

Modelling of Sediment Erosion and Deposition in the Upper Barwon Catchment



FINAL REPORT

- Final
- August 2007



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Document history and status

Revision

Revision	Date issued	Reviewed by	Approved by	Revision type
1	26/07/2006	Bruce Abernethy	Bruce Abernethy	Draft for release
2	08/08/2007	Bruce Abernethy	Bruce Abernethy	Final for release

Distribution

Revision	Copy No.	Issued to
1	1	Greg Peters (Corangamite CMA)
	2	File WC03352
2	1	Greg Peters (Corangamite CMA)

Printed:	10 August 2007
Last saved:	10 August 2007 09:52 AM
File name:	I:\WCMS\Projects\WC03352\Deliverables\03_Final\R04ral_Barwon FINAL_v2.doc
Author:	Rebecca Lett, Bruce Abernethy, Axel Allgaier
Project manager:	Bruce Abernethy
Name of organisation:	Corangamite Catchment Management Authority
Name of project:	Modelling of Sediment Erosion and Deposition in the Upper Barwon Catchment
Name of document:	Final Report
Document version:	Final
Project number:	WC03352



1. Introduction

An essential part of minimising our impact on stream systems is to reduce the mobilisation and delivery of sediments from the land's surface into the stream network. Sediment ingress to the stream network has several potential downstream impacts. High suspended-sediment loads reduce stream clarity, inhibit respiration and feeding of stream biota, diminish light needed for plant photosynthesis, make water unsuitable for irrigation and require treatment of water for human use. Moreover, nutrients (particularly phosphorous) are transported through catchments with sediments. When released into the stream network, elevated nutrient levels can be very harmful to the aquatic ecosystem.

The sediment load of a stream is derived from a number of erosion processes: hillslope erosion (surface wash and rill erosion), gully erosion and riverbank erosion. However, erosion processes are not equally active across the landscape. Indeed, at any given location, one process might dominate the others with the dominant process varying from place to place. Management of sediment ingress to streams, then, should aim to target each process differently. Streambank and gully erosion are best managed by restricting stock access to streams, revegetating bare banks and maintaining vegetation cover in areas prone to gully erosion. Hillslope erosion is best managed by promoting consistent groundcover and maintaining soil structure.

Once in the stream system, sediment is transported either as suspended load (in the case of silts and clays) or as bed load (in the case of sands and gravels). Where streams are unable to transport their bedload, it is deposited, often as sand slugs that bury the bed. Sand slugs are poor habitat. They can prevent fish passage, they fill pools and they are unstable substrates for benthic organisms. Suspended sediments can be deposited in reservoirs or on floodplains, providing fertile alluvial soils. However, the extent of this deposition is highly variable from one river reach to another.

The work presented here is a conceptual study into the critical sources, transport pathways and sinks of sediment in the upper Barwon River Catchment. The study relies on a sediment budget that quantifies all sediment fluxes as a basis for identifying issues relating to the current and future erosion and sedimentation processes within the study area. The study also places the major landuses within their regional context and identifies subcatchments with the greatest potential for downstream impact.

1.1 Report structure

The geology, physiography, soils, climate, vegetation and landuses of the upper Barwon Catchment are described in Chapter 2 of this report. In Chapter 3, a chronology of adjustment is presented. The chronology of adjustment relates to the timeline of those geomorphologically significant events that would have affected the rate of sediment yield and delivery to the channel network and sediment transport within the channel. SedNet model results are presented and discussed in Chapter 4. Results include a sediment budget for the upper Barwon Catchment. This sediment budget provides an estimate of mean annual values for sediment inputs from hillslopes, gullies and bank erosion.

In the final six chapters, we distil our findings into a discussion of options for the management of hillslope erosion (Chapter 5), gully erosion (Chapter 6), riverbank erosion (Chapter 7) and sediment export and deposition (Chapter 8). Chapters 5 to 8 are each divided into five sections. Firstly, we explore the past management of sedimentation and erosion. Secondly, we review SedNet assumptions and model outputs. We then identify priority areas for control works and present a range of management options. A summary is also provided.



A discussion of erosion and sedimentation in the priority areas of the Barwon River, as identified in the River Health Strategy, is presented in Chapter 9. Our findings, recommendations and conclusions are summarised in Chapters 10 and 11.

The appendices provide additional technical information. SedNet data inputs for the upper Barwon Catchment model are listed and described in Appendix A. Information relating to field observations is documented in Appendix B and Appendix C. Information on the management of erosion and sedimentation, and the evaluation of management options, are summarised in Appendix D.



2. Study area

The Barwon River rises on the high-rainfall upper slopes of the Otway Range to drain some 3,880 km² of southern Victoria. The headwaters are composed of numerous small creeks that flow in a generally northerly direction off the Otway Ranges. At Inverleigh, the Barwon is joined by a major left-bank tributary the Leigh River before turning easterly. The Leigh River rises on the Central Highlands near Ballarat. In its lower reaches the Barwon is joined by the Moorabool River, before flowing through Geelong and Lake Connewarre to debouch into Bass Strait at Barwon Heads.

The study area for this study is defined as the Barwon River and catchment upstream of Warrambine Creek. This chapter describes the geology, physiography, soils, climate, vegetation and landuse of the study area.

2.1 Geology

The study area can be divided into four main areas, based on their age and lithology:

- Otway Ranges (folded Cretaceous sediments);
- Dissected Tertiary Plains (mainly Tertiary sediments);
- Basalt Plains (Tertiary and Quaternary volcanics); and
- Alluvial and aeolian sediments (Quaternary).

The Otway Ranges, that form the south and southeastern boundary of our study area, consist of uplifted fluvial, braided stream deposits of Early Cretaceous (Albian) age (Figure 2.1). The sediments are mainly fine to medium grained, consolidated and generally well-bedded or cross-bedded. They consist of volcanolithic sandstone, siltstone, mudstone, mud-clast conglomerate, with feldspar and quartz grains, as well as coal (Edwards, 1996). Due to the considerable and ongoing uplift of the Otway Ranges along the Bambra fault, which runs SW-NE, steep river valleys have been incised (Robinson *et al.*, 2003; Sandiford, 2003).

The Dissected Tertiary Plains are separated by the Bambra Fault from the Otway Ranges. The plains are made up of various Tertiary sedimentary formations (see Table 2.1). The Barwon River and its southern tributaries have cut into these formations during the Quaternary and deposited silt, sand and gravel which is moderately sorted and poorly consolidated.

The Barwon River below Birregurra Creek, and Birregurra Creek itself, form the east-west divide between the Tertiary Plains and the Basalt Plains. These consist of extensive areas covered by Quaternary sheetflow basalt and stony rises comprised of basalt of late Tertiary and Quaternary age. Visible signs of this recent volcanic activity are apparent in the volcanic cones and craters which rise in a number of locations, for example at Mount Gellibrand near Winchelsea (Ollier and Joyce, 1976). The basalt flows have been responsible for shifting the course of all major rivers in the Corangamite region. The Basalt Plains were once covered by a much enlarged Lake Corangamite, which extended 85 km west from Winchelsea to beyond Camperdown, and 35 km north from Colac to Cressy (Jenkins, 1976). When the lake retreated, it left a series of terraces and lunette-like ridges which overlay the basalt.

Alluvial, lacustrine and aeolian Quaternary deposits are found along the Barwon River and its major tributaries and overlying the Newer Volcanics in the area covered by the much enlarged Lake Corangamite, which extended 85 km west from Winchelsea to beyond Camperdown, and 35 km north from Colac to Cressy (Jenkins, 1976).



Due to a combination of relief and lithology, the Otway Ranges and the Dissected Tertiary Plains are most likely to be affected by erosional processes.

Table 2.1: Major geological units in the study area (Edwards, 1996).

Map code	Unit name	Parents names	Age	Origin	Lithological description
Qno1	Unnamed sheetflow basalt	Newer Volcanic Group	Quaternary (Pleistocene) Neogene (Pliocene)	Igneous Extrusive	Undifferentiated lava flows, lava ridges and valley flows; olivine basalt; commonly microvesicular, minor columnar jointing
Qno2	Unnamed stony rises	Newer Volcanic Group	Quaternary (Holocene) Neogene (Pliocene)	Igneous Extrusive	Stony rise basalt, hummocky lava flows; olivine basalt; highly vesicular
Qc1	Unnamed colluvium		Quaternary (Holocene)	Non-Marine Colluvial	Fluvial: "gully" alluvium, colluvium: gravel, sand, silt
Ql	Unnamed lunette deposits		Quaternary (Holocene - Pleistocene)	Non-Marine	Lunette and lake beach deposits: clay, quartz sand, Coxiella shells, reworked tuff near Vaughan Island, minor swamp deposits; moderately sorted and unconsolidated
Qa1	Unnamed alluvium	Heytesbury Group	Quaternary (Holocene - Pleistocene)	Non-Marine Alluvial	Alluvial flood plain deposits: silt, sand, gravel; moderately sorted and poorly consolidated
Nbh	Hanson Plain Sand	Brighton Group	Neogene (Pliocene)	Non-Marine	Fluvial and minor shallow marine deposits: quartz sand, clayey sand, gravel, minor calcareous clay and limonite pisolites; surface may be lateritised
-Pnd	Demons Bluff Formation	Nirranda Group	Oligocene (Rupelian) Eocene (Bartonian)	Marine, Non-Marine	Shallow marine and minor lagoonal deposits: silt, fine sand, clay, clayey sand, carbonaceous, pyritic; arenaceous foraminifers, burrowed
Nhg	Gellibrand Marl		Miocene (Serravallian) Oligocene (Chattian)	Marine	Continental shelf deposit: calcareous silty clay and clayey silt, minor fine to coarse grained shelly calcarenite beds, abundant bryozoans and molluscs, common echinoids, brachiopods, corals, crabs and shark teeth, locally abundant glauconite pellets; strongly burrowed, massive to moderately bedded
-Pwe	Eastern View Formation	Wangeripp Group	Eocene (Lutetian) Cretaceous (Maastrichtian)	Non-Marine	Upper delta plain and flood plain deposits: quartz sand and gravel, minor mudstone and brown coal; generally unconsolidated, trough cross-bedding
Koe	Eumeralla Formation	Otway Group	Early Cretaceous (Albian - Aptian)	Non-Marine	Fluvial, braided stream deposits: volcanolithic sandstone, siltstone, mudstone, mud-clast conglomerate, with feldspar and quartz grains, and coal; fine to medium grained, consolidated, well-bedded, cross-bedded

2.2 Physiography

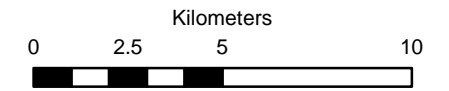
In its upper reaches, the Barwon River is divided into two branches – East and West. Both branches have their headwaters in the Otway Ranges and flow through tall open forest with dense undergrowth. Birch (2003) characterises the topography of the Otways as steep valleys and interlocking ridges and spurs. The northern slopes of the Otway Ranges are more subdued than those of the south, but the additional influences of clay soils and high rainfall make them equally prone to landslips. The highest point of the Otway Ranges is approximately 700 m above sea level.

Figure 2.1



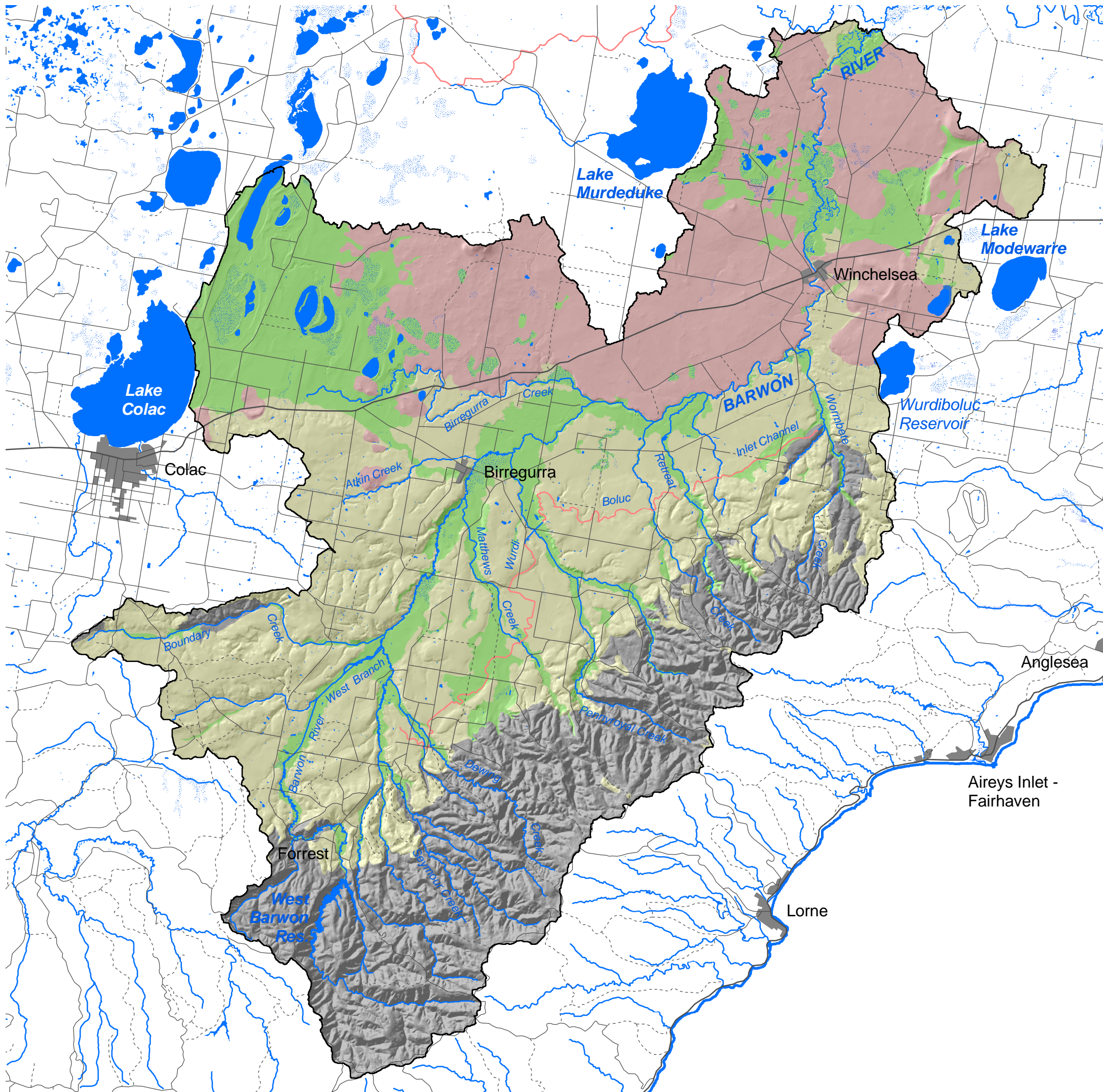
Modelling of Sediment Erosion and Deposition in the Upper Barwon Catchment

SURFACE GEOLOGY



Surface Geology

- Lakes
- Alluvial and aeolian deposits
- Dissected Plains
- Volcanic Plains
- Southern Upland Hills



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The West Branch cuts through Cretaceous Otway Group Sediments, before its headwaters are impounded by the West Barwon Dam, located south of Forrest. Below the dam, the catchment progressively falls away to hills covered by more open forest, to gentle slopes covered by crops or natural and sown grassland. The river begins to meander through a widening floodplain, deposited in the Tertiary Moorabool Viaduct Formation. Between Seven Bridges Road and the confluence with the East Branch, the West Branch has been channelised.

In its headwaters, the East Branch also cuts through Cretaceous Otway Group Sediments. In 1952, a landslide blocked the East Branch, impounding the river at Lake Elizabeth (see also Chapter 3). Below Lake Elizabeth, the East Branch emerges from forest to cut through the Tertiary Dissected Plains. The river meanders towards the confluence with the West Branch, although Craigie *et al.* (2002) observed that some of this section appears to have been channelised also, particularly in the section between the downstream end of the forest and Callahan Creek.

Below the confluence of the West and East Branches, the Barwon River meanders across a wide floodplain. Between Pennyroyal and Brickmans Creek, the Barwon River is sinuous to straight. Here, the river follows a generally northeasterly course, until it meets Birregurra Creek, where it hooks in an easterly direction along the Birregurra fault (Craigie *et al.*, 2002). From this point it is bordered to the north by the Volcanic Plains and flows through a more confined valley.

The Barwon River has a number of right bank tributaries upstream of Winchelsea, all with headwaters in the Otway Ranges. These streams, such as Dewing, Matthews, Pennyroyal, Retreat and Wormbete Creeks, have cut steep sided valleys through Cretaceous Otway Group sediments, before emerging onto the Tertiary Dissected Plains and Quaternary alluvial flats. The major left bank tributaries of the Barwon River are Boundary Creek and Birregurra Creek. Birregurra Creek joins the Barwon below Ricketts Marsh and has a much flatter long profile than the right bank tributaries.

The Leigh River is the Barwon's major tributary, joining from the left bank at Inverleigh after rising on the southern slopes of the Great Dividing Range. The Moorabool River flows into the lower Barwon River, upstream of Geelong. West of the confluence of the Barwon and Leigh Rivers, Mia Mia Creek drains to Lake Murdeduke, forming a closed catchment within the Barwon River Basin. Lake Murdeduke spills into the Barwon River only under flooding conditions. Mia Mia Creek and the Barwon River below the Leigh River are not included in the study area of this investigation.

Lake Moderwarre and Wurdiboluc Reservoir, to the east of Winchelsea, are also excluded from the study area. Lakes located within the study include Lake Burn (situated east of Lake Colac) and Lake Gherang (located east of Winchelsea). Other wetlands of note are all located northeast of Lake Colac, on the basalt plains in an alluvium substrate (see DEH, 2005).

2.3 Soils

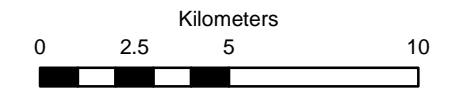
A number of soil studies have been carried out in the study area by various people over a considerable stretch of time (Robinson *et al.*, 2003, p. 43). Some of the areas investigated overlap and have resulted in conflicting assessments of soil properties, due to differing knowledge at the time of the respective studies. The latest attempt to group the large number of soils within the region has been made by Robinson *et al.* (2003). In their study, soils in the CCMA area are grouped into 41 soil groups (Corangamite Soil Groups – CSG). A generalised map (Figure 2.2) based on data provided by CCMA shows the regional distribution of soils in the study area.

Figure 2.2



Modelling of Sediment Erosion and Deposition in the Upper Barwon Catchment

SOILS and RAINFALL STATIONS

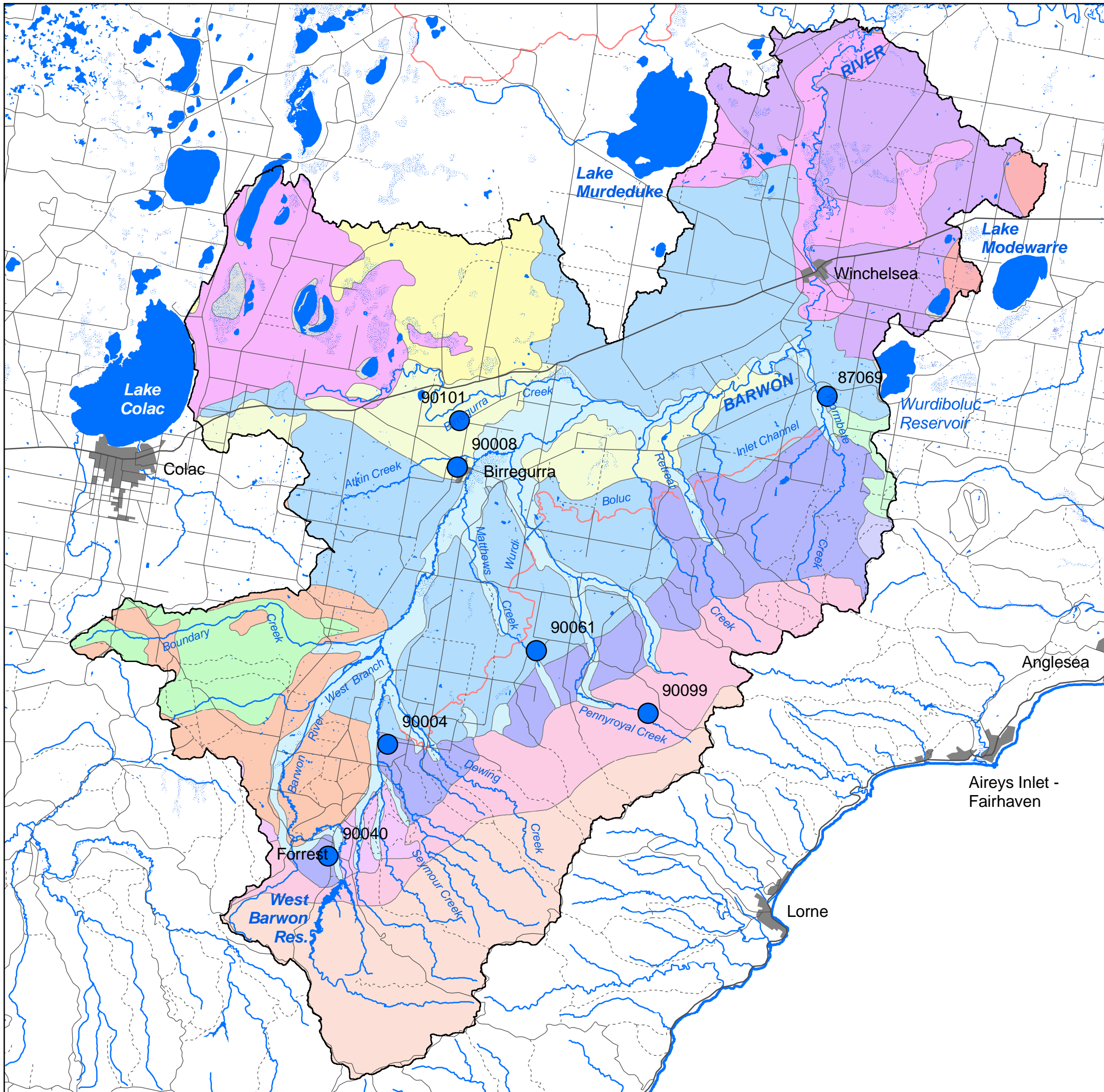


Rainfall stations

- 87069
- 90004
- 90008
- 90040
- 90061
- 90099
- 90101

Soils

- (Bd) Brown calcareous clays
- (Bi) Brown duplex soils, Brown earths
- (Bj) Brown earths
- (Ge) Grey earths
- (Gh) Grey sands
- (Gi) Grey sands, Earths
- (Ma) Mottled duplex soils
- (Me) Mottled duplex soils, Stony yellow earths
- (Mg) Mottled earths, Grey sands
- (St) Shallow stony earths, Dark clays
- (Ya) Yellow duplex soils
- (Yf) Yellow duplex soils, Mottled duplex soils
- (Yk) Yellow duplex soils, Yellow clays
- (Yo) Yellow earths, Grey sands
- (Yp) Yellow earths, Mottled duplex soils
- (Yq) Yellow earths, Mottled earths
- Unclassified



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In the higher sections of the Otway Ranges the soils are characterised by moderately heavy, nutrient rich, Cretaceous sandstones with deep friable profiles. The wetter areas of the range are characterised by strongly acidic soils that have well drained gradational profiles with high levels of organic matter. The drier areas of the Otway Ranges tend to be sodic duplex soils with heavy textured subsoils (Pitt, 1981). According to Pitt, soils in the plains surrounding the Otway Ranges tend to be acidic, alkaline or close to neutral with low organic matter content. Most are characterised by duplex properties and have heavy to medium clay subsoils. Soils developed on basalt, or alluvium derived from basalt, have the heaviest textures with lowest permeability.

The likelihood of soil structure decline and soil erosion vulnerabilities have been assessed for the region by the Corangamite CMA (2003b). The assessment identified dispersive soils throughout the region, especially in the sub soil, which can result in severe erosion problems. Under current landuse, in our study area, the likelihood of soil structure decline ranges from very low to moderate on the northern Otways to very high and high between Forrest and Winchelsea. From Winchelsea to the top of the study area the likelihood of soil structure decline is mostly low, with some patches of high likelihood (CCMA, 2003b). Water logging of the soil occurs in similar areas to those of soil structure decline indicating a correlation between the two soil management issues.

Sheet and rill erosion commonly occur in areas with steep terrain, minimal ground cover and high rainfall. Sheet and rill erosion have been associated with the development of gully erosion and consequent water quality and sedimentation issues. In our study area, the Otway Ranges have a high likelihood of sheet and rill erosion but in the flatter areas downstream of the ranges the likelihood of sheet and rill erosion is classed as moderate (CCMA, 2003b).

Tunnel and gully erosion is most likely to be found in the Western and Southern Uplands where dispersive subsoils occur. Specifically, the likelihood of tunnel erosion is especially great in the Cretaceous Otway Group and also along drainage lines in steeper cleared sections of the catchment. The likelihood of gully erosion is generally low in the northern Otway Ranges and high to very high from Forrest downstream for the remainder of the study area (CCMA, 2003b). Tunnelling occurs predominantly on duplex soils (mainly Sodosols and Chromosols) where the majority of observations are correlated with the acidic yellow duplex (i.e. Dy 3.41) type. In addition, the cracking clays (Vertosols) in southwestern Victoria are also sodic and the upper slopes are affected by tunnel and gully erosion as well as landslips (Boucher, 2007).

The areas most susceptible to gully erosion are cleared uplands which support erodible sodic duplex soils (Sodosols) in areas where the mean annual rainfall is at least 500 mm. The relation between gully erosion and sodic soils in Victoria was discussed by Ford *et al.* (1993). Very low gully density can be expected on broad alluvial plains, aeolian landscapes, basalt plains and uncleared land. The cleared uplands of the Otway receiving more than 1 000 mm of annual rainfall, tend not to be subject to gully erosion due to steep slopes, high drainage density, low subsoil sodicity, high infiltration rates and shallow soil depth. The existing small, steeper drainage lines in these areas are, although actively eroding, not classified as gullies due to their smaller dimensions (Boucher, 2007).

According to the CMA, the Corangamite region is one of the most landslide prone areas in Australia. Landslides occur primarily as a combination of extreme rainfall, slope aspect, vegetation and drainage. Areas at highest risk in the Corangamite Region are the southeastern slopes of the Otway Ranges, slopes of the Barwon River valley occurring in the Otway Group and Gellibrand Marl rock types.



2.4 Climate

The climate of the Corangamite region can be generally described as temperate. At Forrest State Forest (Bureau of Meteorology station number 90040 – see Figure 2.2), average temperatures generally range between 12°C in July and 25°C in January.

The average annual rainfall ranges between 600 and 1100 mm/yr at seven sites within the upper Barwon study area (Table 2.2). Some of the highest rates of precipitation are found in the Otway Ranges. The annual rainfall at Forrest State Forest can exceed 1,300 mm in 10% of years. The average annual rainfall is less in the lower reaches of the study area, where a rain-shadow forms on the central valley of the Basalt Plains. At Birregurra and Winchelsea the average annual rainfall rarely exceeds 800 mm/yr. Rainfall in the region is highest in winter months. Recent (i.e. post 1997) rainfall in Victoria has been below the long-term average.

Table 2.2: Average annual rainfall within the upper Barwon Catchment.

Site No.	Name	Period of record	Years record	Average annual rainfall (10th – 90th percentile)
90040	Forrest State Forest	Apr-1898 to May-2005	92	1,050 (810-1,320) mm
90004	Barwon Downs	Jan-1971 to Aug-2004	31	860 (690-1,010) mm
90099	Benwerrin	Jan-1889 to Jun-1927	35	1,110 (740-1,470) mm
90061	Pennyroyal Creek	Dec-1885 to Dec-2004	119	800 (620-970) mm
90008	Birregurra (Post Office)	Nov-1903 to May-2005	97	670 (530-810) mm
90101	Birregurra (Ripple Vale)	Nov-1876 to Nov-1911	24	600 (470-720) mm
87069	Winchelsea (Kildean)	Mar-1932 to Jun-1957	25	640 (510-760) mm

2.5 Vegetation

Bioregions are used in Victoria to classify ecological patterns throughout the landscape and provide a framework for recognising and managing biodiversity values. Bioregions use the underlying geology, rainfall, elevation and soil type for classification. Bioregions covering the study area of the Upper Barwon River and tributaries are detailed below (see also Figure 2.3).

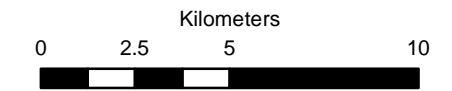
- 1) *Otway Ranges* bioregion is characterised by moist foothill forest complexes and dry foothill forest complexes with smaller occurrences of lowland forest complexes, heathy woodland complexes and valley grassy forest complexes. The moist foothill forest complexes include the wet forest, damp forest, montane wet forest and montane damp forest EVCs. The gullies and rivers support the riparian forest, riparian thicket, and montane riparian thicket EVCs.
- 2) *Otway Plains* bioregion is characterised by coastal plains, river valleys and foothills. Vegetation includes coastal heath and woodland, open forests with understorey dominated by Brown Stringybark and Messmate. At the foothills of the Otways, dry sclerophyll forest dominated by Mountain Grey Gum and Messmate occurs. River Red Gum woodlands occur along some drainage lines.
- 3) *Victorian Volcanic Plains* bioregion is characterised by vast open areas of grasslands (that are floristically rich and usually dominated by Kangaroo Grass with a wide variety of perennial herbs), small patches of open woodland, stony rises denoting old lava flows, the low peaks of extinct volcanoes dotting the landscape and numerous scattered large shallow lakes and wetlands. This bioregion supports a wide variety of reptiles and birds but few mammal species. Orchids are endemic to the Victorian Volcanic Plain and the Striped Legless Lizard is strongly associated with this bioregion (DNRE, 2000).

Figure 2.3

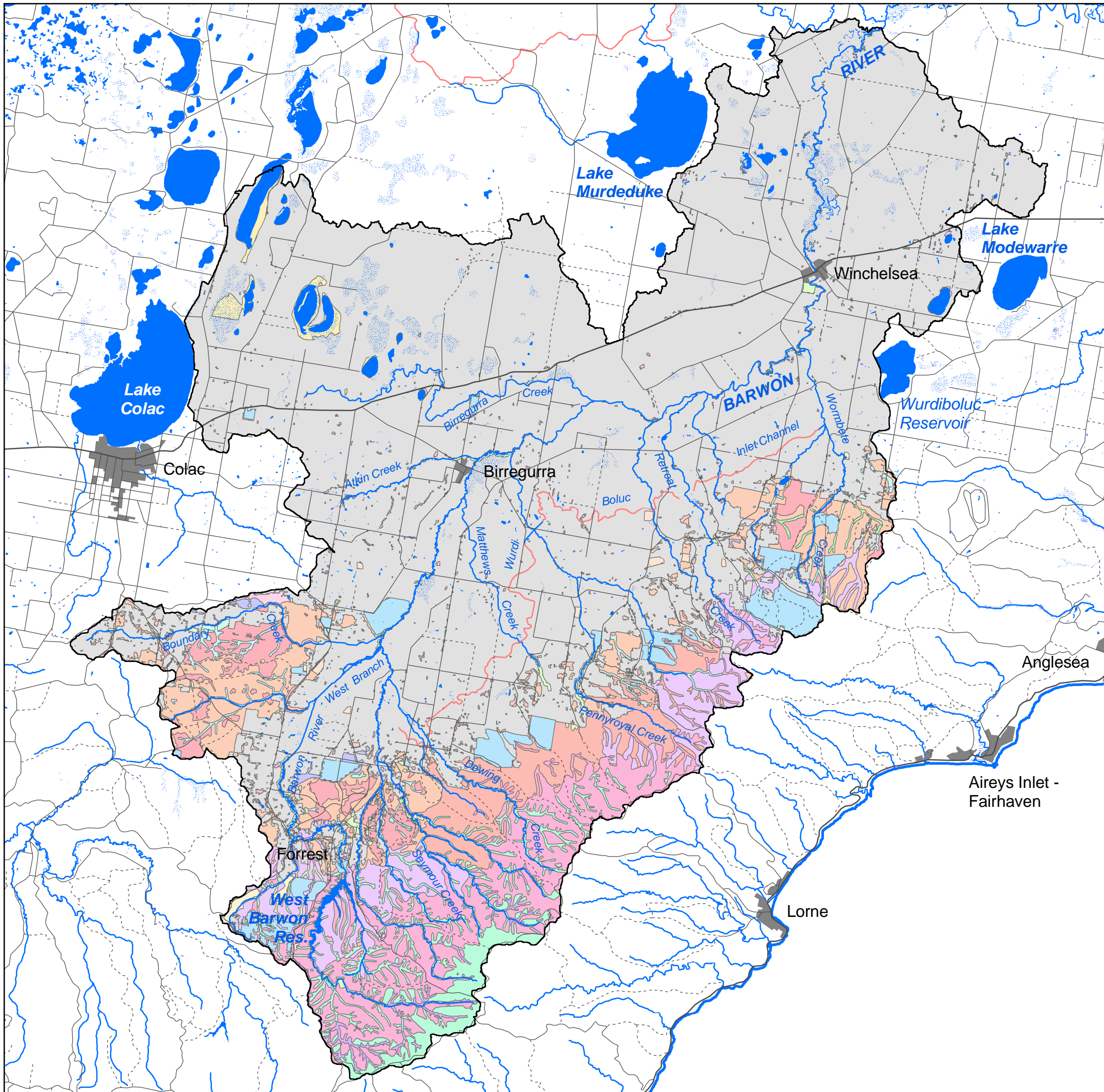


Modelling of Sediment Erosion and Deposition in the Upper Barwon Catchment

Environmental Vegetation Classes (EVC)



- Cleared Severely Disturbed
- Conifer Plantation
- Cool Temperate Rainforest
- Damp Heath Scrub
- Damp Sands Herb-rich Woodland
- Floodplain Riparian Woodland
- Grassy Forest
- Grassy Woodland
- Hardwood Plantation
- Heathy Woodland
- Herb-rich Foothill Forest
- Herb-rich Foothill Forest/Shrubby Foothill Forest Complex
- Lowland Forest
- Plains Grassland
- Plains Grassland/Plains Grassy Woodland Mosaic
- Plains Grassy Woodland
- Plantation (undefined)
- Riparian Forest
- Riparian Scrub Complex
- Scoria Cone Woodland
- Sedgy Riparian Woodland
- Shrubby Dry Forest
- Shrubby Foothill Forest
- Shrubby Wet Forest
- Stoney Rises Herb-rich Woodland
- Swamp Scrub
- Swampy Riparian Woodland
- Water Body-Fresh
- Water Body-Salt
- Wet Forest
- Wet Heathland
- Unclassified



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Within each bioregion are numerous ecological vegetation classes (EVCs). Prior to European settlement the EVCs in the study area included herb rich foothill forest/shrubby foothill forest complex in the Otway Ranges. The foothill forest complex gives way to floodplain riparian woodlands along the Barwon River interspersed with plains grassy woodlands and isolated patches of aquatic herb land/plains sedgy grasslands mosaic downstream of Winchelsea. There were also small isolated patches of swampy riparian woodland. The left bank tributaries of the Barwon River supported lowland forest and sedgy riparian woodland communities (DSE, 2003).

Since European occupation many EVCs have been depleted or entirely cleared. Major EVCs currently include shrubby foothill forests in the Otway Ranges and shrubby wet forest along the Barwon River near Forrest (Table 2.3). Further downstream the riparian zone is highly disturbed and mostly cleared with isolated patches of plains grassy woodlands downstream of Winchelsea. The upper tributaries of the study area are characterised by lowland forest and/or heathy woodland.

Table 2.3: Current extent of Bioregions and EVCs in the study area.

Ecological Vegetation Class (EVC)		Otway Ranges (ha)	Otway Plain (ha)	Volcanic Plain (ha)
ID	Name			
1	Coastal Dune Scrub Mosaic	63	1,044	
3	Damp Sands Herb rich Woodland	303	1,244	
6	Sand Heathland		167	
7	Clay Heathland		32	
8	Wet Heathland	115	1,392	
9	Coastal Saltmarsh		23	
10	Estuarine Wetland	2	57	
16	Lowland Forest	2,064	26,534	
17	Riparian Scrub Complex	105	4,066	
18	Riparian Forest	2213	729	
21	Shrubby Dry Forest	10,163	741	
22	Grassy Dry Forest	275		
23	Herb Rich Foothill Forest	173	1,844	
30	Wet Forest	49,212	271	
31	Cool Temperate Rainforest	155		
45	Shrubby Foothill Forest	26,795	1,199	
48	Heathy Woodland	410	21,677	
53	Swamp Scrub	50	215	128
55	Plains Grassy Woodland		3	558
56	Floodplain Riparian Woodland		169	154
83	Swampy Riparian Woodland	1	334	12
125	Plains Grassy Wetland	1	20	18
128	Grassy Forest		118	
132	Plains Grassland		1	42
161	Coastal Headland Scrub	1,088	633	
163	Coastal Tussock Grassland	37	61	
165	Damp Heath Scrub	85	63	
175	Grassy Woodland		1,221	50
178	Shrubby Foothill Forest Complex	4,107	58	
198	Sedgy Riparian Woodland	72	1,496	
200	Shallow Freshwater Marsh	4		
201	Shrubby Wet Forest	32,440	130	
203	Stoney Rises Herb-rich Woodland		3	1,851
233	Wet Sands Thicket	846	421	
647	Plains Sedgy Wetland		1	76
691	Plains Sedgy Wetland Mosaic		1	96
851	Stream bank Shrubland		5	89
858	Calcarene Dune Woodland		25	
892	Heathy Woodland/Sand Heath Mosaic		84	
894	Scoria Cone Woodland	1		45
897	Plains Grassy Woodland mosaic			22



European occupation brought an introduction of exotic vegetation that is now causing problems throughout the catchment (Craigie *et al.*, 2002). For example, willows cause localised scouring, increased competition for native plants, reduced light penetration to the water column and decreased oxygen levels in the water as the deciduous leaves decompose. Other weeds that have become a problem in the catchment include blackberries and gorse.

2.6 Landuse

Prior to European occupation, the Wathaurong peoples occupied the area encompassing the coastline from Werribee to Lorne and inland to Colac and Ballarat. Within the Wathaurong traditional language were 14 clan groups (CCMA, 2003a). These groups exploited a number of food sources in the region, including seabirds, crayfish, shellfish, fish and seals in coastal areas, and kangaroo, Emu, eels and other fish in inland areas.

In 1837, a favourable assessment by European exploring parties encouraged squatters to move westward from Port Phillip to occupy areas north and west of the main Otway Range (Land Conservation Council Victoria, 1978). The grassy plains of the Corangamite region provided attractive grazing grounds. In the early days sheep were favoured, but in the 1870s many farmers turned to dairying.

Occupation of the Otway Ranges was less attractive, due to the difficulties of clearing large trees and dense scrub. Travel was also a problem within the ranges, until a railway line was completed, from Birregurra to Forrest in 1891 (Land Conservation Council Victoria, 1978). Until the railway was built, timber-cutters were dependent upon ships for transport. In 1886, the first sizeable inland mill began operation on Monday Creek. Timber was transported to the railhead at Forrest. By 1902 the timber industry was booming, only to decline by the 1930s.

Today, the Otway Ranges are still managed for forestry. Logging is undertaken from pine plantations, as well as eucalypts and other natives (CCMA, 2003a). The Otway Ranges also provide opportunities for camping, bushwalking, nature tourism and four wheel driving. Within our study area only a portion of the forested area is maintained as a nature reserve. Indeed, some 85% of the larger Barwon Catchment has been cleared of native vegetation with the principle landuses now livestock grazing, dairy and dryland agriculture (Figure 2.4). Interspersed within the grazing land are blocks where cropping is undertaken and land is irrigated for modified pastures. In a discrete number of locations oil seeds and oleaginous fruits are produced and vine fruits, vegetables and herbs are irrigated. Pig farming is undertaken in a single location near Lake Murdeduke.

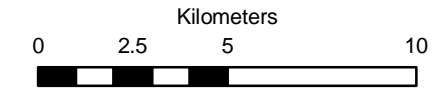
Many townships within the Barwon Catchment support residential, commercial and industrial landuses. Towns located within the upper Barwon area include Forrest, Barwon Downs, Deans Marsh, Moriac and Winchelsea.

Figure 2.4



Modelling of Sediment Erosion and Deposition in the Upper Barwon Catchment

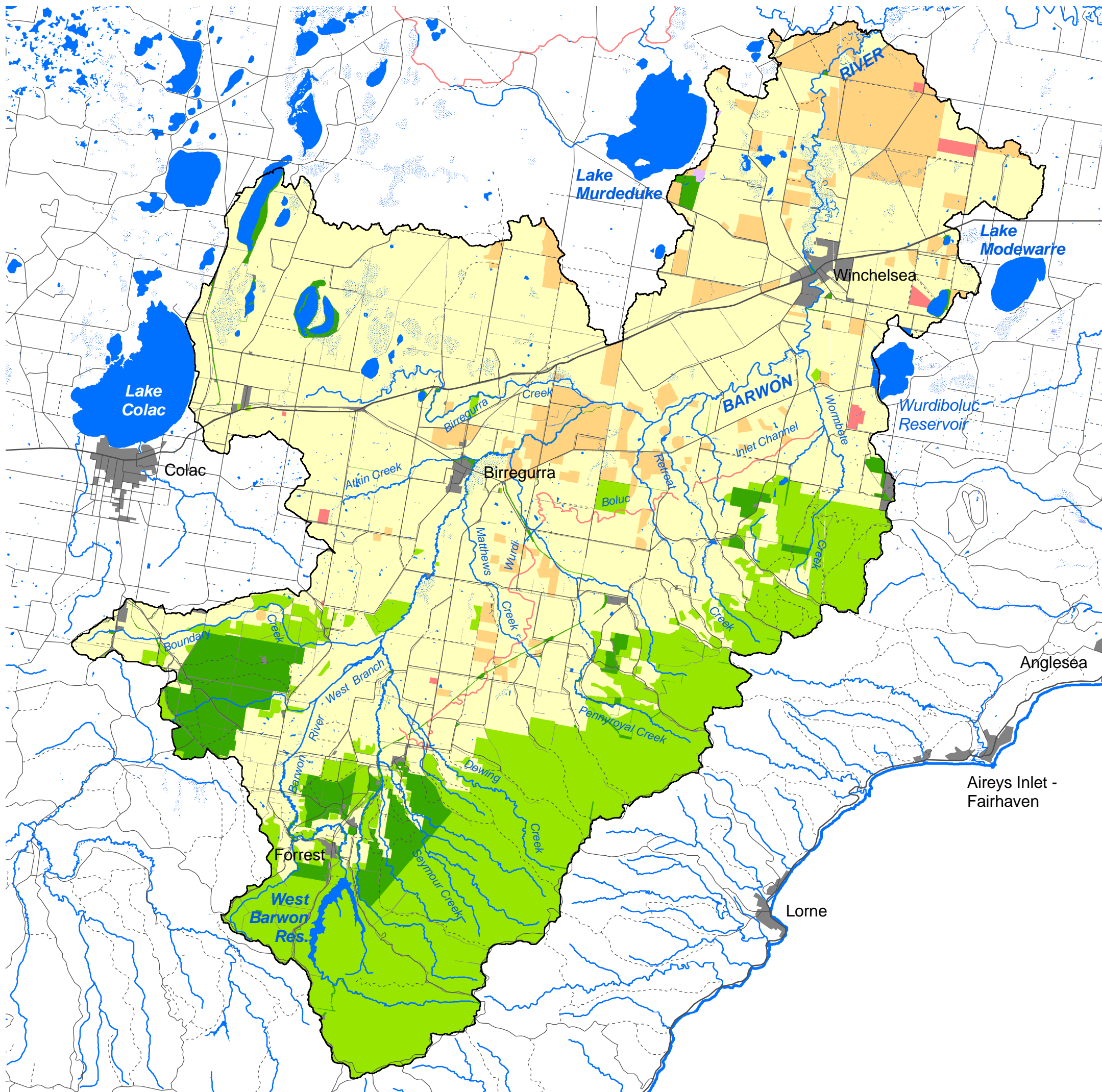
LANDUSE (2002)



This landuse map has been prepared using data compiled by the Bureau of Rural Sciences (BRS) for The Australian Government Department of Agriculture, Fisheries and Forestry. The classification scheme followed here was the Australia Landuse Mapping (ALUM) classification version 5 (BRS, 2001). ALUM version 5 was developed by BRS as a modification of Baxter – Russell Classification, in coordination with State agencies.

Description

- Cropping & cereals
- Grazing
- Lakes & water supply & water treatment
- Misc. agriculture
- Misc. horticulture
- Nature reserve
- Plantations and other forests
- Urban



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Water harvesting

The upper Barwon Catchment is used to supply part of the Geelong urban water demand. This supply is supplemented by a groundwater source at Barwon Downs Wellfield, but most of the flow is sourced from the West Barwon Reservoir and the East Barwon River. Diversions are passed down the Wurdee Boluc Inlet Channel, which can pick up supplementary flows from a number of the tributaries it crosses on the way to the Wurdiboluc storage (Figure 2.5). Flows are picked up using small weirs and branch channels. The flow sources are:

- West Barwon Reservoir;
- East Barwon River;
- Callahan Creek;
- Dewing Creek;
- Gosling Creek;
- Matthews Creek; and
- Pennyroyal Creek.

A study by SKM (2000b) estimated that the water demand is 25% of yield at off-take. The pumping of groundwater at Barwon Downs influences (reduces) flow in Boundary Creek. Since this study was completed, the water supply off takes on Gosling and Dewing Creeks have been decommissioned (Greg Peters, CCMA, *pers. comm.*).

Southern Rural Water (SRW) has direct irrigators throughout the entire Barwon River System. In addition to these demands there are other private diverters such as domestic and stock, commercial and winter fill licences as well as farm dams.

Inter-basin transfers

Beginning in the 1950s, water from the Lake Corangamite Basin has been transferred into Birregurra Creek during times of flood via the Lough Calvert Outlet. Flows in Warrambine Creek (not located within the study area) have also been increased by diversions from Woody Yallock.

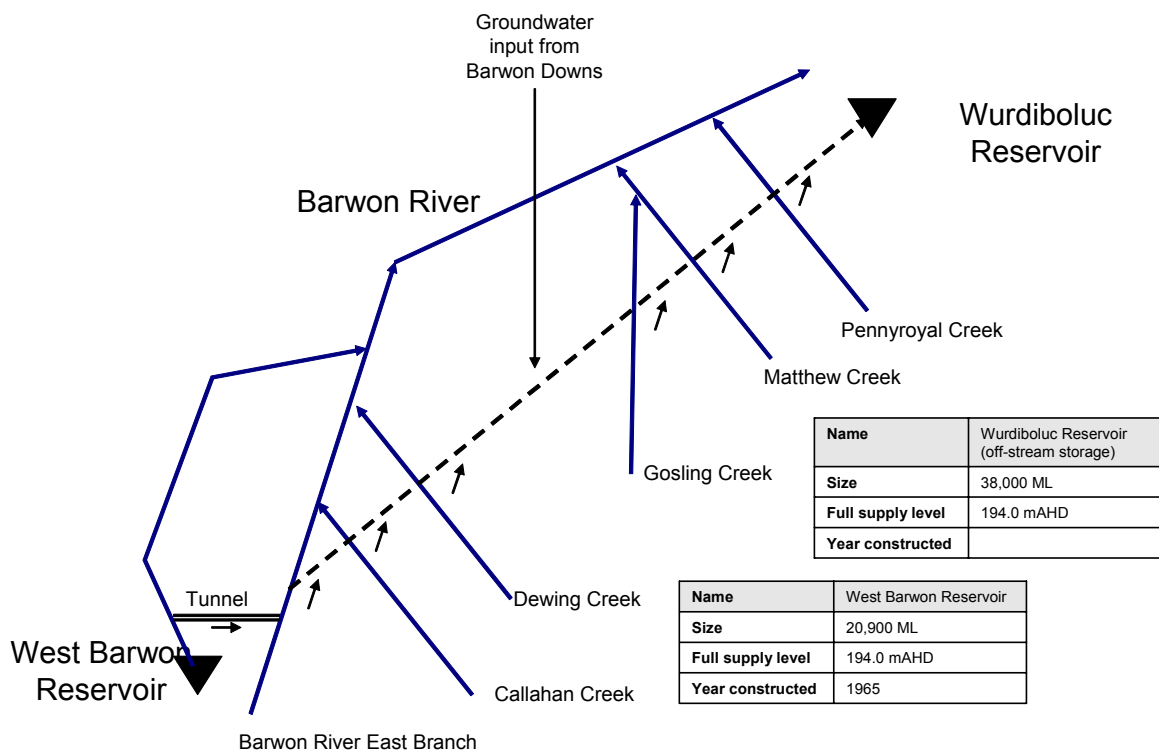


Figure 2.5: Schematic of the diversion network supplying the Wurdiboluc Reservoir.



3. Chronology of adjustment

Our review of the historical information of the upper Barwon Catchment provides us with a general chronology of geomorphologically significant events (Table 3.1). These events would have affected the rate of sediment yield and delivery to the channel network and sediment transport within the channel. The chronology relates to the main independent controls on channel form and indicates punctuation points in the evolving morphology of the stream network. The combined effect of rainfall/flow patterns and the level of catchment disturbance largely determines the rate of change of fluvial processes.

The following review breaks the study area into three zones: the Otway Ranges, the Barwon River below the Otway Ranges and the Barwon Downs. A geomorphically significant event common to each of these zones is the post 1997 drought. Recently, below average rainfall and streamflow has been observed in southeastern Victoria (see Section 2.4). Drought conditions will have stalled the rates of hillslope, gully and riverbank erosion observed within the study area.

3.1 The Otway Ranges

Over 1,000 sites of mass movement have been mapped within the Corangamite CMA area. The upper reaches of the Barwon River, and tributaries such as Pennyroyal and Deans Marsh Creek, are highly susceptible to mass movement. The mass movement event most commonly cited in the literature is a 48 hectare landslide occurring in June 1952, which caused the impoundment of the Barwon River East Branch. A 1.6 km lake resulted, located 5 km south of Forrest. In the following year the landslide was breached, causing downstream sediment deposition and river channel change. Many acres of dairy farm land were covered by 1 m of silt (DEG, 2003).

3.2 Barwon River below the Otway Ranges

Under indigenous land management, the upper Barwon Catchment would have enjoyed relatively stable geomorphic conditions. However, catchment disturbance was initiated by changed landuse, when the original vegetation was cleared for sheep and cattle grazing. In the early 1900s swamps and wetlands were drained and sections of tributary streams channelised in order to promote farming lands. This precipitated a massive phase of channel adjustment that continues to this day.

Flow regulation of the Barwon River began in 1927, with the construction of the Wurdiboluc Reservoir. The Wurdee Boluc Inlet Channel is still used to divert water from the Barwon River East and West Branches and tributaries to the Wurdiboluc Reservoir. The capacity of the reservoir was enlarged in 1955 and in 1965 a dam was also built on the Barwon River West Branch above Forrest. River regulation has caused channel contraction in the West Branch (CCMA, 2004), and has promoted channel invasion by exotic vegetation such as willows (Craigie *et al.*, 2002).

The Soil Conservation Authority has been active in the upper Barwon Catchment and, more recently, Landcare has been an active participant in landscape management. Landcare have initiated pest plant and rabbit control, tree planting and pasture renovation. Currently the Corangamite CMA is continuing with bed and bank stabilisation works (e.g. Matthews and Wormbete Creeks).

3.3 Barwon Downs

The West Barwon Reservoir and the East Barwon River are used to supply part of the Geelong urban water demand. This supply is supplemented by a groundwater source at Barwon Downs Wellfield. SKM (2000a) found that a small amount of subsidence has occurred over the Barwon



Downs Region and that the majority is most likely attributed to the effects of groundwater pumping. Some subsidence was also attributed to reduced groundwater levels associated with drought periods during the survey period. However, the subsidence measured was not considered to be significant.

Table 3.1: Chronology of adjustment for the upper Barwon River Catchment¹.

Date	Event	Significance
Pre-1800s	Indigenous land management.	Relatively stable morphology.
Post 1837	European occupation: – grazing of the Volcanic Plains; and – logging in the Otway Ranges.	– Native vegetation cleared. – Damage to soil by stock. – Introduction of rabbit population.
1927	Wurdiboluc Reservoir constructed.	Flow regulation.
1940s	Channelisation of tributary streams. Drainage of swamps and wetlands (e.g. Wormbete Creek).	Channel incision initiated.
1943	Start of stabilisation works in the Wormbete Catchment.	Bed and bank stabilisation.
1951	Significant flood in the Wormbete Creek Catchment.	
June 1952	Landslide blocks the East branch of the Barwon River.	Barwon River impounded, creating Lake Elizabeth.
1953	Landslide breached.	Downstream sediment deposition and river channel change. Many acres of dairy land covered by silt.
1955	Storage capacity of the Wurdiboluc Reservoir increased.	Flow regulation.
Late 1950s	Lough Calvert Drainage Scheme initiated.	– Diversion of flood water from Lake Colac into Birregurra Creek. – Increased erosion of bed and banks in Birregurra Creek.
1964	Construction of the West Barwon Dam.	– Further flow regulation. – Downstream channel contraction.
1972	Soil Conservation Authority works in the Wormbete Catchment: – head control structures; – silt traps; and – tree planting.	Bed and bank stabilisation.
1976	Major flood in the Wormbete Catchment.	
1983	Barwon Downs borefields begins operation.	– Subsidence. – Reduced flow in Boundary Creek.
Early 1990s	Landcare – 51 Landcare Groups registered across the Corangamite Region in 1993.	Pest plant and rabbit control, tree planting and pasture renovation.
1995	Major flooding in the upper Barwon Catchment.	– Barwon River breaks its banks in Winchelsea. – Severe erosion and damage to existing stabilisation structures in Wormbete Creek Catchment. – Coalmine flood.
Post 1995	Extensive program of stream stabilisation works following the 1995 flood.	
1997	CCMA established by the Victorian Government.	
1990s/2000s	Drought period.	Stalled rates of soil erosion.
c. 2000-2003	Barwon aqueduct landslide.	Embankment failure and reinstatement.

¹Sources: Evans (1986), RWC (1986a), RWC (1986b) Norman (1993), ID&A (2001), Craigie *et al.* (2002), DEG (2003) and EarthTech (2003a).

4. SedNet sediment budget

Sediment budgets identify sediment sources (hillslopes, gullies, riverbanks) and sediment sinks (channel bed, floodplain, lakes and reservoirs) and can be used to identify dominant erosion and sedimentation hotspots. Combined with an appreciation of sediment transport processes, sediment budgets can be used by land managers to optimise erosion control using limited resources.

4.1 Introduction to the SedNet model

SedNet is a computerised river sediment budgeting tool developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO, see Wilkinson *et al.*, 2004b). SedNet computes sediment budgets for individual river reaches, or links, by calculating the net difference between imported sediment at the top of the link and exported sediment at the bottom of the link, after accounting for erosion or deposition within the link (Figure 4.1 and Figure 4.2). Where sediment is exported from a link this material is added to the budget of the downstream link and so on to the lowest link in the system at the catchment outlet. In this way, patterns of erosion and sedimentation can be assessed to identify dominant erosion processes and management hotspots across river networks.

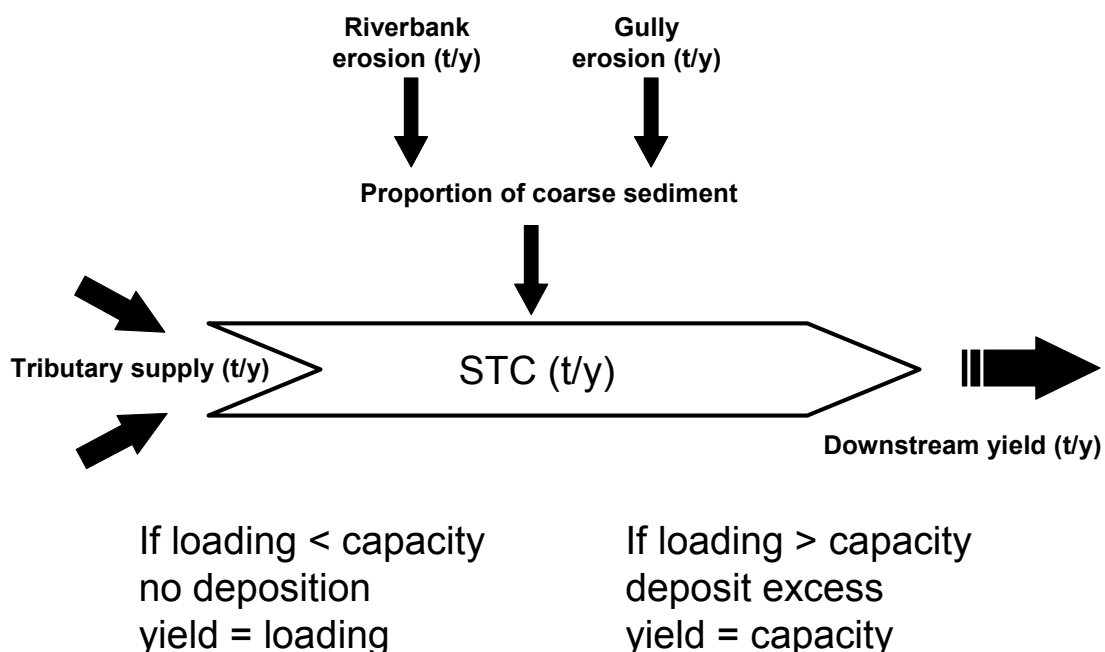


Figure 4.1: Components of the river link bedload sediment budget (where STC is sediment transport capacity, after Wilkinson *et al.*, 2004b).

SedNet requires spatially explicit input data (geographic grids and shapefiles), as well as time series data and parameter information. The resolution and quality of model inputs can have a profound impact on model outputs. The digital terrain model (DTM) of the study area is fundamental to achieving the best possible outcomes from the SedNet modelling process. The DTM is used to derive information such as ground slope, water flow direction, catchment areas and drainage network. The drainage network is subsequently divided into stream links and a sediment budget calculated for each link. The Information on the model inputs and model development are documented in Appendix A.

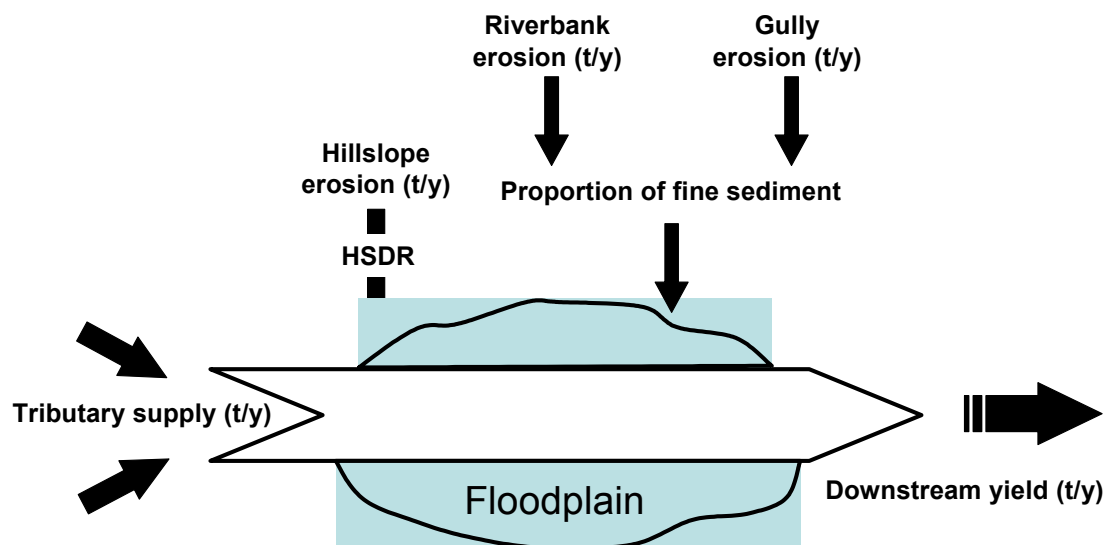


Figure 4.2: Components of the river link suspended sediment load budget (where HSDR is a hillslope delivery ratio, after Wilkinson *et al.*, 2004b).

The SedNet sediment budget provides an estimate of mean annual values (averaged over 100 years) for sediment inputs from hillslopes, gullies and bank erosion. Eroded sediment is either exported from the study area to the lower Barwon River, or stored within the catchment in artificial reservoirs, on floodplains or in channel bed deposits. SedNet calculates separate sediment budgets for the bedload and suspended sediment supply. The components of the bedload and suspended budgets differ slightly. In the case of the bedload budget, there is no input from hillslopes as SedNet assumes that surface sheetwash and rill erosion provide negligible bedload sediment (Wilkinson *et al.*, 2004b). Also, the transport of suspended sediment is supply limited, but the transport of bedload is also limited by the transport capacity of the stream. Note that SedNet does not explicitly model mass wasting.

4.2 SedNet sediment budget for the upper Barwon River

The sediment budget for the study area indicates that, over the past 100 years, bank erosion has been the most important source of sediment input to the upper Barwon River, accounting for two thirds of the sediment yield (Table 4.1). Moreover, approximately 80% of sediment mobilised from source areas within the catchment is exported from the study area. The majority of sediment that remains in the study area is stored on the floodplain, with only 20% stored as bedload in the river channel or deposited in reservoirs.

Table 4.1: Summary sediment budget.

Budget item	Mean annual rate	
	(kt/yr)	(%)
Hillslope erosion	3	2
Gully erosion	48	33
Bank erosion	96	65
Total inputs	147	100
Net reservoir and channel deposition	5	4
Net Floodplain deposition	24	16
Export from the study area	118	80
Total outputs	147	100



Nationally, the proportion of riverbank to gully erosion to hillslope erosion is 0.26:0.35:0.39. The sediment budget for the upper Barwon River Catchment differs significantly from the national average. Like other Victorian catchments, for example the Goulburn-Broken and Western Port Bay Catchments, the proportion of bank and gully erosion, to hillslope erosion, is greater than the national average (Figure 4.3). And like Western Port Bay, the majority of sediment is sourced from riverbanks.

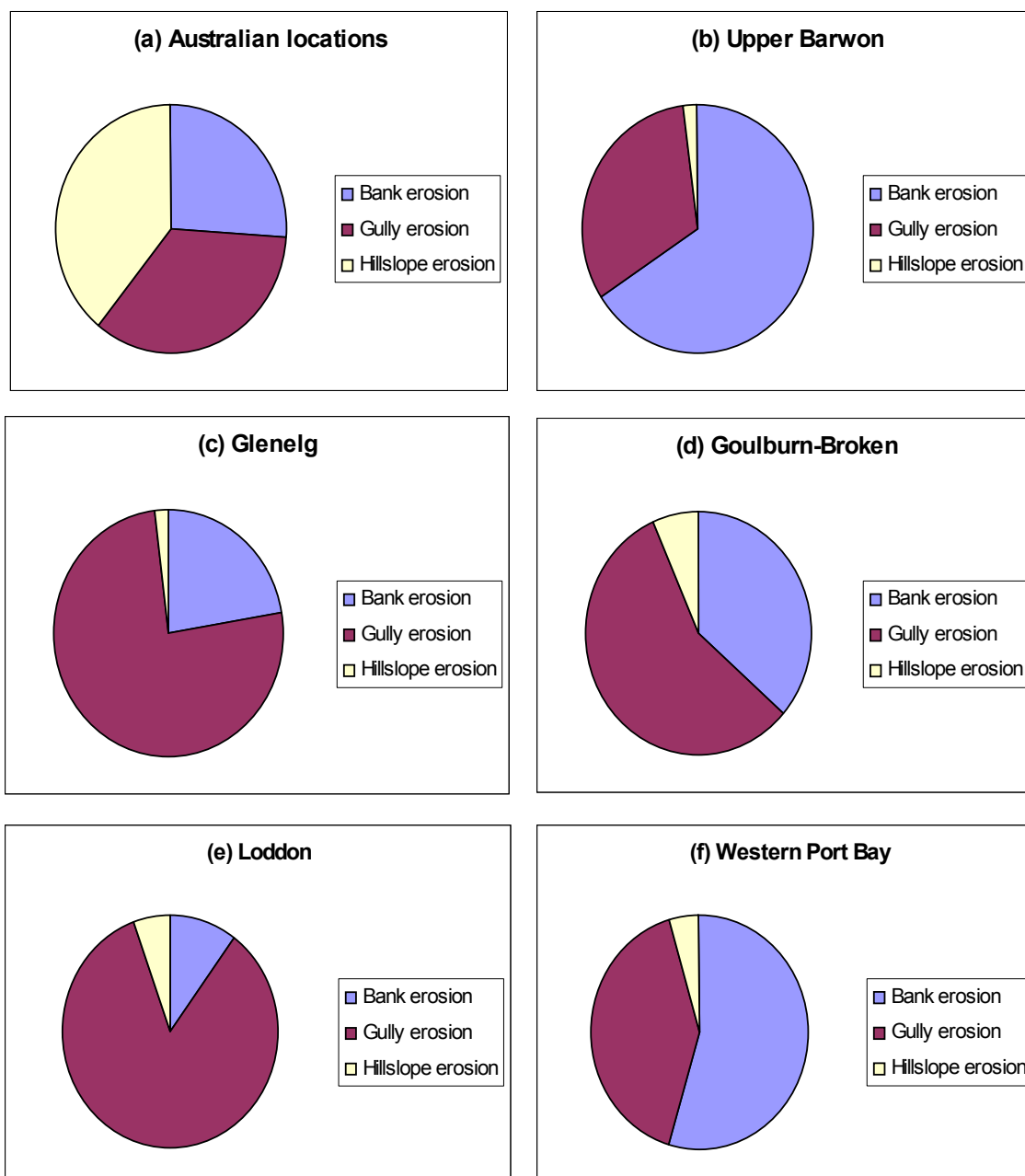


Figure 4.3: Example sediment budgets: a) Australian locations of intensive landuse and their surrounding catchments (NLWRA, 2001); b) the results of the current study; c) the Glenelg River and catchment (SKM, 2005b); d) the Goulburn-Broken catchments (DeRose *et al.*, 2003); e) the Loddon River and catchment (SKM, 2003); and f) Western Port Bay (Hughes *et al.*, 2003).



5. Hillslope erosion

Hillslope erosion refers to soil erosion by sheetwash and rills. The sediment budget for the upper Barwon Catchment indicates that hillslope erosion makes up only 2% of the total sediment input. Although this percentage is small, hillslope inputs may constitute a larger portion of the sediment budget in “hotspot” links as only one third of stream links supply 80% of the sediment to the upper Barwon River. Judicious management in targeted areas may help alleviate sediment ingress from this source.

SedNet assumes that hillslope erosion only supplies fine suspended sediment to the sediment budget, and not coarse bedload. The deposition of fine sediment in downstream reaches of the Barwon River (the Barwon River through Geelong, the Barwon Estuary and Lake Connemara) causes negative environmental and amenity impacts (CCMA, 2004). High rates of hillslope erosion are modelled in water supply catchments, where poor water quality is of economic consequence.

5.1 Past management

Information on the past management of hillslope erosion in the upper Barwon River Catchment is limited (Table 5.1). There are several Landcare groups operating within the Barwon area, and some of these groups have undertaken pest plant and rabbit control, tree planting and pasture renovation works. The Soil Conservation Authority, Landcare and the Corangamite CMA have each been involved in re-vegetation works. Other activities which have been undertaken within the study area for the minimisation of hillslope erosion include the fencing of high risk areas and the management of landslides.

Table 5.1: Past management of hillslope erosion within the upper Barwon Catchment.

Authority	Management action
Landcare and CCMA	<p><i>Riparian buffer strips</i></p> <p>While undertaking fieldwork in January of 2006, SKM observed newly established riparian vegetation and fencing of riparian zones at numerous sites within the study area (see also Table 7.1). Fencing and re-vegetation provides a number of benefits, for example the stabilisation of riverbank. An additional benefit is the provision of riparian buffer strips for the prevention of the ingress of eroded material into the channel by filtering sediment from overland runoff.</p>
CCMA	<p><i>Management of landslides</i></p> <ul style="list-style-type: none"> – Barwon aqueduct landslide. Embankment failure and reinstatement (DEG, 2003). – A landslip site adjacent to the Barwon River upstream of Birregurra is currently under observation by the CCMA. Future works may be proposed to prevent sediment entering the Barwon River at this site.
Landcare	<p><i>Management of rabbit populations</i></p> <p>Second generation landcare funding has been recently granted for an integrated rabbit control project and an integrated furze (gorse) control project in the upper Barwon River catchment (www.dse.vic.gov.au). Gorse provides a harbour for rabbits and other pest animals.</p> <p><i>Pasture improvement</i></p> <p><i>Fencing of high risk areas</i></p> <p>“Whole farm planning courses have been conducted throughout the Corangamite region over the past sixteen years that have encouraged landholders to fence their paddocks according to land capability” (Clarkson, 2003, p. 18).</p>

5.2 SedNet assumptions and outputs

SedNet calculates hillslope erosion by averaging a hillslope erosion input grid over each sub-catchment, multiplied by the sub-catchment area. The hillslope erosion input grid was derived



using the Revised Universal Soil Loss Equation (RUSLE, see Rosewell, 1997), where average annual soil loss by hillslope erosion, A , is given by:

$$A = R K L S C P$$

where R = rainfall erosivity factor, K = soil erodibility factor, L = slope length factor, S = slope steepness factor, C = crop and cover management factor and P = support practice factor (not used).

SedNet calculates the amount of sediment delivered to the stream as 10% of the gross amount predicted by the RUSLE. Work by Prosser *et al.* (2001) showed that 90% of eroded sediment, measured at the plot scale (with the RUSLE), remains on the hillslope in permanent or transient storage and is not delivered into the stream network over engineering time-scales. Figure 5.1 shows the RUSLE hillslope erosion input grid. Further information on the derivation of the hillslope erosion input grid is described in Appendix A.

The SedNet hillslope erosion output is presented in Figure 5.2. In this and subsequent chapters, we present SedNet outputs as high, moderate or low ranges of the mapped variable. We derived the ranking by sorting SedNet streamlinks according to the variable and summing their stream length. High rankings are given to the third of the stream length with the highest values, moderate to the next third of stream length, and low rankings to the third of streamlink length with the lowest variable values. We have chosen to show comparative, rather than absolute, values, as SedNet results are more reliably used to assess patterns of erosion and sedimentation (to identify management hotspots across the catchment) rather than the quantum of sediment mobilised or deposited.

Note that SedNet does not explicitly model mass wasting, for example landslides. Landslides occur primarily as a combination of extreme rainfall, slope aspect, vegetation and drainage. There are a number of areas in the upper Barwon Catchment that are prone to landslides and, relative to hillslope erosion, landslides present a very visible blight on the landscape.

The contribution of landslides to the sediment budget for the upper Barwon Catchment is currently unknown. Although landslide mapping does exist for the study area, without knowledge of the size of the landslide and an appreciation of connectivity to the drainage network, it is impossible to calculate how much sediment would be available for transport downstream.

5.3 Identification of priority areas

All inputs to the RUSLE influence the predicted rate of hillslope erosion, but in our experience the dominant factors relate to the slope steepness factor (S) and the cover factor (C). The cover factor describes the combined impact of vegetative cover and crop management. It is defined as the ratio of the soil loss from land under a variety of landuses compared to that of continuously tilled bare fallow ground (Rosewell, 1997). We assumed that the magnitude of cover factor increases in order of landuse, viz.: Urban Nature < reserve < Forestry < Grazing < Cropping and cereals.

Certain combinations of slope and cover give rise to “hotspot” areas, which are generally located in one of three locations:

- the steep slopes of the Otway Ranges, regardless of landuse;
- the steep flanks of the Barwon River (e.g. upstream of Birregurra) and tributaries (e.g. Boundary Creek southeast of Colac); and
- the moderate slopes where cropping and cereal production, or intense horticulture and agriculture, is undertaken (these hotspots appear as discrete blocks in Figure 5.1).

Figure 5.1

View looking south west along the Barwon River towards the Otway Ranges. Vertical exaggeration = 10X.
 As input to the analysis, a terrain model was compiled to the full extent of the grey area shown. The Barwon River catchment is shown colour coded (green to red) presenting the modelled hillslope erosion rate in tonnes per hectare per year.

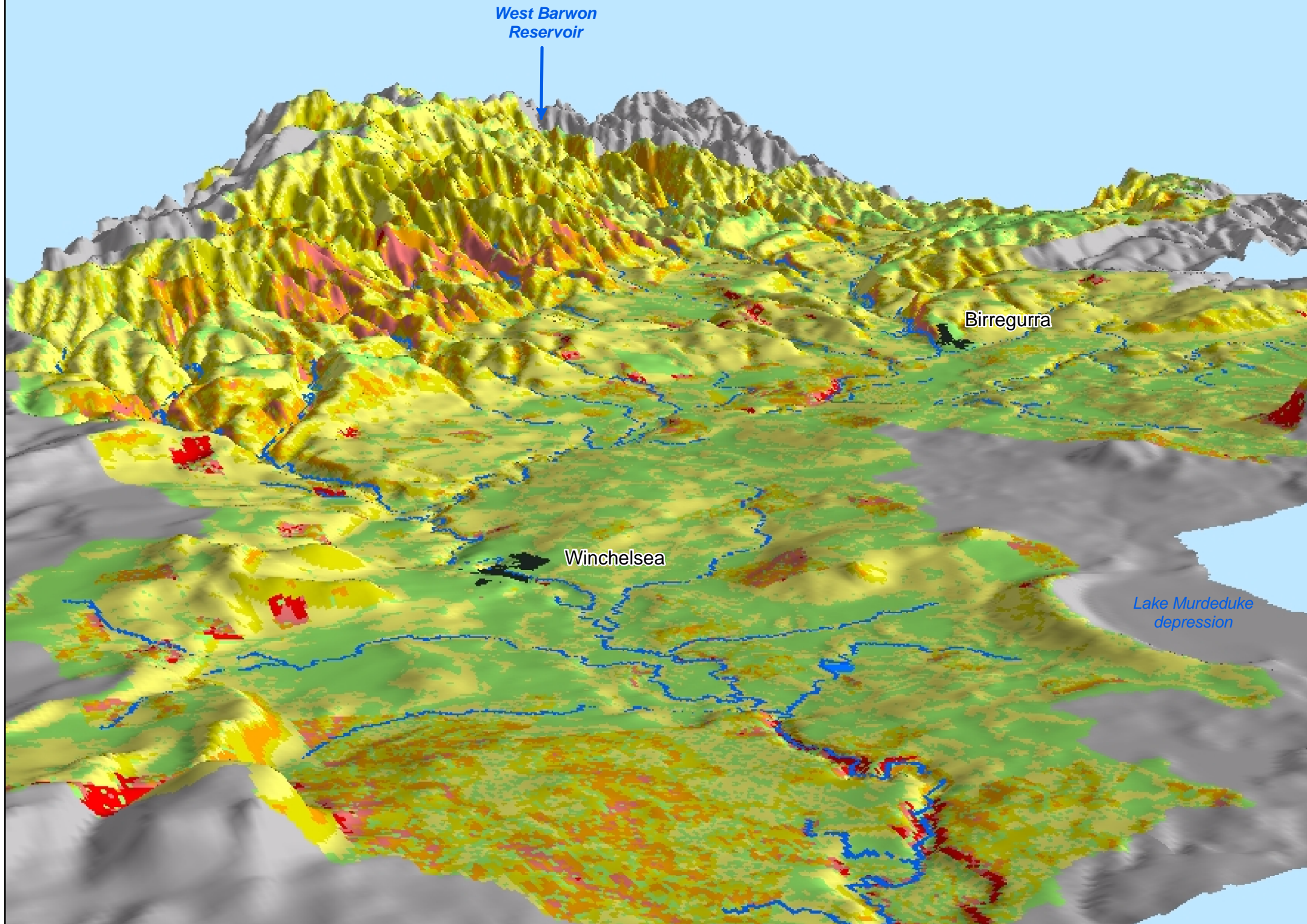


Modelling of Sediment Erosion and Deposition in the Upper Barwon Catchment

HILLSLOPE EROSION

Hillslope erosion (t/ha/yr)

	< 0.1
	0.1 - 0.5
	0.5 - 1.0
	1 - 2
	2 - 5
	> 5
	Not mapped



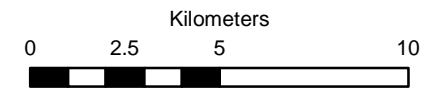
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Figure 5.2



Modelling of Sediment Erosion and Deposition in the Upper Barwon Catchment

**SEDNET OUTPUT
Hillslope Erosion**



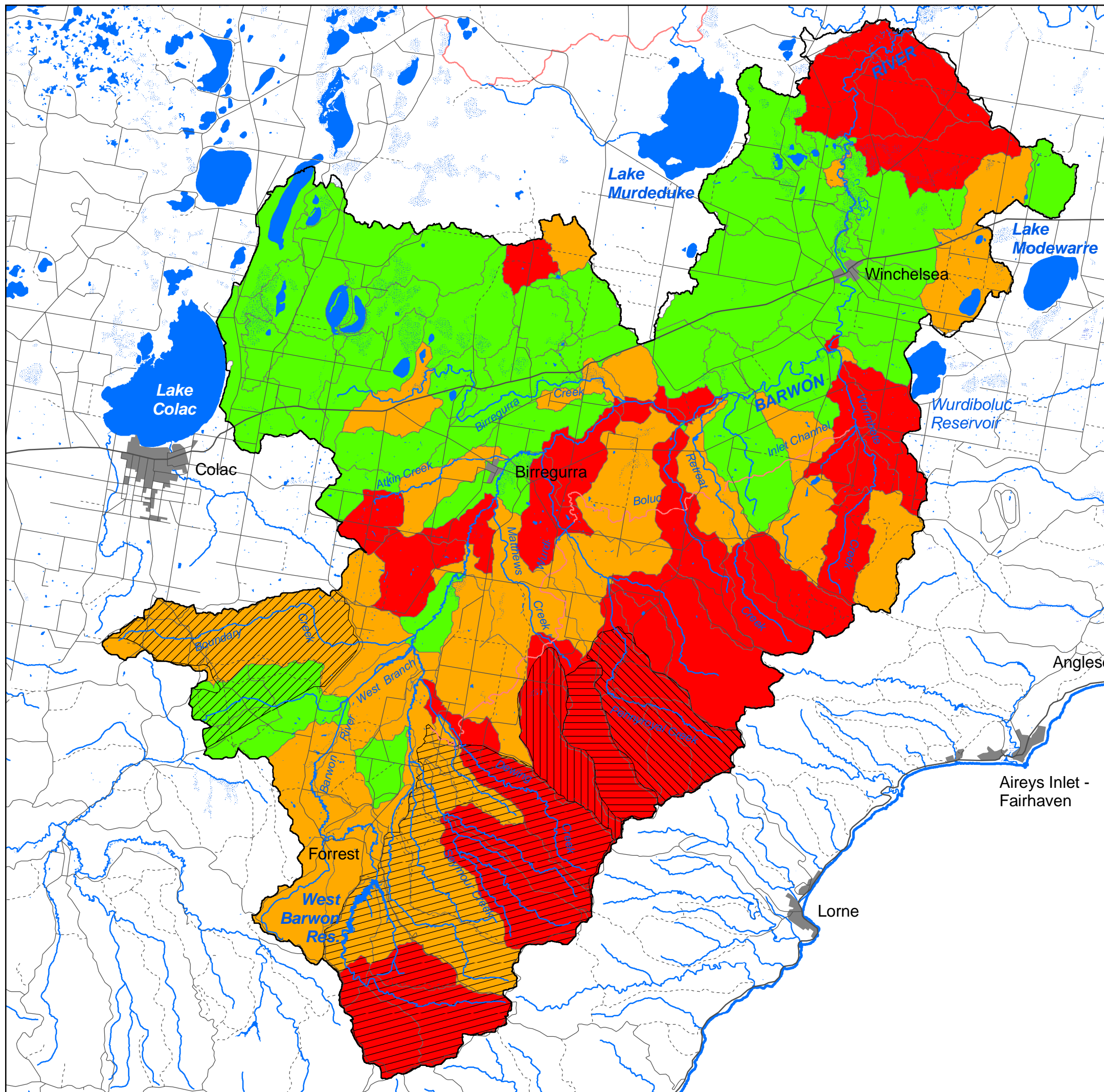
Legend

SEDNET Hillslope Erosion

- Negligible
- Low
- Medium
- High

Water Supply Catchments

- BARWON DOWNS WELLFIELD INTAKE (GEELONG)
- GOSLING CREEK
- MATTHEWS CREEK
- PENNYROYAL CREEK
- UPPER BARWON



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Hotspots of high priority for erosion control include areas where the distance to the drainage network is short. For example, some blocks of cropping and cereal farming are located some distance from the drainage network, but some are located on land adjacent to the Barwon River and tributaries. It is likely that soil lost from the well-connected hillslopes would have a greater chance of being entrained and thus contribute to the downstream sediment budget load. Conversely, sediment mobilised on plots away from the river would have a higher chance of being trapped in farm dams, contour banks, depressions, fences and riparian zones. Similarly, landslide zones well connected to the drainage network are likely to contribute to the downstream sediment budget.

Other hotspots of high importance are those located in water supply catchments. Surface water is currently harvested from Matthews Creek, Pennyroyal Creek and the upper Barwon River. Water is diverted into the Wurdi Boluc Inlet Channel and delivered to the Wurdiboluc Reservoir for storage and later distribution to Geelong and district. Poor water quality increases treatment costs and impacts negatively on the taste and clarity of potable water supply. It is therefore important to minimise the suspended sediment content of water harvested in water supply catchment areas and this can be done (in part) by minimising hillslope erosion rates.

Future priority areas for erosion control and current priority areas may differ, depending on future landuse within the study area. Climate change may impact on mean annual rainfall and the duration and intensity of storms, and this may also impact future rates of hillslope erosion.

5.4 Future management options

If hillslope soil loss is to be reduced, management intervention should seek to influence the crop and cover management factor (C) and the support practice factor (P) of the RUSLE. Other inputs to the RUSLE are dependent upon soil type, location and topography.

An obvious method for reducing the severity of hillslope erosion would be to convert priority areas to forestry, nature reserves or even urban areas; but this is unlikely to be feasible. A more feasible approach could be to improve the way in which the land is managed. That is, to address the support practice (P) factor by introducing various conservative farm and forest management practices (Table 5.2).

Table 5.2 Example methods to reduce soil loss from three landuse types.

Grazing	Cropping and cereals	Plantations and other forests
Landholder education to promote sustainable farming practices: – pasture improvement; – conservative stocking; – rabbit control; and – fencing of high-risk areas.	Landholder education to promote sustainable farming practices. Clarkson (2003) has proposed targets for bed farming, the retention of cereal stubble and direct drilling/minimum tillage.	Promote “Code of Practice” amongst public and private forest managers (Clarkson, 2003). Road design to reduce erosion and sediment entering waterways.

Aside from management actions that treat the source of sediment on the hillslopes, there is strong evidence to suggest that planting riparian buffer strips will prevent the ingress of eroded material into the channel by filtering sediment from overland runoff (e.g. Karssies and Prosser, 1999; Prosser *et al.*, 1999). The greatest benefits would result from the use of buffer strips at priority locations.

A respondent to the Corangamite CMA Soil Health Strategy suggested that education is also required to instruct landholders on how to live in environments prone to landslides.



5.5 Summary

- 1) Information on the past management of hillslope erosion is limited. But the Soil Conservation Authority, Landcare and the Corangamite CMA have each undertaken works in the study area relating to riparian buffer strips, rabbit management, pasture improvement, fencing high risk areas and management of landslides.
- 2) SedNet calculates hillslope erosion by averaging the hillslope erosion input grid over each sub-catchment, multiplied by the sub-catchment area. The hillslope erosion input grid was derived using the Revised Universal Soil Loss Equation. The sediment budget for the upper Barwon Catchment indicates that hillslope erosion makes up only 2% of the total sediment input. SedNet does not explicitly model mass wasting.
- 3) The highest rates of hillslope erosion occur on: (i) the steep slopes of the Otway Ranges, regardless of landuse; (ii) the steep flanks of the Barwon River and tributaries; and (iii) on moderate slopes where cropping and cereal production, or intense horticulture and agriculture, is undertaken.
- 4) It is almost certain that land within the Barwon Catchment will continue to be used for grazing, cropping, cereals and high intensity agriculture and horticulture. In these areas hillslope erosion will continue to contribute to the sediment budget, particularly in steep locations with dispersive soils. Improved land management practices can be used to minimise the rate of soil loss from hillslope erosion, and riparian buffer strips can be planted to prevent the ingress of eroded material into the channel by filtering sediment from overland runoff.



6. Gully erosion

For the purpose of the SedNet model, gullies are defined as steep walled, poorly vegetated incised channels with a small catchment area (Wilkinson *et al.*, 2004b). Gullies are a significant source of sediment within the upper Barwon River Catchment. SedNet modelling indicates that 33% of sediment input to the study area's stream network is derived from gully erosion. This constitutes an average annual supply of 48 kt/yr. Like hillslope erosion, the majority of sediment sourced from gully erosion is input to only a fraction of river links. In this case, 80% of the sediment sourced from gullies is input to just a third of river links.

The consequences of gully erosion include reduced water quality (through the release of suspended sediment) and the loss of productive land. The effective management of gully erosion could potentially improve water quality and minimise the deposition of fine sediment in the downstream reaches of the Barwon River.

6.1 Past management

Information on the past management of gully erosion in the upper Barwon River Catchment is limited. Clarkson (2003 p. 17) provides the best description of past management actions:

“Gully and tunnel erosion sites have been rehabilitated within the Corangamite Region. Works conducted have included construction of diversion banks and rock chutes, battering of banks and stabilising sites with vegetation. Rabbit control prior to works was always essential. Although at times costly, the majority of on-ground works to stabilise erosion have been successful.”

Recently, the Corangamite CMA has actively managed gully erosion. Significant gully erosion sites are under observation by field staff and a study was commissioned by the Corangamite CMA into Wormbete Creek tributary gully erosion (EarthTech, 2004).

6.2 SedNet assumptions and outputs

SedNet requires a gully density map (in units of km/km²) as input. This input is used to calculate the gully length per sub-catchment. The gully length is then multiplied by gully cross-sectional area to estimate the total volume of sediment liberated in each sub-catchment. Average gully age is used to calculate the annual supply of sediment to the drainage network:

$$G_x = \frac{\rho_s \alpha}{\tau} (l_x)$$

where: G_x is the sediment supply, ρ_s is the density of the sediment, α is the mean cross sectional area of a gully, τ is the average age of the gullies and l_x is the gully length. The amount of fine sediment to bedload liberated by gully erosion is specified by the user through the proportion of suspended sediment.

Although the susceptibility for gully erosion has been mapped recently for the Corangamite area and a gully inventory has been produced (Miner, 2007), none of this information is suitable as a direct input for the SedNet model. Due to this lack of definitive gully density data for input to the SedNet model for the upper Barwon River, we derived gully density based on a consideration of the 1:25,000 topographic stream network and our field observations. To this end, we compared the 1:25,000 stream network mapped for the upper Barwon Catchment to the drainage network of



streams produced by the SedNet model using the DTM. The drainage network is used by SedNet to differentiate between sediment inputs from gully erosion over an area and bank erosion to the permanent stream network. The SedNet drainage network and the 1:25,000 stream network approximated each other almost precisely. We then subtracted (excluded) the SedNet drainage network from the 1:25,000 mapped stream lengths. The resulting data set was assumed to approximate the gully network and was formatted for input to the SedNet model. Hence the SedNet gully network input represents all low order channels regardless of channel morphology and hydrology. We excluded potential gullies from forested areas (using tree cover in 1995) as gullies are unlikely to form under trees.

During the fieldwork component of this study we inspected a number of first and second order streams marked on the 1:25,000 topographic network. We found that many of these streams were not contributing sediment to the drainage network (see Appendix C). Consequently, we factored gully density down by half uniformly across the catchment.

Verification of the SedNet input grid

Figure 6.1 shows the gully density input grid, with gullies observed in the field shown with orange symbols. This data is overlain by the default national scale NLWRA gully density grid. This grid was derived by a combination of mapped and modelled data to a cell size of approximately 260 m by 260 m. The mapped data was based on measurements obtained from previous aerial photographs and land degradation reports. The modelled data was based on regression tree models using environmental attributes.

The three sources of information indicate that the highest density of gullies is clumped around the centre portion of the study area. This area corresponds to the Dissected Tertiary Plains. The soil types of the Dissected Tertiary Plains are prone to gully erosion (Boucher, 2007). This finding is supported by an earlier study by Pitt (1981) into the land systems of the catchments of the Otway Range and adjacent plains. Pitt found that gully erosion in the upper Barwon River Catchment was concentrated around the alluvial and estuarine plains, and the hills of the lower- and mid-reaches of the tributaries draining the Otway Range.

The SedNet gully erosion output is presented in Figure 6.2. We present SedNet outputs in this chapter as high, moderate or low ranges of the mapped variable

6.3 Identification of priority areas

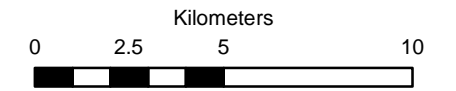
Our modelling, along with mapping by Pitt (1981), CCMA (2003b), Robinson *et al.* (2003) and Miner (2007), suggests that there are a number of land systems within the upper Barwon River that are at risk of gully erosion. However, regardless of risk, the greatest benefits will be gained from the treatment of gullies in areas where the sediment input from gullies constitutes a large portion of the sediment budget – areas where there is the greatest potential for change. For our purposes, such areas are those with high gully density, where the gullies have the potential to erode further and where the gullies are well connected to the drainage network. The treatment of gullies that have eroded to their full extent and that are not connected to the drainage network does not represent a strategic imperative.

Figure 6.1



Modelling of Sediment Erosion and Deposition in the Upper Barwon Catchment

ESTIMATED GULLY DENSITY (km/km²) and GULLIES OBSERVED IN THE FIELD



Estimated Gully Density

(km/km²)

- Negligible
- <0.35
- >0.35

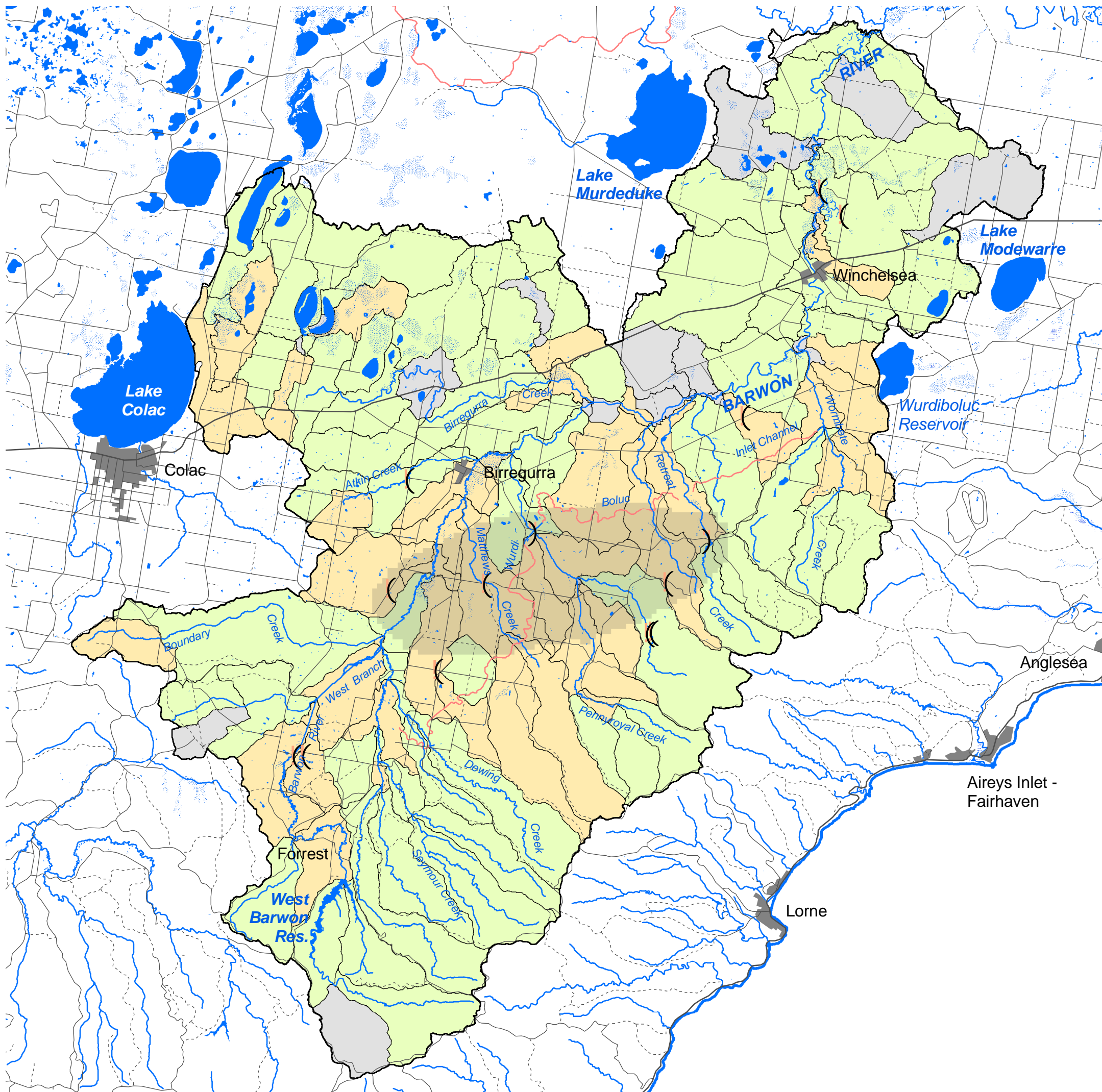
Gully Field Sites

- Gully, continuous with drainage network
- Gully, discontinuous with drainage network

NLWA Gully Density

(km/km²)

- 0
- 0.35 (shaded oval in centre)



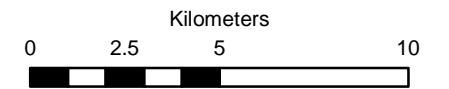
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Figure 6.2



Modelling of Sediment Erosion and Deposition in the Upper Barwon Catchment

**SEDNET OUTPUT
Gully Erosion**



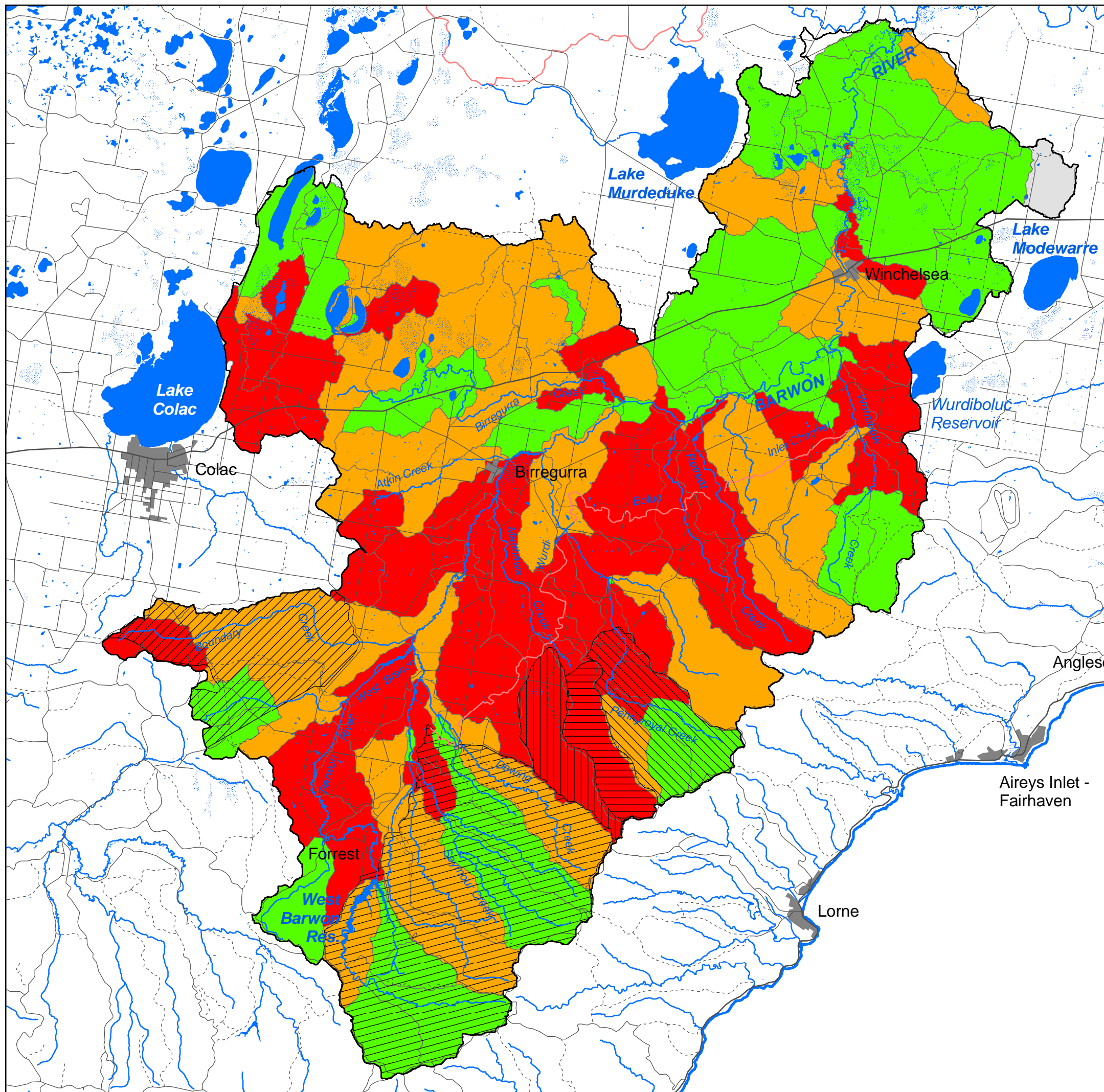
Legend

SEDNET Gully Erosion

- Negligible
- Low
- Medium
- High

Water Supply Catchments

- BARWON DOWNS WELLFIELD INTAKE (GEELONG)
- GOSLING CREEK
- MATTHEWS CREEK
- PENNYROYAL CREEK
- UPPER BARWON



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Gully density

SedNet outputs indicate that the rate of gully erosion varies considerably across the catchment, with one third of SedNet links supplying 80% of sediment input from gullies. The experience of Corangamite CMA staff also indicates that gully erosion hotspots exist within the study area. Greg Peters (CCMA) has indicated the forested headwaters of Wormbete Creek are a priority area for gully management, based on an assessment of aerial photography. Mapping by Pitt (1981) suggests that the headwaters of Wormbete Creek (contained within the Pennyroyal land system) are susceptible to gully erosion. But Figure 6.1 does not show a high density of gullies in the headwaters of Wormbete Creek. However the SedNet gully density input is calculated by taking the average gully density over sub-catchments. This averaging process may hide local “hotspot” areas. Figure 6.1 also suggests that the density of gullies in surface water supply catchments is generally low, with the exception of the headwaters of Matthews Creek.

Potential to erode further

Topography is a strong control on the limits of gully erosion (Prosser and Abernethy, 1996). For a given catchment area, gully heads in steeper terrain are more likely to continue eroding headward than gullies in flatter terrain. Similarly, for a given slope, gully heads with larger contributing areas are more likely to erode headward than gullies with smaller contributing areas. Therefore, priority gullies for erosion control works are those gully heads located in steep terrain and/or with large contributing area, as these are more likely to continue to erode and release sediment. Regardless of their potential activity, however, the majority of gullies observed in the field in high density areas appeared well connected with the drainage network (Figure 6.1).

6.4 Future management options

Rutherford *et al.* (2000) suggest that the rehabilitation of gullies is often an expensive and difficult task, with costs not necessarily commensurate with the benefits gained through reclaimed agricultural productivity. This expense is often due to the extensive length of the gully drainage network, the lack of fill material and poor upstream catchment conditions. Also, land subject to gully erosion is often marginal in terms of its agricultural productivity, and so potential agricultural gains are minimal. However, untreated gullies will continue to erode and deliver sediment to the stream network. Therefore, the “do nothing” approach is unlikely to be an attractive option.

The management principles for stabilising gullies are (after Rutherford *et al.*, 2000):

- aim to accelerate the natural process of recovery;
- always stabilise the bed before the banks;
- encourage colonisation of the channel bed by vegetation to accelerate stability; and
- plan to divert high flow out of the channel, but encourage low flows to assist re-vegetation.

Basically, the management options available are to divert water away from the gully, drop the water gently into the gully floor, or stabilise the gully floor. Potential management actions should also include fencing and re-vegetation, for example re-vegetation above priority gully heads to alter the contributing hillslope hydrology or re-vegetation of downstream areas to trap sediment before entering the stream.

6.5 Summary

- 1) Information on the past management of gullies is limited. Gully erosion control works have included tree planting, physical structures and the control of rabbit populations.



- 2) SedNet modelling attributes 33% of the sediment input budget to gullies. SedNet requires a number of parameters to calculate the sediment supply from gully erosion, including gully length, gully cross-sectional area and average gully age.
- 3) One third of SedNet links supply 80% of sediment input from gullies. For our purposes, priority areas for gully control works are those with high gully density, where the gullies have the potential to erode further and where the gullies are well connected to the drainage network. The highest density of gullies is clumped around the centre portion of the study area, on the dissected plains of the Tertiary Moorabool Viaduct Formation. The density of gullies in surface water supply catchments is generally low, with the exception of the headwaters of Matthews Creek.
- 4) Potential management options for the stabilisation of gully heads are to divert water away from the gully, drop the water gently onto the gully floor, or stabilise the gully floor. Potential management actions also include fencing and re-vegetation, for example re-vegetation above priority gully heads to alter the contributing hillslope hydrology.



7. Riverbank erosion

Riverbank erosion occurs through a number of processes, including slumping and scour. In our study area, bank erosion also occurs due to natural meander processes, stock damage and scour around willows (Craigie *et al.*, 2002). In the early 1900s, swamps and wetlands were drained and sections of tributary streams channelised to increase the area of arable land. The straightening of tributary streams has increased stream power and this has led to bed incision and bank instability. In the upper Barwon River Catchment, banks are formed predominantly in silt, and this is easily dispersed. Channel adjustment continues to this day.

SedNet modelling indicates that bank erosion is the most significant source of sediment in the upper Barwon River catchment. The SedNet sediment budget for the upper Barwon River attributes 65% of the sediment supply to riverbank erosion. But the majority of this is sourced from only a few river links. SedNet attributes 90% of the sediment supply to just a quarter of river links. So the judicious management of hotspot reaches has the potential to improve river health and water quality, and to restrict the downstream supply of fine sediment.

7.1 Past management

Bed and bank incision has been actively managed by the Soil Conservation Authority (SCA), Landcare and the Corangamite CMA (Table 7.1). These organisations have built grade control structures, rock chutes and gabions along Wormbete, Coalmine, Yan Yan Gurt, Retreat, Matthews and Pennyroyal Creeks. It may be too early to determine the success these works as many of the streams are still adjusting. Other activities within the catchment have aimed to stabilise riverbanks by fencing and re-vegetation of the riparian zone. Some willow removal has also been undertaken.

7.2 SedNet assumptions and outputs

SedNet estimates bank erosion as being proportional to bankfull streampower (Wilkinson *et al.*, 2004a). Streampower (Ω) is a function of the density of water (ρ), acceleration due to gravity (g), bankfull discharge (Q_{bf}) and the energy slope approximated by the channel gradient (S_x):

$$\Omega = \rho g Q_{bf} S_x.$$

In SedNet, bank erosion is also dependent upon riparian vegetation and floodplain width. If there is riparian vegetation along the entire length of the stream link, then zero bank erosion is assumed. If there is no floodplain, it is assumed that the channel is constrained by bedrock and that bank erosion will not occur.

For our model, we used the bank erosion coefficient to calibrate the SedNet output. The bank erosion coefficient was adjusted so that the maximum rate of bank retreat matched a realistic rate. In particular, the tributary streams draining the Otway Ranges were examined. Prior to the 1900s, these streams would have consisted of “chain-of-ponds”, swamps and wetlands. But these were drained and sections were channelised in order to promote farming lands. Therefore the channel width of tributary stream, divided by the years since channelisation, would represent the maximum rate of bank retreat for the study area. Despite this, SedNet predicts the highest riverbank erosion rates for the Barwon River, due to the higher mean annual flow rates and wide floodplain, and this was also taken into consideration during the calibration process.

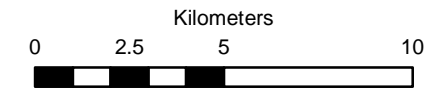
Information on bankfull discharge and the riparian vegetation and floodplain input grids are described in Appendix A. The SedNet bank erosion output is presented in Figure 7.1.

Figure 7.1



Modelling of Sediment Erosion and Deposition in the Upper Barwon Catchment

**SEDNET OUTPUT
Bank Erosion**



Legend

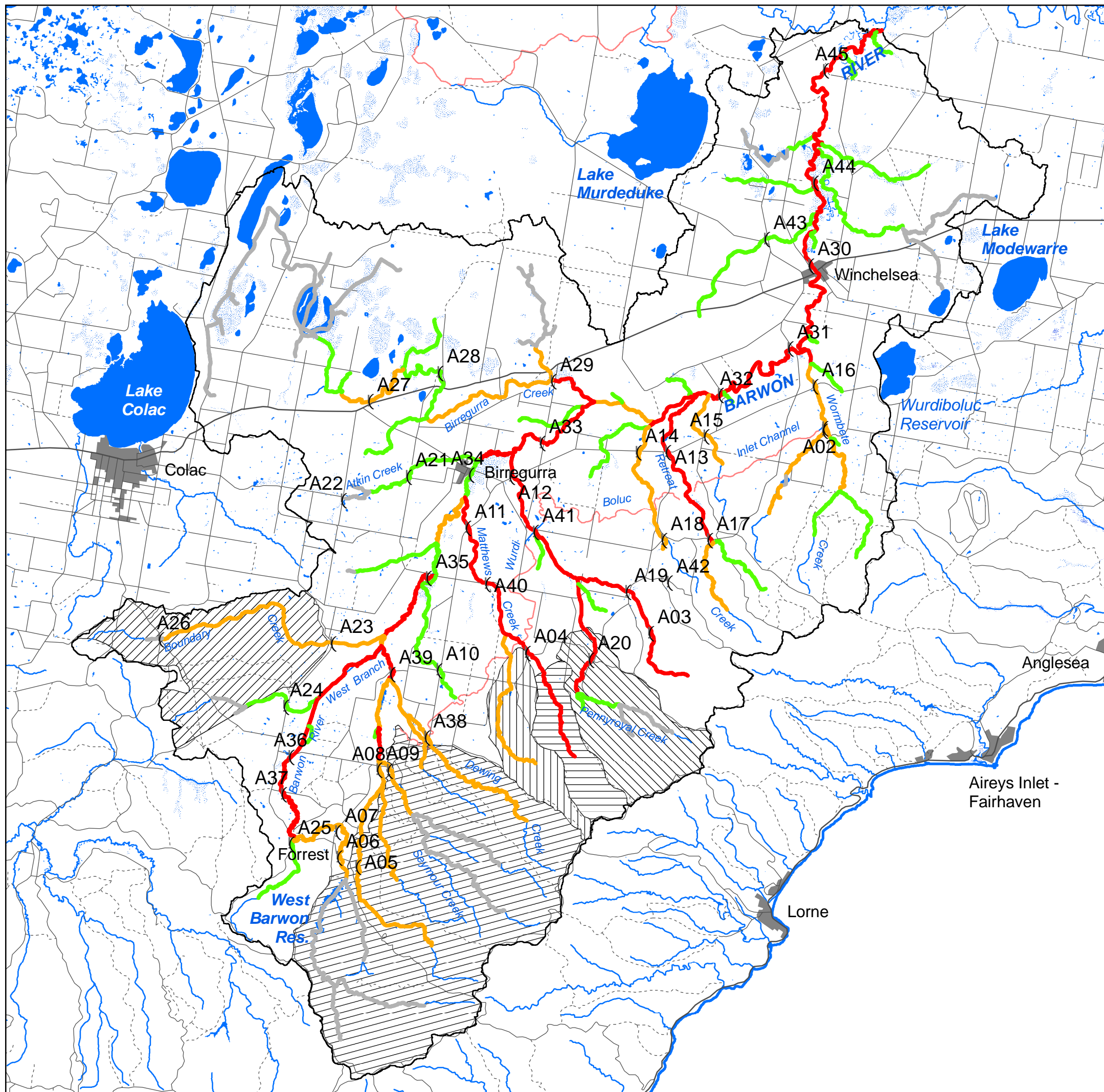
() Field Assessment Sites

SEDNET Bank Erosion

- Negligible
- Low
- Medium
- High

Water Supply Catchments

- BARWON DOWNS WELLFIELD INTAKE (GEELONG)
- GOSLING CREEK
- MATTHEWS CREEK
- PENNYROYAL CREEK
- UPPER BARWON



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One exception to the above was the case of Wormbete Creek. Wormbete Creek was one of the first tributary streams to be drained in the early 1900s in order to promote farming lands. The straightening of Wormbete Creek has increased stream power and this has led to bed incision and bank erosion. Wormbete Creek is now severely incised. At Assessment Site A1 on Wormbete Creek, just upstream of its confluence with Coalmine Creek, the channel is 21 m wide and 12 m deep. But the severity of the erosion problem was not reflected in the SedNet output. So the floodplain input grid was widened along Wormbete and Coalmine Creeks to provide a more realistic outcome, but this still only resulted in a “Moderate” prediction for the severity of the riverbank erosion problem on Wormbete Creek. The raw data output from the SedNet model shows that bank erosion in Wormbete Creek is actually the highest in the moderate category.

To explain this discrepancy we have put together Table 7.3, which contains data for selected SedNet reaches. The data describes factors affecting riverbank erosion rates, such as mean annual flow. This table shows that, although there is practically no vegetation and a moderately wide floodplain on Wormbete Creek, the mean annual flow multiplied by the link slope provides only a moderate result. However, when the SedNet input data are assessed it is clear that Wormbete Creek is very deep and wide for its catchment area when compared to other Otways tributaries (see outliers in Figure A.6 and Figure A.7). However, the input data format smoothes out these outliers and computes bank erosion rates for average width/depth conditions.

It is important to note that SedNet is designed to investigate patterns of erosion and sedimentation at the catchment scale, so it is not necessarily useful to compare SedNet outputs with observations at discrete field sites. Therefore Table 7.2 lumps field results and SedNet outputs at a reach level.

SedNet modelled high rates of bank erosion for the Barwon River (e.g. downstream of Retreat Creek). The extent of this high rating is greater than expected (Greg Peters, CCMA, *pers. comm.*). As mentioned in the previous section, SedNet estimates bank erosion as being proportional to bankfull streampower and also considers riparian vegetation and floodplain width. Thus SedNet has predicted the highest riverbank erosion rates for the Barwon River, due to the higher mean annual flow rates, wide floodplain and intermittent riparian vegetation cover.

7.4 Future management options

The incision of tributary streams is a major source of sediment in hotspot areas. In the past, conservation groups have built grade control structures, rock chutes and gabions along Wormbete, Coalmine, Yan Yan Gurt, Retreat, Matthews and Pennyroyal Creeks. The Corangamite CMA is currently involved in a number of programs to install control structures for the prevention of further incision of tributary streams. SedNet has predicted moderate to high rates of bank erosion for streams where works are located.

SedNet outputs suggest that Matthews, Pennyroyal, Deans Marsh and Retreat Creeks have the greatest need for treatment. However, we know that Wormbete Creek is chronically incised and potentially quite active as well.

In altered landscapes such as the Barwon, significant contributing factors to ongoing riverbank erosion are riparian degradation and unrestricted stock access to the river. Potential control options are stock exclusion fencing, off-stream watering points, stock and vehicle crossings and re-vegetation. Such activities are currently being fostered by the Corangamite CMA. The coordination of these activities could be improved by mapping the continuity and quality of riparian vegetation. The Corangamite CMA could also map the extent of stock access as an aid to its strategic management.



Table 7.2: Riverbank condition and riverbank erosion predicted by SedNet.

Stream reach	Bank condition (after Craigie <i>et al.</i> , 2002)	SKM field assessment	SedNet output	Agreement
Barwon River				
Barwon River West Branch	Channelised in parts. Bank erosion occurs due to natural meander processes, stock damage and scour around willows.	A06 – Stock damage A36 – Channelised A37 – Slumping due to stock damage	Negligible above Reservoir. Mod. to High below reservoir	✓
Barwon River East Branch	Channelised in parts.	A05 – No bank damage observed A09 – Channelised A39 – Widening due to slumping and stock access	Mainly Moderate	✓
Barwon River, from confluence of east and west branch to Pennyroyal Creek	Natural processes include bank erosion at outsides of bends, meander cutoffs and periodic avulsions.	A34 – Stock access and erosion induced by human use. Widening. A35 – Some scour and stock access. Moderate widening.	Low, Moderate and High	✓
Barwon River, from Pennyroyal Creek to Wormbete Creek		A31 – Some scour. Wider and deeper than natural. A32 – Some scour and stock access. Moderate widening. A33 – Looks incised and over-wide, but currently stable.	Mainly High	✓
Barwon River below Wormbete Creek		A30 – Minor undercutting. Has widened and possibly deepened in past. A44 – Stock access has led to mass failure. Moderate widening. A45 – gully side failure and pugging.	High	✓
Otway Range – tributaries of East and West Branches				
Roadknight Creek King Creek	Stream has been channelised in the lower reach.	A25 – Minor scouring. Stable.	Low Moderate	✓
Callahan Creek (+ Mackie and Seymour Creeks)	Bank erosion exacerbated by stock damage and scour around willow.	A08 – Rock beaching protects bank at bridge. No evidence of bank damage.	Negligible to Moderate	✓
Dewing Creek (+ Den Creek)	Stream channelised in parts. Major bank erosion observed – could be a response to bed degradation resulting from channelisation, as well as stock damage.	A38 – Has been channelised. Slumping. Has been subject to incision.	Moderate	✓

/cont.



Table 7.2 (cont.): Riverbank condition and riverbank erosion predicted by SedNet.

Stream reach	Bank condition (after Craigie <i>et al.</i> , 2002)	SKM field assessment	SedNet output	Agreement
Otway Range – tributaries of Barwon River				
Timmins Creek	Extensively channelised. May be affected by bed degradation.			
Matthews Creek (+ Gosling Ck)	Channelised in parts. Bed is degrading.	A04 – Channelised. Has incised and widened. Mass failure A11 – Channelised. Stock access has resulted in widening. A40 – Channelised. Has incised and widened. Mass failure.	High to Moderate	✓
Pennyroyal Creek (+ Deans Marsh Ck)	Channelised and incised in lower reaches. Bank erosion caused by loss of riparian vegetation and stock damage.	A03 – Appears stable. A12 – Channelised and chronically incised. A19 – Channelised. Chronically incised. Over-wide. Slumping and stock access. A20 – Appears stable. A41 – Scour. Is currently widening.	Mainly High, with Low and Negligible links in the upper reaches	✓
Yan Yan Gurt Creek	Channelised in parts. Previously subject to degradation. Parts are now aggrading. Bank erosion caused by bed lowering.	A14 – Appears stable. A18 – Widening due to stock access. A42 – Chronically incised. Mass failure.	Moderate	✓
Retreat Creek	Channelised in parts. Previously subject to degradation. Bank erosion caused by bed lowering.	A13 – Appears channelised. Mass failure on left bank. Moderate widening. A17 – Appears channelised. Slumping due to stock access.	Mainly High, with Low and Mod. links in the upper reaches	✓
Brickmakers Creek	Channelised in parts. Previously subject to degradation.	A15 – Slumping and stock access. Moderate widening.	Moderate	✓
Wormbete Creek (+ Scrubby/Coalmine Cks)	Channelised in parts. Subject to ongoing bed incision and bank erosion.	A01 – Chronically incised. A02 – Chronically incised.	Mainly Moderate, with Low in the upper reaches	✗
Left Bank tributaries				
Dividing Creek	Channelised in parts.	A24 – Appears stable.	Low to Negligible	✓
Boundary Creek	Downstream reaches have been channelised.	A23 – Localised slumping probably caused by stock. A26 – Minor localised bank erosion from stock access.	Moderate	✓
Atkin Creek	Channelised in parts. Has undergone incision. Eroding banks.	A21 – Some slumping and mass failure. A22 – Some slumping. Moderate widening.	Low to Negligible	✓
Birregurra Creek	Channelised in parts.	A27 – Localised stock access. A28 – Stock access. A29 – Channelised. Stock access.	Mainly Low to Mod., with High in the most downstream link	✓



Table 7.3: Factors affecting riverbank erosion rates for selected SedNet reaches.

Stream	Reach (SedNet link number)	Mean annual flow (MI/y)	Link slope	Flow x slope	Riparian cover (%)	Mean floodplain width (m)	Bank sediment supply (t/km/y)	Mean bank retreat rate (m/y)	SedNet ranking
Matthews Creek	Upper Matthews Creek (95)	4,250	0.0113	48	1.5	130	345	0.0984	High
Pennyroyal	Lower Pennyroyal (96)	15,760	0.0020	32	0.1	400	357	0.0844	High
Matthews Creek	Lower Matthews Creek (93)	8,930	0.0034	30	0.0	353	330	0.0831	High
Pennyroyal	Pennyroyal above Deans Marsh Creek (101)	7,350	0.0052	38	0.7	154	305	0.0805	High
Pennyroyal	Mid Pennyroyal (98)	14,080	0.0026	37	0.3	185	325	0.0786	High
Pennyroyal	Deans Marsh Creek (99)	4,880	0.0075	37	1.4	134	277	0.0754	High
Retreat Creek	Retreat Creek, lower branches (111)	5,490	0.0048	26	0.3	229	258	0.0682	High
Wormbete Creek	Wormbete Ck d/s conf w Coalmine Ck (117)	6,920	0.0038	26	0.0	174	238	0.0601	Mod
Wormbete Creek	Wormbete Ck u/s conf w Coalmine Ck (120)	4,090	0.0069	28	0.6	111	196	0.0534	Mod
Wormbete Creek	Coalmine Ck (118)	1,970	0.0111	22	0.3	68	111	0.0322	Mod
Yan Yan Gurt	Yan Yan Gurt (110)	1,980	0.0071	14	0.1	183	134	0.0382	Mod
Matthews Creek	Gosling Creek (94)	2,650	0.0088	23	1.9	59	104	0.0293	Mod
Retreat Creek	Retreat Creek, upper west branch (113)	1,920	0.0103	20	1.0	49	74	0.0225	Mod
Retreat Creek	Retreat Creek, upper east branch (112)	2,570	0.0116	30	2.0	8	21	0.0063	Low



7.5 Summary

- 1) Bed and bank incision has been actively managed by the Soil Conservation Authority, Landcare and the Corangamite CMA. These organisations have built grade control structures, rock chutes and gabions along tributary streams. Other activities within the catchment have aimed to stabilise riverbanks by fencing and re-vegetation of the riparian zone. Some willow removal has also been undertaken.
- 2) SedNet estimates bank erosion as being proportional to bankfull streampower. Bank erosion is also dependent upon riparian vegetation and floodplain width. If there is riparian vegetation along the entire length of the stream link, then zero bank erosion is assumed. If there is no floodplain, it is assumed that the channel is constrained by bedrock and that bank erosion will not occur. The SedNet sediment budget for the upper Barwon River attributes 65% of the sediment supply to riverbank erosion.
- 3) SedNet predicts that the highest rates of riverbank erosion are found along the Barwon River and Matthews, Pennyroyal, Deans Marsh and Retreat Creeks.
- 4) Options for the control of riverbank erosion include stock exclusion fencing, off-stream watering points, stock and vehicle crossings and re-vegetation. Such activities are currently being fostered by the Corangamite CMA.



8. Sediment export and deposition

This chapter addresses the export of sediment from the study area, as well as three types of sediment deposition: bed deposition, floodplain deposition and reservoir/lake deposition. SedNet modelling indicates that, on average, 147 kt of sediment is eroded per year from the upper Barwon River Catchment. Of this, the majority is exported as suspended sediment to downstream reaches. Sediment is also exported as bedload. Only 20% of eroded sediment is retained within the study area as riverbed, floodplain or reservoir/lake deposits.

In-stream sediment deposition occurs where the coarse sediment supply exceeds the sediment transport capacity of a given flow. When present in large volumes, sand can fill in the natural pool and riffle sequence of a stream beds, thus contributing to the loss of in-stream habitat. Sand slugs contribute to the loss of visual amenity and possibly exacerbate flooding risk.

Suspended sediment that does not drop out of suspension in reservoirs, or on the floodplain, is washed downstream. The deposition of fine sediment in downstream reaches of the Barwon River (the Barwon River through Geelong, Lake Connewarre and the Barwon Estuary) causes negative environmental and amenity impacts. High suspended sediment loads reduce stream clarity, inhibit respiration and feeding of stream biota, diminish light needed for plant photosynthesis, make water unsuitable for irrigation and require treatment of water for human use.

Water born erosion can cause sedimentation of farm dams and reservoirs through the impoundment of entrained sediment. Sedimentation results in reduced water storage capacities and will therefore reduce the usefulness of dams. Rates of sedimentation are dependent upon the rate of erosion within the dam catchment, and the trap efficiency of the dam.

8.1 Past management

Information on the past management of sediment deposition in the upper Barwon River Catchment is limited. Flooding in 1995 caused a private reservoir on Coalmine Creek to break its banks and spill sediment into the valley downstream. The sediment deposited on the Coalmine floodplain is being monitored by the Corangamite CMA.

8.2 SedNet assumptions and outputs

The transport of suspended sediment is supply limited, but the transport of bedload is controlled by both the supply of coarse sediment and the transport capacity of the stream. Bed deposition is the mean annual excess of supply of bedload over mean annual sediment transport capacity (STC, Figure 8.1). Bedload transport capacity is calculated using:

$$STC_x = k_1 \left(\frac{\sigma_a S_x^{1.3}}{w_x^{0.4}} \right)$$

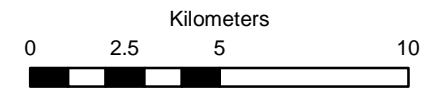
where: S_x is the link slope, w_x is the regionalised estimation of link channel width, σ_a is the annualised value of flow, and k_1 is a coefficient dependent on Manning n and the average particle size of bedload material (Wilkinson *et al.*, 2004b). Note that for six connected river links, SedNet failed to calculate σ_a and therefore STC_x . These links have been labelled “SedNet calculation error”.

Figure 8.1



Modelling of Sediment Erosion and Deposition in the Upper Barwon Catchment

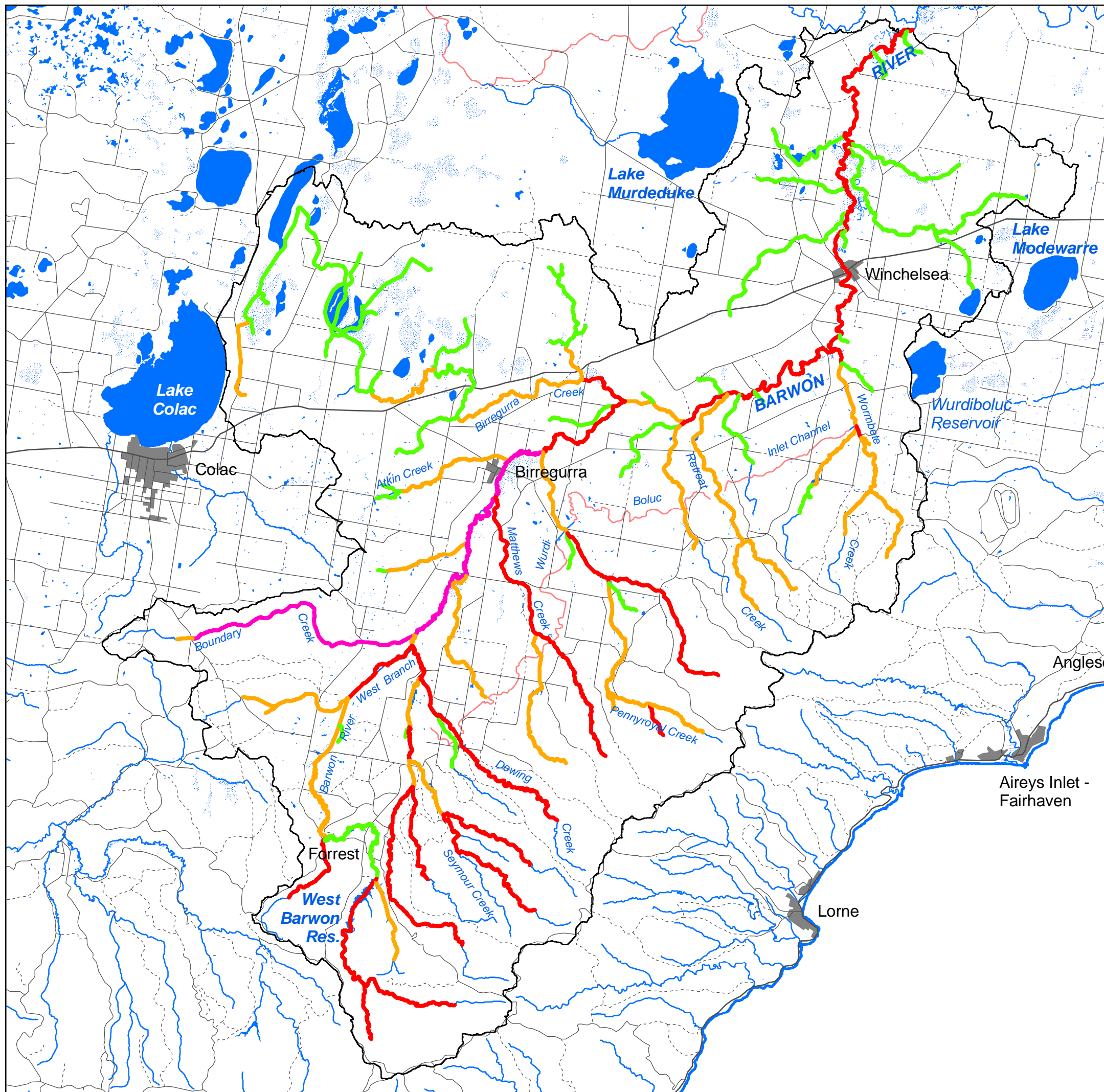
**SEDNET OUTPUT
Bedload Sediment Transport Capacity**



Legend

SEDNET Bedload STC

- SedNet calculation error
- Low
- Medium
- High



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SedNet assumes that there is no bed deposition where STC exceeds supply and that the river has the capacity over historical times to push through all of the bedload supplied. The model further assumes that the natural situation is one where, compared to the present, the bed is in equilibrium with the load and there is no net accumulation. The model spreads bedload evenly over the length and width of the riverbed in each reach considered.

Figure 8.2 shows the distribution of sites for the potential build up of bedload, as modelled by SedNet. These sites include lakes and reservoirs on the stream network, the upper reaches of Birregurra Creek and the Barwon River between Birregurra and Winchelsea.

SedNet assumes that the capacity of Australian streams to transport suspended sediment exceeds the suspended sediment supply. For this reason, suspended sediment is not deposited within the channel. Instead suspended sediment is deposited on floodplains. SedNet assumes that the mass of floodplain deposition is equal to the total suspended sediment load, multiplied by the proportion of overbank flow. Deposition on the floodplain is more common in the upper Barwon River (Figure 8.3), particularly on the floodplain of the Barwon River and Matthews, Pennyroyal, Deans Marsh and Wormbete Creeks.

The model assumes that reservoirs have the capacity to trap both fine and coarse sediment. All bedload is prevented from passing through reservoirs, but the sediment trapping efficiency for suspended sediment is dependent upon reservoir capacity and inflow. Lakes trap bedload, but not suspended sediment. Measured rates of reservoir sedimentation were not available to verify the sedimentation rates predicted by the SedNet model (Peter Brown, Barwon Water, *pers. comm.*).

SedNet models four and a half times as much floodplain deposition as (Figure 8.4). This is, in part, a function of the way in which the SedNet model has been calibrated. We have assumed that the proportion of fine sediment to coarse sediment is 80:20. This ratio is supported by the literature and was selected to reflect the lack of sand observed in the field. If, for example, a ratio of 50:50 was selected then SedNet outputs would indicate greater rates of reservoir and in-channel bedload deposition and reduced rates of floodplain deposition and export of fine sediment from the catchment outlet.

8.3 Identification of priority areas

In-channel bedload deposition

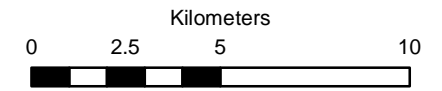
We undertook fieldwork in the upper Barwon Catchment from 16 to 19 January, 2006. Field observation suggested that bed material in the upper Barwon Catchment generally consisted of mud, with the occasional occurrence of boulders. There was only one site where sand deposition was observed in the channel. This was at Assessment Site A32 (Barwon River @ Kildean Lane). The sand did not appear to be particularly deep and only covered the bed in parts (see Figure 8.5). Corangamite CMA staff have also confirmed the presence of sand in the Barwon River at Winchelsea (Greg Peters, CCMA, *pers. comm.*).

Figure 8.2



Modelling of Sediment Erosion and Deposition in the Upper Barwon Catchment

**SEDNET OUTPUT
Bedload Deposition**



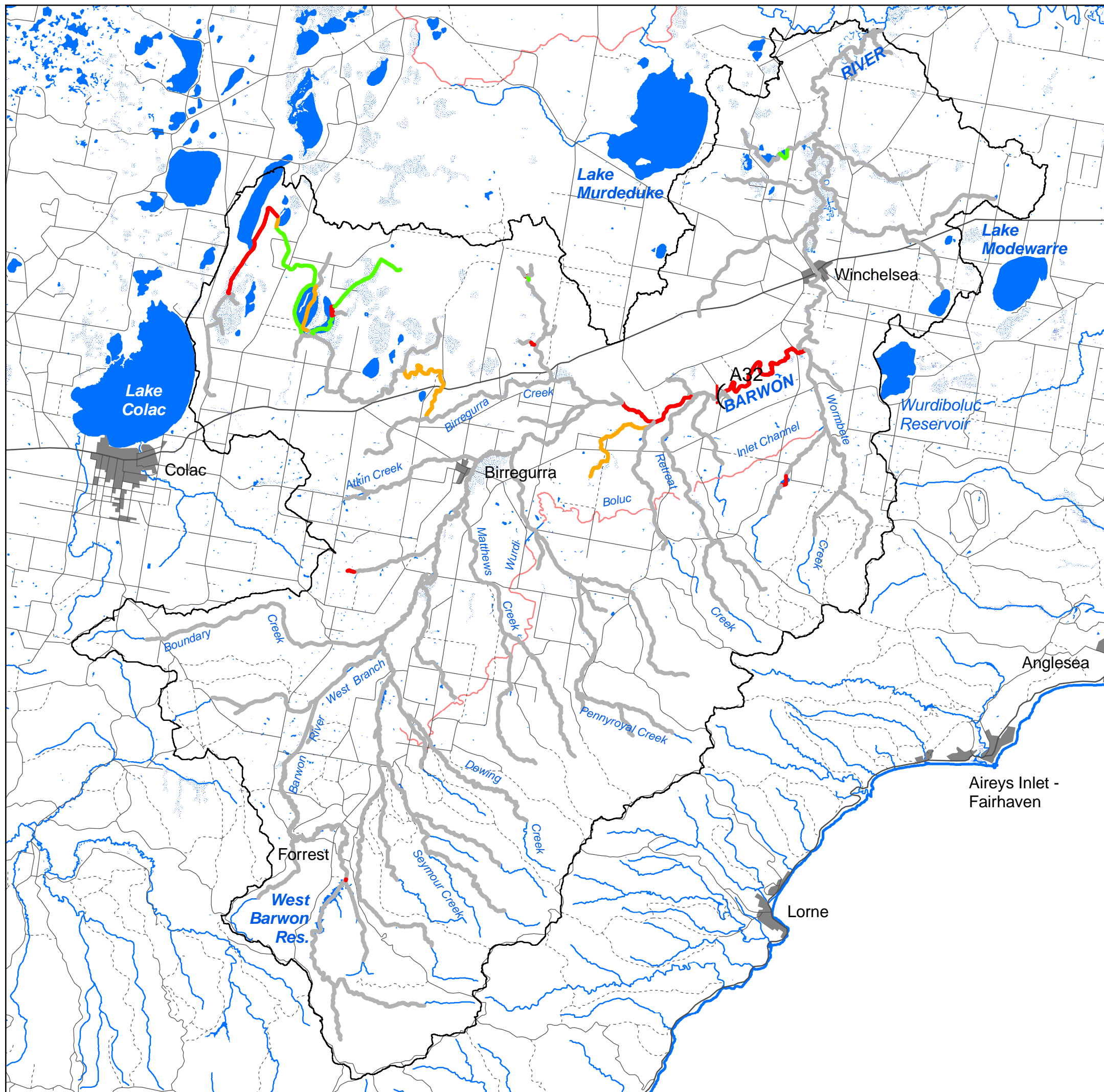
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Field Assessment Site



SEDNET Bedload Deposition

- Negligible
- Low
- Medium
- High



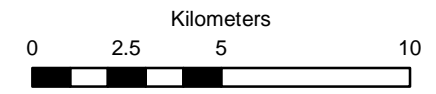
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Figure 8.3



Modelling of Sediment Erosion and Deposition in the Upper Barwon Catchment

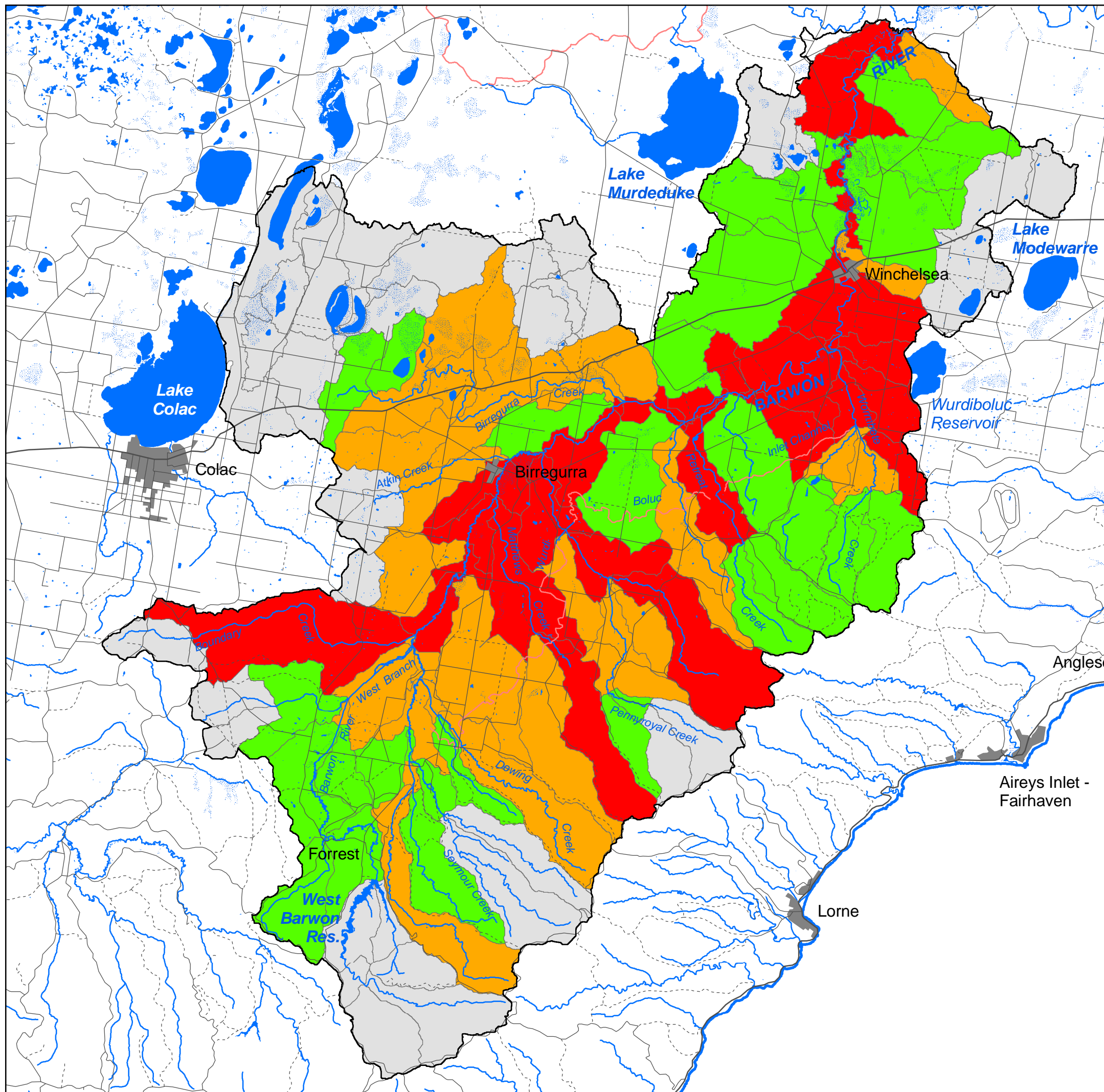
**SEDNET OUTPUT
Floodplain Deposition**



Legend

SEDNET Floodplain Deposition

- Negligible
- Low
- Medium
- High



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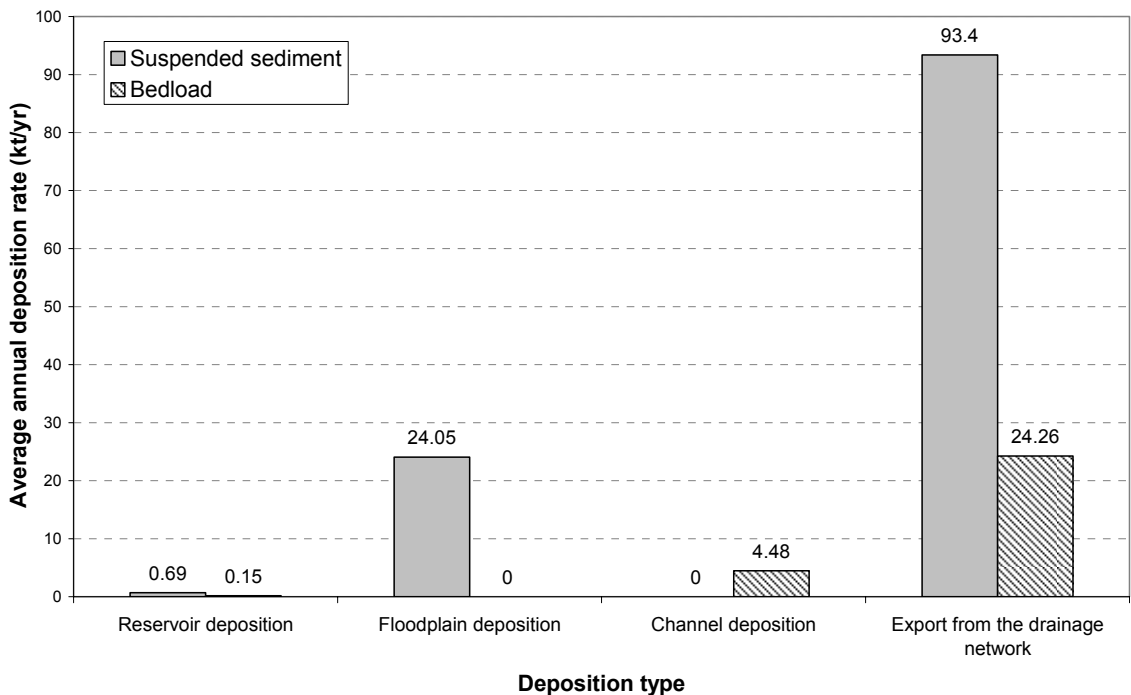


Figure 8.4: Sediment deposition in the upper Barwon River Catchment, by deposition type.



Figure 8.5: Assessment site A32.

SedNet results indicate a high risk of sedimentation for the Barwon River between Birregurra Creek and Wormbete Creek – which is where site A32 is located. Only one site was visited on this reach due access constraints. SedNet also predicted that bedload would accumulate in Birregurra Creek. If sand is not present in these reaches at the moment, there is a risk that sand will accumulate in the future. Large volumes of sand in the lower reaches of Birregurra Creek and Barwon River could smother the river bed and degrade habitat. However, the sand at site A32 is



currently thin and scattered across the channel. This sand poses little threat to the ecological health of the river. In fact, the overall in-stream habitat at this site appears to be excellent.

The upper reaches of Birregurra Creek have been channelised to serve the Lough Culvert drainage scheme – they have little ecological value. But the sedimentation of constructed channels may impact upon the delivery capacity of the Lough Culvert diversion scheme.

Floodplain deposition

Overbank deposition was not observed in the field, but SedNet has modelled overbank deposition of fine sediment for the majority of sub-catchments. The modelled depth of deposits varies, from zero to 1.4 mm/yr, with the largest depths modelled for sub-catchments with a wide floodplain and large suspended sediment supply. SedNet assumes that all suspended sediment deposited on the floodplain remains on the floodplain.

Reservoir deposition

SedNet modelling indicates that sediment will accumulate in most mapped reservoirs and lakes. Predicted sediment depths vary between 0 and 8 m (at the downstream reach of all links located within the West Barwon Reservoir). To our knowledge, the sedimentation of reservoirs and lakes is not a problem within our study area. But if sedimentation continues then this will reduce water storage capacities, potentially with economic consequences. Reservoir deposition would also be a problem if the reservoir was at risk of breaching. Breaching would result in a pulse of suspended sediment being released downstream – as was the case at the Coalmine site.

Sediment export

SedNet modelling indicates that 93.4 kt/yr of suspended sediment is exported from the study area per year. The deposition of fine sediment in downstream reaches of the Barwon River and Lake Connewarre causes negative environmental and amenity impacts

8.4 Future management options

Future management options should be focused on reducing sediment yields, but additional actions can be used to stabilise existing deposits to prevent re-entrainment.

SedNet assumes that all suspended sediment deposited on the floodplain remains on the floodplain. Field observation and SedNet modelling indicates that the magnitude of the bedload deposition problem does not warrant management intervention, as bedload is not currently impacting on in-stream health. But actions such as the exclusion of stock and re-vegetation of the riparian zone will help to stabilise existing sediment stores and prevent them from moving through the system and affecting downstream reaches, while reducing bank erosion rates and the ingress of sediment from hillslopes and gullies.

If sedimentation of farm dams and reservoirs becomes a problem in the future, then landholders could periodically clean existing reservoirs.

8.5 Summary

- 1) Information on the past management of sediment deposition is limited.
- 2) SedNet modelling indicates that 147 kt of sediment is eroded per year in the upper Barwon River Catchment. Of this, the majority is exported as suspended sediment from the catchment



outlet. Sediment is also exported as bedload. Only 20% of eroded sediment is retained within the study area as bed, floodplain or reservoir/lake deposits. SedNet assumes that the transport of suspended sediment is supply limited. The transport of bedload is constrained by both the rate of supply and the sediment transport capacity of the stream.

- 3) There is little sand in the bed. SedNet assumes that all suspended sediment deposited on the floodplain remains on the floodplain.
- 4) Future management options should be focused on reducing sediment yields, but additional actions can be used to stabilise existing deposits to prevent re-entrainment.



9. Discussion

The following discussion relates to erosion and sedimentation in the priority areas of the Barwon River, as identified in the River Health Strategy. Priority areas for the lower Barwon River are:

- the Barwon River through Geelong;
- Lake Connewarre; and
- the Barwon Estuary.

While priority water supply catchments are:

- Upper Barwon (above the dam, East Barwon, King and Callahan);
- Matthews Creek;
- Pennyroyal Creek;
- Gosling Creek; and
- Dewing Creek.

9.1 Sediment supply to the lower Barwon River

The deposition of fine sediment in downstream reaches of the Barwon River causes negative environmental and amenity impacts in the Barwon River through Geelong, Lake Connewarre and the Barwon Estuary. These sites are all located downstream of our study area. The SedNet sediment budget for the study area indicates that, over the past 100 years, bank erosion has been the most important source of sediment input to the upper Barwon River, accounting for two thirds of the sediment yield. The sediment supply from gullies has also been significant, accounting for a third of the sediment budget. Hillslope erosion accounts for only 2% of the sediment budget for the upper Barwon River.

In the future, it is likely that the sediment supply from riverbanks will continue to dominate the sediment budget. The supply of sediment from gullies generally slows over time, as gullies erode to their limit. Hillslope erosion may increase over time depending on factors such as landuse change and land management practices, but it is unlikely that the supply of sediment from hillslopes will increase to the magnitude of the supply from riverbanks. Riverbanks, on the other hand, are likely to erode further. Tributary streams such as Wormbete, Matthews and Yan Yan Gurt Creeks are still adjusting in response to channelisation. And there is potential for additional streams to incise in the same manner.

Field work indicates that, of the sediment liberated by erosion in our study area, the majority is fine sediment. SedNet modelling indicates that this sediment will mostly be exported from our study area. SedNet modelling indicates that 93.4 kt/yr of suspended sediment is exported per year. Only 24.74 kt/yr is retained within the study area as floodplain deposition or deposition in reservoirs or lakes (see also Chapter 8).

The control of riverbank erosion is the most pressing issue in our study area, as riverbanks are the most significant source of sediment now and potentially into the future. The control of riverbank erosion will slow the supply of suspended sediment to the lower Barwon River. SedNet outputs suggest that Matthews, Pennyroyal, Deans Marsh and Retreat Creeks have the greatest need for treatment. But we know that other streams, such as Wormbete Creek and Yan Yan Gurt, are also in need of treatment (see also Chapter 7).

9.2 Water quality in water supply catchments

The upper Barwon Catchment is used to supply part of the Geelong urban water demand. Most of the flow is sourced from the West Barwon Reservoir and the East Barwon River. Diversions are



passed down the Wurdee Boluc Inlet Channel, which can pick up supplementary flows from a number of the tributaries it crosses on the way to the Wurdiboluc Reservoir, namely Callahan Creek, Dewing Creek, Gosling Creek, Matthews Creek and Pennyroyal Creek (see also Section 0). Water quality above the diversion points in water supply catchments is an important consideration for managers, as poor water quality increases treatment costs and impacts negatively on the taste and clarity of potable water supply.

The SedNet sediment budget provides an estimate of mean annual values for sediment inputs from hillslopes, gullies and bank erosion for individual drainage links and their corresponding sub-catchments. Thus, we have been able to derive a suspended sediment budget for the water supply catchments mentioned above. The water supply off takes on Gosling Creek and Dewing Creek have been decommissioned (Greg Peters, CCMA, *pers. comm.*), so Table 9.1 shows the suspended sediment budget for water supply catchments, including and excluding Gosling Creek and Dewing Creek.

Table 9.1: Suspended sediment budget for water supply catchments, including and excluding Gosling Creek and Dewing Creek.

Budget item	Mean annual rate			
	Including Gosling Ck and Dewing Ck		Excluding Gosling Ck and Dewing Ck	
	(kt/yr)	(%)	(kt/yr)	(%)
Hillslope erosion	0.64	4	0.48	5
Gully erosion	5.17	34	3.44	33
Bank erosion	9.44	62	6.57	63
Total inputs	15.24	100	10.49	100

The suspended sediment budget for water supply catchments resembles closely the budget for the whole study area. Over the past 100 years, bank erosion has been the most important source of suspended sediment input to water supply catchments, accounting for two thirds of the sediment yield. The sediment supply from hillslopes makes up 4 to 5% of the sediment budget. Although small, this proportion is slightly higher than that of the budget for the entire study area. A large portion of water supply catchments are located on the steep slopes of the Otway ranges, where high rates of hillslope erosion are predicted.

In light of the above, the greatest improvements to the water quality of harvested water would be gained by the treatment of riverbank erosion. The decommissioning of the water supply off takes on Gosling creek and Dewing Creek has not affected the suspended sediment yield (Table 9.2).

Table 9.2: Suspended sediment yield for water supply catchments, including and excluding Gosling Creek and Dewing Creek.

Parameter	Including Gosling Ck and Dewing Ck	Excluding Gosling Ck and Dewing Ck
Catchment area (km ²)	237.3	184.7
Total suspended sediment input (kt/yr)	15.24	10.49
Input per area (kt/km ² /yr)	0.064	0.057



10. Summary and further work

10.1 Summary

SedNet is a computerised river sediment budgeting tool developed by the CSIRO (Wilkinson *et al.*, 2004b). SedNet computes sediment budgets for individual river reaches, or links, by calculating the net difference between imported sediment at the top of the link and exported sediment at the bottom of the link, after accounting for erosion or deposition in the link. Where sediment is exported from a link this material is added to the budget of the downstream link and so on to the lowest link in the system at the catchment outlet. In this way, patterns of erosion and sedimentation can be assessed to identify dominant erosion processes and management hotspots across river networks.

The SedNet sediment budget for the upper Barwon River indicates that the mean annual sediment input to streams is 147 kt/yr.

Hillslope erosion refers to soil erosion by sheetwash and rills. The sediment budget for the upper Barwon Catchment indicates that hillslope erosion makes up only 2% of the total sediment input. Although this percentage is small, hillslope inputs may constitute a larger portion of the sediment budget in hotspot links as only one third of stream links supply 80% of the sediment to the river. The highest rates of hillslope erosion occur on: (i) the steep slopes of the Otway Ranges, regardless of landuse; (ii) the steep flanks of the Barwon River and tributaries; and (iii) on moderate slopes where cropping and cereal production, or intense horticulture and agriculture, is undertaken.

Gullies are steep walled, poorly vegetated incised channels with a small catchment area that are a significant source of sediment within the upper Barwon River Catchment. SedNet modelling indicates that 33% of sediment input to the study area's stream network is derived from gully erosion. One third of SedNet links supply 80% of sediment input from gullies. For our purposes, priority areas for gully control works are those with high gully density, where the gullies have the potential to erode further and where the gullies are well connected to the drainage network.

The centre portion of the study area, on the dissected plains of the Tertiary Moorabool Viaduct Formation, has the highest density of gullies. The density of gullies in water supply catchments is generally low, with the exception of the headwaters of Matthews Creek. Aerial photography indicates that there is a gully problem in the headwaters of Wormbete Creek.

The SedNet sediment budget for the study area indicates that, on average, bank erosion is the most important source of sediment input to the upper Barwon River, accounting for two thirds of the sediment yield. Riverbank erosion occurs through a number of processes, including slumping and scour. In our study area, bank erosion also occurs due to natural meander processes, stock damage and scour around willows.

In the early 1900s, swamps and wetlands were drained and sections of tributary streams channelised to provide arable land. The straightening of tributary streams has increased stream power and this has led to bed incision and in some cases high unstable banks. In the upper Barwon River Catchment, banks consist predominantly of silt, and this is easily dispersed. Channel adjustment continues to this day. SedNet estimates bank erosion as being proportional to bankfull streampower with the highest rates of riverbank erosion predicted along the Barwon River and Matthews, Pennyroyal, Deans Marsh, Retreat Creeks and a moderate rate for Wormbete Creek.



Approximately 80% of sediment mobilised from source areas within the catchment is exported from the study area. The majority of sediment that remains in the study area is stored on the floodplain, with only 20% stored as bedload in the river channel or deposited in reservoirs.

10.2 Opportunities for improvement of the SedNet model

The resolution and quality of SedNet model inputs can have a profound impact on model outputs. Although every effort was made in the review process to refine the SedNet model (effectively and efficiently), some observations have been made concerning possible future methods of improvement. These methods rely on further data collection and analysis.

High priority actions

Proportion of fine to coarse sediment

The Corangamite CMA could study the composition of gully bed and bank material, and riverbed and bank material, using particle size analysis to determine the proportion of fine material to coarse material. This information could be used to refine the SedNet model for our study area, by confirming the proportion of fine to coarse sediment, which is input as a parameter in the “budget parameter” window. Currently the proportion used is 20:80, bedload to suspended load. This value has been applied based on relatively few field observations.

Hillslope erosion input grid

Landslide mapping (e.g. DEG, 2003) and investigations into landslide connectivity to drainage networks could be used to quantify the contribution of landslides to the sediment budget. The Corangamite CMA could also monitor landuse change over time, and update the RUSLE grid as required.

Low priority actions

Gully density input grid

The Corangamite CMA could initiate a study to validate the gully density grid that was used as input to the SedNet model for the upper Barwon River Catchment. The validation of the input grid could be done in two ways. The first method would be to digitize the gully network from aerial photography. The second would be to ground truth the mapping, by locating gullies in the field and measuring their extent and connectivity. The former approach is probably better as the entire study area could be assessed at a relatively low cost. Both approaches would require judgement as to what constitutes a “gully”.

Model validation

The Corangamite CMA could walk the Barwon River (or use aerial photography) to map locations of in-channel bedload deposition. This information can be used to validate the SedNet output for in-channel deposition. Similarly, the Corangamite CMA could map the location of tributary fans and overbank deposition. Overbank and in-channel deposits should be re-visited over time to determine whether sediment stores are permanent or transient.

Suspended sediment monitoring could be used to validate SedNet outputs. To be representative, suspended sediment monitoring should be undertaken over a range of flow types as the majority of suspended sediment is transported during high flow events. Bedload monitoring (e.g. by use of a Helley-Smith bedload monitor) could also be used to validate SedNet outputs relating to the export of bedload.



11. Conclusions

SedNet has been used to develop a sediment budget for the upper Barwon River. This budget provides an estimate of mean annual values (averaged over 100 years) for sediment inputs from hillslopes, gullies and bank erosion. SedNet model outputs correspond well with field observations. For example, the predicted rate of riverbank erosion is greatest in the main channel of the Barwon River and on the right bank tributaries which drain the Otway Ranges, as observed in the field. Although model outputs must be interpreted with an appreciation of model limitations, the SedNet model results presented here tend to mimic real world conditions and have proven useful in identifying hotspot locations for monitoring and erosion control works (see Appendix D).

The sediment budget for the study area indicates that, over the past 100 years, an average of 147 kt/yr of sediment has eroded from the study area and that bank erosion has been the most important source of sediment input to the upper Barwon River, accounting for 65% of the sediment yield. Furthermore, fieldwork indicates that of the sediment liberated by erosion in our study area, the majority is fine sediment. Approximately 80% of sediment mobilised from source areas within the catchment is exported from the study area. The remainder is stored on the floodplain, or as bedload in the river channel or deposited in reservoirs.

The majority of sediment liberated from riverbanks is sourced from only a few river links. So managing hotspot reaches, rather than the entire system, has the greatest potential to improve river health and water quality, and to restrict the downstream supply of fine sediment. SedNet outputs suggest that Matthews, Pennyroyal, Deans Marsh and Retreat Creeks have the greatest need for treatment. But we know that other streams, such as Wormbete Creek and Yan Yan Gurt, are also in need of treatment.

The Corangamite CMA has taken an active approach to the management of erosion and sedimentation in the upper Barwon River. The Corangamite CMA has fostered revegetation, fencing and pest removal and has monitored hotspot gully and landslip sites. A recent focus of CMA activities has been the construction of grade control structures on key streams, for example Wormbete and Matthews Creeks. Our study suggests that resources have been prudently allocated to waterway management within the study area.

The deposition of fine sediment in downstream reaches of the Barwon River cause negative environmental and amenity impacts in the lower Barwon River. The treatment of riverbank erosion has the greatest potential to stem the supply of suspended sediment to downstream reaches. Similarly, the treatment of riverbank erosion has the greatest potential to improve water quality in water supply catchments.



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Appendix A Barwon SedNet model

In this Appendix, SedNet data inputs for the final upper Barwon Catchment model are listed and described with a description of the data source. The SedNet data requirements are summarised in Table A.1.

Table A.1: SedNet data requirements (Wilkinson *et al.*, 2004a).

	Grids	Shape files	Informational
Configuration/ stream define	DEM Floodplain extent	Catchment boundary* Reservoirs Lakes Dams	Projection file* Drainage area threshold 1st order stream threshold Link length threshold Link channel width parameters
Spatial data	Gully density Present hillslope erosion Natural hillslope erosion Riparian vegetation Mean annual rainfall PET_rainfall ratio Landuse hillslope cover factor	Catchment boundary	Projection file*
Flow		Regulated gauges Unregulated gauges	Flow daily time series
Sedmodel			Maximum bedload depth Minimum link length for bedload Deposition Sediment bulk density Mannings <i>n</i> channel roughness Channel bank height Proportion of fine to coarse Bedload sediment particle size Floodplain settling velocity Hillslope sediment delivery ratio

*Needed for clipping and projecting data only.

A.1 Model extent and configuration

The SedNet model was compiled to cover the area draining to the upper Barwon River, upstream of the junction with Warrambine Creek. This ensured no ambiguity with respect to flow to Warrambine Creek – the downstream outlet of the model was positioned approximately 500 m upstream of the junction. Within the Birregurra Creek catchment, the model boundary was set at the diversion point from Lake Colac. It is beyond the scope of this project to analyse flows into the Lake Colac system.

The SedNet model was extended to the south west into the upper reaches of Love Creek and south east into the upper reaches of the Saint George River to cover the catchments of the following gauges, which are all located in the Otway Basin:

- 235234 – Love Creek @ Gellibrand;
- 235239 – Ten Mile Creek @ Kawarren;
- 235240 – Yahoo Creek @ Kawarren; and
- 235242 – St. George River @ U/S Melba Falls.



This was done to utilise information from these gauges in stream flow calibrations for the SedNet model. Information from these catchments is not presented as part of the report.

Digital terrain model

Compilation of a suitable digital terrain model (DTM) of the study area is fundamental to achieving the best possible outcomes from the SedNet modelling process. The DTM is used to derive information such as ground slope, water flow direction, catchment areas and drainage network. The drainage network is subsequently divided into stream links and a sediment budget calculated for each link.

The DTM for this project (Figure A.1) was compiled from a combination of airborne laser scanning (ALS) and 1:25,000 topographic data. The maximum recommended number of SedNet grid cells is 20 million (Wilkinson *et al.*, 2004b). We compiled the DTM to a 12.5 m grid cell resolution. Grid cells are therefore 12.5 m by 12.5 m within the area SW 718750, 5717900 – NE 775000, 5777100 which equates to 21,312,000 grid cells. A portion of these cells are inactive, being beyond the model area described above.

Stream network drainage area threshold

The drainage area threshold is used in SedNet to set the minimum contributing area of a defined stream within the SedNet stream network. The smaller the threshold, the smaller the catchments, producing a more detailed drainage network. A suitable value strikes a balance between accurately reflecting the permanent stream network and getting accurate ratios of sediments derived from streambank to gully erosion. The latter will provide an important backdrop for formulation of management recommendations.

We set the stream network threshold drainage area to 5 km² for all SedNet modelling. This is the minimum threshold drainage area allowed by SedNet. The decision to use the minimum threshold drainage area was based on a consideration of the resolution of the DTM and the size of the study area.

Minimum first order link length

The minimum first order link length is used to trim short first-order stream links from the SedNet stream network. This is necessary to reduce the occurrence of small catchments with high uncertainties associated with model outputs. After reviewing the accuracy of available DTM data, a value of 0.5 km was adopted.

Results of the model configuration

Model configuration resulted in 151 sub-catchments within the study area. The average size was 8.2 km².

A.2 Grids and shapefiles

Lake and reservoir mapping

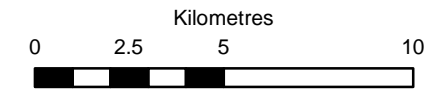
SedNet calculates the volume of sediment trapped in reservoirs and lakes. A data set of all lakes and reservoirs within the study area was sourced from DSE (2005). These water bodies were reviewed for size, hydrological significance and proximity to the stream network. Appropriate subsets of lakes and reservoirs with capacity information were then compiled and formatted for input to SedNet.

Figure A.1

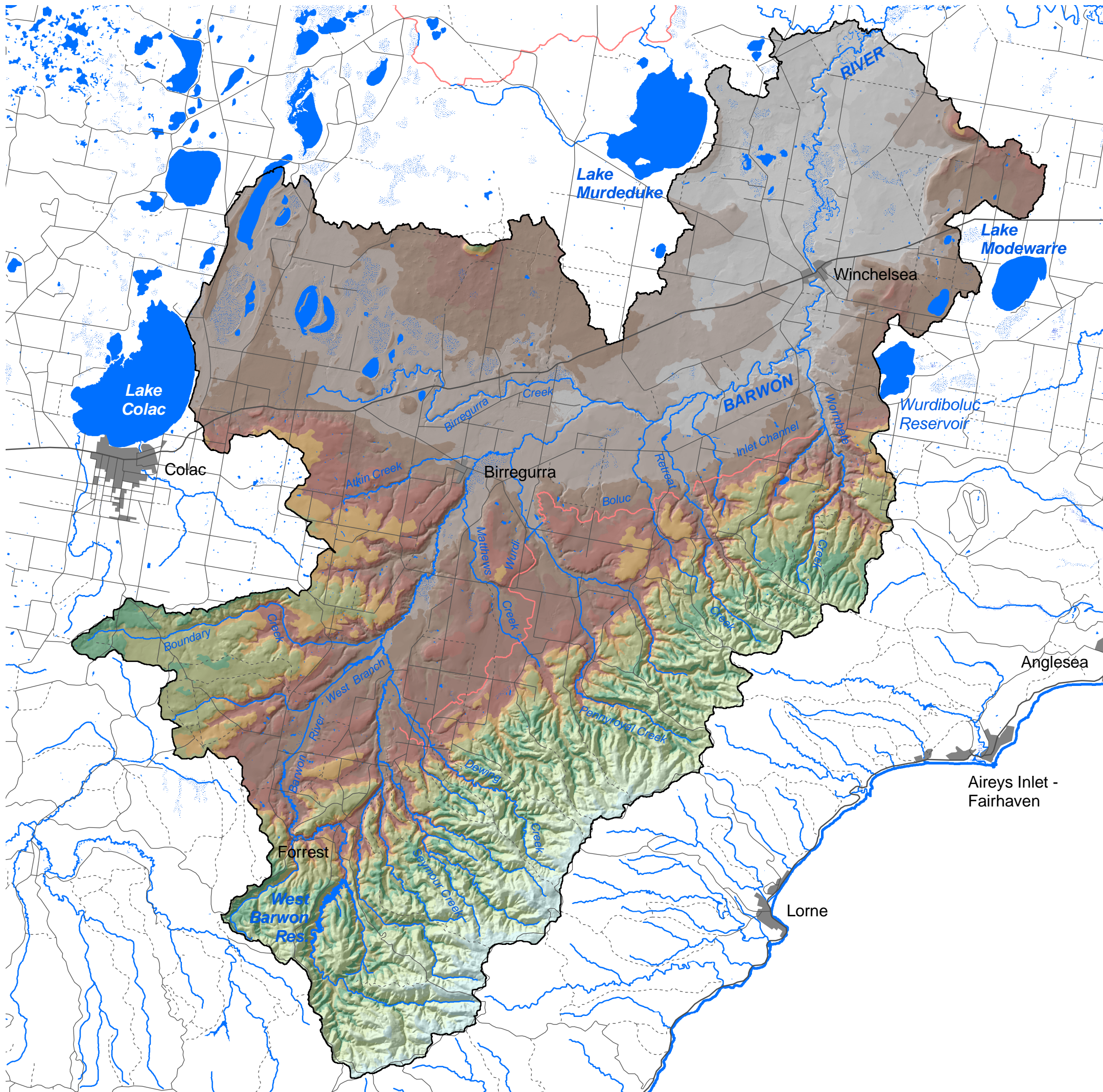
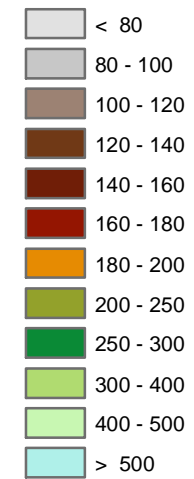


Modelling of Sediment Erosion and Deposition in the Upper Barwon Catchment

DIGITAL TERRAIN MODEL



Ground Elevation (m AHD)



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Nine lakes were included in the dataset, including Lake Burn (situated east of Lake Colac) and the Coalmine Dam on Coalmine Creek. Other waterbodies include wetlands located northeast of Lake Colac, on the basalt plains in an alluvium substrate. The only reservoir of significance is the West Barwon Reservoir, located on the Barwon River west branch near Forrest. The West Barwon Reservoir was constructed in 1965 and has a capacity of 20,900 ML.

Floodplain extent

SedNet requires floodplain information describing the median over-bank flood flow extent, not the extent of the “geographic floodplain”. Such floodplain mapping was not available for the project area. However, we used field observation and geology mapping to identify those stream sections with floodplains “in regular hydraulic connectivity” with flood waters as described above. These streams were selected from the 1:25,000 hydrology data (DSE) and used in conjunction with the DTM as input to GIS utilities to define the floodplain extent. The resultant data was reviewed and formatted for input to the final SedNet model (Figure A.2).

Gully density mapping

Wilkinson *et al.* (2004a) define gully density as the distribution in km/km² of steep walled, poorly vegetated, incised channels with a small catchment area (<10 km²). The default national scale NLWRA gully density grid was derived by a combination of mapped and modelled data to a cell size of approximately 260 by 260 m². The mapped data was based on measurements obtained from previous aerial photographs and land degradation reports. The modelled data was based on regression tree models using environmental attributes.

Nationally, the proportion of riverbank erosion to gully erosion to hillslope erosion is 0.26:0.35:0.39 (NLWRA, 2001). Because of the potential importance of gully sediment sources in the upper Barwon Catchment, we consider the precision of the default data set insufficient for the purposes of this project. We have therefore applied the following refinement process to better capture the erosion and sediment transport characteristics of the catchment.

The 1:25,000 stream network for the upper Barwon Catchment was compared to the drainage network of streams produced by the SedNet model using the DTM. The drainage network is used by SedNet to differentiate between sediment inputs from gully erosion over an area and bank erosion to the linear stream network. The SedNet drainage network and the 1:25,000 stream network approximated each other almost precisely (although, of course, the SedNet drainage network was missing many first and second order streams due to the threshold drainage length imposed).

We then subtracted (excluded) the SedNet drainage network from the 1:25,000 mapped stream lengths. This was after drainage lines located on forested areas were excluded from the data set using tree cover in 1995, as gullies are unlikely to form in national parks, for example. The resulting data set was assumed to approximate the gully network and was formatted for input to the SedNet model. Hence the SedNet gully network input represents all low order channels regardless of channel morphology and hydrology.

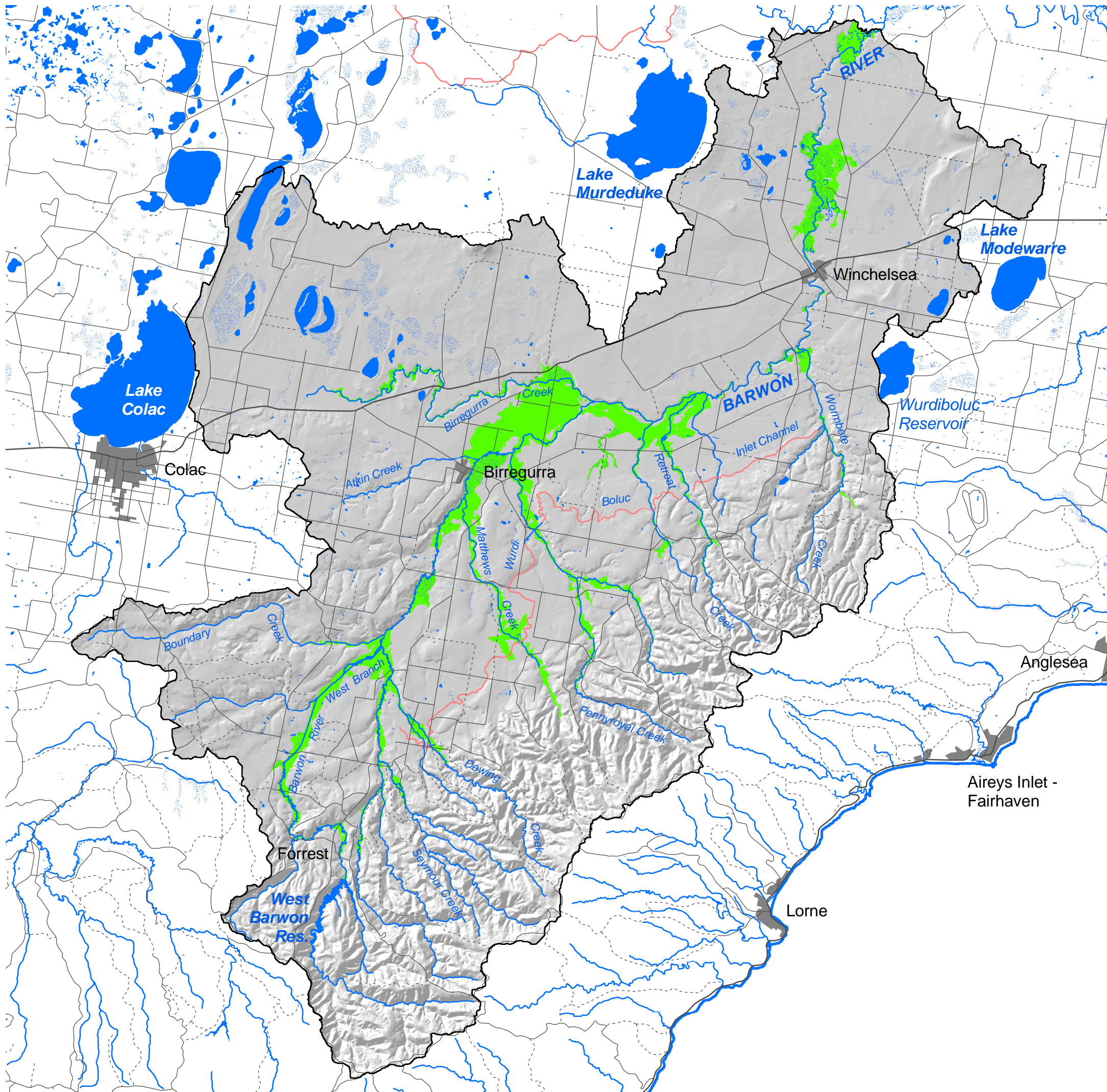
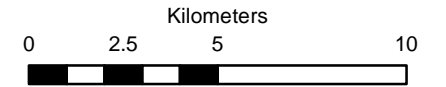
During the fieldwork component of this study we inspected a number of first and second order streams marked on the 1:25,000 topographic network. We found that many of these streams were not contributing sediment to the drainage network. Consequently, gully density mapping was factored uniformly so that the density was halved. The resulting gully density map is illustrated in Figure A.3.

Figure A.2



Modelling of Sediment Erosion and Deposition in the Upper Barwon Catchment

**FLOODPLAIN
(as input to SedNet model)**



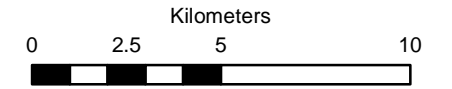
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Figure A.3



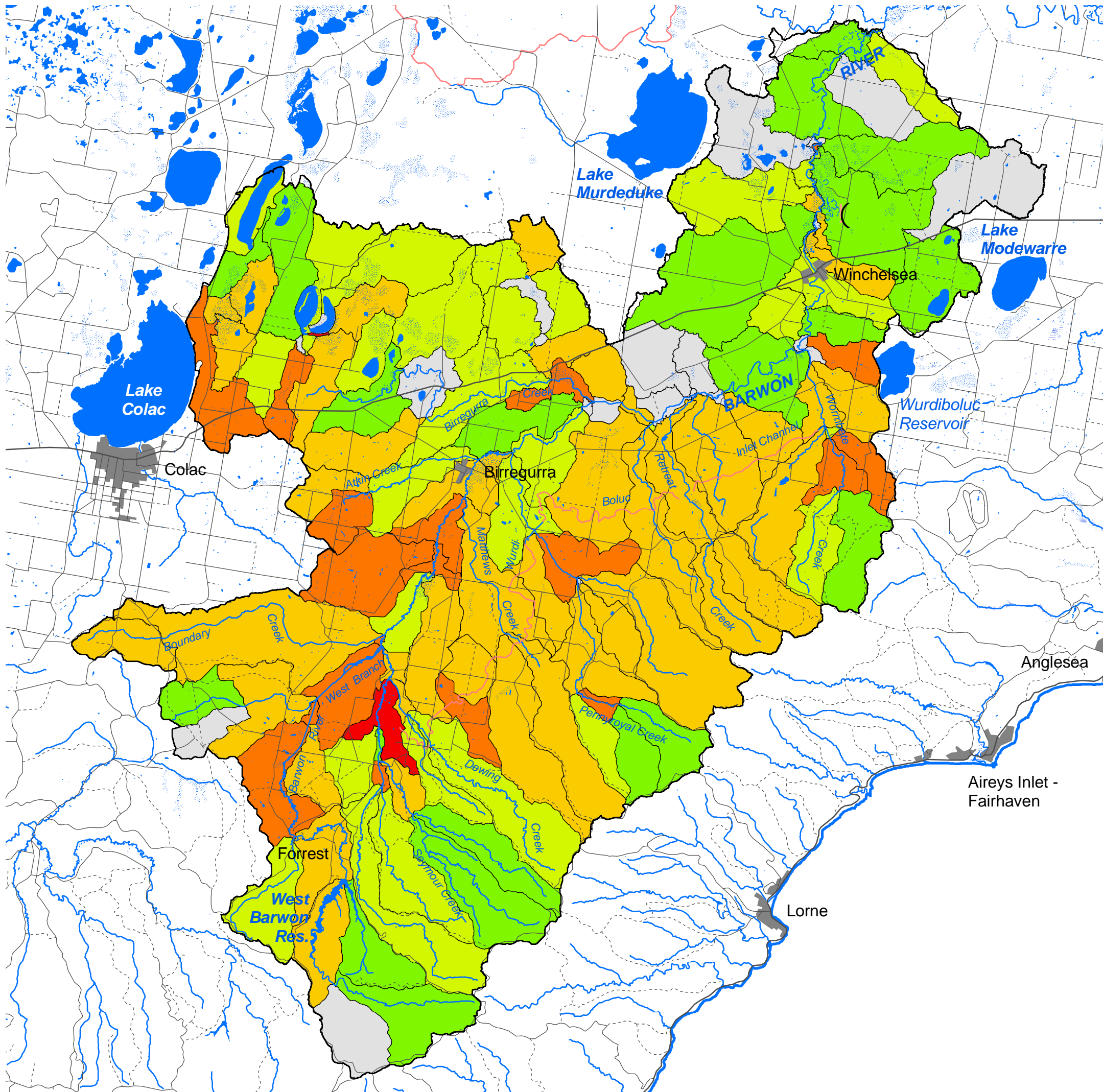
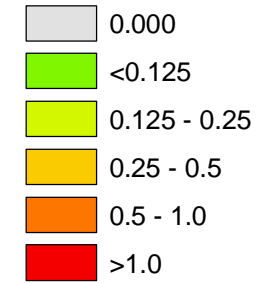
Modelling of Sediment Erosion and Deposition in the Upper Barwon Catchment

ESTIMATED GULLY DENSITY (km/km²)



Gully Density

(Km/Km²)



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Hillslope erosion grid

The NLWRA provides both a grid of hillslope erosion and the individual grids of inputs used to calculate hillslope erosion by use of the Revised Universal Soil Loss Equation (RUSLE). Like the gully density map, the resolution and extent of this mapping could not be confidently applied to our study area. Consequently, we updated the mapping to derive average annual soil loss, A, from the RUSLE:

$$A = R K L S C P$$

Where: R = rainfall erosivity factor, K = soil erodibility factor, L = slope length factor, S = slope steepness factor, C = crop and cover management factor and P = support practice factor (not used).

We used the Upper Barwon DTM to produce a new slope steepness (S) and slope length (L) grid. The Bureau of Rural Sciences has conducted landuse mapping of the Upper Barwon Catchment (BRS, 2002). This mapping is to cadastral precision (Australia Land Use Mapping classification) and was used to refine the cover (C) grid. We did not update the rainfall erosivity factor (R) nor the soil erodibility factor (K) but sourced these grids from the NLRWA web site. The resulting hillslope erosion grid is illustrated in Figure A.4. This grid compared favourably with field results. Cover factors are summarised by landuse in Table A.2.

Table A.2: Adopted cover factor values.

GIS code	Description	Proportion of study area	C-Factor
1	Nature reserve	11.4%	0.003
2	Urban	4.0%	0.001
3	Lakes, water supply and water treatment	4.5%	0.000
4	Grazing	48.4%	0.020
5	Plantations and other forests	24.7%	0.006
6	Cropping and cereals	6.6%	0.118
7	Miscellaneous agriculture	0.1%	0.016
8	Miscellaneous horticulture	0.4%	0.178

Mean annual rainfall

Mean annual rainfall data in grid form was sourced from CSIRO. This is the most suitable information available and was used for all Upper Barwon SedNet model scenarios.

Potential evapo-transpiration-rainfall ratio

The potential evapo-transpiration-rainfall ratio (commonly referred to as the PET-rainfall ratio) grid can be created by dividing a grid of mean annual potential evapo-transpiration (mm) by a grid of mean annual rainfall (mm) in a raster calculator. Mean annual evapo-transpiration data were sourced from CSIRO. This is the most suitable information available and was used for all Upper Barwon SedNet model scenarios.

Riparian vegetation

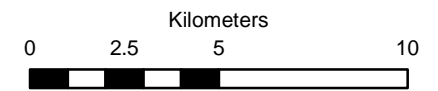
Riparian vegetation extent was compiled by clipping the TREE25 data supplied from DSE's Geospatial Data Library. TREE25 was clipped to within two grid cells (up to 70 m) of the river channel. This process is dependent on the channel width parameters defined for the catchment (refer to later section). Riparian vegetation mapping prepared in this manner compared well to field results. Riparian vegetation compiled in this manner covered the extent of established vegetation. Re-vegetation was therefore excluded from the analysis. This approach is justified as SedNet models the 100-year average condition.

Figure A.4

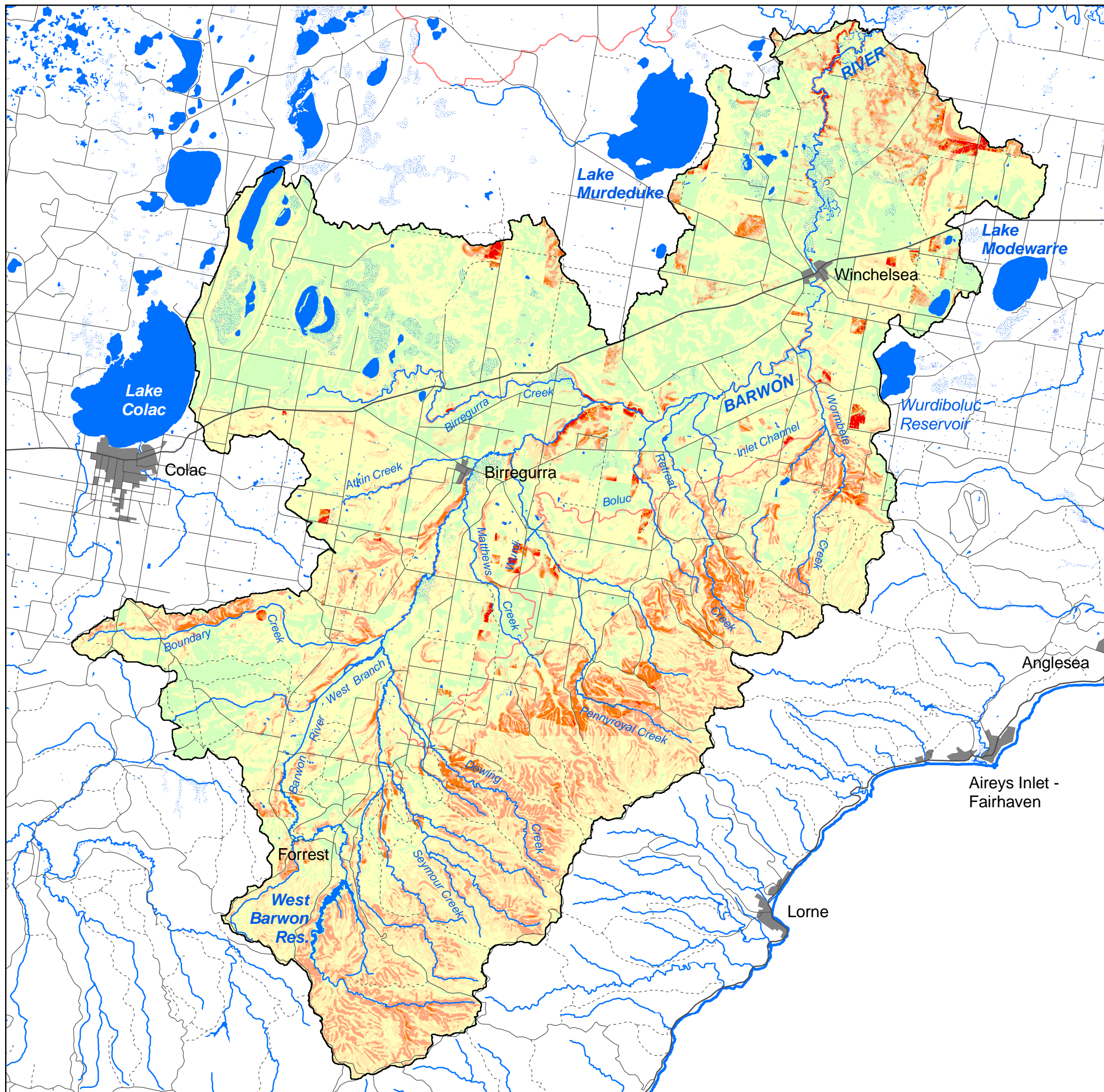
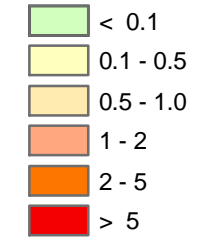


Modelling of Sediment Erosion and Deposition in the Upper Barwon Catchment

RUSLE HILLSLOPE EROSION



Hillslope erosion (t/ha/yr)



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A.3 Hydrology

Streamflow time-series

Time-series data was compiled for all relevant gauge sites within the catchment, representing both unregulated (Table A.3) and regulated (Table A.4) flow. SedNet uses flow time series at unregulated sites to derive a relationship between mean annual flow (MAF) and upstream area. Figure A.5 illustrates the relationship between catchment area (km²) and MAF (ML) for fifteen unregulated flow gauges. Regulated flow series are used to account for the effects of reservoirs, diversions, groundwater pumping and inter-basin transfers.

Table A.3: Sites with time series data representing unregulated flow.

Station ID	Station name	Source of data
233211	<i>Unimpacted flow</i> – Birregurra Creek at Ricketts Marsh (Reach 5)	SKM (2005a)
233214	Barwon River East Branch @ Forrest (Above tunnel)	Thiess
233218	<i>Unimpacted flow</i> – Barwon River at Inverleigh (Reach 2)	SKM (2005a)
233224	<i>Unimpacted flow</i> – Barwon River at Ricketts Marsh (Reach 1)	SKM (2005a)
233228	<i>Unimpacted flow</i> – Boundary Creek (Reach 6)	SKM (2005a)
233250	Agroforestry Site @ Racecourse Paddock (Gerangamete)	Thiess
235234	Love Creek @ Gellibrand (Otway Basin)	Thiess
235239	Ten Mile Creek @ Kwarren (Otway Basin)	Thiess
235240	Yahoo Creek @ Kwarren (Otway Basin)	Thiess
235242	St. George River @ upstream from Melba Falls (Otway Basin)	Thiess
2000600	Penny Royal Creek at Birregurra – Deans Marsh Road	Barwon Water
20001000	Matthews Creek at WBIC siphon	Barwon Water
20001700	<i>Unimpacted flow</i> – West Barwon River Compensation Weir 400 m downstream from spillway	SKM (2005a)
20001900	Dewing Creek at Birregurra – Forrest Road	Barwon Water
20002100	Callahan Creek Compensation Weir	Barwon Water

Table A.4: Sites with time series data representing regulated flow.

Station ID	Station name	Source of data
233204	Barwon River East Branch @ Forrest (below tunnel)	Thiess
233218	Barwon River @ Inverleigh	Thiess
233224	Barwon River @ Ricketts Marsh	Thiess
233228	Boundary Creek @ Yeodene	Thiess
2000600	Penny Royal Creek at Birregurra – Deans Marsh Road	Barwon Water
20001000	Matthews Creek at WBIC Siphon	Barwon Water
20001700	West Barwon River Compensation Weir 400 m downstream from spillway	Barwon Water
20001900	Dewing Creek at Birregurra – Forrest Road	Barwon Water
20002100	Callahan Creek Compensation Weir	Barwon Water

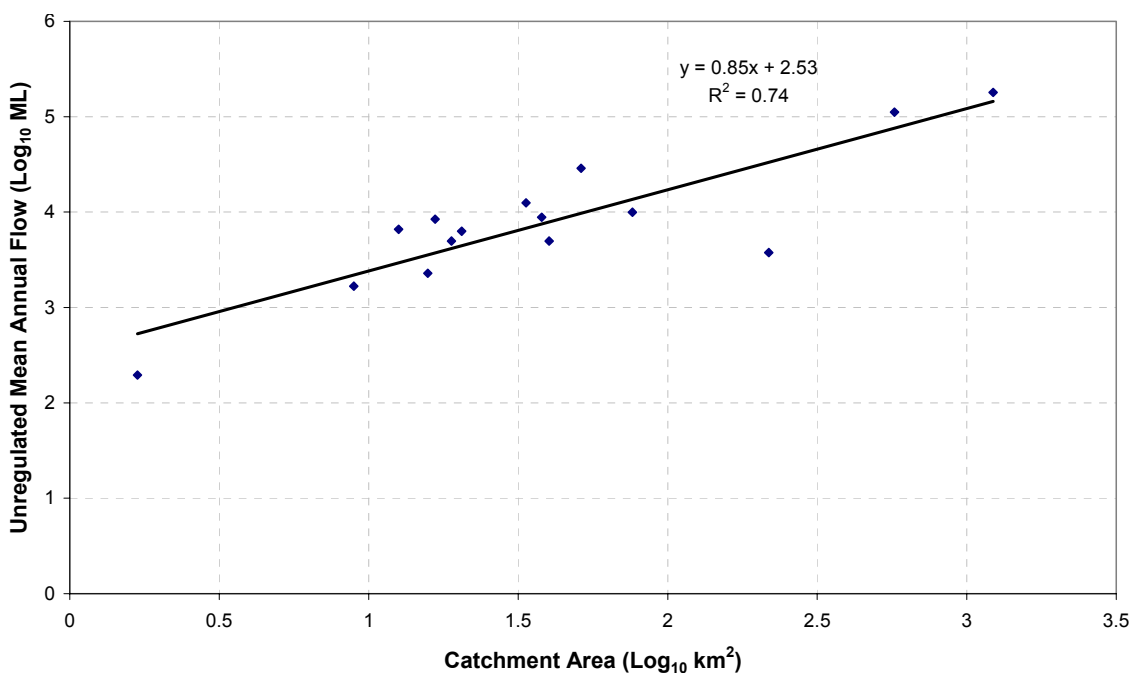


Figure A.5: Catchment area (km²) versus mean annual flow (ML) for fifteen unregulated flow gauges.

The majority of flow data has been sourced from Thiess Hydrographic Services (Thiess) and Barwon Water. Modelled unimpacted (i.e. unregulated) flow series have been prepared for five environmental flow sites in the upper Barwon Catchment as part of a modelling project for the Corangamite CMA (SKM, 2005a). These flow series were also used. Unregulated flow series for Pennyroyal, Matthews, Callahan and Dewing Creeks were prepared by adding back the flow diverted to the Wurdi Boluc Inlet Channel. It was also necessary to make a number of manual adjustments to regulated flow in the “Regulated Flow Window” (Table A.5).

Table A.5: Manual adjustments to regulated stream flow.

Stream link	Natural mean annual flow (ML/yr)	Adjustment (ML/yr)	Resultant regulated flow (ML/yr)
Barwon River East Branch D/S of the East Barwon River Offtake (SedNet Link #84)	4624	-1,156 (-25%)	3,468
Gosling Creek (SedNet Link #94)	3531	-883 (-25%)	2,648
Birregurra Creek (SedNet Link #33)	978	+ 7,700 ML	8,678

Reasons for adjustment:

- 1) The Barwon River East Branch receives flow from the West Branch, via a tunnel, before flow is diverted into the Wurdi Boluc Inlet Channel. There are several gauges on the East Branch, but the gauge downstream of the Wurdi Boluc Inlet Channel has only a few years of data. The mean annual flow in this link was adjusted so that the regulated flow was 25% less than the natural.
- 2) Water is diverted from Gosling Creek into the Wurdi Boluc Inlet channel, but there is no gauged flow on this stream to quantify diversions. Diversions from the Upper Barwon River are up to 25% of the total yield (SKM, 2000), so a 25% reduction has been applied to Gosling



Creek natural flows estimated by SedNet. This reduction in flow is automatically propagated downstream by SedNet.

- 3) Water from the Corangamite Basin is diverted into Birregurra Creek. There are several gauges on Birregurra Creek, but there is no gauge at the top of the creek which is of a suitable length of record for input to the SedNet model. Data analysis for the purpose of the Barwon River REALM model (SKM, 2005a) indicates that average annual diversions into Birregurra Creek are likely to be in the order of 7,700 ML/yr, so this value was added to the top most SedNet link of Birregurra Creek.

The catchment average bankfull recurrence interval was assumed to be 1.5 years. This was based on an assessment of ten gauged flow series (Table A.6).

Table A.6: Average bankfull recurrence interval at unregulated sites.

Station ID	Catchment area (km ²)	Bankfull flow (ML/day approx)	Recurrence interval (years approx)
233214	17	100	1
233250	2	10	1
235234	76	325	1
235240	16	130	1.7
235242	13	96	1
233211 ^a	218	150	1
233218 ^a	1,226	2,000	1
233224 ^a	574	12,000	2.0
233228 ^a	40	15	1

^aUnimpacted flow

A.4 Budget parameters

Budget parameters are summarised in Table A.7 (overleaf). In most cases default values were used, but where additional information was available the selection was refined. We used the bank erosion coefficient to calibrate the model so that the maximum channel erosion rate matched bank retreat rates observed in the field. The sediment transport coefficient was also used for calibration purposes.

Relationship between catchment area and channel geometry

SedNet requires parameters describing the power relationship between upstream catchment area and bankfull width and height. This information is used to calculate riverbank erosion. For the purpose of the preliminary SedNet model, the upstream catchment area, versus bankfull width and height, relationships were derived using data from a number of resources. This equation has now been refined using data from fieldwork.

Forty-five assessment sites were visited during the course of the fieldwork, but five sites were excluded from the dataset. Two were excluded because the bankfull channel width and height was not visible. The remaining three were excluded because the upstream catchment area was less than 1 km² (the minimum allowable stream network threshold drainage area in SedNet is 5 km²). One of these sites appeared to be a floodrunner for the main channel of the Barwon River. The Department of Sustainability and Environment *State of Streams* database provided width and height data for the Barwon River for five additional sites, bringing the total number of data points to 45. Upstream catchment areas were calculated using GIS utilities and the DTM as input.

**Table A.7: Applied budget parameters.**

Budget parameter	Description	Default value	Value applied	Reason for applying value
Natural Conditions	If "Natural Conditions" is "True" then the scenario will be modified to simulate natural conditions.	False	False	The default value of "False" was used as the upper Barwon was modelled assuming contemporary conditions.
Hillslope Sediment Delivery Ratio	The SedNet model assumes that not all sediment eroded from hillslopes remains entrained or suspended long enough to reach the stream network. Hence, the hillslope sediment delivery ratio is used to adjust the rate of soil supplied to the drainage system.	0.05	0.05	The default value is considered appropriate for all Barwon SedNet model scenarios.
Pre-European Riparian Vegetation Bank Height (m)	The proportion of stream length covered by riparian vegetation in the pre-European period. A fixed value of channel bank height is multiplied by the riverbank erosion rate to calculate the volume of sediment delivered to streams from riverbank erosion.	0.95 Fixed	0.95 Variable	The default value is considered appropriate for all Barwon SedNet model scenarios. <i>See section below entitled "Power relationship between upstream catchment area and bankfull width and height"</i>
Bank Erosion Coefficient	SedNet estimates bank erosion as being proportional to bankfull streampower. Further controls are riparian vegetation, floodplain width and the bank erosion coefficient, which is selected by the user. The bank erosion coefficient should be selected to obtain a reasonable maximum bank erosion rate (e.g. < 0.3 m/yr).	0.00002	0.0004	A bank erosion coefficient of 0.0004 was adopted for the Barwon SedNet model. This value meant that the maximum rate of bank retreat was capped at 0.37 m/yr and that the rate of bank erosion was twice that of gully erosion. ***USED TO CALIBRATE MODEL***
Gully Cross Section Area (m ²)	Gully Cross Section Area (m ²) is used to calculate the sediment supply from gullies.	10	10	The default value is considered appropriate for all Barwon SedNet model scenarios.
Gully Erosion Reduction Factor	SedNet uses the Gully Erosion Reduction Factor to reduce the long term fine sediment generation from gullies by the proportion entered to account for contemporary gully stabilisation.	1	1	The default value is considered appropriate for all Barwon SedNet model scenarios.
Years of Elevated Erosion and Accumulation	Number of years over which elevated gully and bank erosion has occurred and bedload deposition has accumulated.	100	100	The default value is considered appropriate for all Barwon SedNet model scenarios.
Bedload Budget Type	The model can be run using either steady-state or transient bedload model.	Steady-state	Steady-state	The steady-state setting is considered appropriate for all Barwon SedNet model scenarios.
Transient Bedload Storage (m)	Only applicable if the transient bedload model is used.	0.15	0.15	N/A
Max Bedload Depth (m)	Maximum bedload depth is input into SedNet to prevent pile-ups of bedload sediment in links with low channel slope. This depth is defined as the depth of the mobile bedload.	1.5	1.5	The maximum in-stream bedload depth observed in the field was less than 0.5 m. However, it is possible that sediment will accumulate in dams and reservoirs to larger depths.

/cont.

**Table A.7 (cont.): Applied budget parameters.**

Budget parameter	Description	Default value	Value applied	Reason for applying value
Sediment Bulk Density (t/m ³)	The weight (tonnes) of 1m ³ of sediment	1.5	1.5	The default value is considered appropriate for all Barwon SedNet model scenarios.
Floodplain Settling Velocity (m/s)	Velocity at which sediment deposits on floodplains.	0.000001	0.000001	The default value is considered appropriate for all Barwon SedNet model scenarios.
Sediment Transport Coefficient	Bed deposition is the mean annual excess of supply of bedload over mean annual sediment transport capacity (STC). The selection of a suitable bedload sediment transport capacity coefficient is based on Mannings n and mean bedload particle size.	560	280	The STC was adjusted so that the pattern of predicted bedload deposition approximated the pattern observed in the field. ***USED TO CALIBRATE MODEL***
Minimum Link Length (m)	Links below this length will pass all bedload straight through. This is because short links can have large errors in slope leading to excessive bedload accumulation.	2000	2000	The default value is considered appropriate for all Barwon SedNet model scenarios.
Proportion of Suspended Sediment	Proportion of bank and gully sediment that contributes to suspended load	0.5	0.8	For the purpose of the preliminary SedNet model we adopted the default 50:50 ratio of fine to coarse sediment. But in the field we encountered little sand in the catchment. A more appropriate ratio is 20:80, bedload to suspended, and this value has been applied.
Proportion of Bedload Sediment	Proportion of bank and gully sediment that contributes to bedload	0.5	0.2	



Using linear regression, we calculated a channel width coefficient of 3.754 and exponent of 0.231 for input to the refined SedNet model:

$$W_{bf} = 3.754A^{0.231} \quad R^2 = 0.314$$

where W_{bf} is bankfull width (m) and A is upstream catchment area (km^2).

Similarly, 45 data points were used to derive a relationship between upstream area and bankfull height. Multiple linear regression produced a channel height coefficient of 1.686 and an exponent of 0.111.

$$H_{bf} = 1.686A^{0.111} \quad R^2 = 0.060$$

where H_{bf} is bankfull height (m) and A is upstream catchment area (km^2).

The fit of both refined regression equations was poor (see also Figures A.6 and A.7). This is not unexpected given the range of stream types and stream conditions present in the catchment – channel width and height are equally as variable. However, the refined upstream catchment area versus bankfull width and height relationships provided the best fit to the data available and are in keeping with previous regression relationships for Victorian rivers.

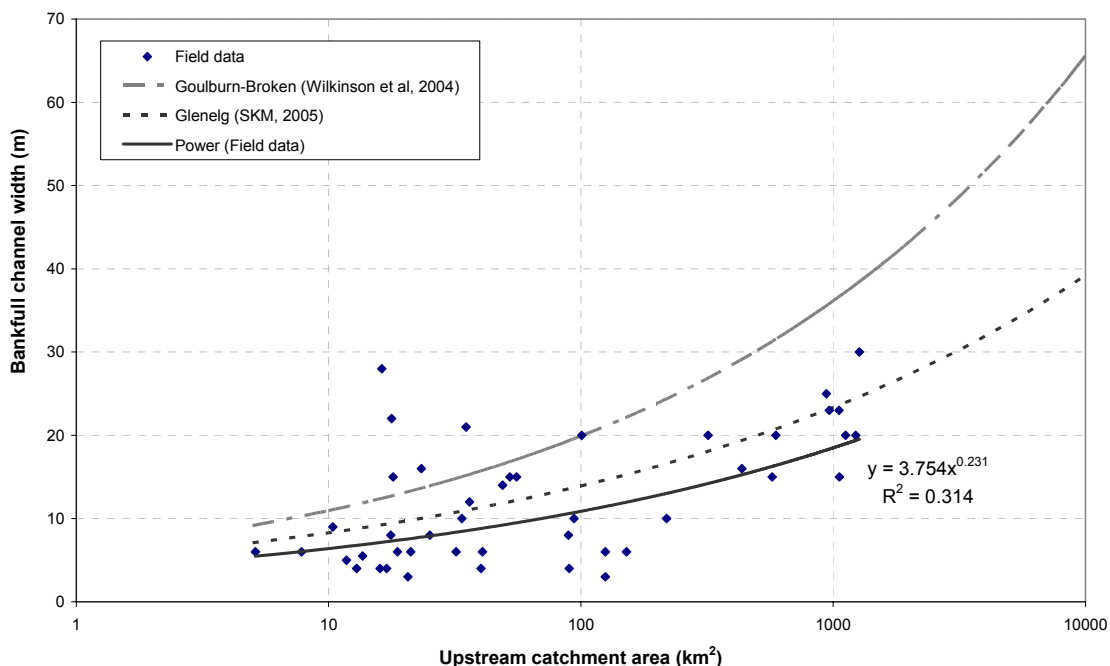


Figure A.6: Relationship between catchment area and bankfull channel width.

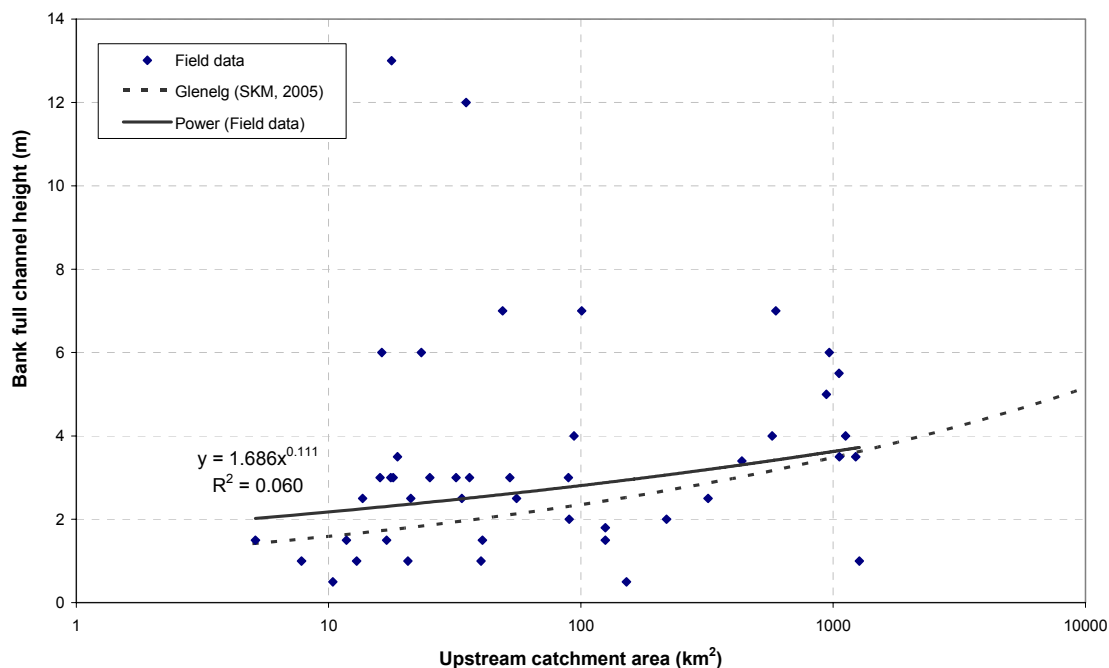


Figure A.7: Relationship between catchment area and bankfull channel height.

A.5 SedNet model documentation

A configuration consists of those things that will not change in a model, for example the stream network itself. It is the framework on which all SedNet modelling is built (Wilkinson *et al.*, 2004b). A scenario contains the datasets, parameters and results associated with a particular catchment condition. For the purpose of the current investigation we have used the contemporary catchment condition.

Several configuration files and scenarios were derived during the model development stage of this project. In order to keep track of the model versions, the following table has been prepared.

Table A.8: SedNet model documentation.

Model configuration name	Scenario name	Description
Ba151105.snfcg	S151105E.sns	Preliminary Upper Barwon SedNet Model
Ba060306.snfcg	Sn060306A.sns	Refined Upper Barwon SedNet Model
Ba300306.snfcg	Sn300306.sns	Refined Upper Barwon SedNet Model, with a wider floodplain on Wormbete Creek
<i>File corrupted by program</i>	<i>File corrupted by program</i>	<i>File corrupted by program</i>
Ba130406.snfcg	Sn130406.sns	Replacement model. Refined Upper Barwon SedNet Model, with a wider floodplain on Wormbete Creek



Appendix B Location of field sites

SKM undertook fieldwork in the upper Barwon Catchment from 16 to 19 January, 2006. During the fieldwork we recorded the conditions at eighty sites within the study area. Three sorts of sites were visited. At stream assessment sites we conducted a full evaluation of the physical and ecological characteristics of the immediate reach. At “gully” sites we examined first and second order streams, to determine whether they were gullies and thus contributing sediment to the stream network. At photo sites we took photographs to record features of interest, such as the Wurdi Boluc Inlet Channel.

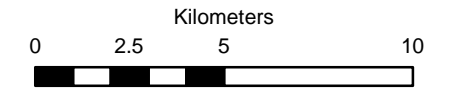
All sites were geo-referenced with a hand-held GPS unit. The sites were scattered across all portions of the catchment area (Figure B.1), excluding the densely vegetated portions of the Otway Ranges, where drainage lines were not visible from the road.

Figure B.1



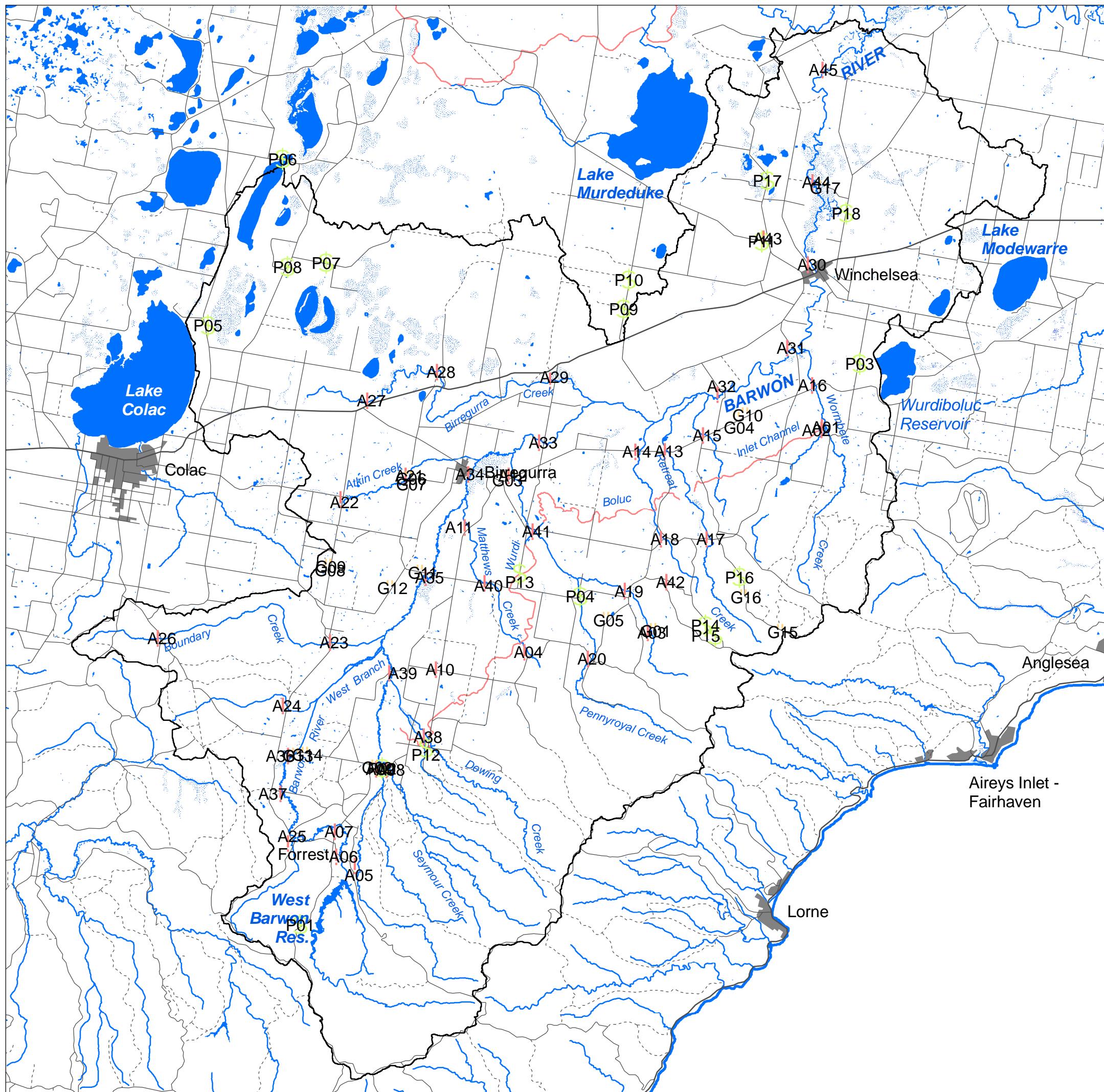
Modelling of Sediment Erosion and Deposition in the Upper Barwon Catchment

FIELD SITES



Field site type

- ! Assessment site
- " Gully site
- \$ Photo site



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Appendix C Categorisation of field sites by gully presence and type

The findings of the fieldwork, which relate to the number and distribution of gullies, are:

- Of the 45 stream assessment sites visited, only 6 had valley side gullies.
- Of the seventeen gully sites visited, six were categorised as gullies and were thought to contribute sediment to the drainage network (e.g. see Figure C.1). Six were categorised as a hillslope or drainage line and were not actively contributing sediment to the drainage network. Four sites appeared to be defined streams.
- One photo site was clearly a gully. At a number of other photo sites we examined channelised waterways, which had been marked as streams on the 1:25,000 topographic maps. These channels are possibly contributing sediment to the drainage network. Many were accessible to stock.
- During the fieldwork we found that forested areas (plantations and other forests, nature reserves) were mainly densely vegetated and free of gullies. There was, however, the occasional logging track which may be a source of sediment and a large gully at site G1 in a cleared area located adjacent to a pine plantation.

Table C.1: Gullies observed in the field.

Sites	Category	Count
Stream assessment	Streams with valley side gullies (continuous with river)	4
	Streams with valley side gullies (discontinuous with river)	2
	Streams with no valley side gullies	39
Gully	Gully	6
	Hillslope / Drainage line	6
	Stream	3
	Other	2
Photo	Gully	1
	Other	17
Total		80



Figure C.1: Example gully field site (site G17).



Appendix D Catchment management

This discussion is divided into two sections. The first section summarises techniques for the management of erosion and sedimentation. The second section discusses possible methods for the evaluation of management options if implemented.

D.1 Management of erosion and sedimentation

Hillslope erosion

Hillslope erosion can be reduced by converting high intensity landuse (such as cropping) to low intensity landuse (such as national parks). But mass landuse change is unlikely to be a feasible management option, so a better approach could be to improve the way in which land is managed, by fostering conservative farm and forest management practices.

Aside from management actions that treat the source of sediment on the hillslopes, there is strong evidence to suggest that planting riparian buffer strips will prevent the ingress of eroded material into the channel by filtering sediment from overland runoff. The greatest benefits would result from the use of buffer strips at priority locations.

Gully erosion

Gully erosion can be mitigated by diverting water away from the gully, dropping the water gently into the gully floor, or stabilising the gully floor. Potential management actions should also include fencing and re-vegetation, for example re-vegetation above priority gully heads to alter the contributing hillslope hydrology or re-vegetation of downstream areas to trap sediment before entering the stream.

Riverbank erosion

The incision of tributary streams is a major source of sediment in hotspot areas. In the past, conservation groups have built grade control structures, rock chutes and gabions along Wormbete, Coalmine, Yan Yan Gurt, Retreat, Matthews and Pennyroyal Creeks. The Corangamite CMA is currently involved in a number of programs to install control structures for the prevention of further incision of tributary streams. SedNet has predicted moderate to high rates of bank erosion for streams where works are located.

In altered landscapes such as the Barwon, significant contributing factors to ongoing riverbank erosion are riparian degradation and unrestricted stock access to the river. Potential control options are stock exclusion fencing, off-stream watering points, stock and vehicle crossings and re-vegetation. Such activities are currently being fostered by the Corangamite CMA. The coordination of these activities could be improved by mapping the continuity and quality of riparian vegetation. The Corangamite CMA could also map the extent of stock access.

Sediment export and deposition

Future management options should be focused on reducing sediment yields, but additional actions can be used to stabilise existing deposits to prevent re-entrainment. SedNet assumes that all suspended sediment deposited on the floodplain remains on the floodplain. Field observation and SedNet modelling indicates that the magnitude of the bedload deposition problem does not warrant management intervention, as bedload is not currently impacting on in-stream health. But actions such as the exclusion of stock and re-vegetation of the riparian zone will help to stabilise existing sediment stores and prevent them from moving through the system and affecting downstream reaches, while reducing bank erosion rates and the ingress of sediment from hillslopes and gullies.



D.2 Evaluation of management options

This section describes potential methods for the evaluation of management options. That is, methods to determine whether management initiatives have been effective in slowing the rate of soil loss from the study area and to determine whether funds have been assigned in a manner that will maximise public benefit.

A low cost option for the Corangamite CMA would be to map the location of on-ground works for the purpose of treating hillslope, gully and riverbank erosion. Such works should include all landholder and Corangamite CMA initiatives, including re-vegetation, fencing and control structures. Mapping of works can then be compared to the distribution of hotspot areas as identified within this document. Hotspot areas are locations where the treatment of erosion has the greatest potential to influence the sediment budget. Of course local expertise will also be required to determine whether erosion control works are located in appropriate locations. Moreover, the benefits of some initiatives are intangible, such as education programs, and thus cannot be mapped.

Additional management approaches could be focused on investigation whether treatment are effective at a reach, rather than catchment, scale.

- *Hillslope erosion* – There are a variety of methods to quantify the effect of changed practice on hillslope erosion rates but these are typically expensive and generally appropriate only at the plot scale. In any case, we know enough of the cause and effect relationships between practice and erosion to be confident that undertaking the works will derive a benefit in reduced erosion rates.
- *Gully erosion* – If gully control works are implemented, the Corangamite CMA could monitor the success of works by revisiting selected gully heads over a number of years. Gully dimensions (e.g. length, width, depth) can be surveyed periodically to determine if the gully is releasing sediment through either the migration upslope of the gully head, the widening of the gully walls, or further incision of the gully floor. The sample gullies should include both treated and untreated gully heads. Untreated gully heads would act as a control.
- *Riverbank erosion* – If a riverbank has been treated with erosion control works, return to the site at regular periods and re-survey to see if works have slowed down erosion rates. Compare all sites to a control site.

Floodplain and in-channel deposition rates are low and would be difficult to measure. But the Corangamite CMA could measure suspended sediment loads over time, to see if the supply of sediment is in decline. To be representative, suspended sediment monitoring should be undertaken over a range of flow types as the majority of suspended sediment is transported during floods. Monitoring would have to take place over a long period of time in order to detect trend of any significance.