



Environmental, Social
and Economic Setting



Part A provides details on the values and assets of public land in the study area, including biophysical, socio-economic, Indigenous land associations and historical aspects of the study area.

2 Geology

Geology underpins the diversity of all life on earth. The interaction between weather and landscape has provided a range of niches and habitats in which the enormous variety of life has evolved and flourished. Both subtle and dramatic changes in these elements have caused extinctions and adaptations over thousands of millions of years. This chapter describes these landscape foundations and changes recorded over geological time in southeastern Australia and, specifically, within the study area.

Over millions of years, geological processes have all left their mark on the Australian landscape and within the River Red Gum Forests study area. More recently, climatic changes have left a distinct imprint with changing sea levels and river flows, extinctions of the unique Miocene-Pleistocene Australian megafauna (giant marsupials and birds) and the arrival of the first people in the last 50,000 years. The unique character, features and resources of the study area can only be fully understood in the broader context of the underlying geology. This chapter provides an overview of the geological history of Victoria with specific reference to the study area. Although few outcrops of older or 'basement' rocks occur in the study area, these form the foundations for the overlying rocks and contain economic resources. More recent sedimentary processes and geomorphology are described in chapter 3.

GEOLOGY OF SOUTHEASTERN AUSTRALIA

Australia's geological history is extensive, beginning with some of the oldest rocks on earth. Australia's continental history began as part of the great Gondwanan supercontinent and continued through its gradual separation from other Southern Hemisphere land masses until final separation from Antarctica and northward drift away from the polar regions. In the western portion of Australia, rocks dated at 3800 million years ago (Ma) with individual mineral grains up to 4000 million years old have been recorded (see timescale in Table 2.1). This region of the continent is known as the Australian Craton (Figure 2.1). The eastern portion of Australia, including parts of Victoria, NSW, Queensland and Tasmania consists of significantly younger rocks—largely from the Phanerozoic eon (542 Ma to present day). These rocks were joined to the much older, consolidated and metamorphosed western rocks of the Australian Craton during a series of tectonic events and now form a belt of folded sedimentary and igneous rocks (known as the Tasman Fold Belt) extending along the east of the Australian continent (Figure 2.1).

Geological Time Scale

The initial occurrence of abundant multi-celled life is preserved in Proterozoic (2500–542 Ma) rocks in the South Australian Flinders Ranges—specifically the Ediacaran period (600–542 Ma). A rapid increase in the number of life forms marks the beginning of the Phanerozoic eon

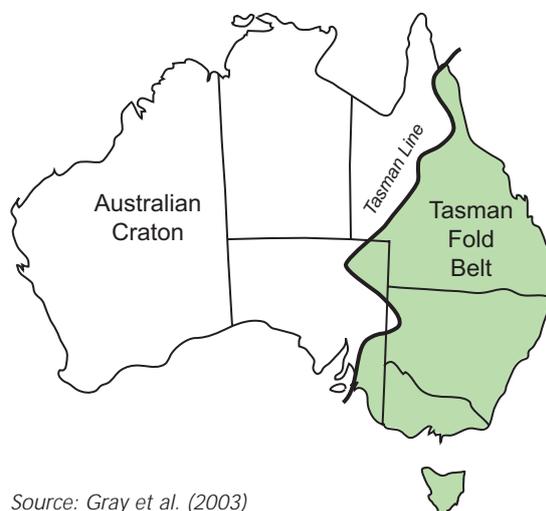
(542 Ma to present day) comprising three eras: Palaeozoic (542–251 Ma), Mesozoic (251–65 Ma), and the Cainozoic (65 Ma to present day). These eras are separated by mass extinctions events. At the end of the Palaeozoic more than 80 percent of all life forms became extinct (Permian extinction), while the end of the Mesozoic is correlated with a meteorite impact event and the decline of a large range of life-forms including the extinction of dinosaurs (Cretaceous extinction) (e.g. Keller 2005). Within each of these eras there is a number of sub-eras or time periods (Table 2.1).

Victoria's Geology

In Victoria, Tasman Fold Belt rocks are subdivided into two major structural divisions—the Delamerian Fold Belt and the Lachlan Fold Belt (Figure 2.2). Both fold belts consist of a similar suite of rocks—mainly marine sedimentary rocks with minor occurrences of submarine volcanics, and granitic intrusions and lavas. The Delamerian Fold Belt is significantly older and comprises Proterozoic and Cambrian age (600–490 Ma) rocks that were folded and faulted during a mountain-building episode, the Delamerian Orogeny (520–490 Ma), followed by intrusion of granites in the Cambrian and Ordovician (520–480 Ma).

The younger Lachlan Fold Belt rocks have a much broader age range, from Early Cambrian (about 530 Ma) to Early Carboniferous (about 340 Ma) and have had a much more complex history, with major mountain-building (or orogenies) occurring during four main events: the Benambran Orogeny (450–425 Ma), the Bindian Orogeny (415–405 Ma), the Tabberabberan Orogeny (400–390 Ma) and several minor events during the Kanimblan Orogeny (370 and 340 Ma). The Lachlan Fold Belt probably formed during the collision of an island arc—such as the present Indonesian island chain—with the Australian Craton (VandenBerg et al. 2000) during which sedimentary and volcanic rocks were fractured and traversed by major thrust faults, and intruded by numerous granitic bodies.

Figure 2.1 Structural architecture of the Australian continent showing the largely Palaeozoic fold belts along the east coast and the older Australian Craton to the west. The boundary between these two regions is described as the Tasman Line.



Source: Gray et al. (2003)

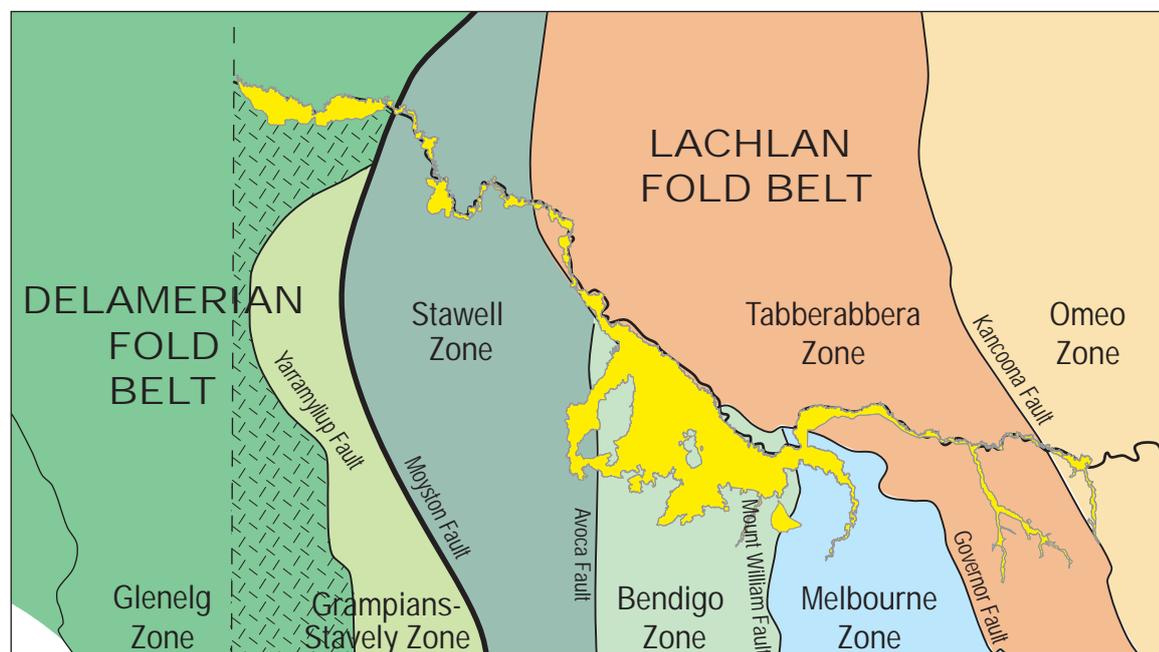
Table 2.1 Geological time scale and major geological events.

Eon	Era	Period	Epoch	Major Geological Event	
Phanerozoic 0–542 Ma	Cainozoic 0–65 Ma	Quaternary 0–1.8 Ma	Holocene	Humans arrive in Australia ~50,000 years ago Extinction of Australian megafauna	
			Pleistocene		
		Tertiary 1.8–65 Ma	Neogene 1.8–24 Ma	Pliocene	First upright walking hominids ~4 Ma
				Miocene	Diversification of mammals and birds
				Oligocene	
			Palaeogene 24–65 Ma	Eocene	Australia separated from Antarctica
				Paleocene	
		Mesozoic 65–251 Ma	Cretaceous 65–141 Ma	Late	Mass extinction of life at 65 Ma Australia separates from New Zealand at ~80 Ma
	Early			Eastern Highlands uplifted ~90 Ma Otway and Gippsland basins formed across the southern margin rift	
	Jurassic 141–205 Ma		Late	Break-up of Gondwana commenced—initial separation of Australia and Antarctica commences at ~140 Ma	
			Middle		
			Early	First appearance of birds	
	Triassic 205–251 Ma		Late		
			Middle	First appearance of dinosaurs	
			Early		
	Palaeozoic 542–251 Ma		Permian 251–298 Ma	Late	Mass extinction of >80 % of all life forms at 251 Ma
		Early			
		Carboniferous 298–352 Ma	Late		
			Early		
		Devonian 352–410 Ma	Late		
			Middle	Kanimblan Orogeny 340 and 370 Ma	
		Early	Tabberabberan Orogeny 390–400 Ma		
		Silurian 410–434 Ma	Late	Bindian Orogeny 405–415 Ma	
			Early		
		Ordovician 434–490 Ma		Benambran Orogeny 425–450 Ma	
		Cambrian 490–542 Ma	Late	Delamerian Orogeny 490–520 Ma	
	Middle				
	Early		First abundant life on Earth		
Proterozoic 542–2500 Ma		Ediacaran 542–600 Ma		Oldest known multi-cellular organisms 600 Ma	
Archaean 2500–4560 Ma				Oldest life known at ~3500 Ma	
Hadean >4560 Ma				Origin of the Earth	

*Ma denotes millions of years

Source: modified after Gradstein et al. (2004)

Figure 2.2 Schematic diagram of fold belt for south-eastern Australia. The boundary between two major geological provinces, the Delamerian Fold Belt and the Lachlan Fold Belt is located along the Moyston Fault (e.g. Cayley & Taylor 1997), as well as the boundary faults separating the structural zones. The River Red Gum Forests study area is shown in bright yellow.



Source: modified after Vandenberg et al. (2000)

The Lachlan Fold Belt can be divided into several zones of similar character (Figure 2.2). Each of these is separated by a major structural fault line within which the rocks are often highly deformed and much older slivers have been emplaced from great depth. A brief description of each of these zones is provided below (Table 2.2). The distribution of these rocks is important for understanding the occurrence of mineral resources throughout Victoria.

These fold belt rocks are known as bedrock or basement and form a solid layer below a more recent—largely Cainozoic—sedimentary cover sequence, deposited by streams flowing out of the highlands of the Great Dividing Range.

Towards the end of the Palaeozoic, erosion exposed the roots of these mountain chains and global cooling formed a large ice sheet over Gondwana, with fingers extending north into what is now Australia. In the Permian (300–250 Ma), these glaciers flowed into a shallow sea with a shoreline that lay in an east–west direction at the latitude of Ballarat.

Prolonged erosion in the early Mesozoic removed much of the rock laid down in the late Palaeozoic, and by Jurassic time (about 200 Ma) Victoria was a land of low relief, with north-flowing river systems that drained into the Sydney Basin and later into a vast sea that became the Great Australian Basin (formerly called the Great Artesian Basin). Around 160 Ma the Gondwanan supercontinent (Antarctica, South America, Africa, India, Australia and New Zealand) began to break-up, a process which continued over a long period with Australia and Antarctica being the last landmasses to

separate. The initial stage of the separation in the Early Cretaceous (145 Ma) opened a rift valley, forming a series of depositional basins across southern Victoria (Otway, Bass and Gippsland Basins). In the Late Cretaceous (95 Ma) continental break-up uplifted the mountain chain that became the Great Dividing Range. At the same time, a large shallow sea formed from Queensland to South Australia called the Eromanga Basin. The Murray Basin (Figure 2.3) was established across northern Victoria in the Eocene (55 Ma) with a thin veneer of sediment laid down from rivers flowing north from the Great Dividing Range. Rifting completely separated the two continents during Eocene times (~45 Ma) with the newly formed Australian continent drifting towards the equator while Antarctica remained near polar latitudes (Veevers 1984).

GEOLOGICAL HISTORY OF THE STUDY AREA

The geological history of Victoria is extremely complex. The following account provides an overview of the geology of the study area and describes the main geological rock sequences and events within it, both outcropping and subsurface. This geology, and the major outcropping rocks, is shown on Map 2.1. Pre-Permian geology is shown on Map 2.2. This history provides a background for the region's current natural resources (see chapter 16 Earth Resources). Greater emphasis is placed upon outcropping sequences and those that contain economic resources within the study area. For more scientific or comprehensive descriptions see Cochrane et al. (1999) and Birch (2003).

Table 2.2 Structural zones identified within Victoria.

Structural zones	Rock types	Main deformation episodes
Delamerian Fold Belt		
Glenelg Zone	Deep-marine sedimentary rocks and very minor basalt of Proterozoic to Early Cambrian age. Deformation and heating converted some of the rocks into schist and gneiss, and granitic rocks. Rocks are mostly buried beneath younger sequences.	Delamerian Orogeny
Grampians-Stavelly Zone	Cambrian age volcanics and sedimentary rocks of the Glenthompson Sandstone. Minor occurrences of serpentinite and ultramafic rocks occur in thin slivers, and have been intersected in drill holes at depth (e.g. Dimboola Igneous Complex).	Delamerian Orogeny
Lachlan Fold Belt		
Stawell Zone	Deep-marine sedimentary rocks and minor basalt of Early Cambrian age overlain by extensive Cambro-Ordovician quartz-rich turbidites (Cambrian St Arnaud/ Early to middle Ordovician Castlemaine Group)	Delamerian Orogeny
Bendigo Zone	Three main sequences: deep-marine sedimentary rocks and minor basalt of Cambrian to Ordovician age comprising Ordovician turbidites (Castlemaine Group); Upper Cambrian shales and cherts; mid to lower Cambrian volcanics and volcanoclastics	Benambran Orogeny
Melbourne Zone	Deep to shallow marine sedimentary rocks of Early Ordovician to Early Devonian age	Tabberabberan Orogeny
Tabberabbera Zone	Deep-marine sedimentary rocks and minor basalt of Cambrian to Ordovician age	Benambran Orogeny
Omeo Zone	Deep-marine sedimentary rocks and minor basalt of Cambrian to Ordovician age, deformed at relatively deeper level so that much of the rock has undergone high-grade metamorphism to schist and gneiss, and melting to migmatite and granite.	Benambran Orogen

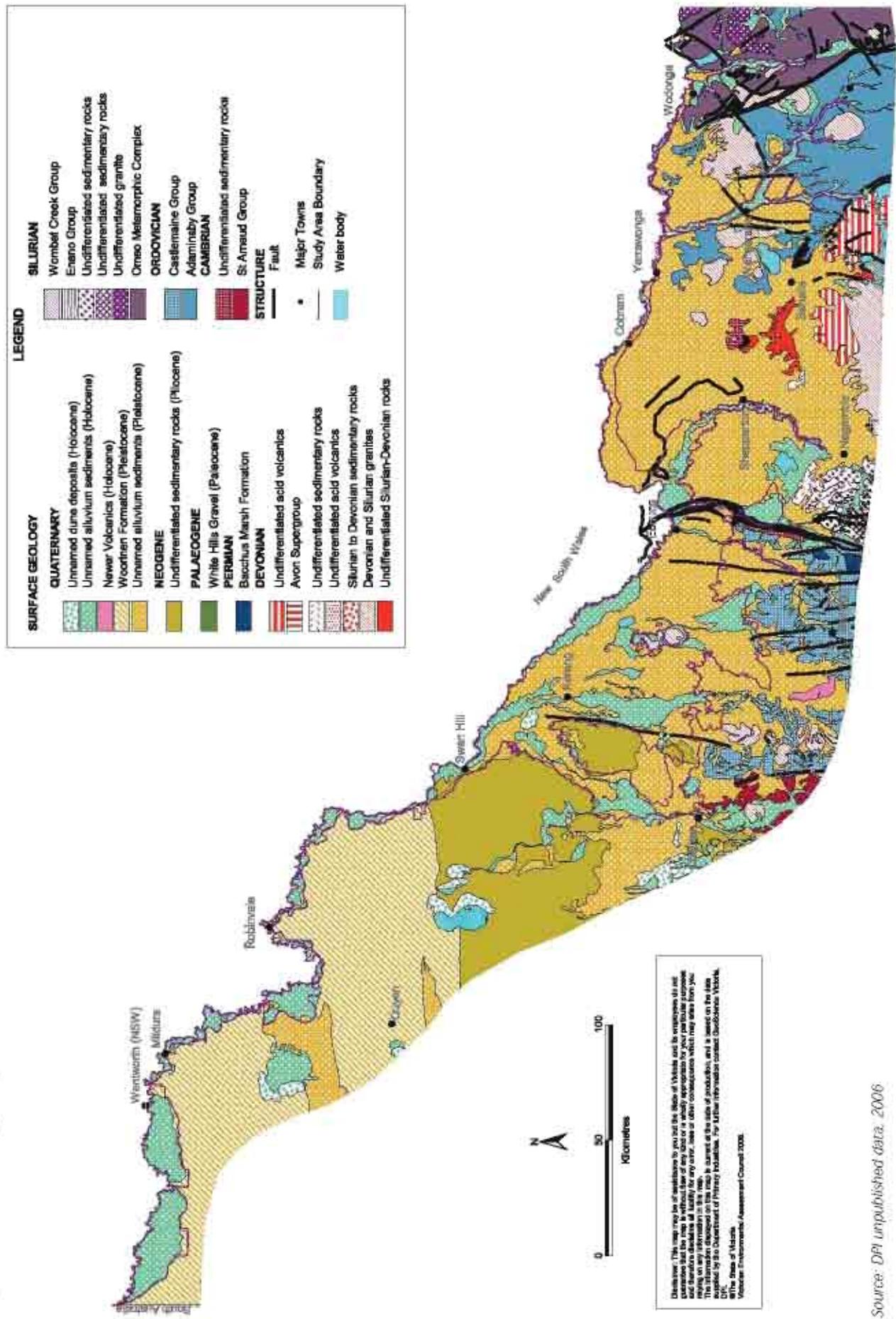
Source: *VandenBerg et al. (2000)*

The major events in Victoria's geological history occurred in three eras. Rocks from the earliest or Palaeozoic era (542–251 million years ago) form the basement underlying the entire study area, but few outcrops occur (see Map 2.1). Mesozoic era (251–65 Ma) rocks are only found at depth within depositional troughs of the Murray Basin (Figure 2.3) and near the eastern part of the study area in the King River valley. Most surface geology is from the extensive Cainozoic era (65–0 Ma) sediments of the riverine plain.

Palaeozoic

The Lachlan Fold Belt (Figure 2.2) comprises most Palaeozoic age rocks in Victoria, specifically from the Cambrian until the Carboniferous. Each structural zone within this sequence has experienced a unique geological history including periods of orogenic mountain building, sediment deposition and granite intrusion, leading to the diverse character of landscape across Victoria today, described in Table 2.2.

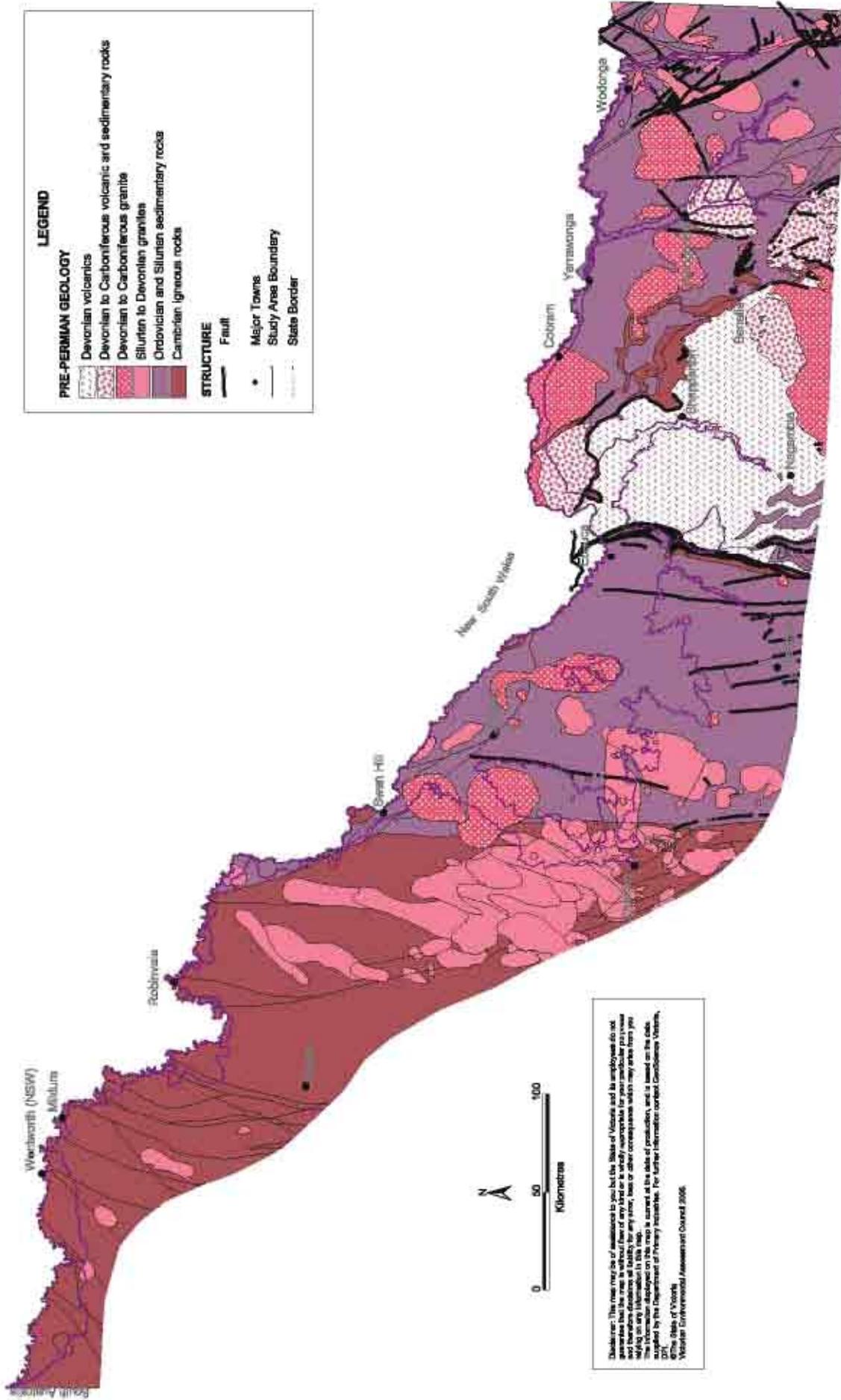
Map 2.1 Surface Geology Map.



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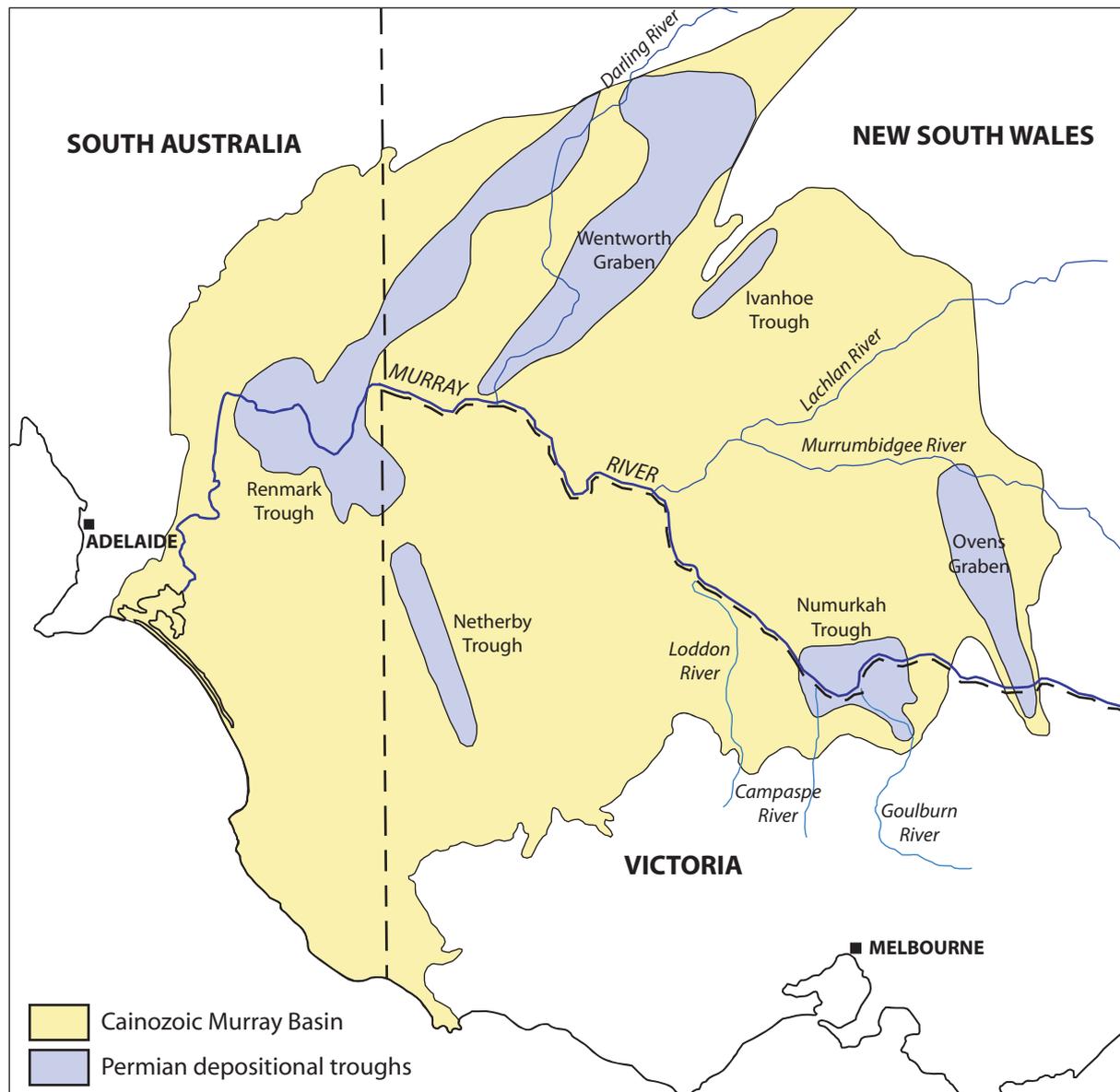
Source: DPI unpublished data, 2006

Map 2.2 Pre-Permian Geology Map.



Source: DPI unpublished data, 2006

Figure 2.3 Murray Basin extent and subsurface depositional troughs.



Source: modified after Belperio (1995)

The oldest Victorian rocks are deep marine sedimentary and minor volcanic rocks of Late Proterozoic to Late Cambrian age (550–490 Ma). These rocks extend from within South Australia, east to the Avoca Fault—encompassing the Glenelg and Grampians-Stavely zones of the Delamerian Fold Belt, and the Stawell Zone of the Lachlan Fold Belt (Figure 2.2). Shallow boreholes have intersected these sequences at various locations below the much younger Murray Basin sediments, but none outcrop within the River Red Gum Forests study area.

Other Cambrian rocks including volcanics, shales and cherts occur along the edge and within major structural faults in the Lachlan Fold Belt. Cambrian rocks of the Delamerian Fold Belt and the Stawell Zone of the Lachlan Fold Belt were deformed during the Delamerian Orogeny (520–490 Ma). Cambrian to Early Ordovician

granites intruded the Cambrian rocks of the Delamerian Fold Belt but are not present in the Lachlan Fold Belt. Following the mountain building of the Delamerian Orogeny, deep-marine sedimentation occurred in a basin located within central Victoria, and extending across the whole of the Lachlan Fold Belt east of the Avoca Fault. These thick Ordovician sediments overlie extensive Cambrian volcanic rocks and consist predominantly of sandstone and mudstone, with a small but important component of black shale.

Within the Melbourne Zone, Early and Middle Ordovician rocks are either absent or represented by thin chert, shale or sedimentary phosphate. There seem to have been major regional differences at this time, with thick sedimentary sequences deposited on both sides of a high area described as the Selwyn Block (VandenBerg

et al. 2000). This Selwyn Block is thought to underlie the Melbourne Zone and extend from similar rocks in Tasmania (Fergusson & VandenBerg 2003).

The Benambran Orogeny had variable effects across the Lachlan Fold Belt and occurred in several pulses between 460 and 420 Ma. This orogeny affected rocks on both sides of the Selwyn Block but not the Selwyn Block itself, which by that time was overlain by the sediments of the Melbourne Zone. Older sedimentary rocks of the Bendigo and Stawell Zones were folded and faulted in a single short-lived but major event during this period. In eastern Victoria the Benambran Orogeny folded and faulted Cambrian, Ordovician and Early Silurian sedimentary rocks, and is associated with granite intrusion and regional metamorphism. Elsewhere, especially in the Bendigo Zone, regional metamorphism was very low and the orogeny is associated with gold and quartz mineralisation within Ordovician sedimentary sequences.

The regional differences between western, central and eastern Victoria that first appeared in the Ordovician became more pronounced after the Benambran Orogeny (450–425 Ma). These differences divide the Lachlan Fold Belt into two belts of different structural evolution from the Ordovician to the Middle Devonian—the Benambra and Whitelaw terranes (VandenBerg et al. 2000). The Benambra Terrane of eastern Victoria comprises the Lachlan Fold Belt east of the Selwyn Block and Governor Fault (Tabberabbera zone and those to the east) and was subject to two episodes of rifting, one in the Late Silurian and the other in the Early Devonian, with an intervening orogeny at about the Silurian–Devonian boundary (Bindian Orogeny described below). The Whitelaw Terrane comprises the Lachlan Fold Belt that lies west of the Governor Fault including the Selwyn Block (Stawell, Bendigo and Melbourne zones). Unlike the Benambra Terrane, the Whitelaw Terrane shows only mild effects from the Bindian Orogeny. The Whitelaw terrane contains the richest gold deposits in the Tasman Fold Belt.

A major episode of granite intrusion occurred in the Benambra Terrane, and also in the Stawell Zone in western Victoria during the Bindian Orogeny (405–415 Ma). In the Stawell Zone this was associated with a major phase of gold mineralisation, and a second phase of gold mineralisation occurred in the adjacent Bendigo Zone. The Melbourne Zone is characterised by continuing deep-marine sedimentation with conditions gradually becoming shallower in the western part of the zone.

Thick and diverse sediments characterise the Lachlan Fold Belt from the Cambrian until the Middle Devonian. Deformation and faulting of these thick sediments, and the later intrusion of granites and eruption of volcanics, forms Victoria's basement geology. In the Melbourne Zone, the Silurian to Middle Devonian sedimentary rocks lie conformably upon Ordovician rocks, as is the case in the Tabberabbera Zone.

In the Silurian to early Devonian, magmatism and granite intrusion occurred in the Grampians–Stavely Zone and in the eastern and western portions of the Lachlan Fold

Belt, but not in the central area. This was reversed in the Late Devonian when central Victoria became the focus with several large granitic bodies intruded during that time (e.g. Cobaw, Harcourt, Strathbogie).

The Tabberabberan Orogeny (385 Ma) affected the whole of Victoria, although its expression varied strongly. The most pronounced effects are observed in the previously undeformed Melbourne Zone, where the thick Ordovician to Devonian sediment succession was strongly folded and faulted. Kilometre-scale movement occurred along the two bounding faults of the Melbourne Zone. West of the Melbourne Zone its effects were very mild, limited to rejuvenation of older faults and generation of strike-slip faults ('cross-courses') in the Bendigo and Stawell zones. Gold mineralisation occurred in the Melbourne Zone, and in the Bendigo Zone to the west, where it was the third phase of mineralisation. The two terranes were amalgamated in the Middle Devonian.

The Kanimblan Orogeny (~340 Ma) was the last of the deformation episodes that built the Lachlan Fold Belt in Victoria. Its effects were mild in Victoria, as the crust across the state had already been deformed and was, by that time, quite strong (VandenBerg et al. 2000). A period of tectonic stability followed that lasted through the Permian until the onset of the break-up of Gondwana in the late Jurassic and Cretaceous. Deposition during this stable interval is most extensive in lows or troughs some of which are preserved below the cover of more recent sediments in the Murray Basin (Figure 2.3).

During the Permian, Victoria lay on the edge of an ice-sheet extending south. Sediments from this time are preserved as a marine and glacial sequence at Bacchus Marsh and Lake Eppalock and smaller scattered patches elsewhere, and marine black mudstone (Urana Formation) within the Numurkah Trough of the Murray Basin (Figure 2.3). The periglacial sediments include fluvial (river-borne) sandstone and mudstone, as well as lacustrine (lake-bed) sediments with 'drop stones'.

Within the River Red Gum Forests study area, basement rocks rarely appear above the largely flat riverine plain, with notable exceptions at Pyramid Hill, Terrick Terrick, Lake Boga, and along the river valleys that extend into the Eastern Highlands.

Mesozoic

The rock record of the Triassic through Jurassic is poorly represented in Victoria and not known from the study area. Triassic granites and volcanics occur in the highlands near Benambra, and a small isolated sedimentary sequence at Bacchus Marsh has also been identified as Triassic (Webb & Mitchell in prep). The absence of Mesozoic deposition may be due to Victoria being an elevated area at the time. Very little definitive Jurassic material has been identified within Victoria—perhaps only limited volcanics and intrusives from the Casterton and Bendigo areas could be reasonably attributed to this time period.

Early Cretaceous age (145–95 Ma) rocks are well represented across southern Victoria with extensive

outcropping and subsurface sequences of volcanogenic and fluvial sandstones and siltstones (Otway, Bass and Gippsland basins) and minor occurrences within the Murray Basin at depth. During the Late Cretaceous (95–65 Ma), the mountains of the Great Dividing Range rose as the rift between Australian and Antarctica spread. Downwarping on the northwestern side of the range enhanced the broad depression of the Murray Basin which rests upon basement rocks with a hilly topography much like the adjoining landscape. Stream deposits on both sides of the Great Dividing Range contain rich alluvial gold deposits accumulated during the prolonged erosion following the Permian glaciation. Subsequent basalt eruption, especially south of the Divide during the Cainozoic, buried the river sediments and gold-rich gravels that are now known as 'deep leads'.

Cainozoic

Sedimentation in the Murray Basin and the rivers draining into it was largely regulated by sea level changes with fault movements throughout the Cainozoic influencing deposition patterns and hydrology more generally (Figure 2.3). For example, movement on the Tawonga Fault influenced the development of the Ovens and King Rivers in the eastern part of the study area. Across much of the study area only small tectonic movement has occurred in the Cainozoic, although even small vertical offsets have resulted in major deflections of drainage lines on the flat land of northern Victoria. The most significant of these is the Cadell Fault near Echuca where the fault block diverted both the Murray and Goulburn rivers prior to 35,000 years ago (see chapter 3 Geomorphology and Land Systems).

Cainozoic sediments, of both marine and terrestrial origin, blanket and infill the basement surface across nearly the entire study area (Map 2.1). Conditions for accumulation of sediments were favourable during three major episodes of the Cainozoic era (65–0 Ma) reflected in three layers comprising the Renmark, Murray and Wunghnu groups. These sediments consist of fluvial-lacustrine sandstones, claystones and minor coals of the Renmark Group (Palaeocene–Early Oligocene), the predominantly marine carbonate Murray Group (Oligocene–Middle Miocene), overlain unconformably by the Late Miocene–Pliocene marine to fluvial Wunghnu Group. In the eastern part of the basin the marine Murray Group is replaced by non-marine sediments.

In general, Palaeocene to Pliocene sediments have limited outcrop in the study area and are largely blanketed by the younger Quaternary sediments of the riverine plains, and the aeolian (wind-blown) sequences of the dunefields and sand plains (Map 2.1).

Renmark Group

The Palaeocene to Oligocene Renmark Group rests unconformably on older basement rocks, infilling the pre-existing topography. The sequence has variable thicknesses up to a maximum of 300 m in the Mildura area, and up to 60 m in the palaeo-drainage systems of the Loddon, Campaspe and Goulburn rivers but less over the palaeo-topographic highs. Renmark Group sand units are important groundwater recharge sources for overlying aquifers. Brown coal seams occur at the top of the Renmark Group, especially in the Kerang,

Torrumbarry and Echuca areas (see chapter 16 Earth Resources). The Renmark Group is overlain by the marine Oligocene–Miocene Murray Group or its non-marine equivalents and does not outcrop in the study area.

Murray Group

The Murray Group refers to all marine carbonate sediments between the top of the Renmark Group and the base of the Late Miocene or Early Pliocene Wunghnu Group. The limited Murray Group outcrop consists predominantly of exposures along river incisions and over the Gredgwin Ridge south of Kerang. It is not present in the Kerang–Cohuna and Goulburn areas of the Murray Basin and non-marine sediment equivalents occur to the east of this region. A complex mix of marine and non-marine sediments occurs across a poorly defined boundary between these areas. The Murray Group comprises a mixture of marine muds, clays and limestones (Ettrick Marl, Duddo Limestone, Geera Clay) and their non-marine equivalents such as the Calivil Formation. The Geera Clay is an important barrier to groundwater and provides a salt source to underlying Renmark Group aquifers, as well as restricting upwards-moving groundwater.

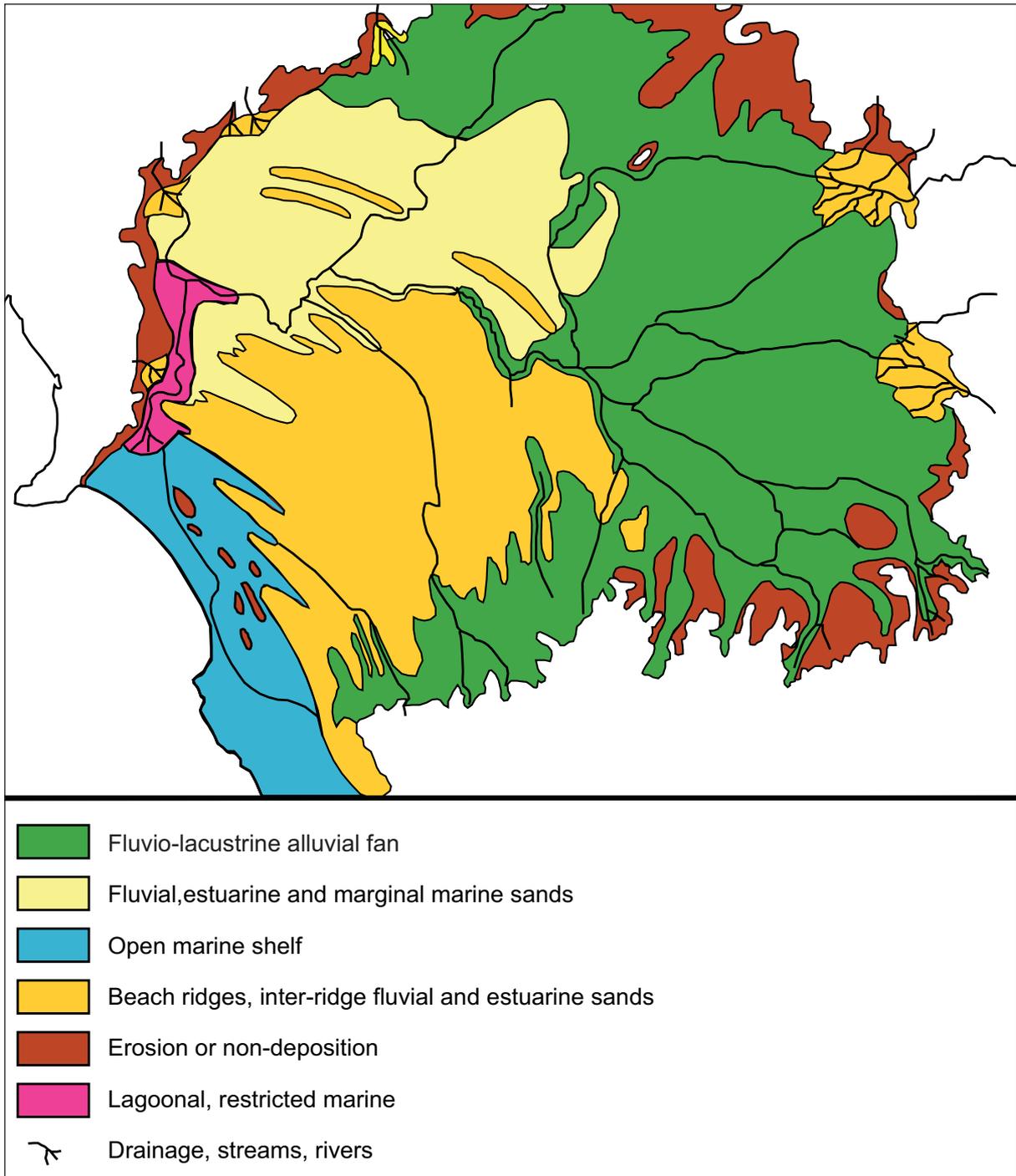
Wunghnu Group

The deposition of the Late Miocene to Pliocene Wunghnu Group commenced with a short-lived marine transgression followed by a slower regression of the sea. Sediments deposited during this time include marine units such as the green micaceous glauconitic marls of the Bookpurnong Beds, marginal marine units such as the Parilla Sand and non-marine equivalents such as the Shepparton Formation. These units are all unconformable on the underlying rocks. The unconformity is likely to represent a Late Miocene–Pliocene tectonic event similar to that identified in other areas of Victoria. This sequence comprises the majority of outcropping rocks throughout the study area and is therefore described in detail below.

The Wunghnu Group is highly variable with both marine and non-marine units from changing conditions of the Murray Basin including increasing climate variability (which affected both drainage and sediment derived from the Eastern Highlands) and changing sea levels. Sandstone aquifers and claystone units within this sequence have varying degrees of groundwater interconnection, both vertically and horizontally, providing significant groundwater resources in the eastern part of the Murray Basin.

The Pliocene Parilla Sand forms a series of sub-parallel ridges separated by swales across the western half of the Murray Basin in Victoria. It extends into the subsurface forming widespread sheet sandstones. These variably ferruginous quartz sands are cross-bedded, medium to fine-grained, and contain some bands of heavy minerals. Individual ridges can be up to 50 m high and several kilometres wide and extend for several hundred kilometres in a north-northwest direction. Beneath the Loddon Plains the formation is subdivided into the Kerang Sand (which laterally replaces the Bookpurnong Beds), an intermediate Tragowel Clay Member and the upper Wandella Sandstone, which is the main outcropping unit.

Figure 2.4 Murray Basin during the Pliocene showing palaeogeography and depositional environment.



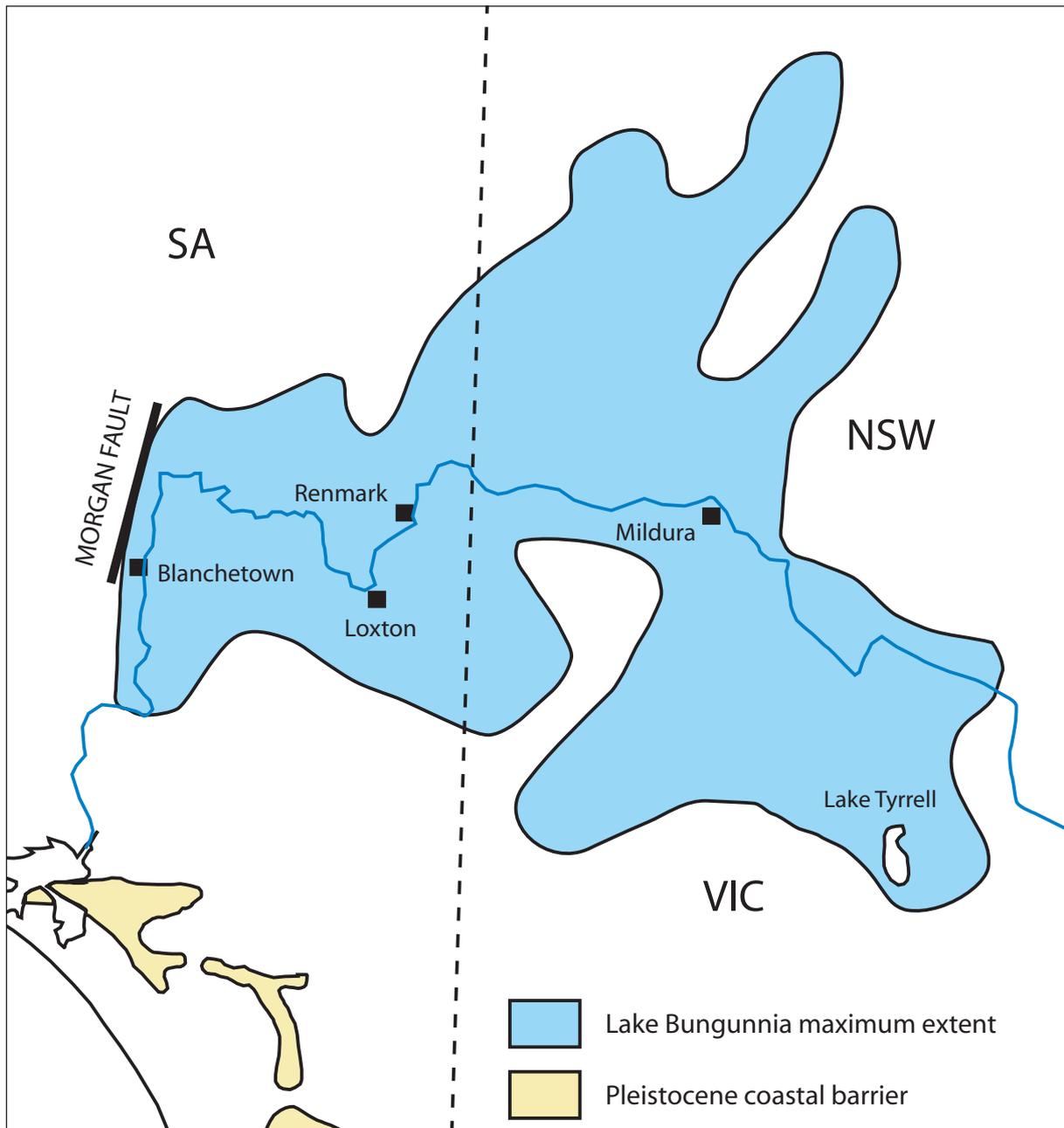
Source: Evans et al. (1990)

A suite of heavy minerals (zircon, ilmenite, rutile, tourmaline and monazite) in low concentration bands has attracted mining companies to the Parilla Sand (see chapter 16 Earth Resources). Where the Parilla Sand overlies Miocene sands, the heavy mineral grain-size appears to increase along with the total heavy mineral content.

Deposition in the Murray Basin in the late Neogene was strongly influenced by sea-level changes. Sea levels

peaked in the Late Miocene to Early Pliocene (about 5 Ma) at about 65 m above present. The sea encroached from the present coast between the Fleurieu Peninsula and Mount Gambier in South Australia, forming a large gulf that extended towards the northeast (Figure 2.4). Continental or non-marine deposition continued in the eastern and northern parts of the basin. Sand, gravel and clay of the Calivil Formation represent river valley fill and alluvial-fan sediments deposited over earlier units of the Renmark Group.

Figure 2.5 Maximum extent of Lake Bungunnia: formed when river flow to the sea was blocked in the Pliocene.



Source: modified after Belperio (1995)

During the Late Pliocene and into the Pleistocene, terrestrial processes predominated in the eastern and northern parts of the basin and deposited poorly sorted sediments of the Shepparton Formation in river, overbank and lacustrine settings associated with river sediment accumulation. Parts of the Shepparton Formation have ancient soil remnants known as palaeosols, typically disconformably buried by younger sequences, relating to discrete episodes of high or low river discharge, as part of an evolving sequence.

Towards the basin margins, the Shepparton Formation appears to cross-cut upper units of the Calivil Formation,

suggesting the two are separated by a disconformity. Channel deposits of Late Pleistocene and Holocene rivers and floodplain sediments comprise the modern-day alluvium of the Coonambidgal Formation.

Pliocene (~3.2 Ma) deposition in the western part of the basin was influenced by tectonism when uplifted areas, impeded outflow and formed a shallow (less than 70 m deep) freshwater to brackish mega-lake, known as Lake Bungunnia, in the western part of the basin (Figure 2.5). These relatively thin locally variable fluvio-lacustrine sediments comprise the greenish-grey, white or mottled red-yellow-brown silty to sandy Blanchetown Clay, with



quartz sand and gravel beds, carbonates and gypsum-bearing layers. Large shoreline migrations and terrestrial channels reworked the underlying Parilla Sand, depositing up to 10 m of clayey fine- to medium-grained quartz sand of the Chowilla Sand and the Irymple Member, lateral equivalents of the fluvio-lacustrine Shepparton Formation. Lake Bungunnia dried out during the Middle Pleistocene (about 0.6 Ma), due to increasing aridity and probably tectonic movement draining the basin or breaching a barrier to the sea. The uppermost Blanchetown Clay sediments are increasingly gypsiferous, suggesting that Lake Bungunnia was quite saline in its later days, when it may have split into smaller lakes (Copper & White 2003).

During the Quaternary, the eastern part of the basin has remained predominantly riverine plain with aeolian features such as source-bordering dunes and lunettes. Alluvial features are associated with the Murray River and its tributaries, including the Kiewa, Ovens, King, Goulburn, Campaspe and Loddon rivers. Rivers located further west, such as the Avoca and Wimmera, fail to reach the Murray and show river features characteristic of the increasing aridity that occurred during the Quaternary. Fluvial and aeolian sedimentary processes have periodically varied in relative importance with Quaternary climatic changes. By the late Quaternary, widespread river deposition was restricted to the eastern Riverine Plain, with wind-blown deposition predominant in the west.

The evaporitic and siliceous deposits of the Yamba Formation are widely dispersed in the northwest of the state, occupying topographic low-points such as the Raak Plain west of Hattah, and becoming sites of groundwater discharge. These gypsiferous clay and sand sediments overlie Blanchetown Clay in places, and were deposited since the Middle Pleistocene.

Aeolian dune deposits of the Woorinen Formation and the Lowan Sand form a thin cover over the earlier sediments and are a further example of the increasing influence of aridity on the late Quaternary landscape. Quaternary sediment input to the Murray Basin was minimal and dune sands were mainly derived from erosion of the underlying Parilla Sand.

Deposition of the Woorinen Formation occurred episodically, with the silty sand, sandy and silty clay members within the dune sequences capped by distinct, often calcareous, palaeosols (fossil soil horizons) perhaps

indicating prolonged periods of dune stability. The youngest Piangil Member lacks soil development, suggesting recent mobilization, and the underlying Kyalite Member was probably mobile at the time of the Last Glacial Maximum (23,000–19,000 years ago).

The Lowan Sand consists of linear, irregular and sub-parabolic dunes and sand plains characterised by a paucity of clay, as they are derived from re-working of Parilla Sand. Irregular to sub-parabolic dunefields have migrated in east-northeast from their source, forming elongated plumes across southeastern South Australia and northwestern Victoria (e.g. the Big Desert and Sunset Country). The study area boundary in this area is essentially where these dunefields end and the riverine plain starts.

Late Pleistocene and Holocene river systems form a contrasting landscape to that of the aeolian dunefields and sand plains. However, many of the river channels and their associated lakes and floodplains are relict or ephemeral features overprinted with a more recent signature indicating a much more efficient hydrological regime operated during the Middle and Late Pleistocene (Copper & White 2003). Modern rivers form the youngest of a sequence of four alluvial terraces that comprise the Coonambidgal Formation. On the riverine plain these features occur within the elevated alluvial terraces of the Shepparton Formation. Many of the present lakes in the Murray Basin are ephemeral or relict features. These features are described in detail in chapter 3 Geomorphology and Land Systems.

Future developments

GeoScience Victoria (Department of Primary Industries) has acquired an enormous amount of new geological and geophysical information from regional Victoria in order to encourage mineral exploration and development in regional Victoria. New, high-quality aerially mapped geophysical data are now available for most of the state, and the geology of important bedrock areas has been remapped in greater detail. New geological investigations by industry in combination with the scientific community has greatly advanced our understanding of the geology and mineral potential of the region. In particular, the complexity of the bedrock, particularly that beneath a cover of younger rocks is now being unravelled. This work provides a greatly improved framework for new mineral exploration, supported by Government funding (see chapter 16 Earth Resources).

3 Geomorphology and Land Systems

This chapter provides an overview of a system for characterisation of land based on the integration of several biophysical components. At the broadest level these are geomorphological characteristics, while detailed land systems are correlated with indigenous vegetation and soil types.

GEOMORPHOLOGY AND GEOMORPHOLOGICAL REGIONS

Geomorphology—or physiography as it was previously known—is the study of the Earth’s surface and processes that form natural features such as mountains, plains, coastlines and rivers. These processes may occur in the present or the past and be influenced by land use practices such as the building of dams, irrigation channels or other structures. This section describes geomorphological processes and landforms within the River Red Gum Forests study area.

The River Red Gum Forests Landscape

The diversity of landscapes in Victoria is due to variations in geomorphological processes across regions with different topography, tectonism, geological history and rock lithology, sea level and climate changes (Joyce et al. 2003). The physical landscape on which we live can be divided into regions of similar character in several ways. Previously divisions were based exclusively on landform or physiography. Other characteristics were subsequently incorporated, such as underlying geology, groundwater systems, climate and elevation. More recently land systems have integrated geomorphological and ecological characteristics. Victoria has been divided (starting with Rowan 1990) into geomorphological regions and further subdivided into geomorphological units on a regional or local scale. Land systems form the third tier of this division of physical characteristics.

The statewide land systems and geomorphological regions and units are currently under review by the Geomorphological Reference Group (GRG), coordinated by Department of Primary Industries. The revised scheme encompasses seven geomorphological regions, including four that are found in the study area: Eastern Uplands, Western Uplands, Northern Riverine Plains and the North West Dunefields and Plains. These regions and their component units are shown in Map 3.1. This section describes the geomorphology of the study area broadly and then in terms of its geomorphological regions. Subsequent sections examine the more detailed sub-divisions— geomorphological units and land systems.

Recent geomorphological processes in southeastern Australia have preserved the soil horizons, dunes and lake sediments that reveal evidence of past climate and changing landscapes. Sea level fluctuations and climate changes during the Quaternary (1.8 million years ago (Ma) to the present), especially increasing aridity in the Pleistocene (1.8 Ma to 10,000 years ago), had a major impact on inland areas of Victoria, and particularly the study area.

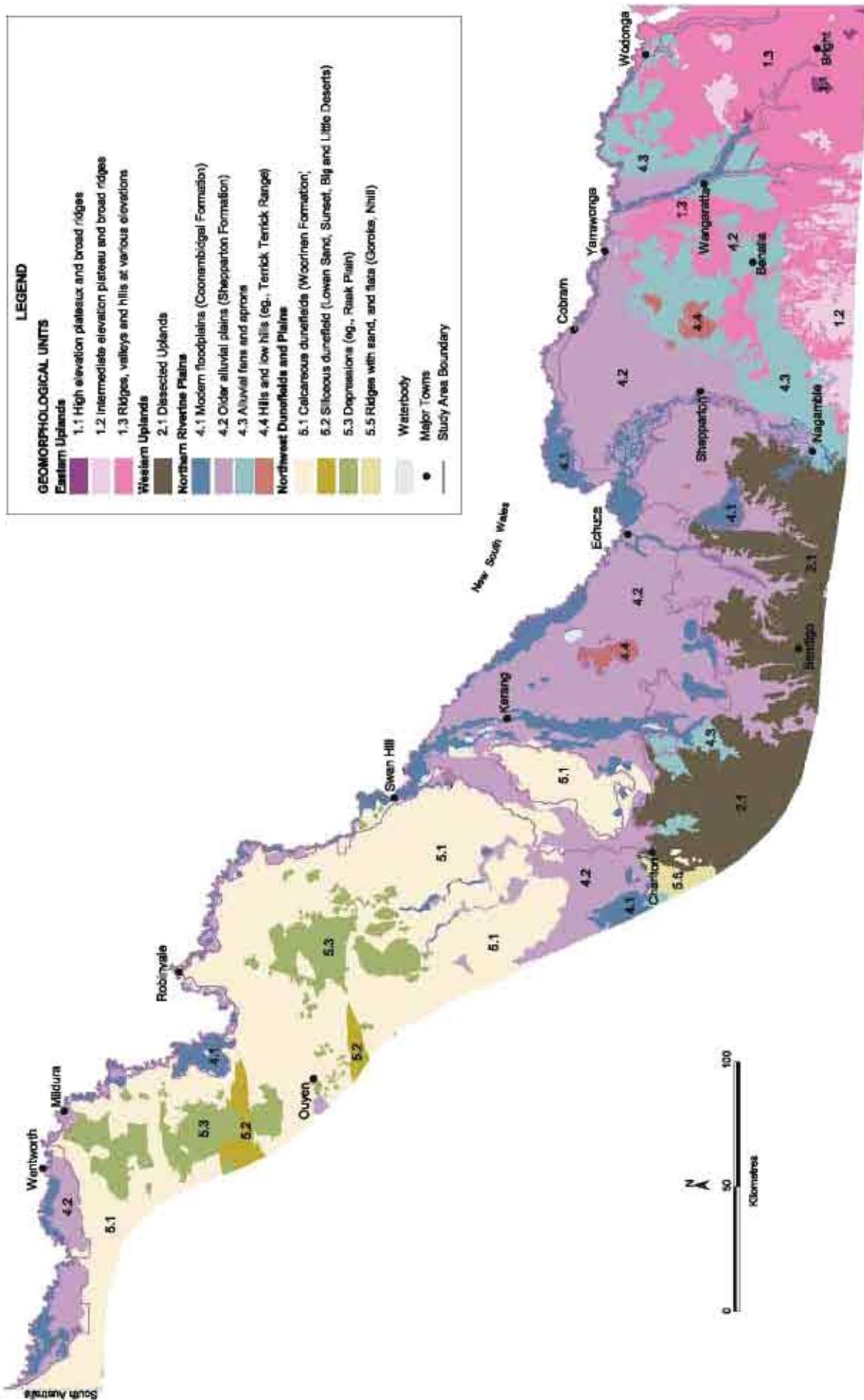
The River Red Gum Forests study area lies in a flat or gently undulating landscape, on the extensive Northern Riverine Plains, that extend inland through New South Wales (NSW). The North West Dunefields and Plains are of relevance in the northwestern part of the study area. Some hilly areas occur in the Eastern and Western Uplands along the southern and eastern edges of the study area.

Geomorphological features of importance in the study area are the lunette-fringed lakes and entrenched meander belts of the river system. Lunettes are crescent-shaped dunes formed by wind-blown (aeolian) movement of sand and clays from dry lake-floors. The larger the lake, the greater the dune source area and hence the largest lunettes form on the down-wind side of many of the biggest lakes across the Northern Riverine Plains during dry climatic phases. In some places the changing climate has left only the lake floor and lunette as evidence of formerly much more extensive bodies of water (Lake Kanyapella, Lake Bungunnia and Hattah Mega-lake—described below). Source-bordering dunes are formed in a similar manner to lunettes and often occur on the northeastern side of large point-bars (see Box 3.1, Figure 3.1) in the major rivers that were deflated and transported locally by aeolian or wind-blown processes during dry climatic phases. These wind-blown deposits are important cultural sites and may contain Aboriginal artefacts or burials such as those at the Willandra Lakes World Heritage Area (Lake Mungo) in NSW.

The present-day river system of the Northern Riverine Plains is the remnant of an older, more extensive system initiated in the Eocene 55–35 Ma (Macumber 1978). Major landforms include streams that leave the major rivers and re-join again downstream (anastomosing anabranches) forming large islands (Gunbower, Lindsay, Wallpolla and Mulcra Islands), large complex wetland and billabong systems (Hattah lakes, Barmah–Moira lakes and forest), and river meanders embedded in larger wavelength meanders inherited from ancient faster flowing streams (see Box 3.1).

Older surfaces, such as where bevelling cuts across changes in bedrock, or where distinctive weathering horizons are preserved, are of significant geomorphological interest. Many are related to the regional sedimentary record, particularly the erosion of uplands and major unconformities within sedimentary sequences.

Map 3.1 Geomorphological Units in and adjoining the study area.

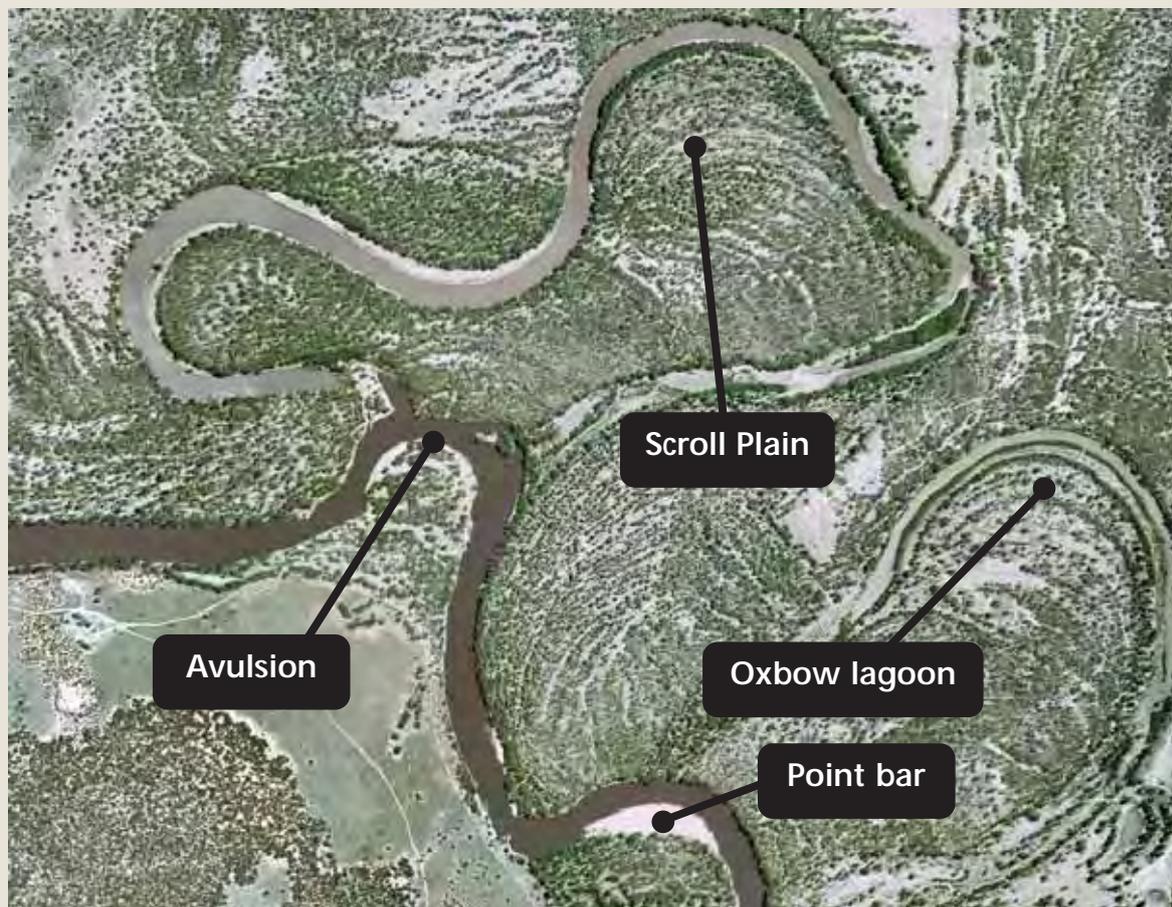


Box 3.1 River Meanders

Rivers rarely maintain a straight route, particularly on floodplains. Often a series of bends and loops known as meanders snake across the landscape, reflecting the way in which resistance to flow is minimised and energy spread evenly along the river course (see Figure 3.1). As water rushes past the outer part of a bend, sediment is eroded from the riverbank. With the slower flow concentrated around the inner side of each bend, coarse sediment accumulates and forms an area of shallow water and sandy beaches or point bars. Through this process incremental channel migration occurs and a new floodplain is created by lateral accretion. Channels bend further with migration until the narrow neck of land between one bend and the next is breached (avulsion). A new shorter flow path is created, and the old channel is abandoned to evolve into an oxbow lagoon or billabong. The size of meanders depends upon the underlying geology and the changing speed and volume of water flow. The rate and direction of channel migration, and the degree of floodplain inundation, are affected by tectonic as well as fluvial or river processes.

Compared with other parts of the world, a relatively small proportion of Australia's rivers are meandering, and the meanders of the River Murray are well developed and relatively unaltered by European settlement. Within the study area no single area of floodplain is representative of the whole Victorian Murray. Rather, some areas demonstrate the effect of local tectonic activity (Barmah forest), some suggest the influence of regional tectonism, and others may not be affected by tectonism at all (Gunbower Island, Yarrowonga reach). Some floodplains appear to show rapid oblique channel migration, the traces of which are not masked by flood deposits, and the result is clearly-marked 'scroll plains' such as those of Lindsay Island. In others, the old channels are semi-parallel to the present channel, and migration is slow enough that the present channel crosscuts the palaeochannels (Kings Billabong near Red Cliffs). Other floodplains such as Belsar Island near Robinvale may have more layers of flood sediments, covering any traces of previous channel migration.

Figure 3.1 Air photo showing meander channel features of the River Murray floodplain, Retail Bend and Murray-Kulkynne Park (see Figure 3.2 for location).



The River Red Gum Forests study area, by design, encompasses particular biogeographic regions which mostly carry river red gum or associated vegetation types. Because biological features are strongly correlated with geomorphological systems, the study area mostly encompasses the Northern Riverine Plains geomorphological region (Map 3.1). Only small areas of other regions—the North West Dunefields and Plains, the Eastern Uplands and Western Uplands occur the study area (and Rees 2000; see Rowan 1990).

Northern Riverine Plains

The Northern Riverine Plain is an extensive alluvial plain associated with the Murray River and its tributaries, which extends north from the Western and Eastern Uplands of the Great Dividing Range to the River Murray. It can be divided into an upland fringing slope with low residual hills, a plain crossed by palaeochannels and modern rivers such as the Loddon, Avoca and Campaspe, and the major alluvial terrace and floodplain-infilled troughs of the Goulburn and Murray rivers. Concentrations of lake and lunette systems, such as the Kerang Lakes, Avoca Marshes and Kow Swamp, occur intermittently across its surface.

Much of the plain is made up of Quaternary alluvial deposits of clay, silt sand and gravel (Shepparton and Coonambidgal Formations), forming broad fans extending and widening northwards from the uplands edge. The sediments were laid down in a fluvial system of floodplains and river channels, and in scattered shallow lakes and wind-blown dunes. The deposits extend from upland valleys such as the Loddon and Ovens and coalesce into an almost continuous mantle across the study area. Leveed channels of several ages are present, sometimes forming ridges above the general elevation of the plains, and may have source-bordering dunes. Higher terraces and aprons of uncertain age occur along the southern edge adjoining the uplands. In places, low rocky ridges of older basement rocks, such as the Terrick Terrick hills, rise above the plains.

Features of floodplain evolution and development can be categorised as modern streams, prior streams, ancestral rivers and lakes and lunettes (e.g. Bowler et al. 1978; Pels 1964; Rutherford 1990). Modern streams are the channels and swamps of the present-day river system (described in more detail under 'River Murray Evolution', below), with generally narrow channels and well-defined levee banks and floodplains. Some, such as the Campaspe, have alluvial terraces. Lakes and swamps lie in cut-off meanders or avulsion channels across the floodplains.

Prior streams are the traces of older rivers characterised as low ridges of silt and sand—former natural levee banks—that lie adjacent to shallow, meandering depressions of the former river channels. Often these channels are perched higher than the present floodplain and may be a great distance from present rivers. Typically, prior streams do not carry surface water, except in high flow conditions, and both channels and levees are broken where they have been partly eroded by later events.

Ancestral rivers are old, abandoned channels that lack levee banks, are incised into the surface of the plain,

and are partly filled with alluvium. They are associated with and often crossed by the modern rivers and may act as floodways during high water flow. Many are wider than those of the present-day rivers, have coarse sand and gravel, and have much larger meanders, indicating they formed at times of much greater river discharge. Modern rivers often form a meander within the larger meander pattern of these ancestral rivers.

Lakes on the riverine plain have formed in three ways, as cut-off meanders and abandoned channels, deflation (wind-eroded) hollows, and as tectonic depressions. Many of these lakes are composite and fed by groundwater. Associated with shallow lakes are lunettes, crescent-shaped dunes composed of clay, silt and fine sand typically along the eastern shoreline. Some are single, but many form complex systems that record the gradual decrease in the size of the adjoining lake (e.g. palaeo-Lake Kanyapella, see Box 3.2). Most of the lunette sediment consists of clay and fine sand blown from the lake floor during dry conditions.

The alluvial terraces and floodplains of the modern rivers (Coonambidgal Formation—see Map 3.1) often have source-bordering dunes on the northeastern sides of channels, formed from fine sand deposited by the same river in times of greater flow. Several former courses of the major rivers, such as the Murray and Goulburn, are marked by extensive meander belts and occur in shallow depressions incised below the plains. These features indicate several phases of channel and dune activity, with many dunes forming along the Murray River during the last major dry glacial period. River channels with wide sandy point bars persisted into the Holocene, but formation of dunes along the river ceased as the climate warmed.

The final episode of river deposition after the glacial and periglacial conditions is present along the length of the River Murray and its tributaries. The current channel of the Murray River may be only a few hundred years old in many places. Some areas on the riverine plain, such as between Tragowel and Pine Grove, have only rare channels and no source-bordering dunes. Much of the central and eastern parts of the plain are overlain by a shallow mantle of calcareous wind-blown deposits (or parna) comprising silt and clay aggregates.

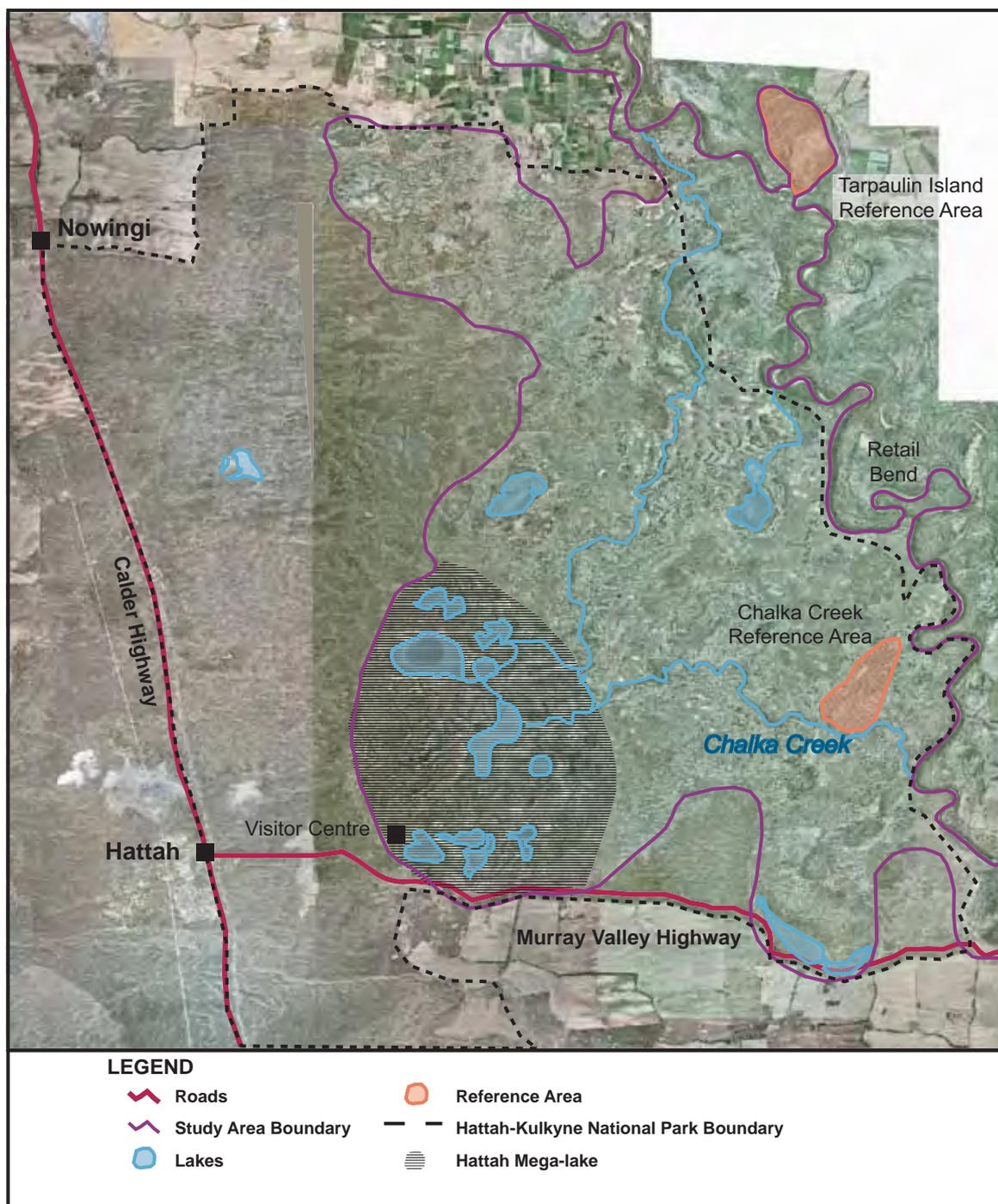
Near Echuca, movement along the Cadell Fault dammed the River Murray to produce palaeo-Lake Kanyapella around 30,000 years ago (see Box 3.2 Bowler 1978; Cupper & White 2003; Page et al. 1991; Rutherford & Kenyon 2005). Other faults (such as the Echuca South Fault) cross the alluvial deposits and alter the earlier leveed stream channels, allowing a chronological sequence of channels to be mapped (see Rutherford & Kenyon 2005). However some previously postulated 'faults' e.g. Leaghur Fault, are now regarded as erosional features, as evidence for displacement or movement cannot be found.

Hattah Lakes is the most extensive lake system along the River Murray, where a series of about 21 interconnected lakes and wetlands formed in a depression at the easternmost limit of the Sunset Country dunefields (Figure 3.2). The lakes are surrounded by longitudinal dunes of the Woorinen Formation and sub-parabolic dunes of the Lowan Sands. Water is supplied to the

lakes by flooding from Chalka Creek:—an anabranch of the River Murray. Several of these lakes lie on the floor of the pre-existing Hattah 'Mega-lake' (in the order of 50 square km in size), which is bordered to the east by a large lunette (Kotsonis et al. 1999; Macumber 1978). The large size of the palaeo-lake, combined with high river discharge in the past, suggests that it contained freshwater, and developed during the pre-glacial wetter climates with significantly more surface water in the Murray Basin. Hattah Mega-lake is entrenched at a topographic level similar to the upper river terrace in this area, and probably developed from an old meander cut-off on this terrace.

Sub-parabolic dunes completely cover the high level terrace at Hattah Lakes and partially cover the Hattah Mega-lake floor, indicating that dune encroachment occurred at similar times to lunette formation and after the drying-out of the lake. The presence of source-bordering dunes and sub-parabolic dunes on the low level terrace suggests a high level of wind activity during deposition of this terrace. The present fluvial regime lacks source-bordering dunes and truncates sandy dunes on older terraces, indicating that dune mobility had ceased when this river system became active about 15,000 years ago. Within the Hattah Mega-lake, this reduction in aeolian activity was accompanied by a

Figure 3.2 Air Photo of the Hattah lakes complex.



change from saline lakes and clay lunette formation to freshwater conditions, as recorded by the presence of freshwater fauna in local midden deposits. Dating of the Northern Riverine Plain landforms has unravelled much of the Late Quaternary climatic history and processes in this region.

Downstream of Hattah the remaining area of the Northern Riverine Plains is represented as an entrenched and more constrained river system containing diverse landforms including anabranches that form large islands such as Lindsay, Wallpolla and Mulcra Islands, as well as meander channels, billabongs, levees and low dunes, with larger overflow lakes and lunettes abutting the semi-arid Mallee region. The area consists of three main geomorphological components: the riverine floodplain (subject to periodic flooding and encompassing numerous oxbow lakes, ephemeral wetlands and active meander belts); broad, flat alluvial plains (infrequently flooded); and alluvial rises or elevated terrace areas that were built up during more arid periods by wind-blown material from the surrounding areas. To the south and flanking the floodplains, lie the North West Dunefields and Plains.

North West Dunefields and Plains

The North West Dunefields and Plains extend north from the edge of the Western Uplands to the margin of the Northern Riverine Plain. In the study area, it occurs only in small peripheral patches west and north of Kerang (Map 3.1). This geomorphological region consists largely of dry, sandy, gently undulating plains with extensive siliceous and calcareous dunefields, becoming more subdued towards the south. Beneath the plains is a low relief bedrock surface, only rarely rising above the plains as low granitic hills (such as at Wycheproof). Rivers in the region, such as the Avoca and Wimmera, rise in the Western Uplands to the south, lose water by evaporation and infiltration as they flow northwards, and do not reach the Murray. Elsewhere across much of the North West Dunefields and Plains there is almost no run-off, except locally after heavy rain. The rivers are linear and relatively fixed, showing little evidence of migration, and are flanked by floodplain and terrace deposits of Pleistocene and Holocene age. Low-lying areas contain saline lake complexes, or freshwater lakes fed by the rivers (e.g. Raak Plain, Avoca Marshes). Clay plains, cemented in places by calcrete, underlie large parts of the dunefields, and salt lakes in the north of the region. Beneath the dune and lake sediments are the curvilinear coastal ridges of the Pliocene Parilla Sands.

There were several separate phases of dune activity comprising siliceous and calcareous dune complexes. A siliceous (Lowan Sand) dunefield (Sunset Country) lies to the south and west of the riverine plain in northwest Victoria and contains both linear and parabolic dunes. The parabolic dunes are often large, with sharp crests, and interspersed with wide sandplains and smaller, often smooth-crested, dunes of variable orientation. The linear dunes are closely-spaced, low and smooth-crested, with narrow, sandy swales. Dunes of both types are oriented east-west to northeast-southwest, parallel to the present dominant wind directions.

The calcareous dunefield forms a large area of the Mallee extending discontinuously from Nhill northeast to

the Northern Riverine Plain, and includes reddish quartz sands (Woorinen Formation). These dunes are vegetated, predominantly linear and oriented east-west, but are not uniformly distributed. In the west quartz sand and carbonate dominate, but in the east, where the dunes have migrated over the clay-rich riverine plain, up to 20 percent clay content is common.

These calcareous dunes and associated palaeosols reflect the alternation of cool and arid conditions with wetter soil forming conditions. The siliceous dunes of the Lowan Sand have a notable absence of clay and carbonate in contrast to the Woorinen Formation dunes.

Large, variably saline lake complexes occupy low areas, such as the Kerang Lakes and the Raak Plain adjoining the study area. These saline lakes are groundwater discharge basins or relict groundwater discharge features, where saline groundwater can emerge and, through intense evaporation, produce hypersaline brines. Sediment is deposited by aeolian input and precipitation from groundwater; typically lake floor sediments are dominated by gypsum.

The freshwater lakes differ from the saline lakes in that they contain fluvial or river sediment and have well-defined elliptical or rounded margins. The eastern sides of most of the lakes have low half-moon-shaped lunette dunes of sand and gypseous silt. Orientation of these lunettes indicates that westerly wind regimes were responsible for their formation, which are thought to have dominated during arid dune-building phases of the Pleistocene.

Eastern Uplands

The River Red Gum Forests study area extends along the King, Kiewa and Ovens rivers into small areas on the northern slopes of the Eastern Uplands (Map 3.1). The Eastern Uplands form part of the broader Great Dividing Range, and are the largest and highest upland areas of Victoria. The region can be divided into two broad areas: the gentler topography of the high plains and the deeply incised valleys of the northern and southern slopes, including some low plateaus.

The northern slopes of the Eastern Uplands consist of steep-sided branching river valleys with thick sediment, separated by high, narrow ridges with mostly young, stony gradational soils caused by the continual movement of weathered material down the slopes. River gradients within the dissected northern slopes are steep, particularly in the upper reaches, but gradually decrease as the valleys widen downstream and enter the study area. River direction is often determined by past geological activity, for example, the Kiewa River follows the north-northwest line of the Kiewa Fault. These northern rivers flow either across the Riverine Plains to join the Murray River (Goulburn, King and Ovens Rivers) or, east of Wodonga, into the Murray directly (Indi (or Upper Murray), Mitta Mitta and Kiewa Rivers).

The lower parts of the river valleys of the northern margin are partially filled with alluvium and have open U-shaped or sometimes angled cross-sections. The alluvial flats are often flooded during late winter and spring in areas where snowmelt contributes to streams. Well-developed alluvial fan aprons have been deposited by ephemeral streams draining the sides of some of the

major valleys. The large, older fans may be cut by subsequent erosion and new fans deposited in the gullies; as many as four 'nested fans' occur in some locations. Paired river terraces are common, and typically several sets can be identified.

Western Uplands

The Western Uplands extend from Kilmore Gap north of Melbourne westwards to near the Victorian-South Australian border. A small area of the Western Uplands occurs in the southern part of the study area near Wedderburn (Map 3.1). The region is low, with an average elevation of about 300 m, which divides drainage areas. The Loddon, Campaspe and Avoca Rivers flow north from these uplands towards the Murray River. The major valleys, terraces and floodplains of the Avoca and Loddon rivers are features of the Western Uplands' northern margin. Between the main valleys, the slopes of ridges and hills are often deeply weathered and mantled by colluvium and alluvium, with fresh to saline springs.

From the northern edges of the Western Uplands two palaeosurfaces extend northwards beneath the Northern Riverine Plain. The Karoonda Surface occurs on the uplands fringe but mostly overlies the Parilla Sands in the Murray Basin, as well as partly underlying the Blanchetown Clay. The Mologa Surface is a highly weathered, low-relief palaeosurface that overlies the upper parts of the Renmark Group and Murray Group within the Murray Basin—see chapter 2 for more details of the formations on which the palaeosurfaces lie.

GEOMORPHOLOGICAL UNITS AND LAND SYSTEMS

In this section, the detailed geomorphological units within each of the four geomorphic regions of the study area are described, before land systems are briefly summarised in the following section.

Geomorphological Units

In total, eight geomorphological units are found in the study area (Table 3.1).

Table 3.1 Geomorphological Units within and adjoining the study area.

Region	Unit	Brief Description	Map symbol
Eastern Uplands	High Elevation Plateaux and Broad Ridges	Subalpine terrain of low relief; source area of major streams and rivers—outside the study area	1.1
	Intermediate Elevation Plateaux and Broad Ridges	Montane terrain of low relief—outside the study area	1.2
	Ridges, Valleys and Hills at Various Elevations	Highly dissected terrain as well as outlying terrain	1.3
Western Uplands	Dissected Uplands	Generally subdued terrain in contact with the plains and dunefields	2.1
Northern Riverine Plains	Modern Floodplains	Present floodplain (Murray valley)	4.1
	Older Alluvial Plains	Shepparton Formation representing the older floodplain extent	4.2
	Alluvial Fans and Aprons	Associated with the erosion of the Uplands and the major river systems	4.3
	Hills and Low Hills	Inliers such as the Dookie Hills and the Terrick Terrick Range	4.4
North West Dunefields and Plains	Calcareous Dunefields	Predominantly linear dunes with various proportions of associated plain or swales	5.1
	Siliceous Dunefields	Adjoining study area only	5.2
	Depressions	Small area north of Swan Hill within study area; larger areas adjoining study area (Raak Plain)	5.3
	Ridges with Sand, and Flats	Adjoining study area only	5.5

Note : Map symbol numbers correspond with those in Map 3.1 and in the text on the following pages.

Northern Riverine Plains Units

The major groupings within Northern Riverine Plains are Modern Floodplains, Older Alluvial Plains, Alluvial Fans and Aprons, and Hills and Low Hills.

Modern Floodplains (4.1) are dominated by the major streams that often have a meander belt below the current plain level, such as those along the Murray, Ovens and Goulburn Rivers. Areas of inundation away from modern channels occur at Gunbower forest, Barmah forest, the Hattah lakes area, Lindsay and Wallpolla islands, Dingee Swamp and the Loddon River fan. There are also young lakes and basins with lunettes such as Kow Swamp, Lake Cooper, Lake Kanyapella depression and Lake Tutchewop.

Older Alluvial Plains (4.2) cover much of the study area, and comprise the extensive elevated plains away from the modern floodplains. This grouping includes plains with leveed channels (prior streams) such as those at Tatura and Naneella, as well as plains with non-leveed channels at Tragowel and Pine Grove. Lakes and depressions with lunettes, such as Lake Mokoan (originally Winton Swamp), are also associated with the Older Alluvial Plains.

At present there is no detailed information below the land systems scale available for significant areas of this group. Future mapping will incorporate work undertaken for irrigation potential in the 1960s and 1970s by the then Department of Agriculture. Unlike the current land systems coverage, the revised scheme will differentiate prior stream and non-prior stream areas, and related cover such as soil associations.

Alluvial Fans and Aprons (4.3) are associated with the elevated areas or uplands as well as the major streams which have deposited material upon leaving the uplands. These areas are quite extensive abutting the study area, but only small areas of low fans carry river red gum or associated vegetation communities. Alluvial fans have formed over much of the middle Broken River catchment (outside the study area) which is bound by the Strathbogie Ranges and the Warby Range, and in parts of the lower Loddon River.

Hills and Low Hills (4.4) such as the inliers of the Terrick Terrick hills and the Dookie hills, interrupt the predominantly flat alluvial plains landscape. Erosion of these hills has provided a source for deposition of coarse-grained material such as gravel and sands, and hence local variations in environment or habitat.

North West Dunefields and Plains Units

The North West Dunefields and Plains includes what was formerly known as the Mallee Dunefields (Rowan 1990) and consists of aeolian or wind-blown dunefields (calcareous and siliceous), basins or depressions, plains and ridge and flat terrain. The revised scheme (based on work by Rowan (1990), particularly that undertaken for the LCC (1987) Mallee Area Review) standardises this geomorphological division to a three tiers system that is used for the remainder of Victoria. The main groupings within the study area are minor occurrences of Calcareous Dunefields, Siliceous Dunefields, and Depressions. The three other major divisions of this geomorphic region occur outside the study area.

Calcareous Dunefields (5.1) consist of aeolian dunefields with various proportions of dune, plains and minor depressions. The dunes decrease in frequency as they approach the River Murray alluvial floodplains. These areas are utilised extensively for cropping due to the moderate to high nutrient status of the soils.

Siliceous Dunefields (5.2) occur in distinct belts alternating from east to west between parabolic and linear dunes. These areas are characterised by low nutrient soils unsuitable for cropping, and have therefore been retained mostly as large tracts of native vegetation on public land that form the large desert parks of the Mallee, including the Sunset, Big Desert and Little Desert National Parks.

Natural depressions or shallow basins (5.3) have formed generally as groundwater discharge areas, which are saline and often gypseous. A notable example is the Raak Depression located west of Hattah, just outside the study area. A small area of this geomorphic division occurs within the study area, to the northwest of Swan Hill. Lunettes associated with these depressions, provide an indication of the past extents of lakes under climatic conditions different to those today.

Eastern Uplands Units

The Eastern Uplands comprises the elevated landscape east of the Kilmore Gap and contain major alluvial valleys such as the Kiewa, Ovens, King, Goulburn, Broken and Murray Rivers that flow out into the Northern Riverine Plain. The area covered by this geomorphological region within the study area is comparatively small, and consists of valleys extending into the uplands. These outliers of the more extensive area of uplands consist of either Palaeozoic sediments or Palaeozoic granites, generally of subdued terrain.

Western Uplands Units

The Western Uplands are elevated regions (generally formed of hard rock) west of the Kilmore Gap. These uplands are generally more dissected and lower than the Eastern Uplands, as well as having a drier climate. The Loddon, Campaspe, Avoca and Wimmera rivers are the main waterways flowing north out of the Western Uplands and towards the Murray River floodplain.

This geomorphological region comprises a comparatively small portion of the study area, consisting of extended valleys into the uplands and as well as outlying units predominantly to the north of Bendigo and Wedderburn. The major divisions within this unit are largely defined by underlying rock lithology which in turn defines hardness and therefore elevation in eroded landscapes. A very small part of the Dissected Uplands (2.1) unit is included within the study area.

Land Systems

Compared to geomorphological units, land systems describe a more detailed level of land information within the geomorphological framework. Land system mapping is used to characterise land in terms of its capabilities, limitation and management requirements, particularly in the context of agriculture use. In addition, prior to the advent of detailed vegetation mapping (e.g. at the ecological vegetation class or EVC level—see chapter 5 Biodiversity), the LCC used land systems as the basis for



recommending representative areas for particular public land uses (typically reference areas and conservation reserves).

Individual land systems have been allocated a key to provide a systematic nomenclature at the statewide level. The land systems set compiled by Rowan (1990) which has been updated (Rees 2000) provides a key for land system description based on geomorphological divisions, landform, surface lithology, geological age, climate (rainfall) and a unit designation. The land systems key is provided in Table 3.2.

As shown in Table 3.2, each land system has a unique range of land components. For example, 4.1 FfQ4-1 indicates that the land system occurs in the Modern Floodplain unit of the Northern Riverine Plains (4.1); it is a Floodplain landform (F), with a fine textured sediment lithology (f) of Quaternary age (Q), has an annual

average rainfall of 400-500mm (4) and is the first designate of this type (1). The tables associated with these statewide land system entries also indicate broad soil and vegetation types as well as a simple assessment of land degradation susceptibilities (Rowan 1990).

A table of the land systems covering the largest extent within the River Red Gum Forests study area is provided below (Table 3.3). Those land systems that comprise a small area have been grouped under broader categories for simplicity. Map 3.2 is an example of a land systems map for an area near Swan Hill. In the northwestern part of this area the interaction of the North West Dunefields and Plains and Northern Riverine Plain may be observed. The modern floodplain occupies the entire floodplain compared to other areas in the southeastern corner of the map where the older floodplain extends laterally and occupies a more elevated or higher level of the landscape.

Table 3.2 Land Systems Key.

Landform		Lithology		Lithological Age		Climate—Av. Annual Rainfall (mm)	
F	Present Floodplain	c	Unconsolidated (coarse)	P	Palaeozoic	2	200-300
P	Plain above flood level	f	Unconsolidated (fine)	M	Mesozoic	3	300-400
D	Dunes	z	Unconsolidated (fine, saline)	C	Cainozoic, undifferentiated	4	400-500
R	Rise	g	Granite and gneiss	T	Cainozoic; Tertiary	5	500-600
L	Low hill	l	Limestone/calcrete (calcareous)	Q	Cainozoic; Quaternary	6	600-700
H	Hill	v	Acid volcanics			7	>700 (temperate)
M	Mountain	b	Basic volcanics			8	>700 (montane)
S	Depression/ Swamp/ lunette complex	m	Metamorphic rocks			9	>700 (sub/alpine)
C	Coastal Complex	s	Sedimentary				

Source: Rees (2000)

Map 3.2 Land Systems for an area near Swan Hill.

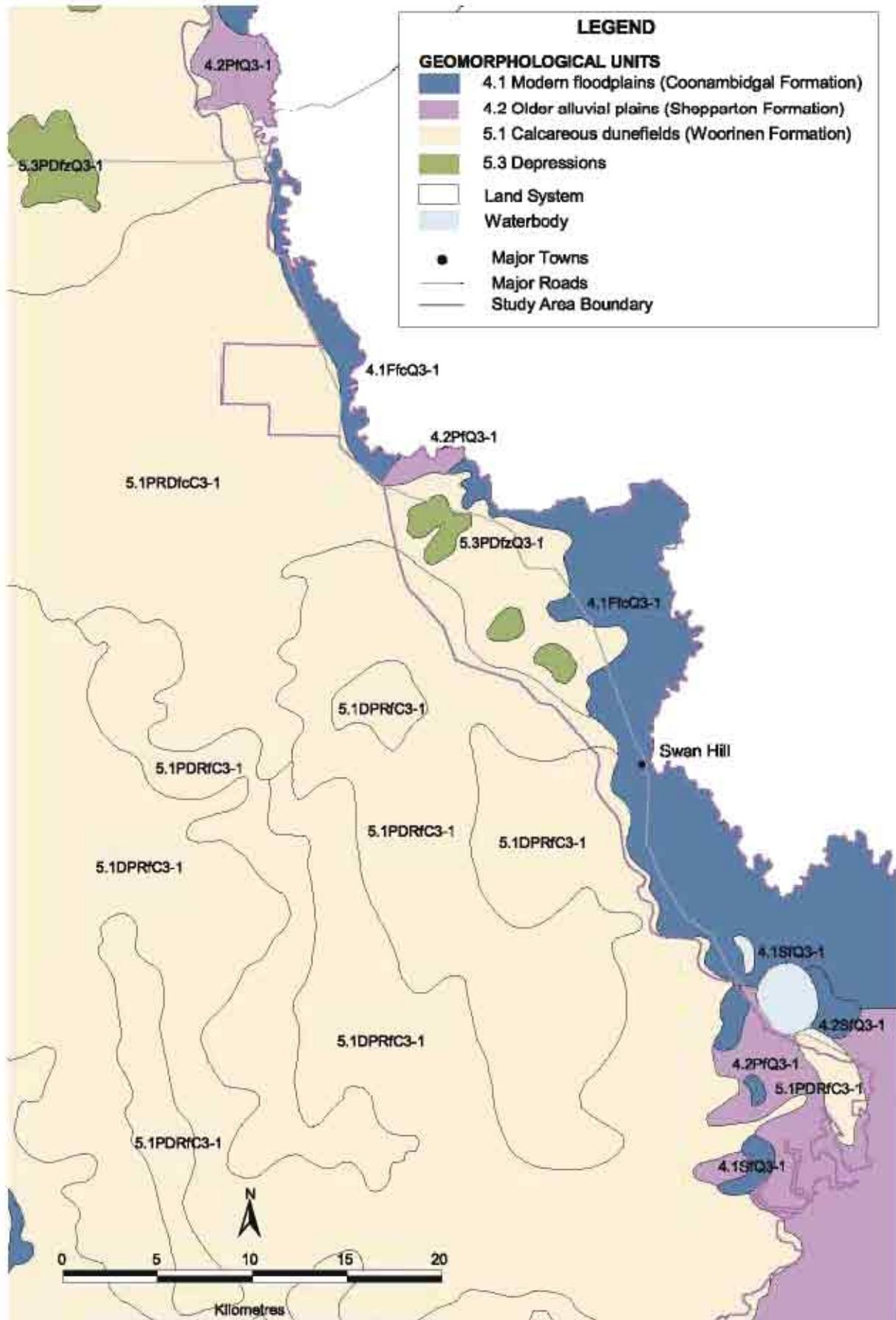


Table 3.3 Land systems in the study area.

Region	Land system
Eastern Uplands	1.1HgmP7-3
	1.1HsP7-5
	1.1HsP7-6
	1.1HsP8-5
	1.1LsP5-1
	1.1MsP8-5
	1.1PfcQ6-1
	1.1PfcQ8-1
	1.1PgP7-4
	1.1RbT7-2
	1.1RsP7-7
	1.3FfcQ7-2
	1.3HgP7-3
	1.3RgP7-4
	1.3RsP7-6
Western Uplands	2.1LmsP3-1
	2.1PfcQ3-1
	2.1Pft4-7
Northern Riverine Plains	4.1DPcfQ2-1
	4.1FDcfQ2-1
	4.1FSfQ3-1
	4.1FSfcQ4-1
	4.1FfcQ2-1
	4.1FfcQ3-1
	4.1FfcQ4-1
	4.1FfcQ5-1
	4.1FfcQ6-1
	4.1PfcQ2-1
	4.1PfcQ3-1
	4.1PfcQ3-3
	4.1PfcQ4-1
	4.1SfQ2-1
	4.1SfQ3-1
	4.1FSfQ4-1
	4.2FfcQ3-1
	4.2PDfcQ2-1
	4.2PfcQ2-1

Region	Land system
	4.2PfcQ3-1
	4.2PfcQ3-2
	4.2PfcQ3-3
	4.2PfcQ4-1
	4.2PfcQ4-2
	4.2PfcQ4-5
	4.2PfcQ4-6
	4.2PfcQ5-3
	4.2PfcQ5-4
	4.2PfcQ5-5
	4.2PfcQ6-5
	4.2PfcQ7-2
	4.2PfcQ4-1
	4.2PfcQ5-1
	4.2SfQ2-1
	4.2SfQ3-1
	4.3PfcQ3-4
	4.3PfcQ4-8
	4.3PfcQ4-9
	4.3PfcQ6-3
	4.4LfbP4-1
	4.4LgP3-1
	4.4RsP4-2
	4.4RsP4-5
	5.1DPRcfC2-1
	5.1DPRcfC3-1
	5.1DPRfcC3-1
North West Dunefields and Plains	5.1DPRfcC2-1
	5.1DPRfcC3-1
	5.1DPcfQ2-1
	5.1FSfQ3-1
	5.1PDRfcC3-1
	5.1PDfcQ2-1
	5.1RPDfcC2-1
	5.1PRDfcC3-1
	5.1PfcQ3-1
	5.3PdzQ3-1

EVOLUTION OF THE MURRAY RIVER

Across the floodplains, evidence of older streams and channels suggest that much more water flowed in the past than the present day. The Murray River itself occupies a channel of varying age and character. Some sections are relatively recent, being constructed on recent floodplain and stream sediments, and having a typically straight and narrow character (e.g. through the Barmah–Millewa forest; see Figure 3.3). Sections within the ancestral river have meanders with large wavelengths and a convoluted and often tortured path to the sea (Figure 3.4). This river is both ancient— with origins over the last 50 million years— and relatively modern (Macumber 1978).

Much research has been undertaken on the geomorphology and hydrological processes that have shaped the Murray River (e.g. Bowler & Magee 1978; Currey & Dole 1978; Macumber 1978; Pels 1964).

The greatest influence on the river character has been the capture of the main channel by large tributaries (i.e. Goulburn and Ovens Rivers) and movements of cross-cutting faults such as the Cadell Fault extending between Deniliquin and Echuca (see Figure 3.3 and Box 3.2). Currey and Dole (1978) divided the Murray into five geomorphic tracts from its source to the Victorian border as shown in Figure 3.4. Rutherford (1990) built on Currey and Dole's model, describing the current path of the river and the key elements and adding the South Australian Gorge and Swamp tracts.

The preservation of these complex ancient streams is an important geomorphological feature of this region. They have persisted largely because of a lack of tectonic activity in southeastern Australia over the last 30 million years. Climate has also played a significant role, with limited weathering or erosion over the last few million years.

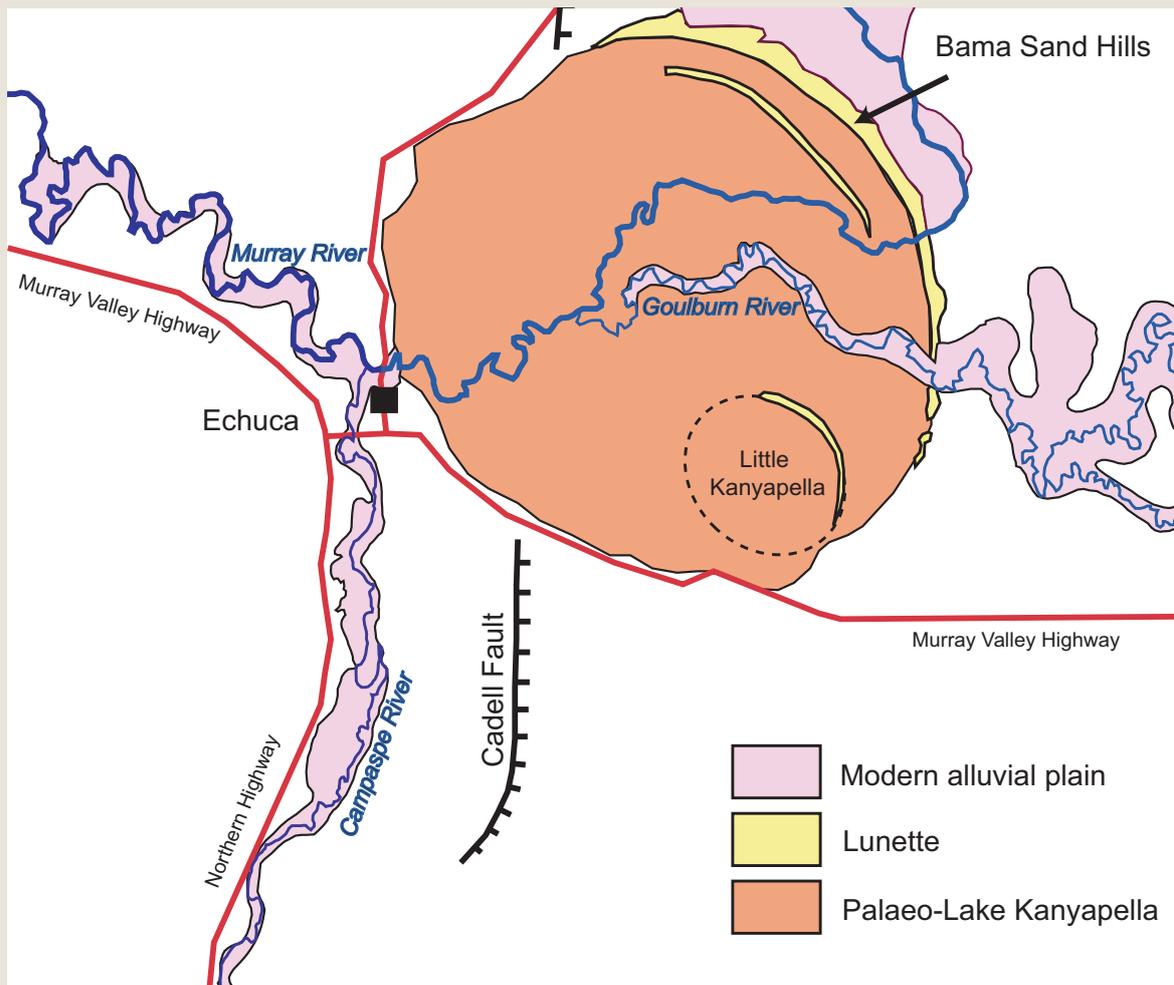
Box 3.2 Barmah Area Geomorphology

The Barmah-Millewa river red gum forests are unique in the Australian landscape. This broadly triangular floodplain forest has developed as a result of the interaction of ancient river drainage patterns and palaeo-levees, and the rise of the Cadell Fault Block (Figure 3.3). Today we observe a narrow channel of the River Murray at the Barmah Choke, cutting through sediments of older river and dune deposits. These dunes rise up to 25 m above the flat floodplain and provide evidence of once extensive lakes formed by the damming of the river system. The largest of these is Bama Sandhill formed on the eastern and northeastern edge of Lake Kanyapella. This landform is now cross-cut by the Cadell Fault, and both the Murray and Goulburn Rivers. Other palaeo-lakes with lunettes are Little Kanyapella and Barmah Lake-Bucks Sandhill, forming part of the associated lunette created as the lake dried periodically. Movements on the Cadell Fault have probably occurred several times during the evolution of the riverine plain.

Dating of channel sediments suggest that the first movement was more than 30-35,000 years ago (Bowler 1978; Page et al. 1991; Rutherford & Kenyon 2005).

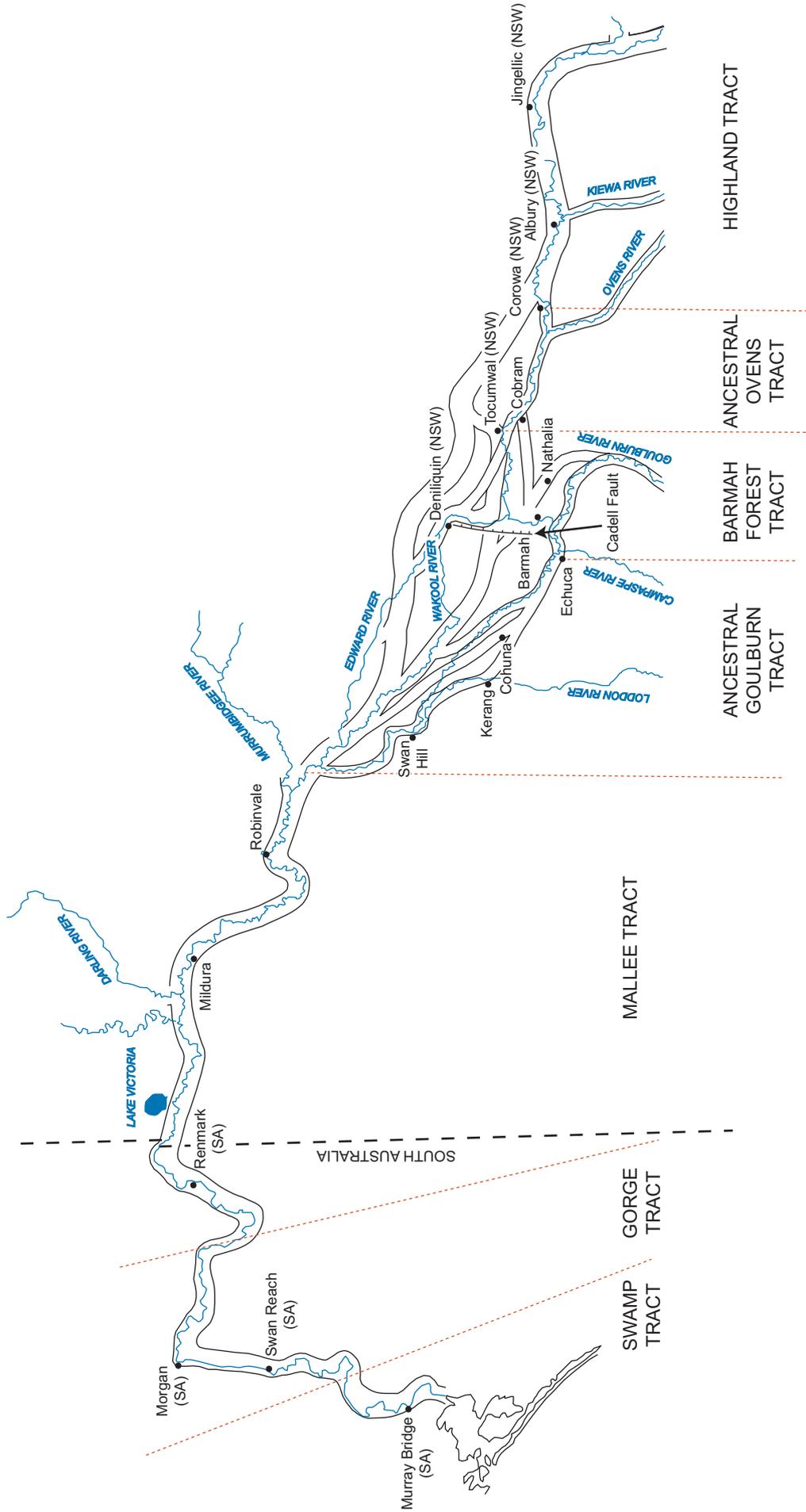
In the past the main channel of the River Murray has occupied various alternate courses including Bullatale Creek, Gulpa Creek, Green Gully and the Edward River, and entered the existing channel through the Mallee at Wakool Junction. It was not until perhaps 8000 years ago that the Goulburn captured the main Murray flow when the lunette bordering Lake Kanyapella was breached. This event is geologically very recent and overlaps with the presence of Indigenous people in the area. Traditional stories of a great flood and the breaching of the lunette may reflect this geological event (Atkinson 2005). As a consequence of this unusual hydrological arrangement between the two rivers, the Murray in this region acts as a tributary of the Goulburn and in times of high flow, the Goulburn will back up water in the Murray and cause flow to run 'upstream'.

Figure 3.3 Map of Palaeo-Lake Kanyapella and Cadell Fault near Barmah



Source: modified after Rutherford and Kenyon (2005); Barberias (1983)

Figure 3.4 Geomorphological tracts of the River Murray.



Source: modified after Currey and Dole (1978); Rutherford (1990)



4 Climate and Hydrological Systems

Australia has the most highly variable climate of any continent. This chapter provides an overview of climatic and hydrological systems in the study area, wildfire occurrence and predicted climate changes as global warming continues into the 21st Century.

CLIMATE

Victoria's climate varies from the hot, dry inland plain of the Mallee region in the northwest to the alpine snowfields of the Great Divide in the northeast. The Mallee typically has the hottest summer temperatures in the state and annual median rainfall is below 300 mm. By contrast, the Alps or Eastern Highlands have the lowest summer temperatures in the state and annual median rainfall in excess of 1900 mm in some areas. This difference in climate is strongly reflected in the vegetation with sparse, stunted mallee scrub in the northwest, through to irrigated plains in central Victoria and towering mountain forests in the northeast.

Australia can be divided into six major climatic regions or Köppen classification groups based on temperature and rainfall, as indicated by native vegetation (Stern et al. 2000; Bureau of Meteorology 2006). Two regions overlap with the study area: 'temperate' and 'grassland (formerly dry)' (Map 4.1). These classifications may be subdivided into classes characterised by seasonal temperature or rainfall patterns. The subdivisions largely reflect variation in rainfall between northern Australia (with winter drought), southern Australia (with summer drought) and central areas that are persistently dry.

'Grassland' occurs throughout much of northern Victoria extending east of Echuca through to South Australia (SA). Rainfall defines this zone, with a clear summer drought. The wettest winter month typically has more than three times the total rainfall of the driest summer month. Within the 'Temperate' area, the dry season is not as strong and the main distinction between classes is based upon the mean maximum temperatures of the warmest month. Hot summer areas with mean maximum temperatures of more than 22°C occur at the lowest altitudes in the west of the study region. Warm summer (18-22°C) and mild summer (less than 18°C with three months of more than 10°C) areas occur towards the east as the Riverine Plains rise into the Eastern Highlands (Map 4.1)

The entire study area is dominated by wet winter and dry summer rainfall patterns. However, there are markedly different mean annual rainfall totals across study area from east to west (see Table 4.1). Many

visitors are attracted to the study area by comparatively pleasant winter daytime temperature. The availability of surface water and hours of daylight also make the area productive for irrigated agriculture.

The ecosystems of the study area, like many in Australia, have developed under highly variable rainfall conditions and are adapted to cycles of periodic wet and dry, including the extended dry conditions we call drought. Weaker than normal monsoon in the north and below average rainfall, water shortages and drought over eastern Australia are associated with El Niño. Its counterpart, La Niña, is often responsible for above average rainfall over much of Australia, especially the eastern states and an earlier than normal start to the northern monsoon season.

The strength of El Niño is partly measured by the Southern Oscillation Index (SOI) which describes surface atmospheric pressure changes between the eastern and western Pacific Ocean (at Tahiti and Darwin). Widespread rain and flooding in Australia often occurs when the SOI shows the high positive values typical of La Niña. During El Niño opposing conditions prevail, with the SOI showing moderate to strongly negative values. This measure, in conjunction with sea-surface temperatures, is the basis for long-range climate predictions. Research during the past decade reveals the SOI's influence across much of the planet and it is important for long term planning in both natural resource management and agriculture (Australian Academy of Science 2002).

CLIMATE CHANGE

Human activities have significantly altered the Earth's atmosphere over the last 200 years. Increasing greenhouse gas concentrations have already warmed the atmosphere, a trend which is expected to continue (Intergovernmental Panel on Climate Change 2001; Whetton et al. 2002; Pittock 2003; NRMCC 2004; Hennessy et al. 2006b). Australia is particularly vulnerable to climate change because of our variable climate, arid landscape and demand for limited water resources (Intergovernmental Panel on Climate Change 2001).

Recent research on climate change trends and impacts in Australia is detailed in the comprehensive volume published by the Australian Greenhouse Office (AGO): Climate Change: An Australian Guide to the Science and Impacts (Pittock 2003). This report found that the average temperature in Australia has risen by 0.7°C over the last century. The report predicts that most of Australia may warm by between 0.4 to 2.0°C by 2030 and between 1.0 to 6.0°C by 2070, with slightly less warming near the coast. A warming of 1°C would threaten the survival of some species in the Australian alpine regions and in southwest of Western Australia (Pittock 2003).

Map 4.1 Climatic classification of Victoria using a modified Köppen classification scheme.

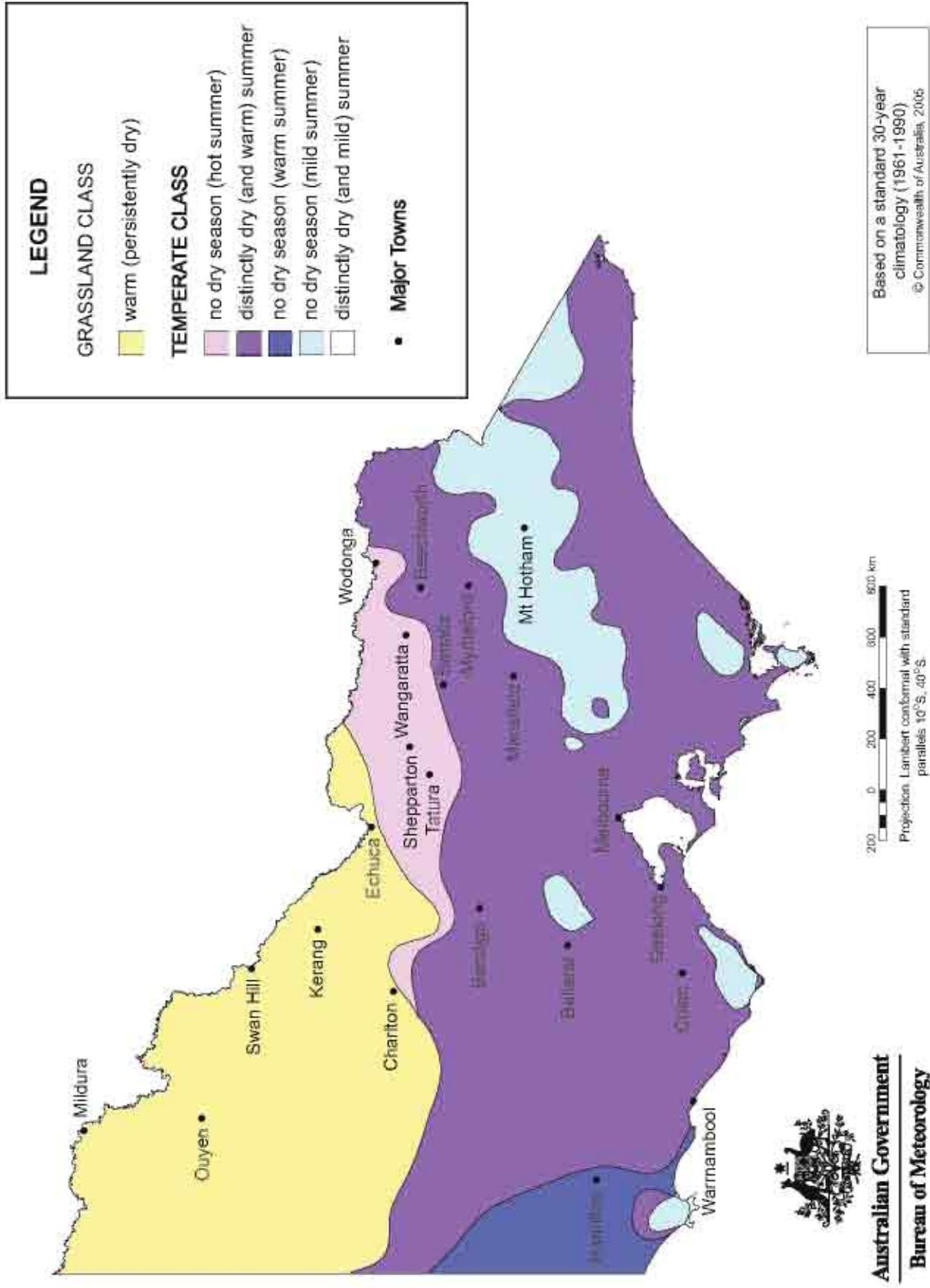


Table 4.1 Meteorological data for major towns within and near the study area.

Location	Elevation (masl)	Mean annual daily max. temp. (°C)	Mean annual daily min. temp (°C)	Mean annual rainfall (mm)	Mean annual # of clear days
Mildura	50	23.7	10.3	289	131
Swan Hill	70	23.0	9.7	349	127
Echuca	96	22.2	9.4	428	93
Kerang	78	22.8	9.4	373	125
Bendigo	208	20.7	7.6	502	99
Tatura	114	21.2	8.3	493	110
Benalla	170	22.0	8.7	670	125
Wangaratta	150	21.9	8.8	637	113
Wodonga	152	22.1	8.9	715	125
Myrtleford	223	21.7	6.6	905	103
Mt Hotham	1750	9.5	2.3	1979	53
Melbourne	31	19.8	10.1	653	49

Notes: Data for Swan Hill, Wangaratta, Wodonga, Myrtleford, and Mt Hotham have been collected over various historic periods. Data from Melbourne and Mount Hotham have been included for comparison.

Source: Bureau of Meteorology, data last modified 16/8/2004

The report also found that rainfall has increased over the last 50 years over northeastern Australia, but decreased in the southwest of Western Australia and in much of southeastern Australia, especially in winter. There were near-record low water levels in much of southeastern Australia's water storages in 2002-03, and little improvement since. There is a substantial risk that this pattern will continue for several decades. Droughts have become hotter and more severe, and this trend is expected to continue; tropical cyclones have become more intense and frequent; and heavy rainfall incidents have become more frequent in many parts of Australia. Increased greenhouse gas concentrations and ozone depletion may both be contributing to a strengthening of the atmospheric winds over Antarctica, dragging rain away from Australia and into the Southern Ocean (Pittock 2003).

The AGO presents a general picture of the trends and potential impacts of climate change in Australia but significant knowledge gaps still exist. However, observations clearly demonstrate that the climate is already changing.

Projections of Victoria's Future Climate

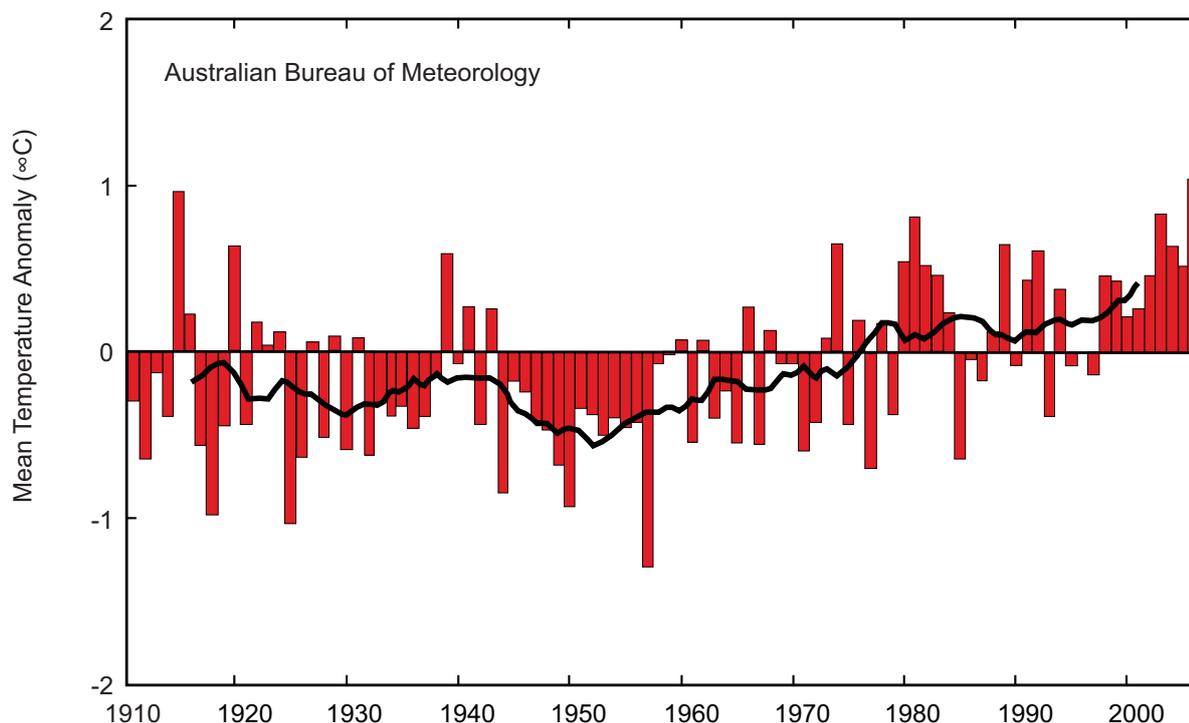
The Victorian Government commissioned CSIRO to undertake high-resolution regional climate change

projections for Victoria in 2002 (Whetton et al. 2002). The projections are based on the results of climate modelling in which the effect of increased levels of greenhouse gases in the atmosphere are simulated. The range of regional climate change projections allows for uncertainty in future greenhouse gases increases, and for differences between the simulated climate change of various climate models. These projections to 2070 were reviewed in 2004.

In each decade since 1950, Victoria's average maximum temperature has increased 0.11°C and average minimum temperature has increased by 0.07°C. When compared to national trends, Victoria's maximum temperature appears to be changing at a faster rate, and our minimum temperature at a slower rate (Whetton et al. 2002). Whetton et al. (2002) predict that Victoria is likely to be 0.7 to 5.0° C warmer than it was in 1990 with the frequency of extreme maximum temperatures expected to increase, with up to three times more hot days in some areas of the state. The frequency of frosts is also likely to decrease, with much of the state likely to become frost-free at the higher levels of projected temperature increases.

This pattern of increasing temperatures is also apparent within the Murray-Darling Basin (see Figure 4.1).

Figure 4.1 Annual anomalies (based on 1961-1990 averages) of mean temperature in the Murray-Darling Basin.



Source: Bureau of Meteorology (2006)

Notes: The black line shows the 11-year moving average.

Extreme rainfall events have increased in Victoria over the past century, and evidence exists of severe droughts during strong El Niño years in northern and southern Victoria with an increasing tendency for more frequent El Niño conditions over the past decade. Whetton et al. (Whetton et al. 2002) predicts that rainfall is likely to decrease, although there could be increases in some areas. Extreme daily rainfall events may become more intense and more frequent in many regions. Projected changes in annual rainfall range from +10 to -25 percent in most southern regions and +10 to -40 percent in most northern regions of Victoria. Warmer conditions will increase evaporation which, combined with reduced rainfall, is likely to increase moisture stress and wildfire risk.

Summaries of predicted climate change and impacts for catchment management regions provide a detailed discussion of the available information and likely results of climate change (DSEa, b, c, d). Some tangible examples compare current climate with predicted 2070 climate with a moderate greenhouse scenario of 2°degree C warming and a 10 to 20 percent decrease in annual rainfall. Under these conditions in 2070, Wangaratta would have the current climate of Dubbo (New South Wales—NSW), while Bendigo would be more like the current climate of Echuca. Mildura would be expected to be more like Menindee (NSW), while Shepparton is expected to be more like the current climate of Condobolin (NSW).

Water Resources

These predicted climate changes are likely to make Victoria's water resources increasingly vulnerable. Increased temperatures and evaporation rates will reduce water supply, affecting agriculture and biodiversity in parts of Australia. Demand for water is likely to increase with warmer temperatures and increased evaporation, although this may be offset by increases in seasonal rainfall patterns. Conservation measures, behaviour change and alternative supplies may also minimise these impacts.

Climate change may reduce and increase variance in rainfall, reducing river flows and run-off (e.g. Jones et al. 2002; Whetton et al. 2002; van Dijk et al. 2006). Preliminary results indicate that average annual run-off for Victoria's surface water management areas will reduce with climate change. In broad terms, the stream flow across the Murray-Darling Basin may be reduced by 5 percent in 20 years (1100 GL) and up to 15 percent in 50 years (van Dijk et al. 2006). In Victoria, a decline in rainfall is predicted to decrease run-off between 0 to 45 percent in 29 Victorian catchments (Jones & Durack 2005). Systems such as the upper Murray River could have up to 20 percent less run-off by 2030 and greater than 50 percent reductions by 2070. Such losses far exceed any savings currently required to provide for environmental water (see chapter 15) which have proved difficult to achieve under current circumstances.

Our need to use water more efficiently is likely to be reinforced by climate change. However, the predicted

change and variability of climate is outside the range of previous experience, even when the highly variable climate of Australia is considered, necessitating new strategies, especially those related to the long-term sustainability of industries and resources (Pittock 2003). These strategies must be informed by an understanding of natural and human systems, but also need to be location and sector-specific.

In addition, water quality may change. The number and types of organisms, water temperature, carbon dioxide concentration, transportation of water sediment and chemicals, and volume of water flow are all likely to affect water quality. Decreases in stream flow, reduced underground water and increased salinity are critical issues for water supply and management as well as natural resource management more broadly.

Within the study area, the variable climate and low rainfall in many areas, combined with increasing pressure on reduced water resources under climate change scenarios, will present considerable challenges for natural resource managers.

Forest Productivity

Future forest productivity depends in part on balancing the benefits of increased atmospheric carbon dioxide concentrations and the patterns of change in rainfall and temperature. For example, a doubling of carbon dioxide with a warming of 3°C and no significant changes in rainfall would encourage tree growth in much of southern Australia, particularly in wheat belt and semi-arid regions. However, these benefits are likely to be offset by higher evaporation rates, fewer nutrients, increased pest and wildfire risk (Hennessy et al. 2006b). Rainfall is also likely to decrease and become more erratic, further impacting on growth rates.

In the floodplain forests of the study area, flood regime—rather than rainfall—is the major water-related determinant of tree health. The frequency, duration and extent of floods in the study area have generally decreased significantly because of human water use (see chapter 15). Reduced flooding has stressed and killed red gum and black box trees and reduced growth rates, thus reducing long term productivity for wood products and nectar production in many areas (see further discussion in chapters 5, 13 and 14). In short, the predicted adverse impacts of climate change on floodplain forest health are likely to more than counterbalance any predicted favourable effects.

Natural Environment and Landscapes

In the past, non-climatic pressures from human settlement have dominated environmental change in Victoria. In the future natural resources and biodiversity will be strongly affected by climate change (Intergovernmental Panel on Climate Change 2001). Ecosystems and species will respond to changing climate conditions, but at the same time have to cope with climate-induced changes in land use, and pests and diseases, particularly invasions by exotic species. These combined effects will become more severe, and ecosystems and species may not be able to adapt quickly enough to survive.

Climate change already affects Victoria's plants and

animals, but further research is needed to identify the precise effects of climate change on biodiversity (see chapter 5 Biodiversity and Newell et al. 2001). Many of Victoria's ecosystems and species may have a limited ability to adapt to climate change (Brereton et al. 1995). Species restricted to small areas, or unable to quickly relocate to changed shifting climatic zones—assuming that all climatic zones will still exist somewhere—are particularly susceptible. The most susceptible include threatened species, those that occur in small patches of remnant vegetation, significantly modified or fragmented landscapes, or those invaded by exotic plants or animals. Reducing habitat fragmentation and protecting biolinks, refuges, and important habitats will be critical for the survival of some species (Brereton et al. 1995; Dunlop et al. 2003; Pittock 2003; NRMCC 2004; Thomas et al. 2004).

Summary

Public land provides an important refuge where native species can adapt, relocate and disperse in response to climate change. As part of the long-term planning for sustainable use of public land, habitat links be particularly important to facilitate migration and adaptation of species under changing climate. However, strategies to mitigate the effects of climate change on both the environment and the economy cannot rely on maintaining the status quo—more capacity, flexibility and conservatism must be built into existing systems. Climate change strongly reinforces the importance of incorporating long-term costs and benefits into decisions involving apparently pressing short-term considerations.

Having said this, there is limited capacity for VEAC to structure future public land use to accommodate the entire range of predicted impacts of climate change. Much of the response to mitigate or adapt to the projected future climate is required on a much larger scale (such as reducing greenhouse gas production), although actions will need to be location and sector-specific (such as farm or plantation forestry to sequester carbon). The full range of co-benefits and conflicts can be difficult to anticipate and to resolve (Pittock 2003), however, some are explored further in chapter 19.

WILDFIRE

Fire is a ubiquitous part of the Australian landscape. Australia's hot, dry and particularly variable climate makes it the most fire-prone continent. Many plants and animals have evolved with a dependence on the rejuvenation and succession provided by bushfire, or wildfire as it has become known more recently. For example, hakeas, banksias and acacias, have hard seed coatings or capsules, which only germinate under conditions associated with fire (Gill et al. 1981; Smith 1992b, a).

Eucalypts have developed markedly different mechanisms to cope with different fire regimes. For example, mountain ash (see Appendix 4 for scientific names of all plants mentioned in the text) grows in high-elevation, cool, moist forests that normally protect it from all but the rare, catastrophic fires it requires every hundred years or so in order to regenerate. Other eucalypts that occur in dry, fire-prone environments,

such as messmate have a thick protective bark layer that insulates the interior of the tree from the heat of an intense fire (Smith 1992b).

Changes in Australia's flora correlate with major shifts in climatic conditions and the increased occurrence of fire in the landscape over thousands and even millions of years. Research finds a rapid increase in the amount of charcoal in lake or swamp deposits during the major dry periods of the last 130,000 years (Singh et al. 1981). These changes occurred as the frequency of fire increased, and fire-adapted species became dominant. Many fire-adapted species are highly combustible and accumulate high fuel loads. Indeed some species such as the hairpin banksia are entirely consumed by fire and regeneration is stimulated through a large number of seeds shed onto the ash bed after the fire passes (Smith 1992b).

Aboriginal people are known to have used fire as a land management tool, creating a new flush of vegetation growth in a mosaic of small probably cool burns and across parts of the Australian landscape. This technique is often referred to as 'firestick farming'. While knowledge of traditional burning practices of local Aboriginal people is not well documented for the Murray floodplain area, it is believed that regular, low intensity burning occurred throughout the floodplain forest, perhaps as often as every five years (Atkinson & Berryman 1983; DCE 1992). High intensity wildfires were probably uncommon prior to European settlement at which time traditional Aboriginal burning practices largely ceased in the study area (Curr 1883; DCE 1992).

Fire management on public land in Victoria is the responsibility of the Department of Sustainability and Environment (DSE). This responsibility includes control of wildfire, prevention of unplanned fire and the intentional use of fire for specific ecological and safety purposes. Fire protection plans are prepared for all Victoria's parks and forests. These plans are prepared in consultation with the community and follow the Code of Practice for Fire Management on Public Land (Department of Conservation and Natural Resources 1995). This

document provides for a review to be undertaken within ten years and DSE has recently undertaken a public comment and consultation process to develop the revised document due for completion in 2006 (DSE in prep). Fire management is described in chapter 9.

On average 620 wildfires occur in Victoria's parks and forests each year, mostly during summer. Approximately two-thirds of all fires are caused by people, either accidentally or deliberately (DSE 2004e). The remaining fires are largely caused by lightning. Devastating wildfires following drought occurred in Victoria in January 1939 (Black Friday, resulting in 71 deaths), February 1983 (Ash Wednesday, resulting in 75 deaths) and 2003 (alpine fires, with one life lost in flash floods) (Wareing & Flinn 2003). The area burnt in Victoria by these fires is estimated to be 1.5 to 2 million ha, 210,000 ha and 1.1 million ha respectively (Wareing & Flinn 2003). By far the largest fires recorded in Victoria were those known as 'Black Thursday' (6 February 1851) in which approximately 5 million hectares or nearly one quarter of what is now Victoria was burnt. Areas affected include Portland, Plenty Ranges, Westernport, the Wimmera and Dandenong districts. Approximately 12 lives, one million sheep and thousands of cattle were lost. None of these major fires occurred within the River Red Gum Forest study area. Large wildfires occurred in 1944 near Benalla and 1952 near Wodonga (Paine 1982), but did not significantly involve river red gum forests.

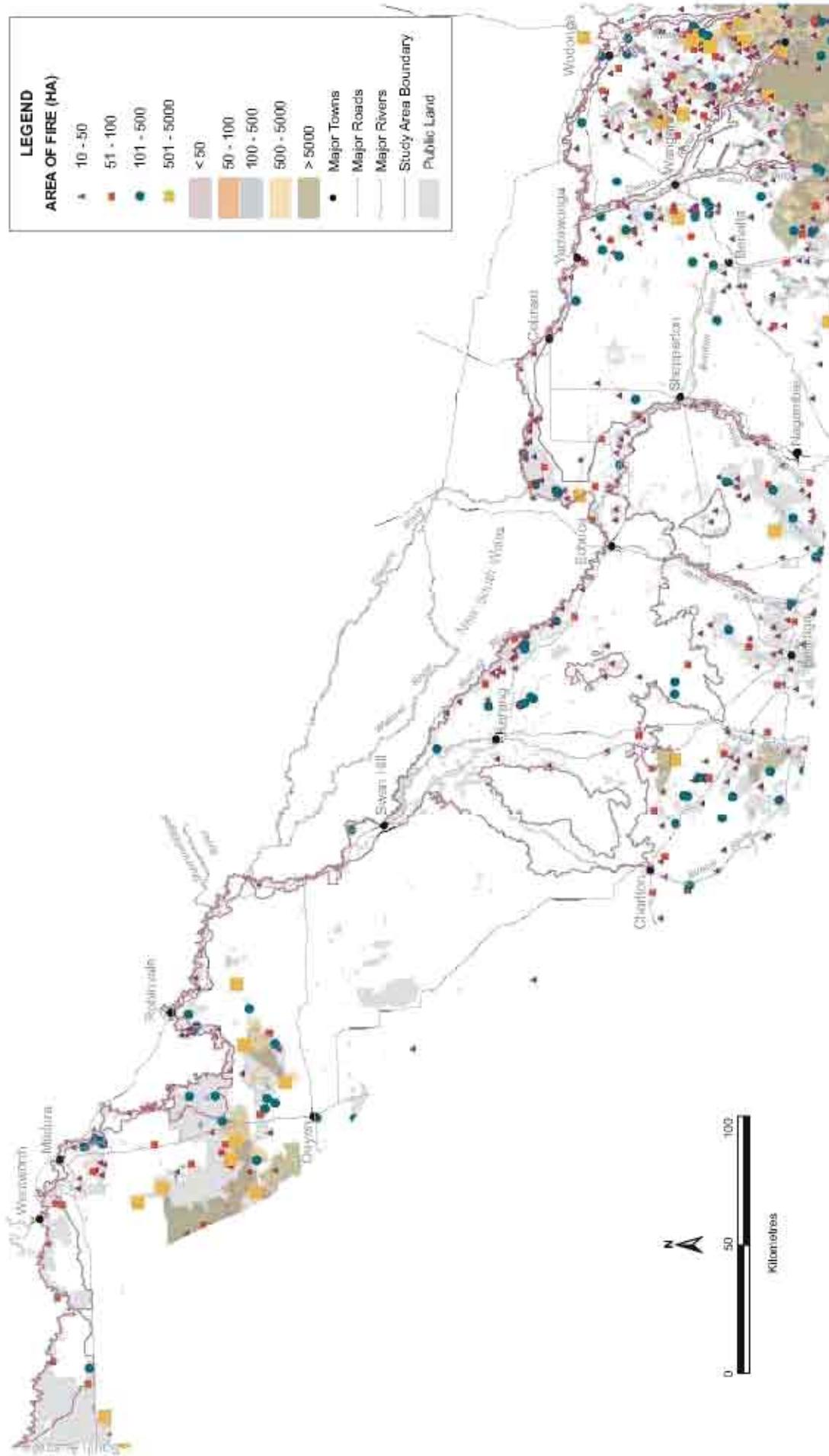
To date there have been few major wildfires, within river red gum floodplain forests, and those that have occurred are of limited extent (Map 4.2). For example, in the Barmah forest (both state forest and state park) there were 112 fires from 1983-84 to 2003-04, which burnt a total area of 302.5 ha (Eyles 2004). Of these fires, 80 burnt less than five hectares each, with the largest single fire in this period about 50 ha in extent. Ten fires burnt 10 ha or more, and 21 fires burnt five ha or more each. Excluding the largest fire, the average fire extent was 2.3 ha. The source and agent of these fires are shown in Table 4.2.

Table 4.2 Source and agents for 112 wildfires recorded in Barmah forest from 1983 to 2004

Sources	No.	% of fires	Agents	No.	% of fires
Lightning	12	10.7	Recreationists	70	62.5
Cigarette / Match	10	8.9	Lightning	12	10.7
Campfire / BBQ	60	53.6	Children	5	4.5
Deliberate	7	6.3	Malicious	1	0.9
			Employee – other	3	2.7
			Employee – DSE	1	0.9
Other	8	7.1	Other	3	2.7
Unknown	15	13.4	Unknown	17	15.1
Total	112			112	

Source: Eyles (2004)

Map 4.2 Wildfire occurrence in the River Red Gum Forests study area.



Source: DSE (2006b)

Recreational users, particularly campers, account for half of the fires in river red gum forests, through escaped campfires, BBQs and discarded cigarettes or matches (Table 4.2) (DCE 1992a). Land managers report that recent public education encouraging clearings around campfires and ensuring that they are extinguished has helped to reduce the numbers of escaped fires. Forests NSW has established a seasonal ban on solid fuel fires in state forests in the Riverina Region of southwest NSW along the Murray River. For further discussion of fire management on public land see chapter 9.

Hennessy et al. (2006a) reported an increase in wildfire risk for southeastern Australia under projected hotter and drier climatic conditions. Key findings for land management agencies are that the number of days on which conditions for prescribed burns are favourable will be reduced and higher fire risk will be experienced in spring, summer and autumn. Additionally, inland areas are at greatest risk for increases in wildfire occurrences.

HYDROLOGY

This section describes the River Murray catchment and its hydrology (the way in which water moves around the atmosphere, land and water systems through the water cycle). This section is closely linked to chapter 3 Geomorphology, chapter 5 Biodiversity and chapter 15 Water Use and Environmental Flows.

The River Red Gum Forests study area is in the vast Murray-Darling Basin (see Map 4.3). While the River Murray and its water fall within the jurisdiction of NSW, ecologically and economically the river supports human and natural activities on adjacent Victorian public land. Any investigation of public land along the River Murray in Victoria must consider the hydrology of the river and its relationship with the river red gum forests and associated ecosystems and landscape.

Overview of the Murray-Darling Basin

The Murray-Darling Basin covers approximately 1.1

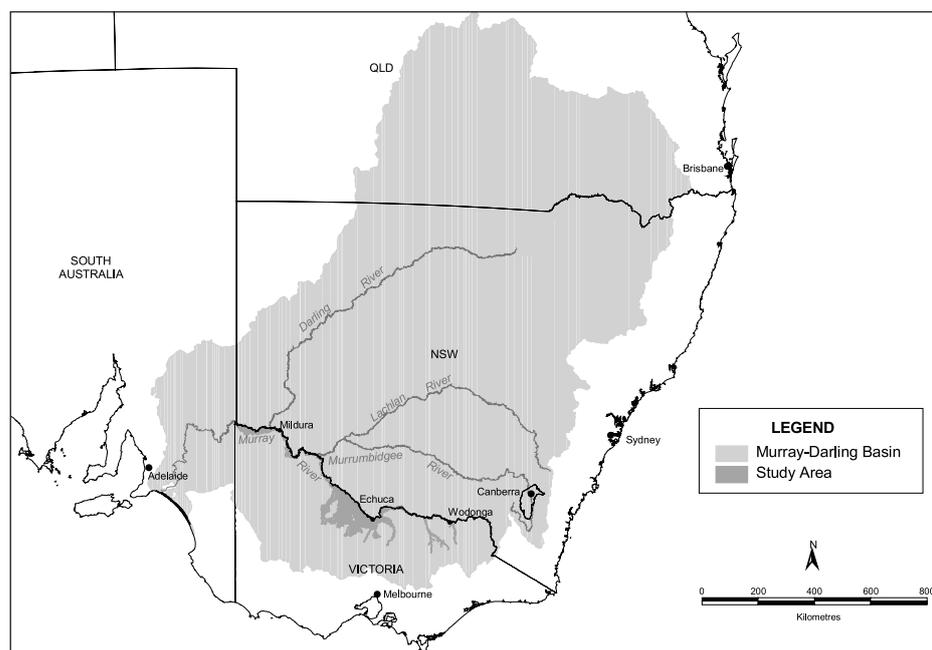
million square km (14 percent of Australia) and is one of the largest catchments in the world. Some 86 percent of the basin contributes virtually no run-off to the river system except during rare extensive flood periods. The major rivers that flow through NSW and into the River Murray are the Darling (with headwaters in Queensland), Lachlan and Murrumbidgee (see Map 4.3 for location of these rivers within the basin). In terms of its length, the River Murray is one of the largest rivers in the world extending over 2000 km (MDBC 2005b).

The rate of flow in the River Murray is highly variable with flow rates oscillating along the length of the river, across seasons and between years. This high variability relates to the River Murray's uniqueness in terms of its size, shape, topography, geology and climate. It also is a major reason for the range of ecosystems found along the river (see chapter 5). Compared with other rivers, the River Murray's flow is relatively low. The entire Murray-Darling Basin is one of the driest basins in the world. For example, every square kilometre of the Amazon River's catchment averages 75 times more water flow than the Murray-Darling river system. To put this into perspective, the average annual flow of the Murray-Darling system would pass through the Amazon River in less than a day.

Because of the river's length and low flow rate it takes about four weeks for the water flow to travel the 1580 km from Hume Dam to the SA border, when flow is below bank-full. A flood-wave with over-bank flow takes about two weeks longer to travel the same distance, a total of approximately six weeks.

The River Murray is, by world standards, one of the most stable rivers of its size. The river's planform (the shape of the river as seen from the air or satellite image) has remained relatively unchanged since the 1860s when the river was first surveyed. However, as described in chapter 3 this has not always been the case as the river has changed channels extensively over thousands of years and geological time (Gippel & Blackham 2002).

Map 4.3 Location of the study area within the Murray-Darling Basin.



Natural Hydrology of the River Murray

Factors Influencing Surface Water Run-off

Around 84 percent of precipitation is either evaporated or taken up by plants and returned to the atmosphere as water vapour in a process known as transpiration. Approximately 1 percent of precipitation infiltrates the soil and reaches the groundwater, while the remaining 15 percent of precipitation reaches waterways via surface water run-off to be discharged into streams, rivers and lakes. Surface water run-off is a crucial aspect of the hydrology of the River Murray, as it determines flow volume and velocity and hence water availability for vegetation and human use.

Surface water run-off is influenced by vegetation cover, topography, climate and soil type.

Tree canopies are highly effective at intercepting rainfall and therefore, the point and time of impact of the rain reaching the ground. Other vegetation types also perform this function but, because of their smaller surface area, are not as effective at intercepting rainfall. The upper catchment areas of the River Murray have extensive tree cover, reducing immediate run-off and leading to more constant discharge and stream flow—vegetation reduces immediate peaks in surface water run-off after rain, and promotes more gradual dispersal over a longer period, allowing rainfall to permeate the soil. This increases base flows of streams because of higher and more constant ground water seepage. Vegetation also reduces soil erosion caused by surface water run-off and filters sediments, nutrients and other 'pollutants' (MDBC 2001). Deep rooted vegetation moves water through the water cycle by tapping into the groundwater table and, through evaporation and transpiration, keeps groundwater tables low (reducing soil salinity in some areas).

Steep terrain causes faster surface water run off and reduces the likelihood of water sinking into the soil. Water that does infiltrates the soil from surface run-off flows down slopes, eventually reaching streams and rivers. The more gradually the water reaches a river the less likely it is to flood. Topography also determines the energy of river flows and the form of rivers. For the Murray River, with a relatively flat topography except in the headwaters, any surface water run-off is relatively slow.

Climatic factors, particularly temperature, wind and humidity, influence evaporation and transpiration rates, which in turn influence the amount of surface water available and run-off potential. In the study area, the variable climate causes large variations in evaporation and transpiration rates. For example, in the western part of the study area high temperatures, relatively strong, dry winds and low humidity conditions cause high evaporation and transpiration rates. This results in almost no surface water run-off to the River Murray (see below) in this area. Rainfall intensity and duration also influence surface water run-off, with heavier and longer rainfalls increasing run-off.

Soil type also influences run-off. There are a range of soil types in the study area but most of the study area (such as the Chowilla floodplain (SA) and Barmah forest) is covered by clay type soils of varying thickness. In the Barmah forest, surface clays vary from 8 to 20 m deep over a short distance and can reach up to 30 m.

On the Chowilla Floodplain, the clay layer is less than 5m deep.

Clay soils are impervious to water leading to rapid surface water run-off and low infiltration. However, when dry, most clays develop deep cracks (around 25 mm wide and up to 2 m deep), allowing water, organic material and animals to enter the soil. Floodwaters enter these cracks leading to deep soil recharge. When the clay soils of the floodplain are not fully dried out or where cracking has not occurred deep soil recharge is reduced. As clay soils become wet they expand, become saturated, close off surface cracks and become impervious to further water. Infiltration into these cracks therefore occurs for a relatively short period at the start of a flood (MDBC 2001).

Recharging of the sub-surface areas of the floodplain is unlikely if the soils are highly unstable clays. This is the case on the Chowilla Floodplain, where 32 days continuous flooding caused saturation only in the top 20-30 cm although soil water increased down to 70 cm. Impenetrable swelling clays are also found in the Barmah forest. Recharge from the surface may be localised if the surface layer is discontinuous and punctured by another soil type. In the Barmah forest, one flood penetrated to 5 m and another comparable flood to only 1 m (MDBC 2001).

Surface water run-off across the study area varies seasonally and annually with variations in weather. Summer and autumn are usually characterised by little if any surface water run-off, winter and spring have high natural stream flows and water levels in wetlands. Flooding of rivers, particularly in the east may also occur naturally in summer when tropical rain depressions move unusually far south (Parliament of Victoria Environment and Natural Resources Committee 2001).

Victorian Catchments Flowing to the River Murray

The headwaters of the River Murray begin in northeastern Victoria on the border with NSW. At Dartmouth Dam, the River is 486 m above sea level and falls to 35 m above sea level at Mildura. From its headwaters above Dartmouth, the River flows north, west and south for 2530 kms before entering the Indian Ocean near Goolwa (SA). Most of the water in the River, however, comes from the first 500 of these kilometres—for the last 2000 km, surface water run-off from the land surrounding the Murray contributes relatively little to river flows (Mackay & Eastburn 1990).

In Victoria precipitation and flows in waterways vary considerably from catchment to catchment in both total volume and amount of variation over time. This variation is evident across the four main catchment regions in the River Red Gum Forests study area. As described in the preceding climate section, precipitation is generally higher and more reliable in the north east region of the study area and declines further westward.

There are four major catchments (North East, Goulburn Broken, North Central and Mallee) in Victoria associated with the River Red Gum Forests study area. The rivers in these catchments are shorter than the Darling and Murrumbidgee Rivers but contribute far more run-off into the River Murray (see Table 4.3). The location of major Victorian tributaries and the four catchments is shown in Map 4.4.

The **North East** catchment region includes the Ovens, King, Kiewa, Mitta Mitta and Upper Murray rivers and covers approximately 1.9 million hectares. Although this is only 2 percent of the Murray-Darling Basin, the region contributes 38 percent of the total water to the system (NECMA 2004). All these rivers enter the River Murray upstream of Yarrowonga.

As its name suggests, the **Goulburn Broken** catchment region includes the Goulburn and Broken Rivers. The Goulburn River is Victoria's largest river basin covering an area of 1.6 million hectares (7.1 percent of the State). The Goulburn River is approximately 570 km long and has a mean annual water discharge of 3040 GL. The Broken River (a tributary of the Goulburn) basin covers 772,386 ha (3.4 percent of Victoria), including the Broken Creek catchment that includes the decommissioned Lake Mokoan. Over half of the annual stream flow occurs between July and September, with a mean annual flow of 325 GL (GBCMA 2003).

The Goulburn and Broken River basins together cover approximately 2.4 million hectares (10.5 percent of Victoria and 2 percent of the Murray-Darling Basin). Combined, the river basins generate around 11 percent of the basin's water resources and flow into the River Murray upstream of Echuca. These rivers provide large volumes of water to the River Murray during floods, thereby avoiding the physical constraint imposed by the Barmah Choke—see below.

Combined, the North East and Goulburn Broken catchment regions contribute 49-50 percent of the Murray Darling Basin's overall water resources.

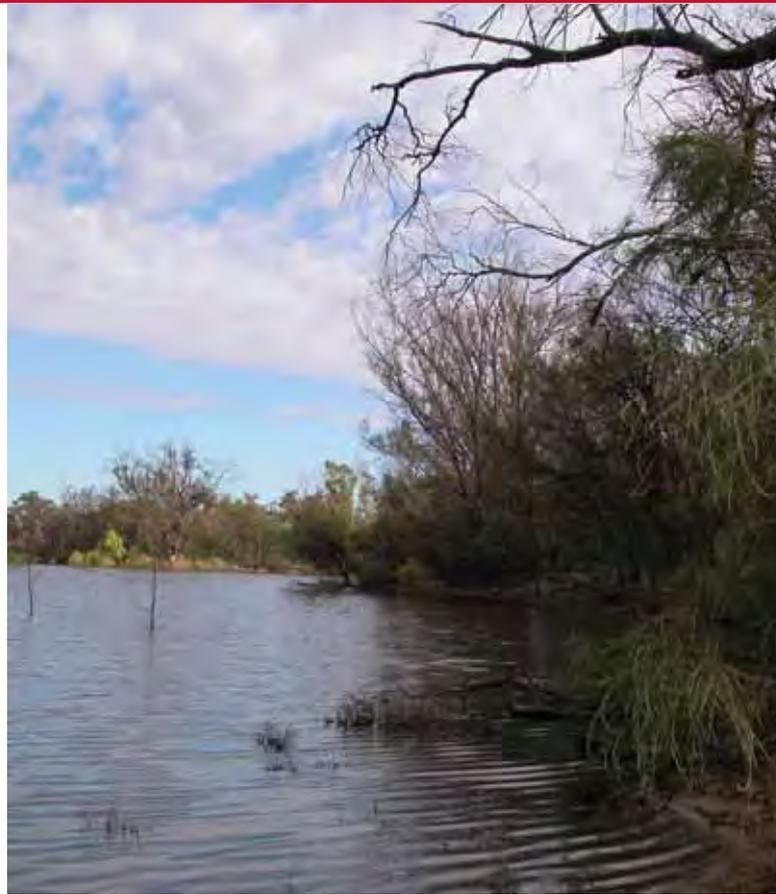
The North Central catchment region contains the Loddon, Campaspe and part of the Avoca River basins. The Campaspe River with an approximate annual flow volume of 315 GL and the Loddon River with 263 GL flow directly into the River Murray. In contrast, the Avoca River discharges into the Avoca marshes and Lake Boga near Swan Hill (NCCMA 2003).

The Mallee catchment region contains three main basins, the Mallee Basin covers 2,802,688 ha, the Avoca Basin covers 1,235,246 ha and the Wimmera River Basin covers 2,401,130 ha (Mallee Catchment Management Authority 2003). Rainfall is relatively variable in this catchment region. Compared with the Goulburn Broken and North East catchment regions, the Mallee catchment contributes little if any run-off into the River Murray system, reflecting its semi-arid climate.

Flood Regimes

Under natural (pre-European river regulation) flood conditions, around half the surface water run-off from the catchments of the Murray-Darling Basin reached the sea. River flows varied considerably across the system in volume and between years. Before river regulation around 11,300 GL of water flowed down the River Murray to its mouth in South Australia during a typical year and varied from approximately 2500 GL during a dry year to 40,000 GL in a very wet year. This variation is a key feature of the flooding and flow regime of the River Murray.

Under current water regulation conditions (see chapter 15), flow is reduced to about 3000 GL in a typical year,



or 27 percent of flow under natural conditions (Murray-Darling Basin Commission 2002). The extraction of this amount of water from the River Murray system has adversely affected many species in the study area, most significantly in wetlands and river red gum forests. It has also significantly affected water quality and salinity (see chapters 5 and 15). However, the extracted water supports important agriculture around the study area (see chapters 8, 13 and 15).

For flooding to occur across the River Murray floodplains, river flow must breach the channels and flow over the river bank onto the surrounding landscapes. Flooding enables some tributaries such as the Lachlan which normally terminates in marshes, to reach the Murray River. Remaining surface water in floodplains and wetlands eventually permeates through the soil to recharge ground water systems. Prior to river regulation the natural flood regime of the River Murray could be divided into three types, large-scale floods, mid-range floods and low flow conditions (Gippel & Blackham 2002).

Large-scale floods generally occurred once every 20 to 100 years. These floods extended from the River Murray channel and out over the vast floodplains (see Map 4.5 for distribution of a 1 in 100 year flood). These floods were crucial for connecting wetlands, swamps and marshes along with the broader floodplain to the main river systems and for transferring energy and nutrients between the river and floodplains. They were also crucial for flushing the entire river system. Large-scale floods lasted for 2 to 6 months, depending on rainfall and snow in the upper catchment. Large floods on the Murray usually coincided with large-scale floods on Victorian rivers such as the Ovens, Broken, Goulburn, Kiewa and King.

Table 4.3 Stream flow in major Victorian rivers associated with the study area.

Catchment region	River	Length (km)	Average annual stream flow (GL)	Maximum annual stream flow		Minimum annual discharge	
				(GL)	Year	(GL)	Year
North East	Ovens	227	1110	2880	1956	195	1982
North East	Kiewa	184	665	1450	1974	193	1967
Goulburn / Broken	Goulburn	563	1680	5930	1974	228	1972
Goulburn / Broken	Broken	192	236	1130	1917	4610	1943
North Central	Campaspe	245	203	886	1974	2830	1902
North Central	Loddon	392	186	461	1974	36,200	1967
Mallee	Avoca	269	47	129	1973	3480	1982

Source: *Cochrane et al. (1999) and DSE(2006i)*

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Flood Regimes

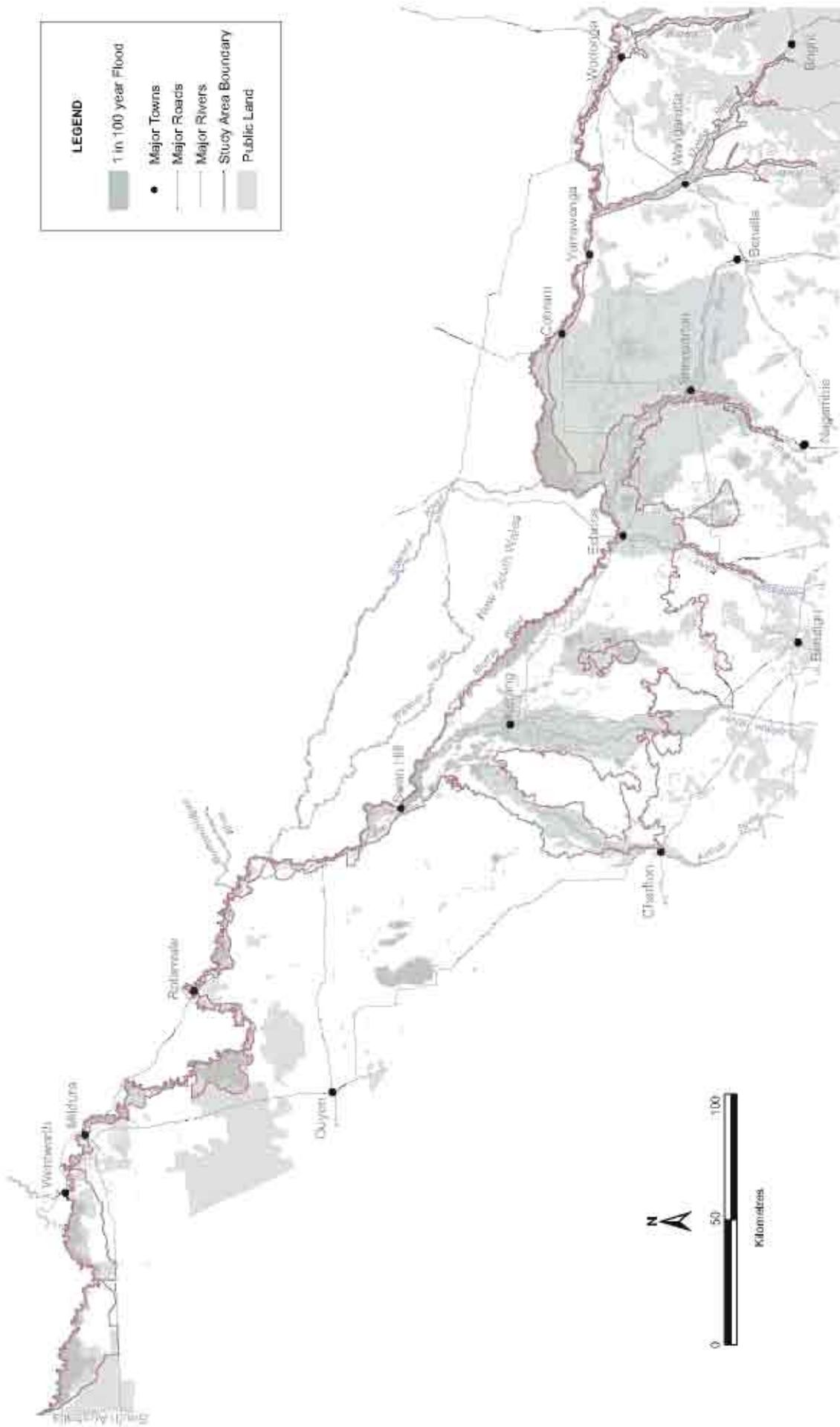
Under natural (pre-European river regulation) flood conditions, around half the surface water run-off from the catchments of the Murray-Darling Basin reached the sea. River flows varied considerably across the system in volume and between years. Before river regulation around 11,300 GL of water flowed down the River Murray to its mouth in South Australia during a typical year and varied from approximately 2500 GL during a dry year to 40,000 GL in a very wet year. This variation is a key feature of the flooding and flow regime of the River Murray.

Under current water regulation conditions (see chapter 15), flow is reduced to about 3000 GL in a typical year, or 27 percent of flow under natural conditions (MDBC 2002). The extraction of this amount of water from the River Murray system has adversely affected many species in the study area, most significantly in wetlands and river red gum forests. It has also significantly affected water quality and salinity (see chapters 5 and 15). However, the extracted water supports important agriculture around the study area (see chapters 8, 13 and 15).

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Map 4.5 Distribution pattern of a 1 in 100 year flood.



Source: Department of Sustainability and Environment Corporate Geospatial Data Library, 2005

Large flood events occurred in 1917, 1956 and 1973. According to Gippel and Blackham. (2002), peak flows recur every 20 years or more and their frequency has remained relatively unchanged with river regulation. Major floods are usually preceded by heavy rain that fills storages and reduces demand for water diversion. With the huge volume of run-off, dam storage capacity is reached, forcing large volumes of water to be released out of the storages (Gippel & Blackham 2002). However, such floods may become less likely in the future, due to climate change reducing rainfall and run-off.

Mid-range floods occurred approximately once every 2 to 10 years and were usually of shorter duration than the large floods (one to six months). Monthly flows at the SA border exceeded 1000 GL and occurred in 45 percent of months (Gippel & Blackham 2002). Such flooding regimes are crucial for the sustainability of the various ecosystems found within the study area.

Today, with regulation these floods are only expected to occur in 15 percent of months, with mid-range floods lasting only one to three months. Studies by Thoms et al. (2000, cited in MDBC 2005b) indicate that these types of floods occur much less frequently now than they did prior to river regulation. Floods that once occurred every second year now occur every 6 to 8 years, while floods that once occurred every 10 years now occur every 25 to 30 years. This change in flow regime through river regulation reduces the frequency of flooding of wetlands, riparian vegetation and floodplains, with dramatic consequences for species and ecosystems that may be able to survive some reduced flooding but not to this extent (see chapters 5 and 14).

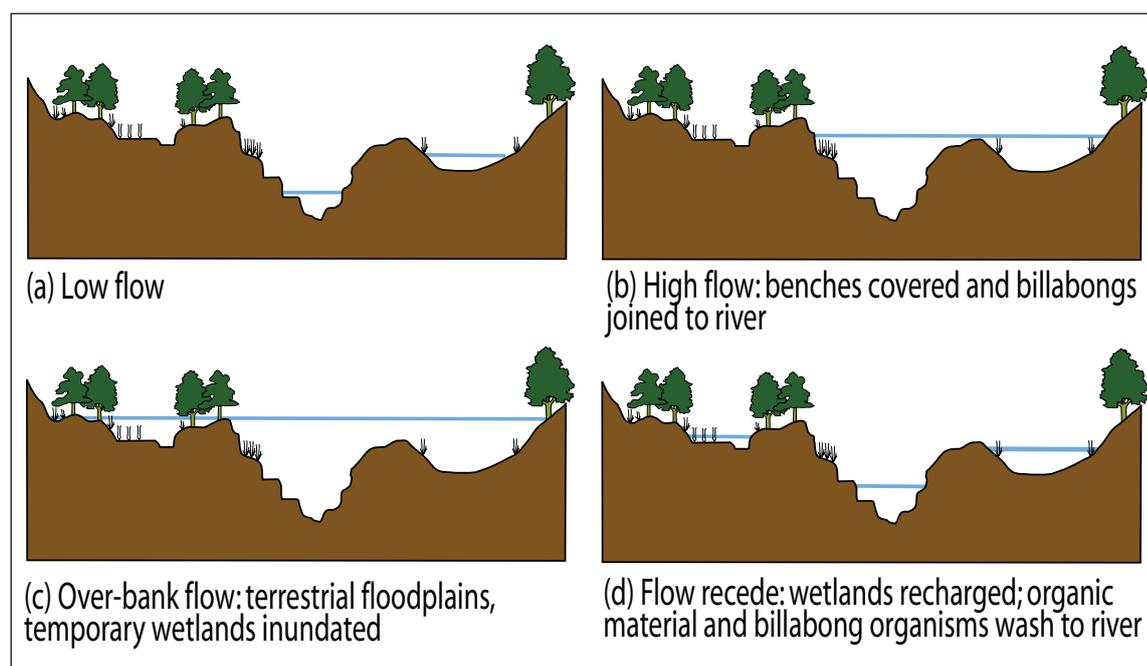
The third type of flow regime is **low flows**, which includes periods of no flow and even—in extreme

droughts—drying of much of the river bed so that the River was reduced to a chain of often saline ponds. Today, with river regulation and the demand for a reliable water supply by downstream water users such events are highly unlikely to occur in the future. Now, there is nearly always some flow in the River other than at the most downstream reaches in SA where regulation is thought to have increased the frequency and degree of low flows.

The flow regime prior to regulation was also characterised by seasonality of flooding. For example, flooding usually occurred from July (winter) to November (late spring). Reduced flows occurred during the drier seasons from December (summer) to May (late autumn). The seasonality of natural flooding also influenced water temperatures. Cold water flowed during late winter–late spring particularly with the melting of snow. Warmer water flowed in summer–late autumn when there was less water and higher land surface temperatures.

The river red gum forests and associated ecosystems have adapted to these conditions of seasonal flow variability, temperature variations, drought, and wet and dry cycles to form the rich biodiversity of the river red gum forests we see today. Figure 4.2 illustrates the relationship between the river's flow regimes and its anabranches, billabongs, lakes and ecological communities—particularly the lateral flow of water under flood conditions across the broader floodplain. Today, the natural variation of the River between floods and low flows has largely been eliminated, resulting in the degradation of large areas of river red gum forests and their associated ecosystems. Environmental flows (see chapter 15) are designed to address these ecological concerns.

Figure 4.2 Relationship between flow regimes of the river and ecological communities.



Source: MDBC (2002)

Groundwater

Hydrology also relates to the movement of water through ground systems and the interaction and interchange between surface and groundwater systems. Groundwater is water stored in the saturated zone (or aquifer) below the land surface. This water may be held in layers of soil or underlying porous materials such as gravel or porous rock. Where there is an impermeable layer both below and above the aquifer, it is known as "confined". An unconfined aquifer has no impermeable layer above the aquifer. A water table occurs where all the openings in rocks and the soils close to the surface are saturated with water.

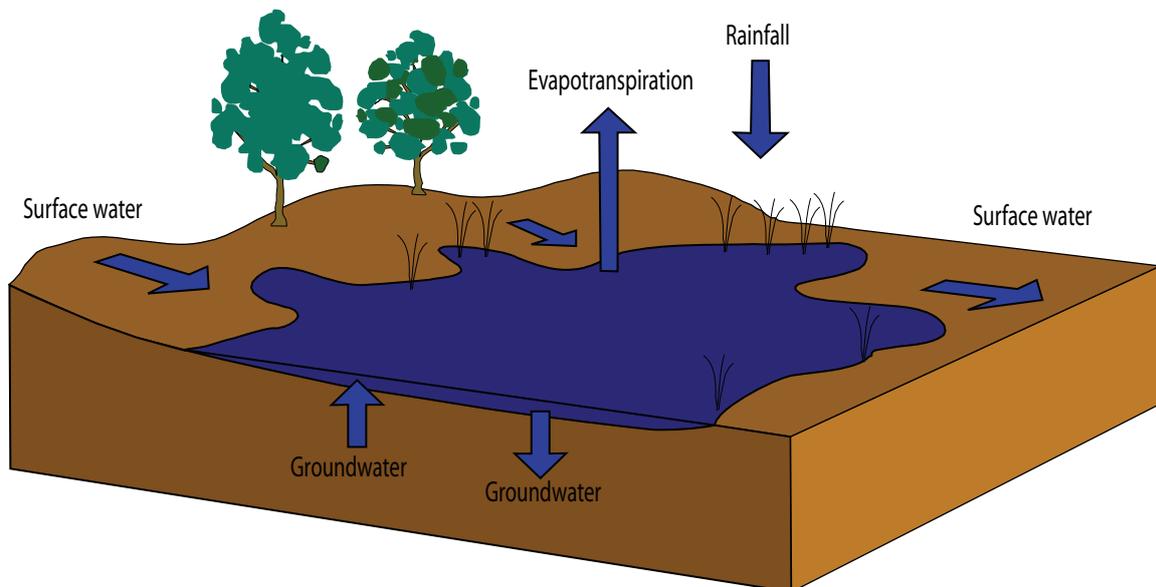
The level of the water table or pressure in an aquifer is dependent on equilibrium between recharge and discharge, which is influenced by the amount of surface water in the upper catchment areas and floodplains. Aquifers, therefore, are dependent on the amount of

water entering from rainfall recharge and watercourse seepage (Parliament of Victoria Environment and Natural Resources Committee 2001).

Extraction of groundwater increases outflows. If there is no increased water input, extraction will lower the water table or pressure in the aquifer and reduce the lateral flow of groundwater into waterways and wetlands. This is particularly important for the River Murray with its semi-arid environment because reduced lateral flow of groundwater provides less water during drought for river flow and in wetlands, billabongs and lakes (for example, see Figure 4.3).

Lower groundwater also affects deep-rooted plants, which may not be able to reach the groundwater during periods of droughts. Examples of this are stressed or dying river red gums downstream of Cohuna due to the changed water table and flood regimes.

Figure 4.3 Groundwater movements and wetland hydrology.



Source: MDBC (2001)

There are four main groundwater aquifers found within the Murray-Darling Basin relevant to the River Red Gum Forests Investigation, as follows.

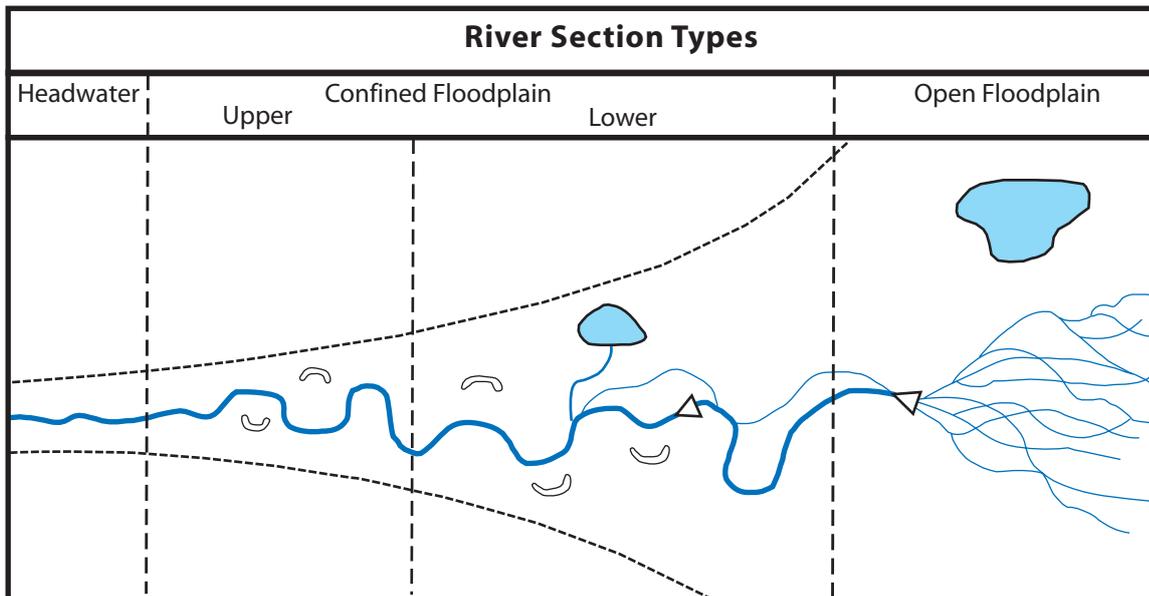
- The Renmark Group aquifer, located around the central western area of the Murray-Darling Basin, is relatively saline. The water pressure in this aquifer results in groundwater leaking upward into the overlying sediments.
- The Murray Group aquifer lies to the south of the River Murray and flows in a north-north-westerly direction from the recharge areas of the southern Wimmera toward a discharge point along the River Murray. Groundwater in this aquifer is relatively fresh.
- The Pliocene Sands aquifer is in the central area of the River Murray. This aquifer has a complex ground water exchange process. Around the basin margins, where the aquifer is unconfined, the water leaks down to the

aquifer from streams and rivers. Where the aquifer is confined, recharge is through downwards leakage from rainfall and by lateral transmission from the adjacent formations. At the eastern end of the aquifer the groundwater is relatively fresh. Towards the west the groundwater becomes more saline.

- The Shepparton Formation aquifer is found in Victoria and southern NSW. This aquifer has a complex local flow regime due mainly to the permeability of the materials forming the aquifer. This aquifer lies below the irrigation areas of the Goulburn Valley and receives recharge through irrigation leakage (Mackay & Eastburn 1990).

These regional aquifers recharge through two processes. The deeper confined aquifers have recharge zones generally around the Murray Basin margins and, more importantly, where the major rivers enter the plains from

Figure 4.4 Different sections types associated with the River Murray and the various features found within each section.



Source: MDBC (2001)

the uplands. The shallower unconfined aquifers receive water from large-scale rainfall over the surface.

Discharge from the deeper aquifers leaks up through confining layers to the watertable. Discharge from the watertable aquifer leaks into the lower reaches of the River Murray and its tributaries as well as by evaporation through capillary action up through the soil profile (Mackay & Eastburn 1990). Flows out of these aquifers into the River Murray are often the only additional water to the river as it flows west.

The River Murray and its Floodplains

The hydrology of the River Murray varies considerably across different sections of the river. The following description focuses on the hydrology of the headwater (upper catchment area) and floodplain sections. Each of the sections is shown in Figure 4.4, as are other sections of the river.

Headwaters

The hydrology of the headwaters of the River Murray (equivalent to the upland section in Figure 4.4) is largely shaped by the mountainous topography, relatively high rainfall during winter/spring and the confined nature of the river channels. The headwaters are mainly located within the North East catchment region of Victoria. River channels are small and narrow, with channel width often being less than 10 times the channel depth. The river banks associated with these channels are usually vertical rather than sloping in nature.

In its headwaters the River Murray channel and form is relatively straight but as it flows from the headwaters to the floodplains, such as below Hume Dam, meandering patterns begin to emerge (as described in chapter 3). Channel slope and gradient is greater reflecting the

higher, more mountainous topography than that of the floodplains and stream flow is consequently more direct and rapid (MDBC 2001).

River Murray headwater channels are associated with bedrock outcrops and ancient sedimentary deposits (see chapters 2 and 3). These channels are often temporary or ephemeral with flow into the headwater section being maintained by groundwater drainage from the upper catchment areas well after rain and surface water run-off have ceased. As a result, river flow rarely drops below a relatively high base level except during periods of severe drought.

There are distinct seasonal variations in run-off and flow in the headwaters. Late winter to mid spring rainfall is greater along with spring snow melts. In contrast, during late spring through to early autumn, rainfall is low and there is little surface run-off. Some streams cease to flow.

A number of land-use activities in the River Murray headwaters affect river flow and condition, particularly extensive land clearing. Reduced vegetation cover increases immediate run-off of surface water; less surface water infiltrates the soil, resulting ultimately in less groundwater discharge into streams and rivers. In combination, greater surface water run-off and vegetation clearing not only increases soil erosion, but also increases stream sediment as the filtering and soil-binding benefits of deep-rooted vegetation are lost. Sediment in the entire River Murray has been estimated to have doubled from 0.5 million tonnes a year to 1.0 million tonnes a year (MDBC 2001). Broad scale plantation forestry in the headwater section, is also believed to change the hydrological balance, intercepting groundwater discharge into streams.

Floodplains

The floodplains of the River Murray (corresponding to the upper and lower lowland sections in Figure 4.4) emerge as the river flows from the headwaters into the flatter and drier landscape. Floodplain sediment is deposited by the meandering river over time (see chapters 3). This section of the River Murray extends from around Albury-Wodonga to Wakool Junction near Swan Hill. As Figure 4.4 illustrates, this relatively shallow and wide section of the river winds, meanders and branches. Like the headwaters the River Murray floodplain has its own unique hydrology. Flow and flood patterns are greatly influenced by the low slope and gradient of the river bed and the associated floodplain areas.

There is more water in the river on floodplains and the fast turbulent streams of the headwaters are absent. The water is significantly warmer than in upper catchment because of higher air temperatures and direct solar radiation. When both flow and water turbulence is low the water may stratify, with warmer water lying on the surface and cooler layers lying closer to the river bed.

Flow and flood vary greatly across seasons and across years in the floodplain section of the River Murray. This variability is due to variation in rain and snow falls in the upper catchments. High flow or flood levels most commonly occur during late winter through to late spring. Reduced flows are usually associated with summer and early autumn. While flood frequency varies depending upon upper catchment rainfall, flood duration is closely linked to both the volume of water causing the flood as well as subsequent rain or snow-fall. Once a flood commences, there needs to be sufficient and ongoing water available to maintain the volume of water over a long period of time.

Water movement onto the floodplain is influenced by the relatively unconfined and low river channels. This channel shape enables water to move laterally out of the main River Murray and onto the surrounding landscape, or to form anabranch channels (channels that leave and then re-join the main river). Anabranches are usually not the major waterway, but may be a major waterway during times of varying flow. Depending on the size of the river flow when they were formed, anabranches may have larger channels than the existing, principal river and hence still carry more water during large floods.

The largest anabranch system on the River Murray is the Edward-Wakool system, which leaves the Murray River at Picnic Point, flows through Millewa forest before rejoining the River Murray at Wakool Junction. Hydrologically, this system is significant because, in times of large floods, it receives most of the flow. For example, during 1975 flood, 55 percent of the total water passing through Tocumwal went through the Edward-Wakool system. The Edward-Wakool system is unique and has its genesis in tectonic movements which created the short, shallow and narrow reach known as the Barmah Choke (see chapter 3). The Choke is a natural constraint on river flow because of its small channel relative to the channel upstream and downstream. For example, the River Murray's channel capacity at Yarrowonga is 25,000

ML per day whereas at the Barmah Choke it is only around 8500 ML per day. During flood periods this natural constriction not only diverts a large percentage of flood water north, then west, into the Edward-Wakool anabranch system but it also acts like a partial dam, forcing water to back up onto the floodplain and inundating extensive forest and wetland areas. This natural constraint has important implications for management of water for irrigation purposes and environment outcomes (see chapters 15 and 19).

Floods, and flooding of the floodplain in particular, achieve both longitudinal and lateral connectivity between different sections of the river and between the river and its floodplains. Longitudinal connection (or flow and flood movement down the entire length of the river) allows energy, nutrients and dispersal of plants and animals along the entire length of the river. Lateral connectivity through flow and flood movements between the river and floodplain transfer energy and nutrients around the floodplain and into various ecosystems as well as replenishing energy (carbon) and nutrients levels within the main river channel.

Water movement on the open floodplain is greatly influenced by evaporation from both land and water surfaces. Where evaporations rates are high, for example around Swan Hill and during summer, any remaining surface water quickly evaporates with little remaining for soil infiltration. Available surface and ground water is affected by the amount of water taken up by vegetation and the amount of floodwater either being returned to the river from the floodplain or remaining within the floodplain itself. As described above, clay-based soils play a significant role in this process.

Remaining Sections of the River Murray

Other sections of the River Murray also have characteristic, unique hydrology.

The Mallee trench is a wide plain of marine origin crossed by the River Murray in a single, well-defined channel which cuts deeper into the surrounding semi-arid plain as it moves downstream. The Mallee trench is broadly defined by the Murravian Gulf, marking the extent to which the sea once encroached across the river valley. The Mallee trench extends from the Wakool Junction near Swan Hill for approximately 850 river kilometres down to Overland Corner (SA). There is little, if any, surface water run-off into the River Murray in this area, where the river is characterised by low stream slope, low energy relative to its length and tiny catchment area relative to the size of the whole basin (Mackay & Eastburn 1990).

The Murray Gorge is found in the South Australian section of the River Murray between Overland Corner and Mannum, a distance of about 280 km. In the Gorge, the River has cut down through hard limestone rock during a period of low sea level, forming steep cliffs along the river channel. The river bed intersects with the regional watertable, and salty groundwater enters the river through aquifers exposed in the cliff face (Mackay & Eastburn 1990). There is virtually no surface water run-off in this section.

The Lakes and Coorong section of the River Murray system consists of the terminal lakes Alexandrina and Albert which, together with the Coorong, once formed a huge estuarine system. Barrages now separate the lakes from the Coorong and retain fresh water in the Lakes.

Summary

The hydrology of the River Murray is characterised by:

- its low and relatively flat gradient and slope;
- the extremes in wet and dry cycles across seasons and across years and its relatively low water flow volumes compared with other major rivers;
- the importance of both longitudinal and lateral connectivity via water flows for energy and nutrient transfer across the entire system;
- the meandering planform and associated wetlands, billabongs, anabranches, lakes and marshes; and
- the unique semi-arid environment through which most of the river flows.

Significant Ecological Asset Sites

The broad overview of the hydrology of the River Murray

presented above reveals wide variations across the different sections. Such variations are formally acknowledged through the work of the Murray-Darling Basin Commission in association with Victorian government agencies. Under the Commission's *The Living Murray, First Steps* program, six unique and at risk significant ecological asset sites along the length of the River Murray have been identified. The sites are shown in Figure 4.5 and include:

- Barmah-Millewa Forest;
- Gunbower-Koondrook-Perricoota Forests;
- Chowilla Floodplain, Lindsay-Wallpolla;
- Lower Lakes, Murray Mouth and Coorong; and
- River Murray Channel.

Each of these sites has their own unique natural hydrology. Replication of these hydrological conditions to achieve environmental outcomes is the basis of their listing (see chapter 15 for discussion of environmental flows). All of these sites, except for the Lower Lakes, Murray Mouth and Coorong, are relevant to the River Red Gum Forests Investigation.

Figure 4.5 Location of significant ecological asset sites.



Source: MDBC (2005)

5 Biodiversity

Biodiversity is important for economic, social and spiritual well-being. This chapter describes the biodiversity of the study area and how we classify those assets across Victoria generally and within the study area specifically. It also describes the threats to biodiversity. The chapter addresses broad patterns of biodiversity, characteristic habitat and species, and the processes impacting on biodiversity.

Biodiversity means many things to different people but can be defined as “the natural variety of all life forms: the sum of all our native species of flora and fauna, plants, animals and micro-organisms, the genetic variation within them, their habitats, the genes they contain, and the ecosystems of which they are an integral part” (DNRE 1997c).

Maintaining, protecting and enhancing biodiversity have become important priorities for communities as well as local, state and Commonwealth governments. People value biodiversity for its own sake and appreciate the opportunity to experience it. Many believe that future generations should have the chance to see a Murray cod or a superb parrot, for instance (see Appendices 4 and 5 for the common and scientific names of species recorded in the study area). Some simply value the existence of biodiversity—taking comfort in the knowledge that it exists even if they cannot experience it themselves. Others believe that all life forms have an inherent right to exist. In addition to its own intrinsic value, biodiversity maintains the health of natural systems more broadly, such as healthy soil and waterways—the term “ecosystem services” has been coined to recognise this role.

BROAD PATTERNS OF BIODIVERSITY

The Murray-Darling Basin is the largest catchment in Australia (see chapter 4), and the river, along with the climate and geomorphology, are the most influential factors on biodiversity within the River Red Gum Forests study area. Important features are the wet–dry cycle and irregular natural flooding. Unlike other great river systems, such as the flooded forests of the Amazon, the timing, frequency, duration and extent of flooding in the Murray-Darling system is not predictable from year to year. Species in the area must adapt to survive for extended, unpredictable dry periods between flood events as rainfall is low and evaporation rates are high. This wet–dry cycle leads to a different suite of species than areas with permanent inundation. A recently filled wetland will initially attract filter-feeding birds but fish-eating birds will not arrive until later in the cycle when fish are more abundant.

The geographic extent of the study area explains the broad patterns of biodiversity. Arid-adapted species at the southern limit of their range are found in the north west. More cold-adapted, higher rainfall species such as mountain swamp gum are found in the upper reaches of the Kiewa and Ovens Rivers, in the foothills of the Alps. Grasslands extend from the Hay Plain, interrupted only by the River Murray and into Northern Victoria, to support a distinctive suite of species.

While the vegetation varies widely across the study area, it shares common features along the river's edge. The rivers are typically banded by open forest/woodland dominated by river red gum and various associated wetland plants. The understorey depends on the frequency, depth and duration of flooding (usually determined by the elevation above the river). For example, in frequently-flooded sites, summer-green grasses dominate the ground layer. In more elevated drier sites, the understorey includes woody shrubs and grasses adapted to drier conditions. In the semi-arid areas of the far north west of the study area, saltbush plains are extensive on the poorly drained, relict floodplain of the Murray River.

Even subtle changes in elevation change the vegetation. In Barmah forest, increases of only 10 to 20 cm in elevation see river red gums replaced by black box. In some higher areas, trapped floodwaters support vegetation similar to that found in lower lying areas, illustrating the complexities of the system.

Many changes have occurred to the vegetation, fauna and water regimes of the study area since European settlement. Some of these are discussed in this chapter.

Bioregional Context

Australia can be divided into broad geographic regions with similar biophysical characteristics (climate, soil and geomorphology) and consequently, similar vegetation. ‘Bioregions’ capture the ecological patterns of the landscape or seascape, providing a natural framework for recognising and responding to biodiversity values. Australian Bioregions are used to assess the status of native ecosystems, their protection in the national reserve system and to monitor and evaluate the Australian Government's current Natural Resource Management initiatives. Victorian Bioregions are the principal units for conservation planning and biodiversity management in the state (DNRE 1997c).

Australia is divided into 85 regions, and further into sub-regions, based on major geomorphic features (Environment Australia 2000). These are referred to as the IBRA Bioregions (Interim Biogeographical Regionalisation for Australia). The River Red Gum Forests study area is almost exclusively (97 percent) within the Riverina region, an ancient riverine plain that includes the Murray River and tributary floodplains.

In Victoria, the landscape is divided into 28 biogeographic regions called Bioregions, which correspond closely with the IBRA subregions. Four main Victorian Bioregions fall within the River Red Gum Forests study area: Victorian Riverina, Murray Fans, Murray Scroll Belt and Robinvale Plain along with a number of smaller sections of other bioregions (see Map B and Table 5.1).

The **Victorian Riverina Bioregion** is an ancient riverine floodplain of the Murray River and its tributaries (the Avoca, Loddon, Campaspe, Goulburn, Broken, Ovens, King and Kiewa Rivers), characterised by flat to gently undulating land. Some rivers, such as the Avoca, drain internally into a series of terminal lakes and wetlands. The Murray River itself intersects this bioregion only between the Ovens and Mitta Mitta Rivers, and for a few kilometres downstream of Echuca (Map B).

Table 5.1 Victorian bioregions intersecting the River Red Gum Forests study area.

Victorian Bioregion	Area falling within the study area (hectares)	Percent of Victorian extent of bioregion intersecting study area
Victorian Riverina	722,500	38
Murray Fans	289,385	66
Murray Scroll Belt	116,143	100
Robinvale Plain	64,185	100

Source: DSE (2006a).

Note: Because the study area boundary was not solely derived from Bioregional boundaries, small areas of other bioregions have also been included in the study area: Murray Mallee (16,541 ha within the study area), Northern Inland Slopes (2966 ha), Wimmera (1419 ha), Central Victorian Uplands (375 ha), Highlands Northern Fall (245 ha) and Goldfields (61 ha).

The majority of this bioregion is less than 160 m above sea level, especially within the study area.

The **Murray Fans Bioregion** (along the River Murray between the Ovens River and Boundary Bend—see Map B) contains alluvial fan-shaped deposits formed when hillside streams slow down and deposit a broadening fan of sediment on the plain (LCC 1989b). The resulting floodplain along the Murray River also includes terminal sections of the wide floodplains of the Avoca, Loddon, Campaspe and Goulburn Rivers. This bioregion is uniformly flat or gently undulating with elevation from 60 m to 120 m above sea level.

The ‘core’ floodplain landform of the Murray Fans Bioregion is typified on Gunbower Island and in Barmah Forest. This floodplain has numerous oxbows and meander scrolls, as well as many source-bordering dunes (typically supporting drier, highly-localised vegetation formations). Flanking the floodplain is a terrace of better-drained riverine plain, sometimes also including wind-blown dunes. Upstream of Echuca, the Kanyapella Basin forms a vast lake/lunette sequence, derived from wind-blown and alluvial sediments, and containing transient and permanent wetlands, fringed by wind-blown dunes (LCC 1983, 1987).

The Murray Fans Bioregion lies between the Murray River and the Victorian Riverina (to the east and south) and the mallee dunefields (the Murray Mallee and to a lesser extent the Lowan Mallee Bioregions to the west). The land systems and associated vegetation is similar to that of the adjoining Victorian Riverina Bioregion between Yarrawonga and Swan Hill. Consequently, the Murray Fans Bioregion shares important environmental issues with flanking bioregions, especially the Victorian Riverina. Salination of streams and wetlands is even more extreme in this bioregion because it is the end the state’s major drainage systems.

Downstream of Swan Hill, where the Murray Mallee Bioregion abuts the Murray Fans, there is a greater contrast in geomorphology and vegetation. In this

region, the floodplain and riverine plain components become more slender, being pressed between the Murray River and the mallee dunefield land systems of the Murray Mallee Bioregion.

The remaining two major Victorian Bioregions in the study area are created by floodplains intruding into the semi-arid Murray Mallee Bioregion. The **Robinvale Plains Bioregion** occupies a thin riverine floodplain along the Murray River from the Wakool River junction to a few kilometres upstream of the Murray and Darling River junction. The floodplain is generally less than 1–4 km from the river, except at Hattah-Kulkyne National Park where it extends up to 15 km inland, encompassing an extensive complex of wetlands. Robinvale Plains includes three different geomorphic components: low lying, periodically inundated floodplains of heavy grey clays (frequently overlain by shallow grey sandy surface soils); raised wind-blown dune hummocks with reddish-yellow sandy soils (most extensive in Hattah-Kulkyne National Park); and lunettes associated with the lakebeds and creek systems of Hattah-Kulkyne National Park.

Downstream of the Robinvale Plains, the **Murray Scroll Belt Bioregion** has a wider floodplain with meandering channels, billabongs, levees and low dunes, and larger overflow lakes and lunettes. This region continues downstream into South Australia. It is affected by summer floods and higher water salinity from the Darling River (NSW National Parks and Wildlife Service 2003). The Murray Scroll Belt Bioregion contains three primary geomorphic components: the riverine floodplain, (subject to periodic inundation and including oxbow lakes, ephemeral wetlands and active meander belts); broad, flat alluvial plains (rarely flooded); and alluvial rises (or elevated terraces of wind-blown material built up during more arid periods).

Ecosystems and Communities

An **ecosystem** is ‘a dynamic complex of plant, animal, and microorganism communities and the non-living environment interacting as a functional unit’ (Millennium

Ecosystem Assessment 2005). Species also interact with the non-living components of the environment including the soil, water and air. 'Ecosystem services' is a relatively new term used to describe the benefits, or 'services', we derive from these interactions, such as the production of goods, regeneration of services, stabilising services, life-fulfilling services (e.g. spiritual inspiration) or preservation of options (Lovett et al. 2004). For instance, nutrients, light and water are transformed by invertebrates, fungi and bacteria into fertile soils essential for agriculture.

There are many different types of ecosystem services (Ecosystems Services Project 2001), including:

- Pollination
- Insect pest control
- Regulation of climate
- Provision of shade and shelter
- Maintenance and regeneration of habitat
- Prevention of soil erosion
- Maintenance of soil fertility
- Maintenance of soil health
- Waste absorption and breakdown
- Maintenance and provision of genetic resources
- Fulfilment of people's cultural, spiritual and intellectual needs
- Water filtration
- Maintenance of healthy waterways
- Regulation of river flows and groundwater levels

Many more ecosystem services and their effects on humans, are described in the report of the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment 2005). Ecosystem services underpin our social and economic health and threats to biodiversity also threaten associated ecosystem services and human well-being.

Ecological communities, or associations of plants and animals inhabiting, and interacting, within a common environment, are open and dynamic. Components of a community are interdependent. New species can enter the community, changing the pattern of occurrence and interaction within the community. Communities change naturally over time (for example, through ecological succession), however, communities may also be damaged when one or more of the component species declines or disappears, and/or when non-indigenous elements are added. Other species that may rely on the declining species may suffer a corresponding decline. Many communities are threatened and some are listed under the *Flora and Fauna Guarantee Act 1988* for protection. Table 5.2 lists the communities potentially in the study area that are listed under the *Flora and Fauna Guarantee Act 1988*.

Ecological Vegetation Classes (EVCs)

The diversity and complexity of vegetation communities requires a framework which can be used to simplify and identify common features. In Victoria, hierarchical Ecological Vegetation Classes (EVCs) have been developed over the past decade to classify vegetation

into ecologically meaningful and useful units. EVCs are defined by a combination of floristics (major plant species), lifeform, position in the landscape, and an inferred fidelity to particular environments.

One hundred and sixty-nine EVCs have been identified in the River Red Gum Forests study area (Appendix 6), including many mosaics and complexes in which the primary EVCs are closely mixed. Many EVCs only occur in the study area on the periphery of much larger occurrences in adjoining bioregions, for example, various mallee EVCs. The vast majority of the natural vegetation in the study area can be defined within 34 EVCs (described in detail in Appendix 7), covering (1) the forests, woodlands and wetlands along the floodplains; (2) the grassy woodlands and grasslands on higher terraces (especially between the Avoca and Campaspe Rivers); and (3) saltbush plains (especially west of Mildura).

The distribution of vegetation types in the study area is shown in Map B. Because of the large number of EVCs, and the closely interwoven occurrence of EVCs in many areas (e.g. see the Barmah forest inset in Map B), it is not possible to discern individual EVCs over much of a map of this scale. Accordingly, EVCs of similar composition and environmental determinants have been grouped under the same colour in Map B.

Vegetation along the rivers has been extensively altered over 150 years of water regulation by levee banks, dams and weirs. Today, many flood-dependent EVCs such as Grassy Riverine Forest and Riverine Swampy Woodland are threatened by the lack of regular flooding and the consequent flushing of salt from the ground surface. As a result, grass species better adapted to drier conditions are now invading communities that once supported flood-dependent grasses. Some shrubs that are relatively tolerant of grazing and flooding are also invading previously regularly-flooded grassy woodlands and forests. Grazing has also had a major impact on the riverine vegetation, eliminating or reducing sensitive species, promoting weed invasion and altering the original vegetation.

Vegetation Condition

While EVC mapping describes the extent of vegetation, it does not provide information on the condition of the vegetation. Recently, the condition of extant native vegetation has been mapped at a broad scale across northern Victoria (ARIER et al. 2004). Vegetation condition was mapped in five classes from 'good' to 'poor' condition, incorporating factors such as vegetation type, geology, climate, tree density, fragmentation and land use based on Landsat satellite imagery. This mapping is useful for broad-scale conservation and management planning but not for small scale planning, such as individual properties.

The results of this work for the study area (see Map 5.1) reveals that the vegetation is generally in best condition around Lindsay, Wallpolla and Mulcra Islands as well as Kings Billabong and Belsar Island. Native vegetation is generally in medium condition in Gunbower and Barmah forests, but mostly poor condition around the Kerang lakes and on floodplains upstream of Lake Mulwala.

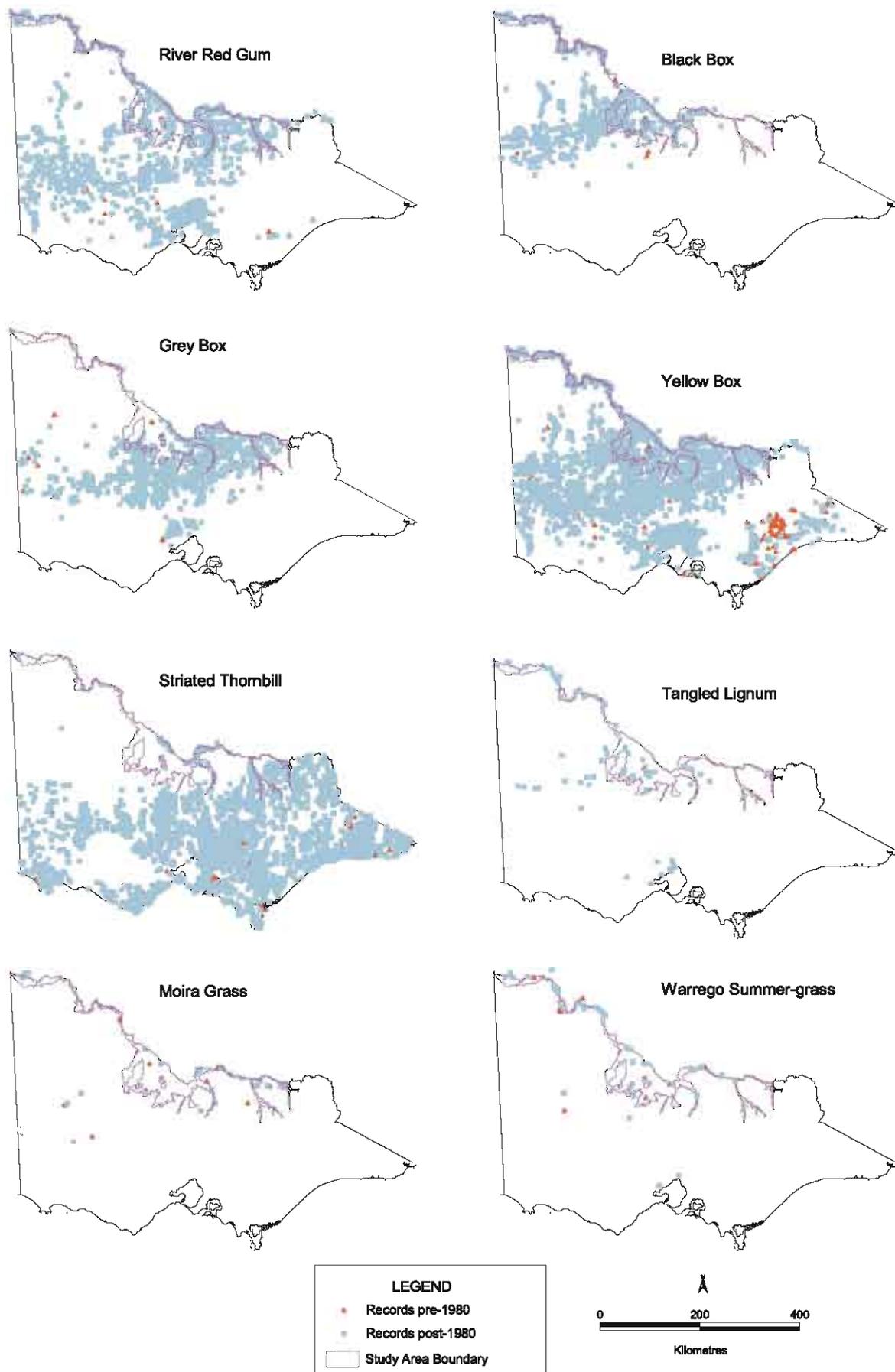
Table 5.2 Communities in the River Red Gum Forests study area listed under the *Flora and Fauna Guarantee Act 1988*.

Community Name	Description
<i>Victorian Temperate-woodland Bird Community</i>	24 bird species (13 species individually listed) that are totally or largely restricted to temperate woodland habitat. Woodlands include box-ironbark, yellow box, cypress-pine and other woodlands. The fauna includes many species of nectar-feeders, ground-seed feeders, open-ground insect-eaters and hollow nesters.
<i>Victorian Mallee Bird Community</i>	20 bird species (8 species individually listed) that are characteristically and commonly found within mallee vegetation/habitats. Threatened by habitat loss, fragmentation and degradation. Also predation by foxes and cats. Large bushfires negatively impact some species.
<i>Lowland Riverine Fish Community of the Southern Murray-Darling Basin</i>	Occurs in the lowland reaches and associated floodplains of the Murray, Darling and Murrumbidgee rivers and their tributaries within Vic, NSW & SA. Includes 15 fin fish species, ten of which are individually listed.
<i>Northern Plains Grassland Community</i>	Distributed across the Northern Plain, primarily on alluvial sediments. Rainfall on average less than 430 mm. The community ranges from open to closed tussock grassland dominated by wallaby grasses, spear-grasses and spider grass, with some herblands or occasionally low chenopod shrubland.
<i>Semi-arid Herbaceous Pine–Buloke Woodland Community</i>	Entirely restricted to public land in northwestern Victoria, including Murray Sunset and Hattah-Kulkyne National Park. Slender callitris-pine in association with buloke. The ground layer is mostly herbaceous species with few shrubs. It is threatened by grazing, soil erosion and lack of regeneration.
<i>Semi-arid Herbaceous Pine Woodland Community</i>	Occurs in the Mallee region of northwestern Victoria. Overstorey dominated by slender callitris-pine and occasionally buloke. Shrubs are uncommon and the ground layer is dominated by herbaceous species. Threatened by clearing along roadsides and railways, fertiliser and weedicide drift, land clearance and overgrazing.
<i>Semi-arid Northwest Plains Buloke Grassy Woodlands Community</i>	Occurs at widespread sites across northwestern Victoria. Buloke as the dominant tree sometimes in association with black box and yellow gum. Gold-dust wattle is the dominant shrub and there are normally a number of grass species. Threatened by clearing along roadsides and railways, fertiliser and weedicide drift, land clearance and overgrazing.
<i>Semi-arid Shrubby Pine–Buloke Woodland Community*</i>	Restricted to the Mallee region in northwestern Victoria where sites occur on public land of varying tenure. Slender cypress-pine usually with buloke. A distinctive shrub layer and herbaceous annuals. Primarily threatened by overgrazing (native and domestic).
<i>Grey Box–Buloke Grassy Woodland Community^</i>	The community was formerly distributed from Jilpanger southwest of Horsham to near Rutherglen. Shrub layer is generally lacking and the ground layer is dominated by grasses. Threatened by stock grazing, timber removal, mining and maintenance of firebreaks.

Notes: * may not be found within the study area

^ formerly found within the study area

Figure 5.1 The distribution of selected characteristic species in the River Red Gum Forests study area.



Source: Data from the Flora Information System and Atlas of Victorian Wildlife, curated by the Department of Sustainability and Environment

Figure 5.2 Hairy darling-pea on a ridge in river red gum/black box woodland on Mulcra Island, west of Mildura.



Species Diversity

This section summarises the flora and fauna species in the study area.

Plant species

Many plant species are found in the study area with over 88,000 records of 2279 taxa (species, subspecies and variants – see Glossary), 167 of which are threatened or near-threatened (Appendix 4). Plant species on the floodplains of the study area are distributed according to the extent, duration and frequency of flooding. Other species, notably grassland species, have been highly depleted and now survive only in fragmented remnants.

The forests of the study area are dominated by the river red gum. Other common eucalypts include grey box, black box and yellow box (Figure 5.1 and below for detailed descriptions). Non-eucalypt trees include cypress-pines, sheoaks, wattles and the semi-parasitic ballarts. The main cypress-pine species are white cypress-pine in the east of the study area and slender cypress-pine in the west. Leafless ballart is found mostly downstream of Echuca, broom ballart is restricted in distribution and found near Hattah-Kulkyne and pale ballart is distributed along the length of the study area but is common in the Gunbower, Benwell and Guttrum forests.

Shrubs are not abundant on the floodplains of the study area, partially due to the long history of domestic stock grazing in these forests. However, they include many wattles (e.g. gold-dust and varnish wattles), over 30 salt bush species and a saltwort. Lignum, a tangled, almost leafless, green shrub (see below), is commonly found on the floodplains west of Tocumwal. There are also many species of herbs, grasses and sedges in the study area, including spear-, wallaby, and kangaroo grasses. The distribution of many grasses and sedges closely follow the watercourses, e.g. warrego summer-grass (Figure 5.1).

Introduced species, including weeds, are common and are discussed below under 'Processes Impacting on Biodiversity'.

Threatened Plants

As listed in column 'Vic' in Appendix 4, the River Red Gum Forests study area includes (or has included) populations of seven extinct plant taxa, 63 endangered plant taxa and 101 vulnerable plant taxa. A further 124 taxa are considered 'rare' and 81 are considered 'poorly known'. Sixty-three plant taxa in the study area are listed under the *Flora and Fauna Guarantee Act 1988*.

The threatened plants of the study area include:

- Trees, such as wilga, northern sandalwood, yarran wattle, weeping myall, swamp sheoak and buloke;
- Shrubs, such as emu-bushes (*Eremophila*), spurges (*Euphorbia*), salt paperbark and a variety of saltbushes (*Atriplex*, *Chenopodium*, *Maireana*);
- Herbs, such as darling-peas and Swainson-peas (*Swainsona*), scurf-peas (*Cullen*) and a wide variety of daisies (e.g. *Brachyscome*, *Leptorhynchos*, *Rhodanthe*, *Vittadinia*); and
- a variety of grasses belonging to the genera *Austrostipa*, *Aristida*, *Sporobolus*, *Eragrostis* and *Digitaria*, along with sedges of the genera *Cyperus* and *Eleocharis*.

The biogeography of the study area is reflected in the relatively high representation of certain genera among the threatened plant taxa, such as *Swainsona* (see Figure 5.2), *Cullen*, *Sclerolaena* and *Ptilotus*, and in the relatively low representation of other groups, such as the orchids.

In habitat terms, many of the threatened plant taxa inhabit grasslands, grassy woodlands and wetlands rather than just river red gum forests. Figure 5.3 shows the very restricted distributions of some of these threatened species.

Figure 5.3 The distribution of selected threatened flora species in the River Red Gum Forests study area.



Source: Data from the Flora Information System, curated by the Department of Sustainability and Environment

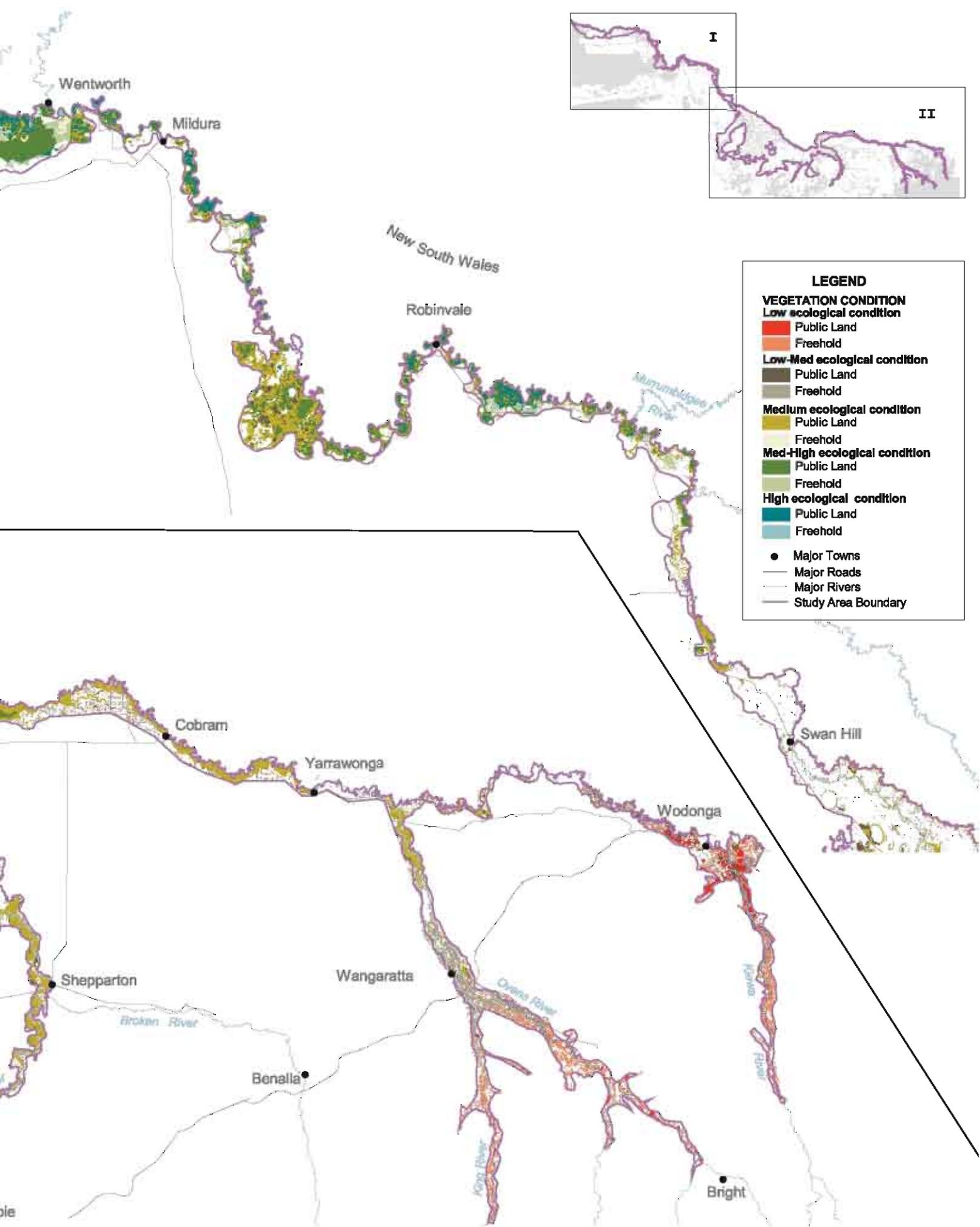


Table 5.3 The number of vertebrate animal species recorded in the River Red Gum Forests study area, by class.

Vertebrate group	Total no. of species	No. of introduced species
Mammals	62	13
Birds	326	11
Amphibians	21	0
Reptiles	76	0
Fish	33	8
Total	518	32

Source: DSE Atlas of Victorian Wildlife 2006

Fauna

There are over 150,000 records of 518 species of vertebrate fauna (Appendix 5 and Table 5.3), including 126 threatened taxa in the study area.

The 62 **mammal** species recorded in the study area range in size from the little forest bat (weighing less than 5 g) to the red kangaroo (with males weighing as much as 85 kg). The mammals inhabit a wide range of habitats but are mostly rarely seen, being either cryptic or most only active at night (e.g. possums, platypus and phascogales).

Bats are the largest group of native mammals in the study area, comprising nearly 40 percent of native mammal species—16 microbats and two species of megabats (or fruitbats, the grey-headed flying-fox and the little red flying-fox). Microbats use echolocation (emitting and receiving high-frequency sounds) to detect prey, predators and obstacles. The white-striped freetail bat emits these sounds within the range of human hearing and can often be heard by riverside campers.

The pig-footed bandicoot, eastern hare-wallaby, lesser stick-nest rat and an undescribed short-nosed bandicoot were once recorded in the study area but are now extinct. The eastern quoll, red-tailed phascogale, western barred bandicoot, brush-tailed bettong, rufous bettong and bridled nailtail wallaby were also recorded in the study area but are now extinct in Victoria. It is possible that the western quoll, kultarr, greater stick-nest rat, Bolam's mouse, desert mouse, and the now extinct white-footed rabbit-rat also occurred in the study area at the time of European settlement (Menkhorst 1995). A number of other threatened mammal species occur in the study area, including the squirrel glider (see Figure 5.4).

Birds are perhaps the most widely known of the vertebrate groups, probably because they are mostly active during the day, are relatively large-bodied and there are many species. Three hundred and twenty-six species of birds have been recorded in the study area, nearly twice the number of all other vertebrate species. The study area provides habitat for raptors, woodland birds, wading birds, migratory birds, colonially-breeding species and rare and threatened species. These include the nationally-threatened plains-wanderer (see Figure 5.4), Australian painted snipe, superb parrot and regent parrot. It also supports important Victorian populations of the

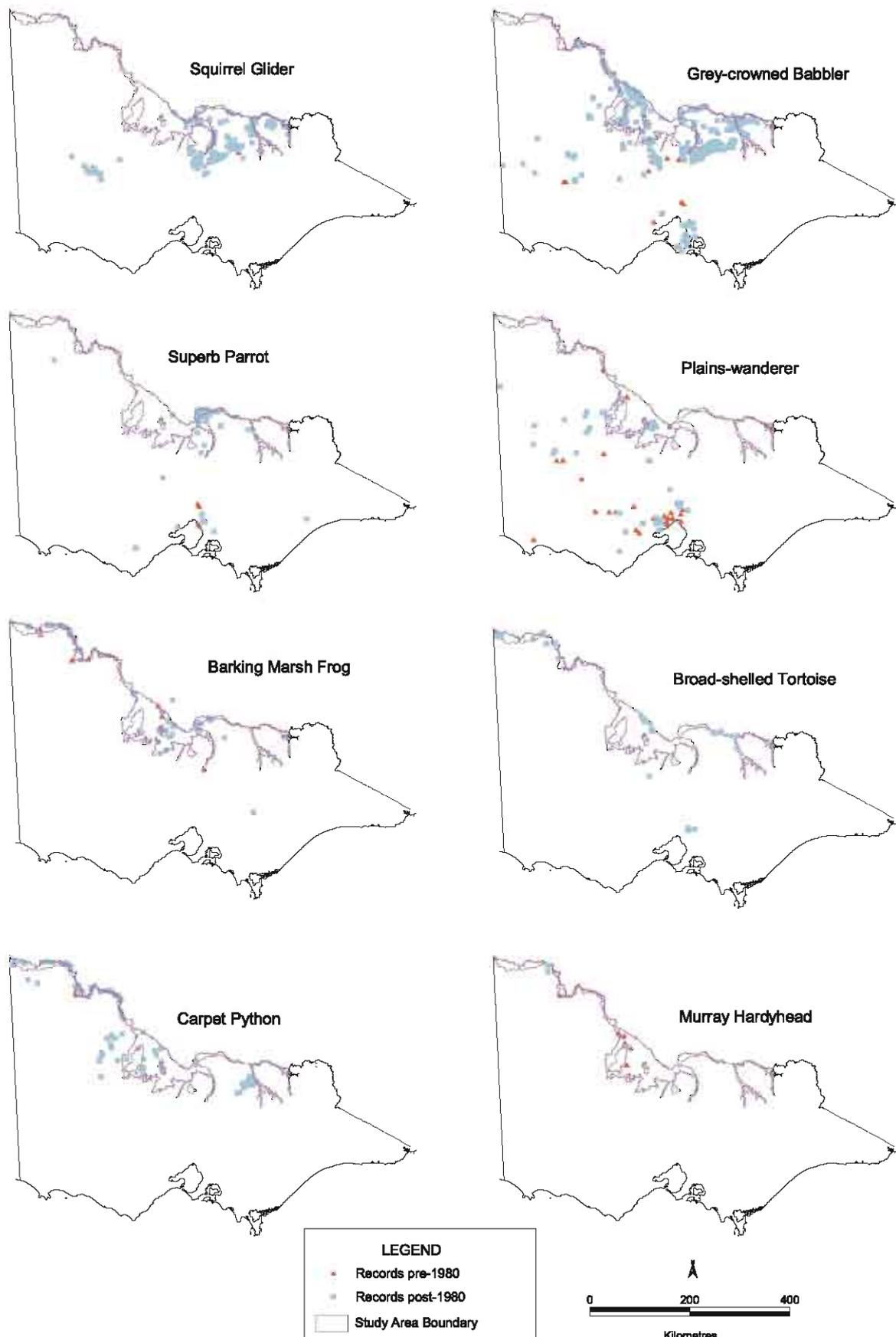
red-chested button-quail, inland dotterel, intermediate egret, little bittern, freckled duck, ground cuckoo-shrike, and grey-crowned babbler.

Australia has bilateral agreements with Japan and China for the protection of migratory birds common to both countries (the JAMBA and CAMBA agreements). The study area includes 34 species listed in each or either of those agreements (Appendix 5). The agreements aim to protect migratory birds from take or trade, protect and conserve habitat, exchange information and build cooperative relationships between the countries and Australia.

Twenty-one species of **amphibians** have been recorded in the study area, including species with only a few records—Lesueur's frog, mallee spadefoot toad and giant bullfrog. Frog breeding is greatly influenced by water regimes. For many species the seasonality, frequency, duration and water temperature of flooding are important. In Barmah forest, the highest frog activity is not in the creek systems but in well-vegetated and actively flooding wetlands. Ponded wetlands without fresh flows show relatively little frog activity (Ward 2004). The importance of water regimes for frogs, in combination with a general decline in worldwide frog populations, makes frog species especially vulnerable within the study area. Some species previously recorded in the study area may no longer occur at those sites. For instance, the common spadefoot toad, Bibron's toadlet, and growling grass frog have not been recorded in Barmah forest for several years despite intensive survey efforts (Ward 2004), and the growling grass frog has also not been recorded in Gunbower forest for the last couple of years (Keith Ward pers. comm).

Seventy-six species of **reptiles** have been recorded in the study area. Although many (38 percent) of these have been recorded fewer than ten times, many common species may be under-reported, while there has been little survey effort for more cryptic species. For example, the common blue-tongued lizard (Figure 5.5) is probably common in the study area but has only been recorded 31 times. Over 80 percent of the Victorian records of five threatened reptiles are within the study area: curl snake, broad-shelled tortoise, eastern water skink, tessellated gecko and red-naped snake—illustrating the importance of the region for those species. Other threatened reptiles with populations in the study area include the hooded scaly-foot, Mueller's skink and carpet python (see Figure 5.4).

Figure 5.4 The distribution of selected threatened fauna species in the River Red Gum Forests study area.



Source: Data from the Atlas of Victorian Wildlife, curated by the Department of Sustainability and Environment

Figure 5.5 A common blue-tongued lizard in Myrtleford, Victoria.



Fish play a vital role in the ecology of rivers, streams, lakes and wetlands (Koehn 2002). They are present in each trophic level as detritivores, herbivores, omnivores and carnivores. Across their life cycles they provide food for many other species and contribute to water quality and nutrient cycling. Thirty-three species of fish have been recorded within the study area. Eight of these are introduced and, of the 21 native species, nine are threatened in Victoria (Appendix 5). Notable threatened fish include freshwater catfish, Murray hardyhead (see Figure 5.4), trout cod, Murray cod and silver perch.

Invertebrates are an important and diverse group, comprising more than 95 percent of the world's animal species. There are an estimated three and eleven million species of invertebrates worldwide. Invertebrates are involved in essential ecological functions such as pollination, herbivory, parasitism, predation, seed harvesting and dispersal, decomposition, scavenging, and soil turnover. All these functions contribute to a sustainable ecosystem.

The invertebrate fauna of the study area varies with geography through the dry-sclerophyll forest, riparian zones, arid zones, as well as having a cosmopolitan element (Mac Nally et al. 2002a). Preliminary studies indicate that river red gums have a very rich invertebrate fauna that changes seasonally in composition and function (Yen et al. 2002). The few studies available on terrestrial invertebrates within river red gum ecosystems indicate that there is high invertebrate species richness at both individual tree and at ground-level, but the extent and variation across the study area is unknown. River red gum ecosystems in different locations may

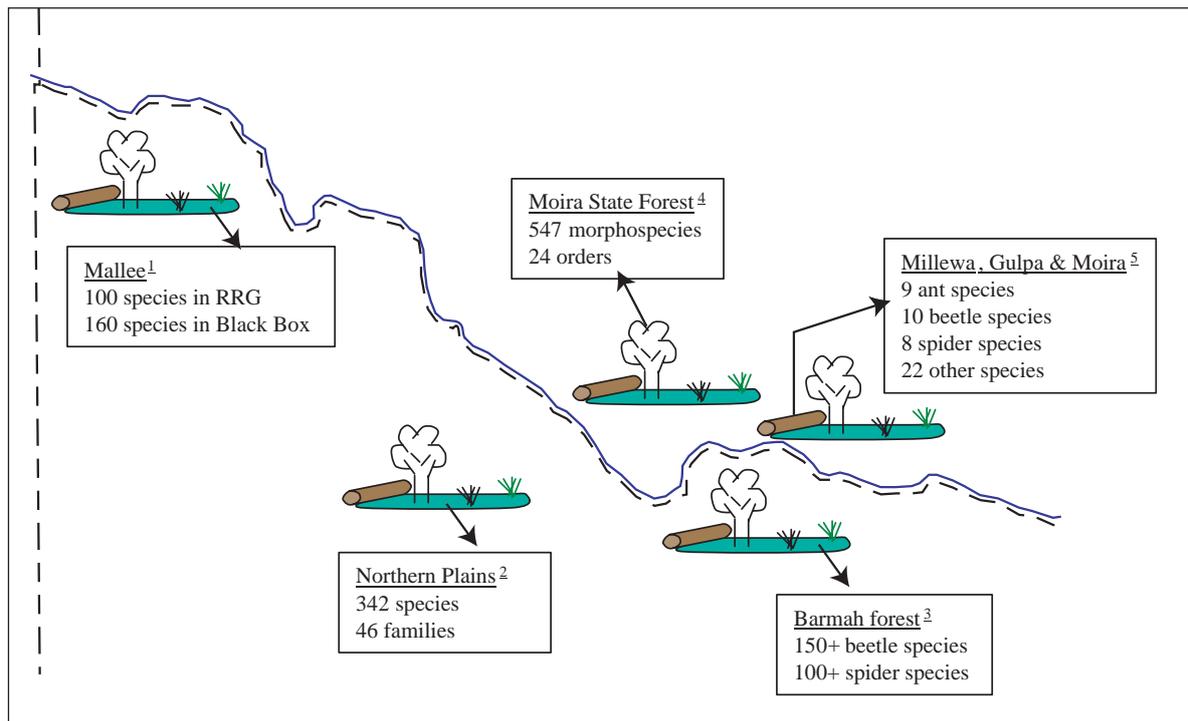
appear botanically similar, but differences in invertebrate fauna may be great.

Little is known about how invertebrate species interact with each other and with their environment, including within river red gum ecosystems. While there is a rich arboreal invertebrate fauna, especially herbivorous insects, with leaf damage and dieback being significant management issues (see below), there is limited information on the importance of river red gums as habitat for these arboreal invertebrate species.

Current information about arboreal, ground-dwelling and log-dwelling invertebrates is represented in Figure 5.6. Robertson et al (1989) collected a total of 100 species of ground dwelling invertebrates in river red gum forest sites and 160 species in black box forest with 52 of these species being found in both river red gum and black box forests (See ¹, Figure 5.6). In a study of remnant river red gum and grey box forests on the northern plains near Echuca, a greater number of ground-dwelling invertebrate orders was found in river red gum compared with pasture (Yen et al. 1996) (See ², Figure 5.6), however there were large seasonal differences in composition. In an examination of 4487 beetles from 342 species (representing 46 families) collected by Yen et al. (1996), Ward et al. (2002) found that summer sampling yielded most species, but winter yielded more specimens.

Flooding patterns also affect invertebrate abundance. Ballinger et al. (2005) examined ground-active terrestrial beetles and spiders before and after a managed flood in Barmah Forest (See ³, Figure 5.6).

Figure 5.6 Diagrammatic summary of the five studies of invertebrate diversity near the study area.



Source: Data from the Atlas of Victorian Wildlife, curated by the Department of Sustainability and Environment

¹Robertson et al. (1989); ²Yen et al. (1996); ³Ward et al. (2002); ⁴Ballinger et al. (2005); ⁵Yen (2003)

Immediately following flooding, the abundance, species richness, and biomass of predatory carabid beetles (which like humid environments) was greatest at sites that had been flooded the longest (approximately 4 months). However another predator of aquatic invertebrates, the lycosid spiders were not affected by the duration of flooding. There was no difference in the number of beetles before flooding, but the differences observed after flooding remained for over two years. Increases in the abundance of large beetles, like these are likely to affect insectivorous vertebrates such as the yellow-footed antechinus.

To collect arboreal invertebrates, Yen et al. (2002) sprayed the canopy of two individual River Red Gum trees in the Moira State Forest (NSW) with insecticide, one in February and one in October (See ⁴, Figure 5.6). A total of 458 invertebrate species was collected from the canopy with only 90 species collected in both February and October. The canopy was dominated by Hemiptera (bugs), Diptera (flies), Hymenoptera (ants and wasps) and Araneae (spiders). A further 69 invertebrate species (mainly spiders) were collected by hand from beneath the bark of the two trees (9 in February and 52 in October 1999, with 8 species found in both months). The large number and diversity of invertebrate species on two individual trees suggests that the total number of invertebrate species in river red gum forests is large, particularly taking into account variation due to season, tree age and condition and local variation. Internal invertebrate species that feed within the leaf or stem such as leaf miners and gall formers, wood feeders, and associated parasitoids, were not collected in this study, but would further add to the total species tally.

A brief survey of 31 large river red gum logs (greater than 60 cm diameter) in the Millewa, Gulpa Island and Moira State Forests in NSW (Yen 2003) (See ⁵, Figure 5.6), found mainly timber feeders, Bostrichidae and Cerambycidae beetles and the termite *Coptotermes acinaciformis*. The few invertebrate species found may have been due to the nature of the timber and/or flooding regimes. River red gums decompose slowly on the ground and may take 175 years (Mackensen et al. 2003). The saproxylic (wood-feeding) fauna of river red gums seems to be poor compared with other forest types (Ballinger & Yen 2002; Yen 2003).

It is worth considering current and potential threats to the diverse river red gum invertebrate fauna despite the overall lack of detailed background. While some threats are obvious, such as clearing river red gum forests for pasture, horticulture or agriculture, many other threats may be more subtle. Threats that can be managed at the local level include fragmentation, habitat simplification (such as loss of coarse woody debris and plant litter by grazing, firewood collecting, trampling and vehicular access for recreation and inappropriate fire), and inappropriate use of chemicals and their effects on non-target groups. Information is required on the effects of these threatening processes on invertebrates filling different ecological roles, in different age structured forests in different areas under varying management regimes. Grazing is a major use in some of these forests, and its effects on the structure and functioning of the ground layer and its associated invertebrate fauna need to be documented. Habitat simplification through loss of coarse woody debris is also a matter of concern for terrestrial invertebrates.

Threatened Vertebrates

Based on conservation status information from the DSE Advisory List of Threatened Vertebrate Fauna in Victoria (2003a), the study area includes (or has included) populations of four 'extinct' vertebrate taxa, three 'regionally extinct' vertebrate taxa, 12 'critically endangered' vertebrate taxa, 28 'endangered' vertebrate taxa and 38 'vulnerable' vertebrate taxa. A taxon is considered 'regionally extinct' if it no longer occurs in Victoria, but remains extant in the wild in other parts of its former range. Eighty-two vertebrate taxa occurring in the River Red Gum study area are listed as threatened under the *Flora and Fauna Guarantee Act 1988*.

Nationally threatened species such as the critically endangered spiny rice-flower and endangered trout cod do not occur anywhere else in the world. Their native environments are highly modified and they face high levels of threats. Further research into these species is being undertaken to increase their numbers and reduce the threats to their survival (Figure 5.7).

Figure 5.7 Measures implemented to protect the nationally endangered trout cod in the Yarrawonga Regional Park.



CHARACTERISTIC HABITATS AND SPECIES

The geology (chapter 2), geomorphology and land systems (chapter 3), climate and hydrological systems (chapter 4) combine to provide the setting for the vegetation communities, resulting in different patterns of faunal and flora assemblages. This section describes those patterns within the study area.

The principal habitats within the study area are:

- floodplains and other wetlands (fresh and saline, ephemeral and 'permanent') including river red gum forests,
- rivers and streams,
- eucalypt woodlands on higher ground, dominated by grey box or yellow box,
- tussock grasslands,
- saltbush plains in the Murray Scroll Belt, and
- mallee, west of Mildura.

Floodplains and Other Wetlands

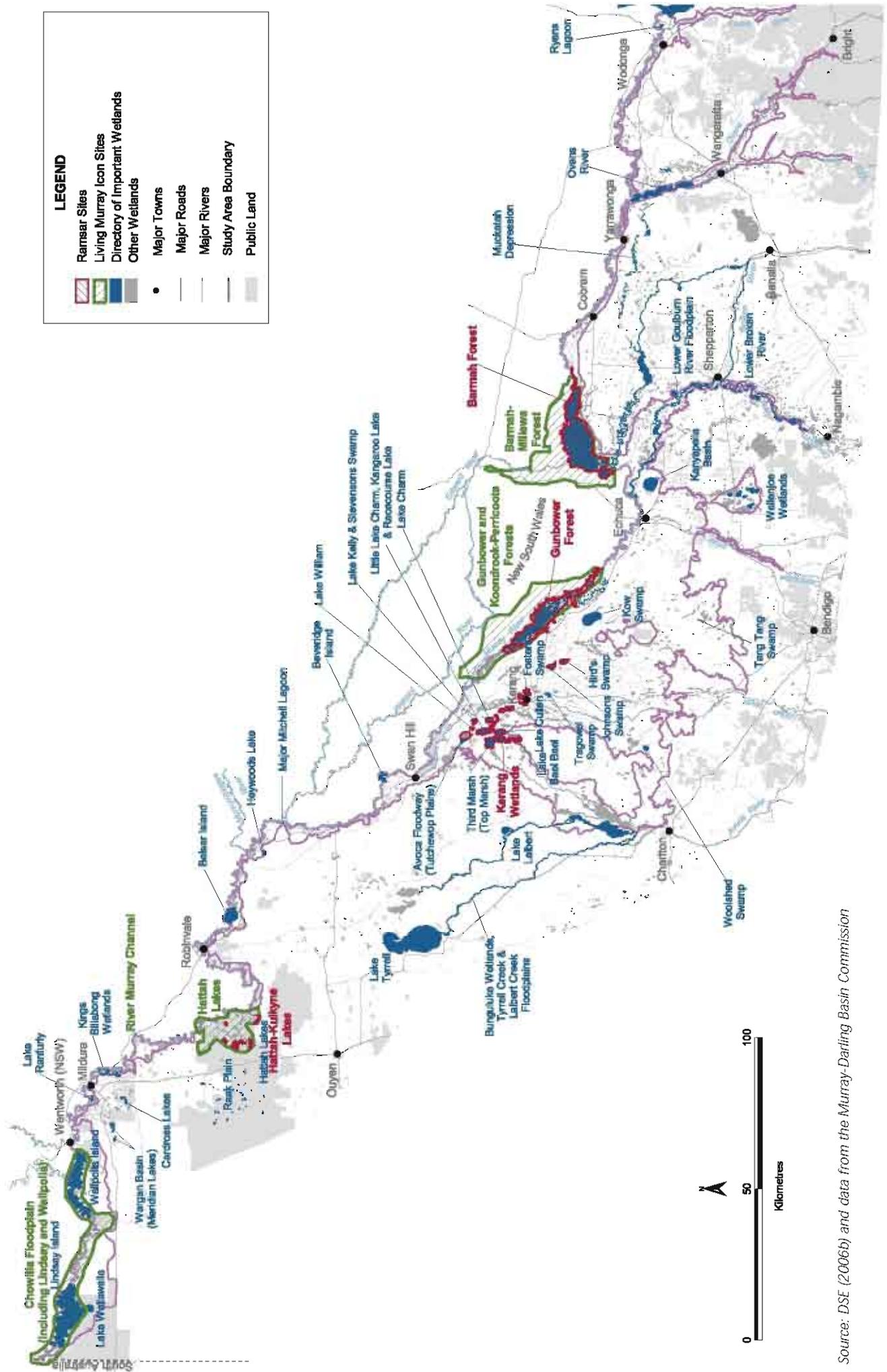
The floodplains of the study area are formed in part by the very low gradient of the Murray River between Lake Hume and the South Australian border. In these areas, natural flooding (described in detail in chapter 4) has played a major role in shaping the local flora and fauna.

Wetlands are an important feature of river red gum floodplains. They are formally defined as 'areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres' (Ramsar Convention undated). In Victoria, there are approximately 16,700 non-flowing wetlands covering 538,943 hectares (DSE 2006b). The Directory of Important Wetlands in Australia (Environment Australia 2001) lists 159 Victorian wetland systems which are recognised as nationally important. Of these 42 are on public land in the study area (Map 5.2).

Box 5.1 Ramsar sites

Victoria is committed to the aims of the Ramsar Convention, namely the conservation and wise use of wetlands and the maintenance of the ecological character of those wetlands listed as of international importance under the Convention (Ramsar sites) (DNRE 1997c). Four of Victoria's 11 Ramsar sites are on public land in the study area: Gunbower Forest, Barmah Forest, Kerang Wetlands and Hattah-Kulkyne Lakes (see Map 5.2). These Ramsar sites are recognised for their high waterbird diversity and numbers, their representative ecosystems, their importance in maintaining regional biodiversity and for supporting threatened species. They also have many additional values, outlined in strategic management plans (DSE 2003b, b, d, 2004h).

Map 5.2 Wetlands in the River Red Gum Forests study area listed on the Directory of Important Wetlands, Ramsar sites and Living Murray Significant Ecological Assets.



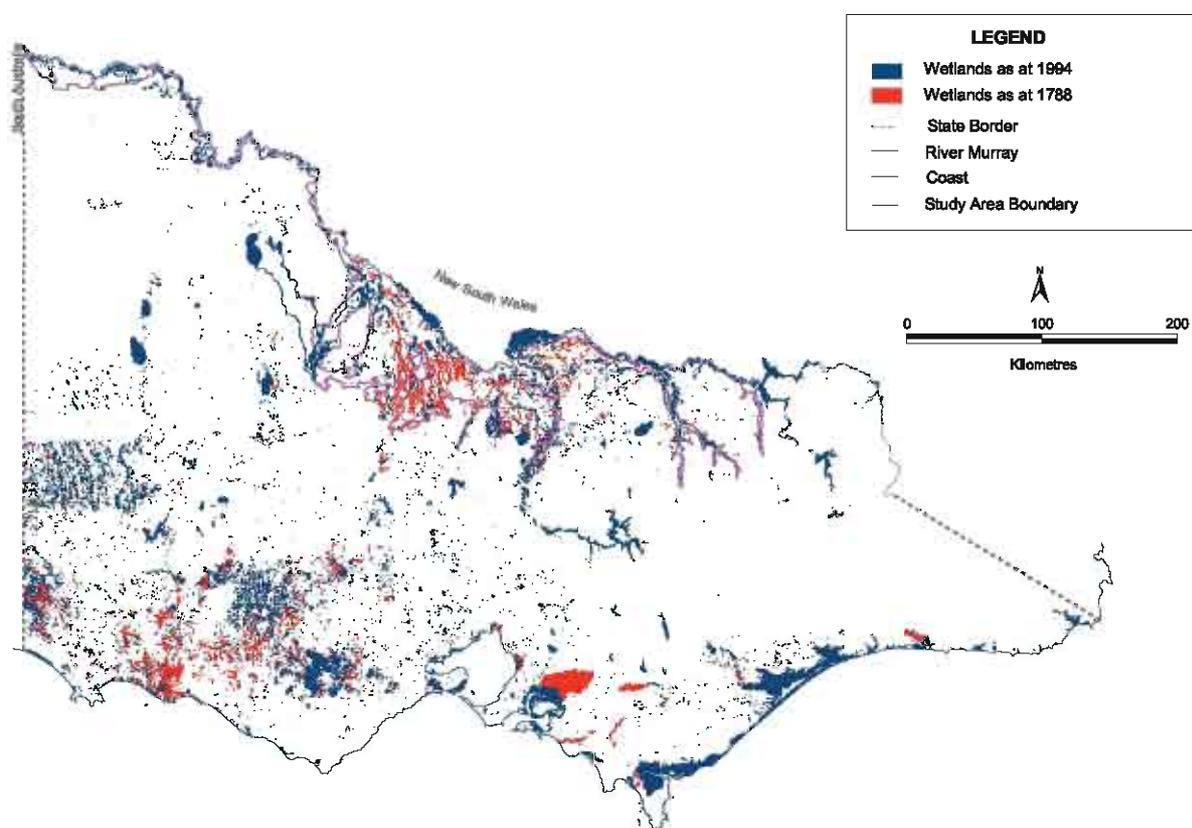
Source: DSE (2006b) and data from the Murray-Darling Basin Commission

Better-known wetlands in the study area include Barmah and Gunbower forests (and neighbouring NSW forests: Millewa and Koondrook-Perricoota), the Hattah-Kulkyne Lakes floodplain and Lindsay-Wallpolla Islands (and neighbouring Chowilla floodplain in NSW and SA). These are the largest near-natural areas of floodplain forest on the Murray River, and are recognised as significant ecological assets under The Living Murray program (see chapter 15). Wetlands in the study area provide a range of significant ecosystem services including maintaining biodiversity, maintaining hydrological stability, retaining sediments, cycling of carbon and nutrients, regulating the local climate and purifying water. They generate economic products, such

as timber and honey, as well as being important in the supply and regulation of water for human consumption and irrigated agriculture. Some are also used for livestock grazing.

The study area is one of the most significant regions for non-permanent freshwater wetlands in Victoria (Map 5.3)—public land in the study area supports almost half of the State’s freshwater meadows, almost 30 percent of its shallow freshwater marshes and approximately 20 percent of its deep freshwater marshes and permanent open freshwater wetlands (Table 5.4). For these wetland types, between 23 percent and 35 percent of the area of wetlands lies on public land outside wetlands of international and national importance (Table 5.4).

Map 5.3 The depletion of Victorian wetlands between 1788 and 1994.



Source: DSE (2006b)

Since European settlement, freshwater meadows have been depleted in Victoria by a third, shallow freshwater marshes by almost 60 percent and deep freshwater marshes by almost 70 percent. In the River Red Gum Forests study area (on public and private land) depletion of these wetland categories has been 60 percent, 61 percent and 55 percent, respectively (Robertson & Fitzsimons 2005g) (Map 5.3). While these three categories have been depleted across the state, the area of permanent open freshwater wetlands has increased by 34 percent in the study area (Robertson & Fitzsimons 2005g) and 55 percent in Victoria, reflecting the building

of, or conversion of other wetland types to permanent water storages.

Rivers and streams are one of the defining underlying elements of river red gum biodiversity. The condition of waterways is measured by the Index of Stream Condition (ISC) (see Map 5.4). The index measures the change from natural conditions and indicates the waterways’ capacity to support a diverse biological community. The study area has 187 km of streams in ‘good’ ecological health (Table 5.5).

Map 5.4 The condition of waterways in the River Red Gum Forests study area, measured using the Index of Stream Condition.

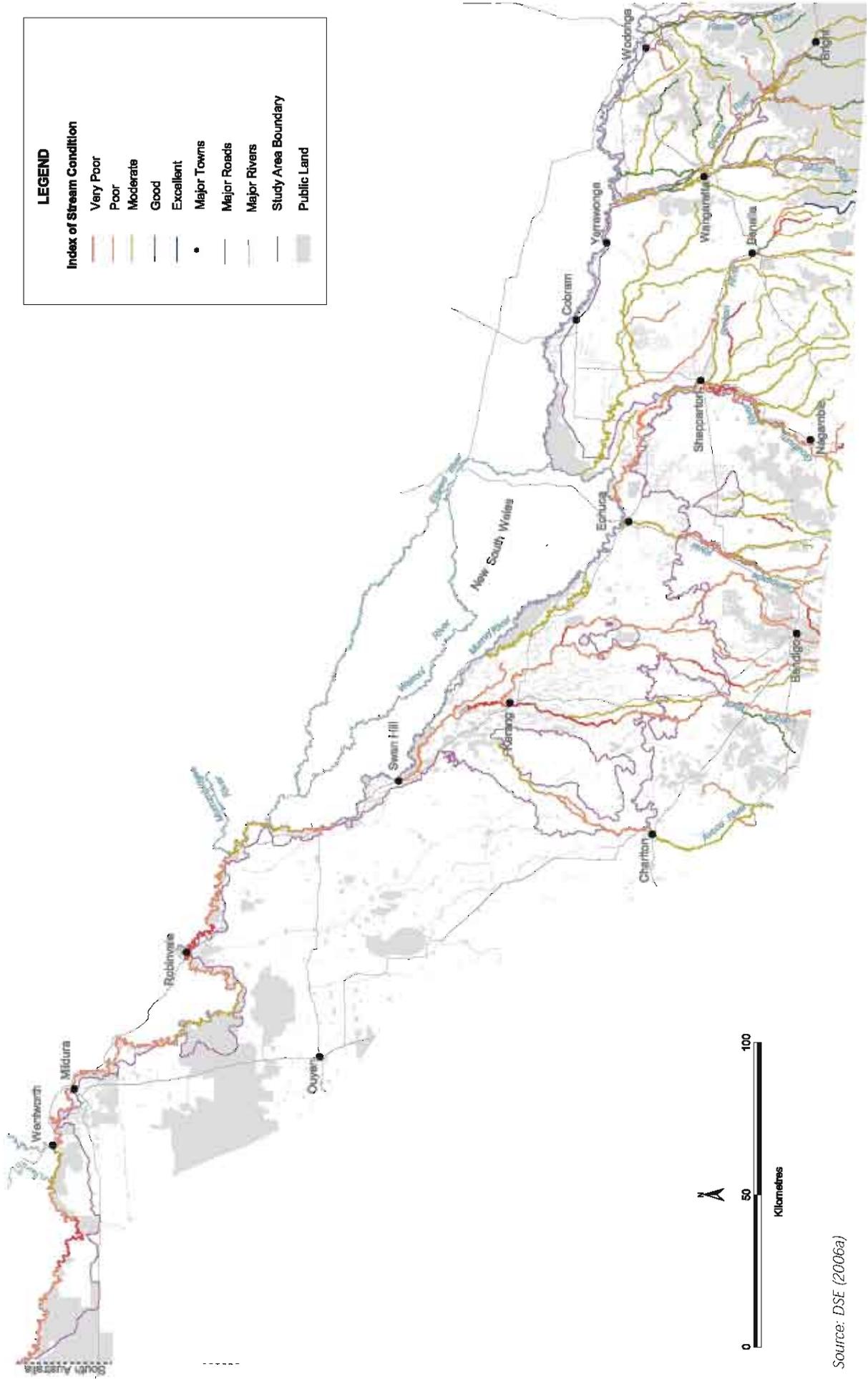


Table 5.4 Extent of wetlands statewide and in the River Red Gum Forests study area, by wetland type.

Wetland category	Area in Victoria (ha)	Wetlands on public land in study area		Percent of area on public land in the study area outside Ramsar Sites and Nationally Important Wetlands
		Area (ha)	As a percent of area in Victoria	
Freshwater meadow	118,174	54,918	46	27
Shallow freshwater marsh	54,496	15,260	28	23
Deep freshwater marsh	54,664	9780	18	35
Permanent open freshwater	180,396	41,626	23	26
Semi-permanent saline	64,264	3312	5	64
Permanent saline	61,327	2222	4	20
Sewage pond	3793	171	5	96
Salt works	1829	not present	—	—
Total	538,943			

Source: DSE (2006b)

Significant plant species of the floodplains

Tree species diversity is low in riparian and floodplain forests compared with most forest types (Roberts & Marston 2000). Although there are more than 500 eucalypt species in Australia, only four occur widely in the study area: river red gum, black box, grey box and yellow box (Figure 5.1). **River red gums** (Figure 5.8) are the most widespread eucalypt in Australia (but do not occur naturally in Tasmania). They can grow to approximately 45 m, with height generally increasing as flood frequency and duration increases (Roberts & Marston 2000).

River red gums have a typically spreading form—subject

to competition for light, water and nutrients. Large areas of river red gums on the fertile soils of the floodplains have been cleared for agriculture and the largest remaining river red gum forests are the Barmah-Millewa and Gunbower-Perricoota forests. The remaining river red gum forests and river red gum dominated EVCs cover approximately 130,900 ha (Appendix 6).

River red gum wood is hard and resistant to decay and termites, making it popular for uses, such as canoes, boomerangs, shields, waddies, sleepers, fencing timbers, house stumps, and wharf and bridge timbers (see chapters 6 and 14). River red gums are also good nectar producers and are important for the bee-keeping industry (see chapter 13).

Table 5.5 Summary of stream condition in the River Red Gum Forests study area.

Condition	Count	Length (km)
Excellent	0	0
Good	13	187
Moderate	71	1,339
Poor	83	1,709
Very poor	27	569
Unknown	8	36
Lakes	9	48

Source: DSE (2006b).

Note: Apart from the stretch between Piangil and the South Australian border, the Murray River is generally excluded from this table, being New South Wales waters.

Figure 5.8 Mature river red gum on Mulcra Island.



Seedling River Red Gums are vulnerable to both heat stress and immersion (either total immersion or water logging of the roots). Successful regeneration of river red gums thus relies on a complex interaction of a range of critical factors (Jacobs 1955; Dexter 1978), including:

- availability of an adequate seed supply;
- a suitable seed bed;
- an appropriate water regime, which includes:
 - > a flood event;
 - > an appropriate period and timing of flood recession (which depends partly evaporation, drainage and elevation);
 - > duration and depth of flooding in the season following germination;
 - > availability of moisture in the sub-soil;
 - > adequate summer rainfall;
- minimal grazing pressure (by native, domestic and feral vertebrates and invertebrates);
- low competition from overstorey trees and other vegetation; and
- establishment of the root system to access reliable groundwater supplies (after about two years).

A distinction needs to be drawn between germination of red gum seed and successful regeneration. With good seed crops, favourable weather and microenvironmental conditions, widespread germination of red gum seeds usually occurs. However, successful establishment of the seedlings requires coincidence of the factors set out above. In particular, spring floods with recession in early summer results in abundant germination but low soil moisture over summer may kill many of the seedlings.

Successful natural regeneration is therefore episodic and unpredictable, and the periods between regeneration events may be lengthy — up to 15 years or more —

resulting in a series of even-aged stands. The decade 1870–80 brought a group of good flood years but surveys in Barmah forest indicate that, between 1880 and 1965, there were only six periods when flooding was suitable for extensive natural regeneration events: 1903–04; 1917–18; 1935–36; 1937–38; 1957–58 and 1961–63 (Dexter & Poynter 2005).

Altered water regimes are changing the patterns of regeneration. Summer flooding provides moisture for seedlings resulting in reduced mortality and stands of thick regrowth (Figure 5.9). River red gum regeneration at Barmah is such that it is displacing other vegetation (see Moira Grass, below), and at Kingston-on-Murray in South Australia it appears to be sufficient to replace old trees dying naturally (George et al. 2005) provided saplings survive into adulthood.

In nature, then, the structure of river red gum forests is largely determined by regeneration events but the presence of large old trees also has an impact. Over time, larger trees develop a 'zone of influence' within which they suppress and ultimately exclude smaller trees competing for water and nutrients in the soil (Opie 1969). Jacobs (1955) hypothesised that the central Murray river red gum forests prior to 1870–1880 were far more open than in the 1950s and comprised comparatively low numbers of large trees that had lived for 500 to 1000 years or more. Other observers, however, described areas of densely wooded forest. These diverse observations probably reflect the variability of the forests, including a range of ages (regrowth to old-growth), differing stand structure depending on distance from water and where the observer was located.

The ecology of adult river red gums, like that of seedlings, is very closely linked to water. Adult trees

Figure 5.9 Dense regrowth of river red gums on a dry lake bed in Hattah-Kulkyne National Park.



obtain water from groundwater, rain and flooding. The lowland floodplains have low rainfall and high evaporation, and growing conditions alternate between very dry and flooded (Roberts & Marston 2000). In extended dry conditions, some trees rely on ground water. The roots of river red gums at Barmah forest extend 10 m into the sub-soil to extract water in the sandy aquifers (Bacon et al. 1993b). They can also reduce water use by shedding leaves.

Nonetheless, particularly in more arid regions, most river red gums require periodic flooding and both the frequency and duration of flooding are important determinants of growth and condition (see Table 5.6). For example, Bacon et al. (1993a) found that short-term flooding of channels that occupied 15-20 percent of the forest floor temporarily improved tree moisture status and this increased tree growth rate in up to 70 percent

Figure 5.11 Black box at Leaghur State Park.



of the forest. However, short duration floods may only result in short-term benefits. Soil water storage returned to pre-flood levels within 40 days of flood recession in Barmah forest (Bacon et al. 1993b).

Although river red gums require periodic flooding, they cannot survive permanent inundation. Roots require oxygen and become increasingly anoxic as the oxygen is depleted leading to stress in the tree. Prolonged inundation reduces growth and can kill trees (Jacobs 1955). How long it takes to stress trees depends partially on the soil, the tree species and growth stage and the flooding regime, but may be several years or more. In Barmah forest, river red gums have survived permanent flooding for two years (Bren 1987) but others died after four years (Chesterfield 1986).

Some river red gum forests are in poor condition due to either insufficient flooding, or near-permanent flooding (Figure 5.10). They are in especially poor condition downstream of Swan Hill where there has been no natural flooding for ten years and the climate is arid (Brett Lane & Associates Pty Ltd 2005). These forests have been given emergency watering (see chapter 15) to help them recovery. Earlier studies on river red gum condition also found that over 30 percent of river red gums and 35 percent of black box trees at sites downstream of Echuca and into South Australia were unhealthy (>40 percent of crown dead) or dead (Margules & Partners Pty Ltd et al. 1990). These measures of condition broadly correlate with the vegetation condition measures discussed earlier this chapter (Map 5.1). It should be noted that factors other than the water regimes, for example insect attack, disease and salinity, also affect the condition of the river red gums (see below).

Black box (Figure 5.11) is an inland species distributed in Victoria from Strathmerton in the east, along the Murray River to the South Australian border and south to around Horsham (Figure 5.1). Black box grows to approximately 20 m depending on flood frequency (Roberts & Marston 2000). In open habitat it has a short trunk and drooping form with some lower branches touching the ground. The leaves are narrow and a dull green colour and the bark is dark, rough and persistent to the small branches.

Black box trees were widely cleared for agriculture and their heavy, durable timber harvested for fencing and firewood. The largest remaining black box forests in Victoria are within the western part of the study area, e.g. Leaghur State Park and Hattah-Kulkyne National Park.

Black box trees are less tolerant of flooding but more tolerant of prolonged dry periods than river red gums and thus tend to occur higher on the floodplain than river red gum (Roberts & Marston 2000). This is evident in Barmah forest where increases of only 10–20 cm in elevation cause changes in eucalypt species. Black box are adapted to dry conditions through very low transpiration rates, small canopy leaf area and leaves hanging vertically to reduce water loss (Roberts & Marston 2000). Mature black box die after inundation for approximately 18 months (Roberts & Marston 2000). Black box often regenerate after flooding but seedlings grow slower if they are flooded for longer than a month.

Figure 5.12 Tangled lignum at Mulcra Island and close-up of flowers.



Figure 5.10 River red gum trees dying and in poor condition on Lindsay Island due to lack of water.



Table 5.6 The influence of flood regimes on rushlands, moira grass plains, river red gum forests and box forests and woodlands in Barmah-Millewa Forest.

Flood Regime ¹	Main Vegetation Type					
	Rushlands	Moira grass plains	River red gum forest			Black box forest ²
			> 30m	21-30m	< 21m	
Ideal time	July–January	September–January	August–December			occasional short flood
Frequency						
natural average	every year	every year	9 years out of 10	7 years out of 10	4.5 years out of 10	1 year out of 10
minimum required	7.5 years out of 10	every year	7 years out of 10	5 years out of 10	3 years out of 10	none required
current	8 years out of 10	7 years out of 10	6 years out of 10	4.5 years out of 10	2.5 years out of 10	1 year out of 10
Duration						
natural average	10 months	8 months	5 months	3 months	1.2 months	1 month
minimum required	2 months	5 months	1 month	1 month	0.5 month	none required
current average	5 months	3 months	2 months	1.5 months	0.7 month	0.5 month

Sources: MDBC (1992; 2000), Ward (1991).

Notes:

1. The base parameter is that 80 percent of the forest is flooded for at least one month.
2. Includes Black Box Woodland and Open Woodland, which is usually briefly inundated in less than 30 percent of years. Yellow Box, Grey Box, Murray Cypress Pine Woodland and Open Woodland are seldom, if ever, flooded.

Many other species of the floodplains are specially adapted to the ecological conditions and water regimes. Two well-known floodplain plants are lignum and moira grass. Three species of **lignum** occur in the study area—tangled (see figure 5.1 and Figure 5.12), spiny and twiggy, although spiny lignum is rare in Victoria. They are typically green shrubs up to 12 m tall with entangled branches, but their form is highly dependent on flooding regimes. They mostly occur along rivers, streams and floodplains, often in association with black box. When flooded, lignum provides important nesting habitat for water birds. It is salt and drought-tolerant but will not survive permanent flooding (Roberts & Marston 2000).

Moira grass (sometimes called spiny mud-grass, see Figure 5.1 and Figure 5.13) is an aquatic to semi-aquatic grass with pyramid-shaped flower heads up to 15 cm long. It forms a turf in dry conditions but can grow up to 1.5 m and form floating mats on open water during flooding (see Table 5.6 for flooding frequency and duration). Moira grass only grows after flooding. Growth rates of 10 mm per day in winter and 20 mm per day in late spring have been documented in Barmah forest (Ward 1991).

Changed water regimes are changing the distribution of Moira grass. In the past, the extended floods killed red gum seedlings but the absence of extended and frequent floods is now causing Moira grass plains to be invaded by river red gum thickets (Bren 2005). Unseasonal summer flooding increases the survival rates of seedlings, which would otherwise die from summer droughts. Reduced spring flooding means seedlings are not inundated for as long or as deep as previously (Bren 2005). Giant rush is also encroaching onto Moira grass areas. Moira grass plains have been reduced from about 4050 ha (13.5 percent) of Barmah Forest in 1930 to about 1650 ha (5.5 percent) in 1980 (Chesterfield 1986). In Barmah forest, a minimum flood duration of 5 months, receding before summer, is required for Moira grass to out-compete river red gum seedlings and milfoil (Ward 1991). Floods need to be approximately 0.5 m to completely submerge river red gum seedlings and prevent premature nodal rooting of Moira grass into the soil. This equates to a flow of approximately 1500 ML per day in the Gulf Creek (Ward 1991). Moira grass is a preferred species for cattle grazing and Roberts and Marston (2000) suggest that the distribution of Moira grass on the floodplain may be explained in part by past cattle stocking rates and practices.

Significant animal species of the floodplains

At a statewide level, riverine forests provide habitat for a wide diversity of vertebrate animals. The forests are important for the conservation of woodland birds, including many of those in the Woodland Bird Community listed as threatened under the *Flora and Fauna Guarantee Act 1988* (see Table 5.2). The mature riverine trees contain hollows which many mammals and birds need for shelter or breeding, including the threatened squirrel glider, superb parrot and regent parrot. These parrots, in particular, are unlikely to survive in Victoria without riverine forests. Fallen woody debris provides shelter for small mammals, ground foraging birds and many reptiles. During winter, many birds, such as the flame robin and pied currawong, migrate from the mountain forests to find food in the river red gum forests.

Figure 5.13 Moira grass in Barmah forest while flooded and close-up view.



Species usually found in higher rainfall areas such as the feathertail glider, sugar glider, koala and striated thornbill (see Figure 5.1) extend their distribution north-west along the mesic corridor provided by the river red gum forests of the Murray River floodplain. De Vis' banded snake, yellow rosella and barking marsh frog are entirely dependent on river red gum forest habitat in Victoria and the ecosystem provides a stronghold for many other species.

Numerous swamps and lakes in the Kerang and Swan Hill districts provide breeding, feeding and drought refuges for some 60 species of waterbird, including 15 waterfowl and 23 species of migratory shorebird. Flooding regimes are particularly important for the survival of egrets. Egrets generally breed in flooded forests but feed away from the nesting sites in more open wetlands. Egrets take longer than other water birds to commence breeding after flooding, and do not breed successfully unless their nesting sites are flooded for three to five months. This is thought to prevent terrestrial predators from accessing the nests.

Egrets generally only breed in living trees with at least half a metre of water beneath them. If the water recedes, the egrets will abandon the nest, even if the young are close to fledging. Following spring floods, the extensive river red gum forests of the Barmah and Gunbower areas provide the only Victorian breeding sites for colonies of great and intermediate egrets, and major breeding colonies of other herons, cormorants, ibis and darter.

The lack of adequate spring floods in recent decades has resulted in an almost complete lack of breeding by many colonial waterbirds, particularly intermediate and little egrets, which are classified as critically endangered in Victoria, and also the great egret, which is endangered. Little egrets bred in Gippsland in 1993, near Geelong in 1998-2004 and in Gunbower Forest in the early 1970s. Intermediate egrets are known to have bred at only two sites in Victoria: Ryans Lagoon (near Wodonga) in 1981 and Gunbower Forest in the early 1970s and one nest in 1993. Great egrets bred at many sites in the 1970s and 1980s but had not been recorded breeding in Victoria since 1993. There are probably fewer than 200 breeding pairs remaining. Increased environmental flows in 2005 under the Living Murray initiative (see chapter 15) resulted in great egrets breeding in Gunbower Forest and both great and intermediate egrets breeding in Barmah Forest.

The **carpet python** is another threatened species found within riverine forests. This species inhabits two distinct habitat types within Victoria: river red gum forests and associated black box woodlands along rivers and streams, and also rocky hills with Blakely's red gum. Increased predation and habitat clearing as well as decreased prey availability are thought to reduce carpet python populations (Allen et al. 2003). Carpet pythons are ambush predators which use fallen timber, ground cover and rocks to hide from potential prey and to shelter from predators. Removing this cover for firewood and landscaping, threatens the survival of carpet pythons. Carpet pythons are also sometimes killed by humans.

River red gums are a keystone eucalypt tree species for terrestrial invertebrates because of they provide both food and shelter, as well as leaf litter and coarse woody debris on the forest floor. Recent research indicates that flooding has significant food-chain implications for terrestrial invertebrates. Larger invertebrate predators, such as carabid beetles and lycosid spiders, increase in response to flooding thereby sustaining larger populations of insectivorous vertebrates that prey upon them.

Aquatic species are likely to be particularly sensitive to changes in the river system. The critically endangered silver perch, for example, spawns partly in response to rises in water level and temperature. Given the great changes in the region's hydrology since European settlement (see chapters 3 and 15), it is perhaps unsurprising that seven of the 21 native fish species recorded in the study area are threatened. Many of the study area's streams and rivers now provide the most important Victorian habitat for species such as the critically endangered trout cod and Murray hardyhead, and the endangered Murray cod (see box 5.2), freshwater catfish and Macquarie perch.

In addition, the Lowland Riverine Fish Community of the southern Murray-Darling Basin is listed under the *Flora and Fauna Guarantee Act 1988*. This community has 15 fin fish species: ten that are listed individually under that Act, and five that are not—golden perch, flat-headed galaxias, bony bream, flat-headed gudgeon and western carp gudgeon.

Eucalypt (Box) Woodland

Woodlands dominated by eucalypts other than river red gums and black box, particularly grey box and yellow box, also provide significant habitat for woodland birds, small mammals and reptiles. These woodlands provide similar kinds of ecological services as the river red gum forests, but have fewer wetlands and do not usually flood naturally. The dominant eucalypts are not adapted to periodic inundation and consequently have not declined with reduced flooding. However, Margules and Partners et al. (1990) estimate that approximately 33 percent of the floodplain vegetation along the River Murray has been cleared and much of this would have been box woodland (not necessarily all in the River Red Gum Forests study area).

Grey box has a wider distribution in the study area than black box, occurring from Wodonga in the east to Kerang in the northwest with an outlying population near Robinvale (see Figure 5.1). Grey Box is the dominant eucalypt on many roadsides in the Victorian Riverina Bioregion. Like black box and river red gum, grey box wood is strong and durable and widely used for products such as fence posts. It was widely cleared from its pre-European distribution and remains mostly on roadsides and as single paddock trees.

Yellow box is widely distributed across Victoria but is largely absent from the north and south west and alpine areas (see Figure 5.1). Yellow box wood has similar characteristics to grey box wood and the trees are also good honey producers, flowering from September to January.

Buloke is a leaf-less tree that grows to 5-15 m. It is distributed in north and west Victoria and is commonly found with grey box and slender cypress-pine. Approximately 97 percent of the original buloke woodland in Victoria has been removed (DNRE 1997b). Most remnant buloke trees occur as scattered trees, many in paddocks and along roadsides. This history has negatively affected many species that inhabit buloke woodlands, such as the grey-crowned babbler.

Buloke Woodlands of the Riverina and Murray-Darling Depression Bioregions have been listed as an endangered community under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. Remaining examples are threatened by continued clearing, weed invasion, fertiliser and herbicide drift and grazing by rabbits and stock. This community is poorly represented in conservation reserves throughout its range.

Large old tree sites

Large old trees are particularly important in both riverine forests and eucalypt woodlands. Large trees provide a more open forest structure, with a greater area and variety of foraging substrate for insectivorous fauna. They also provide abundant bark and fallen timber,

Box 5.2 Murray Cod

The Murray cod is Australia's largest freshwater fish (up to 113 kg)—a premier angling species—and generates considerable public interest because of its size, 'mystique' and excellent eating qualities (see Figure 5.14 and Figure 5.15). This interest elevates the Murray cod's importance from being merely a fish to being a significant part of Australian folklore and cultural heritage. Murray cod were naturally abundant and traditionally a major part of the diet for Aboriginal people in the area, as well as an important cultural icon. Early European settlers ate Murray cod and a substantial commercial fishery existed until the early 1900s. Since then, the species has declined dramatically and is now endangered in Victoria and listed as vulnerable under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. Murray cod are an important component of the native fish communities of the Murray-Darling Basin and share many threats with other fish species.

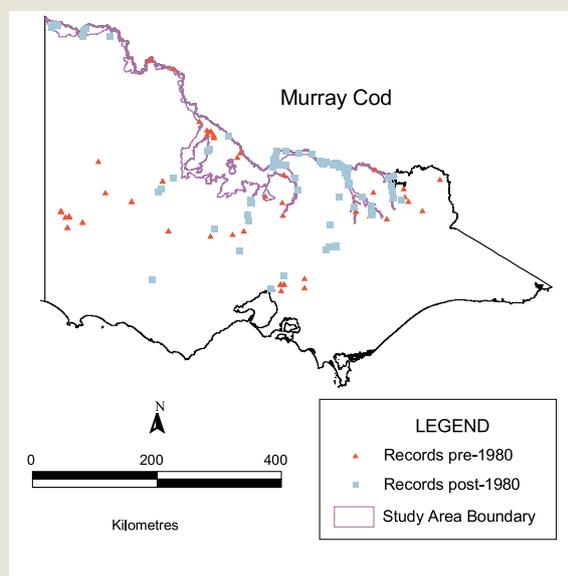
Murray cod lay sticky eggs on hard surfaces like submerged wood, when temperatures rise over 15°C (Koehn & Harrington 2006). The adult male guards the eggs and the hatched larvae drift away from nest sites in the water column, making them susceptible to changes in flow regimes and loss into irrigation off-take channels and pumps. Spawning appears to occur in most years under various flow conditions and the survival of post-larval fish is thought to determine overall population recruitment. Survival of post-larval fish may be enhanced by increased food availability following flooding. Natural flow regimes also provide spawning cues for many other native species. Cold water releases from storages such as Lakes Dartmouth and Hume can reduce spawning and recruitment success, reducing fish populations.

Murray cod migrate upstream (up to 100 km) before spawning and then return downstream, usually to their original location (Koehn 1997), making both upstream and downstream fish passage important factors in their life cycle. Both adult and juvenile Murray cod select habitats with structural wood in the main river channels, close to the banks and with overhanging vegetation.

Figure 5.14 Murray cod.



Figure 5.15 Victorian distribution of Murray cod.



Source: *Atlas of Victorian Wildlife 2006*

Although they will use floodplain channels when they contain flowing water, the cod do not appear to use the floodplain itself. They also prefer slower, shallower waters. Removal of instream woody habitats has been widespread in major rivers in the past and the re-instatement of these habitats is now recognised as an important rehabilitation measure.

Past commercial catches of Murray cod have removed approximately 160 tonnes of fish per year (or 32,000 individuals weighing an average of 5 kg) from the lakes and rivers around Barmah in the 1860s (King 2005). The highest numbers were taken when the fish were spawning. Although these fisheries are now closed, Murray cod are still fished recreationally (Koehn 2005b). There is evidence to suggest that overfishing could be a problem for some populations. Illegal fishing also occurs and, although not quantified, is believed to be substantial in some areas. Artificial stocking of Murray cod to supplement the population is now widespread, but this may have implications for the genetic diversity of the population.

There have been substantial deaths of Murray cod in the Broken Creek, and Ovens and Goulburn Rivers in the past few years (King 2005; Koehn 2005a). These have caused considerable public concern and have resulted in the loss of valuable breeding stocks. While some recovery in Murray cod populations has been reported in NSW and Queensland, any recovery in Victoria is yet to be demonstrated scientifically.

As part of the requirements of being listed as a threatened species under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*, Murray cod will be the focus of actions outlined under a forthcoming National Recovery Plan. This increased management, addressing the key threats and recovery actions for Murray cod is intended to assist in the rehabilitation of the species.

which is essential habitat for some species. Larger trees, however, are favoured for wood products or silviculture, and are therefore less abundant in the forest than other age classes of trees. One study on the northern plains of Victoria found that 55 percent of river red gums were 10-30 cm in diameter, 35 percent were 31-70 cm in diameter and only 10 percent were greater than 70 cm in diameter (Bennett et al. 1994). It is likely that in pre-European times there was a much greater proportion in the largest size class.

Hollow-formation is one of the most important ecological functions of these older trees. Most river red gums are thought to begin forming hollows at approximately 120 years of age (Gibbons & Lindenmayer 2002) although the age varies, depending on soil fertility, wind exposure and fire history (Harper et al. 2005). It takes even longer before the hollows are large enough to suit the full range of hollow-dependent fauna. A study of hollows on the northern plains found that river red gums have fewer hollows than black box, yellow box and grey box (comparing similar-sized trees). Only seven percent of river red gums had hollows overall, but 55 percent of the larger trees (with a diameter greater than 70 cm) had hollows (Bennett et al. 1994).

Hollows are very important for some threatened species and many populations are likely to be limited by tree hollow availability. Scattered clumps of hollow-bearing trees and even single hollow-bearing trees in paddocks can support animals (van der Ree et al. 2006). In Australia, 303 native vertebrate species use tree hollows for breeding and shelter—approximately 15 percent of all terrestrial vertebrate species, or ten percent of reptile species, 13 percent of amphibians, 15 percent of birds and 31 percent of mammals (Gibbons & Lindenmayer 2002).

The **superb parrot** is a threatened bird species characteristic of river red gum forests and woodlands. The birds fly from New South Wales to Victoria to breed between September and December before returning north. At the time of European settlement, the superb parrot was common along the Goulburn River as far upstream as Yea and was frequently recorded near Melbourne (Figure 5.4). As recently as the 1980s, superb parrots were regularly seen along the lower Ovens River. In Victoria, superb parrots are now found only in a narrow strip between Echuca and Yarrawonga and only breed in Barmah State Park and State Forest. The current Victorian population size is estimated to be 300 individuals (Deayton & Deayton 2005).

Superb parrots breed in tree hollows and nesting typically occurs in loose colonies in old healthy (but sometimes dead) river red gum trees with numerous spouts. The trees may be single or clustered but are usually close to water. The birds fly out of the river red gum forests to forage on flowers, fruits and seeds in nearby box woodlands. A key measure to protect nesting areas has been the establishment of Special Protection Zones (SPZs, see chapter 14) where timber harvesting is excluded from nesting areas in Barmah State Forest, although one of these areas was inadvertently logged in 2005.

Tussock Grassland

Native grasslands are tree-less environments that can support a rich diversity of species. Generally, grasslands are not well-recognised or appreciated and when not flowering it may be difficult to tell the difference between nationally significant grasslands and adjacent paddocks of exotic grasses. Native grasslands have been extensively destroyed since European settlement and less than one percent currently survives—mostly in small patches on roadsides, railways, other Crown land and freehold. Few of these remnants are in good ecological condition (Map 5.1). The Northern Plains Grassland Community is one of the most endangered vegetation communities in Victoria and is listed under the *Flora and Fauna Guarantee Act 1988*. Many processes that disturb soil threaten grasslands including cultivation, clearing, road works and compaction, while other threatening activities include inappropriate fires, over-grazing, absence of grazing, fertiliser and herbicide application or spray drift and tree-planting. A high proportion of grassland species are threatened, including the following three examples.

Chariot wheels is a small perennial herb (growing to less than 20 cm, see Figure 5.16) restricted to small areas around Birchip and Mitiama in Victoria and in the western Riverina of New South Wales (see Figure 5.3). It is vulnerable nationally, in New South Wales and Victoria. The species is characterised by the woolly disc-shaped fruit (5-10 mm), which can be seen in spring and early summer. Ants like to eat the seeds and so the fruits can sometimes be found around the entrances to ants' nests. Chariot wheels is not found in areas that have been cropped and populations are restricted to roadsides and isolated remnants. It is further threatened by herbicide use, intensive grazing, tree-planting and soil disturbance.

Figure 5.16 Chariot wheels, a small perennial herb found in grasslands in Victoria.



Red swainson-pea is only found in Victoria to the south and west of Echuca in the Victorian Riverina Bioregion (see Figure 5.3). It also occurs in the riverine plains of New South Wales. It is endangered in Victoria and vulnerable nationally. It is a prostrate perennial herb with bright red, pea-like flowers in spring (Figure 5.17). In summer it dies back to a persistent woody rootstock from which it resprouts the following autumn. Like other grassland species, the red swainson-pea is threatened by soil disturbance, intensive grazing and herbicide use. As it prefers an open grassland habitat (not too dense with wallaby- and spear-grasses), light sheep grazing may be beneficial.

Figure 5.17 Red swainson-pea, a threatened perennial herb.



The grasslands of Terrick Terrick National Park are the Victorian stronghold of the critically endangered plains-wanderer—a quail-like grassland specialist (see Figure 5.4). Plains-wanderers prefer habitat where there is about 50 percent bare ground and most plants are less than 30 cm tall. They use this vegetation as cover from aerial predators but can stand on tip-toe to scan for terrestrial predators. Most of the diet of this bird is made up of insects and seeds from grasses and saltbush. Habitat destruction and modification, including cultivation, over-grazing, dense pasture growth, weeds and wildfire are the major threats to this species (Baker-Gabb 1995).

Saltbush

On the flat alluvial plains of the Murray Scroll Belt, extensive open woodland dominated by saltbush supports flora and fauna more typical of western NSW and SA. These plains provide the only Victorian habitat for Giles' planigale. Other characteristic species include red kangaroo, white-winged fairy-wren, inland dotterel, orange chat and samphire skink.

Giles' planigale is a semi-arid and arid zone species that just extends into the north-west corner of Victoria. The species was only discovered in Victoria in 1985 when individuals were found at Lindsay Island, Wallpolla Island and near Neds Corner (west of Mildura).

Their habitat is confined to cracking clay soils on the floodplain and is mostly black box with dense but patchy ground cover such as lignum. Giles' planigales may also use logs, burrows and grass clumps to shelter from extreme heat and predators. This species is threatened by habitat degradation and predation. Lack of floods, firewood collection, ground cover trampling, overgrazing and recreation may contribute to habitat degradation.

Mallee

Very small parts of the study area between Swan Hill and the South Australian border support mallee vegetation. Mallee eucalypt communities support a characteristic and diverse fauna that includes many elements restricted to the Murray mallee region. For example, the mallee emu-wren inhabits mallee areas with porcupine grass hummocks. This species is responsive to the fire history of vegetation and populations peak 8-10 years after fire but begin to decline at 30 years after fire (Garnett & Crowley 2000).

PROCESSES IMPACTING ON BIODIVERSITY

The management and amelioration of key or potentially threatening processes is vital to conserving biodiversity. Many potentially threatening processes are listed under the *Flora and Fauna Guarantee Act 1988* and the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999* (Appendix 8) which require plans for the amelioration of these threats. An example of a potentially threatening process listed under the *Flora and Fauna Guarantee Act 1988* is 'Prevention of passage of aquatic biota as a result of the presence of instream structures'. Management agencies have sought to reduce the impact of instream structures by installing fish ladders or fish ways (Figure 5.18) to help fish move around dam walls. The major threatening processes in the study area are discussed below under nine broad headings.

Figure 5.18 Fish ladder at Torrumbarry on the River Murray.



Clearing and Habitat Fragmentation

Habitat clearing is one of the major causes of biodiversity decline in Victoria (DNRE 1997b). Clearing reduces the area of habitat in which indigenous flora and fauna can live. For example, large losses of grassland habitat through cropping, ploughing, fertiliser and herbicide use and high levels of grazing have reduced many grassland-

dependent species including darling-peas, swainson-peas and a variety of native grasses.

Habitat fragmentation is a major threat listed under the *Flora and Fauna Guarantee Act 1988* (see Appendix 8). It occurs when native vegetation is cleared, leaving habitat remnants separated from other blocks of habitat by areas with little or no habitat value—typically farmland. Such remnants can be characterised by their size and shape, distance to the nearest neighbour remnant and the land-use of the intervening areas.

Habitat fragmentation has a number of impacts upon biodiversity. Some remnants are too small to support populations of species that have large home ranges, such as barking owls which have home ranges of at least several hundred hectares. Small remnants may only be able to support small populations of other species, making them vulnerable to extinction due to chance events. Habitat fragmentation also increases the amount of edge, which is more vulnerable to disturbance, predation and weed invasion. Additionally, fewer populations can live in small remnants compared with larger ones. Thus, continuing fragmentation results in a simplification of the ecological community, disadvantaging specialist species and leading to a decline in ecosystem services.

Habitat Degradation

Habitat degradation may result from the removal of particular elements, leaving it unsuitable for some species. Firewood collection on public land within the study area is one example. Although the whole forest is not cleared, the removal of this important element can render the area unsuitable for many species that require fallen wood (or coarse woody debris) for protection from predators and extreme temperatures and as a place to forage (Mac Nally & Horrocks 2002a). Fallen timber loads of more than 40 tonnes per hectare are required for some vertebrates (Mac Nally et al. 2002a). Clearance of this habitat element is an important process in the decline of bush stone-curlews, carpet pythons and a range of other threatened species.

Road and track networks may reduce richness and abundance of species including invertebrates (Greenslade & Greenslade 1977) and increase the range and access for foxes. Recreational activities can also degrade habitat. Digging for bardi grubs disturbs the soil, which promotes weed germination. Power boating activities can damage river bank vegetation and contribute to soil erosion and sedimentation of rivers (see chapter 11).

There are many forms of habitat degradation and some of the major ones are described in detail below.

Altered Water Regimes

The Murray River has been increasingly regulated with water diverted for agriculture since Hume Dam was first constructed in 1936. The extension to Hume Dam was completed in 1961. Regulation remained the same until Dartmouth Dam was commissioned in 1979. There was an accelerating increase in diversion of water for agriculture from 1961 to 1995 when a cap was imposed on extraction in Victoria. The changes to the water regimes aimed at providing increased irrigation allocations have changed the river height, flow volumes,

flooding frequency, duration and season of flooding (see chapters 3 and 15 for details).

Changed water regimes (flow, temperature, and flooding frequency, duration and extent) can greatly affect wetlands, floodplains and can greatly change the species composition of an area. Densities of the yellow-footed antechinus increase 20-fold after flooding (Mac Nally & Horrocks 2002), reflecting better survival when there are large numbers of invertebrates available (Ballinger & Mac Nally 2005). These population increases may also occur among bats (Lumsden et al. 2002) and insectivorous birds (Chesterfield et al. 1984; Mac Nally et al. 2001). Many bird species require specific flooding conditions for suitable habitat, particularly for breeding (Parkinson et al. 2002).

For other species, the water temperature and change of flow speed are important cues that conditions are right for breeding. 'The alteration to the natural temperature regimes of rivers and streams' and 'The alteration to the natural flow regimes of rivers and streams' are listed as a potentially threatening process under the *Flora and Fauna Guarantee Act 1988*. For example, the silver perch, a critically endangered species in Victoria, is thought to spawn in late spring and summer after water flow increases and the temperature rises above 23°C. Cold water released from the bottom of storage weirs may lead to localised unsuitable habitat as well as the absence of triggers for breeding. Additionally, eggs may not be as viable and larvae may not be suited to the lower temperatures. Reduced water temperatures are also thought to threaten the critically endangered trout cod, the endangered freshwater catfish, Murray cod and Macquarie perch, and the vulnerable golden perch.

Water flow and flooding regimes greatly affect aquatic and wetland vegetation. As discussed above, mature river red gums require flooding every few years. Seeds of this species germinate as a result of a disturbance such as flooding and a new generation grows. Typically, many of these new seedlings would die during the subsequent flood. With the present flooding regimes, such floods are only achieved infrequently and this results in forests of close growing, even age-structured cohorts surviving. These new trees are invading the Moira grasslands that previously persisted when more frequent flooding killed the juvenile river red gums (Bren 1992).

The main threat to wetlands in the study area is water storage, regulation and extraction associated with irrigated agriculture. Floodplain wetlands, particularly of the Goulburn and Murray Rivers, tend to be flooded less frequently, retain water for shorter periods and may be flooded in summer and autumn when river levels are high to deliver irrigation water instead of in the natural seasons for flooding (winter and spring). Hydrological threats on floodplains are exacerbated by flood control levees in some areas that isolate wetlands from floodwaters.

Many wetlands in the study area have been cut off from their natural floodplains or catchments and incorporated into the water regulation and storage system. Many former temporary wetlands (that went through wet and dry cycles) are often now permanently flooded. This has killed the river red gums and increased rushes such as giant rush. Other wetlands may be permanently dry as a

result of being by-passed by irrigation channels. In other areas, the lack of flooding for many years has weakened or killed many river red gums (Brett Lane & Associates Pty Ltd 2005). Other hydrological changes have resulted from the use of wetlands as areas to dispose of excess irrigation waters or salinity disposal.

A mixed pattern of temporary and more permanent wetlands enables a diverse range of species to inhabit the floodplains of the study area (Figure 5.19) (Parkinson et al. 2002). Temporary wetlands are generally shallow with high light levels and warm temperatures. This leads to a high diversity and abundance of macroinvertebrates which provides a large food resource for wading birds such as egrets and spoonbills. Permanent water bodies may be of greater value to diving birds such as cormorants and azure kingfishers as the open water facilitates fish catching (Parkinson et al. 2002).

Figure 5.19 Lake Murphy, near Kerang, flooded due to an allocation of environmental water.



For the four Ramsar sites in the study area, strategic management plans have documented the level of risk to site values from various activities and processes (DSE 2003b, d, e, 2004h). They are summarised in Table 5.7. Although this summary does not assign a risk of grazing to wetlands in the Kerang wetlands, Gunbower forest and Barmah forest, grazing is detrimental to many species, communities and ecological processes in those ecosystems (Robinson & Mann 1998; Jansen & Robertson 2005).

Pest Plants and Animals and Pathogens

Pests and weeds are broadly defined as species that have undesirable impacts, which may be economic, environmental or social. Pathogens are disease-producing organisms, such as cinnamon fungus *Phytophthora cinnamomi*, that also have undesirable impacts. Many of these species, but not all, are introduced to Australia and their environmental impacts are particularly felt here because of the long prior period of isolation of the Australian continent.

Pest plants and animals are one of the greatest threats to the integrity of biodiversity in the study area (DNRE 2002g). They cause a wide range of impacts on the environment including damage to native vegetation, genetic pollution, displacement and loss of native wildlife and alteration of ecological processes, such as water-nutrient cycles and fire regimes. They affect primary production through, for example, direct competition for

resources and introduction and spread of diseases that affect crops and livestock. They may affect amenity through preventing access to recreational areas and pose risks to human health (e.g. anaphylaxis as a result of bee stings). The seriousness of the threat is underscored by numerous pest and weed species and processes being listed, after rigorous scientific assessment, under the *Flora and Fauna Guarantee Act 1988*.

The *Victorian Pest Management—A Framework for Action* (DNRE 2002a) provides the broad strategic direction for pest management in Victoria. Subsidiary documents cover specific pests such as foxes, rabbits, wild dogs and weeds (DNRE 2002e, f, g).

Significant investment in prevention and control is occurring on public and private land. The Weeds and Pests on Public Land Initiative is a major state government program to support pest plant and animal control in national parks, state forest and other public land in Victoria. The four-year, \$14 million, initiative aims to:

- Protect large areas of high value natural assets by preventing and reducing the impact of weeds and pests;
- Improve public land stewardship through a collaborative partnership approach at the landscape level;
- Minimise the movement of weeds and pests across the public/private land interface; and
- Engage the community in the management of public lands;

This program operates through on-ground projects in reducing pest plants and animals, increased strategic approaches to pest management with a pilot study in the Angahook-Otway region and through an increase in the Good Neighbour program, which supports private landholders by controlling pests and weeds on the border of public land. The complementary 'Tackling Weeds on Private Land' Initiative undertakes wide-ranging activities on private land.

Significant developments in pest and weed management include taking a 'biosecurity' approach, with a focus on preventing new problems. Large scale, cross-tenure, continuous programs, as demonstrated by the Southern Ark fox control project, also have great potential for improved outcomes (DNRE 2002d; DSE 2003g). A cooperative approach to tackling pest animals, weeds and pathogens seems to be the most effective. To this extent, government plays an important role in encouraging cooperation by all those with an interest in dealing with pest animals, weeds and pathogens.

Deliberate and ignorant introduction and spread of species remains a problem. For example, aquarium species are released by often well-meaning people but at great risk to the environment. Policing of these activities benefits from community surveillance and reporting.

A weed is a plant that requires some form of action to reduce its harmful effects on the economy, environment, human health and amenity (Australian Weeds Committee 2006). Weeds threaten the productive capacity of land, water and biodiversity assets in Victoria. It is estimated that they cost Victoria \$900 million annually. Victoria faces new and increasing threats from weeds (despite the success of current approaches) due to the number of new species naturalising.

Table 5.7 Summary of risk levels to Ramsar site values.

Risk	Hattah-Kulkayne Lakes	Kerang Wetlands	Gunbower Forest	Barmah Forest
Altered Water Regimes	•••	•••	•••	•••
Pest Animals	•••	••	••	••
Pest Plants	•••	••	•	••
Salinity	••	•••	•	•
Recreation	•	••	••	••
Resource Utilisation	•	•	••	••
Fire	•	•	••	••
Pollution	•	••	•	•
Grazing	•••	—	—	—
Erosion	—	—	•	•

Source: DSE (2003b,d,e, 2004h)

••• = higher priority risks; •• = medium priority risks; • = lower priority risks.

Increased risk also arises from climate change and globalisation. More than 40,000 species overseas are potential weeds in Australia. This underscores the importance of a greater focus on risk assessment and early intervention.

Weed spread pathways are an important focus of management. Weeds may be assisted by natural or human-induced disturbances, such as fire and soil disturbance, or distribution such as transport of propagules by animals, on clothing, vehicles and machinery, or in hay distributed to feed stock. Quarantine, surveillance and hygiene are important strategies to combat these issues.

Weeds directly affect agricultural production through competition with pastures and crops and effects on livestock health. They indirectly affect agriculture by, altering soil and water health, affecting machinery access and function. The cost of weed control negatively affects the terms of trade of agriculture and thus viability.

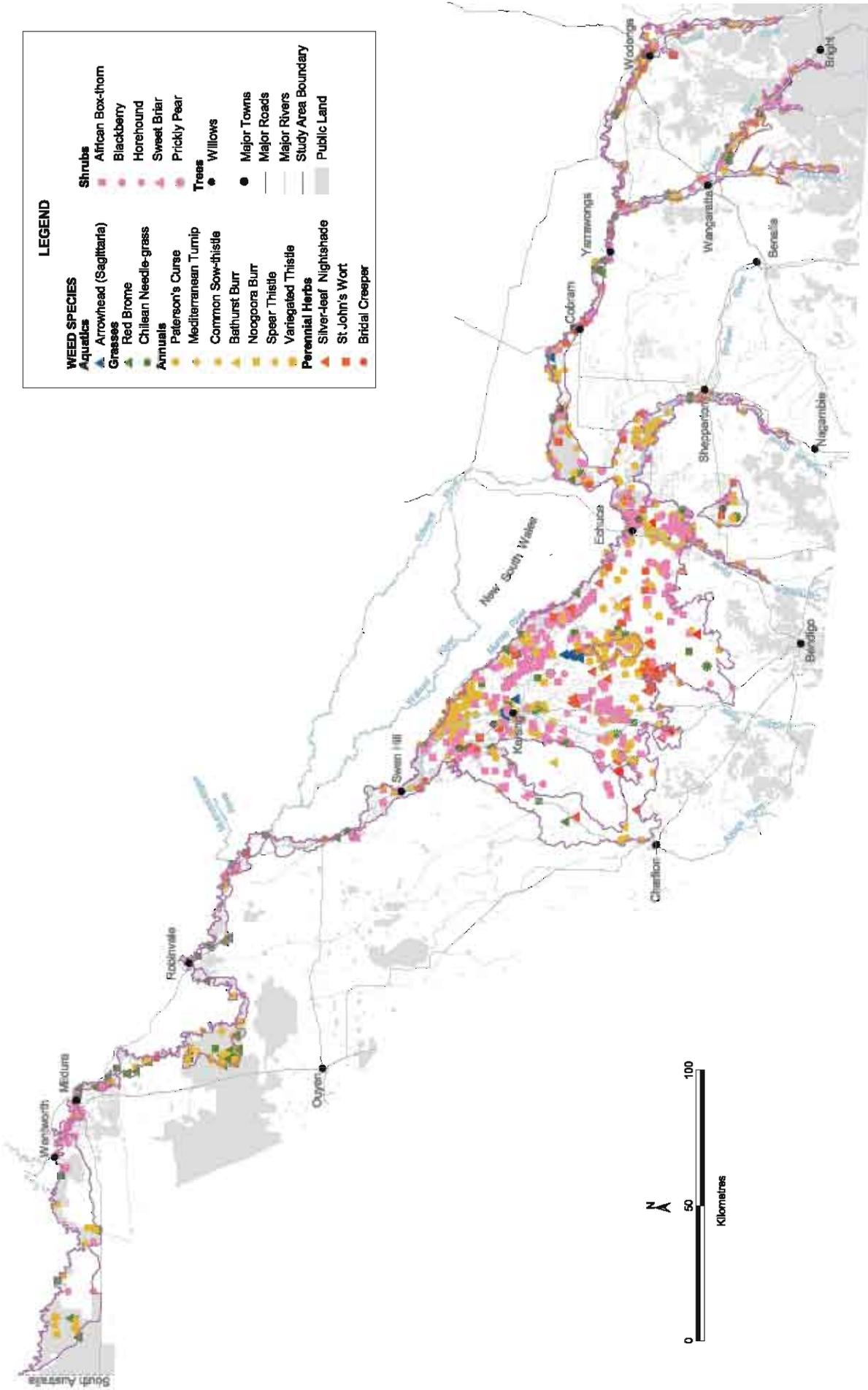
Declared noxious weeds are proclaimed under the *Catchment and Land Protection Act 1994*. Four sub-categories are recognised: State Prohibited, Regionally Prohibited, Regionally Controlled and Restricted with corresponding management obligations on landholders. The list primarily includes weeds of agriculture. Many weed species have not yet been declared. The noxious weed list is currently under review (Weiss et al. 2004).

Weeds are a major threat to biodiversity. Over 570 species of weeds that affect environmental values are recognised. In excess of \$14.6 million was spent on weed management on public land in 2004-05 (DSE 2006d). Some weeds may be indigenous to other parts of Australia but damage local vegetation communities (e.g. Western Australian bluebell creeper invades heathlands, woodlands and forests in Victoria). Some species with benefits for agriculture and amenity (e.g. phalaris, trout) can have negative effects on environmental values.

In 2006, Interim Guidelines for managing the environmental impacts of weeds on public land were released for public comment (DSE 2006d). The Interim Guidelines propose that the priority for management is firstly to prevent new and emerging weeds from establishing and secondly, to adopt an asset-protection approach for all established weeds with the highest value assets at risk from weeds receiving the highest priority. The Interim Guidelines provide a description of the objectives, legislation, principles and priorities and foreshadow an improved strategy for protecting public land values. The government's Weed Alert Rapid Response Plan provides surveillance and a response process for potential, new and emerging weeds in Victoria.

Weed species in the study area differ between regions and habitat types. The fertile floodplains pose particular challenges to weed control methods. Study area weeds include woody weeds (e.g. willows (Figure 5.20), hawthorn, African boneseed), climbers and creepers (e.g. bridal creeper) and broad-leafed weeds (e.g. thistles, St John's wort and horehound), perennial grasses (e.g. Chilean needle-grass, serrated tussock and phalaris), annual grasses (e.g. quaking-grass and *Bromus* spp.) and aquatic weeds (e.g. alligator weed, arrowhead (*Sagittaria*, see Figure 5.21), salvinia and water hyacinths). Arrowhead threatens the health of streams and rivers and the function of irrigation channels. Control is problematic as repeated herbicide application in waterways may have detrimental effects. Some of the more common weeds in parks and reserves include Paterson's curse, African boxthorn, horehound, Bathurst burr and St John's wort. Map 5.5 shows the distribution of selected weeds in the study area, although many weed occurrences have not been systematically or comprehensively surveyed or mapped. For example, while willows are present along the banks of many streams in the northeast of the study area, only a few records show on the map.

Map 5.5 The distribution of selected weed species in the River Red Gum Forests study area.



Source: DSE (2006b)

Figure 5.20 Part of the North East Catchment Management Authority program to remove willows from the banks of the Ovens River in northeastern Victoria.



In the study area, Paterson's curse (also known as salvation jane) is an annual or biennial herb native to the Mediterranean region, with vivid purple flowers. It is a serious pasture weed that also invades native vegetation including lowland grassland and grassy woodland, dry sclerophyll forest and riparian vegetation. It is widespread and well-established in Victoria. Paterson's curse is poisonous to livestock but used as a pollen source by apiarists. It has a rapid early growth rate and spreading rosette of leaves and thus competes with pasture plants and indigenous vegetation. Birds and water disperse the seeds but movement of hay, especially during drought, is also an important means of dispersal. Thus, feeding contaminated hay to cattle on public land will contribute to weed spread. Careful measures to prevent its spread are integrated with herbicidal, physical and biological control techniques to suppress this established weed (Faithfull & McLaren 2004). Several biocontrol agents are established and continuing to spread.

African boxthorn is native to the southern coast of Africa and was probably originally planted in Victoria as a hedge plant forming a barrier to domestic stock. It is a densely branched perennial spiny shrub growing to about 5 m round with bright red berries. Boxthorn invades many habitat types and can form dense thickets, providing refuge to native and introduced animals. The attractive berries are eaten by birds and foxes, which spread the seed, and it will also readily shoot from broken roots. Removal with a chainsaw and subsequent painting of the stem with herbicide is the most effective method of control although follow-up work is required to remove seedlings. In some instances, where alternative accommodation is unavailable, this species provides valuable habitat and protection from predators for species such as small birds. In such circumstances,

Figure 5.21 Arrowhead (*Sagittaria*), an aquatic weed found in natural waterways and irrigation channels.



any programs to remove plants should be integrated with programs to concurrently restore native habitat. There are native plant look-alikes so, as with all weed control activities, identification before control is important.

Horehound is native to many locations including southern and western Europe, western and central Asia, North Africa and is now widespread in southern Australia. It is a perennial, spreading herb growing to about 80 cm and its fruits are burrs that spread attached to the fur and feathers of animals, via water, clothing and vehicle tyres. Horehound invades pastures as well as red gum woodland, mallee shrubland, lowland grassy and grassy woodlands, black box woodlands and open grasslands particularly if the areas have previously been overgrazed or disturbed (Weiss et al. 2000; Blood & CRC Weed Management Systems 2001).

Figure 5.22 Koala in a river red gum on Ulupna Island in Barmah State Park.



A survey of Victorian parks in 1996 estimated that horehound infested 78,200 ha of public land, cost \$19,000 to control and took 1900 work-hours per year (Weiss et al. 2000). Treatment techniques for horehound include the biological control agents horehound plume moth and clearwing moth.

Bathurst burr, introduced from tropical America, is prevalent in northern Victoria. It is an erect, branched herb commonly growing from 30 to 60 cm tall and, like horehound, its fruits are burrs. Bathurst burr is rarely grazed due to its long spines and poisonous seeds and seedlings. It invades grassy woodlands, wetlands and riparian vegetation and forms dense patches capable of excluding other plant species. Bathurst burr can be controlled using herbicides but control programs must extend for more than six years to exhaust the seed bank.

St John's wort is a perennial herb around 80 cm high with bright yellow flowers between October and January. It was first introduced to the Ovens Valley in the late 19th Century. It invades grasslands, woodlands, pastures, open forests, plantations, road and rail sides and riverbanks. St John's wort seeds can be spread by wind, animals, machinery, contaminated fodder, seed or soil, and in garden waste. Biological control agents (beetles and mites) have been partly successful in controlling this weed. There are two indigenous species of *Hypericum* that may co-occur with St John's wort (Blood & CRC Weed Management Systems 2001).

There are hundreds of weed species in the study area in addition to these common species. Less obvious species such as introduced fungi and plant rusts (e.g. Eucalyptus rust) could have significant impacts in the future.

Vertebrate pests such as cats, foxes and rabbits are a major problem in some areas. Their control consumes large parts of land management budgets. Feral pigs are also pests on the floodplains of the Murray. Other feral vertebrates in the study area include brumbies, goats, feral cattle and wild dogs. Eight species of introduced fish are present in the rivers and streams of the study area. Negative effects on river health and biodiversity are known for carp, rainbow and brown trout and mosquito fish.

Foxes have a varied diet. They prey on native species, particularly those weighing between 35g and 5500g (Burbidge & McKenzie 1989). Foxes also consume invertebrates and plant material, and are vectors for some weeds. The most common form of control is via the use of 1080 ('ten eighty') poison baits placed in bait stations. Recent work suggests that large areas of continuous baiting are required for baiting to reduce fox numbers (DSE 2006h). Baiting programs are integrated with Good Neighbour programs, which aim to reduce pests on the adjoining private land and on public/private land interfaces. In this circumstance, baiting is typically timed to protect newborn lambs.

Rabbits are a major problem in much of the study area. Myxomatosis and Rabbit Haemorrhagic Disease (RHD) have reduced populations in some areas. However, history suggests that diseases only offer short-term respite and that ongoing vigilance and control using established techniques is vital, especially while the effects of RHD are apparent. The Mallee Rabbits Project aims to reduce rabbit populations on public land such as Hattah-Kulkyne and Mulcra Island.

Cats and dogs carry disease and prey on native wildlife, including small mammals, birds and reptiles. Cats occur in domestic, farm (semi-domestic) and feral populations. In domestic situations, sterilisation and the use of enclosures can reduce the impacts of cats on the environment. Methods of effectively controlling feral cats have proven elusive although research is currently underway at both the state and national level.

Feral pigs are particularly deleterious in wetland environments where they root up the ground vegetation, leading to increases in soil erosion, sedimentation of waterways and weed invasion. They pose a significant risk to livestock as potential carriers of disease.

Feral cattle and horses (brumbies) pug wetlands and access points to water, trample vegetation and contribute to soil erosion (see grazing, above).

Exotic fish were brought to Victoria by European settlers in the late 1800s to stock waterways with edible and familiar species for angling. More recently introduced exotic aquarium fish are further upsetting the ecology of rivers and streams. Some introduced fish have become dominant, reducing native fish species by competing aggressively for food and for space. Exotic fish also introduce new diseases, parasites and pathogens with the potential to wipe out any native species susceptible to new pathogens.

Carp are recognised as a serious vertebrate pest and have expanded rapidly in distribution and abundance to dominate waterways in the Murray-Darling Basin and southeastern Australia (Koehn et al. 2000). They are the largest and most visible introduced fish species and have received much public and political attention. Barmah forest has been identified as a potential recruitment zone for carp (Stuart & Jones 2006) and although carp numbers have reduced in some areas over the past decade (Nicol et al. 2004) they remain an abundant large fish species, comprising 80 percent of the biomass in 1999-2001 (Stuart & Jones 2002). Commercial harvesting of adult carp in Moira Lake has varied between 76 tonnes in 2001 to less than 20 tonnes in recent years (King 2005). A National Carp Management Strategy and local carp action plans influence management.

Figure 5.23 Gum leaf skeletoniser on a skeletonised leaf.



Figure 5.24 Damage to eucalypt leaves by the gum leaf skeletoniser.



Locally overabundant native animals, while not classified as pests, can inflict significant damage on the local environment. For instance, overabundant kangaroos can severely overgraze landscapes, reducing the forage and habitat available for other native species. In the last financial year (2005-2006) five permits were issued for the destruction of 120 western grey kangaroos and 14 permits for 250 eastern grey kangaroos were issued in Loddon, Gannawarra and Campaspe Shires and Swan Hill Rural City Council (DSE, unpublished data). Overabundant koala populations in Victoria have, in some instances, killed the preferred food trees in an area with many koalas dying as a consequence. The koala (Figure 5.22) population on Ulupna Island (Barmah State Park) is at very high levels and may need future management to preserve the health of both the forest and the koala population.

Additionally, small populations of native animals may become nuisances in recreational areas. For example, birds that are fed in picnic grounds often become less wary of people and will pester them for food while other species may force entry into camp tents. Other native species are agricultural pests. For example, in the study area, cockatoos and corellas eat crops and flocks of small birds such as silvereyes can reduce grape harvests.

Invertebrate Pests

Some species that are becoming more widespread in Victoria include Portuguese millipedes, Argentine ants and European wasps. Argentine ants have been found in towns along the Murray River and European wasps also occur there. There is the danger of other species invading the riverine system, especially in the face of climate change. The main contenders are exotic species of tramp ants such as the red imported fire ant and the big-headed ant. The former is currently located in Queensland (with at least one incursion into Victoria that was destroyed) and the latter occurs along the coast of New South Wales.

A wide range of insect species damage river red gum forests to varying degrees. The majority of these insect pests cause damage on an infrequent basis with the immediate effects generally short-term and localised.

Examples include the larvae of leaf-feeding sawflies and larvae of the leaf-mining leafblister sawfly (Farrow 1996; Phillips 1996; Elliot et al. 1998). While the causes of such outbreaks are not fully understood, factors such as availability of food resources, prevailing climatic conditions, foliage nutrient conditions, age status of individual host trees and stands, and population status of predator species all appear to play a role (Collett 2001).

Observations over many years in Victoria have identified two insect species causing significant economic and aesthetic damage to wide areas of river red gum forest. These species are the gum leaf skeletoniser and the red gum basket lerp psyllid. These outbreaks either occur regularly causing defoliation damage or on an infrequent widespread basis causing significant defoliation.

The **gum leaf skeletoniser** (Figure 5.23) is a defoliating insect native to eastern Australia, capable of causing severe damage to foliage on river red gum in native forests, roadside plantings and plantations (Farrow 1996). It lays eggs in young leaves where the young larvae feed on the upper and lower surface leaf tissue avoiding the oil glands and veins, thereby creating a "skeleton" (Figure 5.24) (Elliot et al. 1998). The first significant outbreaks were recorded in 1933 (DCFL 1986). Subsequently, large outbreaks occurred regularly at decade intervals in 1944 and 1957 along the Murray

Figure 5.25 Feral honeybees in a tree hollow at Heywood Lake in northwest Victoria.



River (Harris 1974) culminating in a major defoliation event in 1975 when more than 40,000 ha of river red gum forest was stripped of leaves in the Murray and Goulburn Valleys (Harris et al. 1977; DCFL 1986). Since then, several smaller localised outbreaks have occurred with the most significant being along the Goulburn River near Shepparton in the mid-1990s. Outbreaks of gum leaf skeletoniser appear to be linked to a lack of flooding. Populations were lower on sites with nearby floodwaters while flooded sites had negligible populations of gum leaf skeletoniser (Harris 1972). It seems likely that increasing length and severity of drought, coupled with increased demands on available water resources, may further increase the incidence of such outbreaks.

The **red gum basket lerp** is a sap-feeding psyllid insect native to south-eastern Australia. It lays eggs on the surface of mature leaves and, once hatched, the larvae construct a shell (known as a 'lerp') from starch derived from the host plant, defoliating the leaf in the process. The lerp probably protects the psyllid insect from predation and desiccation during hot weather. Red gum basket lerp are most active during summer when attacked foliage dries rapidly. By late summer trees can be totally defoliated. Some affected trees die while older trees produce epicormic shoots, which can affect timber quality (Collett 2001). Extensive areas of river red gum have occasionally been defoliated by large populations of lerps near Orbost (1950s), in the Seymour-Euroa area (1950s), Lakes Entrance (1980s and 90s), Mansfield (1940s and 50s) and in plantations around Shepparton and western Melbourne (Collett 2001). Hot weather, high soil moisture, absence of flowering and variations in leaf chemistry (e.g. phenolic feeding inhibitors) have all been associated with psyllid outbreaks (Morgan 1984).

Further research is needed to investigate the interactions between various outbreak factors. A network of regularly examined forest health assessment plots, management of insect pest outbreaks and the associated impacts on tree growth in river red gum forests will assist in quantifying the extent of this problem. In some cases, while the symptoms are obvious, their underlying cause is unknown. Treating defoliation symptoms chemically does not address the underlying cause of the outbreak. However, because the underlying cause is often difficult to determine, alternative, effective more environmentally friendly management is hard to achieve.

European honeybees are an important part of the economy (see chapter 13), yet there is considerable debate on their effects on the Australian environment. While they have been present in Australia for about 170 years, their abundance and distribution has increased dramatically over the last 60 years (Paton 1996). Honeybees potentially affect native flora and fauna through (i) competition for tree hollows (Figure 5.25), (ii) competition for nectar and pollen, and (iii) disruption of plant-pollinator systems. A distinction needs to be made between commercial honeybees housed and transported in hives and feral honeybees occupying tree hollows. Honeybees can forage at least 20 km from their hives or hollows.

Paton (1996) concluded that tree hollow use by feral honeybees broadly overlaps with those used by native birds and mammals, but feral bee colonies appear to only occupy a small proportion of the available hollows. However, he acknowledges that few studies adequately assessed the availability of suitable hollows, particularly their internal characteristics. The low availability of tree hollows is a limiting factor for many threatened species. Even low levels of competition for hollows from feral bee colonies could have significant adverse effects on these species.

Competition between honeybees and native bees may occur when floral resources are low (Schwarz & Hurst 1997). However, studies need to consider the impact of both commercial (short-term bee presence in areas experiencing good flowering) and feral honeybees (year round presence including when floral resources are low). Honeybees are able to forage earlier in the day than native bees and therefore have first access to resources (Paton 1993). This may directly affect the health of native bees. For instance, a native bee (*Hylaeus alcyoneus*) was found to produce about 25 percent fewer nests in the presence of commercial honeybee hives (Paini & Roberts 2005).

Over millions of years, close and specialised relationships have developed between native plants and the species (mostly insects and birds but also mammals) that pollinate them in return for pollen and nectar resources. The establishment of feral bees in an area can disrupt this relationship by out-competing the native species for the resources but failing to pollinate the plant in the process. This may result in a reduced seed-set (Gross & Mackay 1998)

Pathogens

Plant and animal pathogens, including zoonoses (diseases transferable to humans) are a concern in all ecosystems. Pathogens may be natural or introduced. They can be introduced as a result of the introduction of another species. Both native and introduced species can be reservoirs of disease. Inappropriate management, such as faecal or nutrient input to waterways, can affect pathogen populations. Two important arboviral (arthropod-borne) infections, Ross River Virus and Barmah Forest Virus, can be contracted by humans in parts of the study area. They are spread by mosquitoes and are important because of their frequency and the disabling rheumatic symptoms they can cause.

Although the study area is currently considered to be outside the climatic range associated with Cinnamon Fungus, climate change may alter this in the future (DSE 2006). Eucalyptus rust is considered to be one of the most serious offshore threats to Australia's eucalypts (and other genera of Myrtaceae) and the country's hardwood timber industry. The species has recently been detected in Hawaii. A national response plan is in preparation (Office of the Chief Plant Protection Officer 2005).

Mundulla Yellows causes progressive dieback in eucalypts (Figure 5.26) and other native species and was first reported in river red gums in the 1970s. The syndrome was first observed near Mundulla, South Australia, but has since been reported in most states

Figure 5.26 Tree with Mundulla Yellows and close up photo of leaves showing yellowing or interveinal chlorosis.



of Australia. The first symptom of Mundulla Yellows is leaf yellowing or interveinal chlorosis, initially in young leaves and later spreading to mature leaves and causing defoliation. Epicormic growth occurs on branches, and new leaves are stunted and yellow. The symptoms gradually spread throughout the tree, causing the whole canopy, and tree, to die over several years. Mundulla Yellows generally affects disturbed vegetation, particularly near roadsides. At least 87 species and 29 genera have been recorded with Mundulla Yellows-like symptoms in South Australia. Insects were initially thought to be the causative agent, but recent research has shown that Mundulla Yellows is caused by a complex interaction of soil properties (texture and parent material), nutrients, soil compaction, water availability,

Figure 5.27 Cattle on the bank of the River Murray in Barmah State Forest.



increased alkalinity and salinity, and the accumulation of bicarbonate in the soil solution.

Mundulla Yellows has been reported from the leaves of river red gums near Hattah-Kulkyne but soil properties were not investigated. The distribution of Mundulla Yellows within the River Red Gum Forests study area is unknown and further work is required.

Grazing

Domestic stock grazing can potentially lead to pugging, selective plant removal, weed invasion, soil compaction, erosion and increased sediment in rivers and streams. In turn, these processes can simplify the structure of the habitat (Tasker & Bradstock 2006), stock compete for food with native animals and remove habitat (such as abolishing invertebrate burrows through soil compaction). The social and economic benefits of grazing, legislation and administrative arrangements (including licencing and agistment permits) and extent of grazing on public land within the study area are discussed in chapter 13. Some of the effects of grazing have been established, but the wider grazing issue is controversial and is further discussed in chapter 19.

The removal of palatable vegetation alters the composition, function and structure of vegetation communities. The selective nature of grazing has the potential to significantly change the biodiversity of an area. This effect has been well documented for trees and groundcover plants, particularly in riparian landscapes (Robinson & Mann 1998; Robertson & Rowling 2000; Spooner et al. 2002; Jansen & Robertson 2005).

The tendency for domestic stock to graze selectively is well demonstrated in Barmah forest. Early accounts of Barmah forest indicate that cumbungi and common reed were preferentially grazed by cattle and are now restricted in occurrence (Chesterfield 1986).

Cattle are also attracted to Moira grass, in preference to any other fodder. This species grows in flood-prone grasslands and breaks a period of winter dormancy growing prolifically during spring flooding. The combined effects of altered water regimes and the preferences of cattle grazing have substantially reduced the distribution of Moira grass. Domestic stock grazing also limits the recruitment of red gum populations, with this effect decreasing as stocking rates decrease (Jansen & Robertson 2005). This effect is exacerbated by an increased abundance of seed-eating ants at sites grazed by cattle (Meeson et al. 2002).

Other studies found that increased grazing reduces the ecological condition of riparian habitat and results in the loss of bird, frog and plant diversity in river red gum habitats (Jansen & Robertson 2005). Frog diversity and wetland condition declined with increasing grazing intensity on the floodplains of the Murrumbidgee River (Jansen & Healey 2003). Declines in bird populations were found to be related to loss of vegetation structure due to grazing (Martin & Possingham 2005), probably because grazing removes the grass tussocks and shrubs where species such as yellow-faced honeyeaters and rufous songlarks nest (Ford et al. 2001).

There have been no studies on the effects of grazing on river red gum invertebrates although stock grazing in grey box woodlands alters the populations of ground-dwelling invertebrates by inducing changes to vegetation and litter layers (Bromham et al. 1999). In grey box woodlands, ungrazed woodland had a more diverse ground invertebrate fauna, most likely due to the greater diversity of food and habitat resources provided by the less disturbed vegetation. Additionally, soil compaction by grazing animals can result in changes to invertebrate faunal composition by its effect on ground and shrub layer plants and on plant litter (Scrougall et al. 1993).

Grazing may also: reduce the capacity for riparian zone vegetation to act as a nutrient 'filter'; compact soil; and increase erosion where bare soil has been exposed, therefore increasing sediment input into waterways (Figure 5.27).

Alternatively, domestic stock grazing can positively affect the environment if applied in a strategic manner. Grazing cattle and sheep for a limited time in spring can help to reduce weeds by restricting seed set and flowering in certain annual species. Low-level sheep grazing is applied in grasslands such as Terrick Terrick National Park to maintain an open habitat preferred by many threatened flora species.

The limited studies that have been undertaken to determine the effectiveness of different grazing strategies for maintaining and enhancing biodiversity suggest that intermittent grazing provides the best biodiversity outcomes by creating vegetation heterogeneity through both time and space (Dorrrough et al. 2004). Continuous and intensive grazing can cause a significant loss of habitat value through species selectivity, changes to vegetation structure and impacts on habitat values (e.g. Chesterfield 1986; Jansen & Healey 2003). However, a varied vegetation structure can have less useable forage and therefore has not generally been favoured by graziers (Dorrrough et al. 2004). This mismatch in land management objectives is one of the main impediments to the introduction of strategic grazing management with biodiversity conservation as a primary objective across parts of the public land estate.

Changes due to intensive grazing may be irreversible in the short to medium term, and a significant allocation of resources may be required to restore native vegetation. In particular, damage to stream frontages is significant. A site's ability to recover from grazing damage depends on stocking density, soil type, geomorphology and topography and is therefore highly variable (Robertson & Rowling 2000; Martin et al. 2006). There may be a substantial time lag between the time of revegetation and the re-establishment of animal populations (Vesk & Mac Nally 2006)

In addition to domestic stock grazing on public land within the study area, there are native grazers (kangaroos and wallabies) and feral grazers (feral cattle, rabbits, hares, fallow deer, feral horses/brumbies, goats and pigs). When in large populations, these additional grazers contribute to over-grazing of vegetation. The hard-hoofed feral cattle, brumbies and goats also contribute to trampling, soil compaction and erosion.

Climate Change, Greenhouse and Biolinks

Climate change, both natural and due to increased levels of greenhouse gases in the atmosphere, is described in chapter 4. This section looks specifically at the potential effects of climate change on biodiversity. Climate change represents a major new threat to biodiversity and ecosystem services for the 21st century with some predicting mass extinctions (Thomas et al. 2004). Climate change is predicted to change the distribution, configuration and abundance of species and ecosystem services.

The types of species most at risk from greenhouse effects have been divided into six categories (Mansergh

& Bennett 1989; Brereton et al. 1995):

- Genetically impoverished and/or localised populations
- Poor dispersers and annual plants
- Specialised species, especially those dependent on mature vegetation, e.g. superb parrot
- Peripheral or disjunct populations
- Coastal species
- Montane and alpine species

The implications of climate change on the flora and fauna of river red gum ecosystems require further studies, especially for invertebrates. In theory, global warming could affect invertebrates by increasing the developmental rate of species, thus resulting in more generations each year for some species. This could occur both for herbivorous insects and for their natural enemies. Another possibility is that insects from cooler regions of the river red gum range could be displaced by species better adapted to warmer temperatures. This could promote invasive invertebrate species currently only found further north. The knowledge base regarding the invertebrate fauna on river red gums is inadequate to allow further speculation.

Modelled responses of fauna to climate change in southeastern Australia has led to the identification of climatic refugia (areas where species will experience a climate similar to the present) and a series of biolink zones in Victoria (Bennett et al. 1992; Brereton et al. 1995), which have since been recognised in government policy (DCE 1992b). Biolink zones are areas that will maximise the capacity for species to "move", recolonise and reconfigure as they adapt to climate change (see Mansergh et al. 2005). The Murray River and associated riparian vegetation and wetlands have been identified as a key sub-continental scale "biolink".

A National Action Plan (NAP) has been developed for Australian biodiversity in response to greenhouse climate change (NRMMC 2004). In strategy action 5.1 (p. 27) the NAP seeks to implement "*strategies to reduce the physical barriers to movement to facilitate the migration and dispersal of terrestrial species and communities that are vulnerable to climate change*". The River Red Gum Forests study area has been identified as a major link, provided by its contiguity in linking different habitat zones (DCE 1992b; Brereton et al. 1995). However, vegetation conditions could be improved to maximise the river red gum's value as a biolink (ARIER et al. 2004). Further, recommended actions of the NAP include to "*identify and implement opportunities to re-establish native vegetation and enhance habitat for vulnerable species on private land through revegetation, vegetation management and land-use change program*". The varying width of native vegetation (in both NSW and Victoria) along the rivers provide opportunities to improve the area as a biolink.

Fire

Fire (see chapter 4) is vital for many Australian ecosystems and shapes the composition and distribution of plant and animal communities across Victoria. Plants have adapted to fire over millions of years and have various survival mechanisms. Some trees with thick bark may lose their canopy but survive the fire and grow new

Table 5.8 Comments on fire from explorers' journals.

Explorer (year)	Area	Extract
Hamilton Hume William Hovell (1824-25)	Ovens River & Goulburn River	'All the country from where we started this morning is all burning in every direction and the bush is all on fire....the blacks....'. (Hovell 1921:343)
		'...all the country around us appears to be on fire...'. (Hovell 1921:359)
		'The country is on fire in all directions. This appears to be the season for burning the old grass to get new.' (Hovell 1921:361)
Thomas Mitchell (1836)	Loddon River	'Fire, grass, kangaroos, and human inhabitants, seem all dependant on each other for existence in Australia..... Fire is necessary to burn the grass and form those open forests'. (Mitchell 1969:412)
Charles Sturt (1838)	Murray River (near junction with Edwards River)	'..... under a dark wood of gum trees scathed by fire to their very tops.' (Sturt 1838 cited in Sturt 1899:138)
	Murray River (general)	'When timber was again seen it was like the reeds, blackened by native conflagrations. Huge trunks and leafless limbs lay one across another on ground as black as themselves.' (Sturt 1838 cited in Sturt 1899:143)
		'The reeds had been burnt by the natives and in burning had set fire to the largest trees and brought them to the ground.' (Sturt 1838)

shoots from buds on the surface of the trunk and branches. Individual plants in other species may die but produce prolific seed, which take advantage of post-fire light, moisture and nutrients. A substantial proportion of native plant and animal species are dependent on fire for their continued survival and propagation. The life history characteristics (also termed 'vital attributes'; see below Noble and Slatyer (1980)) of individual plant and animal species determine their tolerance to fire. Different habitats and their resident species, such as grasslands, heathlands, woodlands and rainforests all have their own tolerances to fire.

Fire regimes are classified by frequency (interval between fires), intensity, season, and scale. Inappropriate fire regimes are fires occurring at frequencies, intensities, seasons, and scales that lie outside the ecological and physiological tolerances of resident plants and animals. The interplay of fire with plant and animal species and communities is complex, and inappropriate fire regimes are now recognised as a potential threat to sustainable ecosystems and biodiversity conservation under the *Flora and Fauna Guarantee Act 1988* (Scientific Advisory Committee 2003).

Native animals survive fire through mobility, shelter, and survival in unburnt areas. Although many individual animals are killed, populations survive and generally recolonise burnt areas as they recover. Sometimes,

species in isolated small populations occupying a narrow ecological niche, such as the mountain pygmy-possum, may be at risk in a major fire.

Studies of charcoal records from sediment cores indicate that fire has played a role in shaping the landscapes surrounding the Murray River (C. Kenyon unpublished). Extracts from the journals of early European explorers (see Table 5.8) and overlanders suggest that low-intensity fires were a frequent occurrence in the River Red Gum Forests study area (Mac Nally & Parkinson 2005). An early settler in the Barmah region noted that Indigenous people set fire to the region approximately every five years (Curr 1883). Table 5.8, reproduced from Mac Nally (2005), compiles extracts from the journals. Unfortunately these reports do not refer specifically to riverine forests. It is likely that wildfires started by lightning, also occurred in riverine forests.

Current knowledge suggests that while river red gum saplings are fire-sensitive (Dexter 1978), large trees are generally able to survive low intensity fires (Mac Nally & Parkinson 2005). The Arthur Rylah Institute is currently curating and managing DSE's Vital Attributes database. This project includes interim recommendations in relation to the maximum and minimum fire intervals for different vegetation types (Cheal & Carter 2006). According to this data, riverine woodlands and forests are flammable only occasionally (i.e. after seasons with extended

summer rains or flooding promote extensive new grass growth). Few species are geared to regenerate post-fire and thus fire is not a major regeneration opportunity for typical species. Floods are the main regeneration events. If fires occur, they are usually rapid, of relatively low intensity and limited extent, driven by fine fuels in the ground layer. Undisturbed forests are generally less flammable than logged and/or grazed stands as there is less grass in undisturbed forests.

Nor does the succession of plant species found in regenerating river red gum forests suggest that fire is a natural part of their life cycle. This vegetation does not have a suite of fire ephemerals and the hard- or cone-seeded species requiring fire to germinate are neither common nor dominant. Many riverine species from genera usually dependent on fire, germinate successfully and abundantly without fire. For example, while many wattle species (*Acacia*) in other habitats germinate after fire, local riverine species such as eumong and willow wattle do not use fire as their prime germination cue. Further, the river red gum forests and their associated riverine vegetation contain species with regeneration strategies that are keyed to different environmental cues, notably flooding.

DSE's Fire Management Branch is responsible for fire management in state forest, national, state or other parks, reserves or other Crown land. Other bodies, such as the Country Fire Authority, Parks Victoria and plantation managers, assist in both fire prevention and fire suppression activities.

DSE describe three different types of fire:

- wildfires that begin through processes not induced by management agencies (e.g. lightning strikes);
- fuel reduction fires that are lit by management agencies specifically to protect life and property; and
- ecological fires which are the active use of fire to alter vegetation and habitat structure to achieve specific biodiversity outcomes.

As described above, river red gums are particularly sensitive to high intensity fire and as such, fire needs to be managed to provide for low intensity and low frequency fire regimes throughout the majority of red gum forests. Accidental fires from escaped campfires need to be suppressed quickly for protection of both life and property and ecological values.

The maintenance of tracks is an integral part of most fire protection plans, including part of the permanent road network in the study area. Temporary tracks and firelines aid wildfire suppression, control regeneration and fuel reduction burns. These temporary tracks are generally closed and rehabilitated when the particular operation is completed. Development of additional tracks for fire suppression can have negative consequences for biodiversity conservation through direct removal of habitat, fragmentation of habitat and increasing access for predators such as cats and foxes.

Pollution, Chemicals and Salinity

Pollution in the study area occurs in many forms and has many causes. Water pollution by grey water and sewage

into the River Murray from houseboats is discussed in chapter 11. Such pollution can increase nutrients in the water leading to algal blooms and fish deaths. Fertilisers, sediments and herbicides also run off farms into rivers and wetlands and have negative impacts on aquatic fauna. 'Rivertender' projects are currently being conducted in the Ovens River catchment to fence riparian zones and exclude stock with the aim of decreasing sediments introduced to the river systems (NECMA undated).

The broadest recent chemical application in the study area was used against plague locusts. This involved spraying young hoppers with insecticides or the Orthopteran-fungus *Metarhizium*. The non-target effects of insecticides or the fungus have not been assessed. Furthermore, larger-bodied insects such as locusts and grasshoppers are a major food of many water birds, and information of any adverse effects is lacking.

Salinity occurs naturally in the environment but is exacerbated by some current land uses (see chapter 3 for a further description). It is estimated that approximately 140,000 ha of irrigated land and 120,000 ha of dryland in Victoria are significantly affected by salinity, costing about \$50 million per year (DNRE 2000). Salinity occurs when shallow rooted plants (such as annual crops) and the clearing of vegetation allow rain to pass through the root zone and into the ground water. This extra water dissolves salts, which are then drawn up to the surface and kill remaining vegetation. This is exacerbated by a reduction in floods. Intensive salinity can lead drive local fauna and flora extinct. Salinity extends beyond property boundaries (including that between public and private land) and is important for aquatic as well as terrestrial ecosystems.

The Kerang Lakes systems have been greatly changed by the altered water regimes in the area. Many lakes are much saltier and support much less biodiversity than they once did (RMCG & Brett Lane & Associates 2004). This increased salt comes from salty ground water in some cases, while other lakes have been used as salt disposal basins (e.g. Lake Tutchewop in South Australia). On the Chowilla plains 65 percent (greater than 6500 ha) of the floodplain trees are affected by salinisation (Overton et al. 2006).

SUMMARY

The biodiversity of the River Red Gum study area is both rich and rare, providing an important refuge and corridor for many species adapted to floods and wetter environments in an otherwise arid landscape. The forests and their associated wetlands contain significant cultural and environmental values and are internationally, nationally and locally recognised for their importance to a wide range of threatened and vulnerable species, including migratory birds. While little is known about many constituent species of the river red gum ecosystems, such as invertebrates, many threats have been identified and management strategies developed to reduce their effects on the biodiversity of this region.

6 Indigenous Land Associations

This chapter explores the relationship between Indigenous peoples and the land as well as the current extent of Indigenous involvement in land management and ownership. Opportunities to involve Indigenous people, including groups and representative organisations, in future public land management decision-making are examined.

HISTORY OF INDIGENOUS LAND ASSOCIATIONS

Indigenous associations with the land are profound and may be difficult for non-Indigenous people to understand. The Terms of Reference for the River Red Gum Forests Investigation specifically direct VEAC to consider possible opportunities for Indigenous management involvement and the Yorta Yorta Co-operative Management Agreement covering public lands within the study area (see Appendix 9). These matters are explored below together with information on public land management options and general models used for Indigenous involvement in land management. Aboriginal cultural heritage and its management are described in chapter 12 Cultural Heritage.

Relationship with the Land

For at least the past 50,000 years the River Red Gum forests along the Murray River and its tributaries have supported and nurtured Indigenous people. Resources gathered from the forests include plants, animals, water, minerals and stone. These resources were used to sustain a lifestyle that not only serviced basic needs such as food, clothing, tools, medicine, housing and heating, but also a rich cultural life with jewellery, ornaments, transport, mythology, art and crafts (Atkinson & Berryman 1983).

Understanding the physical environment and managing natural resources formed an important and integral part of the lifestyle patterns of everyday living for Aboriginal people. Accumulated knowledge gathered over hundreds of generations about specific foods, weather conditions, and seasonal patterns played an important role in influencing how Aboriginal people lived and practised their cultural beliefs. Significant forward planning and forethought was given to what plant, other food stocks and natural resources would be available in each location at different times of the year.

One of the best-known and most recorded land management practices was use of fire. Small-scale low-intensity fires were used to clear the landscape of bushy growth, and stimulate a flush of new shoots to attract animals to the local area. This practice formed an important food source for many Indigenous communities, although the specific details of timing and intensity have in many cases been lost (Esplin 2003).

River Red Gum forests supported many Aboriginal peoples including Bangerang, Bararapa Bararapa, Dhudoroa, Dja Dja Wurrung, Jarra Jarra, Jupagulk, Latje Latje, Ntait, Nyeri Nyeri, Robinvale, Tati Tati, Taungurung,

Wadi Wadi, Wamba Wamba, Way Wuru, Wergaia, Yorta Yorta, and Yulupna. Each of these groups had deep spiritual links with the land.

These Traditional Owner groups have spiritual ties with specific tracts of land established over hundreds of generations often based on belief systems, practices, social and ceremonial rules and responsibilities that have developed over hundreds of generations and continue to evolve and exist today. The connection between people and land is expressed in terms of 'being related to' rather than 'owning' the land or country. Aboriginal people often express this relationship as being custodians rather than landowners.

Country is a place that gives and receives life. Not just imagined or represented, it is lived in and lived with.

Country in Aboriginal English is not only a common noun but also a proper noun. People talk about country in the same way that they would talk about a person: they speak to country, sing to country, visit country, worry about country, feel sorry for country, and long for country. People say that country knows, hears, smells, takes notice, takes care, is sorry or happy. Country is not a generalised or undifferentiated type of place, such as one might indicate with terms like 'spending a day in the country' or 'going up the country'. Rather, country is a living entity with a yesterday, today and tomorrow, with a consciousness, and a will toward life. Because of this richness, country is home, and peace; nourishment for body, mind, and spirit; heart's ease.

Each country has its sacred origins, its sacred and dangerous places, its sources of life and its sites of death. Each has its own people, its own Law, its own way of life. In many parts of Australia, the ultimate origin of the life of country is the earth itself... (Rose 1996)

In some locations in the study area, Aboriginal people were also very active in altering the physical landscape to take advantage of natural seasonal events. Stone fish traps found at Barmah forest are evidence that local Aboriginal people had successfully manipulated waterways to provide readily accessible food sources.

Hundreds of other Indigenous cultural heritage sites are recorded from the study area including fresh water middens, scar trees, surface scatters, axe grinding grooves and mounds containing charcoal, burnt clay or stone heat retainers from cooking ovens, animal bones, stone tools and burial sites such as those at Barmah and Robinvale. Aboriginal associations with country are not limited to an interest in these particular sites or places, although the physical evidence found today is nonetheless important (see chapter 12).

Geographical or totemic features such as hills and rivers were (and still are) used to define and confirm tribal boundaries or country (see Map 6.1). Aboriginal people moved frequently between areas and met other groups for purposes of trade, ceremony, social gatherings, marriages, and so on. Highly developed and agreed protocols governed movements between or entering the

traditional area or country of another group. Many of these protocols still apply and tribal boundaries are observed by many Indigenous people today.

These protocols are of particular relevance for the River Red Gum Forests Investigation because Traditional Owners continue to assert their right to exercise traditional laws and customs including accessing their homelands, decisions regarding who within the group is authorised to 'speak for country' and what can be spoken about. The continued existence of recognised language and clan groups who have responsibility for areas that form part of the study area will be a major consideration in the development of recommendations for River Red Gum Forests public lands. These Traditional Owner groups are recognised by government as having aspirations and authority to participate in discussions and decision-making processes for specific areas of land or country, particularly in relation to cultural heritage matters (DSE 2004g).

Post-Contact Aboriginal History in Victoria

The first European explorers to travel through the study area were Hume and Hovell in 1824, Sturt in 1830 and Mitchell in 1836, closely followed and in some cases preceded by cattle drovers and squatters who began to settle the region with little regard for the Indigenous inhabitants. Squatting was legalised in 1836 and Aboriginal dispossession increased as more people moved to the area.

By 1838 Aboriginal peoples had started a concerted resistance campaign retaliating against the invasion of their homelands by harassing stock and killing isolated Europeans (e.g. conflicts at Faithfull Creek near Benalla, Rufus River near Lake Victoria in NSW). Europeans responded by attempting to arrest Aborigines, frequently resulting in large numbers of Aboriginal deaths (Clark 1999). There are reports of massacres, abuses and deliberate poisoning—in many cases involving ancestors of the present-day Traditional Owners from the study area (Christie 1979; Clark 1995; Clark 1999).

The official response to these problems was to concentrate the Aboriginal population in missions or reserves. Missions were established and progressively disbanded at Buntingdale near Geelong (1836–1848), Mitchellstown on the Goulburn River (1839–1940), Lake

Figure 6.1 Canoeing at Maloga (Caire, N.J. c.1884). The River Murray near Echuca and Barmah has always been an important site for Yorta Yorta and Bangerang peoples.



Source: Reproduced with permission of National Library of Australia, Image: an3096938-3-v.

Boga (1851), Yelta near Wentworth (1869–1885), Coranderrk near Healesville (1863–1924), Gayfield at Kulkyn Station (1874), Maloga NSW (1874–1888), Ebenezer near Dimboola (1859–1904), Cummeragunja near Moama NSW (1881–1953), Wahgunyah or Lake Moodemere (1891–1937) and Moonacullah near Balranald NSW (1916–1961). A number of Aboriginal people and families who originally occupied land in the study area were forcibly moved to other parts of Victoria or New South Wales. Many were relocated to missions at Mitchellstown, Maloga, Cummeragunja and particularly to Coranderrk where many children were sent (Atkinson & Berryman 1983).

Illness and starvation brought about by dispossession forced many Aboriginal people to depend on mission life. Although initially people were free to come and go, others were forcibly removed from their land and families. The social conditions of missions were usually very harsh and at some missions the policy of removing children began almost immediately with rations withheld if the children remained with their parents. Managers had a great deal of control of the movements of people to and from the mission grounds. Typically Indigenous languages and other customs were forbidden. Aboriginal people were frequently exposed to violence and abuse outside and sometimes also within missions (Clark 1999).

What written documentation exists of traditional Indigenous culture was largely prepared by squatters and missionaries, who may have been biased or lacked in-depth understanding of social structures or practices. However, a vast volume of oral history has been passed on by Indigenous communities, consistent with past traditions.

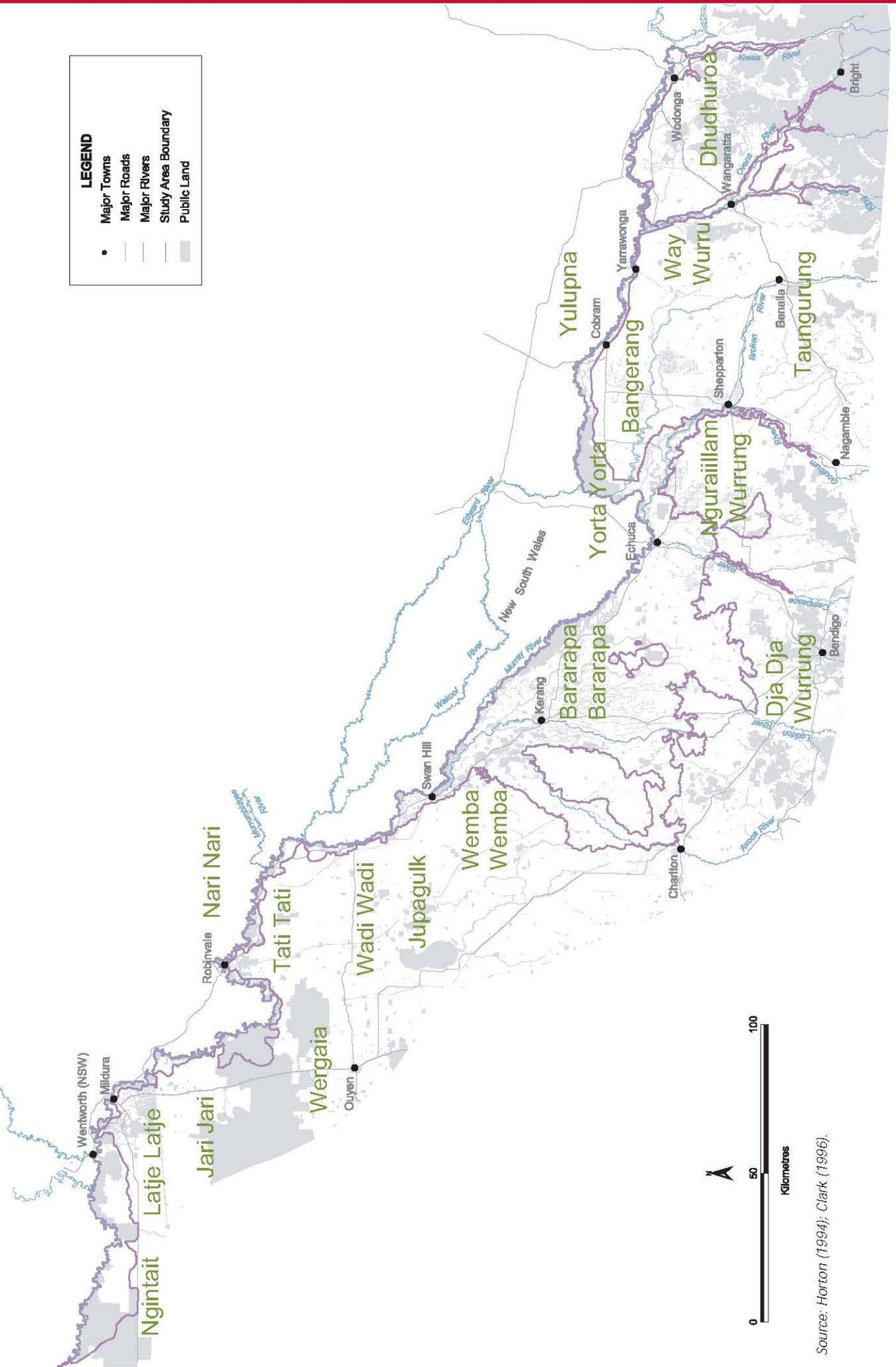
By the end of the 19th century only a small population of Aboriginal people lived on missions and government stations, with most living and working in nearby areas. Most missions and stations were phased out by the 1920s. Some mission lands are now under the control of Aboriginal communities (e.g. Cummeragunja and Coranderrk).

Present Day

Aboriginal people have continued to live throughout Victoria, often with strong ties to their original clan and tribal areas. Today, Aboriginal people contribute a vibrant and valued aspect of Australia's multi-cultural landscape expressing unique cultural identities, and having an important role to play in providing advice to government about land management issues. Whilst open racism has declined as a result of more enlightened community attitudes and anti-discrimination legislation, Aboriginal disadvantage in health, education and employment remains a challenge for governments and for Aboriginal people (see chapter 8 Current Social and Economic Setting).

For many years, equality and social justice has been the highest priority for Aboriginal people. Recent Australian history has been marked by an ongoing effort to gain official recognition and compensation for Indigenous peoples' individual and collective cultural rights. In 1835, John Batman signed a 'Treaty' with eight Aboriginal 'Chiefs' to acquire large tracts of land in what is now

Map 6.1 Approximate location of Language Groups of the study area.



Source: Horton (1994); Clark (1996).



Source: Reproduced with permission of National Library of Australia, Image: an3096938-2-v. Caire, N. 1884.

the State of Victoria. The British Government repudiated the Treaty asserting that (under British law) Aboriginal people did not have title to or ownership of the land—the notion of *terra nullius* (for further discussion of this complex issue see Borch 2001; Buchan & Heath 2006).

Successive generations of Aboriginal people have used the legal system and other means to gain recognition for their rights and to regain control and title over their traditional lands. Significant events include:

- Correnderrk Indigenous community petition to the State government (1886) requesting permission to leave the premises for work and the good of their health;
- Cummergunja 1939 walk-off in which over 200 Indigenous residents protested the poor conditions—the first mass strike of Aboriginal people in Australia;
- the 1967 Referendum to alter the Australian Constitution conferred legal responsibility for all Aboriginal people in Australia on the Commonwealth Government;
- the Land Rights Movement in the 1960s which led to the 1968 Yirrkala Aboriginal people (Arnhem Land, NT) claim seeking recognition of traditional title to land;
- the Aboriginal Tent Embassy set up on lawns of Parliament House (Canberra) in 1972;
- the first motion in the new Parliament House (Canberra) in 1988 acknowledging Aboriginal and Torres Strait Islander people as ‘the original occupants of Australia’;
- the 1992 ruling by the High Court of Australia rejecting the doctrine that Australia was *terra nullius* (land belonging to no-one) at the time of European settlement confirming that the common law of Australia recognised the existence of native title to land (*Mabo v. Queensland*);
- the 1993 High Court majority decision which held that Queensland pastoral leases under consideration in the *Wik* case did not confer exclusive possession upon the lessees;
- the Commonwealth *Native Title Act 1993*,
- Yorta Yorta Native Title claim and appeal (described in more detail below); and
- in Victoria, the 2005 Wotjobaluk, Jaadwa, Jadawadjali, Wergaia and Jupagulk native title claim negotiated agreement which confirmed that native title exists in parts of the determination area comprising some 45 ha of public land in western Victoria.

Access to natural resources on public land remains a commonly expressed aspiration of Indigenous people within the study area. This includes take and use of wildlife, fish and plants for personal, domestic and under certain conditions commercial use. Aboriginal people are subject to the same laws or policies as other people in relation to use of resources. However, the *Native Title Act 1993* allows native title holders to carry out certain activities under certain conditions, including hunting, fishing, gathering and camping. Similarly, the *Wildlife Act 1975* allows the Secretary of DSE to permit the take, use and so on of wildlife for Aboriginal cultural purposes while the *Fisheries Act 1995* enables a special permit to be issued for fishing associated with a cultural or ceremonial event.

CURRENT AND POTENTIAL INDIGENOUS INVOLVEMENT IN LAND MANAGEMENT

Indigenous Land Ownership in Victoria

Indigenous policy, strategies and resources are fragmented and distributed across various government and non-government bodies. There is no central database or land registry containing specific information about the amount of land owned by Victorian Aboriginal people, groups and organisations or by Victorian Aboriginal businesses (private).

The total area Aboriginal people ‘own’ and manage in Victoria is approximately 11,340 ha equating to approximately 0.05 percent of the state (228,138 km²) (Strategy for Aboriginal Managed Lands in Victoria Project team 2003). This land comprises the following:

- 8158 ha (68 percent) is used primarily for non-commercial activities. Except for Lake Tyers the seven largest blocks of land are in southwest Victoria:
 - > Lake Condah 1820 ha
 - > Lake Tyers 1627 ha
 - > Framlingham Forest 1120 ha
 - > Deen Maar Indigenous Protected Area 453 ha
 - > Framlingham 248 ha
 - > Tyrendara Indigenous Protected Area 480 ha
- 3770 ha (32 percent) is used mainly for commercial purposes.

These figures do not include land purchased by the Commonwealth under the Community Housing Infrastructure Program (CHIP) or land purchased by the Aboriginal Housing Board of Victoria. Approximately 1000 ha at Cummergunja Mission is owned by the NSW Aboriginal Land Council and occupied by Aboriginal people—the majority of whom are from Victoria—and 4047 ha of land at the Warrakoo property in NSW near Mildura owned by Mildura Aboriginal Corporation.

Properties ‘owned’ by Indigenous communities or groups purchased through Commonwealth and State or Territory governments and the Aboriginal and Torres Strait Islander Commission (ATSIC) have caveats on the title which constrain or restrict the sale or mortgaging of property subject to approval by the relevant agency. The existence of caveats means that, in most cases, the land cannot be used by Aboriginal land holders to secure finance for enterprise development.

Table 6.1 Summary of area in Victoria owned by Indigenous people.

Land Acquisition Method	Area (ha)	% of Total
Land acquired through Victorian Legislation	1710	15
Land acquired through Commonwealth Legislation	1163	10
Land acquired through ILC purchases	4273	38
Land acquired through Government Department grants*	4196	37
Total	11,342	

Note: Asterisk denotes that ATSIC land is included in this category

The Indigenous Land Corporation (ILC) has purchased 28 properties on behalf of Indigenous people or groups in Victoria. In limited circumstances, the ILC has allowed land holders to seek loans using the land as security, and in some instances provided security on behalf of the land holder.

When compared with land owned or controlled by Indigenous peoples in most other Australian States and Territories, the amount of land owned by Victorian Aboriginal people, groups and organisations is small (Table 6.2). This partly reflects higher Indigenous population numbers interstate, both numerically and as a proportion of the general population, and the existence of more Aboriginal specific communities in these States and Territories (many of which are overseen by Aboriginal Local Governments).

It should be noted that information contained in Table 6.2 is a minimum estimate. The actual extent of land holdings by Aboriginal people has increased since these calculations were made as a result of land purchases by the ILC and governments, and under various management agreements, although detailed information is difficult to obtain and no nationwide summary has been prepared for more than ten years e.g. Mutawintji National Park (NSW) was returned to its Traditional Owners in 1998 and comprises 68, 912 ha.

Native Title

On 20 May 1982, Eddie Mabo and others of the Meriam people began their legal claim for ownership of the island of Mer in the eastern Torres Strait. It was not until 3 June 1992—by which time Eddie Mabo had died—that the case was decided. The High Court determined that the Meriam people did have traditional ownership of their land and that British possession had not eliminated their title—‘the Meriam people are entitled as against the whole world to possession, occupation, use

and enjoyment of the lands of the Murray Islands’ (Mabo and Others v. QLD (No. 2) 1992).

The judgments of the High Court in the Mabo case inserted the legal doctrine of native title into Australian law. In recognising the traditional rights of the Meriam people to their islands, the Court also held that native title existed for all Indigenous people in Australia prior to Captain Cook’s declaration of possession in 1770 and the establishment of the British Colony in 1788 (AIATSIS 2004). The new doctrine of native title replaced the doctrine of *terra nullius* (no-one’s land) on which British claims to possession of Australia were based. In recognising that Indigenous people in Australia had prior title, the Court held that this title exists today in any portion of land where it has not legally been extinguished. This decision altered the foundation of Australian land law.

Following the High Court decision, the Federal Parliament passed the *Native Title Act 1993*, enabling Indigenous people throughout Australia to claim traditional rights to unalienated Crown land. The Act adopts the common law definition of ‘native title’ as a recognition of rights and interests over land and water possessed by Indigenous people in Australia under their traditional laws and customs.

The Act was extensively amended in 1998 (the ‘Ten Point Plan’) following the 1996 *Wik v Queensland* High Court native title decision, which clarified that native title rights and interests may co-exist over land which is or has been subject to a pastoral lease, and possibly other forms of leasehold tenure.

The main objectives of the *Native Title Act 1993* are to:

- provide for the recognition and protection of native title;
- establish ways in which future dealings affecting native title may proceed and to set standards for those dealings;

Table 6.2 Area owned in Australia by Indigenous people (areas are in thousands of square kilometres).

Category	NT	WA	SA	QLD	NSW	Vic	Tas	ACT	Total	% of Aust
Freehold	516.8	-	189.0	20.5	0.4	<0.1	-	-	726.7	9.5
Leasehold	19.2	126.1	0.6	18.9	1.1	<0.1	-	-	165.9	2.1
Reserve	-	199.4	-	2.8	-	-	-	-	202.2	2.6
Total	536.0	325.5	189.6	42.2	1.5	-	-	-	1,094.8	15.24
% of Total	49.0	29.7	17.3	3.9	0.1	<0.1	0.0	0.0		

Source: Land Tenure database 1993, Geoscience Australia, ©Commonwealth of Australia

- establish a mechanism for determining claims to native title; and
- provide for the validation of developments invalidated because of the existence of native title.

The Act also established the National Native Title Tribunal and governs how native title applications are administered across Australia. A number of Aboriginal groups have submitted claimant, non-claimant and compensation applications to the National Native Title Tribunal. A 'Claimant Application' made to the Tribunal over land owned by Commonwealth or State or Territory governments does not confer land ownership to the applicant. The Tribunal may confirm that 'native title' exists to a specific area of land, however, this usually relates to the applicant having the right to continue to practice their law and customs over traditional lands and waters while respecting other Australian laws. This could include visiting an area to protect important places, making decisions about the future use of the land or waters, hunting, gathering, and collecting bush medicines (NNTT 2000).

Victorian Traditional Owner groups have continuously stated that they and previous generations have never sold, traded or freely given their traditional lands to European settlers or any Australian government. This includes all public land within the River Red Gum Forests study area. To date, Victorian Aboriginal people have lodged 73 native title applications with the Tribunal (NNTT 2006c).

Yorta Yorta People Native Title Claim

One of the first native title applications was submitted on 21 February 1994 by Victoria's Yorta Yorta people. The claim area covered 1140 sq km of land and waters along the Murray, Ovens and Goulburn Rivers in Victoria and 720 sq km of land and waters in New South Wales bounded roughly by Albury, Finley, Deniliquin, Cohuna, Shepparton, Benalla and Wangaratta. A significant portion of public land within the study area lies within traditional country claimed by the Yorta Yorta people. The Yorta Yorta people sought (among other rights):

- the right to use, occupy, inhabit and possess the area and the natural resources;
- the right to restrict access to the claimant area;
- the right to exercise their rights, obligations and duties in accordance with their traditional laws and customs; and
- the right to use mineral and natural resources found in or below the area.

On 18 December 1998, Justice Olney of the Federal Court determined that native title did not exist in relation to the claimed land and waters because a continuity of acknowledgment and observance of traditional laws and customs could not be demonstrated. On 28 January 1999 the Yorta Yorta people appealed this decision asserting, among other things, that an incorrect test was applied to decide whether native title existed. The Yorta Yorta people also argued that Justice Olney had erred in his evaluation of the oral evidence of the native title claimants. The appeal made to the Federal Court in February 2001 and a subsequent appeal made to the full bench of the High Court in December 2001 were both dismissed, albeit not unanimously. The

determination issued by the National Native Title Tribunal stated that 'native title does not exist' in areas claimed by the Yorta Yorta people. Yorta Yorta people continue to pursue land justice and compensation for loss of their traditional country.

This process of litigated native title determinations has proven to be extremely long, expensive, resource-intensive, with long-term uncertainty for all parties involved. It has also proved painful and divisive with many assumptions and interpretations of past Indigenous relationships to country made by non-Indigenous people, and places modern legal judgements upon what current practices are 'traditional' in order to demonstrate continuity with country. In essence native title is a legal concept that has developed a specific legal meaning as cases have been pursued through the courts. The anthropological meaning of native title—traditional law and customs and connection to country—is likely to be in many cases very different to the legal definition that has evolved under the *Native Title Act 1993* (Ellemor 2003).

The very slow progress with Victorian native title claims through the courts is evident. Current Victorian Government policy is to mediate rather than litigate native title applications and to comply with the provisions of the *Native Title Act 1993* (DoJ 2000). Government has developed Guidelines for Proof of Native Title, Victoria (DoJ 2001).

The native title process has been the main mechanism used by governments to determine whether the rights of Indigenous people still exist for specific Crown land areas. There are, however, a number of other options that can be implemented which will significantly reduce the costs associated with a native title claim and recognise the relationship that Indigenous people have with country.

Negotiated Agreements Approach —Yorta Yorta Co-operative Management Agreement

On the June 10, 2004, the Victorian Government signed a Co-operative Management Agreement with the Yorta Yorta People which established a formal and on-going role for Yorta Yorta people in the management of 50,000 hectares of Crown land and waters. The agreement covers Kow Swamp, Barmah State Park, Barmah State Forest, and public land and waters along the Murray and Goulburn Rivers. The Agreement does not affect fees or access arrangements to parks, forests or reserves. An extract from the agreement is presented in Appendix 9. The Joint Body was formally appointed in December 2005 at which time the agreement commenced. There is an opportunity for ongoing internal review of the Joint Body role and structure and review by the Minister after two years.

The Yorta Yorta Co-operative Management Agreement is a partnership based on recognition, mutual respect and shared goals under which the State of Victoria recognises the cultural connection Yorta Yorta people have to areas covered by the Agreement. Key points under the Agreement include the establishment of a committee known as the Yorta Yorta Joint Body to provide advice to the Minister for Environment in relation to management of designated Crown land and

waters. The Joint Body is funded to employ staff for work outlined under the agreement and provides a forum in which ideas may be exchanged, management issues discussed and recommendations made for the future use of land and water under the agreement.

Government decision-making processes and management outcomes involve Traditional Owners, and the Minister must consider recommendations of the Joint Body as well as other bodies with management responsibilities. The Minister for Environment retains ultimate decision-making authority.

Indigenous Land Use Agreements (ILUA)

Aboriginal native title groups may enter into voluntary Indigenous Land Use Agreements (ILUA) with land holders over the use and management of land and waters as well as about matters such as exploration and mining developments, sharing land and exercising native title rights and interests. ILUAs can be made separately or as part of a formal native title determination. Courts are not involved in the ILUA process which is conducted entirely between the parties and may relate to specific issues such as future developments, coexistence of native title rights with other rights, access to an area, extinguishment of native title, and compensation.

By making agreements, Aboriginal people have in some places gained benefits such as employment, compensation and recognition of their native title whilst other parties to the agreement may obtain the use of land for development or other purposes. Since the *Native Title Act 1993* was amended in 1998 the Native Title Tribunal has registered 229 ILUAs (area agreements) throughout Australia between Indigenous groups and others—including pastoralists, miners, state, federal and local governments (NNTT 2006a) (Table 6.3). A broad range of agreements has been reached over national parks, exploration areas, local government areas and pastoral leases (NNTT 2006a). Examples of recent agreements are provided below.

Wotjobaluk, Jaadwa, Jadawadjali, Wergaia and Jupagalak Native Title Determination

The Wotjobaluk, Jaadwa, Jadawadjali, Wergaia and Jupagalk native title determination (finalised in December 2005) was the first to be made by agreement or consent in Victoria. All parties agreed, through mediation, that the native title claimants have non-exclusive rights under traditional laws and customs over part of the area they claimed in the Wimmera region of western Victoria. These rights are also subject to the laws of the State of Victoria and the Commonwealth of Australia and the terms and conditions of co-existence protocols between the parties established under the agreement (NNTT 2006d).

The consent determination is limited to approximately 26,900 hectares of Crown reserves along the banks of the Wimmera River, and does not include the waters of the river. This represents about two to three per cent of the original claim area. Part of the agreement comprises the grant of freehold title to three parcels of land (15.7 ha in total) over which the native title holders demonstrated a strong cultural and historical connection (including land near the former Ebenezer Mission site). The terms of the settlement involve a determination that native title does not exist over the remainder of the claim area, although native title holders will have other rights and benefits in the remaining area (see below).

The ILUA sets out how and when the native title holders will engage with the Victorian and Australian Governments about future dealings in the agreement area. The rights of others, whether covered by the agreements or where native title exists, have not changed. All non-native title interests within the area are recognised and protected by the determination. For example, a person with a grazing licence in the area is able to continue to operate according to their grazing licence and there will be no change to current public access to the area.

Among other things, the ILUA ensures that the Wotjobaluk, Jaadwa, Jadawadjali, Wergaia and Jupagalk peoples will continue to have a say about certain types of developments in the area where their native title rights have been recognised. The ILUA acts as an umbrella agreement for several other related agreements that form part of the settlement package between the native title claimants and the Victorian Government but which are not part of the consent determination. These related agreements provide for a range of other measures, including:

- recognition (including signage) of the cultural ties the native title claimants have to the area;
- establishment of a consultation process for certain types of developments;
- streamlined processes for the approval of licences and permits for Traditional Owners to hunt, fish, gather and conduct cultural events;
- co-operative management of some areas e.g., national parks; and
- funding to support administrative expenses, capital funding for a cultural centre and freehold land improvements.

Adnyamathanha Native Title Claim (South Australia)

A recent ILUA and associated co-management agreement negotiated between the South Australian Government and the Adnyamathanha native title claimants provides for the Traditional Owners to co-

Table 6.3 The numbers of Indigenous Land Use Agreements (Areas) registered to 30 June 2006 in each State or Territory.

ILUA	QLD	NT	Vic	NSW	SA	WA	ACT	TAS	Total
Total	117	73	22	5	9	3	0	0	229

Source: NNTT website last updated 30-6-2006, ©Commonwealth of Australia

manage the Vulkathunha-Gammon Ranges National Park in the northern Flinders Ranges (NNTT 2006b). This is the first such agreement relating to a national park in South Australia. As part of the agreement, the native title claimants excised the park from the claim area in exchange for recognition of traditional rights and interests, and equal representation on the board appointed to manage the park. Public access to the area encompassing about 128,000 ha will not be affected by the ILUA.

Resolution of the native title claim covering the national park via an ILUA process has allowed the claim over the remaining area to proceed. This process has been facilitated by a statewide ILUA strategy (SAMLISA Steering Committee 2000) and supported by the 2004 amendments to the legislation governing national parks in South Australia (NNTT 2006b).

Models of Indigenous Involvement in Land Management

Indigenous people are involved to varying degrees in land management throughout Australia. Various models of land management have been used to describe the level to which Aboriginal people are involved.

A spectrum of arrangements exists for the involvement of Indigenous people in land and resource management. These can be divided into several categories, with a grouping of three categories commonly referred to as co-operative management (Figure 6.2).

The difference between the various co-management and consultative arrangements, in particular, is not always distinct. Consultative management is considered by some to be a lower-level decision-making structure than forms of co-management and joint management. However, this is largely dependent upon the relationship established between Traditional Owners and land management bodies.

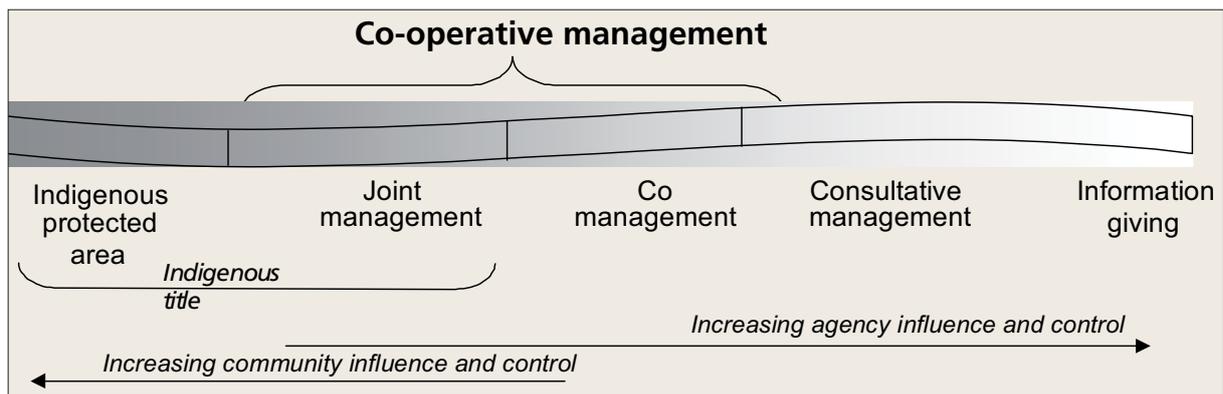
While there is no blueprint for successful arrangements, the arrangements offer an important and flexible mechanism to test and develop cooperative relationships between management partners, making long-lasting agreements easier to achieve. It is possible a Traditional Owner group may initially become involved in land and resource management through a consultative model and progress to another model with more decision-making power as partnerships, capacity and capabilities develop.



This staged approach perhaps offers a way of limiting the disappointment felt by Traditional Owners when aspirations for governance and decision-making powers have not been met because plans for increased involvement have progressed only where community capacity and management relationships have become established. It also limits outside criticisms that target a perceived inability for a ‘new’ Indigenous land management regime to meet mainstream expectations or standards.

Described below are examples of existing arrangements under Consultative, Co-management, Joint management and Indigenous Owned or Managed Land models, with examples provided for each. Possible approaches for Indigenous land management and the way in which these models have been used is described in chapter 19.

Figure 6.2 Current arrangements for Indigenous involvement in public land management.



Source: Modified after Borrini-Feyerabend (1996).



Consultative Management

Consultative Management involves consulting Indigenous people and groups about management matters, but without any formal role in decision-making and limited recourse if a decision is unfavourable or contrary to Traditional Owner practices or desires for land management. This is the main model used by the Department of Sustainability and Environment (DSE) and Parks Victoria (PV) in its dealings with all stakeholders, including Indigenous groups. Consultative management arrangements provide an entry into public land management that may progress to arrangements with greater decision-making responsibilities over time.

The Yorta Yorta Co-operative Management Agreement is an attempt to establish a model for Indigenous Community participation in public land management in a more structured and formal way. While called a co-management arrangement, there is no authority vested in the Joint Body with regard to land management decision-making.

Co-Management

Co-management enables certain public land management issues to be addressed in a close working relationship between government and one or more Aboriginal groups, in accordance with a memorandum of understanding or other forms of agreement. Management decisions are shared to varying extents between the Aboriginal group or groups and the state agency commonly through a body such as a board, committee of management or advisory body, with ultimate decision making powers remaining with the jurisdiction. In other forms of co-management, the body could also include other interest groups in, for example, an advisory group or committee of management comprising representative interests.

In Victoria, management arrangements with the Wotjobaluk, Jaadwa, Jadawadjali, Wergaia and Jupagalk

and Yorta Yorta peoples are restricted to an advisory capacity under the current provisions of the *National Parks Act 1975*. Management responsibility, including resource allocation, remains with the government land management agency and overall responsibility with the Minister. These examples are more clearly *consultative* than *co-management* models of land management.

The Forests Act 1958 and the *Crown Land (Reserves) Act 1978* contain provisions that enable increased levels of involvement and shared decision-making with Indigenous groups in State forests and Crown reserves. Recently a co-management arrangement has been established between government and Latji Latji Traditional Owners and other key community members for two areas of cultural heritage significance in Wallpolla West State Forest. The area will be managed as an Archaeological and Natural Interests Reserve under the *Forests Act 1958*. The committee of management has evolved from a working group established in 2003 to undertake rehabilitation and protection works for Aboriginal burial sites located on the floodplain forests west of Mildura.

An example of co-management is the recent agreement between the South Australian Government and the Adnyamathanha native title claimants to jointly manage the Vulkathunha-Gammon Ranges National Park (see above). Under the ILUA the Traditional Owners will be involved in all management decisions and have equal representation on the board appointed to operate the park (NNTT 2006d). In NSW the National Parks and Wildlife Service (NPWS) has established at least nine co-management arrangements in which the government and local Aboriginal groups share responsibility for management and decision-making.

Joint Management

Joint Management transfers title to Crown land to an Aboriginal group or groups and then leased back to the

State for a finite period or some other form of agreement where existing rights and interests are guaranteed. This is sometimes referred to as a 'hand-back lease-back' model of land management. Management decisions are shared between Traditional Owners and the relevant land management agency of government (the lessee) normally through a body of management. The lease agreement continues beyond its agreed term until a new lease is negotiated. This guarantees the continuation of existing rights and interests, including those of the State's for decision-making authority, and is usually secured by legislation.

An example of Joint Management is Kakadu National Park and World Heritage Area in the Northern Territory comprising approximately 50 percent Aboriginal land under the Commonwealth *Aboriginal Land Rights (Northern Territory) Act 1976*. Key features of this agreement are the lease arrangements between the Aboriginal owners and the Commonwealth Government over a 99-year term. A breach in the lease conditions will return full control of the land to the Aboriginal owners and the termination of the lease. An annual rental and percentage of park revenue is returned to the Traditional Owners as well as enterprise development opportunities including tour operators' induction schemes, Aboriginal involvement in park management, encouragement in business and commercial initiatives. The original lease agreement did not provide for formal joint management structures, but this was subsequently incorporated. Other examples exist at five NSW national parks at Mutawintji, Biamanga, Gulaga, Mount Grenfell Historic Site (NSW), Booderee and Booderee Botanic Gardens near Jervis Bay (Commonwealth Territory) and some 30 further parks and reserves in the Northern Territory including the Nitmiluk National Park encompassing Katherine Gorge.

To date, no joint management arrangements for national parks have been entered into between Traditional Owners and the Victorian Government. Amendment to the *National Parks Act 1975* would be required to enable this management arrangement to be established over any Victorian land scheduled under the Act.

Indigenous Owned or Managed Land

An example of Indigenous owned or managed land can be found at the *Tyrendarra Indigenous Protected Area*, which is owned and managed by the Winda Mara Aboriginal Trust (see detail below).

In Victoria, such lands may have been acquired through site-specific legislation (e.g. *Aboriginal Land (Ebenezer, Ramahyuck and Coranderrk) Act 1991*), a restricted Crown grant or through funds provided from the Commonwealth Indigenous Land Fund. In the Wotjobaluk, Jaadwa, Jadawadjali, Wergaia and Jupagalk Native Title settlement the State Government has allocated funds and three parcels of culturally significant land totalling some 45 ha and \$2.6 million over five years to meet costs associated with land management activities.

For protected areas, agreements may be reached with government agencies for support in areas such as pest plant and animal control, fire protection, threatened species management and management planning. Such

arrangements enhance the opportunities for increased Indigenous participation in the management of government-controlled protected areas, including through contracted services or co-management arrangements.

Examples of Aboriginal owned or managed land in Victoria include:

- Deen Maar Indigenous Protected Area (428 ha) which is a nationally significant ephemeral wetland system on the southwest Victorian coast near Yambuk. Purchased in 1993 by ATSIC (the now abolished Aboriginal and Torres Strait Islander Commission) for the Framlingham Aboriginal Trust, the area is culturally significant having connections with Deen Maar Island and the Creator Spirit Bunjil. It is also a site where numerous battles were fought with colonists during the Eumeralla wars in the 1840s and 1850s.
- The Tyrendarra Indigenous Protected Area (480 ha) owned and managed by the Winda Mara Aboriginal Trust was purchased in 1997 by ATSIC. The site contains archaeological remains of a large-scale pre-contact aquaculture system of the Gunditjmarra people which is still visible today.
- Wallpolla West State Forest contains a number of culturally significant sites. Government land management agencies have established a joint committee of management with the Latji Latji Traditional Owners under the *Forests Act 1958* to formalise working relationships established during rehabilitation and management of Aboriginal cultural heritage sites.

In other states, Aboriginal communities have freehold ownership of land. In Queensland, 55 Land Trusts have been established under the state's *Aboriginal Land Act 1991* or *Torres Strait Islander Land Act 1991*. In this case the grantees may restrict access to the land, however it can never be sold or transferred, and any lease issued to a non-Indigenous person or group for more than 10 years must be approved by the Queensland Minister responsible for Natural Resources.

Public Land Use Categories

VEAC and predecessor bodies have in the past encouraged government and Indigenous peoples to work together in public land management (VEAC 2004). However, to date there has been no public land use category that specifically requires Indigenous management. In some cases, Indigenous people have been more concerned with the level of Indigenous involvement in management than the underlying land use category (e.g. VEAC 2004). Implications of increased Indigenous involvement for the existing public land use system are explored in chapter 19 Emerging Themes.

VEAC will undertake a special consultation program to pro-actively seek the views of Indigenous people and groups in the study area on opportunities for increased involvement in public land management. The models described above will serve as the basis for this consultation, but should not limit the development of variations to the models—or indeed entirely new models—to suit particular local circumstances.

7 Non-Indigenous History

The resources of the river red gum forests and floodplains along the River Murray have sustained European settlement since 1836. This chapter explores key themes of European history and locations of significant cultural heritage.

European explorers, travellers and settlers have responded in various ways to the physical environment of the study area. Their responses have, in turn, shaped the cultural landscape of the river red gum region. The post-contact history of the study area can be traced through the key stages of settlement including pastoralism, gold seeking, selection and closer settlement. Records of the various waves of settlers who made homes for themselves, and the government infrastructure, which has supported European settlement, survives in many places, today.

The most enduring legacies of the first white explorers and overlanders are the names they chose for places and features of the study area. Markers and cairns trace their physical tracks. These memorials are typified by cairns to Sturt east of Merbein, to Hume and Hovell at Myrtleford and to Mitchell at Mount Hope. Substantial homes define the later squatting era. For the most part, little remains of the original pastoral complexes except for tanks, sheep washes and small graveyards, for example on the former Boort run. The remains of a stub fence belonging to Tyntynder station can be seen on a section of the Murray Valley Highway north of Swan Hill.

Gold discoveries in the early 1850s in the Ovens Valley brought thousands of prospectors to the areas of Myrtleford, Rutherglen, Wahgunyah and other places just outside the study area. The physical evidence of the fevered hunt for gold is found today in many places within these townships and in the nearby forests.

The riverboat or paddle-steamer industry, focused on the port of Echuca, played an important role in transporting timber and wool to markets—a role consolidated by the building of the railway in 1864 connecting the town to Melbourne. The intact wharf, port area and paddle-steamer of Echuca provide an evocative link with that period of history. Markers noting distances were used for navigation and can still be seen along the banks of the River Murray.

The era of selection, especially under the *Land Act 1869*, saw the subdivision of the study area into wheat and sheep farms, and has broadly defined land subdivision and land-use since that time. Many farmhouses built at this time of settlement survive today. Several townships surveyed during selection continue to serve their farming hinterland while all that remain of other settlements are sites—some on public land—of schools established under the state system of education from 1872, lone community halls, churches and cemeteries.

Roads and railways connected communities within the study area with larger townships and markets. Part of an early coach road between Swan Hill and Wentworth can be seen at Wood Wood, north of Swan Hill. Surveying of

railways often initiated the establishment of townships and, in some cases, resulted in towns being moved to take advantage of rail services. Rochester was moved from east of the Campaspe with the opening of the Echuca line in 1864, and Pyramid Hill was moved in 1883 when the Kerang line was built. A chimney, cemetery and a commemorative plaque mark the former Pyramid Hill town site.

Other lines were built to transport raw products. In 1899, a narrow gauge railway between Wangaratta and Whitfield, perhaps initially used for timber, later transported local produce such as tobacco. Parts of it can still be seen today, as can the Kerang-Koondrook light rail which opened in 1924 and transported timber from the River Murray region. Bridges were also important connections between regions. Significant bridges in the study area include those over the Goulburn River, for example, Stewarts Bridge at Kanyapella, McCoys Bridge at Wyuna and Yambuna Bridge between the two.

Water supply to the study area started with the establishment of irrigation trusts from 1883. A pump shaft and canal at Murchison hint at an ambitious scheme by the United Echuca and Waranga Waterworks Trust to irrigate a large tract of land between the Goulburn and Campaspe Rivers in 1885. The old Cohuna headworks (from around 1889) can be seen on the River Murray at Gunbower Island. Much of the irrigation infrastructure constructed by the State Rivers and Water Supply Commission for closer settlement from the early 1900s is still in use. This infrastructure demonstrates how water was brought to the area and, after the effects of waterlogging and salinity were realised, how surface water was drained away. The Waranga channel, surveyed in 1905, is a significant example of how water is transported for stock, domestic and irrigation use through the one system. Flumes were erected in the 1920s to carry water across the Mallee and can still be seen at Miralie. Large pumping stations to raise water to channel levels are evident at Mildura, Redcliffs, Merbein, Millewa and Robinvale.

Several former forest mill sites are known with other forest activities, such as grazing, exemplified by the muster yards in the Barmah State Forest. Arbutnots mill at Koondrook and Murrays mill in Echuca are still in use as timber mills on public land. These themes are explored in more detail below.

SETTLEMENT

European settlement of the study area commenced in 1836 and may be characterised by a number of themes including exploration, settling, transportation, water management, industries and recreation. Each of these are important for understanding the history of the region and are described in detail below.

Explorers and Overlanders

The earliest recorded European view of the study area was by Hamilton Hume and William Hovell on an exploratory expedition from New South Wales to Corio Bay. They crossed a large river they named the Hume (the Murray) near the site of present day Wodonga in 1824 (Figure 7.1). They crossed the Hume again and the

Mitta Mitta above their junction, and named the Ovens, near present day Everton, and the Goulburn, near Cathkin (Powell & Duncan 1982).

Charles Sturt charted the course of the River Murray in 1830 below the junction with the Murrumbidgee and gave the river its present name in honour of George Murray, British Secretary of the State for the Colonies (Davison et al. 1998). Surveyor General Major Thomas Mitchell made an exploratory excursion through the area in 1836. Mitchell named the Loddon, Campaspe and Avoca Rivers on this expedition. Mitchell made several errors in identifying rivers, naming a stream at Swan Hill, the Goulburn when it was actually the Marraboor (Little Murray) River which connects the Loddon River and River Murray. He also named a watercourse the Yarrayne, which was already known as the Loddon. On two later occasions he crossed this same stream again, this time identifying it as the Avoca (Mitchell 1839).

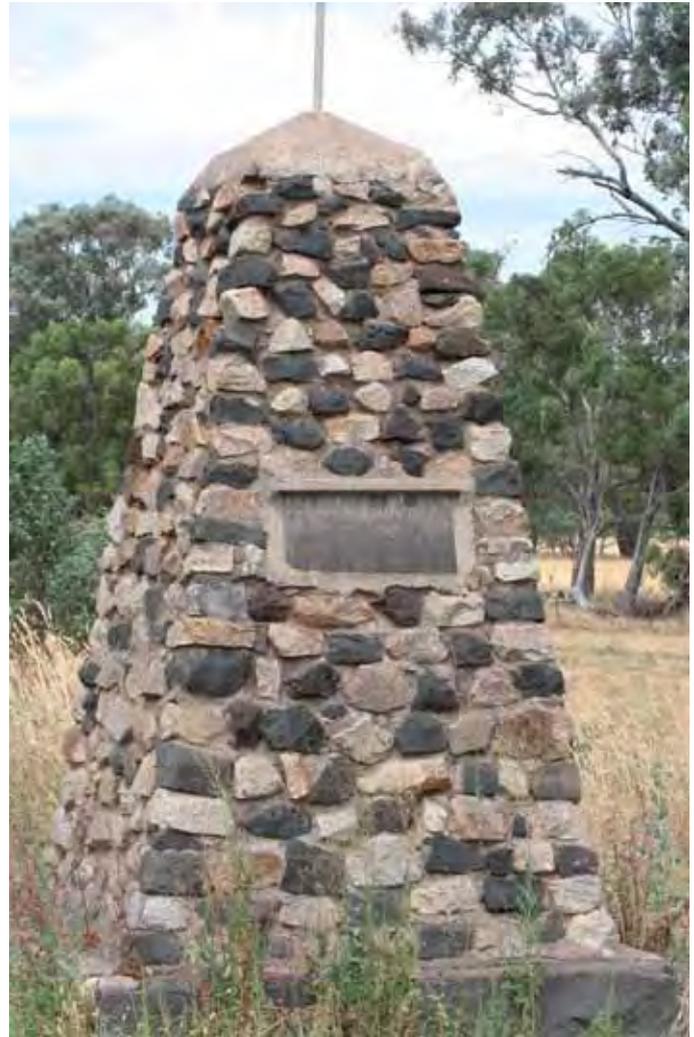
Following the positive reports of earlier explorers, Edward John Eyre made for Port Phillip and Adelaide in December 1837 with 300 cattle from near the site of present day Canberra. Eyre crossed the Goulburn and headed to the Loddon River but became hopelessly lost. He eventually arrived in Adelaide some seven months after his date of departure. In January 1838 Joseph Hawdon and Charles Bonney drove a mob of cattle from Howlong (near Albury) to Adelaide via the Goulburn River and River Murray. They travelled close to today's site of Echuca. Hawdon's experience of the country crossed by Mitchell was coloured by the hues of a hot summer. From the vantage point of Mount Hope in February he described the vastness of the plains being of the 'worst description' (Hawdon 1952).

Sturt returned in 1838 to drive his cattle along the Murray crossing to the left bank at Barmah Forest and moving on to Adelaide using the tracks of Hawdon and Eyre. By 1866, it was estimated that 350,000 sheep were being moved along this route (Holmes 1948). The first overlanders were able to ford the rivers they came across with reasonable ease, suggesting dry conditions. The routes taken by these explorers and overlanders are today marked by cairns and plaques (Figure 7.1). The intensive use of the River Murray track led to clashes between Aboriginal people and overlanders. The worst of these collisions occurred at Rufus River (Lake Victoria) during 1841 when 4–5 overlanders and at least 30 Aboriginal people were killed in battle (Sinclair 2001).

Pastoralism

It was Mitchell's triumphant view of the country he crossed, published and widely promoted, that brought a wave of squatters to the Port Phillip district. The advance of pastoralism was rapid, especially in the years 1838–40 after the official opening of the Port Phillip District in 1836. 'The Major's Line', the track left by Mitchell's 1836 expedition, marked a clear path followed by overlanding graziers searching for the abundant natural pastures Mitchell had labelled 'Australia Felix'. Translated from the Latin as *happy* or *fortunate southern land*, this was used by Mitchell to describe the lands of the Port Phillip district, and later the Colony of Victoria. The Major's Line acted as a kind of internal boundary line for the province. It was used by subsequent overlanders and runs were defined in relation to the line. Parts of the

Figure 7.1 Cairn near Wodonga commemorating the 1824 exploration route of Hume and Hovell.



track were still visible in the 1850s and can still be seen near Heathcote today with the name remaining in use in the 1880s.

Many squatters arrived in the study area by striking out from Mitchell's tracks and river crossings. Land within the study area was taken up for sheep and cattle grazing from as early as 1835. Bonegilla station (near present day Wodonga) was claimed by William Wyse on behalf of Charles Ebden in that year. White settlement was halted when overlanders encountered resistance by Aboriginal people along Mitchell's route on the Broken River in April 1838. For two to three months after conflicts at Faithfull's Creek near Benalla, in which eight white men and several Aboriginal people were killed, there was open warfare between 'blacks and whites' in this region (Christie 1979).

Runs were taken up on the best land along the rivers of the study area. A general trend saw the River Murray plains taken up from Ebden's run to the Goulburn, then west along the Murray. The lower reaches of the Campaspe, Loddon and Avoca Rivers were taken up to the north along those river courses with the plains being settled in later years. Runs were also taken up along the Murray in an easterly direction from South Australia. The

Figure 7.2 Murray Downs homestead (NSW) near Swan Hill.



vast Neds Corner run was established on the South Australian border by Ned Bagot in 1857.

The 1847 Order-in-Council provided for the issuing of leases through the Colonial Secretary which enabled squatters to take up the choicest agricultural land and river frontages. By 1850, most of the country of the study area was divided into sheep stations. Homesteads were located on river and creek frontages and boundaries were defined by blazed trees, ploughed furrows and the deployment of stock. Squatters and their herds and mobs were quick to make their mark on the land. The rapid introduction of domestic animals with hard hooves affected vegetation cover and soils as did introduced grasses.

Evidence today of the period of squatting occupation include homesteads which still stand at the sites of the Strathmerton, Wharparilla, Restdown Plains, Terrick Terrick, Mount Hope and Madowla Park (formerly Lower Moira) runs. Remains of sheep wash areas are found in various locations such as those at Woolshed Lake near Boort. Murray Downs (NSW) and Tyntynder homesteads near Swan Hill, and Burramine homestead near Yarrowonga are open to the public, and the Swan Hill Pioneer Settlement also evokes this era (Figure 7.2).

Gold Mining

Alluvial gold was discovered in the study area in 1852, in the 'Buffalo Ranges' of the Ovens district. Subsequent goldfields were opened at Myrtleford in 1853, Eldorado in 1854 and Wahgunyah and Rutherglen in 1858. The major gold discoveries in nearby areas such as Bendigo, Rushworth and Beechworth also had significant implications for settlement in the study area. The vicinity

of Myrtleford was dredged from 1908. Cyaniding of deep lead dumps was undertaken at Wahgunyah and Rutherglen between 1937–1950 (Heritage Victoria 2005). The impact of gold mining on affected parts of the region was devastating. Vegetation was cleared and topsoil turned over. Trees were felled to line drives and mine shafts and to stoke boilers. Creeks and rivers were polluted, silted, and riverbanks eroded and removed. Material reminders of the gold era exist today in the areas of Myrtleford and Wahgunyah (DNRE 1999).

Selection

Agriculture in the study area began in earnest with the passing of the Land Acts in 1860, 1862, 1865 and 1869. The aim of the Land Acts was to settle a class of yeomen farmers on small holdings across the colony of Victoria. The motives that fed the pursuit of this ideal were complex and varied, but the clear objective of the Land Acts was to break the squatter stronghold. Each consecutive Act brought with it conditions that made it more difficult for squatting interests to select land. Despite this, squatters had actually consolidated their holdings by 1869 by manipulating how the Acts were implemented by 'dummying' (nominal selectors acting on behalf of someone else) and 'peacocking' (selecting prime land such as waterways and fertile areas so as to make surrounding land untenable).

Most of the Riverine Plain of the study area was divided into 320 acre farms under the *Land Act 1869*. This Act required lessees to live on the selection for at least two and a half years, and within three years build a house, to fulfil residency conditions. They also had to fence the selection, cultivate at least ten per cent of the land, and improve their selection through clearing vegetation,

constructing of water storages and erecting outbuildings. If all the conditions were met, at the end of three years the selection could be purchased. By the dry year of 1876 however, farmers in the area were experiencing difficulties. The onset of drought, continuous cropping and the depletion of soil nutrients, the invasion of rabbits, low commodity prices, and the reorganisation of marketing and handling facilities to provide for local consumption, all impacted on farmers. These years of hardship brought another wave of change to the landscape. Many selectors left the land enabling those who were already established to buy up neighbouring properties to increase their holdings. By 1885, those who managed to stay had established an expanding wheat industry on the plains.

In 1883, the Mallee was chosen as the new frontier for the Land Acts in an effort to rid the area of rabbits and to preserve the land for the Crown for disposal in 1903. Under the *Mallee Pastoral Leases Act 1883*, the Mallee was divided into 'fringe' and 'interior' sectors. The 'fringe' sector comprised 500–1200 acre to 20,000 acre blocks. The 'interior' land was divided into 'A' and 'B' blocks of 60 to more than 500 square miles. 'A' blocks fronting water sources (mostly the River Murray) were expanded through grazing licences and were made available on twenty year leases. 'B' blocks were leased for five years. Those farmers able to endure the hardships of establishment experienced more favourable conditions in ensuing years. Subsequent Land Acts of 1901, 1911 and 1915 saw the Mallee Pastoral Leases divided up when they expired. The stump-jump plough and the mallee roller helped clear, large tracts of the Mallee for wheat farms by the 1920s. In an attempt to boost exports during the onset of the depression in 1929, the Commonwealth Government initiated a 'grow more wheat' campaign. By 1930 this had resulted in a huge increase in wheat production accompanied by a collapse in prices. In the early 1930s, the clearing and bare-fallowing had caused wind erosion and billowing dust storms across the Mallee and northern Victoria.

Some Mallee Pastoral Leases were retained so that not all Mallee land passed into private ownership. An example of such a lease was that issued for the Berribee property, a soldier settler block, now part of the Murray Sunset National Park.

Figure 7.3 Big Lizzie, built to remove mallee vegetation can now be seen along the Calder Highway at Barkly Square, Red Cliffs (see Figure 12.3).



Source: Reproduced with permission State Library Victoria H2002.106/144.

Closer Settlement

The drive to settle more people on the land continued with a number of closer settlement schemes made attractive and accessible through government support. The first of these was in response to the 1890s depression. The *Settlement of Land Act 1893* established villages to settle unemployed people from Melbourne on the land 'to bring idle hands and idle land together'. The Act provided settlers with one to twenty acres and cash advances while they cleared and began farming. Village settlements were set up in the study area in the areas of present day Nyah–Vinifera, Wood Wood and Kunat Kunat, and at Echuca East. The *Closer Settlement Act 1898* allowed the government to acquire large estates by agreement with the owner, subdivide them, and sell the small blocks under an instalment plan. However, it was not until closer settlement was linked with irrigation schemes administered from 1905 by the State Rivers and Water Supply Commission (SRWSC) that intense farming of smaller blocks began in earnest.

By 1913, in preparation for closer settlement, land near Shepparton, Swan Hill, Nyah, Cohuna, Merbein, Bamawm, Nanneella, Koyuga, Tongala, Rochester and Cornella Creek had been subdivided into blocks averaging 27–86 acres (Priestley 1984). But a Royal Commission in 1916 concluded that the results of closer settlement did not justify the expense. Blocks were too small or infertile, too few settlers from overseas had been attracted and those who did arrive had insufficient capital or experience (Broome 1984).

The Discharged Soldiers' Settlement Acts of 1917–24 in conjunction with the Closer Settlement Acts of 1915, 1918 and 1922 formed the legislative basis for Australian soldier settlement. More land was made available for farming through the resumption of old Crown grazing leases, Mallee blocks and the compulsory and voluntary purchase of large properties. Further irrigation channels were established in 1919–20 and soldier settlers took up irrigation blocks in the areas of Swan Hill, Shepparton, Rochester, Kerang, Woorinen, Nyah, Tongala, Red Cliffs, Robinvale, and in the Mallee. New technology enabled soldiers to pursue dairying, intensive cropping or fruit-growing.

A Royal Commission on Soldier Settlement in 1925 found that the scheme was mostly a failure due to a settlers' lack of capital and experience, the inadequate size of blocks and drainage problems. The War Service Land Settlement Agreement of 1945, however, continued to establish soldiers returning from World War II on farms. Dryland farms were allocated for soldier settlement in the Mallee and at Rochester. Irrigated blocks at Robinvale were also made available. Soldier settlements were provided in the Murray–Goulburn Irrigation Area around Cobram and Numurkah with the development of 120,000 acres of irrigated blocks for fruit growing and dairying. War memorials and road names in many districts attest to the profound impact distant conflicts had on the history of the study area.

The siting of major defence facilities at Bonegilla in 1940 and Bandiana in 1942 stimulated local farm production. These permanent camps consisted of rows of huts, canteens, kitchens, ablution and toilet blocks. Some of the facilities at Bonegilla were used for a Migrant

Reception Centre established in 1947. After the war Bonegilla camp housed 300,000 migrants during their first months or years in Australia. It closed in 1971 (Priestley 1984). The Kiewa Hydro Electricity Scheme and expansion of the Hume Reservoir provided employment for large numbers of post-war immigrants who subsequently settled in the area.

The study area, like most of rural Victoria, experienced a loss of population from the 1930s. The 1950s saw a return to better times with good seasons, extension of irrigation, control of rabbits and record prices for wheat and wool.

OTHER THEMES

Transport and Communications

One of the first heavily used tracks was the overland route between Sydney and Melbourne, with the section from Albury becoming known as the Port Phillip road. After the 1836 Faithfull Creek conflicts, mounted police parties were stationed along the track. Eventually towns were established as part of a military strategy to secure the route. The towns of Albury and Wangaratta were surveyed in 1839 as part of this strategy (Pennay & Pennay 1998). A mail run operated between Melbourne and Sydney from 1838.

Early tracks made by the movement of stock between markets and stations were stamped on the landscape from the late 1830s. On his 1838 journey, Sturt referred to the overland path made by Hawdon and Eyre as a 'high-road' (Holmes 1948), and indeed, the Murray became the most favoured route by which to deliver stock to the market of Adelaide from New South Wales. Some stock-routes were included in the first surveys as Three Chain Roads. An 1853 map of Victoria shows 'roads' or 'bush tracks' following the rivers of the study area and diverging to the head stations of the district's pastoralists (Ward & Lock 1853). Other more permanent tracks were turned into roads along bullock wagons and coaches routes.

By the late 1850s it was becoming increasingly obvious that the task of road making in Victoria was beyond the ability of one central body. The responsibility for road works was thus handed over to local districts with support given through government grants, rates and tolls under the *Roads Act 1853*. The *Local Government Act 1863* allowed municipalities to become boroughs and enabled larger road districts to become shires. Much of the early activity undertaken by local government authorities involved removing trees and stumps from roads, constructing kerbs, channels and pavements in red gum, and building of drains. Until 1860, most Central Roads Board funds were used to construct a road north to the River Murray via the gold diggings at Mount Alexander. The road terminated at Hopwood's punt at Echuca and is known today as the Northern Highway.

Bridges replaced punts as the arrival of railway lines increased traffic flows. A flurry of bridge building occurred on the rivers within the study area in the 1870s and 1880s. Stewarts Bridge, for instance, built across the Goulburn River at Kanyapella, was opened in 1879 and is still in use today although a new bridge is under construction (Figure 7.4).

Figure 7.4 Stewarts Bridge was constructed across the Goulburn River at Kanyapella in 1879.



Rivers

The major rivers and streams of the study area were important trade routes for the developing agricultural economy of the region. Squatters who moved into the region from 1836 used river crossings made by Hume and Hovell and Mitchell. As wool and meat production increased to supply Victoria's goldfields, punts were established to transport livestock across the waterways. Colonial parliaments were granted the right to impose custom duties on goods coming in from other colonies in 1850. Ports with associated infrastructure were established at Echuca, Swan Hill, Albury and Wahgunyah to oversee the collection of custom duties.

Trade on the Murray–Darling river system served South Australia, western New South Wales, the Riverina, and northern Victoria. Steamboats or paddle-steamers were introduced to the Murray in 1853 for commercial trade and operated principally between Goolwa and Echuca. Albury was the upper navigable limit of the Murray navigation, being reached by a paddlesteamer in 1855. To ensure safe navigation, 'snagging' steamers cleared the river of snags. Echuca became the major port of the trade being visited by 189 boats between 1866 and 1875 (Ward 1992). Red gum, valued for its durability, strength and resistance to air, water and insects, comprised the bulk of trade. Timber was sent to Melbourne, Sydney, Adelaide and to the British colonies such as India for railways. Later, wool and wheat were also significant. Boat building and maintenance was another significant river activity. A total of 124 steamboats and barges were built at Echuca between 1858–1913 with the industry peaking in the 1870s (Ward 1992).

The Goulburn River was made navigable through de-snagging by 1875. Steamers and barges engaged in regular trade between Echuca and Shepparton, and hauled timber, railway sleepers and logs for the fellers and saw millers in the red gum forests near the Goulburn–Murray junction.

River traffic declined in the 1880s with the building of railway lines to the region. By 1888, with the exception of red gum collection in the Barmah–Millewa forests, commercial traffic above Echuca had all but ceased. Trade between Shepparton and the Murray ceased in 1890. River transport from the western Riverina ended when rail lines were opened from Echuca to Balranald in 1926. Today paddle-steamers operate as a tourist attraction on the River Murray, principally from Echuca, Swan Hill and Mildura.

Railways

Significant changes were mooted for the colony of Victoria when the Surveyor General, Captain Andrew Clarke, was authorised to survey for railways throughout the central portion of the colony in 1855. Routes had been opened as far as Ballarat and Sandhurst by 1862 and then to Echuca by 1864, establishing the town as a major inland transport hub between river trade and the emerging rail network. A railway bridge over the River Murray for the line between Deniliquin and Moama was opened at Echuca in 1878. The Melbourne–Wodonga line reached Wangaratta and Wodonga in 1873 and branch lines were opened to Beechworth and Myrtleford in 1883. Albury was linked with Sydney in 1881. The Melbourne–Swan Hill line opened in 1890. The Mallee railway network to Yelta, Morkalla and the Nowingi line were constructed between 1891–1923. After demands from closer settlers, railway lines were extended to serve other communities. The railways continued to convey passengers and goods well into the 1950s when diminishing returns caused by the declining rural population and competition from road traffic lead to closures. Further closures took place in the 1970s, the late 1980s and early 1990s.

Water supply and management

Pastoralists

Squatters in the area watered their stock at rivers, creeks and Aboriginal soaks. With cycles of dry seasons and increasing stock numbers, river and creek systems were modified to meet the growing number of stock. Dams, or tanks, were excavated and levees built across rivers to create weirs. Frederic Godfrey at Boort station in 1850 made a cutting from the Loddon River to the Kinypanial Creek allowing water into a former swamp creating Lake Boort. He also constructed a weir at the inlet to Lake Boort on the Kinypanial Creek, remains of which are still in evidence.

Goldminers

Creeks were dammed or diverted by channels and races to provide the water for puddling and washing gold. Race-holders often made a better living selling water than the diggers did seeking gold. The availability of water not only affected activity on the goldfields but also their hinterlands. By 1865 goldmining activity, especially in the Bendigo area, had silted up the Loddon and Campaspe Rivers and many creeks, rendering them unfit for drinking. Sludge in the Ovens River filled up creeks and alluvial flats downstream and accounted for surface elevation through the Tarrawingee and Wangaratta districts down to the River Murray.

Goldmining raised the issue of managing public resources for the 'perpetual benefit of the people' rather than for the benefit of a minority. Editorials in local and city newspapers raised questions about the ownership of water and condemned the continued pollution of water sources by mining activity. By 1860, the need to improve control of access to and use of water throughout the Colony was judged a priority. Reserves protecting water frontages of watercourses were introduced under the *Land Act 1860*.

Wells and Dams and Other Schemes

Wells were sunk in towns and on farms as the first

attempts at supplying water to growing populations. Waterworks were constructed in towns. Standpipes, which provided water from local water supplies, were a feature of early settlements. Creeks and rivers were accessed where possible. Swamps were drained and dams were built by farmers. Community tanks, often waterholes once used by squatters, were fenced and new ones sunk eight to nine miles apart by local government throughout the study area for both stock and domestic use. Government dams can still be seen on the Murray Valley Highway at Tongala. Selection from 1860 and the settlement of the Mallee provided stock and domestic water supplies via open channels. Water trains delivered water to the Mallee until the channel system of supply was finished in the 1920s.

Irrigation Trusts

A series of dry years in the late 1870s led to the formation of the Water Conservancy Board in 1880. In 1881, all unalienated land within one-and-a-half chains of watercourses was reserved. Water trusts were constituted under the *Water Conservation Act 1883* and given authority to carry out water supply projects. The *Irrigation Act 1886* vested in the Crown the right to the use of water in any stream, lake or swamp, and provided that no riparian rights could be established in the future which might prevent the use of water for irrigation.

Water supply and irrigation schemes instigated by Trusts at this time often relied on weirs built on rivers or creeks. Water was diverted from these storages down natural watercourses or constructed channels. An example of such a scheme was that undertaken by the Loddon United Water Trust in 1882. The Trust constructed a weir at Bridgewater to divert the Loddon River through sluice gates to a main channel running across country linking with Bullock Creek to the east with subsidiary channels to Myers and Piccaninny Creeks, to Serpentine township and to Bears Lagoon and Calivil. To supply the west side of the Loddon River, a timber weir was built below the off-take of Kinypanial Creek in 1885 to direct water via channels to Lake Leaghur and Lake Boort. Remains of this weir can be seen today.

Private irrigation schemes were set up in 1886 by the Californian Chaffey brothers in Mildura and at Renmark in 1887. Due to financial difficulties, the Chaffey Brothers Irrigation Company was disabled in September 1892. In December 1895 the Mildura Irrigation Trust Act was passed by the Victorian Government establishing the First Mildura Irrigation Trust, that exists today. The Chaffey's house, Rio Vista was built in Mildura in 1889 and is open to the public as a museum.

In 1887 the first national irrigation storage project was started—the Goulburn Weir. Work began on a second Goulburn River water storage, the Waranga Basin, formerly Gunns Swamp, in 1902. With farmers reluctant to take up irrigation and problems with irrigation infrastructure, most trusts were in financial difficulty by the turn of the century—a situation which paved the way for state ownership and management of water.

Centralised Control

The *Water Act 1905* made three significant policy changes in the management of water. First, irrigation

and rural water supply became the responsibility of a central 'expert' Commission. Second, the beds and banks of most watercourses were 'nationalised'. Third, properties were given a fixed water right attached to a compulsory minimum payment (Powell 1989). Land for irrigation districts was purchased by the SRWSC at White Cliffs (Merbein), Swan Hill, Cohuna and Nyah along the River Murray, at Rochester, Bamawm and Nanneella along the Campaspe, and at Shepparton, Koyuga and Tongala in the Goulburn Valley (Dingle 1984). Tresco was re-developed as an irrigation area in 1913. These areas were supplied mainly from the Murray and Goulburn Rivers or their tributaries. Irrigation infrastructure established in the study area in this era included the Waranga Western Main Channel (1909) and a siphon under the Campaspe River north of Rochester. Wood powered the steam and gas pumps used for irrigation in the Sunraysia region until the late 1950s. During the irrigation season, the pumps consumed 32 to 35 tons of wood per 24 hour day, and stockpiles of several thousand tons were frequently maintained (Powell 1993).

Under the terms of the River Murray Waters Agreement of 1915, all run-off into the Murray system above Albury was to be shared between New South Wales and Victoria, with provision made for agreed minimum quantities to pass down to South Australia. The River Murray Commission was appointed in 1917 to implement the River Murray Waters Agreement and coordinate the construction of locks on the Murray to ensure sufficient depth of water for river transport. Other works undertaken included the building of the Torrumbarry Weir in 1924, the Hume Weir begun in 1919 and the Yarrawonga Weir completed in 1939. Water from these storages greatly increased irrigation in the Murray Valley.

In 1945, the SRWSC embarked on a post-war construction expansion. By the 1960s irrigation waters were supplied to the study area from Waranga and Eildon (Goulburn River), and Torrumbarry (the River Murray) storages, as well as from the Campaspe and Loddon Rivers. Approval was given in 1960 for the Lake Cooper-Greens Lake project to store 20,000 acre feet of unwanted flood and drainage water (Webb & Quinlan 1985).

In 1984, the Rural Water Commission was established to operate and maintain most of the State's water supply system, including storages and watercourses. In 1992, with the establishment of the Rural Water Corporation, regions were consolidated and greater local management powers given to Regional Management Boards. Rural water authorities were created in 1994. Current water management is described in more detail in chapter 15.

While irrigation has massively changed the economy and society of the study area, it has also had a significant environmental impact. Land was subdivided and fenced into smaller holdings. Channels were built on the highest ground, often on sand dunes that marked the banks of former rivers. The building of channels and levee banks in addition to roads and railways has interfered with natural flooding and drainage processes and altered winter flood hazards. By 1911, salt-affected

land caused by rising water tables induced by irrigation was in evidence near Cohuna. By the early 1930s salt was threatening more than 300,000 ha of irrigation country around Kerang (Powell 1993). Drainage channels were constructed for a more regular watering regime to leach out the salt. Surface drains often followed the routes of the beds of prior streams. In 1990, more than sixty percent of the Campaspe West irrigation area had water tables within two metres of the soil surface. In 1988, the Salt Action: Joint Action program was put into place to evaluate and ameliorate secondary salinity in Victoria (ECC 1997). Major surface drains continue to take irrigation water into local swamps and the River Murray. The effects of water regulations on the biodiversity of the study area are detailed in chapter 5 and 15.

Industries

River Trade

As described above, river trade centring on the port of Echuca made a significant contribution to the local economy from 1858 until 1888 when a decline occurred in favour of railway transportation routes. Imports peaked in the years 1875 (£2,206,620), 1880 (£2,502,750) and 1881 (£2,278,248). Exports were significantly high in 1878 (£352,990) and 1885 (£349,212) (Priestley 1984).

Agriculture

The trend post World War II has been to extend farm sizes, increase mechanization and reduce farm employment in response to the global trade in horticulture and agriculture .

Grazing and Cropping

The first industries in the study area were those developed by the squatters. Those able to access the gold-mining markets were involved chiefly with cattle raising. Other pastoralists were involved in raising sheep for wool. Selectors taking up land in the study area from the 1860s, and later soldier settlers, grazed sheep and cattle as a supplement to their cropping activities. Grazing licences, issued from 1869 under the Land Act of that year, allowed the holder to depasture livestock upon any park lands, reserves or other Crown lands. Many of these licences were issued for the forests of the study area. The growing of wheat was the mainstay of agricultural activity on the Riverine Plain of the study area before the introduction of irrigated horticulture from 1910. Some areas located principally in the western section of the study area, are still employed for cropping activities, however grazing and dairy industries dominate agriculture (see chapter 13).

Dairying

The centrifugal cream separator, invented in the 1870s, established a factory-based dairy industry. From the mid 1880s, settlers took their milk and cream to a centrally located butter factory or creamery. With the advent of irrigation from 1910, dairying took place on 50-100 acre farms with a carrying capacity of 12-15 cows milked by hand. Superphosphate, introduced in the 1930s, increased the carrying capacity of the land and hence milk production. Technological advancement of the industry, including the milking machine, refrigerated holding vats and transport, the herringbone shed and

bulk milk collection, further increased production. More recently, dairy deregulation has led to rationalised and larger farming units. Dairying remains an important industry within the study area, particularly around the Kerang, Echuca and Shepparton districts see chapter 13.

Horticulture

Viticulture enterprises centred on the areas of Mildura, divided into irrigation blocks by the Chaffey brothers in 1886, and Mulwala from the 1890s. Irrigation today continues to support vineyards, as well as the cultivation of fruit, olives, nut groves and vegetables in Victoria. Major production areas are the Goulburn Valley, Robinvale–Mildura, Swan Hill and Cobram areas. Tobacco and hops are grown in the King, Kiewa and Ovens valleys. Each region has its own characteristics and produces a range of different products (see chapter 13).

Forestry

Timber Production

The river red gum forests of the study area have been utilised for timber production over the years of European settlement, and before that time, were extensively used by Indigenous people. The first white settlers harvested timber for fence posts, housing and fuel. The cypress pine of the Riverine Plain and the Mallee, for instance, was sought for constructing outbuildings and fence posts. Similarly, swamp woodlands in the study area were felled for construction materials and fuel. The exploitation of red gum forests was most evident during the paddle-steamer and gold eras, especially with the operation of quartz reef mining during the 1860s and 1870s. Estimates suggest that on average, a steamer burnt half a tonne of fuel an hour in its boilers (LCC 1987). The massive demand for timber for boat building, underground timbering and fuel for boilers had taken a significant toll on forests by the early 1870s.

Early sawmills were established at sites where timber grew. Commercial sawmills were established along creeks, rivers and on swamps. With the opening of the railway from Melbourne to Echuca in 1864, several mills set up in the area to provide red gum to the export markets of the British colonies which were heavily engaged in railway and wharf building (Priestley 1984). In some parts of the study area timber tramways transported logs to mills. The remains of a timber tramway are in evidence east of Echuca.

Foresters experimented in planting non-endemic species especially from the 1930s. Softwood plantations were established near Myrtleford between about 1930 and 1980. Commercial forestry is conducted today in both hardwood and softwood plantations on private and public land using modern machinery, in contrast to the hard physical labour of hand felling. Forestry on public land in the study area is discussed in more detail in chapter 14.

Charcoal Burning

Charcoal burning occurred during the gold rush to meet demand for blacksmiths. By the early 1900s, goldmining companies were attempting to reduce firewood consumption by introducing steam boilers and gas-producer plants to power crushing batteries. These plants were fuelled by charcoal. The industry received

Figure 7.5 Alf (left) and Frank Corry, near Moira Lakes, early 1900s River Murray.



Source: Reproduced with permission National Library of Australia Image: an24548312-v.

another boost during World War II when charcoal became a vital alternative to liquid fuel used in the military, such as kerosene. Today charcoal burning is still conducted in red gum forests, but is a small industry largely used for specialised purposes.

Forest Management

The *Land Act 1865* enabled reserves to be declared for 'the protection and growth of timber.' Timber reserves were put aside, and from 1866 state forests were established. Timber reserves were to be used by settlers until the supply was exhausted, while state forests could only be used by approved licensed timber millers and fellers. Under this legislation, the Moira, Barmah and Yielima state forests were proclaimed in 1870. Further reserves were created at Gunbower, Nyah and Walpolla.

An export duty was placed on red gum in 1877 causing some mills to close, however red gum forests on the Murray continued to be heavily exploited for saw logs. Such was the ongoing denuding of the forests that a series of bills to actively conserve forests, repair damage and encourage growth were presented to Parliament in 1879, 1881, 1887 and 1892 (DSE 2003h). None of these bills were enacted by successive governments because of their commitment to land settlement and pressure from interested parties (Dingle 1984).

The 1901 Royal Commission on State Forests and Timber Reserves noted that the Barmah Forest had been cut over several times, and that at the current rate of cutting would yield no more than five years supply (Fahey 1987). In 1908 the first effective forests legislation in Victoria, the *Forests Act 1907*, came into operation. A Department of Forests was formed to more effectively manage forest resources. The Forests Commission was established in 1919. Initiatives such as fire protection, thinning and coppicing and reforestation of forests were put into place in the 1920s and 1930s (Fahey 1987).

Fisheries

The collapse of the Murray cod fishery is one of the earliest, least known and most dramatic examples of poor natural resource management in Australia's history. In 1855 Joseph Waldo Rice established the Murray River Fishing Company at Moira Lake and along the River Murray to Picnic Point—probably the first inland commercial fishing enterprise. By 1869 the company was netting the lakes and over two hundred miles of the river. The majority of the fish were Murray cod but also included golden perch, silver perch and goldfish (not carp). Murray cod typically weighed over a hundred pounds. In the late 1860s the catch varied seasonally between 1 to 6 tons per week equating to an annual figure of approximately 160 tonnes of fish. At the time the company was criticised for taking large quantities of fish during the spawning season and there was conflict between commercial, recreational and Indigenous fishing.

By the 1890s, the catch had declined substantially with an annual catch of about 35 tonnes, primarily of golden perch. In 1896 the Victorian Government introduced a closed season, aimed at protecting Murray cod (Leslie 1995; King 2005). Current limits such as closed seasons, size and number apply to fishing for Murray cod in NSW, South Australia and Victoria. There are now no commercial fisheries based on the River Murray, however recreational fishing attracts many visitors to the region (Figure 7.6, chapter 11).

Other Industries

Other industries in or near the study area included salt harvesting and gypsum extraction across the Mallee, and the quarrying of granite at Mount Hope. Chapter 16 describes these industries in more detail.

Recreation

Leisure activities enjoyed by European settlers have centred on the natural features of the study area. The River Murray and its tributaries have been the focus of

social interaction since the first days of settlement. Sand bars attracted swimmers who bestowed them with familiar names such as 'St. Kilda'. Favourite swimming holes in later years sported other facilities. Horseshoe Bend near Swan Hill, for example, was a popular swimming place made more so by the addition of a floating platform in the 1920s. Picnics were traditionally held on Boxing Day and New Year's Day. Some of the earliest picnics were those organised by the Officer family of Murray Downs station near Swan Hill in the 1870s. A punt was provided to ferry children to the other side of the river where they were transported to a nearby lake to play games. Sunday School picnics were held regularly at Pental Island. The information centre at Torrumbarry Weir gives a sense of riverside recreation from the 1920s onwards.

Fishing, camping and water skiing have proved popular recreational pursuits. Yacht clubs have been formed at Lake Boga and Lake Mulwala. The forests of the study area have continued to provide popular picnic spots (Figure 7.7), as have the weirs built for water storage. Current recreation and tourism on public land in the study area are described in more detail in chapter 11.

Figure 7.6 Murray cod fishing on the River Murray.



Source: Reproduced with permission Museum Victoria collection.

Figure 7.7 Picnicking on the River Murray in the 1930s.



Source: Reproduced with permission Museum Victoria collection.

8 Current Socio-Economic Setting

This chapter reviews the socio-economic characteristics of the River Red Gum Forests study area. Population distribution and change over the past two decades provides a context for understanding the range of community characteristics across this diverse region.

Although people generally live outside the boundaries of public land, the proximity and nature of communities near public land affect how it is used and managed. Towns near public land are often a major source of visitors, volunteers and resource users. In turn, public land provides economic and ecosystem services to the surrounding community. As communities change, the nature of these community-public land relationships also changes. Public land planners and managers therefore need to understand local communities and the socio-economic factors affecting them. This chapter reviews the socio-economic characteristics of the population within the study area and its immediate surrounds.

Key sources of data in this chapter are Australian Bureau of Statistics (ABS) census data and the Victorian Government publication *Regional Matters. An Atlas of Regional Victoria 2005* produced by the Department of Sustainability and Environment (DSE 2005g). In this Atlas, as in this chapter, regional Victoria is defined as "all parts of Victoria outside the Melbourne metropolitan area".

Where possible, socio-economic analysis has been undertaken at the smallest geographical level available in

order to compile and match data to the study area boundaries. For census data, the smallest available unit is the Census Collection District (CCD), generally comprising 200–400 households. CCDs vary in size with population density, so the degree to which census boundaries can be matched with the study area boundary varies, particularly for sparsely populated areas. Because time-series data are not available at CCD level larger geographical units such as Statistical Local Area or Local Government Area are used instead.

HUMAN SETTLEMENT PATTERNS

The study area follows natural boundaries rather than human settlement boundaries. As a result, it is difficult to estimate the total population for the study area. Use of public land and its various assets is likely to vary across different sectors of the community and community groups. Recreation and firewood collection activities are a case in point. The population catchment area for public land will be determined by factors such as catchment size, visitation levels, population density and proximity to major regional centres.

Patterns of population density may be a more useful measure than total population, in relation to public land use (Figure 8.1). There are clear variations between the more densely settled areas to the east and in the Goulburn Valley, and the more sparsely settled country to the northwest. Hotter and drier conditions to the northwest have limited population density and, while irrigation supports higher numbers, these are largely confined to relatively narrow corridors along the River Murray.

Figure 8.1 Population density 2001, ABS Census Collection Districts in and near the study area.

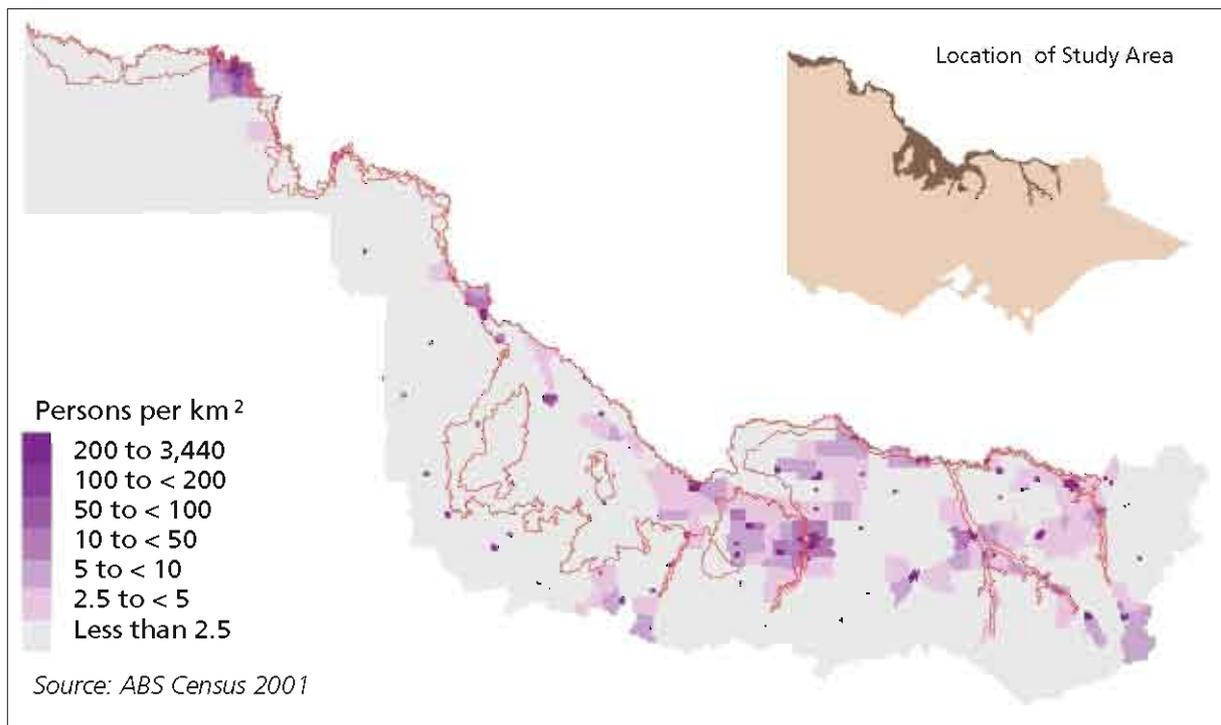


Figure 8.2 Urban settlement patterns in the study area, 2001.



Urban settlement patterns also reflect the difference between eastern and western parts of the study area. The largest city is Shepparton which had a population of 28,951 at the time of the 2001 Census. Of similar size are the regional cities of Wodonga in the east with a population of 28,160 and Mildura in the west with a population of 26,626 (Figure 8.2).

Shepparton, Wodonga and Mildura have very different geographic and hinterland characteristics. In both economic and social terms the 'hinterland' (or more sparsely inhabited area surrounding a major town, city or river) often provides a significant source of much economic activity and wealth generation for the city, as well as being a general sphere of influence for the city's services and employment opportunities. Mildura, located in the Mallee, has a concentrated population within the area of irrigation infrastructure. Beyond this, the Mallee landscape comprises large scale dryland farming and national parks. The population density is therefore very low beyond the immediate area of Mildura. In many ways, Mildura and its irrigated surroundings form an 'island' within a relatively remote and inhospitable region. In contrast, Wodonga and Shepparton have more densely settled hinterlands which are more suited to small scale farming and hobby farms. Consequently population densities within their hinterlands are higher than in western parts of the study area and the range of economic activities more varied.

Apart from these three regional centres, there are approximately 35 settlements which have populations of more than 100 people. Their economic and demographic characteristics are largely determined by whether they are located within irrigation or dryland farming areas. These primary economic bases influence the types of secondary and tertiary industries found in the region. The production of perishable horticultural goods often leads to secondary industries such as fruit and vegetable processing. Dryland products such as wheat and wool were historically exported in bulk with

little, if any, processing. Small towns servicing dryland agriculture may be more vulnerable to change with their economies heavily dependent on one industry.

The issue of change and its effects on small towns raises the question of town size and population thresholds to maintain services. While it seems logical that larger towns provide more services, other intervening factors can also affect services. For example, increases in personal mobility and car ownership as well as improvements in car design, safety and road quality, allow people to travel further and more often in regional areas. At the same time there have been structural and economic changes—goods and services are delivered in larger more centralized ways. There is less need for small rural towns to have general stores when nearby regional cities have large supermarkets. Public services are also delivered in line with principles of economic efficiency and smaller government leading to amalgamation of Local Government Areas in the 1990s and concentration of government services into larger centres. The combined effect of all these changes has been to alter any 'threshold' of population size for particular services.

Surprisingly, however, the forces of concentration are not the only influences at work in regional areas of Australia. Around the larger regional centres, hinterlands have seen a growth in population both in rural areas and in small towns. The important factor here is the ability of individuals to access services within a reasonable distance and time rather than whether a service is located within the small town itself. Furthermore, those areas which have more densely settled hinterlands are more likely to see this kind of small town growth than areas which have very low population density in their hinterlands. For this reason, understanding the demographic differences between Mildura's or Wodonga's hinterland is important for understanding the social and economic dynamic of each region.

POPULATION CHARACTERISTICS AND TRENDS

Indigenous Population

Indigenous populations within the study area tend to be concentrated in specific towns and cities—a settlement pattern which reflects the historical loss of Aboriginal lands and the settlement policies through the 19th and 20th centuries by various state and federal governments (see chapters 6 and 7).

The proportion of Indigenous people in cities such as Shepparton, Swan Hill and Mildura, and in smaller centres like Robinvale and Barmah, is very high compared to most other regions in Victoria (Figure 8.3). According to the 2001 Census, Shepparton had the highest number of Indigenous residents of any town in regional Victoria (1460) while Robinvale had the highest proportion (9 percent). Indigenous people comprise approximately 1 percent of the total population in regional Victoria compared to 0.4 percent of Melbourne's population (for further details see chapter 6).

It is difficult to determine accurately population changes among Indigenous people in Victoria over recent decades because census counts rely on self-reporting of Indigenous status and this varies between individuals. Community attitudes towards Indigenous people have changed over the past half century and this has led to a greater degree of self-reporting. Nevertheless, even with higher levels of self-reporting, there can still be problems of 'undercounting' of the Indigenous population. Census collection can be difficult in areas where population levels fluctuate or where housing shortages create homelessness. In Robinvale both these factors have been identified as contributing to undercounts of Indigenous

and immigrant populations in the town (Success Works 2004).

While exact numbers of Indigenous people may be difficult to ascertain, Victoria's Indigenous population overall has very different demographic characteristics compared to the total Victorian population. A combination of higher than average fertility and mortality rates among the Indigenous population has created a much younger age structure than for Victoria overall (Figure 8.4). Life expectancy rates vary enormously with Indigenous Victorians expected to live around 18 years less than their non-Indigenous counterparts (DSE 2005g).

The Overseas-born Population

Migrants from the United Kingdom and New Zealand account for a large number of people born overseas in country towns. However, there are a number of ethnic groups including Italian, Turkish, German and Dutch communities, living in the study area. Shepparton, Mildura and Robinvale show the greatest diversity of non-English speaking migrant groups. Overall, however the ethnic diversity of regional areas is much lower than for major metropolitan areas such as Sydney and Melbourne.

Irrigation areas along the River Murray and around Shepparton show higher proportions of overseas-born people than in the dryland farming areas of regional Victoria (Figure 8.5). The labour-intensive nature of some irrigation farming has continued to attract workers from a variety of countries. The larger cities of Mildura, Shepparton and Wodonga have more diverse economic bases and this too has contributed to the general attraction of people from a range of backgrounds.

Figure 8.3 Indigenous people as a proportion of total population for Census Collection Districts in and near the study area.

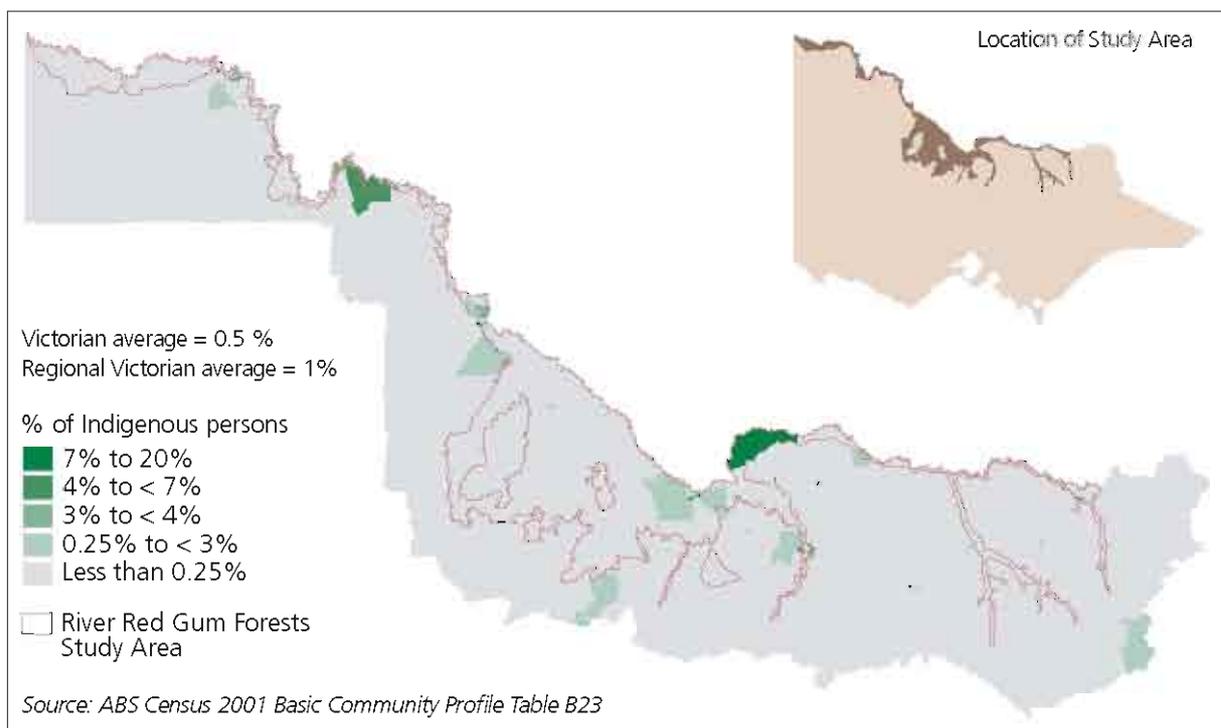


Figure 8.4 Age structure of Victoria's Indigenous and non-Indigenous population 2001.

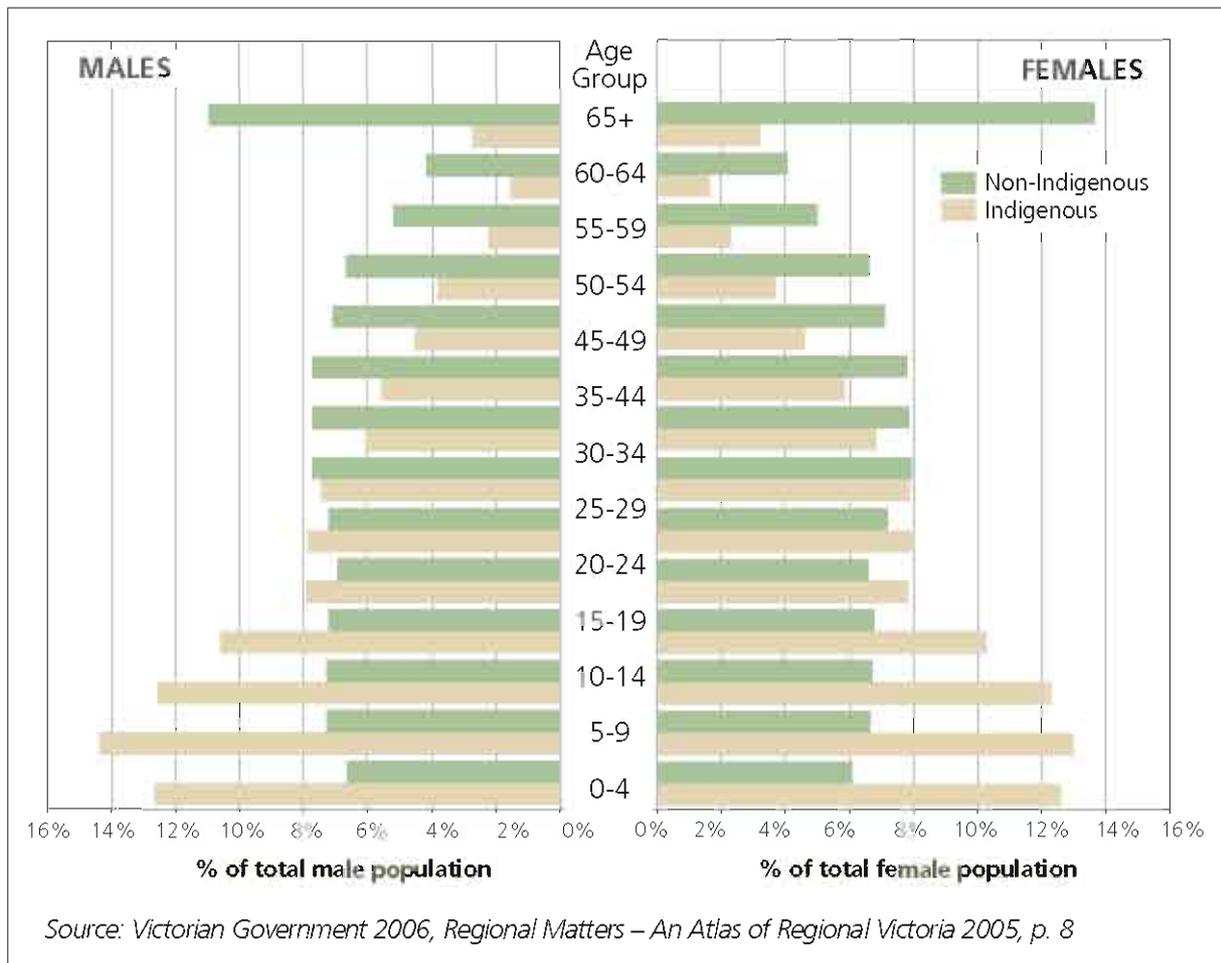
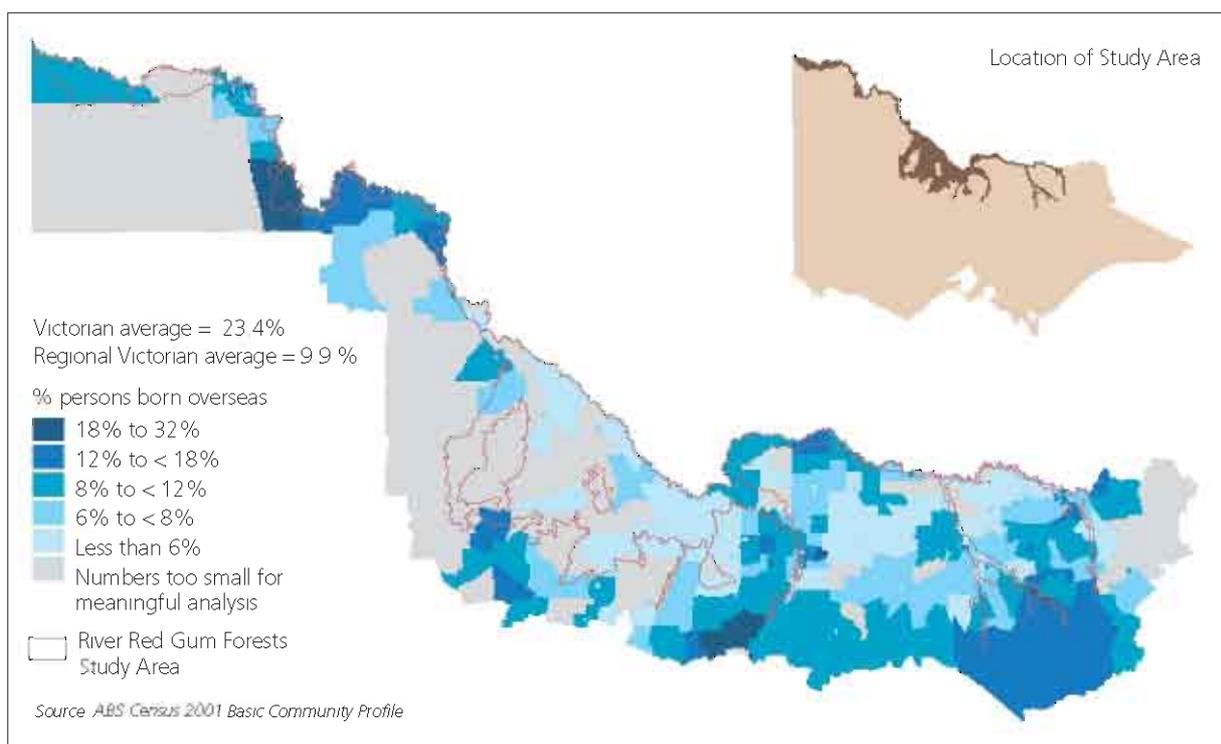


Figure 8.5 Overseas-born people as a proportion of total population for Census Collection Districts in the study area.



Population Growth and Decline

Populations have risen and fallen across regional Victoria, often quite rapidly. Areas which have experienced population growth over the past decade include:

- Areas within 100–200 kilometres of Melbourne, especially along the coast;
- Areas attracting retirees and tourists, especially those with water features such as Echuca and Yarrawonga and those with unique landscape values such as the alpine areas;
- Larger regional cities such as Shepparton, Mildura and Wodonga; and
- Irrigation areas associated with diverse primary and secondary industry economic bases.

Areas which have experienced population decline include:

- Dryland farming regions in the western third of the State;
- Declining irrigation districts such as around Kerang; and
- Remote regions in the northeast, southeast and southwest of the State.

The range of geographic and economic characteristics results in areas of rapid population growth as well as areas of ongoing population decline (Figure 8.6). The largest cities, Shepparton, Mildura and Wodonga, have grown strongly in recent years (Figure 8.7). Between 1996 and 2001 Shepparton grew by an annual average of 2.7 percent, Mildura by 2.0 percent and Wodonga by

1.4 percent. The average annual population growth rate for regional Victoria was 0.7 percent during the same period.

Cities along the River Murray have used their riverside location and sunny winter climates to attract tourists and retirees, thus maintaining economic diversity and population growth. Intensive agriculture has provided a base for secondary processing industries and enabled the development of specialist irrigation engineering enterprises and producer services, for example around the Shepparton region. The development of these specialist industries adds to economic diversity and provides a greater range of employment opportunities and services within the local economy. Wodonga, Echuca, Shepparton and Mildura are important key transport nodes in the national road freight network and this has boosted transport and logistics employment. Echuca and Wodonga are also key nodes in the national rail freight network.

More working age people are found in irrigation areas than other areas, because of the higher labour intensity of irrigation agriculture compared to other forms of farming, as well as employment in related manufacturing and service industries. In contrast to this, the dryland farming areas have developed capital-intensive agriculture requiring relatively few labour inputs. Advances in private transportation, technology and infrastructure (such as freeways) have increased peoples' mobility and allowed more remote working arrangements and longer distance commuting. The outcome is a landscape with fewer townships and service centres than in the past.

Figure 8.6 Average annual population change from 1981–2001 for Statistical Local Areas in the study area.

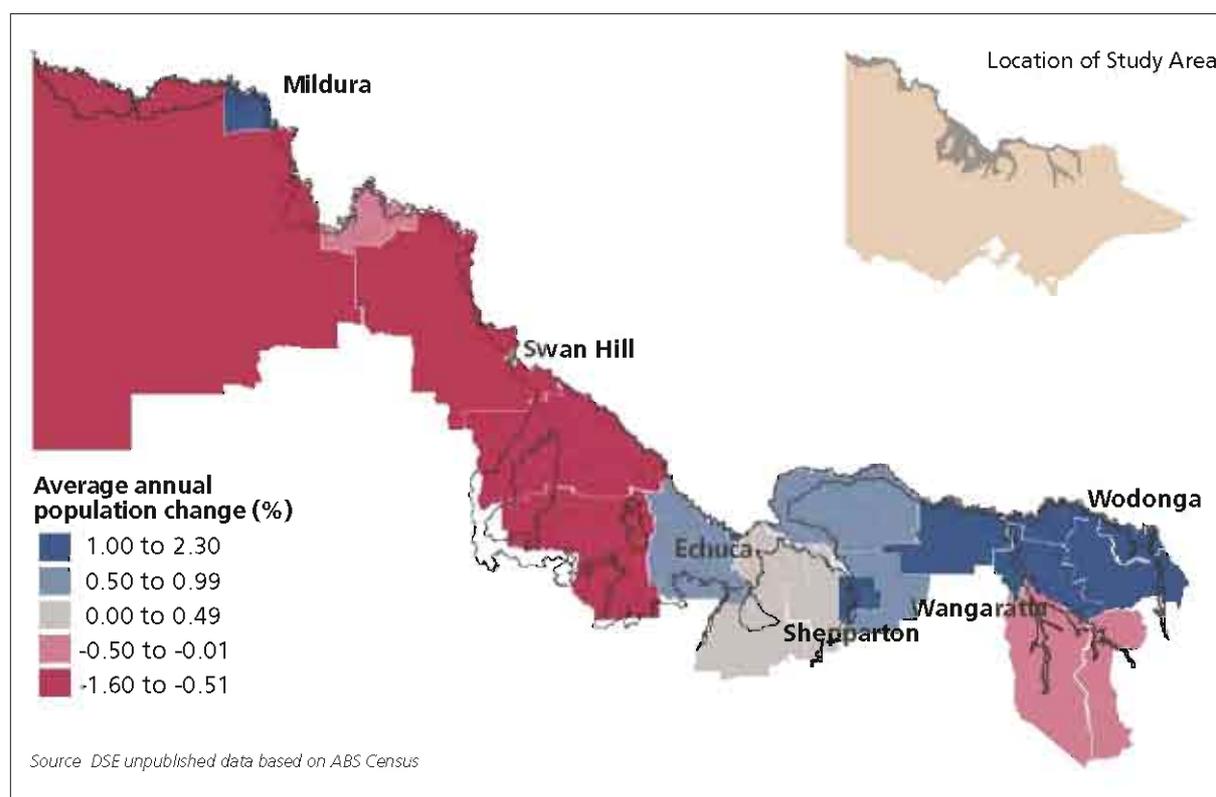
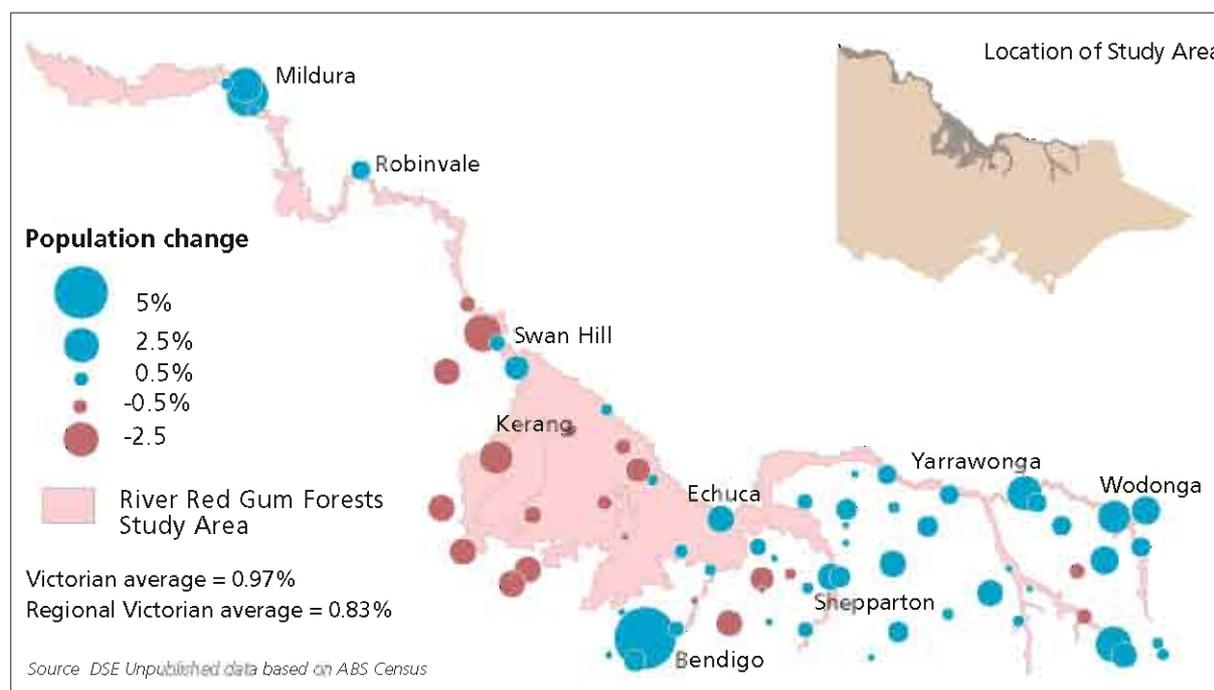


Figure 8.7 Average annual population change from 1981–2001 for towns and cities in the study area.



The rural, non-irrigated parts of Mildura, Swan Hill, Gannawarra and Loddon, share similar characteristics:

- net migration loss across most age groups but especially young adults;
- ageing in place of existing residents leading to a much older than average age profile;
- low numbers of women of child bearing age (15–44 years) and very low number of births;
- an increasing number of deaths due to the older age structure of the population); and
- limited, if any, immigration to the area.

Population projections for areas like Gannawarra predict losses in numbers of people across all but the very oldest age groups over the next 25 years (Figure 8.8).

Another feature of these dryland areas is a noticeable gender imbalance among young adult age groups (20–29 years of age) with fewer women than men. A greater degree of out-migration by women than men is the contributing factor. It highlights a significant demographic issue in that these age groups are those most associated with partnering and child-bearing. Out-migration of these women is potentially removing future children from the community. For men who remain, the issue of remaining single is a significant social issue and has been implicated in problems of isolation, loneliness and depression in some rural areas.

Implications of Population Growth

Population growth is often seen as a positive trend in regional communities, but it can place demands upon infrastructure and local service capacities. Rapid growth can cause pressure on housing, resulting in shortages and increased cost. Demand for new housing affects farmland and public land. In almost all cases housing attracts a higher price per unit of land than other land uses, meaning urban land use generally 'out-bids' other land uses.

Population growth caused through immigration may change the social and economic composition of a community. Education, income, age, occupation and industry characteristics of the population may change, causing changes in the demand for services. Volunteer emergency services (e.g. Country Fire Authority, State Emergency Service) may need to increase services as larger populations increase the risk of fires and accidents.

Population growth near public land is likely to increase visitor numbers and may increase resource demands, for example through local firewood collection or recreational fishing. Use of camping areas and other recreational facilities may also increase the workloads of Committees of Management and volunteer service providers involved in public land management. A growing population potentially increases the pool of available volunteers for Committees of Management activities, but only where the role of volunteers in public land management is publicised and encouraged.

Population growth may also alter demand for the protection of key environmental values, when newcomers have different environmental values and when existing residents wish to protect environmental values from the effects of increased use. New residents may have stronger commitments to environmental values, or may lack an understanding of rural and public land management issues such as weed and pest animal invasion, illegal firewood collection or unregulated camping.

Implications of Population Decline

Regions where population have declined over a long period are likely to experience a cycle of service loss and further population decline. Loss of young adults over time represents a loss of potential community capacity and regeneration. While remaining populations often show a high degree of social involvement and volunteering, the ageing of such populations challenges longer term continuity in community building and regeneration.

Figure 8.8 Projected change in population by age group for Local Government Areas, 2001 to 2031.

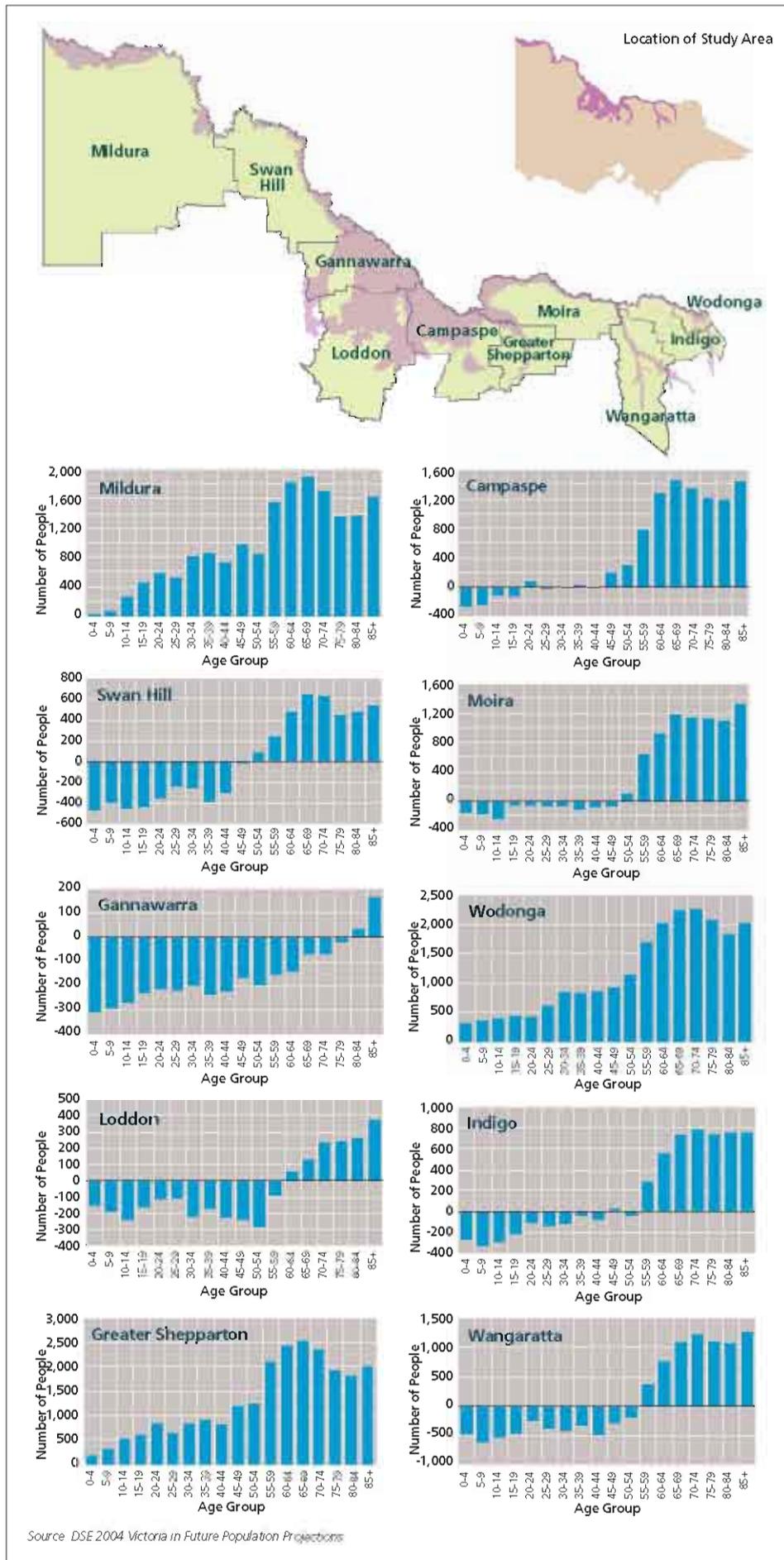
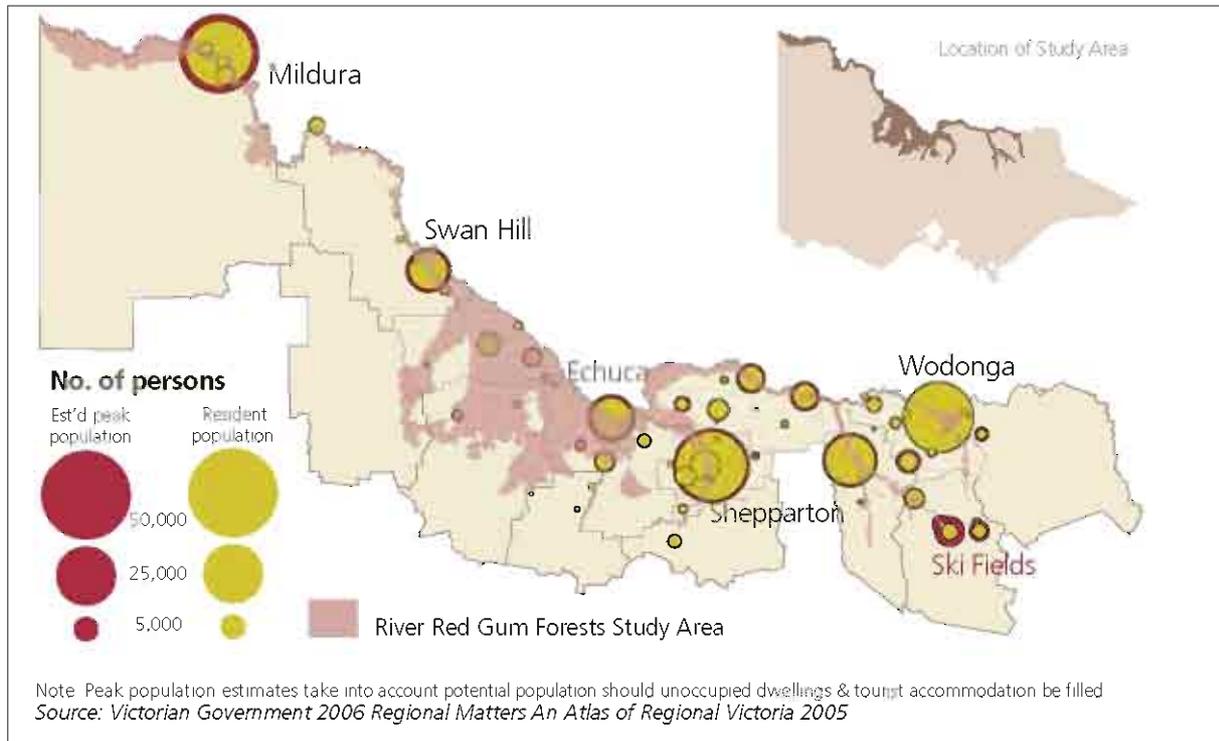


Figure 8.9 Peak population estimates for selected towns in the study area, 2001.



Community engagement may also be difficult in areas where population is widely dispersed. Populations have declined in most dryland farming regions of the study area because of more economically efficient agriculture. Changing settlement patterns are inevitable as farming moves towards more capital intensive private land management practices.

Temporary Populations

Most population counts are based on permanent resident populations. However, some regions display large variation in population depending on the time of year and the nature of housing and land use (e.g. holiday purposes, part-time or full-time residence). The size of the peak population is important for planning infrastructure and services and for assessing potential environmental impacts. Temporary populations, by definition, are unlikely to provide a strong and sustained base for community development and engagement.

Within the study area there are several places with highly variable populations. Tourists are attracted to river locations such as Echuca, Swan Hill and Mildura, as well as Shepparton, often visiting for short periods (Figure 8.9). These populations may place additional demands on infrastructure and services (e.g. water and waste) especially if there are seasonal peaks in visits.

Populations also vary with seasonal harvesting labour, particularly in horticulture. Thousands of harvest labourers are employed throughout the irrigated parts of the study area (Figure 8.10). Although some centres along the River Murray now harvest throughout the year, this does not necessarily mean that casual labour will be drawn from the permanent resident population. This casual workforce may have limited ties with a particular community or may remain marginalised from the day-to-day activities of longer term or more permanent residents in the district.

The degree to which the unemployed, homeless or those on low incomes are transient is unclear. Gathering reliable quantitative and qualitative data on mobile or marginalised populations is extremely difficult. Analysing problems such as temporary encampments on public land needs to take into account this difficulty as well as recognising that some may be living in these areas out of necessity because of housing shortages and social marginalisation. Solutions to such social problems are likely to require integrated social and economic responses, rather than simply being seen as an issue of illegal use of public land.

Age Structure

The general age structure of regional Victoria shows a distinct pattern of fewer people in the 15 to 29 year age groups (Figure 8.11). This reflects the net migration loss to metropolitan areas of this age cohort as young adults seek education and employment opportunities. Despite this net loss, regional areas generally gain in all other age groups.

Ageing of the population and retiring 'baby boomers' is contributing to a shrinking work population in most industries. Horticultural industries are somewhat protected from this broad trend because of their younger age structure. However, even in these industries the issue of skills shortages has emerged (DSE 2005g).

Using the regional Victorian pattern as comparison, population age structures across the study area reveal four distinct patterns, examples of which are presented in Figure 8.12 and described below:

Cities

Swan Hill, Wangaratta and Wodonga are regional cities which show relatively even age structures across all age groups. This reflects the ability of such locations to attract and/or retain young adults, family groups and

older age people. Mildura, while having fewer young adults still has many family and older age groups. In many cases these cities are acting as 'sponge' cities—a term which describes their tendency to draw in people from the hinterland who are seeking better access to facilities and services than can be found in rural areas or small towns.

Retirement Destinations

Echuca and Yarrawonga have age structure patterns weighted to older age groups, highlighting the degree to which they have attracted retirees. Retirees often have many active years left in their lives, however, the oldest residents of the communities may have limited capacities for involvement and place increased demands on certain services such as health and community services.

Unlike most other rural areas, irrigation districts retain young adult populations. This is due to the greater labour intensity of irrigation agriculture and associated industries compared to dryland farming. The Statistical Local Area of Robinvale is an example of this type of age profile.

Dryland Farming Areas

Populations in dryland farming areas have declined over many decades as agriculture has become more capital-intensive, personal mobility has increased and services

have withdrawn. This population loss is particularly apparent among young adults, with young women being more likely to leave the study area (e.g. Statistical Local Area of Loddon North) than young men, resulting in a gender imbalance in this age group. This imbalance greatly reduces the potential for child-bearing in the population and reduces partnering opportunities, exacerbating isolation and depression among young male farmers. These problems may contribute to higher suicide rates in such regions (Molloy & Fox 2002).

ECONOMIC CHARACTERISTICS

Industry Profile

Census data on employment and industry provides insights into the region's economic profile. It also provides information on variables such as education which are both social and economic in nature. Although agriculture dominates the rural landscape of the study area, the labour needs of agriculture have declined over the past 50 years as capital inputs and farm sizes have increased. In some areas like the Shire of Loddon, around half of the workforce is still employed in agriculture, but the absolute numbers involved are still relatively small (1,500) (Figure 8.13). Rural communities are not synonymous with farming communities, with

Figure 8.10 Estimated labour demands for harvest seasons in selected towns 2004.

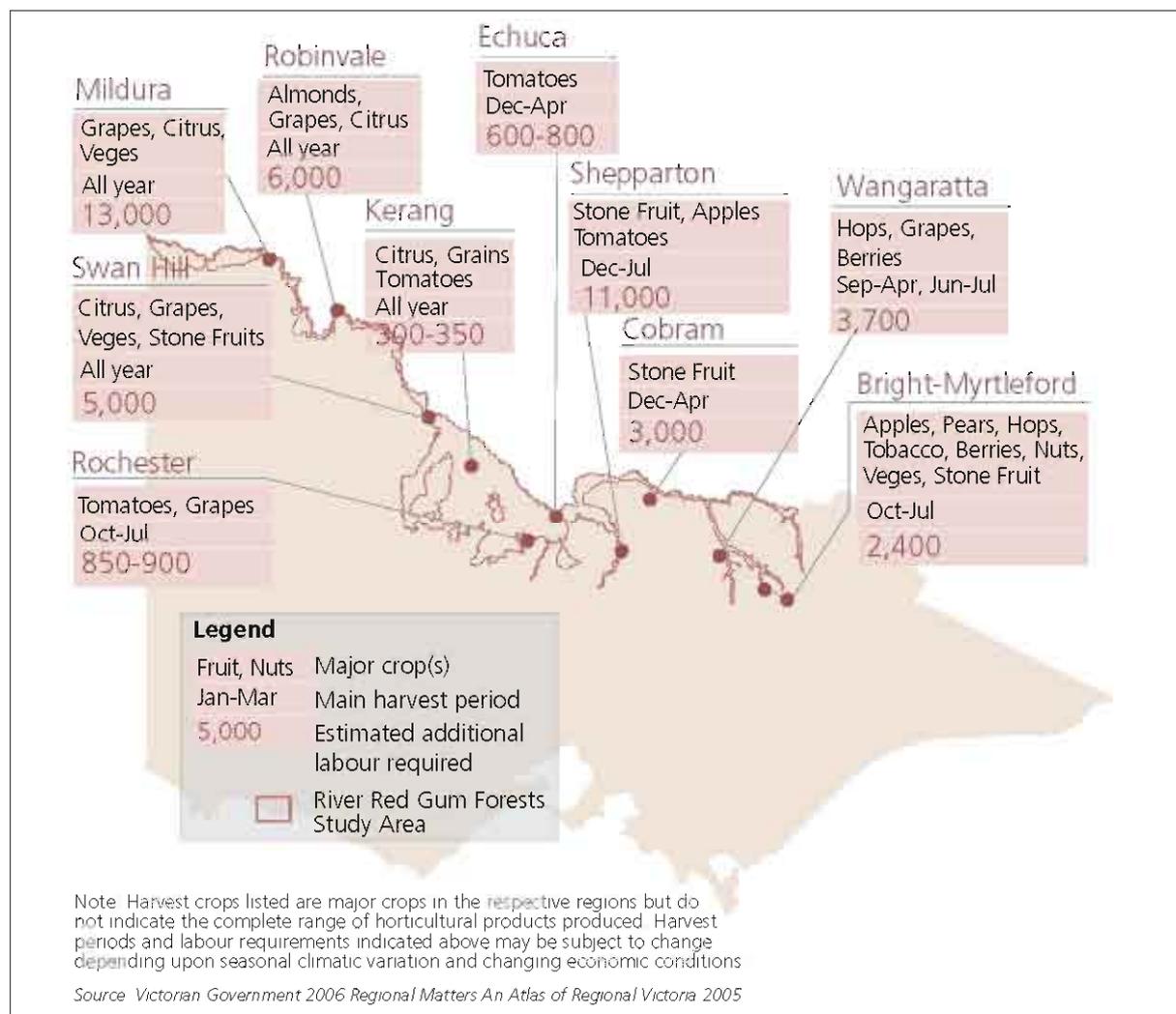
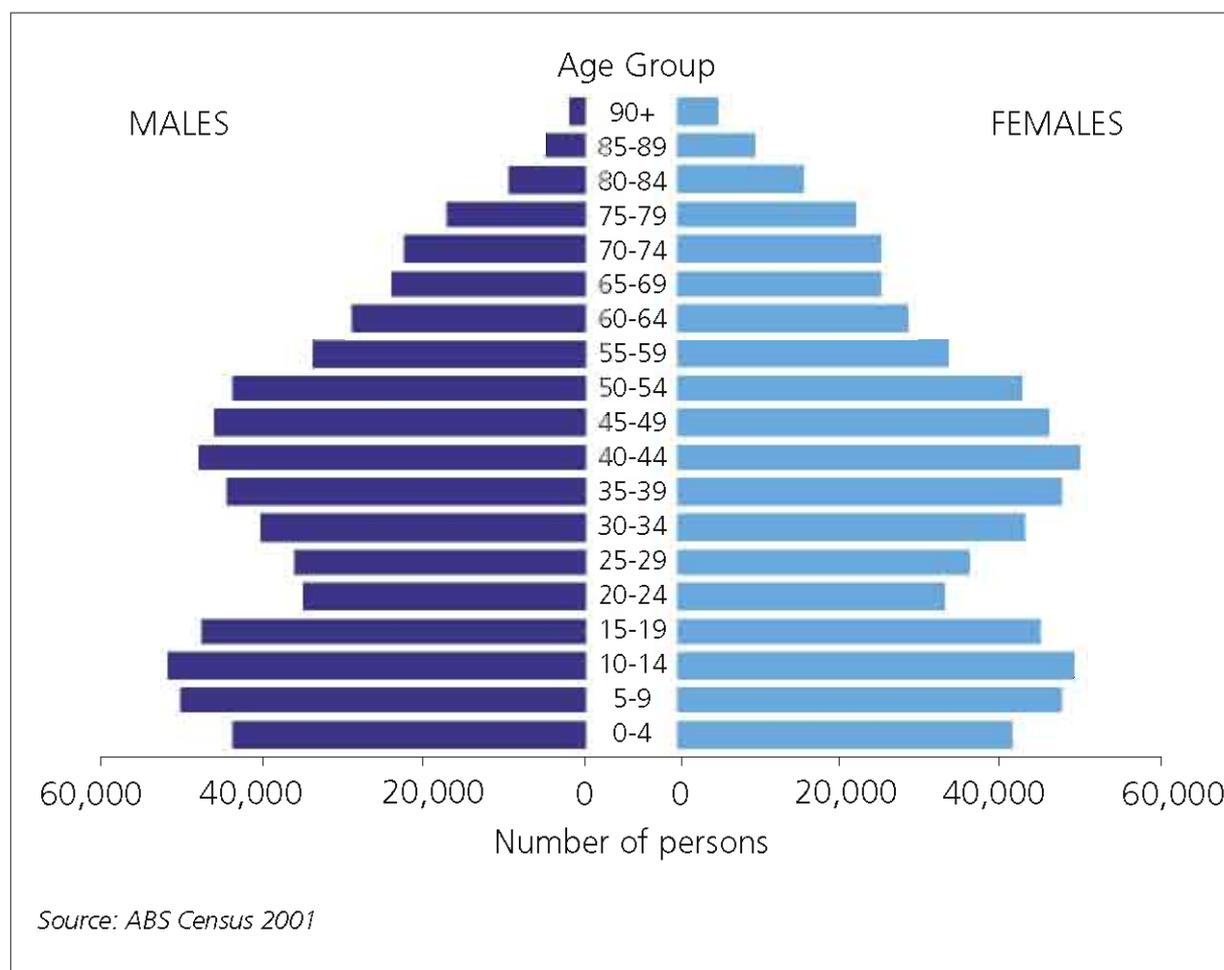


Figure 8.11 Age and sex structure for regional Victoria 2001.



more people employed in retail, manufacturing or community services. Engagement with regional communities needs to recognise this variability.

Employment in secondary industries varies in importance across the study area with Shepparton and Campaspe Shires maintaining high employment in this sector. Of greater significance, however, are consumer services, particularly retail trade, for most of the region. While much retail activity provides a service for local markets, it also contributes to the tourist trade. Estimates of tourism employment include a proportion of retail employment along with other tourism-related industries such as accommodation, cafes and restaurants. On the basis of such estimates the main region attracting tourism lies along the River Murray from Wodonga to Swan Hill as well as the cities of Shepparton and Mildura (Figure 8.14).

While the agricultural workforce has consistently declined between 1981 and 2001, the pattern of change has been more complex for secondary industries where restructuring has had different effects. In the early 1990s the Victorian manufacturing sector experienced economic downturn, industry restructuring and movement of some industries offshore. These trends left many regional centres vulnerable to change. Job losses and unemployment rates tended to be higher in the early 1990s than before or since. Manufacturing employment has since expanded in most regions (Figure 8.15).

The greatest increase in employment has been in the

services sector, particularly consumer and community services. The ageing of Victoria's population is one factor in the expansion of industries such as health services. Unlike manufacturing or agriculture, such sectors require considerable labour and therefore account for a large proportion of workforce employment.

Employment change is not necessarily an indicator of industry success. Like agriculture, some secondary industries have seen a move towards more capital intensive enterprises which may still contribute to economic growth within a community even if actual job numbers appear to have declined. Furthermore, restructuring in some industries like manufacturing has created a 'category-jumping' effect in situations where certain functions are outsourced and become categorized as service employment (e.g. consultancy or contracting services) rather than manufacturing employment.

Education

Patterns of educational attainment show a clear urban-rural difference as well as a distinct east-west difference across the study area (Figure 8.16). The urban-rural difference can be explained by the greater range of professional occupations located in larger centres. In part this also explains the east-west difference as the western parts of the study area are generally more rural in character comprising fewer and smaller settlements. Labour force characteristics also affect the east-west difference as areas with a strong

Figure 8.12 Age and sex structure characteristics for selected Statistical Local Areas.

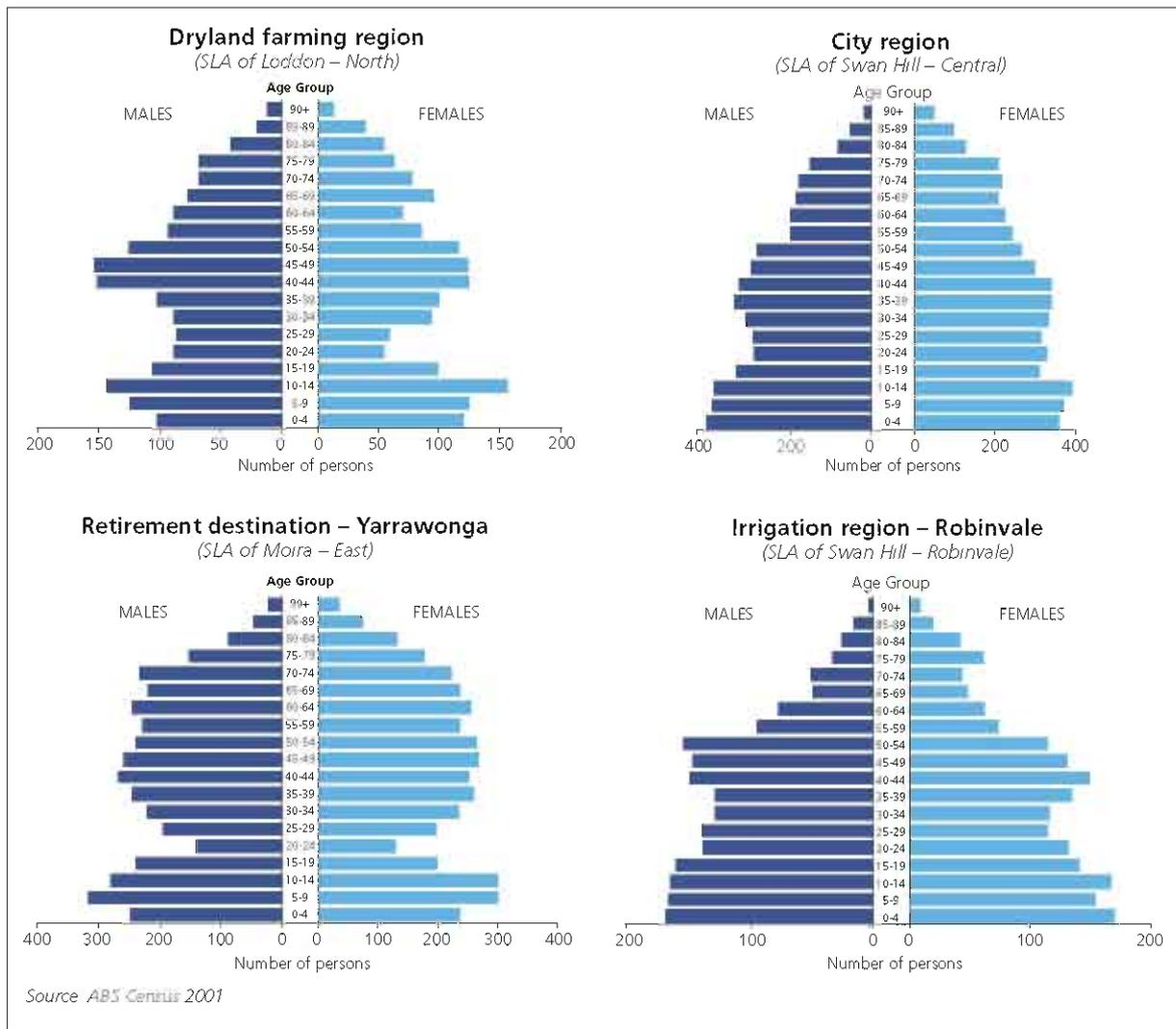


Figure 8.13 Employment by industry 2001 for Local Government Areas.

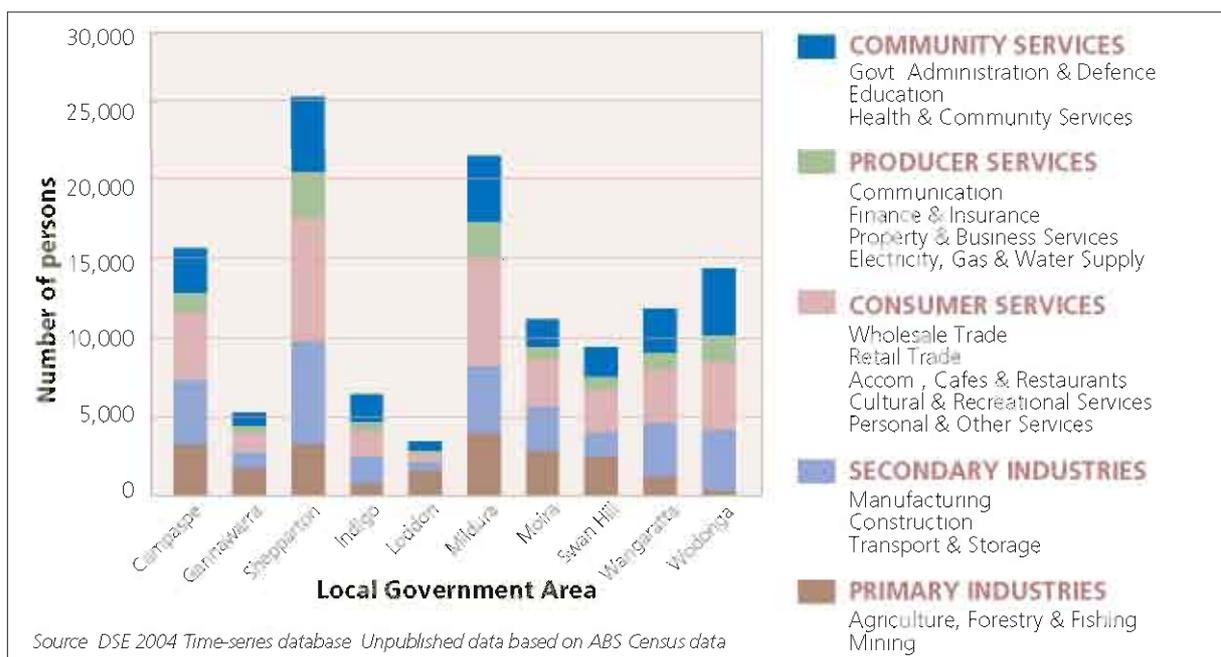


Figure 8.14 Estimates of tourism employment, 2001 for Statistical Local Areas.

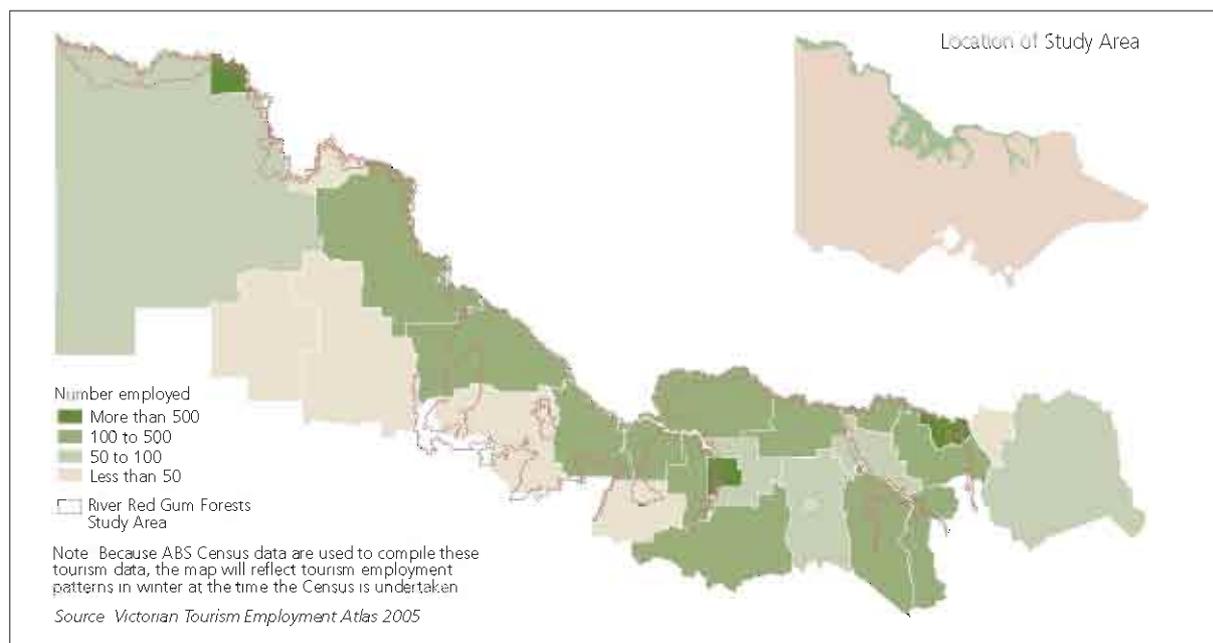
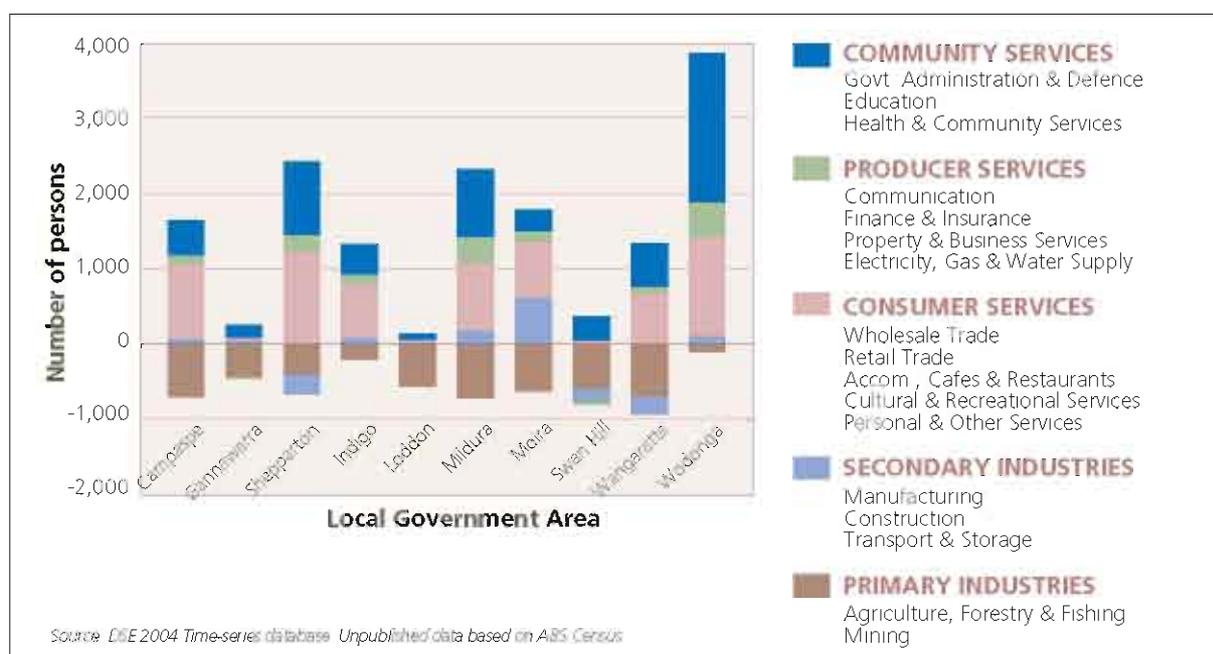


Figure 8.15 Change in employment by industry 2001 for Local Government Areas.



horticultural base are likely to have labour trained through vocational qualifications such as specialist diplomas or certificates.

In dryland farming areas, age structure is important in understanding the higher proportion of people with no post-school qualifications (Figure 8.17). Recent generations have higher levels of educational qualification—a result of increasing professionalisation of the workforce and requirements for training and qualification across most industries. Older generations have, on average, lower levels of tertiary qualifications. The age structure of farming communities in dryland regions of western Victoria is relatively old and hence a lower level of educational attainment would be expected.

The proportion of the population having no post-school qualifications is higher in regions downstream of Swan Hill. Despite having a relatively young age structure compared to other rural areas, this region has low levels of educational attainment. This may be partly explained by the fact that activities such as harvesting can be undertaken with relatively unskilled labour. There is also likely to be a greater degree of vocational or trade-related qualifications held by members of these communities rather than university qualifications.

Income

Income is an important indicator of socio-economic well-being. Low incomes indicate a lower capacity to access

goods and services and may limit life choices. However, low income characteristics can be misleading in areas where residents are income-poor but asset-rich. Farmers and older people often fall into this category when land assets form a high proportion of their wealth (Figure 8.18).

Small numbers also confound income data in sparsely settled rural areas. Low income earners or unemployed tend to move out of such regions to access a wider range of employment opportunities. Unemployment figures for townships and rural areas also bear out this pattern of low unemployment rates in rural areas (Figure 8.19).

High incomes show some degree of dispersion across the study area although larger settlements show higher incomes reflecting more higher paid professionals (Figure 8.20). Around Mildura, Shepparton and Wodonga there is also evidence of higher incomes in the urban areas surrounding the city. In part this reflects the attraction of such areas for rural resident professionals, but in the case of Shepparton and Mildura it may also reflect high value agricultural production activities.

For public land management, the varying educational and income profiles of communities within the study

Figure 8.16 Proportion with people over 15 with a Bachelor degree or higher by Census Collection District.

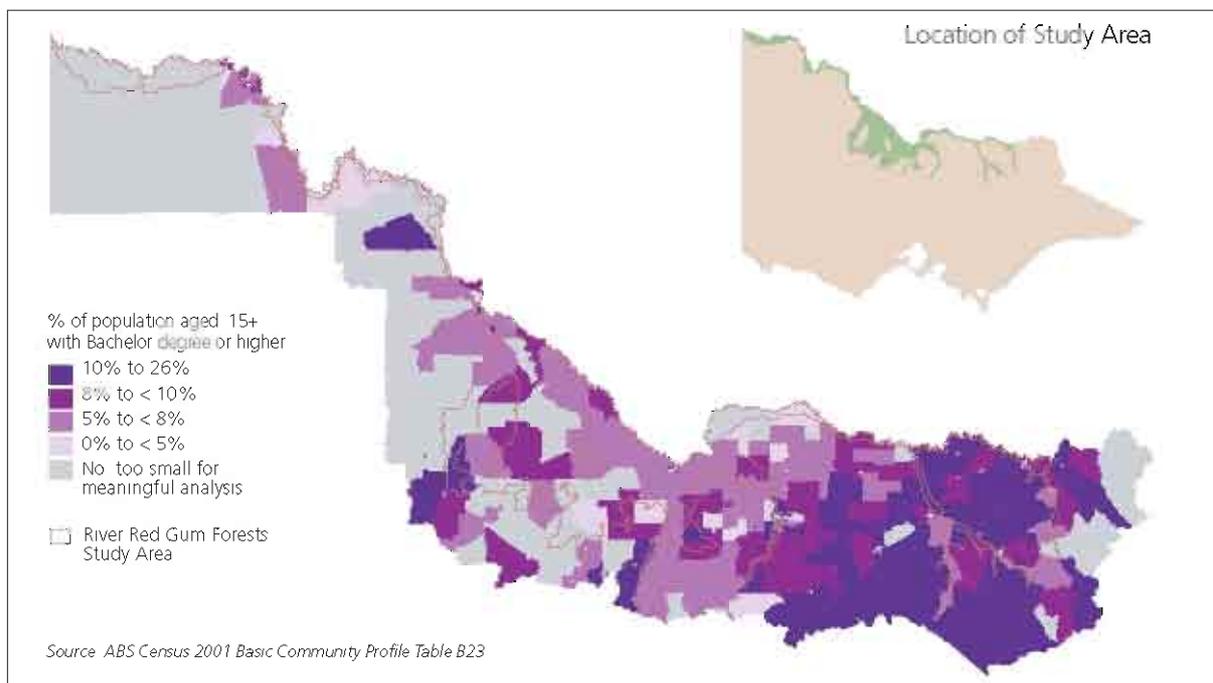


Figure 8.17 Proportion of people over 15 with no post-school qualifications by Census Collection District.

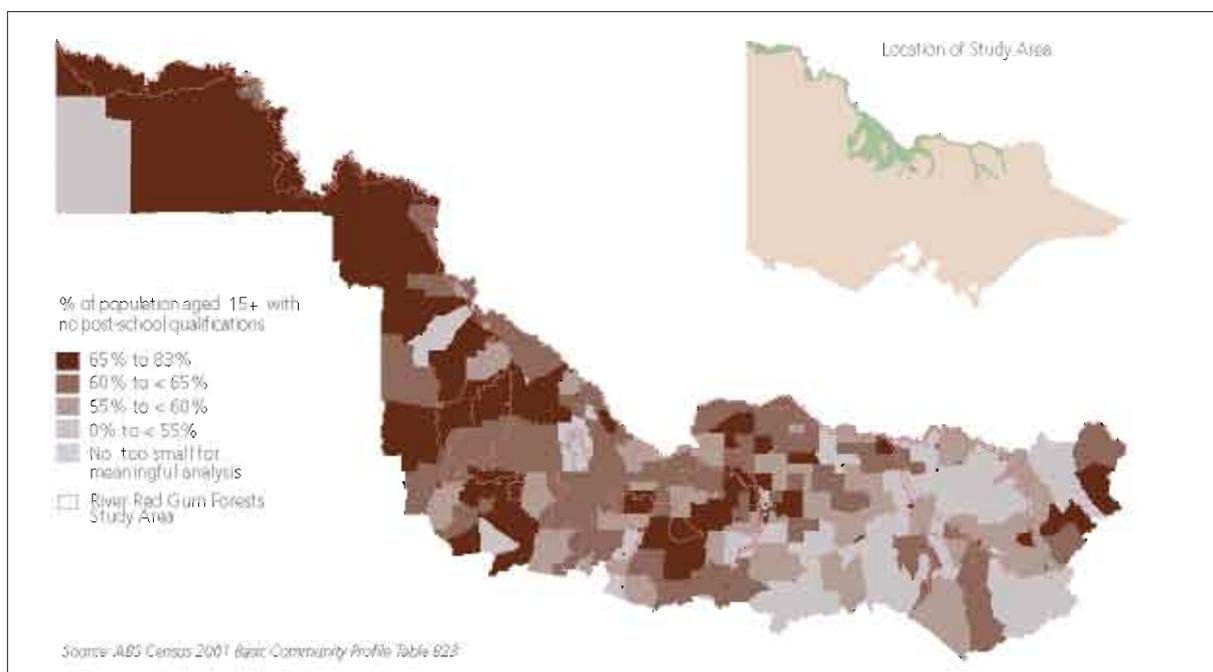


Figure 8.18 Proportion of households with gross income of less than \$300 per week by Census Collection District.

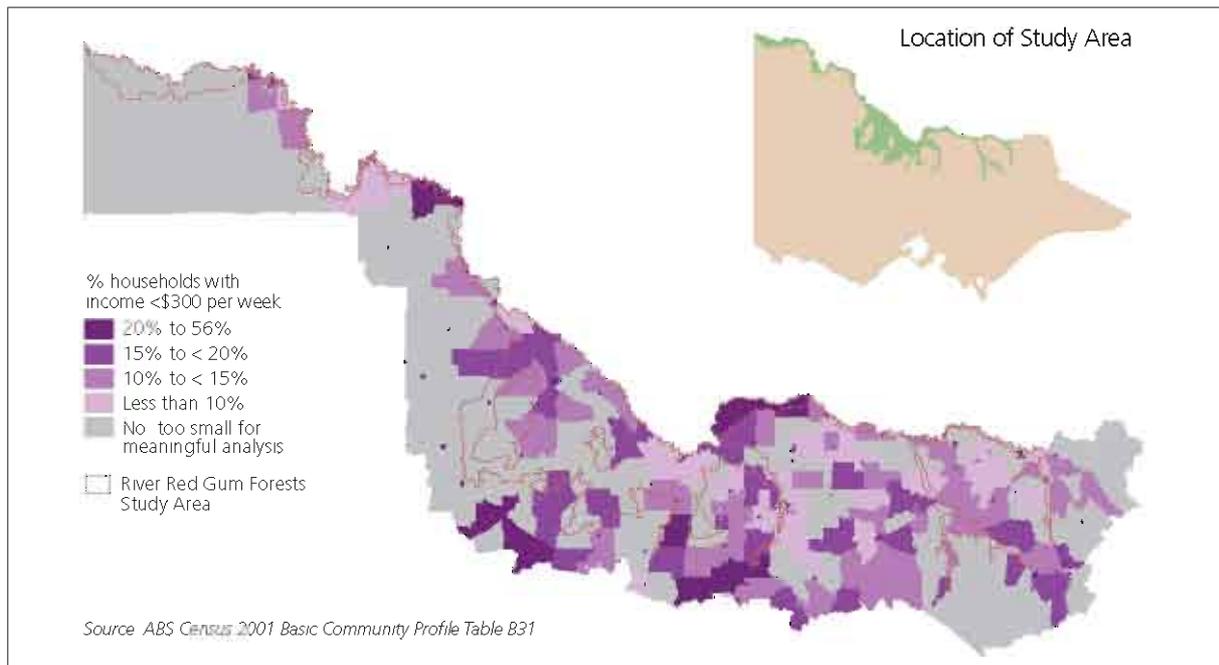
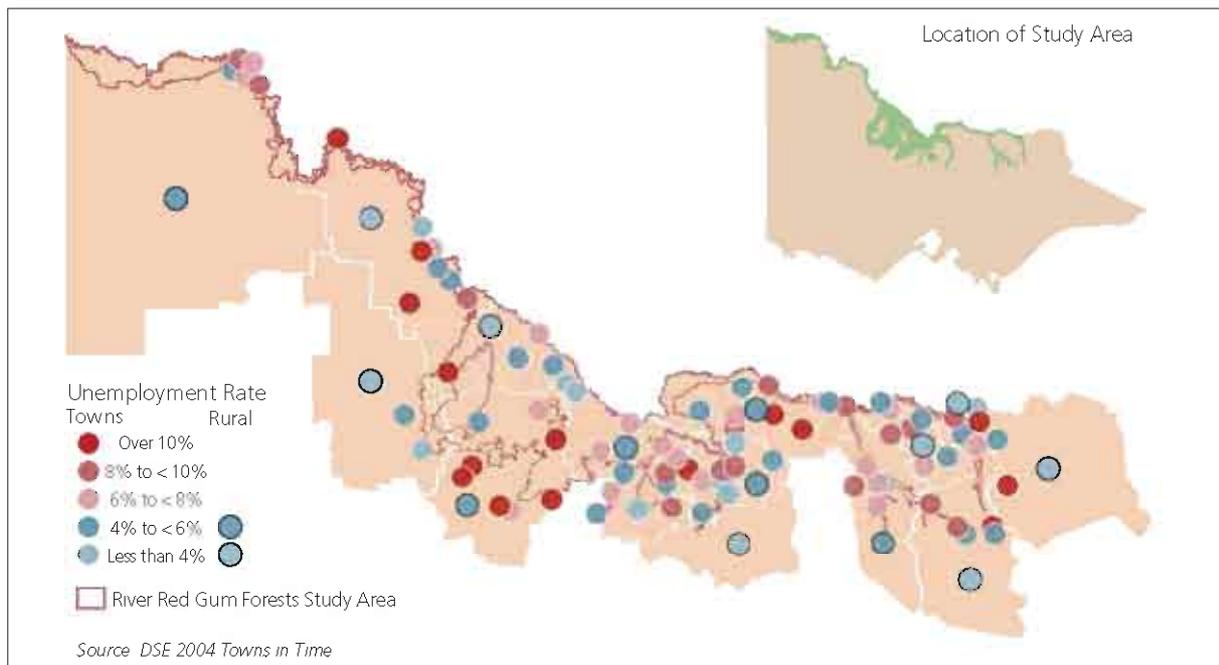


Figure 8.19 Unemployment rates for urban centres, rural localities and rural balances in the study area.



area may indicate a need for different communication and engagement strategies.

Summary

In socio-economic terms, a key challenge for public land management in the study area is community diversity. Public land in the south eastern part of the study area is closer to population centres. Even nearby rural areas house urban workers who commute to larger settlements. Communities can therefore be quite mixed in terms of urban and rural characteristics. In contrast, areas downstream from Echuca tend to have much more distinct differences between urban/irrigated areas and

dryland rural areas. Dryland farming areas contain very dispersed, older and ethnically homogenous populations. Nearby irrigation areas along the Murray have younger population profiles, with more people who were born overseas, more Indigenous residents as well as high proportions of mobile or seasonal populations.

There are likely to be significant differences between communities in the study area in terms of: how long people have lived in the area, how well-connected they are and how much they wish to participate in their community. Some people are more mobile and have better access to transport. Some communities have

strong levels of community activity and volunteering while others do not. Some communities have better familiarity with public land issues than others while income, education and culture also differ widely.

Such diversity is apparent when looking at an indicator such as involvement in volunteer activities (Figure 8.21). The Local Government Areas within the study area display a wide spectrum of volunteering levels from 31 percent (Shepparton) to more than 50 percent (Buloke, Loddon and Towong) (DVC 2005). These socio-economic differences between and within communities are

challenges for communicating policy initiatives and management strategies for public land. Diverse communities challenge management agencies to identify all those who may have an interest in various public lands. Along the River Murray stakeholders are as diverse as tourists, recreational users, nearby residents and more distant communities, as well as upstream and downstream users of land and water resources. Recognition of this diversity within and across the regions is important when considering how public land is to be used in the future.

Figure 8.20 Proportion of households with a gross income of more than \$1000 per week by Census Collection Districts.

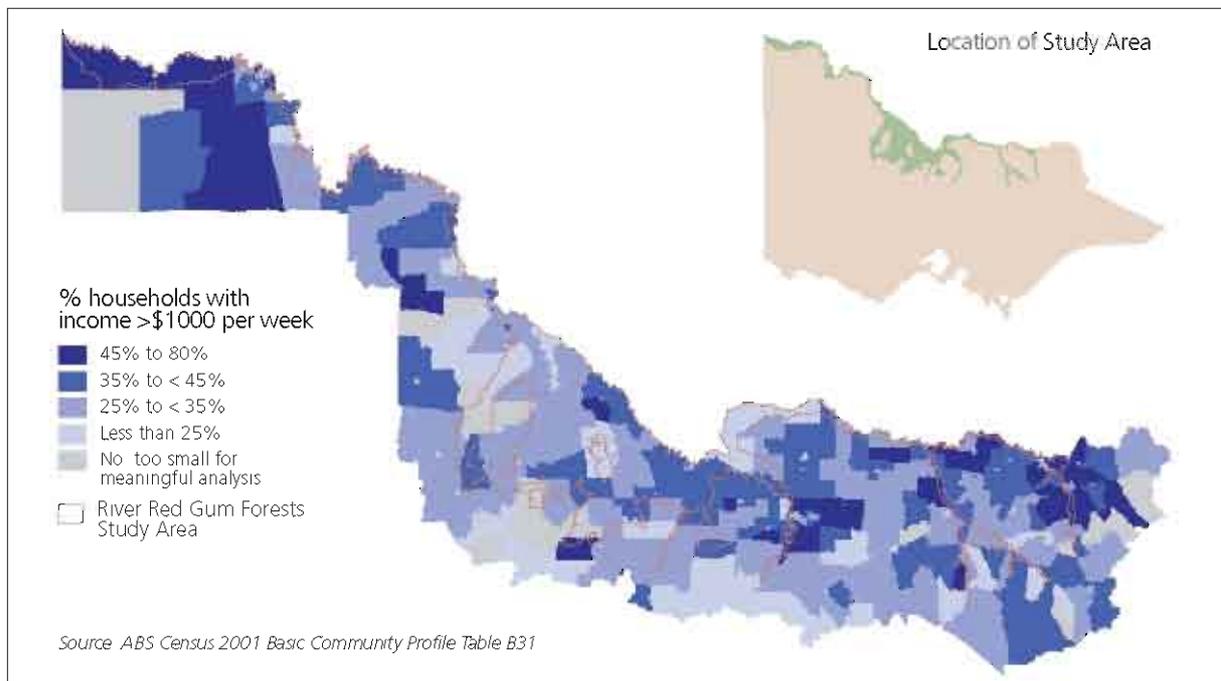


Figure 8.21 Proportion of residents who volunteer by Local Government Areas.

