'; by carefully judging what can be confidently achieved with the resources and community support likely to be available over the long term. For example, rather than aiming to restore a weed infested ditch to a full stream ecosystem, maybe simply removing the more serious weeds and restoring the tree canopy is a more viable option. Later, as community support for stream restoration grows, with a general increase in environmental awareness among the broader community, a second step can be taken to return the understorey, and then aquatic habitat and so on. Stream restoration and management will be incremental, a step taken at a time as skill, expertise and community support gradually grow.

9.2 River groups, statutory bodies and Integrated Catchment Management

River or catchment management groups come in two basic kinds, voluntary and statutory. Both types communicate and work together through a loose framework of coordinated management involving community groups, local government and State government agencies, known in WA as Integrated Catchment Management (ICM).

Voluntary catchment groups

On-the-ground work, usually at the sub-catchment or stream section scale, is generally carried out or led by relatively small voluntary groups. A typical group may be a relatively tight-knit team of neighbours or members of a conservation group or a loose collection of farmers, townspeople, State agency staff and school teachers and their students, coordinated by a core team of particularly energetic individuals. In some cases the group is the local Land Conservation District Committee and in others different groups may work together or assist each other in particular projects. As the groups work across the landscape, they generally enlist support and inspire action by landowners who often prefer to act alone, some of whom are already leaders in landcare or may need a little encouragement and assistance.

There are coordinating groups at catchment or basin[5] level which support the smaller groups by obtaining funding and technical guidance; by bringing parties together to create a synergy that gains results that would not ordinarily occur; by developing subregional plans or strategies; and by developing guidelines and policies and influencing legislative change. The Blackwood Basin Group and the Swan Catchment Council are good examples. Some large catchment wide groups, like those for the Frankland-Gordon and Oyster Harbour, also become involved in on-the-ground action. Coordinating groups are most useful in guiding and representing the many hundreds of smaller groups and thousands of individuals who operate at ground level.

Regional groups comprising community members and government agency personnel oversee regional land and water care strategies and sustainable development initiatives. Such regional strategies are promoted by the State and Commonwealth Governments to achieve sustainable resource use and further development. A good example occurs in the South Coast Region, extending from Walpole to Esperance, where the South Coast Regional Initiative Planning Team has prepared a regional strategy, known as Southern Prospects, and is coordinating work across the region (SCRIPT 1996). Regional groups have been formed in most parts of Western Australia. The largest and most powerful in Australia is the Murray-Darling Basin Commission, which is also a statutory body.

Statutory bodies

The State Government has established statutory waterways management bodies where river management problems are particularly serious or complex and there is strong community support for action.

The establishment of a statutory body is usually preceded by a period in which an advisory committee of community and State agency representatives provides coordinated advice to the local governments and State agencies in the area in question. Statutory bodies can be set up under the *Waterways Conservation Act 1976*. In the past these bodies have taken the form of management authorities, having some regulatory powers over proclaimed management areas which may be limited to the waterway and adjacent land or may be catchment wide. These authorities are made up of community, local government and government agency representatives appointed by the relevant Minister. They have a mandate from government and the community to promote and coordinate action which will protect waterways. Management authorities exist for the Avon, Peel-Harvey, Leschenault, Wilson and Albany Harbours waterways.

Recently a statutory body, known as GeoCatch, without actual regulatory powers, was established under the Water and Rivers Commission Act to coordinate catchment management in the Geographe Bay catchment. At the other end of the statutory spectrum, the Swan River Management Authority was replaced by the Swan River Trust under its own Act in 1988. The Swan River Trust has powers to both manage the waterways and control development on the foreshores.

[5] A basin is a physiographic formation synonymous with catchment

All of the above bodies are represented by their chairpersons on a group known as the Rivers and Estuaries Council, which provides advice to the Board of the Water and Rivers Commission who have the task of overseeing the management of water resources in WA.

Land Conservation District Committees (LCDCs) are also statutory, set up under the Soil and Land Conservation Act. In 1997 there were about 110 LCDCs and about 300 smaller catchment groups in WA (WRC data). Their main area of interest is generally the prevention of land degradation, which includes soil erosion, salinisation and nutrient loss, all of which are very relevant to the management of river systems. Many groups are also interested in nature conservation, which includes the protection of remnant bushland and improving amenities in their areas. Indeed the four LCDCs in the Oyster Harbour catchment, which come together as the Oyster Harbour Catchment Group, have a strong river management focus (see below). The State body which oversees the management of land degradation in agricultural areas is the Soil and Land Conservation Council (SLCC) which comprises community and government representatives. Another major player is Greening Australia (Western Australia), which supports and promotes catchment revegetation. At present the role and regulation of the SLC Act is being reviewed to bring it up to date and include concepts of sustainable rural development.

Integrated Catchment Management

If this book has done nothing else, it must by now have convinced the reader that the physical and biological processes of catchments are strongly interrelated and therefore catchment management activities must be integrated. If not, different land care and land use activities may work against each other, instead of being complementary to achieve more than the sum of all of the individual activities put together. Integration is also necessary to keep a full account of all the costs and benefits of any proposed new land use, to ensure that the outcomes have a net benefit to the country and do not impose a burden on future generations.

Integrated catchment management (ICM) is both a concept of working together and a framework for making it happen. Essentially it involves communication among all parties involved in catchment management, so that they may develop complementary, rather than conflicting objectives, provide mutual support to achieve their respective objectives and coordinate their activities on the ground. The bureaucratic framework of boards and committees may change over time, with changing governments and administrative fashions, but the principles of ICM will remain more or less the same.

9.3 River management in south-west Australia

9.3.1 River surveys and protection on the south coast

The rivers and estuaries of the south coast are among the Australia's great scenic and environmental attractions. When something goes wrong with them people notice. And so it was, when in the early 1980s fishers and scientists noticed the substantial die-off of the beautiful and productive seagrass beds of the Albany Harbours (EPA 1990). In the case of Oyster Harbour, seagrass death was attributed to smothering by excessive algae growth nourished by large quantities of nutrients being washed from the agricultural Kalgan and King River catchments. Ensuing research by the South Coast Estuaries Project (SCEP) of Agriculture WA identified the importance of well-vegetated riparian zones in reducing nutrient transport (SCEP 1992; Weaver & Prout 1993; Weaver et al. 1994, 1996). In September 1993, the Oyster Harbour Catchment Group (OHCG), an amalgam of the four LCDCs in the harbour's catchment, called for fencing of the Kalgan River between the ocean and the Stirling Range. This was a courageous action and received considerable criticism from some farmers battling hard economic times, especially the downturn in the wool industry.

But the OHCG, itself made up of farmers, pressed on and was supported by the Albany Waterways Management Authority (AWMA) who volunteered staff time to conduct a survey of the Kalgan River. The survey, over 110 km and carried out on foot, was conducted in late 1992 with the assistance of Agriculture WA (then Department of Agriculture) project officers from the South Coast Catchment Centre and farmers. A number of these people walked sections of the river with the surveyor and a draft report of the survey, the first of its kind in WA, was completed in 1993 (Pen 1994). The report and a photographic record of the survey were used to promote the values of the river, describe its condition and to prioritise fencing and revegetation works. Armed with the survey results, the group obtained NLP funding for fencing and revegetation, which was mainly carried out by farmers and Green Skills[6]. At the time of the survey 63% of the river between the harbour and the Stirling Range was fenced. By the end of 1994 the figure stood at 80%, and today it is about 90% and work continues. In 1995 the OHCG won the Living Streams Award for their efforts (OHCG 1995). Since then the OHCG and the AWMA have broadened their attention to take in the major tributaries of the river. About 10-15 km of fencing has been constructed and new Commonwealth Government funding obtained to support more work, which has been guided by recent surveys of the tributaries (see below).

Since 1994 other rivers on the south coast have been surveyed. Green Skills has surveyed the Hay, Denmark, Little and Scotsdale Rivers and the major tributaries of

[6] Green Skills is a non-profit environmental works and training group based in Denmark and Fremantle.

the Kalgan (APACE Green Skills 1996, 1998; APACE Green Skills and Pen 1995, 1997), and the results have been used to encourage stream fencing in priority sections of south coast rivers. Green Skills, working with the Denmark Environment Centre and Shire of Denmark, also have a program for providing financial support for stream fencing. Between 1989 and 1996 about 150 km of streamline had been fenced in the Wilson Inlet catchment (APACE Green Skills 1997). The Frankland-Gordon Catchment Management Group conducted a community-based survey of the Frankland-Gordon River between Frankland and Tambellup (APACE Green Skills and Pen 1998). The survey was completely carried out by community members, a first for any catchment and covered a distance of 128 km.

9.3.2 Streamlining in the Peel-Harvey

Since the 1960s the Peel-Harvey estuary has been troubled by excessive algae growth, including blooms of toxic phytoplankton. During many years of research the principal cause was found to be large quantities of nutrients, mainly phosphorus, leaching from heavily fertilised sandy soils of the coastal plain and being carried to the estuary in an extensive system of artificial drains and degraded creeks (Hodgkin et al. 1980). Actions taken to reduce nutrient leaching from farmland soils have met with some success (Bradby 1997). However, in the early 1990s farmer groups and staff of Agriculture WA, operating principally out of the Pinjarra Community Catchment Centre, took a different approach. They decided to tackle the transport of nutrients by re-establishing the natural biofiltration and erosion control functions characteristic of well vegetated streams. This was done by fencing and replanting the flanks of drains where some compromise of drainage efficiency was acceptable to the then drain managers, the Water Authority of WA. The approach was dubbed 'streamlining' (Heady and Guise 1994; Bradby 1997).

The term streamlining was coined to replace the obvious connotation of managing drains to accelerate the flow of water, with one of lining them with vegetation to restore some semblance of a stream ecosystem (Neil Guise pers. comm.). Ecosystem processes would assimilate a portion of the nutrients and the vegetation would slow their transport to the estuary. In other words the coils of the 'nutrient spiral' would be re-wound and tightened, reducing the rate and quantity of nutrients reaching the estuary. The viability of the approach had been amply demonstrated by a number of drains which had by good fortune retained vegetation but still operated efficiently. To these streams, farmers, school groups and other community members have added a further 150 km of streamlined drains or creeks (Bradby 1997). While this is a significant achievement in itself, the total length of streamline requiring some form of management in the catchment is well over 4000 km (Heady and Guise 1994). Nevertheless, this relatively small amount of work has been tested in a scientific study which demonstrated the effectiveness of streamlining in reducing nutrients in stream waters (Cronin 1998).

Streamlining also encompasses many other aspects of stream management in an agricultural landscape. This is exemplified by work on the Serpentine River. Here groups such as the Serpentine River Group and Serpentine-Jarradale LCDC, have been active in fencing off the formerly 'desnagged' and now much incised Serpentine River. Efforts are also being made by farmers to develop off-channel stock watering facilities, such as solar-powered pumps, and using fencing to limit livestock access to particular watering points along the river, such as the inside of meander bends. Some landowners are even exploring the replacement of the woody debris to recreate stream habitats and are experimenting with rocky riffles for channel stabilisation. The Serpentine still retains a section of streamline close to its natural condition in an area know as the 'Lowlands'. The importance of this river section as one of the few remaining relatively natural streamlines anywhere on the Swan Coastal Plain, is well appreciated by the local landcare community.

9.3.3 On the Blackwood

In 1994 the Blackwood Catchment Coordinating Group (BCCG), now the Blackwood Basin Group (BBG), teamed up with the Water Authority (now Water and Rivers Commission) to initiate a community survey of the Blackwood River foreshores between Nannup and the Albany Highway. Community members were trained in the survey method at a number of half day workshops. The work was completed in 1997 and involved farmers, townspeople, employment trainees and conservation groups. The data was collated by environmental consultants, who drew up large maps to present the condition of the river and its major tributaries in the study area (Chambers and Galloway 1997; Pen 1998). In all about 300 km of the main channel and major tributaries were surveyed. The information is presently being used by the BBG to promote river management. In 1998 the survey was extended to the stream systems downstream of Nannup.

One group that put in a significant amount of volunteer effort was the Blackwood Environment Society (BES 1997). They surveyed 70 km of river either side of Bridgetown. The group has also weeded and revegetated between 5 and 12 km of the downstream section. This work is especially innovative as it involves a detailed survey of plant species distribution on foreshores, thorough control of weeds and the propagation of local native plant species stock, not only to maintain the local species but also to maintain local plant species biodiversity. The group has gained the assistance of the Kings Park Board to establish a herbarium and to develop methods for the propagation and regeneration of especially sensitive species. A manual, which has considerable application in the south-west, is being developed. The BES won a State Landcare Award for their efforts in 1997.

9.3.4 Work on the Avon River

In 1993 the Avon River Management Authority (ARMA) was formed to coordinate community based management of the river system (WA Government 1993). Since then about 200 km of the main channel has been surveyed and a survey has been conducted of the twenty-two river pools, most of which are filled or partially filled with sediment (Ecoscape and Jim Davies and Assoc. 1996; Jim Davies and Assoc. 1997). River section management plans and pool management plans, for selected pools, are being developed by ARMA in close consultation with local communities (ARMA 1998a, b, c). Through the Natural Heritage Trust, ARMA also provides funds to assist river fencing projects. By the end of 1998 114 km of fencing had gone up along the Avon. In 1996 sediment was excavated from Gwambygine Pool, one of the few pools on the Avon to retain significant depth. The York River Preservation Society, with support from the ARMA, has been steadily working towards fencing and revegetating the foreshores of a significant portion of the river between York and Beverley. So far 15 km of river fencing has been erected (YRPS 1997). The Society is also involved in detailed faunal studies and the management of Gwambygine Pool and a 300 m stretch of the river near York, which is one of the few sections on the river that retains a natural braided form.

9.3.5 'Living Streams' in urban areas and country towns

Across the Perth Metropolitan Area small community groups and local governments have been involved in the restoration of creek ecosystems or the creation of 'living streams' out of weed infested drains. This represents a significant change in attitude and involvement in stream management in recent years. On the lower Canning small groups have removed weeds from the Litoria and Bannister Creeks and planted paperbarks and sedges. On the Southern River the Friends of the Canning River and the Gosnells City Council have removed a heavy weed infestation on the Southern Wood Creek and covered the banks with matting to protect plantings of native trees, shrubs and sedges. A few rocky riffles have been created to add habitat and prevent incision of the bed and a cascade made from concrete rubble at the steep downstream end. In the northern suburbs the Bennett Brook Catchment Group has worked with the local Noongar Community, for whom the stream has great historical and spiritual value, to control weeds and re-establish native plants.

The Bayswater ICM (BICM) Group is one of the oldest ICM groups in the State. It has been active in improving the condition and water quality of the Bayswater Main Drain that in the 1980s, before the group's efforts took effect, was a major source of nutrients and other pollutants to the Swan River Estuary. In an area that has no natural streams, the Bayswater City Council has agreed to include the banks of the drains in its parkland, and in 1998 trials began into the costs and benefits of converting drains into living streams. This work is being done with the participation of the Water Corporation, which has responsibility for managing Main Drains.

Across the river in the City of Belmont is one of the best examples of how a drain can be converted to a linear park. It is to be found on the lower reach of the Belmont Main Drain which has been landscaped. A walkway, with sitting areas, now winds its way along and across the drain. Although much of the drain has been landscaped with exotics, recent work involved Australian species, and if you peek under the gums you can obtain a partial vision of an Australian living stream, with shade and gum leaves. With a little more work on the drain, involving local native plants and pool/riffle construction, a natural creekline could be created in the heart of Perth.

In the hills above Perth, the Friends of Quenda Creek obtained approval from the Department of Land Administration to manage an unvested reserve along the creek, to maintain wetland habitat and an important ecological corridor connecting bushland habitats in the Helena catchment. With assistance from Greening Australia, the Australian Trust for Conservation Volunteers, students from Midland TAFE Landcare Course and the Kalamunda Venturer Scouts, they have battled invasive weeds, mainly watsonia, and replanted the creek with natives. Today the reserve is vested in the Council and the group is promoting its values to the local community.

South of Perth, the Donnybrook River Improvement Program, known as DRIP, has been busy removing weeds and improving the ecological and amenity value of the Preston River near the town, and has produced a comprehensive management plan to guide future activities (McPherson 1997). A school teacher and her class from St Mary's Primary School in Donnybrook cleared away heavy infestations of weeds from around many remnant native shrubs along a small section of Noneycup Brook. In Albany, Yakamia Primary School has adopted the section of Yakamia Creek that borders the school. Teachers and students have cleared away the weeds, stabilised the banks with matting and planted native species. Work has also been carried out on other sections of the creek.

In Katanning, the Katanning Creek Catchment Group (KCCG) has taken on the full range of catchment management activities, involving itself in pollution control, revegetation and biodiversity protection, environmental monitoring, fund raising and education and public awareness. The group's activities have included management of the rubbish tip and saleyard effluent, catchment planning, workshops on a whole range of subjects, the rehabilitation of creek corridors including 105 km of fencing and 368 ha of revegetation, and the establishment of a community nursery for growing local provenance stock (KCCG 1997). All of these activities and more are done in partnership with the Shire, schools, Ribbons of Blue, government agencies, local businesses and many others. At the base of the catchment are a cluster of pools known as Police Pools. At the turn of the century government troopers and their families came to the pools to picnic and swim, hence the name Police Pools. The Aboriginal name is roughly Twonkwillingup. Today the pool area is salinised, sedimented, polluted with organic matter, choked with weeds, mosquito ridden and unsightly from the death of trees and the excavation of the adjacent area for sand. But the KCCG has taken on the pools also, realising that the rehabilitation of the catchment will be rewarded by improvement in water quality in these pools. Twonkwillingup will once again become valuable stream habitat and an environmental amenity for humans. In 1998 the KCCG won an Australian Landcare Award.

9.3.6 Work on other rivers

A few community based river management projects were described above. It is impossible to do justice to all the groups working on rivers throughout the south-west, but a few quick examples will give the reader some indication of the scale of action. Most of this work has been made possible by volunteer work and financial support from the Natural Heritage Trust and, on the Swan Coastal Plain and in areas of the wheatbelt, also by Alcoa.

East of Esperance the Coolinup Catchment Conservation Group is erecting about 30 km of fencing and replanting 40 ha along or near major creeklines. The Esperance LCDC and five catchment groups (CGs) are working to manage the streams feeding into the internationally significant (RAMSAR) Lake Warden wetland system. This includes fencing off and replanting hundreds of kilometres of creekline. West of Esperance, the Upper-West and Lower Dalyup CGs are between them fencing and revegetating about 120 km of creekline. The Oldfield Landcare Group is enhancing the bushland corridor along the Oldfield River which links the coastal reserve around the Oldfield Inlet and the Ravensthorpe Range. The Kateup Creek CG is fencing and replanting 24 km of creekline and protecting 139 ha of riparian bush. On the West River, in the Phillips River catchment (on the eastern edge of the Fitzgerald River National Park), the West River CG has already fenced 104 km of creekline and is working on another 87 km.

East of Albany, Landcare groups, including the Corackerup Catchment Group and the Gnowangerup, North Stirling, Tambellup, Broomehill and Jerramungup LCDCs, have been busy fencing and replanting hundreds of kilometres of streamline in the Pallinup, Bremer and Gairdner catchments east of Albany for many years.

North of Bunbury, foreshore surveys have been completed on the Wellesley and Preston Rivers where the Leschenault Catchment Coordinating Group and Leschenault Inlet Management Authority have been very active (Pearce 1996). Above the Wellington Dam, the Collie LCDC is working on river fencing and foreshore vegetation protection. West of Busselton a small group, with assistance from the Australian Trust for Conservation Volunteers, has surveyed the lower reaches of the Carbunup River and is now working to protect what is a very pretty and ecologically valuable river. The Sussex and Capel LCDCs are quite active in stream management in the Busselton Region.

North of Perth the Moore Catchment Group is undertaking catchment wide management of the Moore River system. Already foreshore surveys have been carried out on Gingin Brook and the Moore River. South of Geraldton about 120 km of fencing has been errected on the Irwin River by the Mingenew and Irwin LCDCs and about 60,000 trees have been planted in the catchment.

All of this work is supported to some degree by government agencies and local government, community service groups and in some cases by businesses. All are examples of that most necessary element in environmental management, the will to do something now, without waiting for others and particularly government to make the first move. In other words, leadership and commitment.

9.4 RIBBONS OF BLUE AND THE ART OF STREAM MONITORING

Ribbons of Blue

Ribbons of Blue (ROB) is a school and community based program which promotes a 'stream care ethic' across the community. A network of coordinators supports school and community groups who are involved in protecting water quality in their local areas. Through water monitoring, participants build an awareness and understanding of the factors affecting stream and wetland health. At one end of the spectrum, the awareness and educational role of Ribbons of Blue encourages a positive attitude towards integrated catchment management as the way to protect waterways. At the other end, ROB participants are using their data as a basis for planning and evaluating stream protection projects.

Initially, water quality monitoring dominated the program but whole stream assessment is becoming more important, with habitat survey and the study of aquatic invertebrates now included in most local monitoring programs. While education will always be a crucial component of the ROB program, the recent implementation of quality control measures ensures that water quality data, stored on each regional Waterwatch data base, is of an assured standard. Such data will inevitably become an important component of whole catchment environmental health indicator assessments and thus an essential 'pulse taker' of the health of our stream ecosystems.

The Ribbons of Blue program has been operating in WA since 1989, and since 1992 has been part of the national Waterwatch program. At present, ROB has eleven part-time regional coordinators working in ten catchments or regions around the State. The program is possible because of the combined support and collaboration of several agencies. To match the NHT funding from Waterwatch Australia, the Water and Rivers Commission and the Education Department of WA support statewide ROB coordination, with Agriculture WA, Bunnings Treefarms, the Shire of Manjimup, GeoCatch, and Water and Rivers Commission assisting regional projects. Importantly, many local sponsors around the State provide the funds and materials to make local action a reality.

Monitoring River Health Program

Research over the last twenty years has highlighted the value of stream invertebrates as indicators of the health, or otherwise, of stream ecosystems. The presence or apparent absence of particular diagnostic species can tell a lot about a stream that it would otherwise take years of direct water quality monitoring to show. For example, a certain species may be extremely sensitive to flushes of saline water. Its absence indicates periods of raised salinity that occur only in times of flood when a normally dry upper catchment discharges saline water or as a result of the clear felling of forest. On the other hand a number of species may be typical of polluted conditions and their presence may set off alarm bells. Knowing the environmental relationships of key species can tell ecologists and stream managers a lot about a stream and its management needs.

With this understanding in mind the Commonwealth Government initiated the Monitoring River Health Program (MRHP) in 1994. The aim of this program was to develop methods for stream monitoring and data analysis, using stream invertebrates and other indicators that are applicable to the major regions of Australia (Anon. undated). The program involves sampling relatively natural and degraded streams across Australia to gain an understanding of habitat and water quality relationships that will indicate the various biogeographic regions and types and degrees of disturbance. One advantage of using stream invertebrates is that many groups are relatively large and easy to identify, so that the results of the MRHP will lend themselves to ROB-style monitoring, improving its scientific rigour and enabling it to generate powerful information of use to catchment management groups, scientists and government agencies charged with the responsibility of reporting the State of the Environment.

9.5 LISTENING AND LEARNING

It would be a great mistake to think that all the knowledge needed to manage the streams of the south-west resides in any one place or group, such as a government agency or research institution. Right now many individuals, community groups and local governments are trying their hand at stream management, albeit far too few. This represents a considerable amount of effort in experimentation and innovation, made all the more impressive by the fact that these works must fit into the economics of farm management and local government, and the day to day family lives of those people involved.

It is essential to the development of river management that the successes and failures of those actually doing the on-the-ground work are documented, so that the broad community and government can benefit from their wisdom. This wisdom includes an understanding of the immediate practical problems that prevent people from tackling stream management and the management burden that ensues from rehabilitating riparian corridors.

In river management, like life in general, mistakes will be made. The value of mistakes is that they can be treated as experiments to learn from. As such, it is essential that stream rehabilitation projects are monitored for successes and failures. We need to find out what works and what doesn't, and where particular techniques are appropriate or represent, initially and in the long term, the most cost effective response to a stream management problem.

9.6 WIDER INTEGRATION WITH LANDCARE

Waterways management is but one aspect of catchment management and must be integrated with other landcare activities to contribute to an overall rural or urban ecology. This includes both natural and artificial elements of land use. For example, naturally vegetated riparian zones are useful wildlife corridors and windbreaks, and species chosen to create nutrient and sediment buffers to riparian zones can have commercial value. In salinised areas, upslope tree planting may be required to improve water quality so that revegetation of the riparian zone can take place. In many cases, stream salinity will remain elevated above normal levels, despite much effort in the catchment, and specially selected salt-tolerant plant species will be required to restore watercourses.

Ideally, stream restoration should take place as part of a whole of catchment approach to land and water care. This will require a high level of cooperation among the government agencies involved, so that well integrated support can be provided to the community.

9.7 Passing on our river heritage

The Kalgan River near Albany is not an easy river to get to. While a number of roads cross it and a track and road run along the lower and upper sections, most of the more scenic parts are flanked by farms and are not generally accessible. For this reason the river, and particularly its beauty, were known to only a handful of people of the Albany region, that is until the river survey of 1992. Even those farmers who lived by the river and took part in the survey, said that they were seeing the Kalgan for the first time. In the ensuing photographic presentation of the river, which toured the catchment, the region's people learnt about and saw for the first time what they had in the Kalgan River, a truly wild and scenic river in the process of slow degradation. They saw a splendid river gorge stretching for 4 km, a 20 km section of river passing through a long and quite broad corridor of remnant vegetation on high hills, some topped with outlying granite domes of the small and ancient Porongurup Range, a patch of tall karri forest growing right in the river valley, many long deep placid pools shrouded in flooded gums and paperbarks, a pool backed with a colourful rocky cliff and wild river runs with steep high embankments densely clothed in near-pristine fringing forest that masked the adjacent farmlands. They also saw points of horrendous bank erosion, large washouts big enough to park a semi-trailer in and stretching for hundreds of metres, large sediment plumes slowly snaking their way downstream and filling river pools, stagnant polluted pools and worst of all the creeping cancer of salinisation in the upper reaches. In one short presentation the Albany region community saw what they had and what they were losing. At one presentation an old lady, on seeing a particular pool, stagnant and polluted, described how as a child her family and friends would visit it to swim and picnic. Few people visit the pool today.

The Kalgan River survey is but one example of how a community came to know its river. In this case, it has generated a sense of ownership of the river among some in the community and roused groups and individuals into action to protect it. Elsewhere in the south-west, people one way or another are recognising river values and are responding with on-the-ground action. These people know that if our river heritage is to be passed on to future generations, it will be up to them to roll up their sleeves and, if only for a time, become river keepers. Like so many aspects of the environment, the well being of our rivers is mostly in the hands of ordinary people.

Chapter 9

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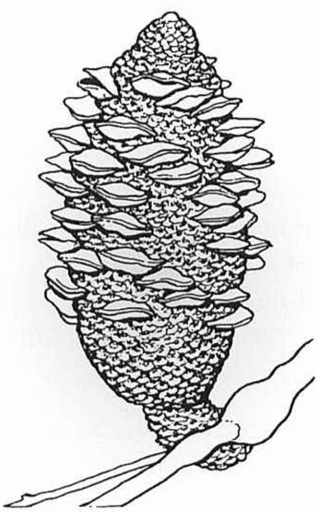
chapter

10

The future

- CLIMATE CHANGE
- INCREASING DEMAND FOR WATER
- RISING GROUNDWATERS AND SALINITY
- MORE OF THE SAME



This book has dealt with the nature, use and degradation of river systems. It has also covered what is required to repair and manage rivers so that they do not deteriorate any further and may even improve over time. But the world is not static; three factors or processes will make river management a good deal more challenging in the future. These are climate change, increasing diversion of water by humans and rising groundwaters. These processes, in themselves, will affect rivers in ways which will have serious consequences for human activities and stream ecosystems; but because they are strongly related, they will also interact unpredictably, producing problems impossible to manage unless we plan now and give ourselves every opportunity to deal with them.

This chapter will explore possible consequences of the above processes on south-west rivers. It cannot be more than exploration because our understanding of climate change and groundwater discharge into river systems is limited. But it should get people thinking. We still have some time, and thinking, researching and planning is just what we need to do.

10.1 CLIMATE CHANGE

There is considerable debate at the moment on climate change. Many scientists agree that there is a detectable warming of the atmosphere and that this is possibly caused by an enhanced greenhouse effect (Colls and Whitaker 1990). The actual greenhouse effect is not in question, only the extent to which it has increased over the last century through the release of huge quantities of carbon dioxide (the principal greenhouse gas) into the atmosphere, caused by burning fossil fuels and clearing vegetation (Lamb 1995; DEST 1996). Here in the south-west the CSIRO had suggested that the climate will become warmer and drier, with perhaps a 20% decline in average rainfall (Sadler et al. 1988). However, more recent estimates are less certain and indicate a change in rainfall of somewhere between an increase of about 2% and a decrease of about 8%, with perhaps a higher frequency of high intensity storms (CSIRO 1996; Ruprecht et al. 1997).

Scientists are uncertain about the rate of global warming and its effect on the weather (Crowder 1995). Some have pointed out that trends in atmospheric conditions, whether upwards or downwards, are less important than 'natural' climate variability (Lamb 1995). People in the south-west of Australia should be familiar with climate variability, as this region has had a significant reduction in average annual rainfall since the 1930s and especially since the mid-1970s (Sadler et al. 1988; Wright 1992; Stokes et al. 1996; Ruprecht et al. 1997) (Figure 10.1a). In those areas where the declining trend is most pronounced, just inland of the west coast and on the south coast near Walpole, the decline in rainfall has been between 3 and 4 % per decade (Ruprecht et al. 1997). No one argues whether the south-west has become drier in the last fifty years. However, whether the decline is part of the natural climatic variation and there will be a return to wetter times, or is part of the effects of global warming, is very much an open question.

Whatever the case, significant changes in rainfall have major ramifications for the nature of rivers. Everything else being equal, lower rainfall means drier catchments and less groundwater discharge and runoff; hence lower prevailing flows and less frequent and intense flooding (Figure 10.1b). Channel forming flows will decline in magnitude and channels will shrink as sediment is deposited rather than transported. Overall, catchment drainage density will contract, seasonal streams becoming more intermittent and permanent streams becoming more seasonal. Permanent habitats such as river pools may dry up completely. As river systems dry and wetter habitats contract to the wetter and cooler parts of the south-west, the distribution of many plants and animal species will likewise contract.

With the return of a wetter period lasting a number of decades the whole process is reversed. The most marked effect will be the scouring of channels of built-up sediment as channel forming flows increase in magnitude. The river channels will become 'rejuvenated' (see Chapter 1).

In the south-west we may look forward to a process of river rejuvenation if rainfall ever returns to the pattern and intensity of the 1930s and 40s. But today many of our catchments and rivers are denuded of

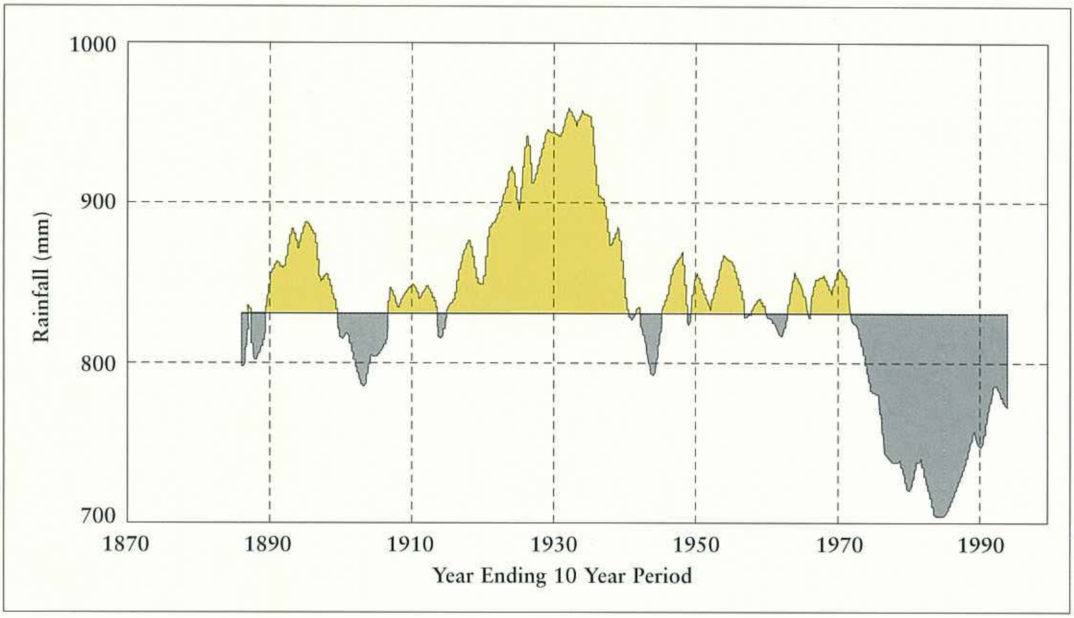


Figure (a) Rainfall Recorded Perth Airport - 10 Year Moving Average of Apr-Mar Rainfall. From Australian rainman version 2.1

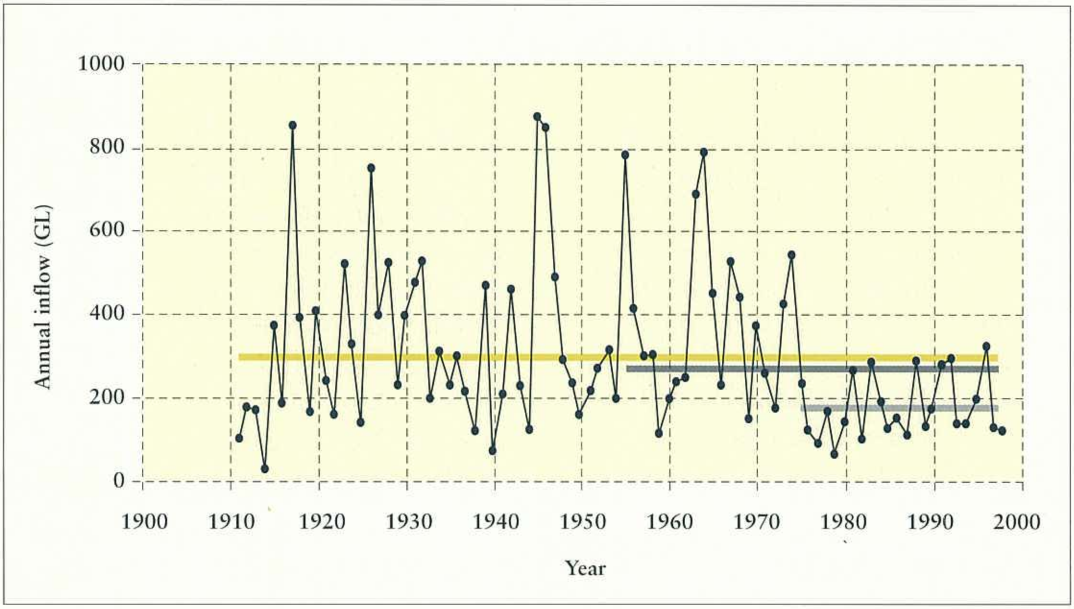


Figure (b) Average 1975 to 1996 Average 1955 to 1996 Long term average

Figure 10.1

(a) average rainfall at Perth Airport from the 1880s to the 1990s, shown as a ten year moving average (ie. the rainfall for any year expressed as the average of the previous ten years) and shown as a 'surplus' above the long term average of 'deficit' below the long term average (Data from the austrlalian Rainman Version 2.1); and

(b) streamflows of the perth hills rivers from 1911 to 1998, showing long term, 1955-96 average and 1925-96 average (WRC data).

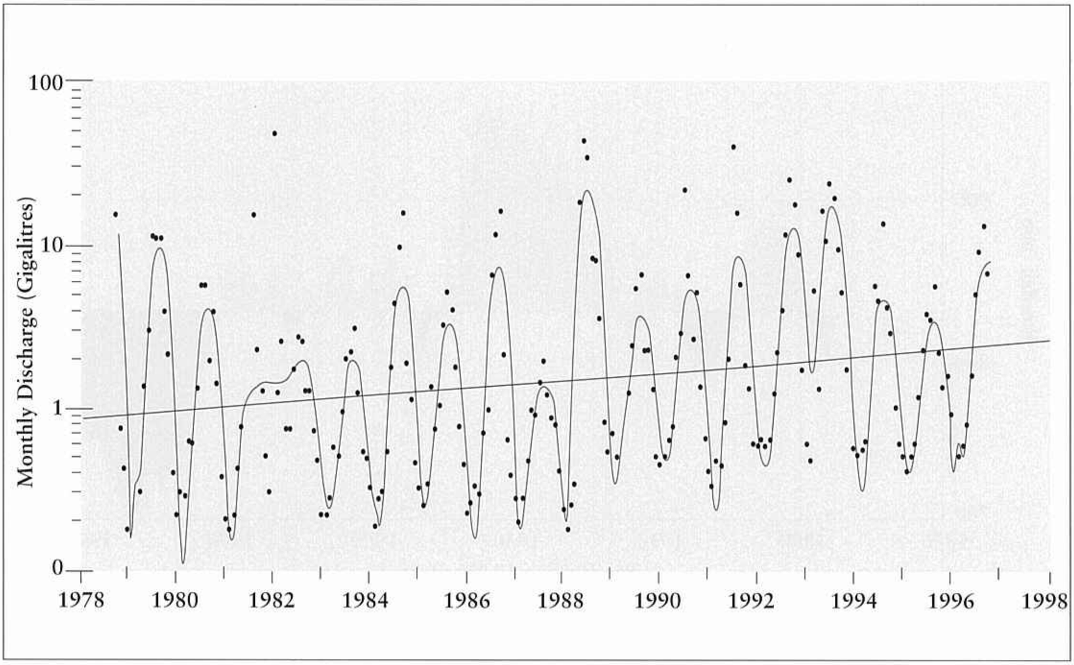


FIGURE 10.2: STREAMFLOW FOR THE KALGAN RIVER NEAR ALBANY, ILLUSTRATING A RISING TREND IN THE BASE FLOW. NOTE THE LOG (MULTIPLICATIVE) SCALE ON THE Y AXIS (WRC DATA; GRAPH PREPARED BY DAVID WEAVER, AGWEST).

protective vegetation and if they should ever be subject to the sort of flooding characteristic of last century and the first half of this century, flood damage to the beds and banks of river valleys and to floodplains is likely to be significant. In addition, many country towns of the south-west are built on floodplains or at least very close to steep river embankments and are prone to flood damage. Floods of sufficient magnitude to cause damage will probably occur quite frequently because most catchments now have higher runoff rates as a result of clearing and large areas of seasonal waterlogged land through rising groundwater. After a number of wet winters, these cleared agricultural catchments will become 'saturated' and will seemingly shed most of the water that falls upon them.

Right now, in a relatively dry period lasting some thirty years, it is hard to imagine frequent and widespread flooding causing havoc across the south-west. To get some idea of the possibilities consider the Avon, which flooded sixteen times between 1900 and 1964 (Harris 1996). For the people living in the towns of the Avon Valley, all of which are located on the river, the big flood of 1955 was the last straw and the government was called upon to act, which it did in the form of the Avon River Training Scheme of the 1960s (see Sections 6.4 & 7.2.5). Other flood mitigation works have been carried out on the Preston, Harvey, Collie and Vasse Rivers, but only one since the mid-1970s when the climate began a significant drying trend (Bretnall pers. comm). Floods in the south-west have been infrequent and of relatively minor consequence to human activities since this time; complacency has set in and just who is responsible for maintaining most of the flood control structures has become unclear (WAWA 1994). But with a return to a period of wet winters such as occurred in the 1930s and 40s, river flooding will once again become a dominant factor in land use planning and land management, requiring a significant proportion of the State's funds and resources. Planning now for future flooding is a financially prudent course of action and will save much human heartache. For this reason, floodplain mapping is carried out by the Water and Rivers Commission to guide development away from flood prone areas (see Section 8.8). In 1997 the State Government revisited the issue with the formation of the State Floodplain Task Force, a panel of community representatives, government agency staff and experts, to look into the roles and responsibilities of government in long-term flood management in Western Australia (WA Govt. 1998). This process has received added incentive from local flooding at Busselton and Moora in the late 1990s.

10.2 INCREASING DEMAND FOR WATER

The human population of the south-west is growing rapidly and nowhere more so than the city of Perth, where it is expected to rise from about 1.2 million in 1997 to 2 million in 2021. This means that Perth may require a further 100 gigalitres (GL) of water over this time, in addition to the 297 GL currently available, of which 64% is from surface water resources in the Darling Range (Stokes et al. 1995; WRC 1997). However, these estimates are based on meeting water use efficiency targets, which hopefully will add up to a 50% reduction in per capita water consumption in the long term (WRC 1997). Failure to meet these targets will place considerably greater pressure on the water resources of the south-west. Outside of Perth there will be increased demand for water from some of the growing country towns and irrigation for large horticultural and farming developments in the lower south-west (WAPC 1997). On top of public water supply needs there will be a growing need for water for private self-supply schemes which support horticulture and aquaculture.

Most of the streams which will be selected for diversion will be located in the more forested and high rainfall catchments where water quality is of a high standard. These streams often also retain high conservation value and the Water and Rivers Commission is planning to minimise if not exclude water extraction on the more ecologically and recreationally valuable systems (Pen 1997). This should be done by allocating certain streams to non-consumptive uses only and on others by limiting dam size, allocating a portion of water collected in dams to environmental flows and requiring fishways where necessary (see Section 8.5.5).

A complicating factor in balancing the demand for water and the sustainable management of rivers is climate change. South-west streamflow is very sensitive to changes in rainfall. The declining rainfall pattern experienced since the mid-1970s has resulted in a significant reduction in streamflow. For example, a 10% reduction in annual rainfall has led to a reduction in annual streamflow of jarrah forest catchments of 30-40% (Ruprecht et al. 1997) (Figure 10.1b). This means that existing water supply dams are hard pressed to deliver the amount of water presently required by Perth and some country towns. As a consequence restrictions on the use of scheme water have been in place for a number of years[1]. What is more, new dams or alternative forms of water supply, such as desalination, may need to be built sooner if rainfall does not return to pre-1970s levels in the coming decades (Stokes et al. 1996). But if the recent relatively dry rainfall pattern, rather than the wetter long-term pattern, is used to determine available water and hence the timetable for building new water supply schemes, a return to wet years will yield a surplus of water and an unnecessary investment in water supply infrastructure. This is one of the reasons that a program of water efficiency is so important. By saving water we are essentially finding new water supplies and, through the use of water efficient technologies, at a much reduced cost (see Chapter 5 in Stokes et al. 1996).

Much as climate variability represents a dilemma for those people charged with planning the State's water supply future, it is life or death for stream ecosystems, especially those on rivers which are heavily regulated. A typical large storage dam essentially imposes year round drought conditions on the stream section below it. While the dam may be designed to take 70% of annual flows under average 'normal' climatic conditions, during low rainfall years it may take as much as 100%. Thus dams compound the effects of drought on stream ecosystems. It is also in drought years that environmental releases of water are most crucial to ecosystem health, not just in summer but throughout the year. So there is a second dilemma, between maintaining supply and providing for environmental water releases; another good reason to pursue water efficiencies and invest in water saving technologies.

Reducing the risks of unnecessary expenditure on water supply facilities and impacts on stream ecosystems is largely in the hands of the south-west community. While developing and implementing technologies and regulations for the efficient use of water makes a large contribution to reducing the demands on our rivers and aquifers (and saving dollars), they are no replacement for individual initiative and responsibility in water saving. If we wish to have a number of south-west rivers to walk along, swim in, boat on, fish from, camp and picnic by, live on, attract visitors to our State, maintain full stream ecosystems, enhance the beauty of country towns and Perth's suburbs or simply to live in our own memories, an essential prerequisite is water. We must all make a contribution to leaving water in our rivers[2], especially if prolonged dry spells are ahead of us and are a normal part of the south-west climate.

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1 The probability of needing to impose at least moderate water restrictions has increased from a design level of one year in ten to one year in three. The Water and Rivers Commission and the Water Corporation have recently agreed to revise the estimated supply capacity of the Perth metropolitan supply system. The system capacity has been reduced by 17%, from 297 GL to 247 GL per year.

2 And leave water in our shallow aquifiers for the protection of wetlands.

10.3 RISING GROUND WATERS AND SALINITY

When the south-west was well vegetated with forest, woodland and mallee, very little rainfall escaped from the land as runoff into streams. Most of it evaporated or was intercepted by the vegetation and transpired back into the atmosphere. In the wetter parts of the south-west only about 20-30% would escape the land as streamflow (Ruprecht et al. 1997), while in the drier parts of the wheatbelt less than one per cent was left to generate very meagre streamflows (McFarlane et al. 1992; George et al. 1995). Over thousands of years salt deposited by the rain accumulated in the soil in huge quantities in all but the wettest parts of the south-west. With widespread clearing for agriculture less vegetation became available to intercept and transpire water, so there has been a net recharge of water to the groundwater and this at a time of declining rainfall. Across south-west agricultural areas groundwaters are rising.

Dryland and stream salinisation are two problems caused by rising groundwaters which are well understood by land managers and well appreciated by the concerned public. But two other potential problems may occur in the future: increasing prevailing streamflows as a result of increasing groundwater discharge, and more frequent flooding caused by higher runoff rates on increasingly waterlogged catchments. It has been estimated that when groundwater rise has stabilised, in about the year 2050, as much as 30% of agricultural land will be salt-affected or have a shallow watertable (WA Govt. 1996; Ferdowsian et al. 1996), and much of this land will be at least seasonally waterlogged and may be discharging into creeks and rivers. Therefore even if the south-west does not see a return to the heavier rainfall pattern of the first half of this century, prevailing flows of streams and flood frequency and intensity can be expected to increase.

As we have seen in Chapter 2, a river system is built by the relationship that water has with the land and the vegetation which it supports, which consumes and recycles water back into the atmosphere and slows the rate at which water moves over the land surface. Alterations to rainfall and vegetation will alter the relationship that water has with the land and in turn this will alter the river system. In many areas of the wheatbelt farmers are digging drains to intercept rising groundwaters before they affect valuable farmland. Whether drainage is carried out or not, rising groundwaters will eventually intercept the land surface and begin increasing the amount of water flowing over the land, forming new watercourses and increasing the prevailing flows of existing creeks and rivers. Already the Kalgan River on the south coast is exhibiting a rising trend in base flows (Figure 10.2, WRC/AgWA data). These are the ordinary flows between floods and they are showing a general increase over the years. This can only be caused by increasing groundwater discharge from the upper catchment where rising groundwaters and salinisation are a serious problem (SCRIPT 1997). Essentially, rising groundwaters will cause an increase in the drainage density of inland areas and higher flows on our rivers, mostly of brackish and saline water. It should be mentioned however, that evaporation will account for much of the groundwater as it nears and then reaches the land surface. For this reason, there is great uncertainty as to just how large an increase in prevailing flows will result from rising groundwaters.

Higher groundwater and longer prevailing streamflows have a number of effects. Firstly they increase the extent and duration of waterlogging of river valleys, particularly of the flatter, more low-lying valleys of the wheatbelt. The increased waterlogging together with salinisation kills any remaining vegetation, which had been adapted to shorter periods of waterlogging and raised salinity. This is already happening on the upper parts of the longer rivers of the south-west where broad riparian zones are shrouded in dead trees. The broad Gordon River is a good example of where this process is already well advanced. This loss of vegetation has exposed the river valleys to erosion, especially during floods, which are likely to be of greater frequency and intensity due to catchment clearing.

Secondly, the higher groundwater discharge, which generates the higher prevailing flows, will probably raise stream salinities even more, further impacting stream ecosystems especially in coastal downstream sections where the higher salt loads will not be so well diluted by freshwater tributaries draining forest areas. Thirdly, higher prevailing flows will increase discharge to river lake systems, such as Yarra Yarra Lakes on the Moore, the Yenyenning Lakes on the Avon and Lake Dumbleyung on the Blackwood. It is possible that these lakes will then hold water for longer periods, drowning some of their fringing vegetation, which has not already been killed by salt and waterlogging, and reducing their very valuable flood mitigation capacities. If the lakes are already part or wholly filled by prevailing flows, a portion of flood flows will simply be transferred downstream. So it is possible that the frequency and intensity of floods on the lower reaches of the larger rivers, such as those mentioned above, may increase in the future.

To get some idea of the seriousness of this potential problem, it is worth considering an example. Scientists have estimated that recharge to groundwater has increased by between 6 and 10 mm in the below 350 mm rainfall zone through catchment clearing (George et al. 1997). If we conservatively accept that at least 10 mm of extra rainfall is contributing to groundwater recharge in the cleared part of the Blackwood catchment, some 17,900 km^2 all of which actually has an average annual rainfall in excess of 350 mm, then this amounts to a volume of water about 25% of the Blackwood's average annual flow. This does not sound like such a troublesome amount when considering what flows out at the ocean mouth, but most of the volume will actually be generated in the much 'over-cleared' middle and upper catchments, where the percentage increases for the Beaufort and Coblinine Rivers are 40 and 250% of catchment runoff respectively, based on current catchment runoff estimates (WRC data)[3].

Remember that much of the groundwater that approaches or reaches the land surface will actually evaporate (if not immediately then at some point downstream, such as in a lake). Nevertheless, some water will wet-up the land surface and some will run off and contribute to streamflow. To what extent

[3] The actual increase in recharge to groundwater for the Blackwood catchment, as a whole, is about 30-50 mm. The higher level of 50 mm across the catchment would see a doubling of the Blackwood's average annual flow (George pers. comm.)

the pattern of streamflows will be altered by rising groundwaters is not known. But it is worth giving one example for both base and flood flows combined: the Coblinine River where annual average flow has increased from 900 megalitres (ML) prior to clearing, to about 11,000 ML in the 1990s (WRC data). This represents what is known as an 'order of magnitude increase'. What will it be in the future? Taken across the south-west, the effect amounts to an appreciable increase in flows on upper catchment streams, and will very likely contribute to a significant increase in riparian zone waterlogging, salt loads, inundation of lakes systems, downstream river flows and new channel formation.

At the same time that the amount of water leaving the catchments is increasing, creeks and rivers are still losing their supportive vegetation. Greater flows on exposed watercourses will result in serious erosion and in some cases, especially during floods, catastrophic channel widening and channel shift, frequently resulting in the loss of property, including valuable farmland and infrastructure. In some areas, floodplains needed to contain floodwaters and dampen their damaging power have been lost through landfill and levees, further compromising the capacity of rivers to cope with floods.

Just as with a return of wet winters, a major task for hydrologists arises from the potential effects of rising groundwaters. That task will be to carry out whole river system planning and especially to model the performance of river systems in relation to the changing hydrological regime of the south-west, with respect to both rising groundwaters and climate change, as the effects of these phenomena will interact and compound one another.

10.4 MORE OF THE SAME

Without climate change, increasing demand for water and rising watertables, the rivers of the south-west would still have to contend with what might be called the ordinary everyday impacts of human land use. These impacts include eutrophication, pollution, stagnation, erosion and sedimentation, damming, weeds and feral animals. As land uses intensify and extend to what few areas remain to be exploited, river degradation can be expected to similarly intensify. And then come the secondary impacts. Some of them we already know, such as large blooms of toxic phytoplankton which are becoming more frequent on our rivers, and major sedimentation of rivers like the Moore and the Pallinup which threaten to lift floodwaters onto lands that would otherwise seldom, if ever, be flooded. What other problems lurk around the corner? The extinction of a native fish species perhaps? The complete strangulation of a river valley by weeds? A river section of many kilometres in length typically supporting a toxic algae bloom every summer and no longer available for recreation? Another section of river where fish deaths are an annual and expected occurrence? All of these scenarios are plausible and just around the corner. Think about how terrible it would be if these occurrences are simply accepted by our children. Think how much worse it will be if we do not surmount the larger problems of climate change, altered catchments and increasing water demand. The job at hand to protect and enhance our rivers is a large one. It belongs to all those people who claim the south-west of Western Australia as their home.

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Appendices

- APPENDIX 1 - RIVERS OF THE SOUTH WEST REGION

  The approximate length, catchment area, median catchment rainfall, extent of clearing, estimated mean annual discharge and water quality of the larger stream systems of the south west region.

- APPENDIX 2 - FURTHER INFORMATION

  Further reading, management and restoration design information, survey and monitoring techniques, manuals, technical advisory notes and fact sheets available from the Water and Rivers Commission.

Appendix 1 rivers of the south-west region

The approximate length, catchment area, median catchment rainfall, extent of clearing, estimated mean annual discharge and water quality of the larger stream systems of the south west region.

SYSTEM	RECEIVING COASTAL WATER BODY OR WETLAND	APPROX. LENGTH OF MAIN CHANNEL (km)	CATCHMENT AREA (km^2)	MEDIAN RAINFALL (mm)	CLEARING (%)	MEAN ANNUAL FLOW (ML)	WATER QUALITY
Hutt	Ocean	60	1,240	440	60	13,000	Brackish
Bowes	Ocean	40	640	440	80	8,800	Brackish
Oakabelle Ck	Ocean	10	55	470	70	1,100	Brackish
Oakajee	Ocean	10	50	470	40	510	Brackish
Chapman	Ocean	80	1,600	470	65	19,700	Brackish
Greenough	Ocean	110	11,850	350	50	21,000	Brackish
Hunt Ck	Allanooka Swamp	30	-	-	-	-	-
Irwin	Ocean	90	5,360	430	65	32,990	Brackish
Arrowsmith	Arrowsmith Lake	80	810	510	60	4,400	Marginal
Eneabba Ck	Lake Logue	25	-	-	-	-	-
Bindoon Ck	Lake Indoon	25	-	-	-	-	-
Stockyard Gy	Stockyard Gy Cave	20	-	-	-	-	-
Cockleshell Gy	Coastal Lakes	15	70	540	0	110	-
Hill	Ocean	80	2,800	560	25	8,250	-
Numbung	Cave	35	420	600	35	2,400	
Mullering Bk	Cooljarloo Swamp	60	450	620	85	6,000	-
Minyulo Bk	Coastal swamps	60	610	610	85	8,000	-
Caren Caren Bk	Nanning Lake	35	425	640	82	5,700	-
Moore	Ocean	210	14,400	500	82	98,000	-
Swan/Avon	Swan Est.	280	120,000	405	63	520,000	Brackish
Canning	Swan Est.	80	1,150	900	15	~80,000	Fresh
Serpentine	Peel Inlet	90	1,700	1050	11	210,000	Fresh
Murray	Peel Inlet	190	8,000	810	48	500,000	Brackish
Harvey*	Harvey Est. & ocean	60	450	1080	40	100,000	Fresh
Collie	Leschenault Inlet	110	3,500	850	33	400,000	Marginal
Preston*	Leschenault Inlet	70	1,100	1000	47	170,000	Fresh
Capel*	Ocean	45	620	950	30	62,000	Fresh
Ludlow	Wonnerup	30	210	915	25	17,000	Fresh
Abba	Vasse-Wonnerup	20	140	895	35	12,000	Fresh
Sabina	Vasse	25	105	900	54	11,300	Fresh
Vasse*	Ocean	45	270	900	70	35,500	Fresh
Buayanup*	Ocean	25	160	1010	70	30,000	Fresh
Carbanup*	Ocean	30	170	1050	55	30,000	Fresh
Mary*	Ocean	30	90	1050	60	15,000	Fresh

SYSTEM	RECEIVING COASTAL WATER BODY OR WETLAND	APPROX. LENGTH OF MAIN CHANNEL (km)	CATCHMENT AREA (km^2)	MEDIAN RAINFALL (mm)	CLEARING (%)	MEAN ANNUAL FLOW (ML)	WATER QUALITY
Gunyulgup	Ocean	10	50	975	70	8,000	Fresh
Wilyabrub	Ocean	15	90	1100	70	20,000	Fresh
Cowaramup	Ocean	10	20	1030	59	3,800	Fresh
Ellen	Ocean	12	30	1060	50	5,000	Fresh
Margaret	Ocean	60	470	1075	23	65,000	Fresh
Boodijup	Ocean	12	60	1105	40	11,000	Fresh
Calgardup	Ocean	6	30	1105	35	4,800	Fresh
Turner	Ocean	6	50	1175	65	14,000	Fresh
Blackwood	Hardy	330	21,400	610	85	740,000	Brackish
Scott	Hardy	35	670	1080	30	120,000	Fresh
Donnelly	Ocean	60	1,670	1200	11	310,000	Fresh
Warren	Ocean	150	4,310	850	35	380,000	Marginal
Meerup	Ocean	17	120	1405	5	24,000	Fresh
Doggerup	Ocean	11	80	1390	0.5	14,000	Fresh
Gardner	Ocean	35	530	1420	16	125,000	Fresh
Shannon	Broke	47	610	1320	10	145,000	Fresh
Forth	Broke	10	20	1420	5	5,000	Fresh
Inlet	Broke	14	60	1410	5	12,000	Fresh
Deep	Nornalup	120	1,000	1120	3	140,000	Fresh
Walpole	Walpole	15	60	1415	13	19,100	Fresh
Collier	Walpole	6	15	1320	20	4,100	Fresh
Frankland	Nornalup	400	4,650	600	56	200,000	Marg./brak.
Bow	Irwin	20	250	1200	15	41,000	Fresh
Kent	Irwin	100	2,040	780	42	123,000	Marginal
Kordabup	Parry	12	120	1150	50	28,000	Fresh
Little	Wilson	10	30	1200	40	6,600	Fresh
Denmark	Wilson	60	690	850	15	45,000	Fresh/marg.
Hay	Wilson	80	1,280	760	60	78,000	Marg./brak.
Sleeman	Wilson	22	90	890	80	15,000	Fresh
Cuppup (drain)	Wilson	10	60	1005	80	13,000	Fresh
Lake Saide (drain)	Wilson	8	30	1050	20	3,800	Fresh
Torbay Main Drain	Torbay	20	70	1010	85	45,000	Fresh
Marbellup (drain)	Torbay	20	210	920	50	30,000	Fresh
Robinson (drain)	Princess Royal Hbr	10	15	940	80	3,600	Fresh
Yakamia Ck	Oyster Hbr	8	20	900	95	3,700	Fresh
King	Oyster Hbr	27	370	860	90	40,000	Fresh
Johnstone	Oyster Hbr	18	16	800	38	1,500	Fresh
Kalgan	Oyster Hbr	140	2,560	600	70	52,000	Brackish
Taylor tribs.	Taylor Inlet	2	10	800	70	1,400	Fresh
Goodga	Moates Lk	12	50	870	30	4,200	Fresh

SYSTEM	RECEIVING COASTAL WATER BODY OR WETLAND	APPROX. LENGTH OF MAIN CHANNEL (km)	CATCHMENT AREA (km^2)	MEDIAN RAINFALL (mm)	CLEARING (%)	MEAN ANNUAL FLOW (ML)	WATER QUALITY
Angove	Angove Lk	11	40	850	5	3,000	Fresh
King Ck	Ocean	12	25	840	60	4,300	Fresh/marg.
Normans	Normans Inlet	6	20	-	46	1,800	Fresh/marg.
Waychinicup	Ocean	17	160	760	41	8,000	Fresh/marg.
Bluff	Ocean	13	20	720	10	530	Fresh/marg.
Little Bluff	Ocean	10	20	710	10	610	Fresh/marg.
Wongerup	Ocean	9	70	650	20	1,500	Fresh/marg.
Molloculllup	Merumbeen Lake	7	20	630	0	240	Fresh/marg.
Cordinup	Cordinup	21	110	610	27	1,700	Fresh/marg.
Wilyunup	Ocean	15	110	610	40	2,100	Fresh/marg.
Eyre	Cheyne	13	70	610	40	1,800	Fresh/marg.
Pallinup	Beaufort	150	4,970	410	80	36,000	Saline
Bremer	Wellstead	70	720	465	75	14,000	Saline
Hunter	Hunter	5	20	490	0	50	Fresh/marg.
Kelly's Creek	Kelly's Creek	8	15	490	0	40	Fresh/marg.
Gairdner	Gordon	130	1,770	430	40	10,700	Saline
Boondadup	Boondadup	10	40	480	0	90	Fresh/marg.
St. Mary	St. Mary	15	170	480	0	360	Fresh/marg.
Unnamed	Lake Nameless	8	50	470	0	100	Fresh/marg.
Fitzgerald	Fitzgerald	80	1,610	420	35	5,400	Brackish
Copper Mine Ck	Dempster	25	320	460	0	410	Fresh/marg.
Dempster	Dempster	15	140	475	0	340	Fresh/marg.
Hamersley	Hamersley	50	840	440	10	1,160	Brackish
Phillips	Culham	50	1,940	400	35	2,000	Saline
Steere	Culham	30	360	450	30	1,400	Saline
Jerdacuttup	Jerdacuttup Lakes	65	2,320	415	30	8,800	Saline
Oldfield	Oldfield	95	2,480	440	30	8,100	Brak./sal.
Torradup	Torradup	15	90	550	50	1,200	Fresh/marg.
Young	Stokes	120	1,610	400	75	5,880	Brak./sal.
Lort	Stokes	100	2,800	375	60	6,000	Saline
Coomalbidgup	Wetlands adjacent to Barker Inlet	13	130	500	95	1,400	Brackish
Coobidge	Carbal/Kubitch Lakes	35	220	470	85	3,800	Brackish
Dalyup	Lake Gore	35	660	450	80	11,000	Brackish
Kateup	Lake Mortijinup	20	150	530	75	3,200	Brackish
Coramup	Lake Warden System	25	260	570	80	8,300	Brak./sal.
Bandy	Mullet Lake System	30	1,380	465	85	6,400	Brak./sal.
Daily	Ocean	10	50	610	80	1,500	Brak./sal.
Munglignup	Ocean	15	140	590	60	3,200	Saline
Alexander	Ocean	10	70	595	30	1,000	Saline

SYSTEM	RECEIVING COASTAL WATER BODY OR WETLAND	APPROX. LENGTH OF MAIN CHANNEL (km)	CATCHMENT AREA (km^2)	MEDIAN RAINFALL (mm)	CLEARING (%)	MEAN ANNUAL FLOW (ML)	WATER QUALITY
Blackboy	Ocean	13	90	595	25	1,100	Brak./sal.
Thomas	Ocean	10	130	560	30	1,500	Brak./sal.
Jenamullup	Ocean	7	20	580	5	150	Fresh/marg.
Cape Arid	Ocean	5	8	580	20	230	Fresh/marg.
Jorndee	Ocean	7	2	580	0	190	Fresh/marg.
Poison	Ocean	15	2	580	0	100	Fresh/marg.
Fern	Ocean	8	20	500	0	60	Fresh/marg.
Weanerjungup	Ocean	5	50	480	0	90	Fresh/marg.

Notes:

The streams systems detailed above are those which discharge into the ocean or a coastal inlet, lagoon, lake or swamp. In other words the above stream systems are not tributary to any other stream system. Information in the table was provided by the Surface Water Hydrology Section of the Water and Rivers Commission. The above information is subject to change as new analyses benefit from an increasing flow record and more accurate interpretations of catchment characteristics.

Catchment and flow characteristics of the rivers between and including the Arrowsmith and Moore are presently being determined.

Fresh (0-500 mg/L), marginal (500-1500 mg/L), brackish (1500-5000 mg/L) and saline (>5000 mg/L).

* Denotes a stream which is diverted or partially diverted to the ocean from its natural outlet.

Appendix 2
further information

The nature of water and rivers

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Manuals, Water Notes and Water Fact Sheets available from the Water and Rivers Commission

Manuals:

- Planning and Management : Guidelines for Preparing Waterways Management Plans in Western Australia
- Planning and Management: Foreshore condition assessment in urban and semi-rural areas of south-west Western Australia
- Planning and Management: Foreshore condition assessment in farming areas of south-west Western Australia
- Revegetation: Revegetating riparian zones in south-west Western Australia
- Revegetation: Case studies from south-west Western Australia

Manuals in preparation:

- Stream ecology
- Stream hydraulics
- Stream hydrology
- Stream channel analysis
- Stream stabilisation
- Long-term management

Water Notes in preparation:

- WN1 Wetlands and weeds
- WN2 Wetlands and fire
- WN3 Wetland vegetation
- WN4 Wetland buffer zones
- WN5 Wetlands as bird habitat
- WN6 Livestock management: Construction of livestock crossings
- WN7 Livestock management: Watering points and pumps
- WN8 Habitat of rivers and creeks

- WN9 The value of large woody debris (Snags)
- WN10 Protecting riparian vegetation
- WN11 Identifying the riparian zone
- WN12 The values of the riparian zone
- WN13 The management and replacement of large woody debris in waterways
- WN14 Lamprey guides
- WN15 Weeds in waterways

Water Notes in preparation

- Sedges and rushes
- Demonstration sites
- Livestock management: locating fencing & grazing control
- Riffles, weirs and drop structures
- River and estuary landscape appreciation and protection
- Brushing
- Groynes - brush
- Groynes - rock
- Jacks
- Log walls
- Mesh fencing
- Retards
- Revetments
- Rock gabions

Water Notes planned

- Battering
- Controlling deciduous trees on rivers
- Filter strips
- Foreshore reserves
- Native plant species lists for south west streams
- Planning stream restoration works
- Pool/riffle fishways
- Slope stabilisation
- Stream flow monitoring
- Stream restoration and the Aboriginal Heritage Act

Water Facts

- Water Facts No. 2: Macroinvertebrates and Water Quality
- Water Facts No. 4: Living Streams

Water Facts in preparation

- Flooding in WA (forecasting and warning)
- Floodplain management (floodplain protection)
- Stream sediment, origin, transport & effects
- Living wetlands

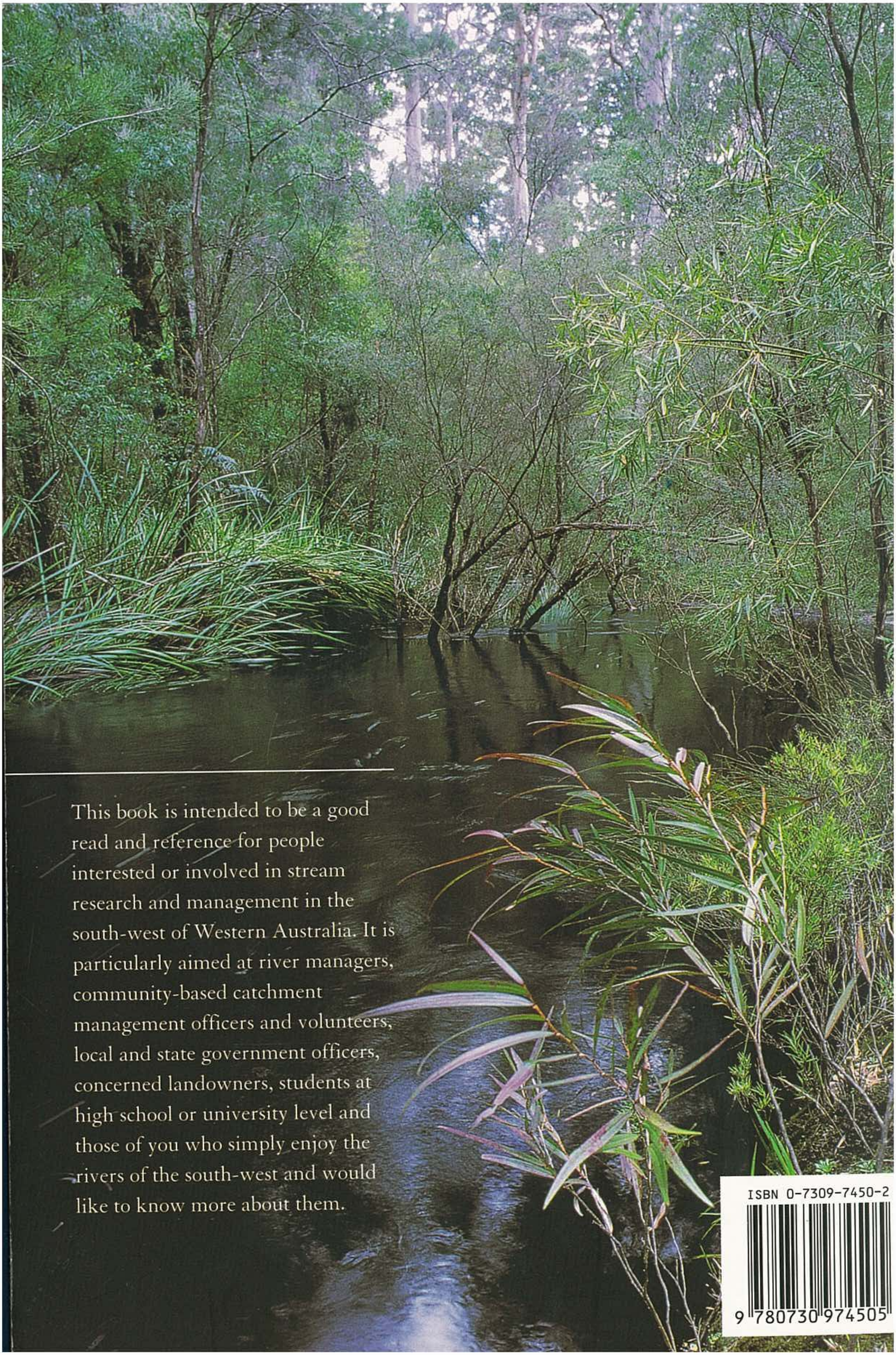
About the author

Courtesy WA Newspapers

Luke Jerome Pen has a B.Sc (Hons) in Environmental Science and PhD in biology from Murdoch University. He has been involved in research into the ecology of rivers and estuaries of south-west Western Australia since 1981. His post-graduate honours studies were on the fringing vegetation of the Swan and Canning rivers. Between 1984 and 1990 he was employed as a research officer at Murdoch University conducting research into the effects of mine water effluent and agricultural land use on the flora and fauna of the Collie River. He has also been involved in a number of minor research projects with various State Government agencies, mainly involved in stream ecology. During this time he completed a Doctorate on the ecology of freshwater fishes of south-western Australia. He is author of many scientific papers and reports on the ecology of south-western freshwater fish, the fringing vegetation of the rivers and estuaries of the south-west and the plant communities of Rottnest Island. In 1991 his career largely turned from research to the management of water resources, mainly stream systems.

Before coming to the Water and Rivers Commission in 1996, he was a Research Officer and Policy Analyst with the Water Authority of WA for about two years, involved in the identification of river and wetland values as a part of regional water resource allocation throughout the State. Prior to 1994 he was an environmental officer with the Waterways Commission for about three years, mainly in Albany, involved in environmental planning, impact assessment and pollution control. These positions provided opportunities to evaluate, describe, classify and map riverine fringing vegetation, evaluate the condition of a number of river systems in WA and promote river management with landcare groups throughout the State. His current position has as its main responsibility, the restoration and management of waterways in Western Australia.

Luke is married and has three daughters.



This book is intended to be a good read and reference for people interested or involved in stream research and management in the south-west of Western Australia. It is particularly aimed at river managers, community-based catchment management officers and volunteers, local and state government officers, concerned landowners, students at high school or university level and those of you who simply enjoy the rivers of the south-west and would like to know more about them.

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