
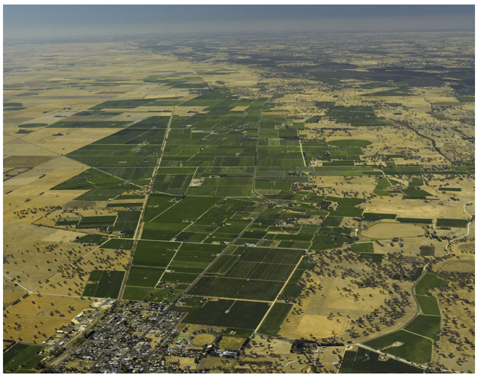

Coonawarra Edition

Unearthing Viticulture in the Limestone Coast

The climate, geology, soils, hydrology and environment of South Australia's Limestone Coast

Unearthing Viticulture in the Limestone Coast

The climate, geology, soils, hydrology and environment of South Australia's Limestone Coast

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First edition published October 2011

Design by helloFriday
www.hellofriday.com.au

ISBN 978-0-646-56744-0

Table of Contents

Acknowledgements

This document was made possible by funding from the “Grass Roots” Grape and Wine Research Development Corporation Regional Initative with matching funds from the Australian Federal Government. It was produced and jointly funded by the Limestone Coast Grape and Wine Council. The following people are also acknowledged for their contribution:

- The project steering committee: Ben Harris of Wynns’ Coonawarra Estate, Hans Loder of Katnook Estate and Sue Bell of Bellwether Wines. This group dedicated themselves to this project from the outset and contributed invaluable feedback and direction throughout the entire project. Thanks to each of you for your individual contributions of time and effort.
- For their time and invaluable feedback during the compilation of this document, the external review panel: Peter Dry of The Australian Wine Research Institute, Peter Bissell of Balnaves Coonawarra, Allen Jenkins of Wynns’ Coonawarra Estate and Karen Ronning of Zema Estate.
- The Phylloxera and Grape Industry Board of South Australia, especially Brendan Tully, for the provision of vineyard planting data and maps for use in this document.
- Thanks to all the vineyard personnel who contributed data to this document, especially the technical staff from Treasury Wine Estates at Padthaway, Bordertown, Coonawarra and Robe, Tidswell Wines, Yalumba Wines, especially Dan Newson, and Terry Strickland.
- For his assistance with the background information and interpretation of the Gaussen climatograms, thanks goes to Max Loder, retired Viticulture Lecturer formerly of Riverina-Murray Institute of Higher Education.
- Jan Rowland of the Department of Environment and Natural Resources prepared the soil zone, elevation and terrain maps and undertook all geographic information system-based data analyses. Her expertise and endless patience are gratefully acknowledged.
- James Hall of the Department of Environment and Natural Resources kindly gave his permission for the use of all soil profile images. His cooperation is appreciated and acknowledged.
- Members of the regional associations of the Limestone Coast Wine Zone for providing the regional introductions and contributing images to represent their regions.
- Peter Waring of Primary Industries and Resources of South Australia for the development of maps, adviceon the South Australian Resources Information Geoserver and supply of published images.
- The Staff of the Department of Water for supply of images and information, particularly those staff at the Mount Gambier office.

gwrdc GRAPE AND WINE RESEARCH AND DEVELOPMENT CORPORATION

THE LIMESTONE COAST GRAPE & WINE COUNCIL INC.

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Mardi Longbottom

Mardi Longbottom has a degree in Agricultural Science (Viticultural Science), Masters in Viticulture and Doctor of Philosophy from The University of Adelaide. Mardi began her career in viticulture in 1992 when she was involved with the establishment of her family's vineyards at Padthaway in the Limestone Coast.

As a new graduate Mardi worked as a vineyard technical officer in Coonawarra and later as a viticulturist in the Adelaide Hills and McLaren Vale, South Australia. Mardi returned to The University of Adelaide in 2001 and taught in the undergraduate and post graduate viticulture programs whilst establishing her research career. At the completion of her PhD which investigated aspects of grapevine flowering and fruitset, Mardi spent time in the USA working in viticulture research and industry extension. Mardi currently consults to clients across a range of viticulture industry stakeholders and retains strong links with her family's vineyard business as well as working as viticulturist at The Australian Wine Research Institute.

AUTHORS

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Markus has an Honours Degree in Environmental Science and an extensive and varied background in technical, agricultural and academic pursuits. Markus is an Associate Lecturer, Laboratory and Field Support in the School of the Environment at Flinders University of South Australia. Markus is a coordinator and lecturer in Geology and Hydrologic Field Investigations, and presents tutorials across Australia for the National Centre for Groundwater Research and Training.

Markus has worked on hydrologic studies including the investigation of drainage at Kelly Hill Caves on Kangaroo Island (Dept Water Land and Biodiversity Conservation), a study of the transport of carbon in streams and soils of an Adelaide Hills catchment, and a long term data collection and sampling programs in an Adelaide Hills Catchment hydrogeological field site which has resulted in publications in scientific journals (Flinders University in conjunction with Adelaide University, University of South Australia and SA Water).

David Maschmedt

David has a degree in Agricultural Science from Adelaide University, and worked for 37 years with the State Departments of Agriculture, Primary Industries (and Resources) and the Department of Water, Land and Biodiversity Conservation. During the latter years of this time, David collected, collated, interpreted and presented soil and landscape information to assist in better management of rural land in South Australia. He was responsible for the planning and implementation of the State Land and Soil Mapping Program (1987-2001), which resulted in the production of maps, descriptions and data describing South Australia's agricultural districts, and the development of standards for classifying land and interpreting land use potential.

As South Australia's representative on the National Committee on Soil and Terrain, David played a significant role in the development of the Australian Soil Classification System, and ASRIS, the new national soil information system. At the time of his retirement from the Public Service in 2009, David was Principal Soil Scientist with DWLBC. He is currently involved in part-time consultancy work.

Introduction

The Limestone Coast of South Australia has a rich human and geological history, and its wine regions of Padthaway, Wrattonbully, Mount Benson, Coonawarra, Robe and Mount Gambier all have their own unique stories to tell.

The 250 growers with 15,800 hectares of vineyard spread throughout the Limestone Coast are presented with very different environmental resources and challenges. It is important that we characterise this complexity, as understanding and preserving our natural resources provides the foundation of the winemaking diversity, and success of the Limestone Coast.

This document is an authoritative reference that summarises the Limestone Coast's physical characteristics including the vineyards, climate, soils, landscape, geology, hydrology, and environmental resources.

I encourage and invite you to take an exploratory tour, not only of our formal GI Regions, but also the other smaller viticultural areas that have their own interesting and distinctive attributes.

Allen Jenkins,
President, Limestone Coast Grape and Wine Council

The Limestone Coast Wine Zone

1

Mardi Longbottom

The 'Limestone Coast' was officially registered as an Australian Geographical Indication (GI) in 1996. It is located in the south east of South Australia (Figure 1.1). and encompasses the wine regions, from north to south; Padthaway, Wrattonbully, Mount Benson, Robe, Coonawarra and Mount Gambier (Figure 1.2). Vineyards outside of the Limestone Coast regions are known collectively as Limestone Coast Wine Zone Other. For the purposes of this document, those vineyards have been grouped and nominally labeled 'vineyards near Bordertown and Mundulla', 'vineyards near Lucindale / Bool Lagoon' and 'vineyards near Penola'.

Figure 1.1. Wine regions of Australia (Wine Australia 2011).

The data presented in this chapter was primarily sourced from the vineyard register maintained by the Phylloxera and Grape Industry Board of South Australia (PGIBSA) (Personal Communication PGIBSA, January 2011).

PGIBSA collect a complete and accurate register of grapegrowers in the state. The data is compiled from all vineyards greater than 0.5 hectares. Planting data is current as at February 2011 and includes all plantings from the 2010 planting season. Vines planted in a particular year may include topworked or replaced vines, as well as new plantings in virgin ground. Where vines have been replaced or topworked, the old variety record is removed, therefore the data presented does not include any data for plantings which, for various reasons, may no longer exist.

Winegrape production in the Limestone Coast accounts for approximately 13% ($120m) of the total primary industry production in the area with beef cattle (approximately 20%) and forestry (approximately 17%) being the main contributors. Grapevines occupy around 20% of the irrigated crop area and use 9% of the irrigation water in the region (PIRSA 2010).

The Limestone Coast has approximately 20% of South Australia's vineyard plantings (PGIBSA 2010). Over the past nine years fruit from the Limestone Coast has contributed between 8% to 20% of the state crush and between 13% to 24% of its estimated value (Table 1.1). In 2010 the Limestone Coast produced a total of 116, 799 tonnes of grapes, or 8% of the total winegrape production in Australian (Table 1.2).

Table 1.1. Limestone Coast and South Australia (SA) vintage summary 2002–2010. Adapted from PIRSA (2010).

	Total Crush (T)	Total Crush % Of SA	Estimated Value $M	Estimated Value % Of SA
2002	59, 236	8	$89.7	13
2003	79,757	12	$118.8	19
2004	172,415	19	$188.6	23
2005	109,472	12	$110.1	16
2006	131,485	15	$118.1	19
2007	65,716	11	$73.0	17
2008	160,801	20	$158.7	21
2009	104,634	14	$118.2	24
2010	116,799	17	$102.4	24

Table 1.2. Australian winegrape production 2010 (ABARE 2010).

State / Zone	Tonnes	% Total AUS
Limestone Coast, SA	*116,799*	*8*
South Australia	730,628	48
New South Wales	442,608	29
Victoria	284,055	19
Western Australia	66,467	4
Tasmania	7,388	0.5
Queensland	1,452	0.1
Australian Capital Territory	648	0.0
TOTAL AUS	**1,533,246**	

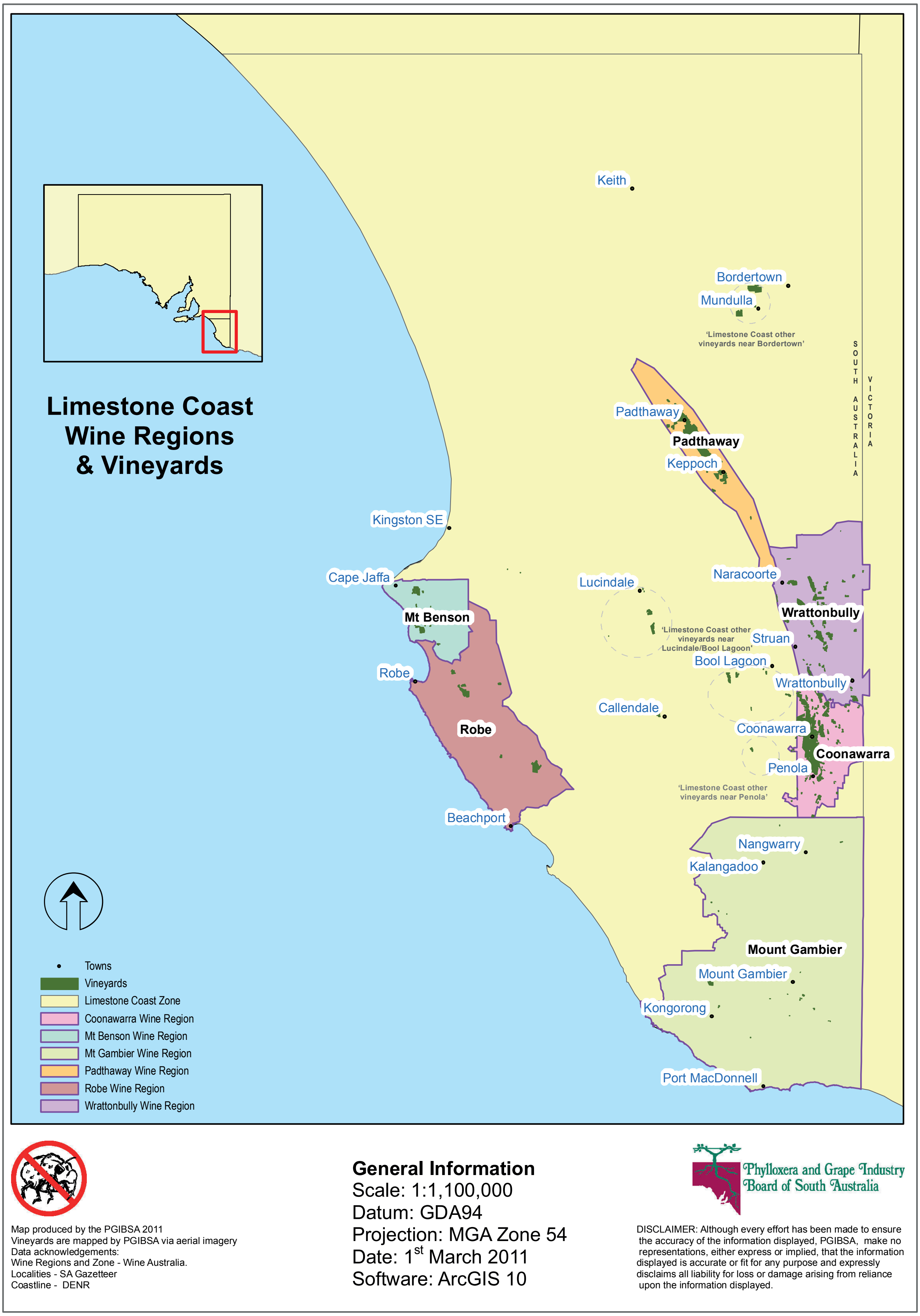


Figure 1.2. The Limestone Coast Wine Zone, wine regions and vineyards.

Description of Winegrape Plantings

2

2.5 Coonawarra

www.coonawarra.org

Coonawarra was founded over a century ago by John Riddoch, a 'larger than life' Scottish migrant, gold miner, trader, pastoralist and parliamentarian. In 1861, only ten years after arriving in Australia, Riddoch purchased the 35,000 acre 'Yallum' sheep run just west of Penola for £30,000. He then rode the booming wool process of the 1860s and, amazingly, twelve years later, he and his brother had amassed 123,000 acres of land and owned 1,110,000 sheep.

Always a visionary and entrepreneur, Riddoch established the Penola Fruit Colony in 1890. He subdivided 1,000 acres in to 10 acre blocks, planted vineyards, supported small growers, and built his landmark triple gabled winery (now Wynns') in 1896. The name 'Coonawarra' was formally adopted at Riddoch's suggestion, in 1897. The Coonawarra siding was opened in 1898 and facilitated commerce and communication in the region.

John Riddoch died aged 73 in the Federation year 1901 and Coonawarra struggled as a winemaking district for the next fifty years. Most of the grapes were used for brandy or fortified wine making. Samuel and David Wynn's purchase of Riddoch's winery and many of the original estate vineyards in 1951 signaled a resurgence and success for fine red table wines from Coonawarra. Other early winemaking enterprises including the Redman and Brand families, Mildara and Lindemans all worked hard to realise the potential of Coonawarra wines.

Significant vineyard expansion occurred in the 1970s and the 1990s. Today Coonawarra is recognised as a premium wine region with world class wines noted for their style and longevity.

The Coonawarra wine region contains the two townships of Coonawarra and Penola and is home to 130 grapegrowers (Figure 2.22).

Coonawarra has the oldest recorded vineyards in the Limestone Coast, three hectares of Shiraz planted in the 1890s. There are very few plantings from the early 1900s until 1970. During this period vineyard plantings were dominated by Cabernet Sauvignon and Shiraz and the current dominant white varieties, Chardonnay and Riesling were planted. During the next major phase of vineyard expansion in the 1990s the vineyard area in Coonawarra more than doubled to in excess of 5,000 ha. The most recent records have the total vineyard area in Coonawarra at 6,005 ha (Figure 2.21) which includes small areas of alternative varieties such as Shalistin.

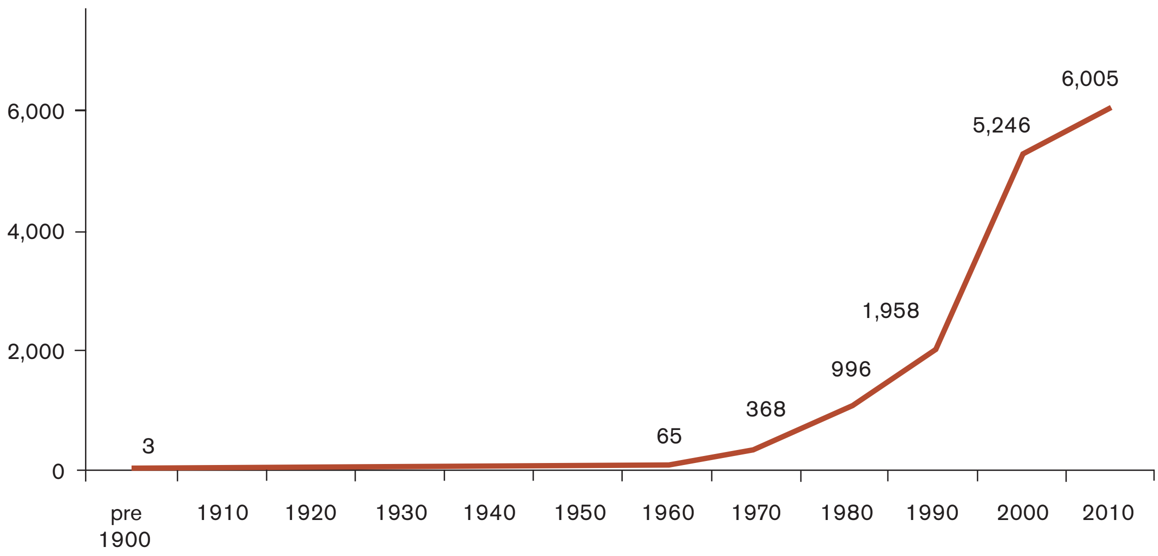


Figure 2.21. Growth in vineyard area (hectares) in Coonawarra, pre-1900-2010 (PGIBSA 2011).

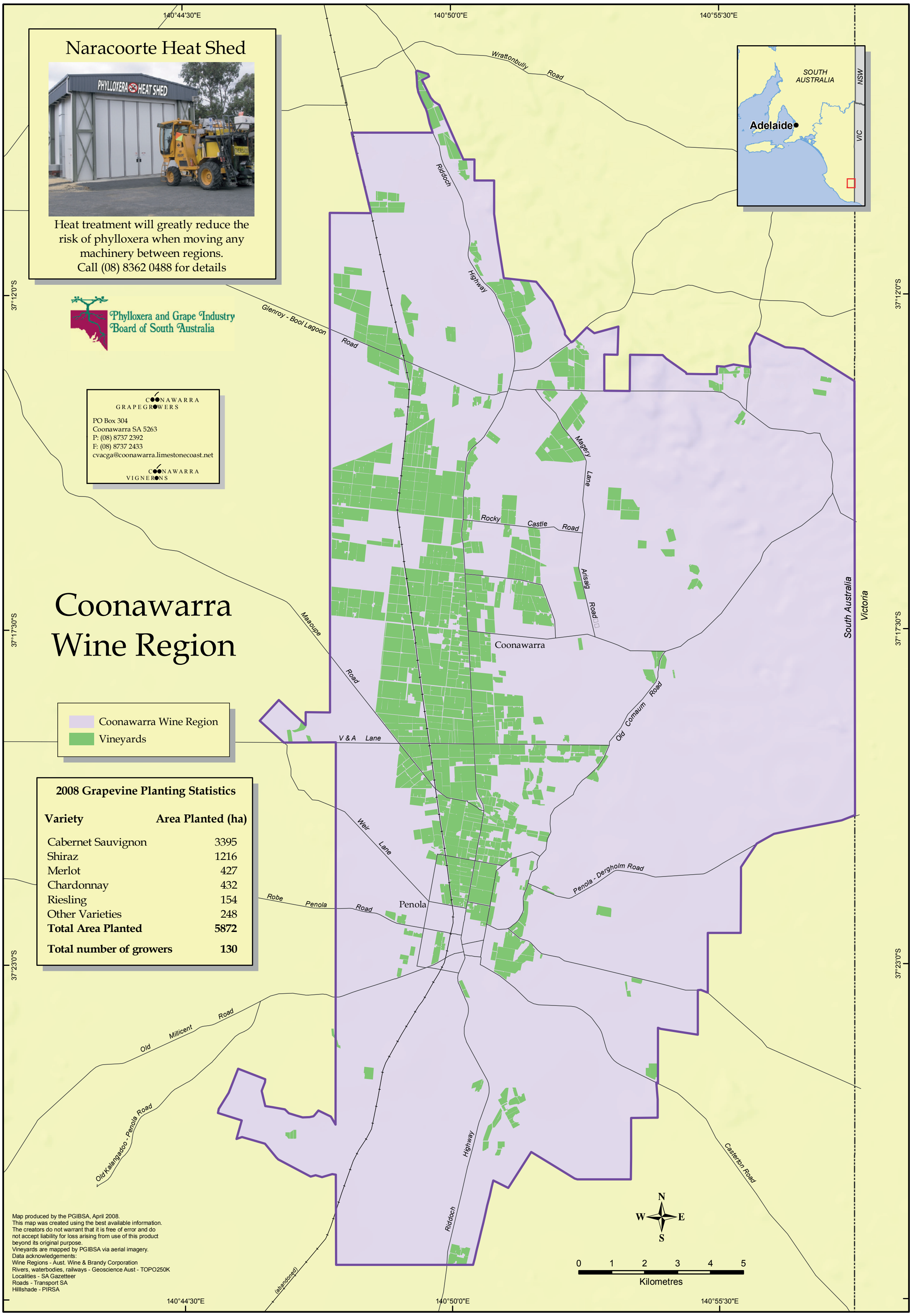


Figure 2.22. Coonawarra Wine Region (PGIBSA 2008).

More than half of the vineyards in Coonawarra are between 10 and 20 years old and 13% are less than 10 years old. Vineyards with plantings between 21 and 30 and 30-50 years old make up around 30% of the total area. Vines greater than 50 years old contribute 1% to the total vineyard area in Coonawarra (Figure 2.23).

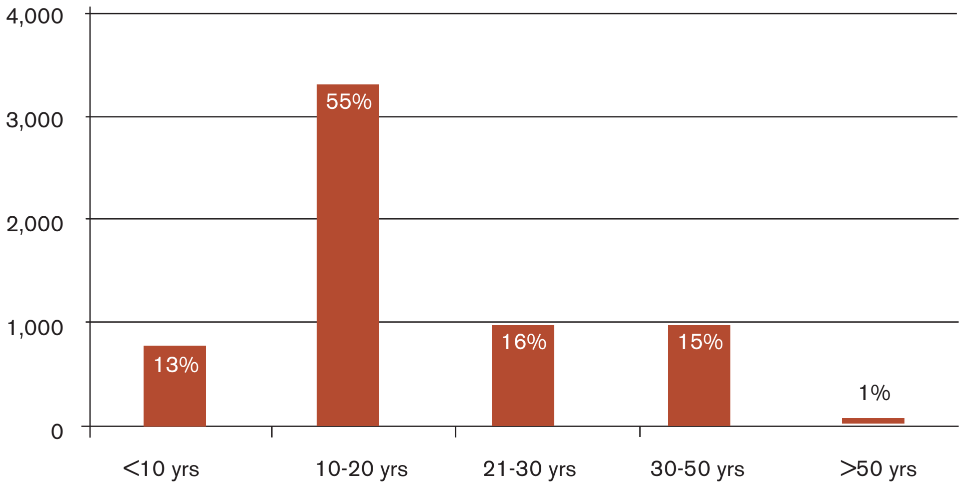
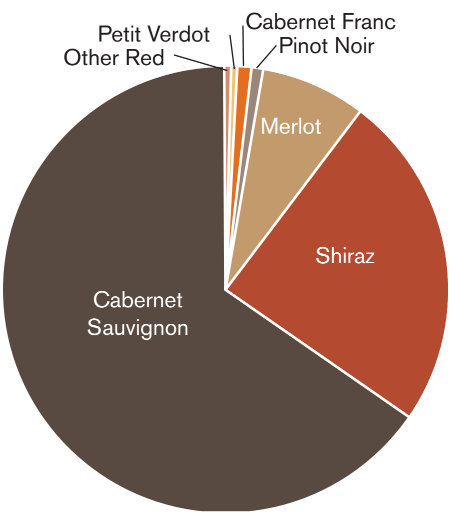


Figure 2.23. Total area (hectares) of vineyard plantings in Coonawarra by vine age (PGIBSA 2011).

Varieties by area and value

Vineyards in Coonawarra are dominated by red winegrape varieties. Cabernet Sauvignon, Shiraz and Merlot contribute almost 90% of the total vineyard area and 90% of the total grape value from the region. Chardonnay is the most significant white variety in Coonawarra contributing 6% of the total vineyard area and 9% of the total grape value. Sauvignon Blanc and Riesling equally share 4% of the total vineyard area in the region, however, Riesling contributes more to the total value of grapes from Coonawarra (Figure 2.24 and Table 2.3).



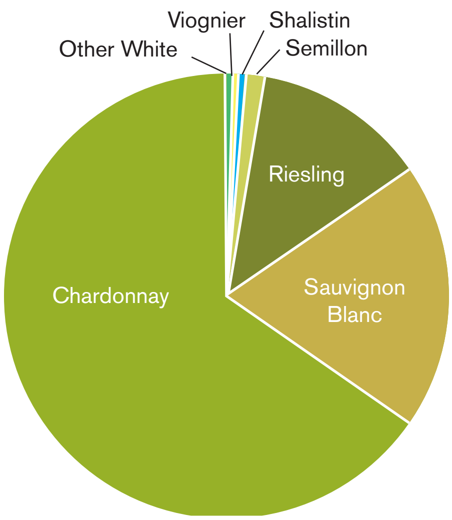


Figure 2.24. Red (90%) and white (10%) winegrape varieties in Coonawarra (by area) (PGIBSA 2011).

Table 2.3. Estimated value of key winegrape varieties in Coonawarra in 2010 (PGIBSA 2010).

Variety	Estimated Total Value	% of Total Value
Red		
Pinot Noir	$354,179	1
Merlot	$1,778,553	5
Shiraz	$6,454,732	20
Cabernet Sauvignon	$20,924,543	63
Total Red winegrapes	**$29,861,105**	**91**
White		
Sauvignon Blanc	$466,177	1
Riesling	$724,348	2
Chardonnay	$1,862,489	6
Total White winegrapes	**$3,103,165**	**9**
Grand Total winegrapes	**$32,964,271**	

Rootstocks

The majority of vineyard plantings (95%) in Coonawarra are planted on their own roots. No one variety has a significant proportion of its area on rootstocks. Cabernet Sauvignon and Shiraz total 4% and 7% of their area planted to rootstocks and similarly Chardonnay and Sauvignon Blanc have 6% and 8% on rootstocks. The most common reported rootstocks in Coonawarra are 140 Ruggeri (18%), 5C Teleki (12%) and Schwarzmann (9%) (Figure 2.25).

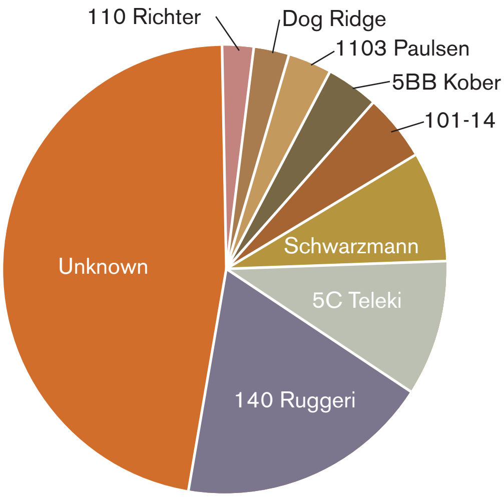
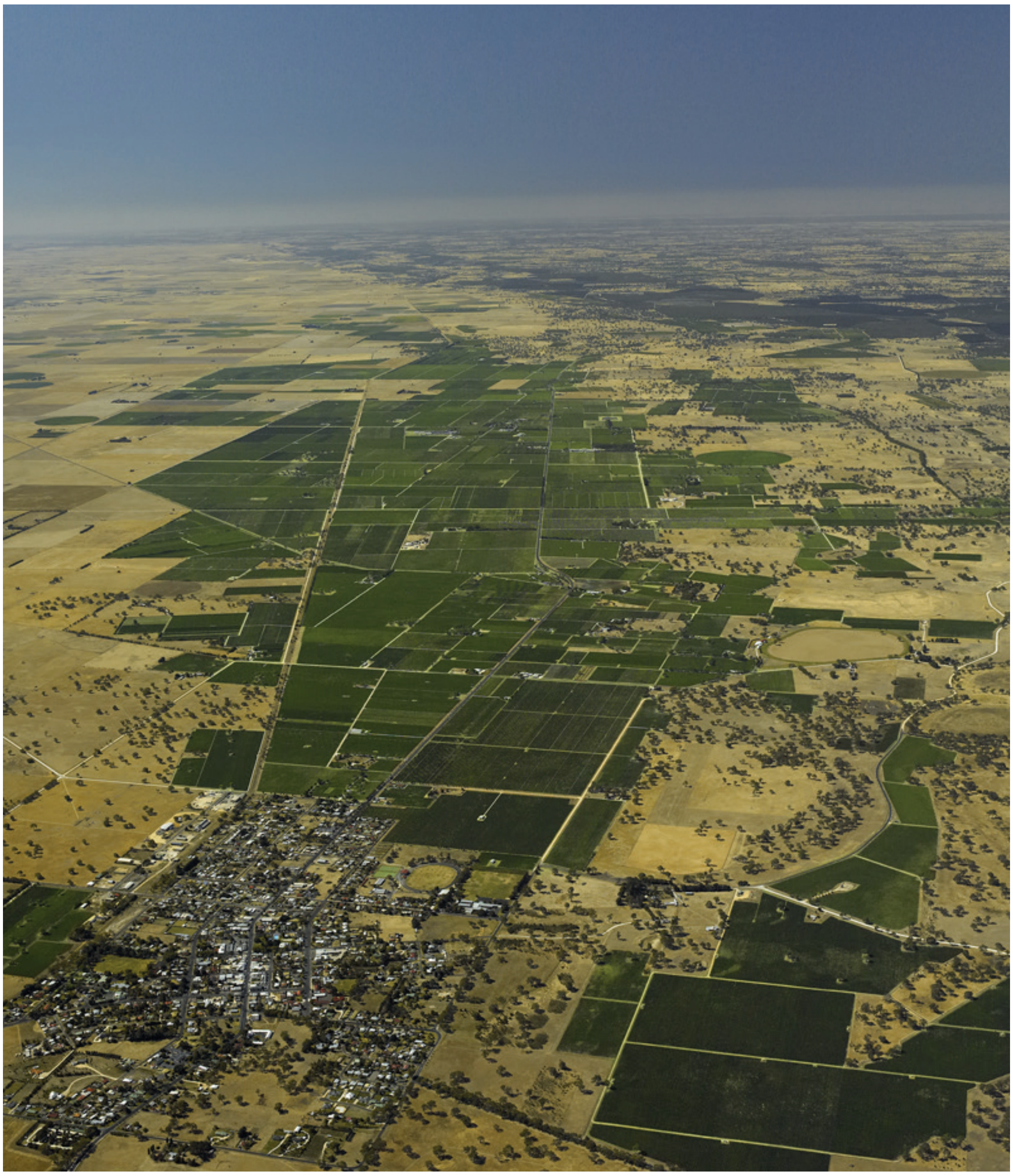


Figure 2.25. Rootstock distribution in Coonawarra (displayed as a percentage of the area of vines planted on rootstocks) (PGIBSA 2011).

Terra Rossa soil profile, Coonawarra


Coonawarra winemakers


Penola and Coonawarra from the air

2.8 References

ABARE (2010) [www.abares.gov.au] accessed online January 2011.

PGIBSA (2010) [www.phylloxera.com.au] accessed online January 2011.

PIRSA (2010) South East of South Australia Regional profile.

Wine Australia (2011) [www.wineaustralia.com/australia] accessed online August 2011.

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Climatic Profile of the Limestone Coast Wine Zone

3

Mardi Longbottom

3.1 Regional Climatic Information

The role of climate in viticulture is paramount. Climate governs the varieties that can be grown and in broad terms, the wine styles that can reliably be produced (Gladstones 2004).

The data quoted herein were sourced directly or calculated from long term average (LTA) climatic data provided by the Australian Government's Bureau of Meteorology (BOM). The period of data collection varies between stations. Station details and a summary of the data used is provided in the Appendix. The data presented does not take into account site influences such as altitude, aspect or soil type that may affect individual vineyard sites. A guide to the terrain and elevation across the Limestone Coast Wine Zone is provided in Figure 3.1. Regional soil data is provided in Chapter 4. No corrections have been made for any data except for stations discussed below.

The weather station data has been used to demonstrate climatic variability across the Limestone Coast. In the absence of long term weather data that is representative of that experienced in most of the Wrattonbully region, data from Struan may be used as a guide to conditions in that region. No weather station data was available for Bordertown; however, the climatic conditions near Bordertown are similar to those at Padthaway and Keith.

Long term average data for Padthaway was calculated from two separate BOM stations, station 026089 which operated between 1978 and 2000, and station 026100 which began operating in 2001 and remains open at the time of writing this document. The two stations are separated by approximately 6km and are both at an altitude of 37m.

The BOM station at Struan (026082) operated between 1977 and 1999. This is noted because the LTA dataset does not include the hot and dry period between 2001 and 2010. The data has been included because of its proximity to the vineyards of Wrattonbully and vineyards near Bool Lagoon.

Some regional climatic information and indices have been calculated and presented for the ten years between 2001 and 2010. This period was the hottest and driest on record in Australia and the data is provided for comparative purposes only.

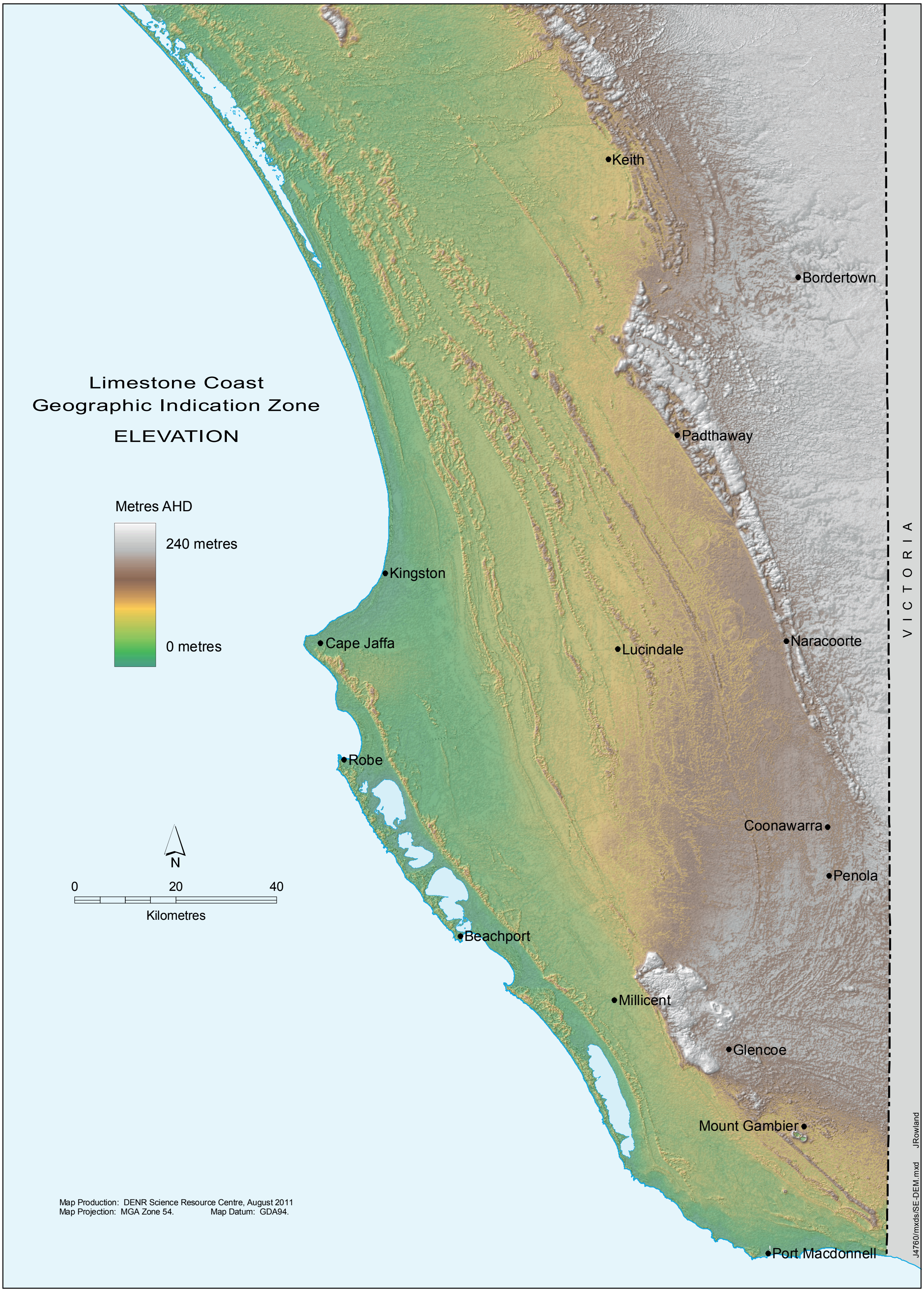


Figure 3.1. Elevation (metres Australian Height Datum) across the Limestone Coast Wine Zone.

3.2 Climate Overview

3.2.1. Temperature

Temperature is the primary climatic control of grapevine phenology, that is, the progression of grapevines through dormancy in winter to budburst, flowering and fruitset in spring followed by veraison and harvest in summer and into dormancy again in autumn and winter. In a particular environment, temperature determines which grape varieties can ripen and when (Gladstones 2004).

Temperature also governs grapevine productivity, or biomass accumulation, via its effect on photosynthesis and other growth processes such as assimilate transport, metabolism and cell division (Gladstones 2004). In terms of grape yield, temperature is critical at all stages of yield determination from the initiation of inflorescence primordia to flower differentiation, flowering and fruitset and final berry size.

For the purposes of comparison of regional temperature across the Limestone Coast, several temperature indices have been calculated and are discussed in more detail in later sections.

3.2.2. Rainfall

The long term average annual rainfall recorded at BOM stations across the Limestone Coast ranges from 463 mm in Keith to 710 mm in Mount Gambier (Figure 3.2). Mount Benson (Cape Jaffa), Naracoorte and Padthaway share a similar long term average annual rainfall of approximately 490 mm. Wrattonbully (Struan), Coonawarra, Lucindale and Robe average 552 mm, 576 mm, 600 mm and 672 mm respectively. During the recent extended dry period 2001-2010 the annual rainfall was lower than the LTA at Keith, Naracoorte, Padthaway and Robe. Mount Benson (Cape Jaffa), Coonawarra and Mount Gambier recorded higher annual rainfall during the 2001-2010 period compared to the LTA (Figure 3.2).

Long term average rainfall during the growing season (October – April) ranges from 171 mm in Mount Benson (Cape Jaffa) to 290 mm in Mount Gambier. Keith, Padthaway and Wrattonbully (Struan) receive approximately 195 mm during the growing season similar to that in the Barossa Valley. Naracoorte and Robe both receive approximately 213 mm. Lucindale and Coonawarra have LTA growing season rainfall of approximately 230 mm. The growing season rainfall at Margaret River is between that of Coonawarra and Mount Gambier. Marlborough and Bordeaux receive higher growing season rainfall compared to the regions of the Limestone coast Wine Zone (Figure 3.3).

All stations across the Limestone Coast, with the exception of Keith, received a higher than average growing season rainfall during 2001-2010 (Figure 3.3). This increase was by 9 mm on average.

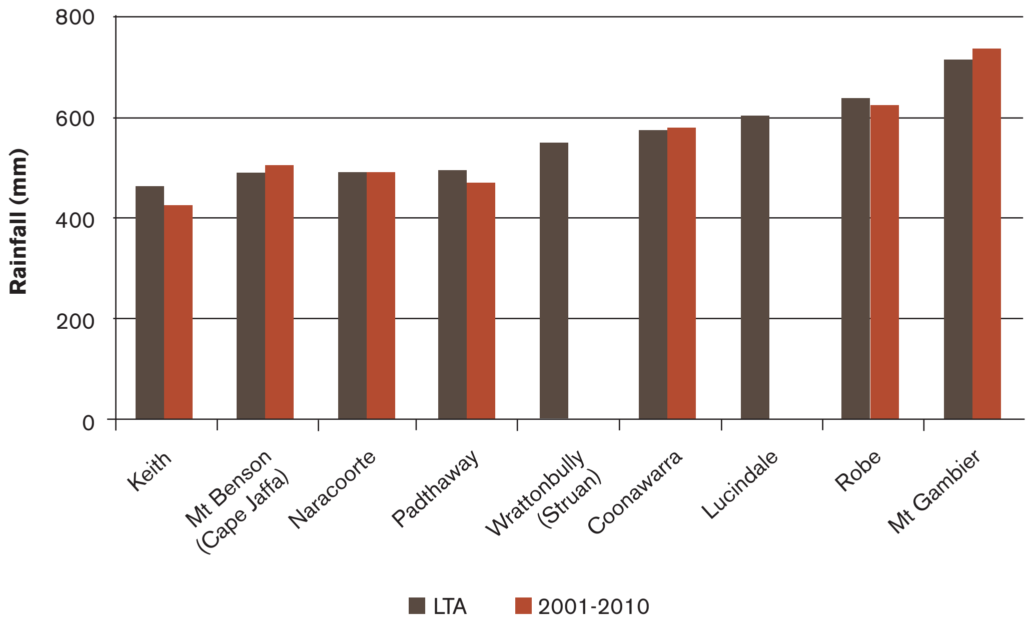


Figure 3.2. A comparison of mean annual rainfall (mm) calculated from long term average (LTA) and 2001-2010 data from across the Limestone Coast (Bureau of Meteorology 2011).

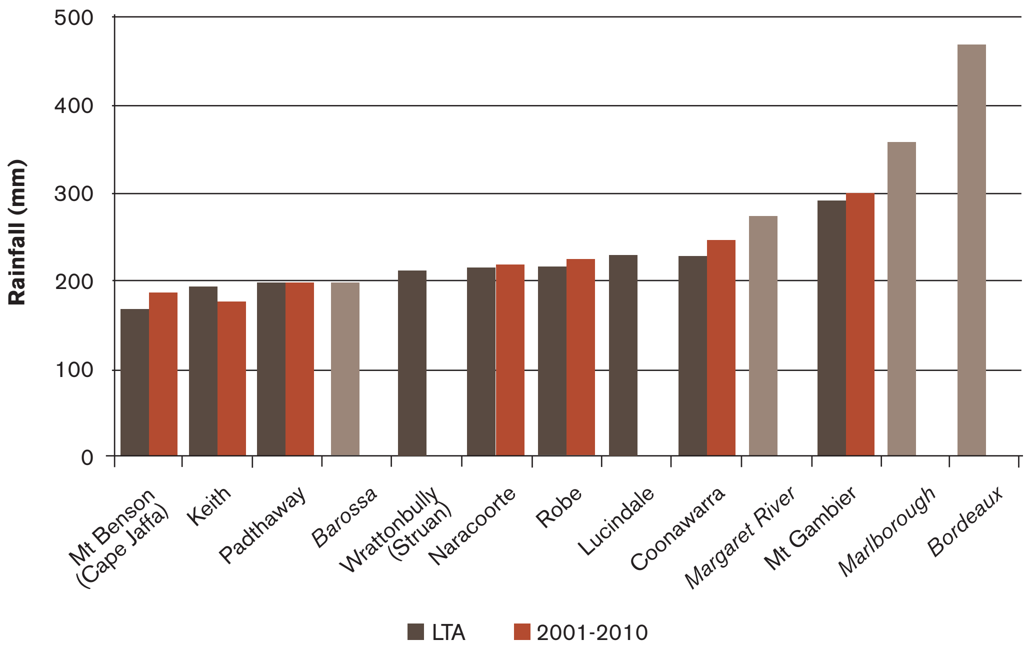


Figure 3.3. A comparison of growing season (October – April) rainfall (mm) calculated from long term average (LTA) and 2001-2010 data from across the Limestone Coast (Bureau of Meteorology 2011) and other wine regions. Margaret River data from Gladstones (1992). Marlborough (Blenheim airport), Bordeaux (Mérignac Airport) and Barossa (Nuriootpa) from Gladstones (2011).

3.2.3. Evaporation

The standard measurement of evaporation at BOM weather stations is performed using a Class A evaporation pan, however, this information is not collected at all stations across the Limestone Coast. The measurement of evaporation is important in viticultural production as it provides information about potential vine water use and water availability. Of the stations which measure evaporation, Mount Gambier has the lowest LTA growing season evaporation followed by Wrattonbully (Struan), Coonawarra and Padthaway with the highest (Table 3.1).

Table 3.1. Growing season (October – April) evaporation (mm) in the Limestone Coast (Bureau of Meteorology 2011).

	Evaporation (mm) (Oct-Apr)
Mt Gambier	1,028
Wrattonbully (Struan)	1,145
Coonawarra	1,168
Padthaway	1,297

Comparing evaporation across the year, during winter and early spring the total monthly evaporation is similar at the Padthaway, Wrattonbully (Struan), Coonawarra and Mount Gambier stations. In summer, when evaporation is greatest, the difference in total monthly evaporation between Mount Gambier (lowest) and Padthaway (highest) exceeds 50 mm (Figure 3.4).

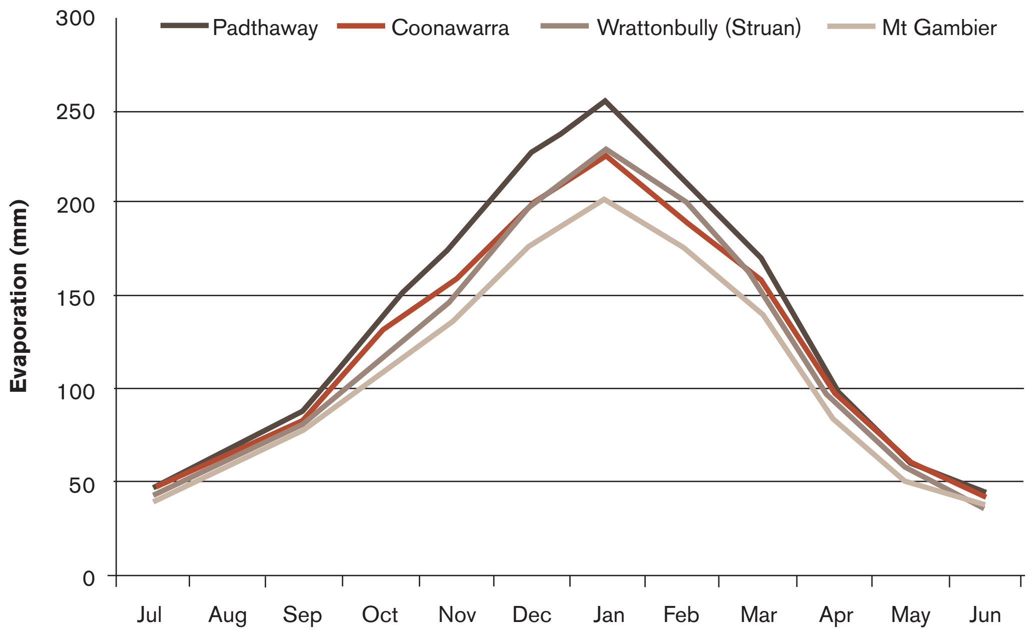


Figure 3.4. Total monthly evaporation (mm) calculated from weather station data at different locations across the Limestone Coast (based on long term average data) (Bureau of Meteorology 2011).

3.2.4. Relative humidity

Relative humidity (RH) describes the amount of water vapour held in the atmosphere as a percentage of its total capacity for holding water (saturation) at a given temperature (Gladstones 2004). There is little variation in the 9am RH across viticultural regions of Australia. However, differences between the 3pm RH can highlight significant regional differences in terms of challenges to viticultural management.

Humidity is critical to viticultural production because of its influence on the development of fungal diseases such as downy and powdery mildews and Botrytis. High humidity will favour fungal growth.

Differences in humidity across regions will also influence water use efficiency. Under conditions of high humidity, evaporative losses from vine leaves are lower and efficiency of water use is higher. Coastal regions commonly experience relatively high afternoon humidity, a result of afternoon sea breezes. Coastal regions of the Limestone Coast tend to have higher afternoon humidity compared to inland regions. The coastal regions of the Limestone Coast have similar LTA relative humidity to Marlborough, Margaret River and Bordeaux. The relative humidity in the Barossa is lower than that recorded at the weather stations across the Limestone Coast (Table 3.2).

Table 3.2. Average relative humidity (3pm) (October – April) in the Limestone Coast and other wine regions (in italics). Limestone Coast data based on long term average climatic data (Bureau of Meteorology 2011). Margaret River data from Gladstones (1992). Marlborough (Blenheim airport), Bordeaux (Mérignac Airport) and Barossa (Nuriootpa) from Gladstones (2011).

Station	Relative humidity (3pm) (Oct-Apr)
Barossa	37
Keith	39
Naracoorte	40
Coonawarra	45
Wrattonbully (Struan)	45
Padthaway	46
Mt Gambier	50
Marlborough	*56*
Margaret River	*56*
Mt Benson (Cape Jaffa)	58
Bordeaux	58
Robe	64

3.2.5. Wind patterns

Strong winds can have a devigourating effect on vine growth which is especially problematic during vineyard establishment. Early spring shoot growth may also be damaged by strong winds. During flowering, wind can disrupt pollination and result in decreased yields. High winds also increase evaporative losses from grapevine leaves and decrease the vine water use efficiency. Strong winds have been troublesome in some regions of the Limestone Coast and wind breaks have been installed to prevent damage from wind. However, the effects of wind are not all negative. Mild winds can be beneficial to the microclimate within the grapevine canopy, assist to minimise disease and increase canopy and fruit exposure (Gladstones 2004).

Wind patterns vary considerably across the Limestone Coast, in particular mean wind speed at the coastal station, Mount Benson (Cape Jaffa), is significantly higher than at the inland stations. Wind speeds across the Limestone Coast tend to be higher than at Marlborough (Table 3.3).

Table 3.3. Wind patterns in the Limestone Coast 2001-2010. Mean monthly wind speed and highest average monthly wind speed during the growing season (October – April) (based on long term average data) (Bureau of Meteorology 2011). Data for Marlborough, New Zealand (in italics) sourced from Marlborough Research Centre, 1986-2011 (Marlborough Wine Research Centre 2011).

Station	Mean wind speed (km/h) (Oct-Apr)	Highest average monthly wind speed (km/h) (Oct-Apr)
Marlborough	*11.7*	*13.1 (November)*
Keith	14.5	16.0 (December)
Lucindale	16.9	19.5 (December)
Robe	17.4	18.7 (September)
Padthaway	18.0	21.3 (September)
Wrattonbully (Struan)	18.3	19.9 (September)
Coonawarra	19.9	22.5 (September)
Mt Gambier	22.4	24.3 (January)
Naracoorte	22.7	25.1 (September)
Mt Benson (Cape Jaffa)	30.0	32.4 (February)

The relationship between wind speed and intensity from January to December for each of the BOM stations across the Limestone Coast is shown in Figure 3.5. These wind roses were sourced from the BOM (2011) and have been constructed in the following way:

- The percentage of calm conditions is represented by the size of the centre circle - the bigger the circle, the higher is the frequency of calm conditions.
- Each branch of the rose represents wind coming from that direction, with north to the top of the diagram. Eight directions are used.
- The branches are divided into segments of different thickness and colour, which represent wind speed ranges from that direction. Speed ranges of 10km/h are used in these wind roses. The length of each segment within a branch is proportional to the frequency of winds blowing within the corresponding range of speeds from that direction.

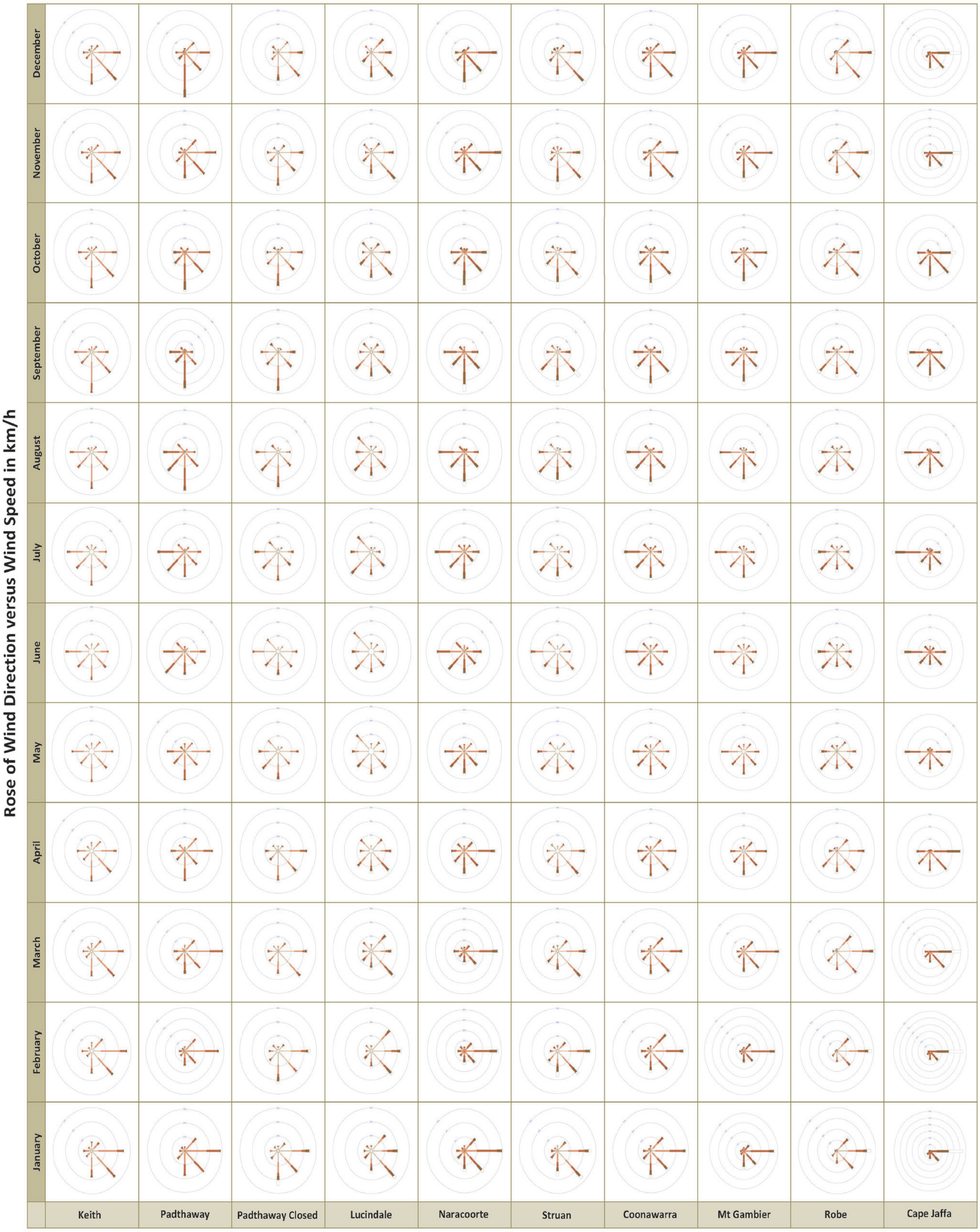
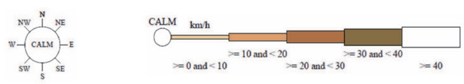


Figure 3.5. Wind speed and intensity across the Limestone Coast (Bureau of Meteorology 2011). Station details can be found in the appendix.



Example of wind breaking treelines in Mount Benson wine region

3.3 Local climate indices

3.3.1. Mean January temperature

The mean January temperature (MJT) approximately represents the month of the highest annual temperature (Smart and Dry 1980) and correlates well with degree days. This is an internationally used index used to compare regions, however, it is noted that in some regions of the Limestone Coast January is not the hottest month.

MJT was calculated from long term average (LTA) from Limestone Coast BOM stations. Across the Limestone Coast MJT ranges from 18.1 at the coldest station (Robe) which has an MJT close to that of Marlborough. Padthaway and Lucindale share an MJT of 20.2 with Bordeaux. The warmest Limestone Coast station is Keith (MJT = 21.5) which is slightly warmer than the Barossa (Figure 3.6).

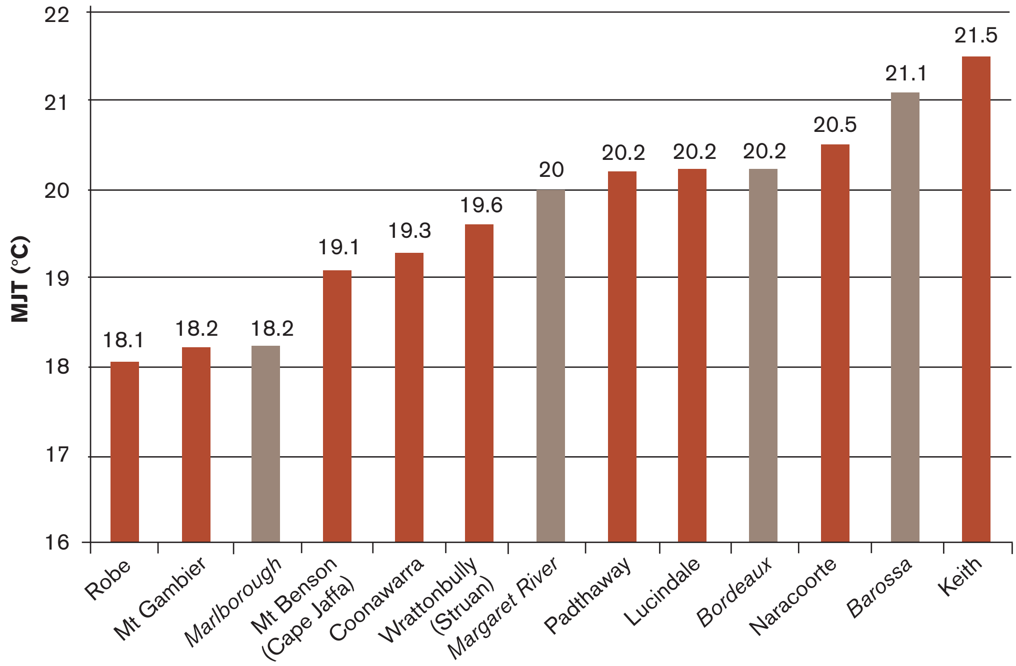


Figure 3.6. Comparison of mean January temperatures (MJT) (degrees Celsius) across the Limestone Coast and other wine regions (light brown). Limestone Coast calculations based on long term average (LTA) climatic data (Bureau of Meteorology 2011). Margaret River data from Gladstones (1992). Marlborough (Blenheim airport), Bordeaux (Mérignac Airport) and Barossa (Nuriootpa) from Gladstones (2011).

During the ten years from 2001-2010 Australia experienced the hottest decade on record (BOM 2011). The effect of increased temperature on MJT was variable across the Limestone Coast. There was no change in MJT from 2001-2010 at Mount Benson (Cape Jaffa), however; at Mount Gambier and Keith MJT increased by 0.6 during the same period (Figure 3.7).

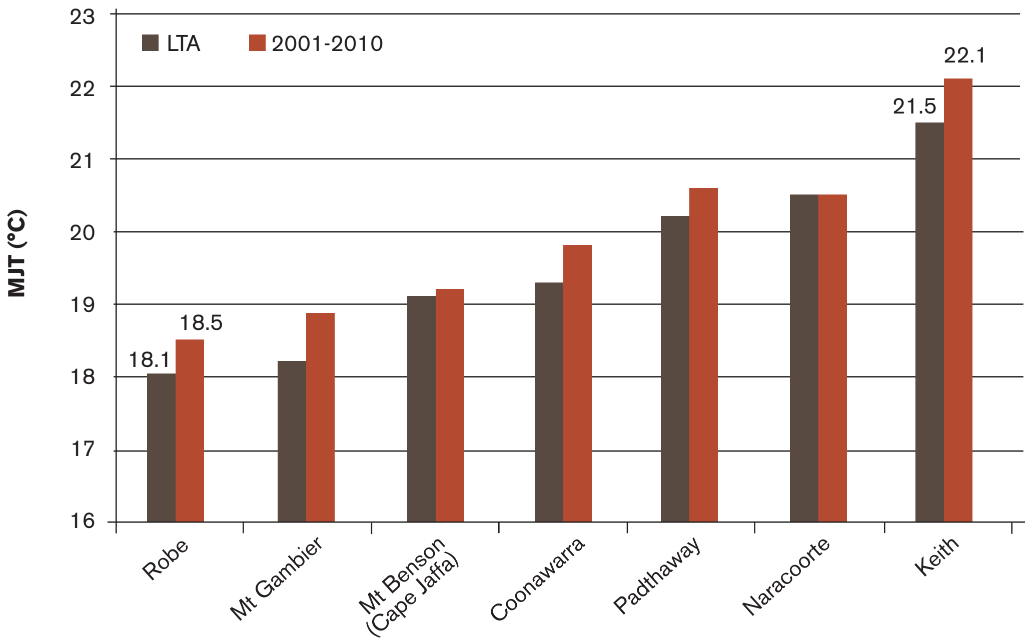


Figure 3.7. Comparison of mean January temperatures (MJT) (degrees Celsius) across the Limestone Coast based on long term average (LTA) and 2001-2010 climatic data (Bureau of Meteorology 2011).

3.3.2. Mean daily range

The mean daily range (MDR) (diurnal range) is the difference between the average daily maximum and minimum temperatures and indicates the extent of cooling that occurs overnight.

The inland regions of the Limestone Coast tend to have a higher MDR during the growing season compared to the coastal regions (Figure 3.8). This is especially evident during the October to April period. Similar trends in MDR are seen for coastal locations Noarlunga (McLaren Vale / Adelaide, South Australia) and Mount Benson (Cape Jaffa). The MDR is significantly less in those regions compared to the more inland regions, for example Naracoorte, which has the highest growing season MDR of the Limestone Coast stations. The comparison of monthly MDR between Loxton (Riverland, inland South Australia) and inland regions of the Limestone Coast shows that the MDR is similar during the growing season; however, during winter the MDR is greater at Loxton, a function of both higher maximum temperatures and lower minimum temperatures at Loxton (BOM 2011).

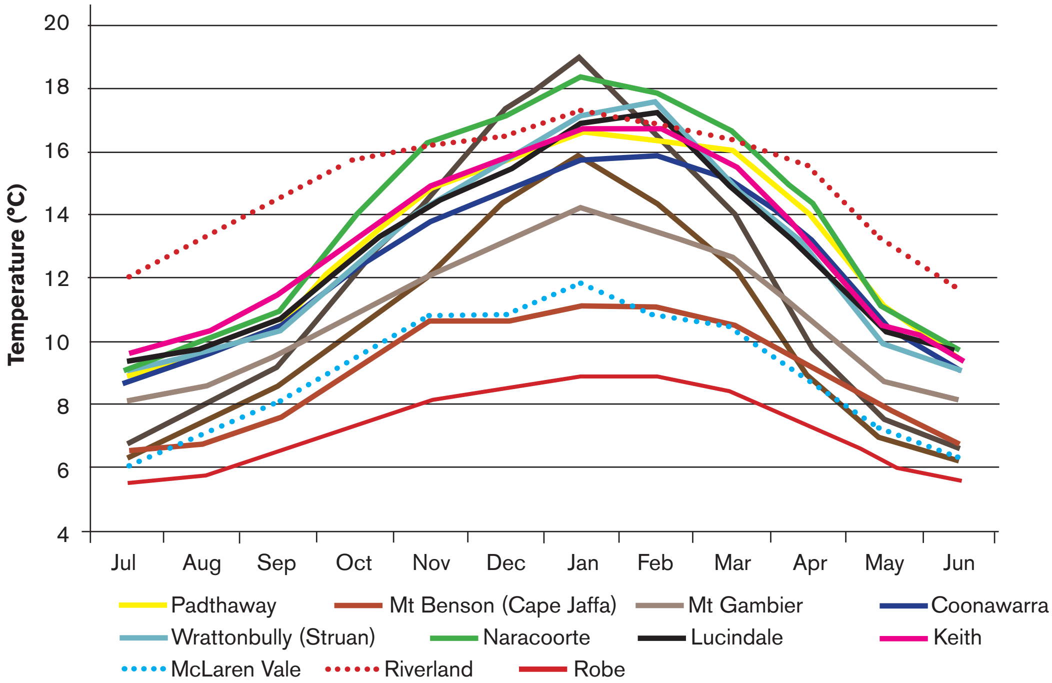


Figure 3.8. Monthly average mean temperature (degrees Celsius) (calculated from long term average data) across the Limestone Coast including Noarlunga and Loxton (South Australia) as a comparison (Bureau of Meteorology 2011).

3.3.3. Continentality

'Continentality' (CTL) is an index used to illustrate climatic differences between inland and coastal regions during the hottest and coldest months of the year. This has been simplified to the difference between the mean January and mean July temperatures (Smart and Dry 1980) and adopted here. Inland regions with a 'continental' climate tend to experience more rapid seasonal changes compared to maritime regions. The benefits of this include rapid onset and even budburst, and similar rapid decrease in temperature going into autumn which promote even ripening (Gladstones 2011). 'Maritime' regions are influenced by the relative slower heating and cooling of the ocean, the result being fewer seasonal temperature extremes (Gladstones 2004). Regions with maritime climates experience a slower onset of budburst which in extreme cases may be problematic. However, maritime climates tend to have an extended autumn period and greater potential for good ripening (Gladstones 2011).

The Limestone Coast is particularly influenced by maritime conditions because of its west-facing coast (Gladstones 2004). The modifying effects of maritime conditions on weather and climate across the Limestone Coast are thought to be enhanced during the latter growing season (November – March) by upwelling of the Southern Ocean between Cape Jaffa and Portland (Figure 3.9). Upwelling describes the rise to the surface of cold, deep ocean waters (Figure 3.10) (Nieblas et al. 2009). The strong high pressure systems that are common along the south east coast of South Australia in summer are associated with an increase in frequency of south easterly winds. These winds run parallel to the coast and influence upwelling. The cold water that is brought to the sea surface during upwelling produces sea fog and increased moist air along the coast. There is also a moderate influence on temperatures as a result of strengthened seas breezes under upwelling conditions (Personal Communication Darren Ray, Australian Bureau of Meteorology 2011).

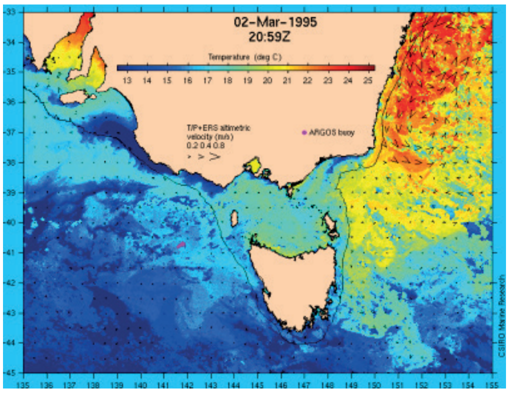


Figure 3.9. Sea surface temperature image showing strong cold water upwelling in the Bonney Coast in March 1995 (Butler et al. 2002). Reproduced by permission of CSIRO Australia, copyright CSIRO.

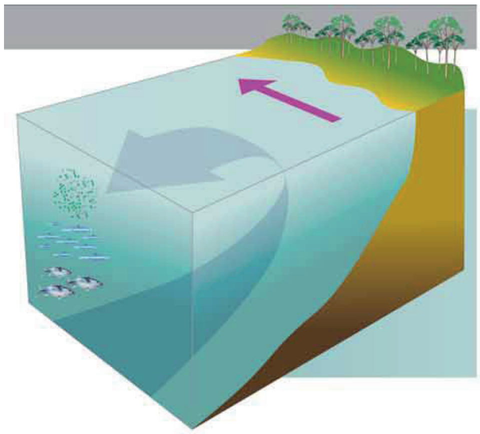


Figure 3.10. Upwelling in the current climate off a southern hemisphere coast. Wind is parallel to the coast, and water is deflected to the left of the wind by the Coriolis force. Surface water is pushed offshore and is replaced by cool, nutrient-rich water from depth. (Image: Louise Bell, reproduced by permission of CSIRO Marine & Atmospheric Research).

Continentality across the Limestone Coast varies from Keith being most continental (CTL = 11.6) to Robe, having the most maritime influence (CTL = 7.3) (Figure 3.11). From an Australian perspective, Robe and Mount Benson (Cape Jaffa) have a more maritime climate than Swansea, Tasmania and Margaret River, Western Australia. However, those stations within the Limestone Coast with the most continental influence (Keith, and Naracoorte) have values significantly lower than Australian viticultural regions further inland, for example Riverland, South Australia and Mudgee, New South Wales (Figure 3.11).

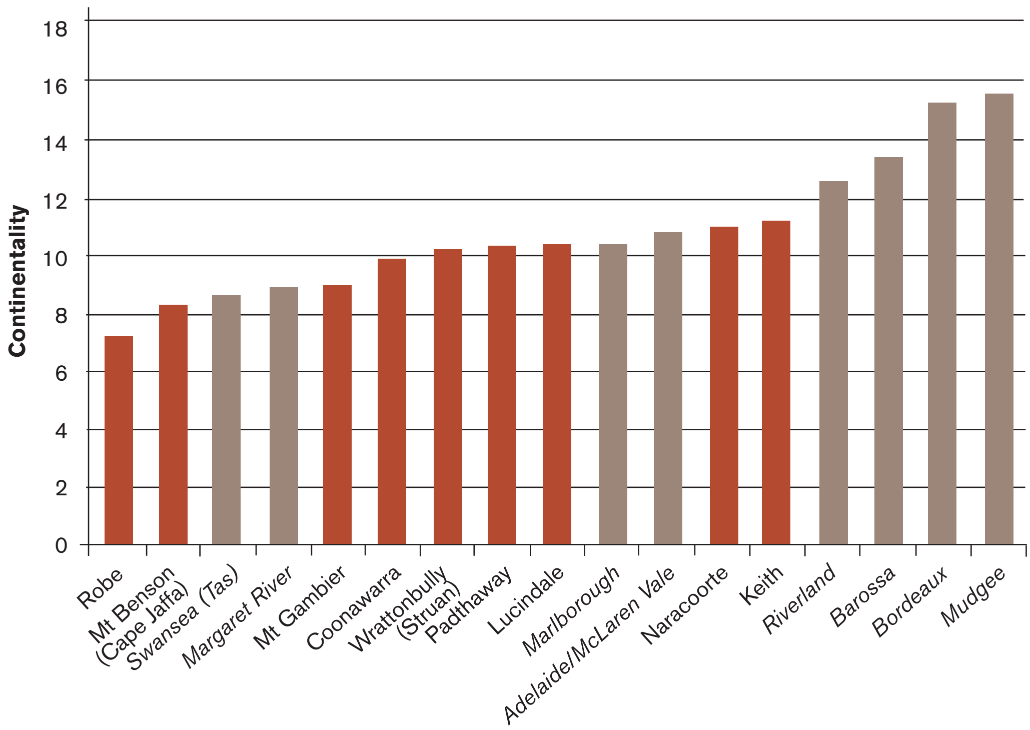


Figure 3.11. Continentality (mean January minus mean July temperature) across the Limestone Coast (calculations based on long term average climatic data) (Bureau of Meteorology 2011) and other viticultural regions (light brown) (Gladstones 1992).

3.3.4. Gaussen climatograms

A Gaussen climatogram is used to demonstrate long term climate averages in graphical form. It allows one to appreciate the typical local climate of an area, demonstrated by the interaction of average temperature and rainfall curves on a 1:2 (temperature: rainfall) ratio. The interaction of the two curves was found by Gaussen (1955) to be the best way to characterise a local climate. Furthermore, temperature and rainfall data are obtainable from virtually every weather station on earth, as demonstrated in the World Atlas of Climatograms (Walter and Leith 1960). Climatograms reflect average trends for regions and can be used to quickly determine typical annual weather. For this reason, climatograms can be a helpful tool for site selection and vineyard management.

Temperature and rainfall

The interaction of the climatograms' curves can indicate differences in climate types, for example Mediterranean, defined as having a predominance of winter rainfall and summer drought, versus tropical climate, characterised by summer rainfall and winter drought. Across the Limestone Coast all of the climatograms in Figure 3.12 indicate a maritime climate. Shallow curves are indicative of a mild climate (lacking extremes), while a steep curve may indicate a continental climate with extreme differences in temperature and low summer rainfall.

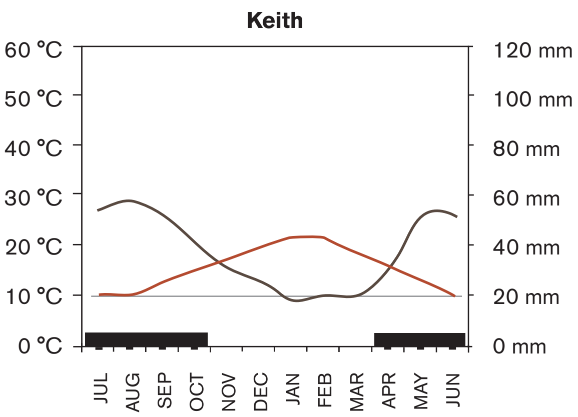
The point at which the rainfall curve intersects and falls below the temperature curve indicates that rainfall is deficient and grapevines are likely to suffer from moisture stress. The date at which this occurs can broadly indicate when supplementary irrigation may be required. Across the Limestone Coast this ranges from November at Keith and Padthaway to December in Mount Gambier (Figure 3.12). Another feature of the climate of the Limestone Coast is a late burst of spring rain around November.

The Frost Bar and 10°C Line

The gap between the solid black bars at the base of each climatogram can be considered as the period of vegetative growth and represents the time during which frost events are unlikely. It is also a useful indicator of the approximate length of season for viticultural production during which development is possible without being adversely affected by damaging frost. Knowing the period of frost is critical, as in spite of the beginning of growth usually being indicated by the temperature line crossing above 10° C, this period may be shortened drastically by the incidence of frost. A few examples from the Limestone Coast may illustrate this (Figure 3.12).

Limestone Coast climatogram summary

The climatograms all reflect relatively small differences across the regions of the Limestone Coast, with the overall climate type being Mediterranean with winter dominant rainfall and relative summer drought. An area such as Robe which has high winter rainfall (as indicated by a steep rainfall curve) and a shallow temperature curve indicates mild maritime conditions. A comparison of the climatograms of Keith and Robe, shows that the climate at Keith is more continental (see large gap in rainfall between November and April) which is in agreement with the data in section 3.3.3 above.



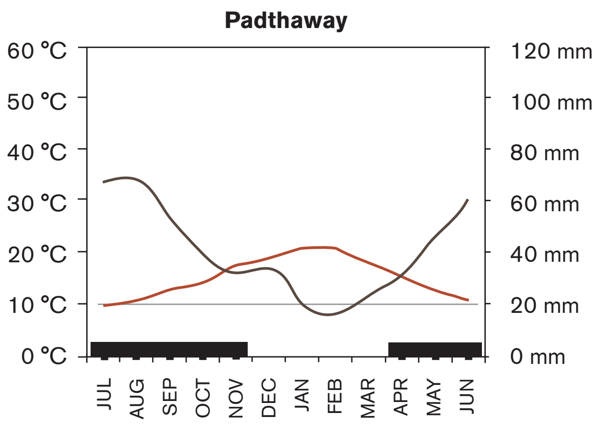
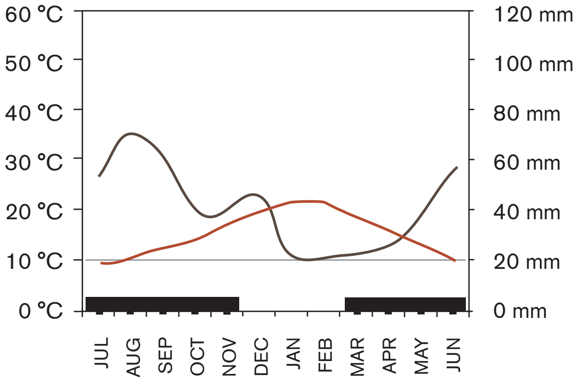
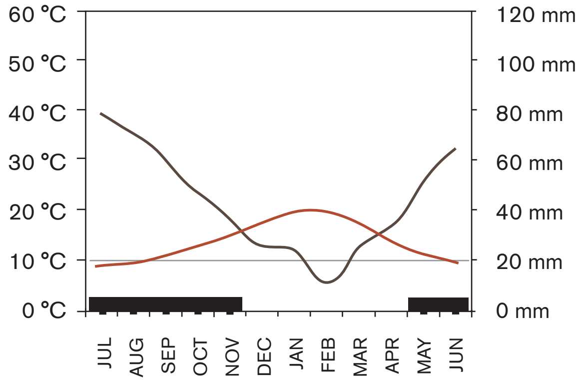


Figure 3.12 (pages 59 and 60). Climatograms for weather stations across the Limestone Coast. The brown represents mean monthly rainfall and the red line represents mean monthly temperature based on long term average data (BOM 2011). Note the vertical scale of temperature:rainfall = 1:2. Black bar on the x-axis represents the incidence of frost.

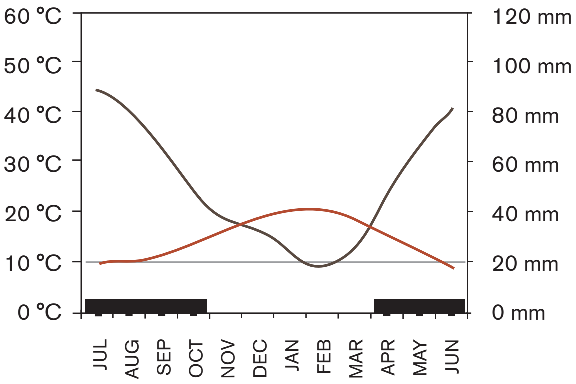
Naracoorte



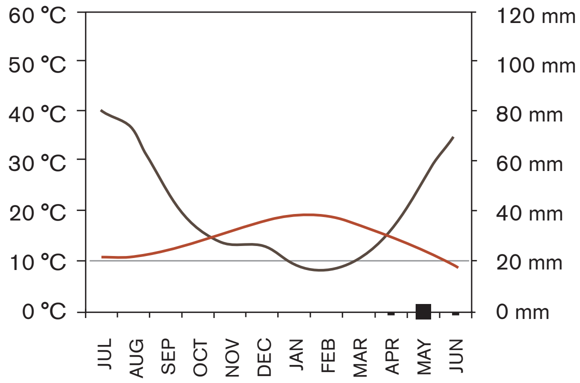
Wrattonbully (Struan)



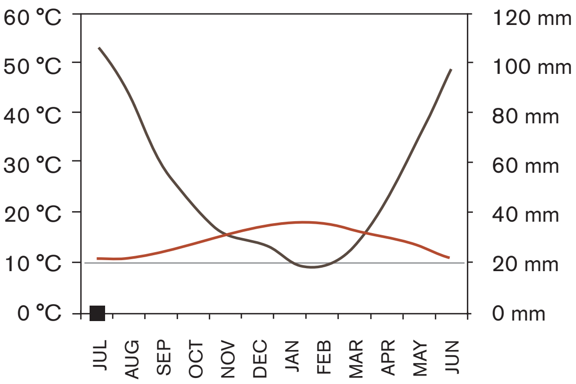
Lucindale



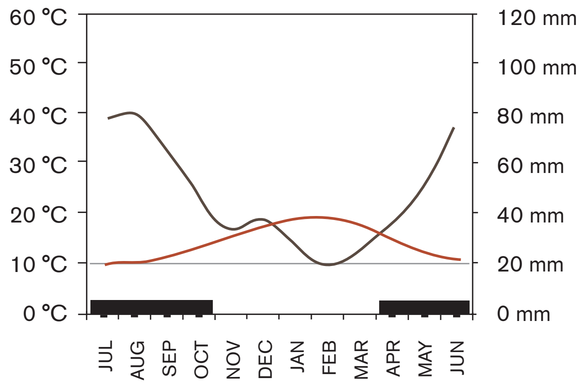
Mt Benson (Cape Jaffa)



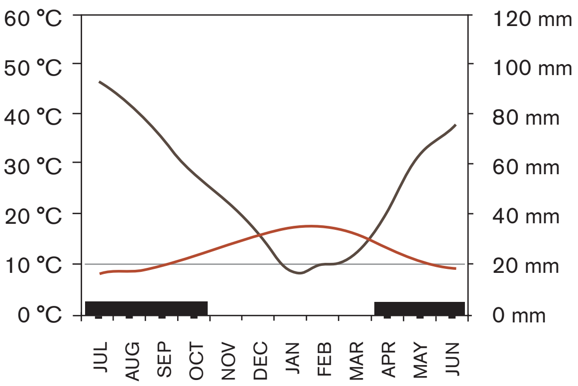
Robe



Coonawarra



Mt Gambier



3.3.5. Short term temperature variability

Short term temperature variability describes the combination of day / night (diurnal) temperature range with that from day to day or week to week (Gladstones 2004) and explains weather events that cause damage to grapevines by heat or cold extremes. One of the most common examples of short term temperature variability in the Limestone Coast is spring frost. Using the number of days between October and April with temperatures less than or equal to zero and two degrees Celsius as an indicator of frost risk, BOM station data supports the theory that the risk of spring frosts increases with increasing distance from the coast where the modifying effects of the ocean are least (Table 3.4). However, localised geography and terrain also influence frost risk and coastal regions are not completely excluded from the risk of frost.

Table 3.4. Incidence of short term temperature variability (cold) across the Limestone Coast. Data based on long term average climatic data (Bureau of Meteorology 2011).

	Total # days (Oct-Apr) ≤0 degrees C	Total # days (Oct-Apr) ≤2 degrees C
Mt Benson (Cape Jaffa)	0	0
Robe	0	0
Keith	0.3	2
Mt Gambier	0.4	3
Wrattonbully (Struan)	0.3	4
Lucindale	0.6	4
Padthaway	0.8	6
Coonawarra	0.9	8
Naracoorte	4.2	14

High temperatures can be directly and indirectly detrimental to vine growth and development. Devigouration, poor flowering and consequent fruitset, and fruit and / or foliage burn are all examples of the effects of extreme heat. Using the number of days during October to April with temperatures greater than or equal to 35 degrees Celsius as a measure of risk from high temperature effects, coastal regions of the Limestone Coast are buffered against this risk (Table 3.5).

Table 3.5. Incidence of short term temperature variability (heat) across the Limestone Coast. Data based on long term average climatic data (Bureau of Meteorology 2011).

	Total # days (Oct-Apr) ≥35 degrees C
Robe	1
Mt Benson (Cape Jaffa)	5
Mt Gambier	8
Wrattonbully (Struan)	10
Coonawarra	12
Lucindale	16
Padthaway	17
Keith	22
Naracoorte	24

3.3.6. Degree days

The summation of degree days approximately describes the useful heat (i.e. greater than 10°C and less than or equal to 19°C) for vines over the growing season (Gladstones 2004). Degree days are calculated using the monthly mean temperature minus 10, multiplied by the number of days in the month summated from October to April.

Mount Gambier has the lowest number of degree days (1,227) accumulated during the growing season similar to that of Marlborough. Naracoorte, Lucindale and Padthaway have a similar number of degree days to Margaret River. The degree days of Bordertown (not presented here) is likely to be similar to that of the Barossa (Figure 3.13).

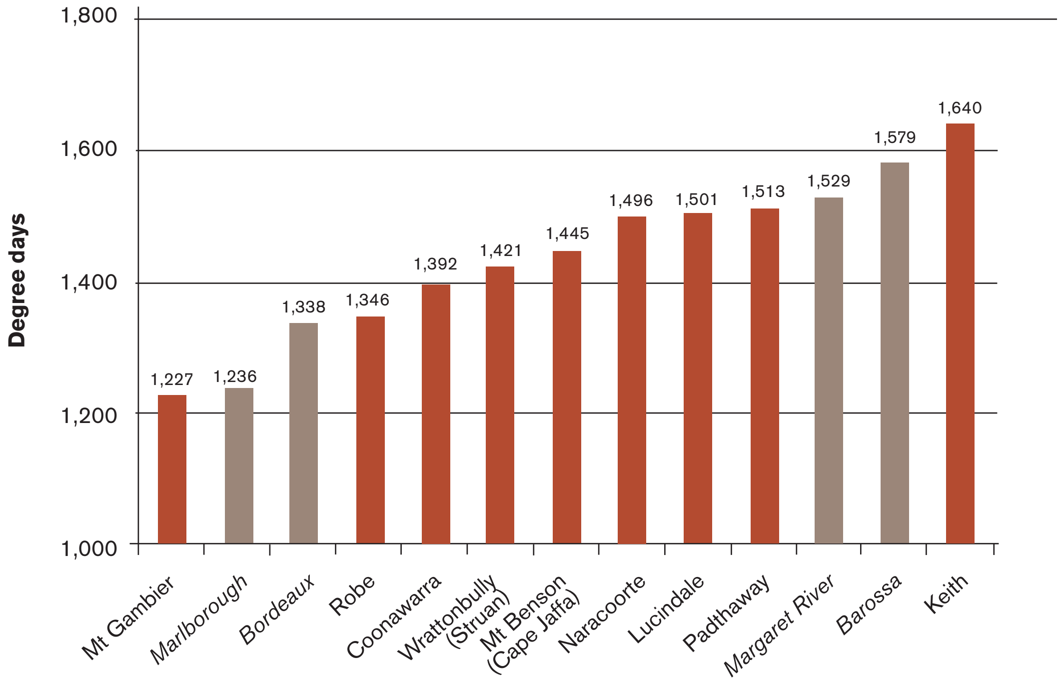


Figure 3.13. Degree day (19/10 truncated) summation (October – April) calculated from weather stations across the Limestone Coast (based on long term average climatic data from Bureau of Meteorology 2011) and other wine regions (light brown). Margaret River data from Gladstones (1992). Marlborough (Blenheim airport), Bordeaux (Mérignac Airport) and Barossa (Nuriootpa) from Gladstones (2011).

The comparison of accumulation of degree days from October to April shows that Keith has a similar pattern of degree day accumulation to the Barossa. Marlborough and Mount Gambier share a similar total degree days (Oct-Apr) (Figure 3.14) however, the degree day accumulation is more rapid in Marlborough from October to March and slower in April. Bordeaux and Robe have a similar number of growing season degree days; however the accumulation is much more rapid at Robe until the end of February (Figure 3.14).

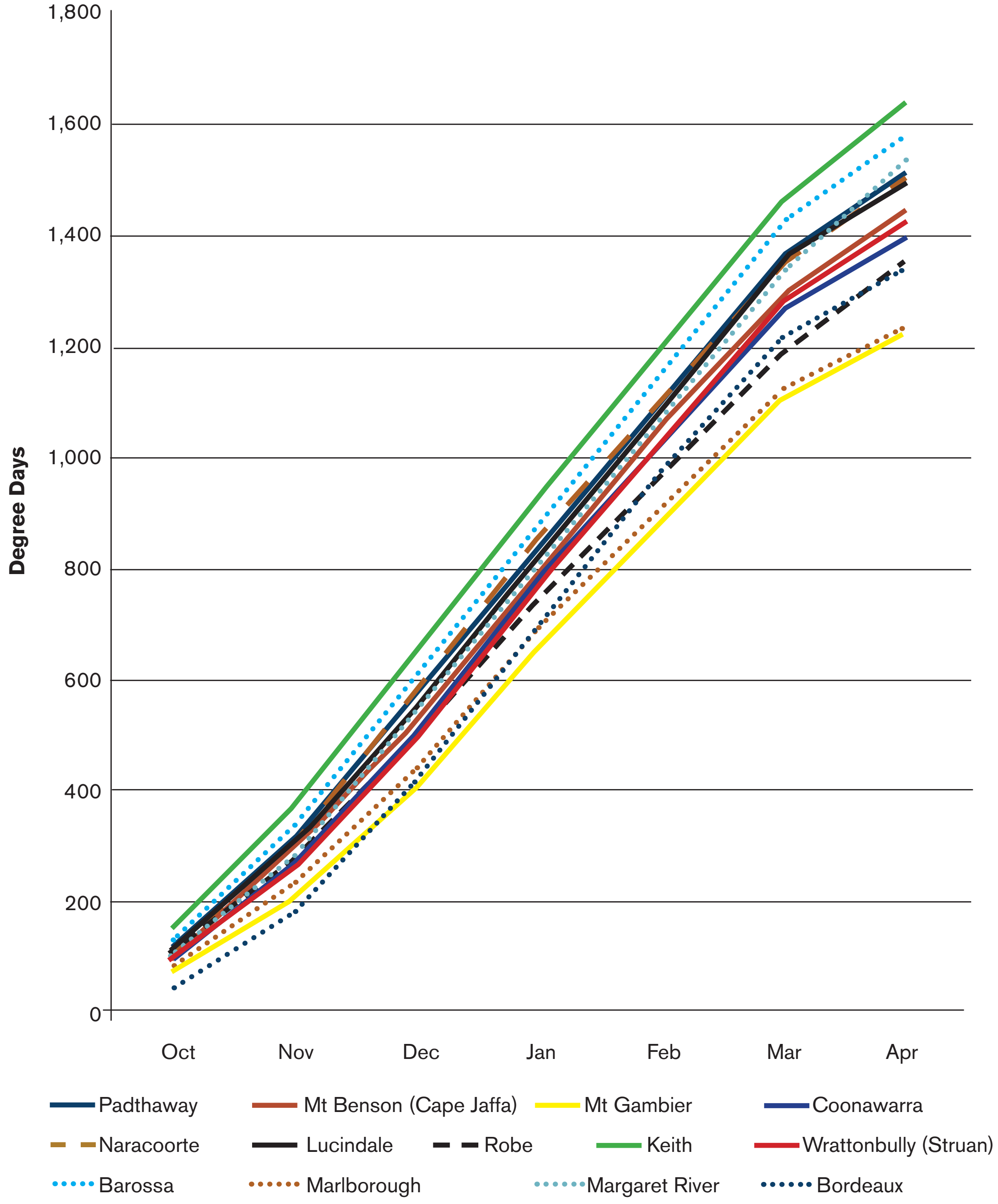


Figure 3.14. A comparison of the accumulation of degree days (19/10 truncated) between October and April across the Limestone Coast (Bureau of Meteorology 2011) and other wine regions (Bordeaux is April-October but presented as inverted growing season) (Gladstones 2011). Margaret River data from Gladstones (1992).

3.3.7. Biologically effective degree days

Biologically effective degree days (BEDD) is calculated by adjusting degree days (above) for latitude / daylength and topography (not performed here) for the October to April growing season (Gladstones 2011). Seasonal summation allows comparison to grape maturity groups proposed by Gladstones (2011) (Table 3.6).

Table 3.6. Grape maturity groups, with biologically effective degree days to maturity and representative varieties (from Gladstones 2011) reproduced with permission of Wakefield Press.

Maturity Group	Effective Degree Days	Varieties
1	1,020	Madeleine Angevin
2	1,080	Chasselas, Mueller Thurgau
3	1,140	Pinot Noir, Chardonnay
4	1200	Semillon, Riesling
5	1,260	Cabernet Franc, Shiraz
6	1,360	Colombard, Cabernet Sauvignon
7	1,380	Grenache, Petit Verdot
8	1,440	Trebbiano, Mataro
9	1,500	Doradillo, Biancone, Tarrango

The Limestone Coast BEDD data presented here are calculated from long term average data and are presented for comparison of weather stations. They are not corrected for individual vineyard sites and further information should be sought before planting decisions are made.

The BEDD at Mount Gambier shows that the region is most suited for growing varieties in maturity groups 1 and 2 (Table 3.6 and Figure 3.15). The BEDD at weather stations across all other regions in the Limestone Coast show that varieties in maturity groups 1-5 which include the major varieties produced in the Limestone Coast (Chardonnay, Shiraz and Cabernet Sauvignon) may ripen in an average year (Table 3.6 and Figure 3.15).

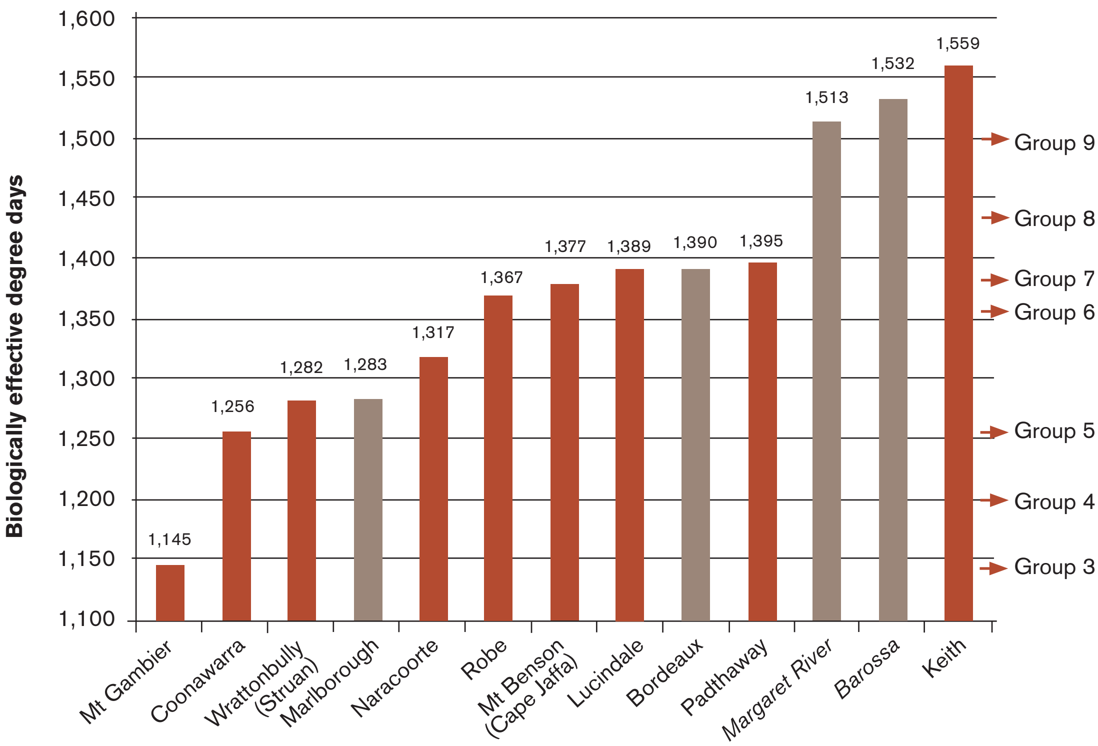


Figure 3.15. Biologically effective degree days at weather stations across the Limestone Coast and other wine regions (light brown). Limestone Coast calculations based on long term average climatic data (Bureau of Meteorology 2011). Margaret River data from Gladstones (1992). Marlborough (Blenheim airport), Bordeaux (Mérignac Airport) and Barossa (Nuriootpa) from Gladstones (2011). Group numbers refer to grape maturity groups in Table 6 (Gladstones 2004).

3.3.8 Mean rpening month temperature

Mean ripening month temperature is the temperature conditions in the 30 days proceeding harvest (Gladstones 2004). Harvest date varies between varieties, regions and seasons depending on accumulated temperature, yield and desired grape composition. For simplicity the mean monthly temperatures for the Limestone Coast are presented for the calendar months January, February, March and April (Figure 3.16).

Across the regions there is little difference between the January and February temperatures at each station; however, there is a significant decrease in mean temperature in March and again in April. This is likely to have a significant impact on late ripening varieties especially in the coolest regions, Mount Gambier and Coonawarra (Figure 3.16). Note that the decrease in mean temperature between March and April for coastal stations Robe and Mount Benson (Cape Jaffa) is less than that at the inland stations because of their proximity to the modifying effects of the ocean (refer to 3.3.3 for background information).

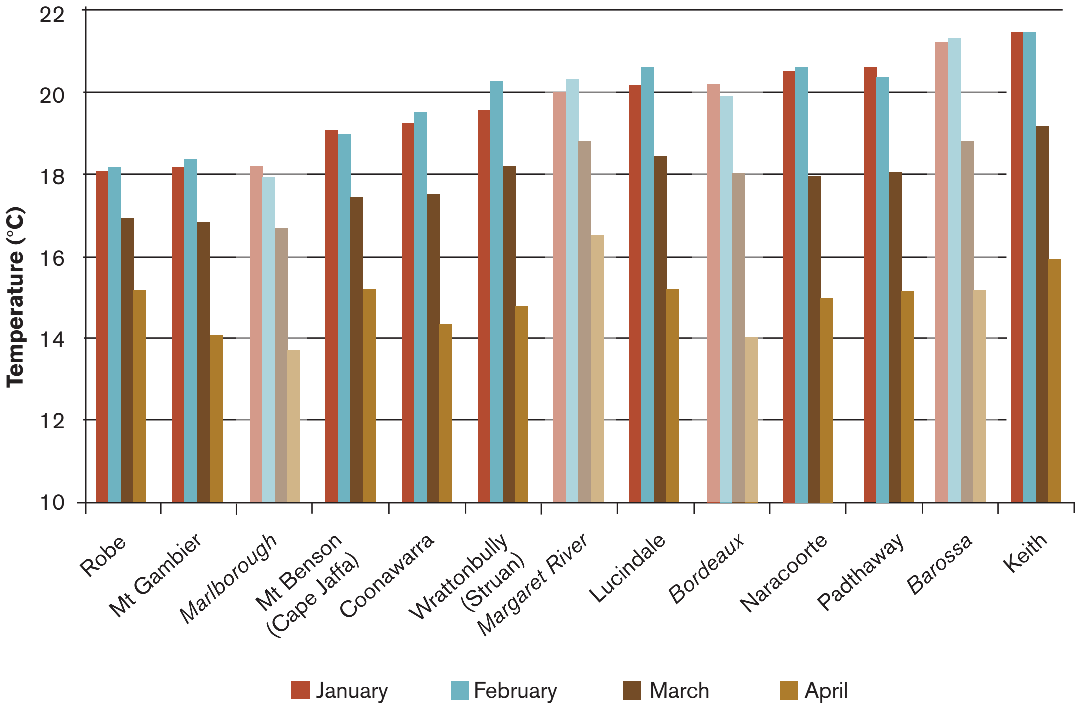


Figure 3.16. Mean monthly temperature (degrees Celsius) during ripening across the Limestone Coast and other wine regions. Limestone Coast data calculated from long term average climatic data (Bureau of Meteorology 2011). Margaret River data from Gladstones (1992). Marlborough (Blenheim airport), Bordeaux (Mérignac Airport) and Barossa (Nuriootpa) from Gladstones (2011).

Wrattonbully Wine Region

3.4. Climatic consequences & impacts

3.4.1. Phenology

Grapevine phenology describes the progression of vines through different developmental stages over a season. For the purpose of comparison across regions within the Limestone Coast, phenological data was compared for the varieties Chardonnay, Sauvignon Blanc, Cabernet Sauvignon and Shiraz during the 2008-09 season. That season was chosen primarily because of the availability of reliable data from most regions.

The phenological data presented was collected for the key phenological stages budburst, flowering (50-80%), veraison (50%) and harvest. Because of the difficulty in pinpointing the exact day at which a particular stage was reached, each month was divided into 4 weeks and the timing of each stage can be interpreted as occurring in the 1st, 2nd, 3rd or 4th week of that month (Figure 3.17, Figure 3.18, Figure 3.19, Figure 3.20). Because of the relative small size and newness of the Mount Gambier region, accurate phenology records were not available at the time of writing this document. General comments have been made about phenological development in Mount Gambier. Phenological records for Mount Benson were also not available.

Budburst and harvest tended to be earliest at Padthaway and Robe in 2008-09 followed by Bool Lagoon and northern Coonawarra. The latest regions to harvest were southern Coonawarra and Robe, despite Robe's early start to the season (Figures 3.17 – 3.20). Phenological information sourced from Mount Gambier suggests that harvest dates were one to two weeks later than in southern Coonawarra (Personal Communication, Terry Strickland, Mount Gambier 2011).

Cabernet Sauvignon and Shiraz were the most consistent time period between each of the phenological stages and the variability in timing of each stage between regions was not large (Figure 3.19 and Figure 3.20). The timing of harvest of these varieties, especially in southern Coonawarra and Robe is an important consideration in most years. Delay of harvest into late April can coincide with opening season rains which can pose a significant risk to fruit quality and harvest logistics.

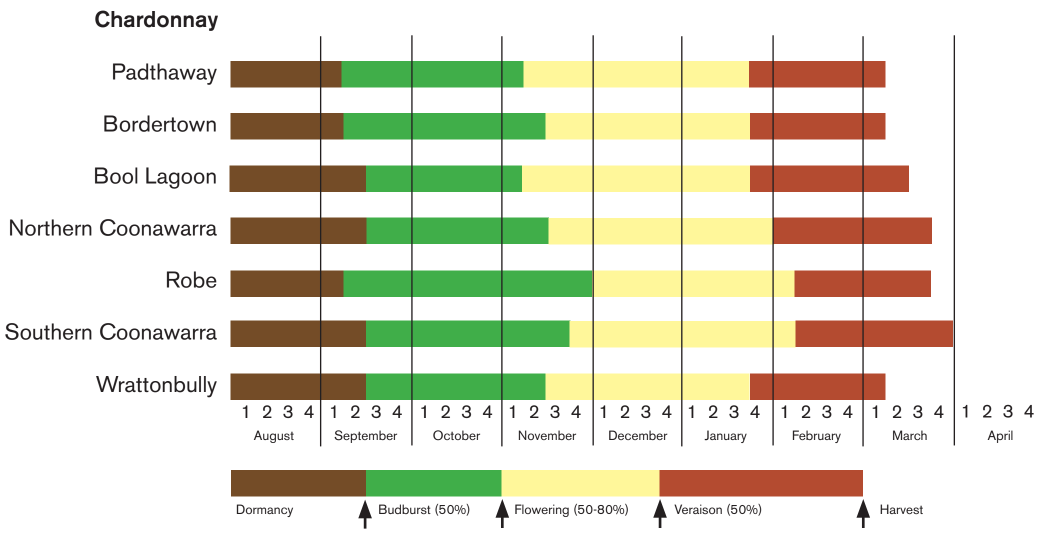


Figure 3.17. Phenological development of Chardonnay in the Limestone Coast in 2008-09. Numbers represent the weeks of each month. Data for northern Coonawarra was collected from vineyards near the township of Coonawarra. Data for southern Coonawarra was collected from vineyards near the township of Penola (south of Maaoupe Road).

Sauvignon Blanc

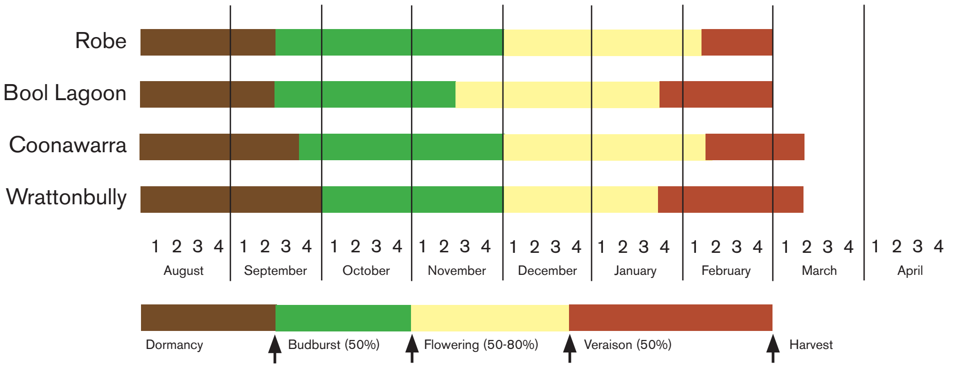


Figure 3.18. Phenological development of Sauvignon Blanc in the Limestone Coast in 2008-09. Numbers represent the weeks of each month.

Cabernet Sauvignon

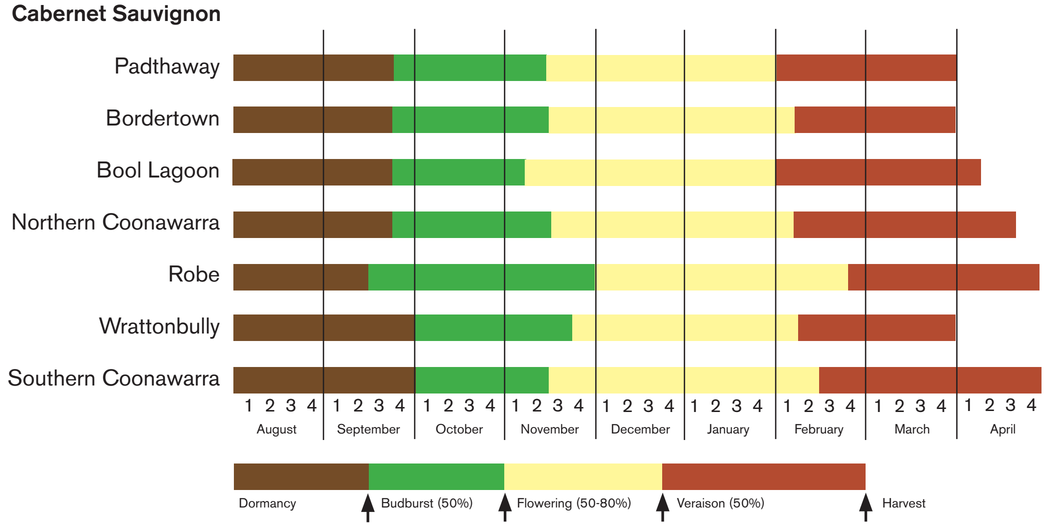


Figure 3.19. Phenological development of Cabernet Sauvignon in the Limestone Coast in 2008-09. Numbers represent the weeks of each month. Data for northern Coonawarra was collected from vineyards near the township of Coonawarra. Data for southern Coonawarra was collected from vineyards near the township of Penola (south of Maaoupe Road).

Shiraz

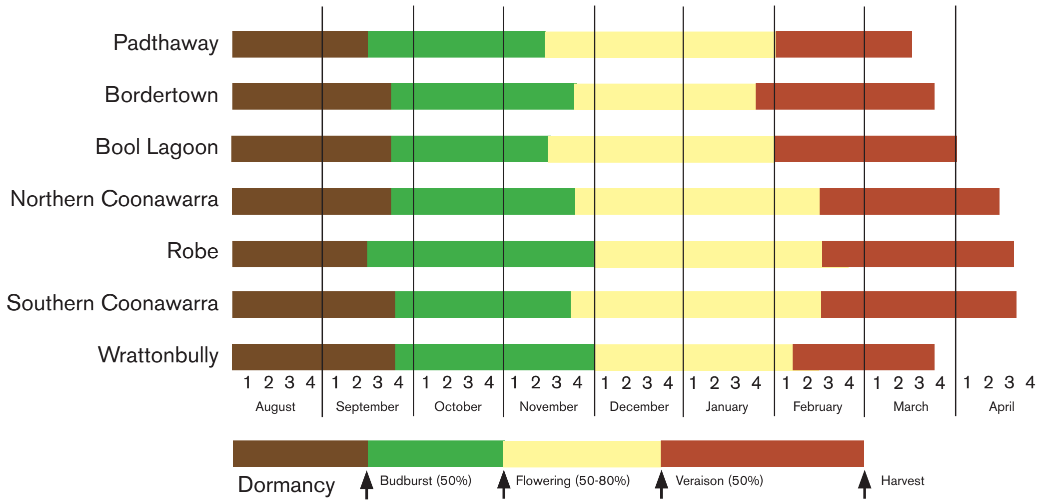


Figure 3.20. Phenological development of Shiraz in the Limestone Coast in 2008-09. Numbers represent the weeks of each month. Data for Northern Coonawarra was collected from vineyards near the township of Coonawarra. Data for Southern Coonawarra was collected from vineyards near the township of Penola (south of Maaoupe Road).

3.4.2. Pest & Disease

Downy and powdery mildew

Downy *(Plasmopara viticola)* and powdery *(Erysiphe necator)* mildews occur across Limestone Coast to varying degrees depending on seasonal weather conditions. Most vineyards use a protective fungicide program to prevent significant infection by downy and powdery mildew.

Botrytis

Botrytis *(Botrytis cinerea)* poses it's greatest threat close to harvest time; however, in most years it is only seen in susceptible varieties such as Semillon, Chardonnay. Riesling and Sauvignon Blanc. Most vineyards use a combination of canopy management and protective fungicides to manage Botrytis.

Phomopsis

Phomopsis *(Phomopsis viticola)* is a disease that is most prevalent in wet springtime conditions.

Eutypa

The effects of Eutypa *(Eutypa lata)* on grapevine production have increased in recent years especially in older plantings across the Limestone Coast. Many vineyards with vines that are severely affected by Eutypa are in the process of re-working or replacing vines.

Phylloxera

One of the greatest threats to the Limestone Coast is from grape Phylloxera, an insect that feeds on grapevine roots. Phylloxera is currently confined to viticultural regions outside of South Australia. State legislation and industry protocols currently protect the Limestone Coast region from the introduction of this pest.

3.4.3. Climate change

Global climate change is occurring as a result of an increased concentration of carbon dioxide (CO2) and other greenhouse gases in the atmosphere (IPCC 2007). The extent to which warming of the climate system will occur is uncertain and depends on the level of global emissions and the sensitivity of the climate to these emissions (Webb et al. 2008). For example, inland regions are likely to experience increased warming compared to coastal regions (Whetton and Hennessy 2001) because of the moderating effect of the ocean on land temperature.

A range of scenarios that address the uncertainty of climate change have been used by numerous climate scientists to model the extent of global climate change across Australia. On a global scale the predicted direct effects of global climate change on weather and climate are:

- increased global mean surface temperature,
- increased intensity, frequency and longevity of heat waves,
- decreased incidence of cold episodes,
- increased mean water vapour, evaporation and precipitation,
- increased intensity of precipitation

(IPCC 2007)

These predicted changes, together with increased atmospheric carbon dioxide concentration, will have direct and indirect effects on grapevine growth and yield and grape composition and will affect vineyard and winery management in the future. The Limestone Coast is well positioned to buffer impacts of climate change (personal communincation Webb, L. 2011) but the extent to which regions are impacted will vary.

Coastline of the Limestone Coast

Winter vines, Mount Gambier

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Soils of the Limestone Coast Wine Zone

4

David Maschmedt

4.1 Introduction

The soils of the South East of South Australia were described and mapped in broad brush terms by the CSIRO Division of Soils in the 1950s and early 1960s (Blackburn 1959, 1964). In the 1990s, more detailed mapping and soil investigations were undertaken by the then Department of Water, Land and Biodiversity Conservation (DWLBC), as part of a programme to describe the landscapes and soils of South Australia's agricultural areas. This information is available on DVD (DWLBC Soil and Land Program 2007). Parts of the data sets are also available on-line via the Australian Soil and Land Information System (ASRIS) website (www.asris.csiro.au). The information presented in this document is based entirely on the DWLBC data – no new work was undertaken.

The soils of the six Geographic Indication Regions (Coonawarra, Mt Benson, Mt Gambier, Padthaway, Robe and Wrattonbully), and two non-gazetted districts (Lucindale and Mundulla), can be categorised into 28 classes. Of these, 20 are significant for viticulture. The soils are assigned a two character code consistent with the state-wide mapping programme.

The soils fall into several broad groupings:

Shallow soils over calcrete

This broad group (codes B1 – B9) includes all soils which overlie a hard calcrete layer within 50 cm. Calcrete is a lime rich material forming a cap on the calcareous materials which underlie much of the Limestone Coast. Stones are common on the ground surface and in the profiles. Surface textures range from sands (B7, B8) to clay loams (B5, B9), and three of the classes have distinctive subsoil clay layers (B6, B7, B9). With the frequent exception of the B5 class (also known as rendzina), the soils are generally well drained (unless in low lying sites). Their fertility depends on surface soil clay content, the sandier types being infertile, the clay loamy types most fertile. All have restricted water holding capacities due to their shallow depth and stoniness. The underlying calcrete is generally rippable, providing additional root zone depth and water holding capacity. Provided that stone content is not excessive and soil depth is greater than 25 cm, the sandy loam to loamy types are well suited to viticulture, especially classes B3, B4 and B6, all of which have been called terra rossa, although the B4 class best matches the terra rossa concept of rich red colour, friable structure and no obvious layering. Classes B1 (in particular) and B2 have nutrition issues related to high surface carbonate levels, B5 types are often too shallow and wet, and B7 and B8 are infertile.

Texture contrast soils

These are soils which have a distinctive boundary between a sandy or loamy surface layer, and a clayey subsoil. In the Limestone Coast Zone, the variations within this broad category are due to surface clay content (i.e. sand, sandy loam, clay loam), depth to clayey subsoil, and structure of the subsoil. The texture contrast soils are represented by codes D2 and D3 (sandy loams with red clay subsoils), F1 and F2 (sandy loams with brown subsoils), and G2, G3 and G4 (sandy surfaces). G2 has a thick surface (more than 300 mm) with friable clayey subsoil, G3 also has a thick surface with tight clay subsoil, and G4 has a thin surface with tight clay subsoil. All are used for viticulture, with the more clayey D and F types being more fertile, and D2 and F1 having well structured subsoils compared with their D3 and F2 counterparts. The better structured subsoils provide deeper root zones and better drainage. The sandy G soils are infertile, and the tight clayey subsoils of G3 and G4 are root restrictive. G4 in particular is an unfavourable soil due to its thin surface and potential for developing a perched water table close to the surface. G2 and G3 soils are suitable for viticulture provided that nutrition is managed.

Gradational loamy to clayey soils

These include soils with loamy to clayey surfaces with more clayey subsoils, but no obvious layering. Soil codes C3 (red clay loamy soil), C5 (black clay loamy soil), both with highly calcareous deep subsoils, and M2 (clay loamy soil with little subsoil carbonate), are deep, fertile and moderately well drained. They provide excellent growth conditions, but can cause excessive vigour. E3 and E1 soils are grey/brown and black (respectively) cracking clay soils. These are deep and fertile, but are commonly imperfectly drained and have very high wilting points, meaning that maintaining adequate moisture levels is difficult. They are also associated with excessive vegetative growth. M1 (deep sandy loams) and M4 (poorly structured gradational clay loams) are not common and insignificant for viticulture.

Deep sands

These are widespread soils characterized by at least 800 mm (and usually well over 1000 mm) of loose sand. They are very infertile, and prone to wind erosion. Most are water repellent, and some are strongly acidic. H1 soils are essentially crushed shells and occur on near-coastal land. They are extremely infertile and not used for viticulture. H2 soils are brown sands, relatively the most fertile of the grouping, but only common in Robe and Mt Benson. H3 soils are bleached sands, and the most widespread of all. They are rapidly drained with deep root zones, but lack of clayey layers for water and nutrient retention limits their productivity. The I1 and I2 soils (also called podzols) are very highly leached, and are characterized by a deep subsoil enrichment of iron and organic compounds (evidence of strong leaching). Managing nutrition on these soils is very difficult, so they are rarely used for viticulture.

Wet soils

Peats (N1), saline soils (N2) and other waterlogged soils (N3) are widespread in the Limestone Coast Zone, but not used for viticulture.

Categorising and mapping soils

The 28 soil classes represent a compromise between simplicity and 'information overload'. There will be differences between representative examples of the soils and the corresponding local soil, but the intention is to convey the essential characteristics.

A break-down of the occurrences of the soils in each of the regions / districts, total areas, and areas under vines are provided in Table 4.1.

Soil types vary over short distances, so mapping the distribution of individual soils at a regional level is not feasible. The best compromise is to map areas which are recognisable by their surface features, and which have a relatively narrow range of dominant soils. In this study, such areas are termed 'Land Units'.

This chapter includes the following sections:

1. One page 'fact sheets' for each of the 28 soil classes of the regions and districts.
2. A table summarizing the key characteristics of the significant viticultural soils in each region / district.
3. Land unit maps and descriptions for the six Geographic Indication regions, and two districts.

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Main Soils of the Limestone Coast Zone

Soil Profiles

Twenty eight soils typical of the Geographic Regions and districts of the Limestone Coast Zone are described in this section, on one-page fact sheets. Not all of these soils are used for viticulture – some presently unused soils have potential, others have more or less permanent limitations. Nevertheless, all of these soils, productive or not, are part of the viticultural landscape.

Each fact sheet includes a photograph of a characteristic profile, notes on key visual features, and dot points highlighting the important qualities of the soil. A table at the top of each sheet indicates the relative viticultural significance of the soil

Note that there are significant variations within a soil class, so the photographs are indicative only, and the notes are generalized. More details on selected soil properties are presented in Table 4.2.

All profile photographs are reproduced by kind permission of the Department of Environment and Natural Resources. Site-specific soils data are available on the DWLBC DVD, Regional Land Resource Information for Southern South Australia (DWLBC Soil and Land Program 2007).

Table 4.1. Summary of total area and vineyard area* of each soil class per region / district (ha)

Region	Coonawarra		Lucindale		Mt Benson		Mt Gambier		Mundulla		Padthaway		Robe		Wrattonbully	
Soil	TOTAL	VINES	TOTAL	VINES	TOTAL	VINES	TOTAL	VINES	TOTAL	VINES	TOTAL	VINES	TOTAL	VINES	TOTAL	VINES
A7	58	4	0	0	61	0	1565	0	0	0	62	0	952	1	0	0
B1/B2	1080	198	301	4	2459	24	2574	0	549	22	5179	379	4497	74	791	93
B3	501	247	925	50	5697	154	27712	40	499	161	1365	328	10790	253	656	96
B4	1955	1004	479	1	0	0	2947	0	730	288	2036	482	476	17	1502	112
B5	4940	946	734	0	563	0	2564	2	922	36	5708	439	2243	13	775	18
B6	1745	758	1404	170	3776	167	16131	8	121	11	2209	753	4610	141	1262	186
B7/B8	1797	230	943	2	4077	109	16176	40	0	0	4590	358	8919	148	453	12
B9	0	0	172	0	0	0	31	0	0	0	0	0	125	1	0	0
C3	12	0	0	0	0	0	902	1	0	0	451	237	0	0	0	0
C5	1719	214	0	0	0	0	1256	0	0	0	0	0	293	0	4	0
D2	395	207	0	0	0	0	59	0	1023	271	609	223	0	0	344	43
E3/E1	2412	294	1691	0	0	0	1966	0	670	65	2	0	47	0	22	0
F1	182	14	0	0	0	0	4089	16	2109	165	1341	361	0	0	11921	567
F2/D3	2560	350	0	0	0	0	3932	5	2260	244	147	0	227	0	15755	657
G2	1109	45	740	0	0	0	7681	2	22	0	2195	95	51	0	2394	166
G3	7500	621	1419	0	702	0	45095	16	35	3	1161	256	2671	18	5376	265
G4	1479	176	42	0	0	0	1089	0	0	0	629	5	307	0	2570	59
H1	0	0	0	0	551	0	1754	0	0	0	0	0	6659	0	0	0
H2	0	0	0	0	467	5	3005	0	0	0	0	0	7683	14	0	0
H3	2091	69	872	9	2940	60	13629	5	8	0	5845	295	3260	62	4714	239
I1/I2	2981	75	956	2	874	3	62478	16	0	0	1267	2	1650	18	2801	78
M1	173	10	0	0	13	1	29	0	30	0	34	0	0	0	125	3
M2	1282	379	358	0	27	0	3733	0	75	1	520	1	409	0	3350	152
M4	420	10	39	0	32	2	1173	0	0	0	0	0	17	0	0	0
N1	149	0	1	0	163	0	7711	0	0	0	0	0	2372	0	1102	0
N2	64	0	46	0	476	0	464	0	0	0	60	0	13500	0	0	0
N3	2104	0	438	0	698	0	13421	0	0	0	245	0	4031	0	0	0
O1	0	0	0	0	0	0	15556	23	0	0	0	0	0	0	0	0
RL †	682	0	119	0	4096	0	7166	0	0	0	192	0	5520	0	442	0
WB †	466	0	18	0	130	0	1258	0	312	0	85	0	7959	0	287	0
Totals	39856	5851	11697	238	27802	525	267146	174	9365	1267	35932	4214	89268	760	56646	2746

** In the absence of better information, it is assumed that vineyard plantings are evenly distributed across all soils within a mapping unit. The areas are derived directly from geographic system analysis of DWLBC mapping data, and have not been rounded. Despite the apparent precision of the data, they are intended to provide estimates only.*
† RL = rocky land, WB = water body, swamp etc.

SOIL CODE
A7

Calcareous clay loam over marl

% of vineyards planted on A7 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
<1	0	0	0	0	0	1	0

- Well structured calcareous loam to light clay, becoming more calcareous and clayey with depth.
- Grades to marly substrate between 50 and 100 cm.
- Occurs on imperfectly to poorly drained flats.

- High inherent fertility due to high clay content. However, where carbonate content is high, fixation of some nutrients occurs.
- High calcium saturation leads to favourable structure.
- Readily available water holding capacity up to 75 mm.

Shallow calcareous sandy loam on calcrete

SOIL CODE
B1/B2

% of vineyards planted on B1/B2 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
3	2	5	0	2	9	10	3

- Up to 50 cm sandy loam to clay loam, calcareous from surface. B1 soils are strongly calcareous throughout.
- Substrate is calcreted calcarenite or lagoon bed limestone.
- Occurs on stony rises (old coastal dunes), and stony flats (old lagoon beds).

- Moderately low to moderate inherent fertility – depends on clay and carbonate content.
- High calcium saturation – open structure with good aeration and drainage.
- Readily available water holding capacity linked to depth to calcrete - varies from a few mm to 35 mm.

Shallow stony red sandy loam on calcrete

SOIL CODE

B3

% of vineyards planted on B3 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
4	21	29	23	13	8	33	4

- Massive red to brown non calcareous sandy loam with variable stone.
- Substrate is calcreted calcarenite or lagoon bed limestone.
- Occurs on rises (old coastal dunes), less commonly on flats (old lagoon beds).

- Moderately low to moderate fertility – depends on clay content.
- Usually stony and with low clay content - very good aeration and drainage
- Water holding capacity linked to depth to calcrete and stone content - varies from a few mm to 30 mm (readily available).

Shallow red loam on limestone (TERRA ROSSA)

SOIL CODE **B4**

% of vineyards planted on B4 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
17	<1	0	0	23	11	2	4

- Well structured red sandy loam to clay loam.
- Little change with depth
- Substrate is calcreted calcarenite or lagoon bed limestone.
- Occurs on rises (old coastal dunes), less commonly on flats (old lagoon beds).

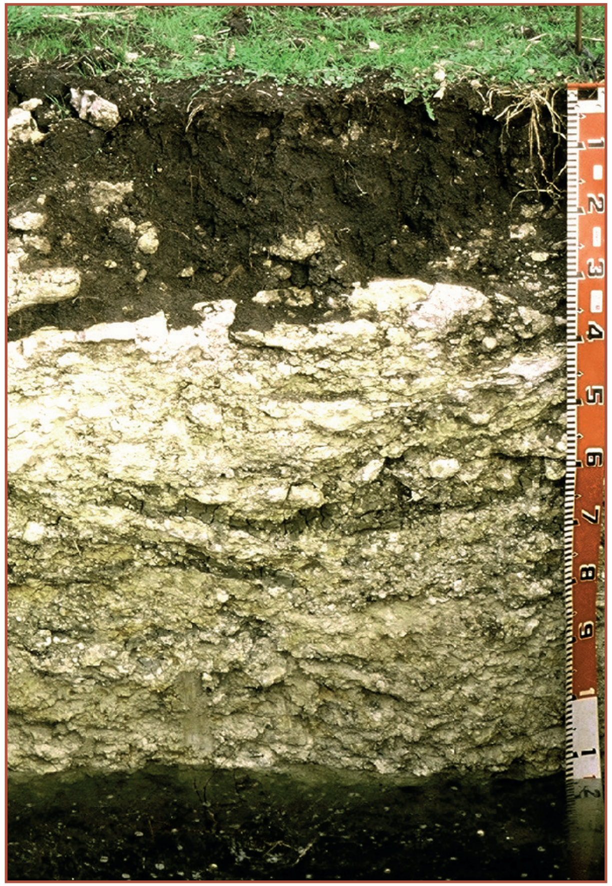
- Moderately low to moderately high inherent fertility – depends on clay content.
- Very high Ca saturation - open crumbly structure with good aeration and drainage.
- Water holding capacity linked to depth to calcrete – varies from a few mm to 50 mm readily available.

Shallow dark clay loam on calcrete (RENDZINA)

SOIL CODE
B5

% of vineyards planted on B5 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
16	0	0	1	3	10	2	1



- Black well structured clay loam to clay
- Usually shallow (less than 50 cm) over calcrete
- Substrate is limestone or marl – lagoon bed sediment
- Seasonal water table within 1.5 m
- Occurs on plains

- High inherent fertility
- Rootzone limited by calcrete (where unfractured) or highly calcareous clay
- Drainage is imperfect, inundation common
- Readily available water holding capacity varies from approx. 10mm to 40mm

Sandy loam over red clay on calcrete

SOIL CODE **B6**

% of vineyards planted on B6 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
13	71	32	5	1	18	19	7

- Reddish massive loamy sand to sandy clay loam surface.
- Red well structured clay subsoil on calcrete within 50 cm of surface.
- Substrate is calcreted calcarenite or lagoon bed limestone.
- Occurs on rises and plains.

- Moderately low to moderate inherent fertility, depending on clay content
- Rootzone limited by calcrete. Ripping allows some deeper penetration.
- Drainage is moderate to good.
- Readily available water holding capacity in the 20-50 mm range.

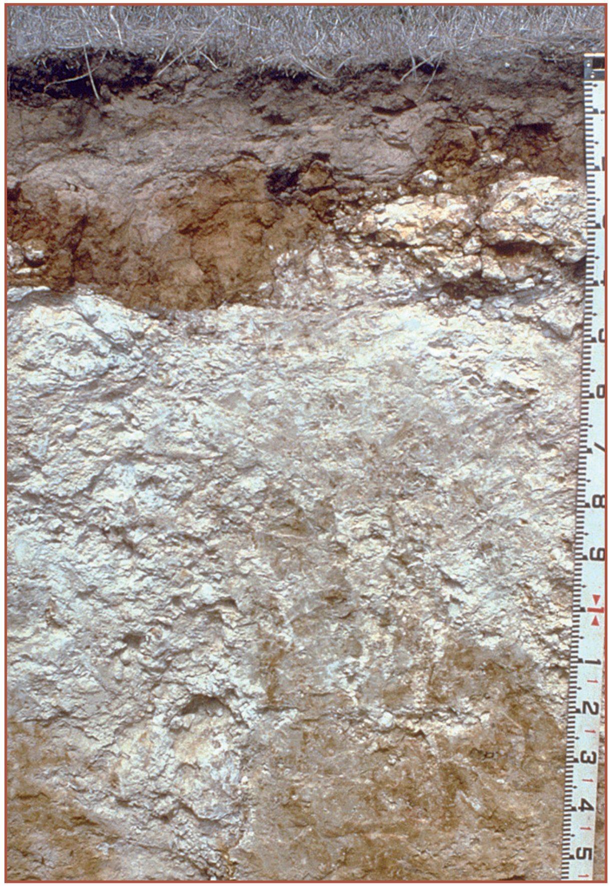
Shallow sand over clay on calcrete

SOIL CODE

B7/B8

% of vineyards planted on B7/B8 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
4	1	21	23	0	9	20	<1



- Bleached sandy topsoil. Generally has thin clayey subsoil (B8 soils have no clay).
- Calcrete shallower than 50 cm.
- Substrate is either consolidated dune sand or lagoonal limestone
- Occurs on plains and stony rises.

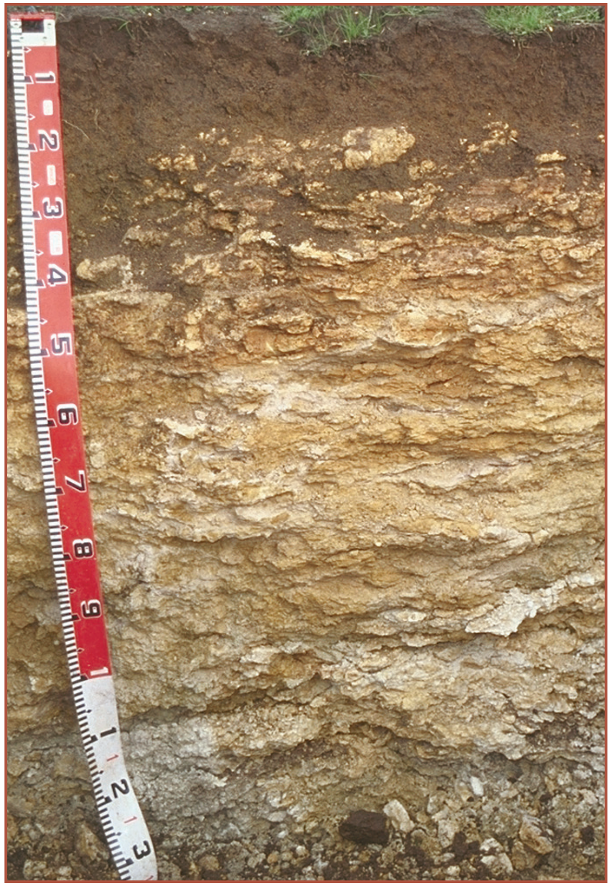
- Low inherent fertility due to sandy surface.
- Limited readily available water ~ 10-30 mm.
- Well drained on rises (and on flats, except where shallow water table present).
- Susceptible to water repellence and wind erosion.

Clay loam over brown clay on calcrete

SOIL CODE **B9**

% of vineyards planted on B9 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
0	0	0	0	0	0	<1	0



- Brown massive sandy loam to clay surface, usually less than 30cm thick.
- Brown mottled poorly structured clay subsoil on calcrete within 50cm of surface.
- Substrate is calcreted calcarenite or lagoon bed limestone.
- Occurs on plains.

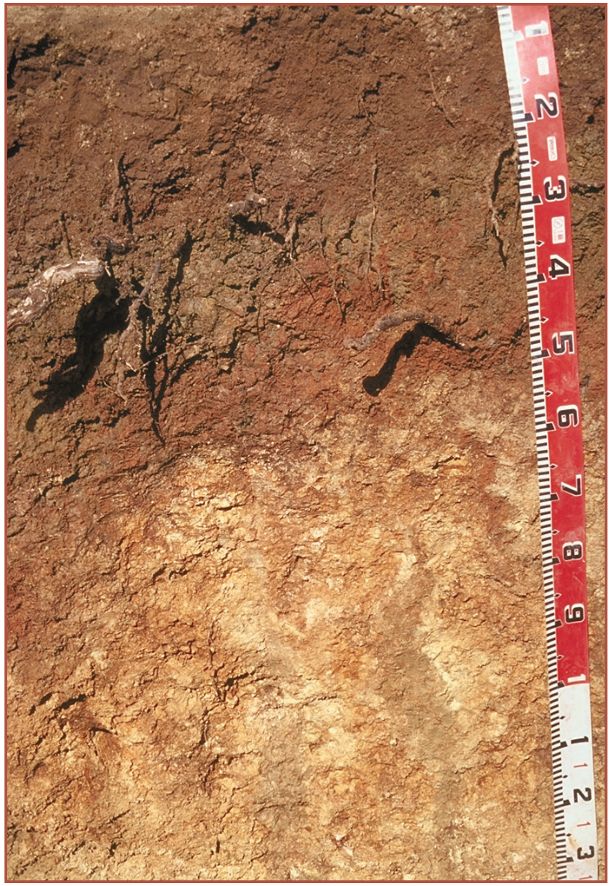
- Moderate to moderately high inherent fertility depending on clay content
- Rootzone limited by calcrete. Ripping allows some deeper penetration.
- Drainage is moderate to imperfect.
- Readily available water holding capacity in the 25-35mm range.

Gradational loam

SOIL CODE
C3

% of vineyards planted on C3 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
0	0	0	1	0	6	0	0



- Brownish hard loam to clay loam topsoil, grading to brown or red well structured clayey subsoil.
- Soft to semi-hard carbonate from around 50 cm.
- Substrate is calcareous clay
(old lagoonal sediment, or more recent alluvium).
- Occurs on plains.

- High inherent fertility due to relatively high clay content surface.
- No major restrictions to root growth, but most activity occurs above the carbonate.
- Up to 50 mm readily available water holding capacity.
- Moderately well to imperfectly drained.
Waterlogging can occur in low lying areas.

Dark gradational clay loam

SOIL CODE
C5

% of vineyards planted on C5 soil							
COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
4	0	0	0	0	0	0	0

- Dark well structured loam to light clay, becoming more clayey with depth.
- Soft to semi-hard carbonate occurs at depths usually of between 50 and 100 cm.
- Overlies old lagoonal sediment, or more recent alluvium.
- Occurs on plains.

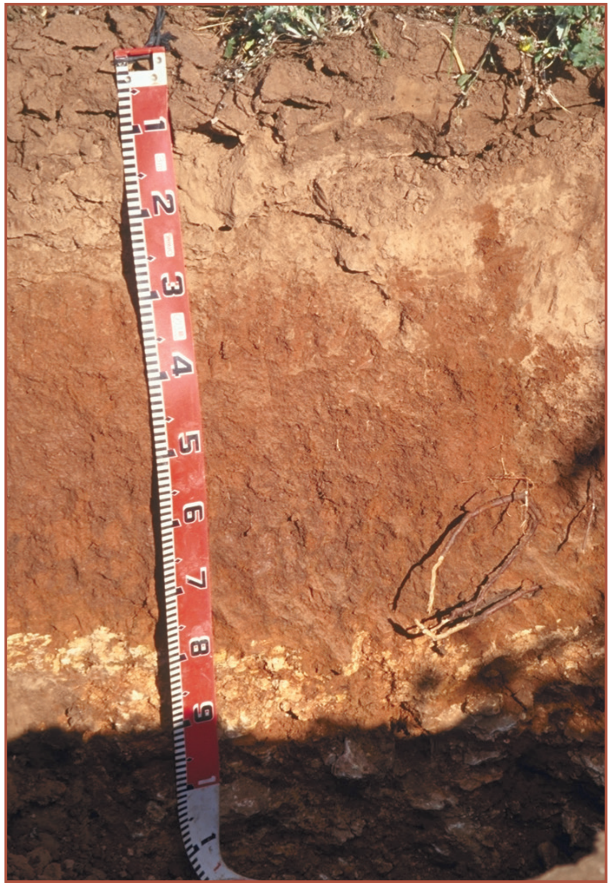
- High inherent fertility due to high clay content surface.
- No major restrictions to root growth, but most activity occurs above the carbonate.
- Up to 60 mm readily available water holding capacity.
- Moderately well to imperfectly drained. Waterlogging can occur in lower lying areas where water tables are shallow.

Sandy loam over well structured red clay

SOIL CODE
D2

% of vineyards planted on D2 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
4	0	0	0	21	5	0	2



- Up to 40 cm brownish friable to hard sandy loam to clay loam with a paler sub-surface.
- Topsoil abruptly overlies a well structured red clay subsoil.
- Soft to semi-hard carbonate in lower subsoil.
- Substrate is calcareous clay (old lagoonal sediment, or alluvium).
- Occurs on plains and rises adjacent lagoons.

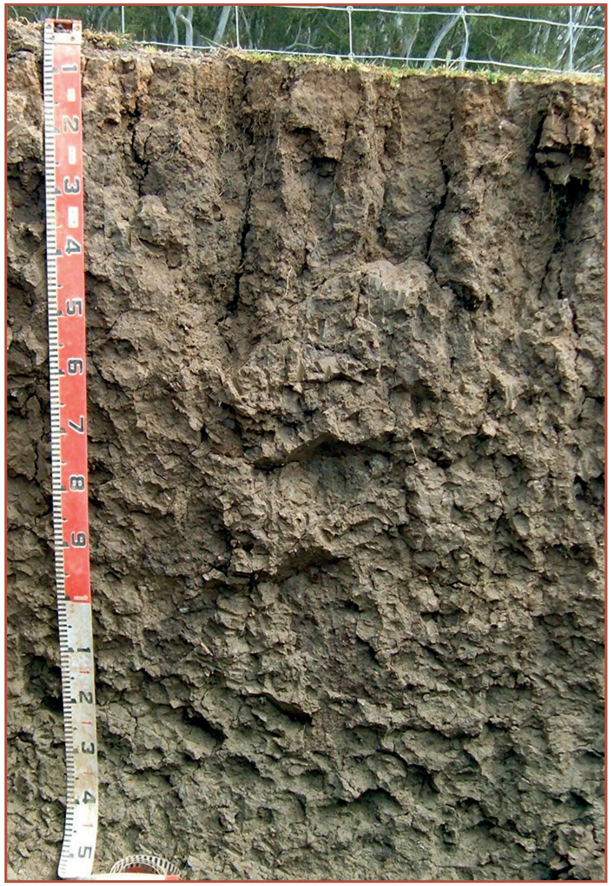
- Moderate inherent fertility.
- No major restrictions to root growth, but most activity occurs above the carbonate.
- Up to 60 mm readily available water holding capacity.
- Moderately well drained.

Grey to brown cracking clay

SOIL CODE
E3/E1

% of vineyards planted on E3/E1 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
5	0	0	0	5	0	0	0



- Crumbly to hard grey to brown clay, seasonally cracking.
- More clayey with depth – variable carbonate content in subsoil.
- Substrate is fine grained lagoonal or alluvial sediment.
- Occurs in depressions.

- High inherent fertility, due to high clay content. Can cause excessive vigour.
- Imperfectly to poorly drained.
- Poorly structured subsoil clay causes uneven root distribution, limiting rooting depth.
- Between 20 and 40 mm readily available water holding capacity. High wilting point of clays means that maintaining available water content is difficult.

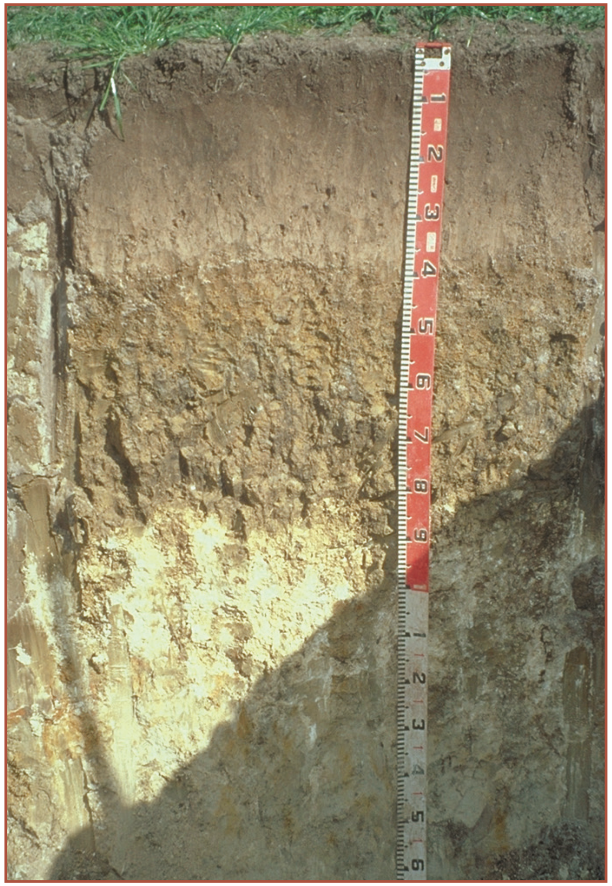
SOIL CODE

F1

Sandy loam over well structured brown clay

% of vineyards planted on F1 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
<1	0	0	9	13	9	0	21



- Up to 50 cm brownish friable to hard sandy loam to clay loam with a paler sub-surface.
- Topsoil abruptly overlies a well structured brown clay subsoil.
- Soft to semi-hard carbonate in lower subsoil.
- Substrate is calcareous clay (old lagoonal sediment, or alluvium).
- Occurs on plains.

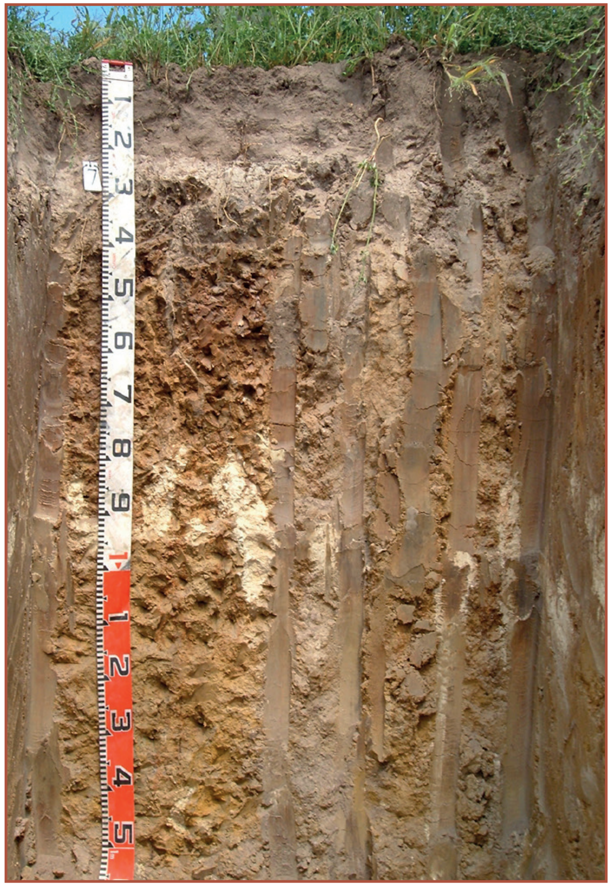
- Moderate inherent fertility.
- No major restrictions to root growth, but most activity occurs above the carbonate.
- Up to 60 mm readily available water holding capacity.
- Moderately well to imperfectly drained. Waterlogging can occur in lower lying areas.

Hard sandy loam over poorly structured clay

SOIL CODE
F2/D3

% of vineyards planted on F2/D3 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
6	0	0	3	19	0	0	24



- Up to 30 cm hard sandy loam to clay loam with a bleached subsurface.
- Topsoil abruptly overlies a coarsely structured hard brown or red clay, often with mottled colours.
- Calcareous at depth.
- Substrate is medium to fine grained lagoonal or alluvial sediment.
- Occurs on plains.

- Moderate inherent fertility, depending on surface clay content.
- Imperfectly drained due to poorly structured, dense and usually sodic subsoil.
- Poorly structured clay causes uneven root distribution, limiting root zone depth.
- Up to 40 mm readily available water holding capacity.
- Surface soil prone to compaction.

SOIL CODE
G2

Thick sand over sandy clay loam

% of vineyards planted on G2 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
1	0	0	1	0	2	0	6

- Up to 80 cm soft sand with a thick bleached subsurface.
- Variable thickness porous sandy loam to sandy clay loam subsoil.
- Usually underlain by calcarenite.
- Occurs on rises (old coastal dunes)

- Low inherent fertility due to the low clay content of the topsoil.
- Well drained due to sandiness of soil and porosity of underlying calcareous material.
- Depth to carbonate defines root zone, but roots will penetrate for additional moisture.
- Between 40 and 80 mm readily available water holding capacity, depending on soil depth.
- Surface soil prone to water repellence and wind erosion.

Thick sand over clay

SOIL CODE
G3

% of vineyards planted on G3 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
11	0	0	9	<1	6	2	10

- More than 30 cm grey sand with a bleached subsurface.
- Topsoil abruptly overlies a coarsely structured, hard brown or red clay, often with mottled colours.
- Calcareous at depth.
- Substrate is medium to fine grained lagoonal sediment.
- Occurs on plains.

- Low inherent fertility, due to sandy surface.
- Moderately well to imperfectly drained depending on depth and density of subsoil clay.
- Potential root zone variable, depending on depth to, and structure of subsoil.
- Up to 50 mm readily available water holding capacity.
- Surface soil prone to compaction.

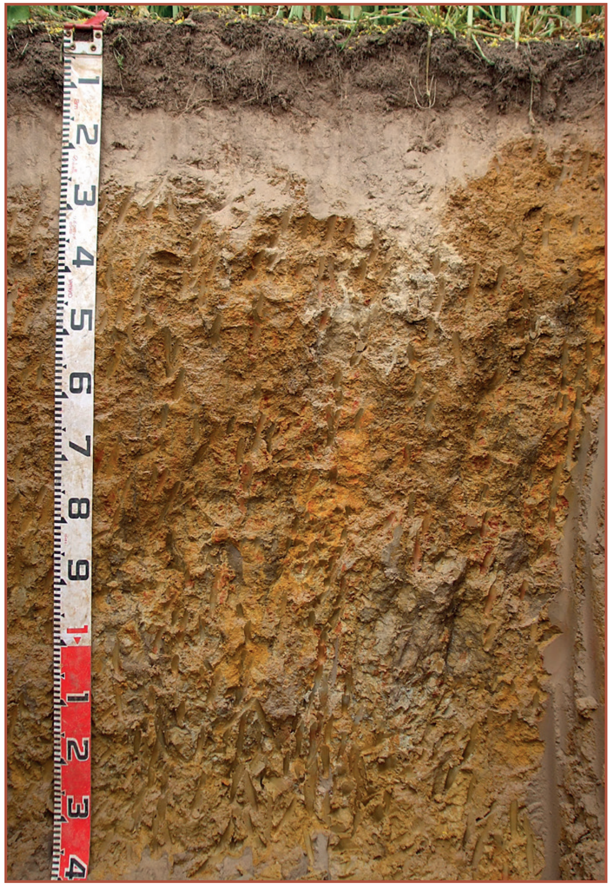
Thin sand over clay

SOIL CODE

G4

% of vineyards planted on G4 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
3	0	0	0	0	<1	0	2



- Less than 30cm grey sand with a bleached subsurface.
- Topsoil abruptly overlies a coarsely structured, hard brown or red clay, often with mottled colours.
- Calcareous at depth.
- Substrate is medium to fine grained lagoonal sediment.
- Occurs on plains.

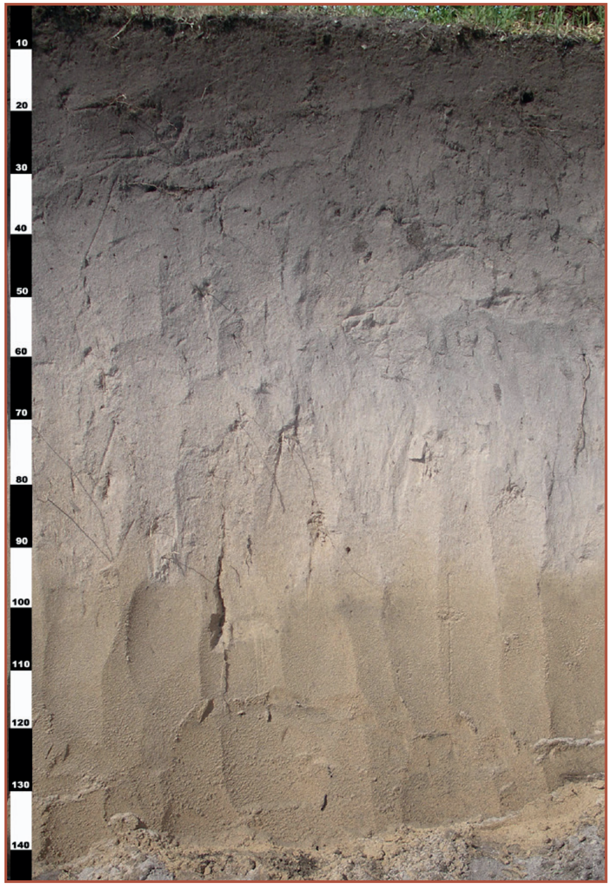
- Low inherent fertility, due to sandy surface.
- Imperfectly drained. Water perches on top of tight clay for significant periods.
- Potential root zone confined to topsoil. Poor root growth in high density clay.
- Up to 35 mm readily available water holding capacity.
- Surface soil prone to compaction.

Deep shell (carbonate) sand

SOIL CODE
H1

% of vineyards planted on H1 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
0	0	0	0	0	0	0	0



- More than 80 cm coarse sand composed of mainly crushed shells.
- Little change with depth apart from lightening of colour.
- Calcarenite usually occurs at depth.
- Occurs on modern coastal dunes and back dunes.

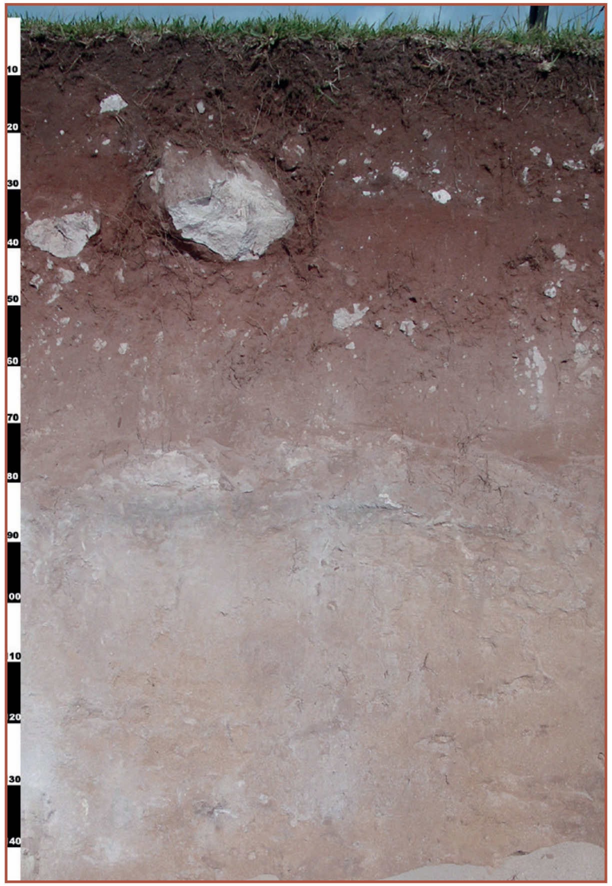
- Very low inherent fertility due to negligible clay content and alkaline pH. Most macro and micro nutrients are deficient.
- Excessively drained due to sandiness of soil and lack of impeding layers.
- Potential root zone depth limited by very low nutrient status.
- Up to 30 mm readily available water holding capacity.
- Surface soil prone to severe wind erosion.

Deep siliceous sand

SOIL CODE **H2**

% of vineyards planted on H2 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
0	0	1	0	0	0	2	0



- More than 80 cm pale brown to pale red sand to loamy sand.
- Often calcareous with depth, and sometimes calcareous throughout.
- Calcarenite usually occurs at depth.
- Most commonly occurs on modern coastal dunes and back dunes, but also found on inland dunes.

- Neutral to alkaline - low inherent fertility, but most favourable of the deep sands.
- Well drained due to sandiness of soil and lack of impeding layers.
- Potential root zone depth limited by low nutrient status.
- Up to 45 mm readily available water holding capacity.
- Surface soil prone to wind erosion.

Deep bleached sand

SOIL CODE
H3

% of vineyards planted on H3 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
1	4	11	3	0	7	8	9

- More than 80 cm soft sand with a thick bleached subsurface.
- Yellowish sandy subsoil.
- Underlain by windblown sand, although calcarenite usually occurs at depth.
- Occurs on rises (old coastal dunes), and recent sandhills superimposed on rises.

- Very low inherent fertility - low topsoil clay content and negligible subsoil reserves.
- Rapidly (excessively) drained due to sandiness of soil and lack of impeding layers.
- Potential root zone depth limited by very low nutrient status of deep subsoil.
- Up to 40 mm readily available water holding capacity.
- Surface soil prone to water repellence and wind erosion.

Highly leached sand (PODZOL)

SOIL CODE
I1/I2

% of vineyards planted on E3/E1 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
1	1	1	9	0	0	2	3

- Grey surface sand.
- Thick bleached subsurface sand.
- Iron oxide / organic matter accumulation (coffee rock or ortstein) subsoil.
- Seasonal water table may occur at depth in lower lying areas.
- Occurs on rises (old coastal dunes)

- Very low inherent fertility, and prone to acidification. Most elements deficient.
- Usually well drained (I1), but shallow water tables or low permeability coffee rock can cause seasonal waterlogging (I2).
- Up to 40 mm readily available water capacity – root zone limited by coffee rock.
- Surface soil prone to water repellence and wind erosion.

Deep sandy loam

SOIL CODE **M1**

% of vineyards planted on M1 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
<1	0	<1	0	0	0	0	<1

- Brown to grey soft sandy loam topsoil up to 30 cm thick.
- Paler brown subsoil, sometimes with slight clay increase.
- Substrates are coarse grained wind or water deposits.
- Occurs on creek flats and lunettes.

- Moderate to low inherent fertility due to relatively low clay content in surface.
- No significant restrictions to root growth.
- 50 - 80 mm readily available water holding capacity.
- Moderately well to well drained. Waterlogging can be an issue in lower lying areas.

Gradational clay loam

SOIL CODE

M2

% of vineyards planted on M2 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
7	0	0	0	<1	0	0	6

- Brownish clay loam topsoil, grading to brown or red well structured clayey subsoil.
- Profile has little or no subsoil carbonate.
- Substrate is semi-hard to hard calcreted limestone or marl (old lagoonal sediment).
- Occurs on plains.

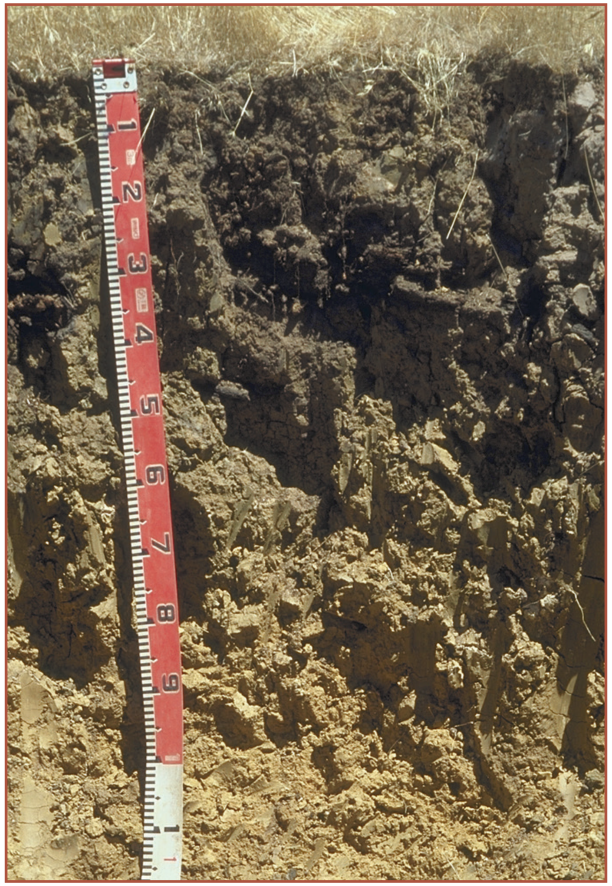
- High inherent fertility due to relatively high clay content in surface.
- No significant restrictions to root growth above substrate carbonate layer.
- Up to 60mm readily available water holding capacity.
- Moderately well drained. Waterlogging can be an issue in lower lying areas.

Hard gradational clay loam

SOIL CODE

M4

% of vineyards planted on M4 soil							
COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
<1	0	<1	0	0	0	0	0



- Brownish hard loam to clay loam topsoil, grading to a poorly structured clayey subsoil.
- Profile has little or no subsoil carbonate.
- Substrate is old lagoon floor clay.
- Occurs on plains.

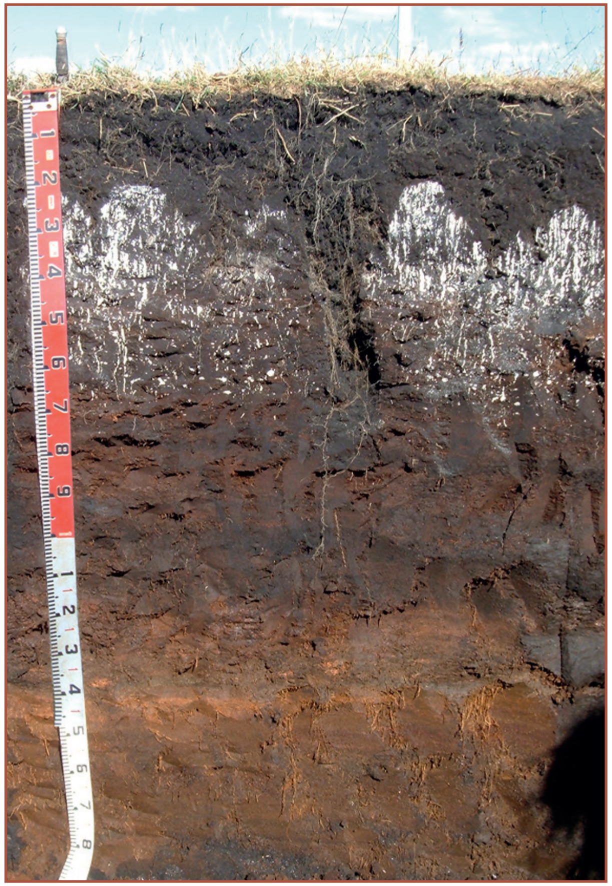
- Moderate to high inherent fertility due to relatively high surface clay content.
- Poorly structured subsoil clay prevents optimal root development.
- Readily available water holding capacity less than 40 mm due to restricted root zone.
- Imperfectly drained. Waterlogging likely to be an issue in lower lying areas.

Organic wet soil (PEAT)

SOIL CODE
N1

% of vineyards planted on N1 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
0	0	0	0	0	0	0	0



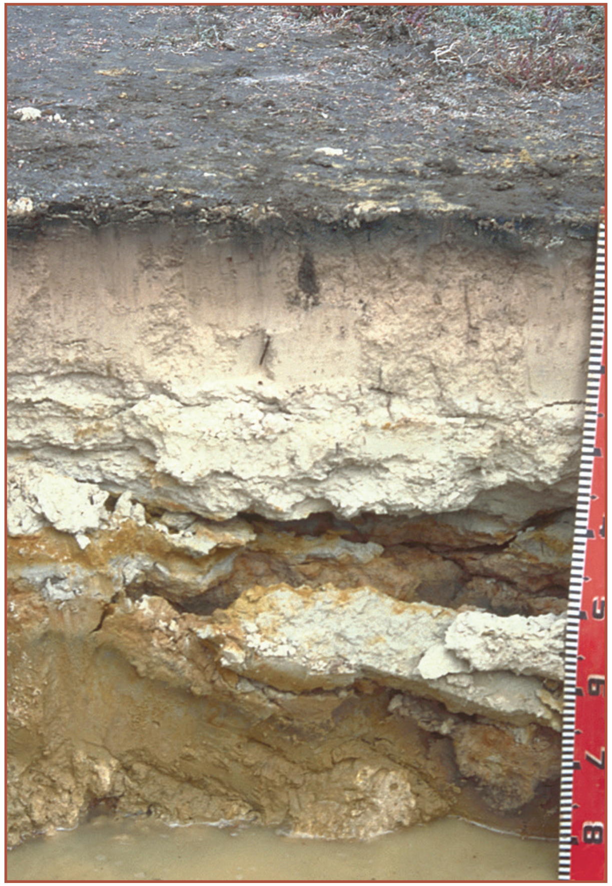
- Partly to fully decomposed plant remains with organic carbon content of at least 12% (usually much more).
- Depth is highly variable from 20 cm over limestone to several metres.
- Usually associated with water table.
- Occurs in swamps.

- Profile usually wet, so agricultural use generally restricted to grazing.
- May be acidic, neutral or alkaline.
- Commonly used as constituent of potting mixes.

Saline wet soil

SOIL CODE **N2**

% of vineyards planted on N2 soil							
COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
0	0	0	0	0	0	0	0



- Defining feature is a near surface saline water table, and soil salinity sufficiently high that only salt tolerant species can survive.
- Profile ECe typically more than 16dS/m.
- Profile features highly variable, but dark clay loam surface is typical.
- Occurs on salt flats and saline swamps.

- No viticultural potential due to high salinity and poor drainage.
- Agricultural uses limited to light grazing of salt tolerant pastures.

Wet non saline soil

SOIL CODE

N3

% of vineyards planted on N3 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
0	0	0	0	0	0	0	0

- Defining feature is a shallow water table which causes saturation of most of the profile for most of the year.
- Water table typically within a metre of the surface (summer) and close to or at the surface (late winter).
- Non to marginally saline.
- Occurs in swamps and swampy plains.

- Virtually no viticultural potential due to extended soil wetness and difficulty in draining.
- Agricultural uses restricted to grazing.

Volcanic soil

SOIL CODE

O1

% of vineyards planted on O1 soil

COONAWARRA	LUCINDALE	MT BENSON	MT GAMBIER	MUNDULLA	PADTHAWAY	ROBE	WRATTONBULLY
0	0	0	13	0	0	0	0

- Well structured dark loamy topsoil over a paler and often stony sandy loam to clay loam subsoil.
- Profile up to a metre thick.
- Substrate often stratified hardened volcanic ash overlying older soils.
- NOTE: volcanic influence often seen as ashy deposits over older soils.
- Occurs on slopes and plains near old volcanoes.

- Moderate to high inherent fertility due to relatively high clay content and young age.
- Generally well drained.
- Up to 70 mm readily available water for 100 cm deep profile.
- Usually neutral or alkaline due to influence of regional limestone on erupting volcanic material.

Table 4.2 (Pages 106-107). Summary of key soil characteristics for the significant viticultural soils of the Limestone Coast

The data presented in the table are derived from the DWLBC DVD, Regional Land Resource Information for Southern South Australia (DWLBC 2007). Where possible, data from actual sampling sites have been used. Where not available, estimates are provided, based on analyses of similar soil materials from elsewhere in the region. The data are intended to be indicative only, and significant variations from presented values can be expected. Most characteristics are to some extent influenced by land management practices such as irrigation, ripping, fertilizer applications and liming. Above all, natural variations in both horizontal and vertical dimensions are continuous and unpredictable. Significant soils for the purpose of this table are those which account for either more than 5%, or more than 100 ha, of the vineyard soils of a Region.

Soil	Region / district	Percent-age of vineyard area	Rootzone depth natural (& post ripping)	Substrate material	Surface soil clay % (and stone content)	Subsoil clay % (and stone content)	Subsoil structure	Surface cation exchange capacity (cmol+/kg)	Subsoil cation exchange capacity (cmol+/kg)	Surface calcium saturation	Subsoil exchange sodium (ESP)	Surface organic carbon	Surface pH	Subsoil pH	Readily available water (RAW)
A7 Calcareous clay loam over marl	No significant plantings on this soil														
B1 Shallow highly calcareous sandy loam on calcrete	No significant plantings on this soil														
B2 Stony calcareous sandy loam to clay loam on calcrete shallower than 500 mm	Coonawarra	< 5%	400 (650) mm	Calcreted limestone	30% clay, up to 10% stone	30% clay, up to 30% stone	Friable	15	20	80	< 5%	2%	7.5	8.0	20-35 mm
	Padthaway	5-10%	300 (500) mm	Calcreted limestone	20% clay, up to 10% stone	20% clay, up to 50% stone	Friable	10	10	80	<5%	1.75%	7.5	8.0	15-30 mm
	Robe	5-10%	200 (400) mm	Calcreted calcarenite	10% clay, up to 20% stone	10% clay, up to 50% stone	Friable	10	5	80	<5%	1.75%	7.5	8.0	10-25 mm
B3 Stony sandy loam to loam on calcrete shallower than 500 mm	Coonawarra	5-10%	300 (600) mm	Calcreted calcarenite	20% clay, up to 15% stone	20% clay, up to 25% stone	Friable	10	10	85	< 5%	1.5%	7.0	7.5	20-30 mm
	Lucindale	20-25%	300 (600) mm	Calcreted calcarenite	15% clay, up to 15% stone	15% clay, up to 25% stone	Friable	10	10	85	< 5%	1.5%	7.0	7.5	20-30 mm
	Mt Benson	25-30%	250 (400 mm)	Calcreted calcarenite	10% clay, up to 50% stone	10% clay, up to 50% stone	Friable	5-10	5-10	90	5%	1.5%	7.5	8.0	10-20 mm
	Mt Gambier	20-25%	150 (200) mm	Calcreted marine limestone	15% clay, up to 25% stone	15% clay, up to 80% stone	Friable	5-10	5-10	90%	< 5%	2%	6.5	7.0	5-15 mm
	Mundulla	10-15%	350 (650) mm	Calcreted limestone	15% clay, up to 10% stone	20% clay, up to 10% stone	Friable	10	10	85%	< 5%	1.25%	7.0	7.5	15-25 mm
	Padthaway	15-20%	300 (600) mm	Calcreted limestone	15% clay, up to 15% stone	15% clay, up to 25% stone	Friable	10	10	85%	< 5%	1.5%	7.0	7.5	20-30 mm
	Robe	30-35%	250 (400 mm)	Calcreted calcarenite	10% clay, up to 50% stone	10% clay, up to 50% stone	Friable	5-10	5-10	90%	5%	1.5%	7.5	8.0	10-20 mm
B4 Red loam to clay loam on limestone shallower than 500 mm	Coonawarra	15-20%	400 (600) mm	Calcreted limestone	35% clay, up to 10% stone	40% clay, up to 25% stone	Friable	25	25	80%	< 5%	2.5%	7.0	7.5	25-50 mm
	Mundulla	20-25%	300 (500) mm	Calcreted limestone / calcarenite	25% clay, upo to 10% stone	30% clay, up to 25% stone	Friable	20	20	80%	< 5%	2%	7.0	7.5	20-40 mm
	Padthaway	5-10%	300 (500) mm	Calcreted limestone / calcarenite	25% clay, upo to 10% stone	30% clay, up to 25% stone	Friable	20	20	80%	< 5%	2%	7.0	7.5	20-40 mm
	Wrattonbully	5-10%	300 (500) mm	Calcreted clay / calcarenite	25% clay, up to 10% stone	30% clay, up to 25% stone	Friable	20	25	80%	< 5%	2%	6.5	7.0	20-40 mm
B5 Dark clay loam on calcrete shallower than 500 mm	Coonawarra	15-20%	200 (450) mm	Calcreted marl and limestone	40% clay, up to 10% stone	50% clay, up to 25% stone	Firm, medium blocky	40	35	85%	< 5%	5%	7.5	7.5	10-40 mm
	Padthaway	10-15%	200 (450) mm	Calcreted marl and limestone	40% clay, up to 10% stone	50% clay, up to 25% stone	Firm, medium blocky	40	35	85%	< 5%	5%	7.5	7.5	10-40 mm
B6 Sandy loam over red clay on calcrete shallower than 500 mm	Coonawarra	10-15%	350 (600) mm	Calcreted calcarenite	20%	45% clay	Firm, fine blocky to massive	15	20	75%	< 5%	2%	6.0	6.5	25-50 mm
	Lucindale	70-75%	350 (600) mm	Calcreted clay / calcarenite	15% clay	35% clay	Firm, fine blocky to massive	15	20	75%	5-10%	2%	6.5	7.0	20-40
	Mt Benson	30-35%	350 (600) mm	Calcreted calcarenite	10% clay	35% clay	Firm, fine blocky to massive	5-10	20	75%	5-10%	1%	6.5	7	15-35 mm
	Padthaway	15-20%	350 (600) mm	Calcreted calcarenite	20% clay	45% clay	Firm, fine blocky to massive	15	20	75%	< 5%	2%	6.0	6.5	25-50 mm
	Robe	15-20%	350 (600) mm	Calcreted calcarenite	10% clay	35% clay	Firm, fine blocky to massive	5-10	20	75%	5-10%	1%	6.5	7	15-35 mm
	Wrattonbully	5-10%	400 (700) mm	Calcreted calcarenite	15% clay	45% clay	Firm, fine blocky to massive	10	20	755	5-10%	1%	6.5	7	25-50 mm
B7 Sand over clay on calcrete shallower than 500 mm	Coonawarra	< 5%	350 (600) mm	Calcreted marl or limestone	5% clay	35% clay	Massive to fine blocky	5	15	55%	< 5%	1%	6.5	7.5	15-30 mm
	Mt Gambier	20-25%	250 (400) mm	Calcreted marine limestone	5% clay	35% clay	Massive to fine blocky	5	15	60%	< 5%	1.5%	6.0	7.0	10-20 mm
	Padthaway	5-10%	350 (600) mm	Calcreted marl or limestone	5% clay	35% clay	Massive to fine blocky	5	15	55%	< 5%	1%	6.5	7.5	15-30 mm
	Robe	10-15%	400 (700) mm	Calcreted marl or liomestone	5% clay	45% clay	Massive to coarse blocky	5	20	50%	5-10%	1.5%	7.0	7.0	15-25 mm
B8 Sand over calcrete shallwoer than 500 mm	Mt Benson	15-20%	350 (700) mm	Calcreted calcarenite	5% clay	5% clay	Soft, sandy	5	< 5	na	na	1%	6.0	6.0	15-20 mm
	Robe	5-10%	350 (700) mm	Calcreted calcarenite	5% clay	5% clay	Soft, sandy	5	< 5	na	na	1%	6.0	6.0	15-20 mm
B9 Clay loam over brown clay on calcrete	No significant plantings on this soil														

C3 Gradational loam	Padthaway	5-10%	600 mm	Clay	30% clay	45% clay	Hard, medium blocky	15	35	65%	< 5%	1%	6.5	7.0	40-50 mm
C5 Dark gradational clay loam	Coonawarra	< 5%	750 mm	Clay / marl / limestone	35% clay	50% clay	Firm, medium blocky	30	35	70%	5-10%	2.5	7.0	8.0	45-60 mm
D2 Sandy loam over well structured red clay	Coonawarra	< 5%	800 mm	Clay with limestone	20% clay	45% clay	Medium coarse blocky	10	40	70%	< 5%	1.5%	6.0	7.0	50-60 mm
	Mundulla	20-25%	700 mm	Clay	10% clay	35% clay	Medium coarse blocky	10	20	70%	5-10%	1%	6.5	7.0	45-55 mm
	Padthaway	5-10%	800 mm	Clay with limestone	15% clay	45% clay	Medium coarse blocky	10	40	70%	< 5%	1.5%	6.0	7.0	45-60 mm
D3 Hard sandy loam over poorly structured red clay	Mundulla	5-10%	600 mm	Clay	20% clay	50% clay	Very hard coarse columnar	20	50	65%	10-15%	1.5%	6.5	7.5	30-40 mm
E3/E1 Brown, grey or black cracking clay	Coonawarra	5-10%	800 mm	Heavy clay	50% clay	50% clay	Very hard coarse blocky	45	40	70%	10-15%	4.5%	7.5	7.5	30-40 mm
	Mundulla	5-10%	800 mm	Heavy clay	50% clay	60% clay	Very hard coarse blocky	30	40	70%	20-25%	2%	7.0	8.0	25-35 mm
F1 Sandy loam over well structured brown clay	Coonawarra	<5%	1000 mm	Clay	20% clay	50% clay	Hard medium blocky	10	25	55%	5-10%	1.5%	5.5	5.5	50-60 mm
	Mt Gambier	5-10%	1000 mm	Flinty marine limestone	20% clay, up to 50% flints	50% clay with up to 10% flints	Hard medium blocky	25	40	70%	< 5%	5%	6.0	7.0	50-60 mm
	Mundulla	10-15%	650 mm	Alluvial clay	25%	50%	Hard medium blocky	15	35	60%	10-15%	3.5%	6.5	8.0	35-45 mm
	Padthaway	5-10%	1000 mm	Clay	20% clay	50% clay	Hard medium blocky	10	25	55%	5-10%	1.5%	5.5	5.5	50-60 mm
	Wrattonbully	20-25%	900 mm	Clay	15% clay, up to 25% ironstone	50% clay	Hard medium blocky	5	20	80%	< 5%	2.5%	5.5	6.5	50-60 mm
F2 Sandy loam over poorly structured brown clay	Coonawarra	5-10%	650 mm	Clay	20% clay	55% clay	Very hard coarse blocky	15	30	75%	10%	2%	6.5	7.0	35-45 mm
	Mundulla	10-15%	600 mm	Clay	15% clay	55% clay	Very hard coarse blocky	10	30	65%	20-25%	2%	6.0	6.5	30-40 mm
	Wrattonbully	20-25%	600 mm	Clay	15% clay	55% clay	Very hard coarse blocky	10	30	65%	20-25%	2%	6.0	6.5	30-40 mm
G2 Thick sand over sandy clay loam	Wrattonbully	5-10%	1000 mm	Calcreted calcarenite	5% clay	25% clay	Firm massive	<5	10	70%	< 5%	15	5.5	7.0	50-70 mm
G3 Thick sand over clay	Coonawarra	10-15%	700 mm	Clay	5% clay	50% clay	Very hard coarse prismatic	<5	20	70%	< 5%	1.5%	5.0	6.0	35-45 mm
	Mt Gambier	5-10%	750 mm	Marine limestone	5% clay	40% clay	Very hard coarse blocky	<5	20	70%	5%	1.5%	4.5	6.0	35-45 mm
	Padthaway	5-10%	700 mm	Calcarenite / clay	5% clay	60% clay	Very hard coarse prismatic	5	30	70%	< 5%	1%	6.5	6.5	30-40 mm
	Wrattonbully	5-10%	650 mm	Sandy clay	5% clay	40% clay	Hard coarse blocky	<5	15	70%	10%	1.25%	5.5	5.5	30-40 mm
G4 Thin sand over clay	Coonawarra	< 5%	600 mm	Clay	5% clay	50% clay	Very hard coarse columnar	5	20	70%	15%	1.5%	6.0	7.0	25-35 mm
H1 Deep carbonate (shell) sand	No significant plantings on this soil														
H2 Deep siliceous sand (not bleached)	No significant plantings on this soil														
H3 Deep bleached siliceous sand	Mt Benson	10-15%	Up to 1500 mm	Sand over calcarenite	<5% clay	5-15% clay (below 1000 mm)	Soft, massive	5	5	70%	Up to 10% (below 1000 mm)	1%	5.5	6.5	40-60 mm
	Padthaway	5-10%	Up to 1500 mm	Sand over calcarenite	<5% clay	5-15% clay (below 1000 mm)	Soft, massive	5	5	70%	Up to 10% (below 1000 mm)	1%	5.5	6.5	40-60 mm
	Robe	5-10%	Up to 1500 mm	Sand over calcarenite	<5% clay	5-15% clay (below 1000 mm)	Soft, massive	5	5	70%	Up to 10% (below 1000 mm)	1%	5.5	6.5	40-60 mm
	Wrattonbully	5-10%	Up to 1500 mm	Sand over calcarenite	<5% clay	5-15% clay (below 1000 mm)	Loose to soft and massive	5	5	70%	Up to 10% (below 1000 mm)	1%	5.5	6.5	40-60 mm
I1 Deep highly leached sand	Mt Gambier	5-10%	Up to 1500 mm	Sand over coffee rock	< 5% clay	< 5% clay	Loose	< 5	1	NA	NA	1%	4.5	4.5	40-50 mm
M1 Deep sandy loam	No significant plantings on this soil														
M2 Gradational clay loam	Coonawarra	5-10%	1000 mm	Clay / limestone	30% clay	50% clay	Firm medium blocky	20	25	75%	5%	2.5%	6.0	6.5	55-65 mm
	Wrattonbully	5-10%	700 mm	Clay	35% clay	50% clay	Hard medium blocky	15	30	65%	20%	1.5%	5.5	7.5	35-50 mm
M4 Hard gradational clay loam	No significant plantings on this soil														
N1, N2, N3 Wet soils	No significant plantings on this soil	These soils are too wet and/or saline to sustain viticulture													
O1 Volcanic soil Highly variable, one example only	Mt Gambier	10-15%	750 mm	Hard volcan-ic ash with carbonate	25% clay	25% clay	Massive, porous	30	20	75%	< 5%	5%	6.5	8.0	40-70 mm

4.2 Land Units of the Limestone Coast Geographic Indication Regions and Districts

As indicated previously, the information presented in this chapter is derived from DWLBC soil landscape mapping (DWLBC 2007). The primary mapping unit in the DWLBC work is the land system, a broad tract of country within which there is a repeating pattern of landforms, soils and vegetation communities. Each land system is subdivided into a number of soil landscape units. A soil landscape unit is a recognizable tract of land formed in a specified geological setting, with a distinct topographic pattern (e.g. plain, undulating hills, dune-swale etc.), and a limited range of soils. The scale of the mapping varies from 1:50,000 to 1:100,000, and as such, delineation of individual soil types is impractical. In any case, the level of detail in the field data sets doesn't allow this level of resolution. The information cannot therefore be used to draw conclusions about conditions on individual properties, including vineyards.

For this report, in each of the Geographic Indication Regions (or districts), soil landscape units are amalgamated into 'Land Units' according to similarities in their constituent soils. This has resulted in a much simplified map, the purpose of which is to provide an overview of the soils and their characteristics for the regions. Between eight and 15 Land Units are defined for each region. These are summarised in terms of landscape, main soils and key features.

Each of the soils has a two character code. Codes coloured red are hyper-linked to the appropriate soil fact sheet.

Note that no responsibility can be accepted for errors, omissions or inconsistencies in the source information.

Notes on use of the maps:

- The information is derived from limited field inspections.
- Boundaries between mapping units should be treated as transition zones.
- The maps are intended to provide regional overviews and should not be used to draw conclusions about conditions at specific locations.
- Under no circumstances must the scale of the map be enlarged beyond its scale of publication.
- Specialist advice should be sought prior to commercial decision making.

4.7 Land Units of the Coonawarra Geographic Indication Region

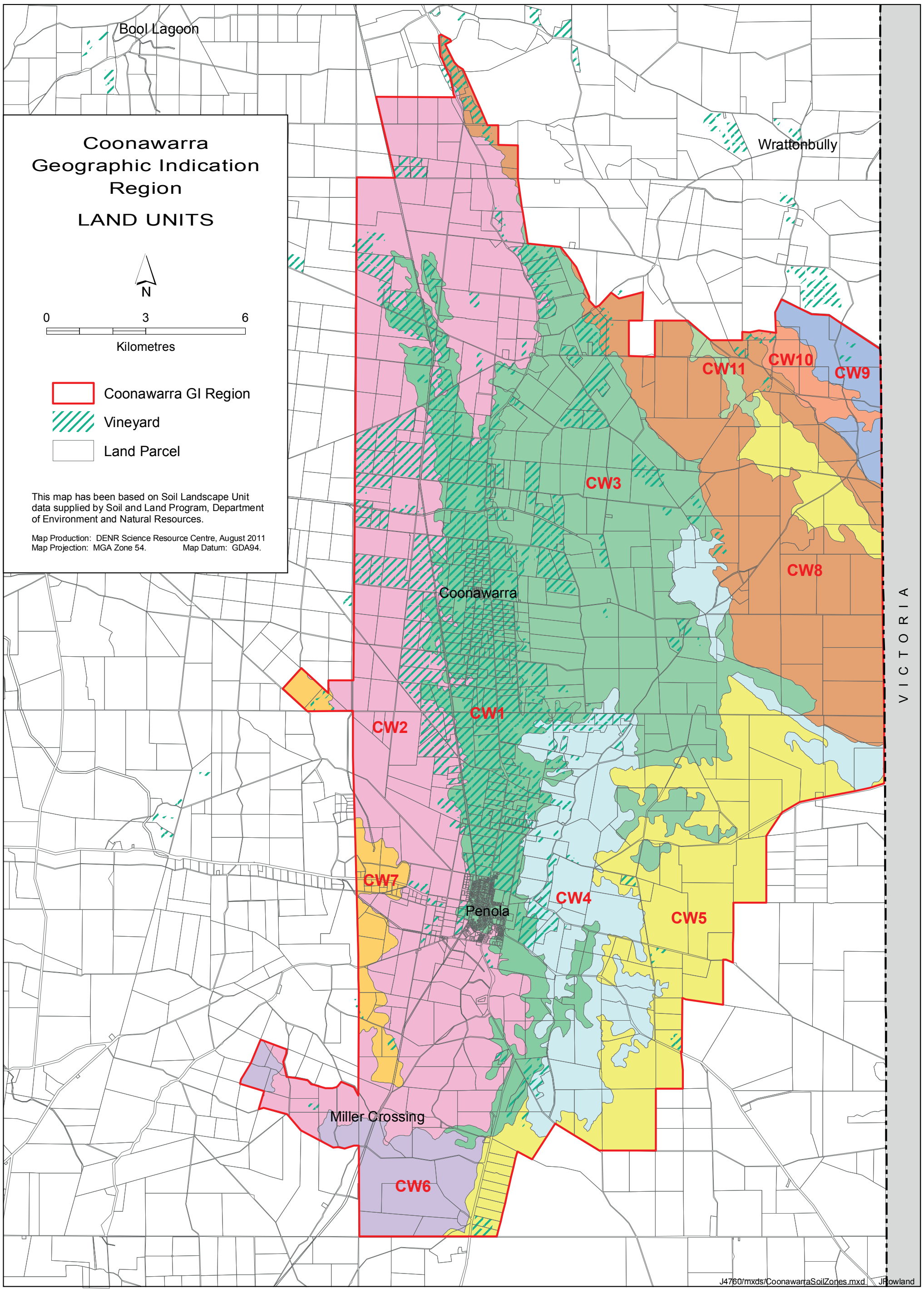


Figure 4.5. Land units of the Coonawarra Wine Region.

	LANDSCAPE	MAIN SOIL	ASSOCIATED SOILS
CW1	Low rise	Red loam on calcrete	- Various shallow soils on calcrete - Deep gradational clay loam
CW2	Plains	Shallow dark clay loam	- Shallow sandy loam on calcrete - Deep dark clay loam to clay
CW3	Gently und. plains	Sand over clay	- Sandy loam over clay - Shallow sand over clay on calcrete
CW4	Plains with swamps	Sand over clay	- Wet soil - Shallow dark clay loam on calcrete
CW5	Sand plain	Sand over clay	- Deep highly leached sand - Deep sand
CW6	Plains with swamps	Hard gradational sandy loam	- Dark cracking clay - Wet soil
CW7	Plains with swamps	Deep gradational loam	- Dark cracking clay - Shallow dark clay loam on calcrete
CW8	Range	Deep sand	- Sand over sandy clay loam / clay - Misc. shallow soil on calcrete
CW9	Flats and low rises	Sand over clay	- Sandy loam over clay
CW10	Flats and low rises	Sandy loam over clay	- Sand over clay - Shallow loam on calcrete
CW11	Flats between ranges	Sand over clay	- Shallow dark clay loam - Sandy loam over clay

Summary of Coonawarra (CW) Region

The Coonawarra Region is divided into eight Land Units, as follows:

Land Unit	Area (ha)	% of Region	Area Vines (ha)	% Vines *	Features
CW1	4,821	12.1%	2,783	47.6%	Coonawarra 'cigar', a very low rise, with mostly shallow red soils on calcrete. Well drained and moderately fertile. Premium viticultural land.
CW2	10,649	26.7%	1,598	27.3%	Flats with dark medium to heavy textured soils, and rises similar to CW1. Flats subject to waterlogging. Good viticultural potential on rises and better drained flats.
CW3	7,126	17.9%	919	15.7%	Gently undulating plains with sandy and loamy texture contrast soils, many subject to waterlogging. Better drained soils well suited to viticulture.
CW4	3,834	9.6%	270	4.6%	Plains similar to CW3, but with swamps. Wetter than CW3, so less suitable for viticulture.
CW5	5,182	13.0%	67	1.1%	Gently undulating sand plain with mostly deep but highly infertile soils. Limited viticultural potential.
CW6	1,277	3.2%	0	0%	Plains with extensive swamps. Deep, medium textured fertile soils, but waterlogging is main limitation.
CW7	748	1.9%	22	0.4%	Imperfectly drained plains with extensive rises which are suitable for viticulture, but are too scattered.
CW8	4,974	12.5%	172	2.9%	Ranges with mostly deep sandy soils, mixed with some shallow stony types. Well drained land, but mostly infertile.
CW9	671	1.7%	11	0.2%	Gently undulating land with sand and sandy loam over clay soils of low to moderate fertility.
CW10	417	1.0%	9	0.2%	Flats and rises with sandy loam over clay, sand over clay and shallow soils. Loamier and shallow soils suitable for vines.
CW11	157	0.4%	0	0%	Flats between ranges with infertile sands, clay loams prone to waterlogging, and sandy loam soils suitable for viticulture.
TOTAL	**39856**	**100%**	**5,851**	**100%**	

** Proportion of the Region's vineyards, based on mapping data provided by the Phylloxera and Grape Industry Board of South Australia (2011)*

Land Unit CW1

Landscape

This is the Coonawarra 'cigar' or 'strip', an elongated north-south trending low rise, possibly the remnant of an old reef. The surface is flat to very gently undulating, and in places, its elevation above the surrounding plains (Land Units CW2, CW3 and CW4) is imperceptible. Substrate materials are typically coarse textured calcareous materials, consisting of semi-indurated masses interspersed with hard fragments in an unconsolidated matrix. A thin calcreted capping is usual. In places this cap occurs at the surface as reef rock. Surface stones are common in places. The subterranean surface of the calcrete cap is irregular, presumably the result of uneven dissolving of the calcareous materials. Deeper soils occur in these areas.

Soils

Calcreted calcarenite underlies three quarters of the Land Unit at shallow depth, giving rise to the distinctive 'terra rossa' soils for which the area is noted. A variety of deeper, mostly loamy surfaced soils occupy the hollows and solution holes in the subsurface calcrete sheet.

Soil	Symbol	% of Unit	Comments
Shallow loam to sandy loam	**B4/B3**	40%	Red sandy loam to clay loam over calcrete within 50 cm, often much shallower. 75% of profiles (B4) are well structured crumbly loams to clay loams, the rest (B3) are sandier and weakly structured.
Shallow sandy loam over red clay	**B6**	20%	Reddish sandy loam to loam abruptly overlying a red clayey subsoil, with calcrete shallower than 50 cm.
Other shallow loam and outcropping reefs	**B***	15%	Includes shallow dark clay loam (B5), shallow calcareous sandy loam (B2). Patchy surface stone and rocky reefs are distinctive features.
Deep gradational clay loam	**M2**	10%	Well structured fine textured soil, becoming more clayey with depth.
Loam over red or brown clay	**D2/F2**	10%	Brown to grey surface sandy loam to loam over red to brown / yellow clay with variable structure.
Sand over clay	**G3**	5%	Usually more than 30 cm grey sandy surface over tight brownish clay subsoil.

Key features of the Land Unit are:

- Shallow to very shallow, well drained red loamy soils are distinctive. Laboratory data indicate that they are highly calcium saturated. They have moderate to high fertility status depending on clay content. They are highly sought after soils for viticulture. Their favourable qualities are probably attributable to some combination of low water holding capacity (providing opportunities for regulating soil moisture), excellent drainage and aeration, and high calcium status.
- The deeper soils are mostly loamy and fertile, but have much higher water holding capacities, and are less well drained (particularly soil F2) than the shallow soils.
- The minor sandy soils are infertile and imperfectly drained, with root restrictive subsoils.
- Most surface soils are neutral to acidic in their natural state, but become less acidic over time due to the influence of alkaline irrigation water. Ripping of shallow soils brings calcrete and calcarenite to the surface, further increasing alkalinity.

Land Unit CW2

Landscape This unit encompasses most of the plains to the west and north of the Coonawarra 'strip'. The plains are underlain by marls and other fine grained calcareous sediments of an ancient lagoon bed. These materials commonly occur at shallow depth, and have a hard calcrete capping. Low rises account for about 20% of the landscape – these may be remnants of small islands or reefs. Calcrete capped calcarenite generally underlies the rises at shallow depth. There are 5-10% swamps where slight hollows have formed as a result of some dissolving of the underlying sediments. Surface stone is common on rises, limited on flats. There are minor outcrops of sheet rock, mostly on rises.

Soils Half the soils are shallow on calcrete. The rest are deeper, mostly dark and fine grained, and with gradationally textured soils. Texture contrast soils account for about 15% of the unit – two thirds are sandy surfaced.

Soil	Symbol	% of Unit	Comments
Shallow dark clay loam	**B5**	35%	Can be very shallow, especially on rises. Commonly associated with a water table on flats – often called 'groundwater rendzina'.
Other shallow soil	**B2/B4**	15%	Mostly calcareous sandy loam (B2) and red loam (B4), with sheet rock. More common on rises.
Grey to black cracking clay	**E3/E1**	15%	Seasonally cracking (when able to dry out), generally more clayey with depth. Occur on plains and in depressions.
Dark gradational clay loam	**C5**	10%	Typically well structured, more clayey and highly calcareous with depth.
Sand over clay	**G3/G4**	10%	Surface sand thicker than 30cm (G3) in two thirds, and thinner than 30 cm (G4) in one third.
Wet soil	**N3**	5-10%	Occur in low lying areas. Saturated for significant periods, and include swamp soils generally inundated most of the time.
Gradational clay loam	**M2**	5%	Similar texture profile to C5 soils, but often redder, and with much less subsoil carbonate.
Sandy loam on clay	**F2**	$<5\%$	Sandy loam to sandy clay loam surface, sharply overlying poorly structured subsoil clay.

Key features of the Land Unit are:

- Most soils on the flats are prone to waterlogging, principally as a result of shallow water tables. They are either inaccessible to machinery during winter / early spring, or likely to suffer compaction. Whilst root zones may be above the water table during the growing season, water at relatively shallow depth can promote excessive vegetative growth. Soils on slightly higher ground (e.g. B2/B4 profiles) are adequately drained. Wet soils (N3) are not suitable for viticulture.
- Inherent fertility of the B5, E3/E1, C5 and M2 soils is high, due to their high surface clay contents. In combination with shallow water tables (see previous dot point), this can lead to vigorous or excessive vegetative growth. The sand over clay soils are the least fertile, but account for only 10% of the unit.

Land Unit CW3

Landscape

This unit is the northern part of the very gently undulating plains between the Coonawarra 'cigar' and the Naracoorte Range. The southern part (mapped as Land Unit CW 4), has more swamps and is less well drained. Scattered across the plains are about 10% swampy depressions and about 10% sandy rises, some of which abut the lower slopes of the Naracoorte Range. Underlying the plains are Padthaway Formation sediments, comprising mostly clays with interbedded soft and hard calcareous materials. Ironstones are common in places.

Soils

Texture contrast soils are predominant, with sandy surfaces about twice as common as loamier types. About a quarter of soils overall are shallow on calcreted sediments. Wet soils in swamps and depressions account for a little under 10% of the area.

Soil	Symbol	% of Unit	Comments
Sand over clay	**G3/G4**	35%	Two thirds have thick (>30 cm) surfaces (G3). Ironstone gravelly subsurface layers are common. Clayey subsoils usually poorly structured. 15-20% have acidic deep subsoils.
Sandy loam over poorly structured clay	**F2**	25%	Topsoil usually 20-30 cm thick, often with ironstone gravelly subsurface. Tight mottled brownish clay subsoil, usually calcareous at depth.
Sand over clay on calcrete	**B7**	20%	Hard calcreted layer within 50 cm of surface
Wet soil	**N3**	10%	Variable including peats, generally non saline, but unsuitable for viticulture.
Other	**B*, M2/M4, H3/I2, F1**	10%	Minor occurrences of shallow red sandy loam (on calcrete), deep brown gradational clay loam, deep bleached sand, and sandy loam over well structured brown clay.

Key features of the Land Unit are:

- About three quarters of the soils (mostly the texture contrast types, G3/G4, F2 and some B7) are imperfectly drained. This means that at least part of the potential root zone is saturated for weeks to a couple of months per year. This is generally not a problem for summer growing crops, but can restrict winter access. Heavy summer rain events (especially if co-incident with an irrigation) may cause temporary waterlogging.
- Low inherent fertility of sandy soils. The sands are generally bleached, indicative of absence of the clay minerals and organic matter needed for improved fertility status.
- Restrictive subsoil clays (i.e. hard with coarse aggregates) prevent uniform and vigorous root growth, but this is not necessarily a problem – it may help control excessive vigour.
- The shallow sand over clay soils (B7) have limited water holding capacity and low fertility, but can be successfully managed for viticulture - some gradational clay loams are imperfectly drained, and the deep sands are infertile.
- Natural soil acidity in many of the soils is rapidly neutralized by irrigation water.

Land Unit CW4

Landscape This unit is the southern part of the very gently undulating plains between the Coonawarra 'cigar' and the Naracoorte Range. It is less well drained than the northern part (mapped as Land Unit CW3), with more swamps, but otherwise has many features in common. Underlying sediments are clays, marls and limestones of the Padthaway Formation. Calcrete capping of these sediments occurs over about 20% of the unit area. Low lunettes are commonly associated with swamps. Low sandy rises and some stony rises occur throughout.

Soils The most notable feature is the high proportion of wet soils. Associated soils include sandy and sandy loam texture contrast types, and shallow soils over calcreted Padthaway Formation sediments.

Soil	Symbol	% of Unit	Comments
Wet soil	**N3/N1**	25%	Variable soils including peats, with the common feature of being saturated for at least several months due to shallow water table and/or inundation.
Sand over clay	**G3/G4**	25%	Most soils have thick (more than 30 cm) surface sand layers, with generally poorly structured subsoil clays.
Shallow dark clay loam	**B5**	15%	Well structured black clay loam, shallow to very shallow over calcrete or limestone (rendzina). Often associated with water table at shallow depth.
Sandy loam over poorly structured clay	**F2**	10%	Poorly structured clay subsoil usually within 30 cm of surface.
Deep gradational loam	**M2/A7**	10%	Loam to clay loam surface, more clayey with depth. Highly calcareous at depth (throughout in case of A7).
Variable shallow soil over calcrete	**B7/B6/ B4**	5%	Includes shallow sand over clay, sandy loam over red clay, and shallow red loam.
Deep sand	**I2/H3**	5%	Most are strongly leached, and all are bleached and deeper than 80 cm
Gradational sandy loam	**M1**	5%	Deep sandy loam, more clayey with depth, often with water table.

Key features of the Land Unit are:

- The predominant wet soils are highly variable, but all are unsuitable for viticulture from both operational and production perspectives.
- About 40% of the remainder of the landscape is poorly drained, with low viticultural potential. The sandy and sandy loam texture contrast soils, and the shallow dark clay loams are most affected.
- The better drained sand over clay soils (on rises and more elevated flats) are infertile with restrictive subsoil clays. However, they can be successfully used for viticulture.
- Where drainage is adequate, the minor soils generally have viticultural potential. The deep gradational loams are highly fertile and may cause excessive vigour. The shallow soils have restricted water holding capacities, and the deep sands are highly infertile.

Land Unit CW5

Landscape This unit is a gently undulating sand plain in the south eastern part of the region. Also included is a lower lying sandy plain within the Naracoorte Range (Land Unit CW8). The underlying sediments are clays, marls and limestones of the Padthaway Formation. The characteristic sand of the unit was however most likely derived from old coastal dunes and accumulated by the prevailing westerly winds against the foot of the Naracoorte Range.

Soils Sandy soils dominate this unit – only about 5% of soils don't have sandy surfaces. Sands are commonly deeper than 100 cm, but clay subsoils generally occur at between 30 and 60 cm. Coffee rock (partially cemented iron/organic material) in highly leached sands is typically much deeper. It appears that this sandy unit is the result of wind driven accumulation of sands from the ancient coastal dunes.

Soil	Symbol	% of Unit	Comments
Sand over clay	**G3**	50%	Surface sand thicker than 30cm in most of these soils. Subsoil clay is moderately well to poorly structured.
Highly leached sand	**I2/I1**	35%	Strongly bleached with coffee rock deep subsoil. Most are imperfectly drained due to restrictive subsoil layer.
Deep sand	**H3**	10%	Bleached and well drained. Deeper than 80 cm.
Other	**M2/E3/ N3**	5%	Deep gradational clay loam (M2), grey cracking clay (E3) and wet soil (N3) occur in lower lying areas and swamps.

Key features of the Land Unit are:

- The dominant sand over clay soils (G3) have low natural fertility due to the low capacity of the surface soil to retain nutrients. Building up and maintaining organic matter levels is also more difficult than on heavier soils. These soils are generally moderately well to imperfectly drained, meaning that they are rarely saturated for more than a few weeks (winter/early spring).
- The deep highly leached sands are extremely infertile and acidic, requiring specialist nutritional management. The I2 type has a restrictive subsoil layer (coffee rock) which can impede drainage and may be associated with a water table. The I1 types are better drained.
- The deep sands (H3) are also infertile and excessively drained.
- All soils are naturally acidic. Irrigation and liming usually correct this condition.

Land Unit CW6

Landscape This unit is a flat with about 20% sandy rises and 20% depressions or swamps. It is formed on marls and clays deposited on the beds of ancient lagoons. The sands on the rises are possibly derived from sandy layers within the lagoon floor sediments, or from small dunes and drifts associated with the old lagoons. The sand has been reworked by wind into low rises.

Soils 80% of soils are texture contrast (i.e. sandy to loamy surface abruptly overlying a much more clayey subsoil). Shallow stony soils characterize the old dune remnants.

Soil	Symbol	% of Unit	Comments
Gradational sandy loam	**M4**	30%	Hard sandy loam to sandy clay loam topsoils grading to poorly structured clayey subsoils.
Black to grey cracking clay	**E1/E3**	25%	Friable to hard seasonally cracking clay (black (E1) types are better structured than grey (E3) types), becoming more clayey with depth. Often in depressions.
Wet soil	**N3**	20%	Variable soils, often fine textured, but generally in swamps or depressions subject to inundation.
Sand over clay	**G3**	20%	Surface soils usually more than 30 cm thick over tight mottled clay subsoil. Mostly on low rises.
Other	**B4/F2**	5%	Includes shallow loam over calcrete (B4) on rises and sandy loam on clay (F2) on flats.

Key features of the Land Unit are:

- Excessive wetness is the main issue affecting this Land Unit. 30% of the land is either swampy or wet for sufficiently long to preclude viticulture. A further 50% is imperfectly drained, meaning that part of the soil profile is saturated for several weeks at a time. Only the sandy and stony soils on rises are adequately drained.
- The majority of soils have poorly structured clayey subsoils (although in the cracking clays, the black types can be moderately well structured). Tight clayey subsoils exacerbate problems caused by waterlogging by further restricting effective root zone depth.
- Most soils are inherently moderately to highly fertile, but the most suitable soils for viticulture (from a drainage perspective) are mostly sandy, with low inherent fertility.

Land Unit CW7

Landscape This unit is on the western boundary of the region and comprises flat plains with 30-40% low stony rises and lunettes, and about 25% swamps, most of which are saline. Underlying sediments are clays, marls and limestones of the Padthaway Formation. Harder carbonate underlies stony rises, presumably indurated by more extreme moisture fluctuations than on plains.

Soils Most soils have clay loamy to clayey surfaces, sandy soils are rare. Deep dark gradational loams, with cracking clays account for most of the soils of the plains. Shallow soils on calcreted deposits are typical of rises.

Soil	Symbol	% of Unit	Comments
Deep gradational loam	**C5/M2**	30%	Loam to clay loam surface, more clayey with depth. Mostly on plains, a third of C5 soils in swamps.
Grey/brown cracking clay	**E3**	20%	Two thirds are on plains, one third in swamps where they are generally saline.
Shallow black clay loam	**B5**	15%	Mostly on rises, limited occurrences on plains.
Shallow sandy loam on red clay	**B6**	10%	Occurs on stony rises.
Shallow red loam	**B4**	10%	Occurs on stony rises.
Wet saline soil	**N2**	10%	Variable profiles, but all are wet and saline.
Sandy loam over clay	**F1/F2**	5%	Mostly on plains, F2 more likely to occur in swamps.

Key features of the Land Unit are:

- Although 30-40% of the unit comprises rising ground with well drained soils on calcrete or other hard carbonate (B4/B5/B6), the rises are scattered, so there are rarely extensive areas of these soils in contiguous blocks.
- The flats between the rises and swamps are imperfectly drained and marginally saline over much of their area, indicating low potential for viticulture. Not all soils are saline, but the presence of some salinity in flat landscapes suggests that future salinization is possible.
- The dominant soils of the plains are fine (heavy) textured, indicating high inherent fertility and high water holding capacity. However, clayey soils don't release their water as readily as sandy types, so a significant portion of stored water is unavailable (i.e. the soils have high wilting points). This indicates that it will be difficult to keep water up to vine demand.

Land Unit CW8

Landscape

This is the Naracoorte Range. The range is a massive ancient coastal dune comprising calcareous sands which have hardened near the surface into a limestone–like rock called calcarenite. Much of the land surface is covered by siliceous (i.e. mainly silica) sands, which have occasionally been reworked by wind into low dunes. Depressions within the range may be remnants of ancient Coorong-like lagoons, or they may be solution holes in the calcarenite cap. They generally contain more clayey sediments than the slopes. The largest of these in the Coonawarra Region has been included in Land Unit CW5, with which it has more similarity.

Soils

Although virtually the entire Land Unit is underlain by calcarenite, it is the siliceous sandy covering that gives rise to the majority of soils.

Soil	Symbol	% of Unit	Comments
Deep sand	**H3/I1**	45%	Two thirds deep sand (H3) and one third highly leached (podsolized) sand (I1)
Sand over sandy clay loam	**G2**	20%	Thick to very thick bleached sand over a more clayey (but friable and permeable) subsoil
Sand over clay	**G3**	20%	Surface sand usually thicker than 30 cm, with variable subsoil clay, tight to moderately well structured.
Shallow soil on calcrete	**B***	15%	Includes shallow sandy loam over red clay (B6), shallow loam (B3/B4), shallow sand over clay (B7/B8), shallow calcareous sandy loam (B2), and sheet rock. Limited to extensive surface stone is a feature.

Key features of the Land Unit are:

- Low inherent fertility, due to the predominance of sandy soils. The sands are generally bleached, indicative of absence of the clay minerals and organic matter needed for improved fertility status. The highly leached sands (podzols) are more infertile than the more common deep bleached H3 sand.
- Generally good drainage. The soils are either very sandy, or formed on porous or fractured calcarenite. These are highly permeable materials. Only on some lower slopes and depressions is drainage likely to be a problem.
- Deep potential root zones in the sandy soils, especially the deep and gradational sands (H3, I1 and G2). Generally only the upper 10-30 cm of the calcarenite in the shallow soils are hard enough to form a root barrier, so ripping usually increases potential root zone depth.
- Generally acidic surface soils in the natural state. Exceptions are the shallow loamy soils which tend to be neutral. Natural soil acidity is rapidly neutralized by irrigation water.

Land Unit CW9

Landscape

This unit is an elevated gently undulating landscape formed on sandy clays to clayey sands of Tertiary age (i.e. much older than the lower elevation plains to the west of the Naracoorte Range). There are isolated remnants of ancient coastal dunes, (similar to Land Unit WY3). Fine grained calcareous particles eroded from these dune remnants have been blown about the landscape, and leached into many soils. Small swamps are scattered across the landscape.

Soils

Over 90% of soils are texture contrast (i.e. sandy to loamy surface abruptly overlying a much more clayey subsoil). The key difference between this unit and Land Units WY4, WY6 and WY7 (which occur in similar locations), is the significantly higher proportion of sandy surfaced soils.

Soil	Symbol	% of Unit	Comments
Sand over clay	**G3/G4**	50%	Surface sand thicker than 30cm in G3, and thinner than 30 cm in G4. The two soils are equally common.
Sandy loam on clay	**F2/F1**	45%	80% have poorly structured subsoils (F2); the other 20% have well structured subsoils (F1).
Other	**M2/N3**	5%	Deep gradational clay loam (M2) and wet soil (N3) occur in lower lying areas and swamps.

Key features of the Land Unit are:

- The dominant sand over clay soils have low natural fertility due to the low capacity of the surface soil to retain nutrients. Building up and maintaining organic matter levels is also more difficult than on heavier soils.
- All the major soils (F2, G3 and G4) have poorly structured clayey subsoils. These restrict uniform root growth, thereby reducing effective soil depth. They also cause water to perch on the clay at the base of the topsoil, resulting in waterlogging during winter or following heavy rain or over-irrigation during the growing season. The G3 soils have thicker surface layers, so subsurface waterlogging has less effect on surface roots than is the case for the other soils. Winter waterlogging can restrict machinery access, or result in soil compaction. Summer waterlogging is less likely, but can have significant impact on root growth early in the growing season.
- Deep ripping or delving with gypsum incorporation are options, but typically results are variable.

Land Unit CW10

Landscape This unit is an elevated flat to gently undulating landscape formed on sandy clays to clayey sands of Tertiary age (i.e. much older than the lower elevation plains to the west of the Naracoorte Range). There are isolated remnants of ancient coastal dunes, (similar to Land Unit WY3). Fine grained calcareous particles eroded from these dune remnants have been blown about the landscape, and leached into many soils. Small swamps are scattered across the landscape.

Soils 80% of soils are texture contrast (i.e. sandy to loamy surface abruptly overlying a much more clayey subsoil). Shallow stony soils characterize the old dune remnants.

Soil	Symbol	% of Unit	Comments
Sandy loam on clay	**F2/F1**	50%	Mostly with poorly structured subsoils (F2), well structured subsoils (F1) are minor.
Sand over clay	**G3/G4**	30%	Surface sand thicker than 30cm (G3) 60%, and thinner than 30 cm (G4) in 40%. Occasional deep sand (H3).
Shallow soil on calcrete	**B4/B2**	10%	Includes shallow loam (B4) and shallow calcareous sandy loam (B2). Limited to extensive surface stone is a feature.
Deep gradational loam	**M2**	10%	Loam to clay loam surface, more clayey with depth.

Key features of the Land Unit are:

- The dominant sandy loam over clay soils are generally suitable for viticulture, but note dot point below.
- The majority of soils have poorly structured clayey subsoils (F2, G3/G4). These restrict uniform root growth, thereby reducing effective soil depth. They also cause water to perch on the clay at the base of the topsoil, resulting in waterlogging during winter (may affect seasonal operations). Potential for growing season problems in the event of heavy rainfall or over-irrigation.
- Sandy soils have low fertility. The sands are generally bleached, indicative of absence of the clay minerals and organic matter needed for improved fertility status.
- Shallow soils on calcrete are well drained, and root zone depth can be modified by ripping.
- The deep gradational loams are fertile with high water holding capacity. They are productive, but can cause excessive vigour.

Land Unit CW11

Landscape This unit represents the long, narrow flats between the ranges of Land unit WY1. They are the ancient beds of lagoons associated with coastal dunes, similar to today's Coorong. Swamps occur in the lowest lying parts, and much of the remainder is subject to inundation in wet seasons. Isolated low rises scattered across the flats are probably remnants of islands or reefs in the ancient lagoons. The sediments underlying the flats (and on which modern soils have formed), are typical of the present-day Coorong – mottled grey clays with interbedded sands, limestones and dolomites.

Soils The variation in soils is indicative of the underlying sediments (clayey, sandy or limestone), and the influence of sand blown in from the adjacent ranges.

Soil	Symbol	% of Unit	Comments
Sand over clay	**G3/G4**	35%	Surface sand thicker than 30cm (G3) in two thirds, and thinner than 30 cm (G4) in one third.
Shallow soil on limestone	**B***	25%	70% of B soils are shallow dark clay loam (B5), with 30% other shallow soils (B3, B6, B7), often on stony rises.
Sandy loam on clay	**F1/F2**	20%	Mostly well structured subsoils (F1), limited poorly structured F2 soils.
Wet soil	**N3**	10%	Occur in low lying areas. Saturated for significant periods, and include swamp soils generally inundated most of the time.
Other	**H3/M2/ E1**	10%	Include deep gradational loam (M2), deep sand (H3), and cracking clay (E3).

Key features of the Land Unit are:

- Waterlogging in wet seasons. Except in swamps, this is not usually a problem during the growing season, but can affect winter operations.
- Low inherent fertility of sandy soils. The sands are generally bleached, indicative of absence of the clay minerals and organic matter needed for improved fertility status.
- The shallow dark soils are fertile and often associated with a shallow water table. This may result in excessive vine vigour.
- The sandy loam over clay soils are well suited to viticulture where not in low lying sites.

4.4 References

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Landscape

5

Markus Pichler

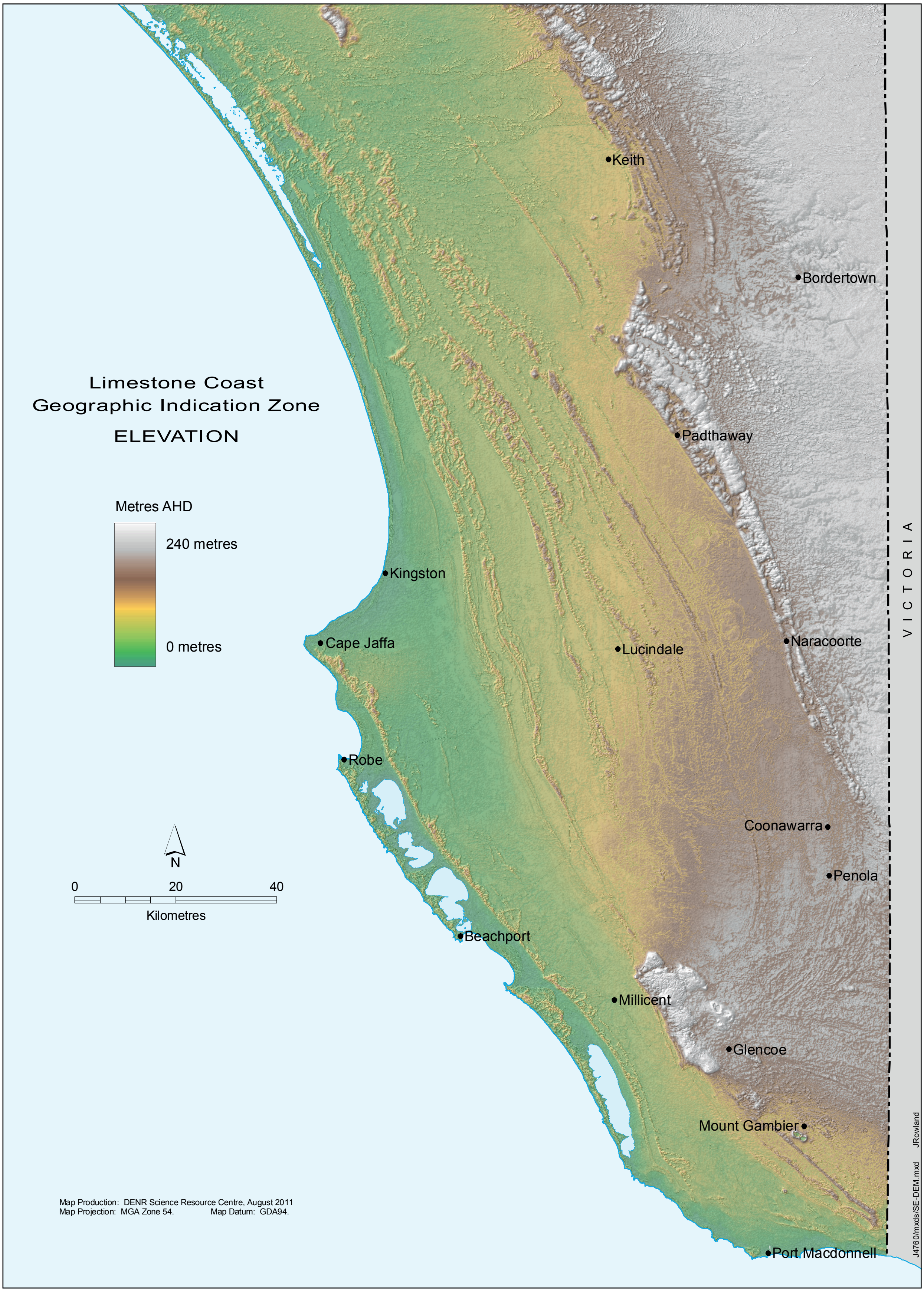

Figure 5.1. Elevation (metres Australian Height Datum) across the Limestone Coast Wine Zone.

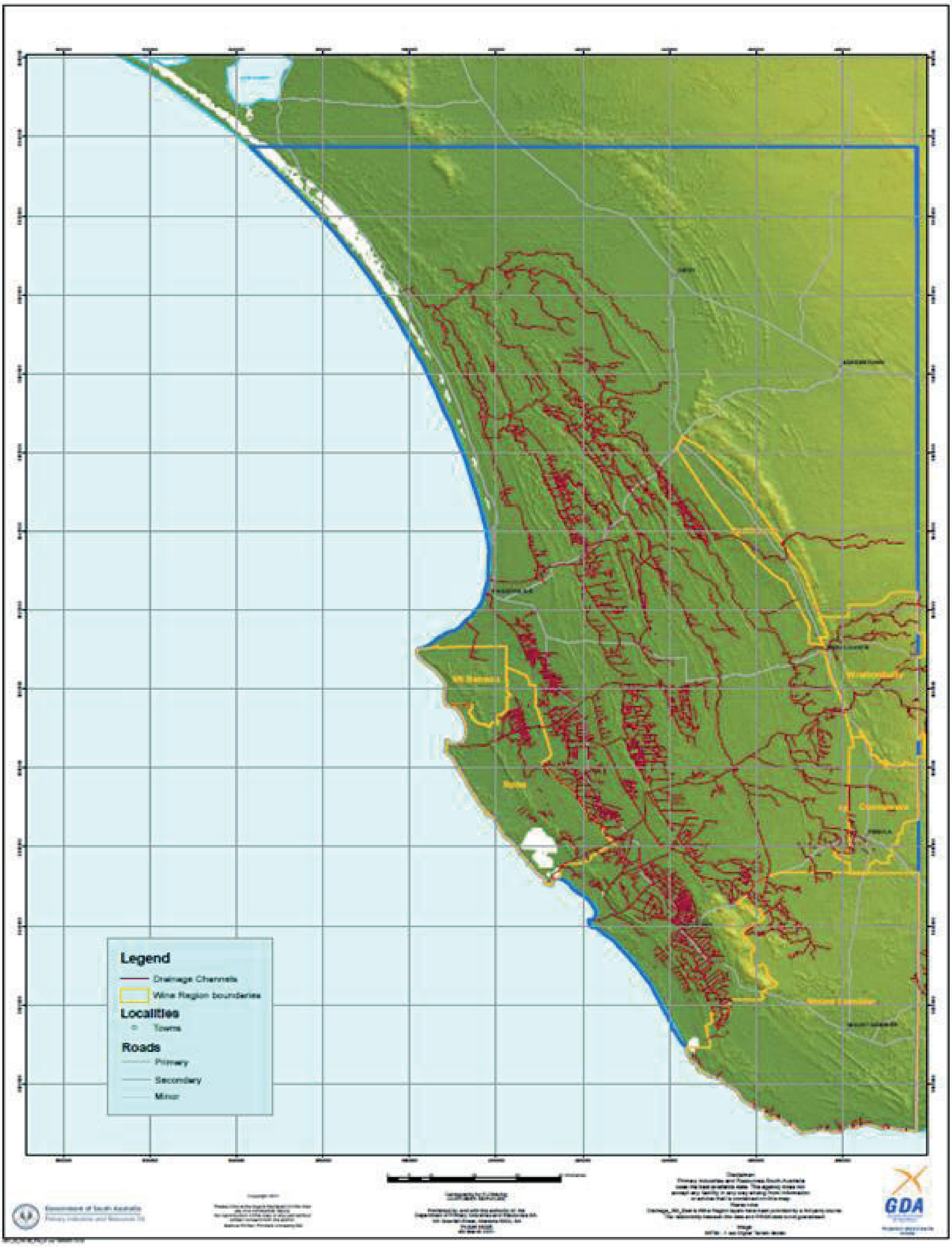

Figure 5.2. The Limestone Coast Wine Zone Boundaries, Terrain & Surface

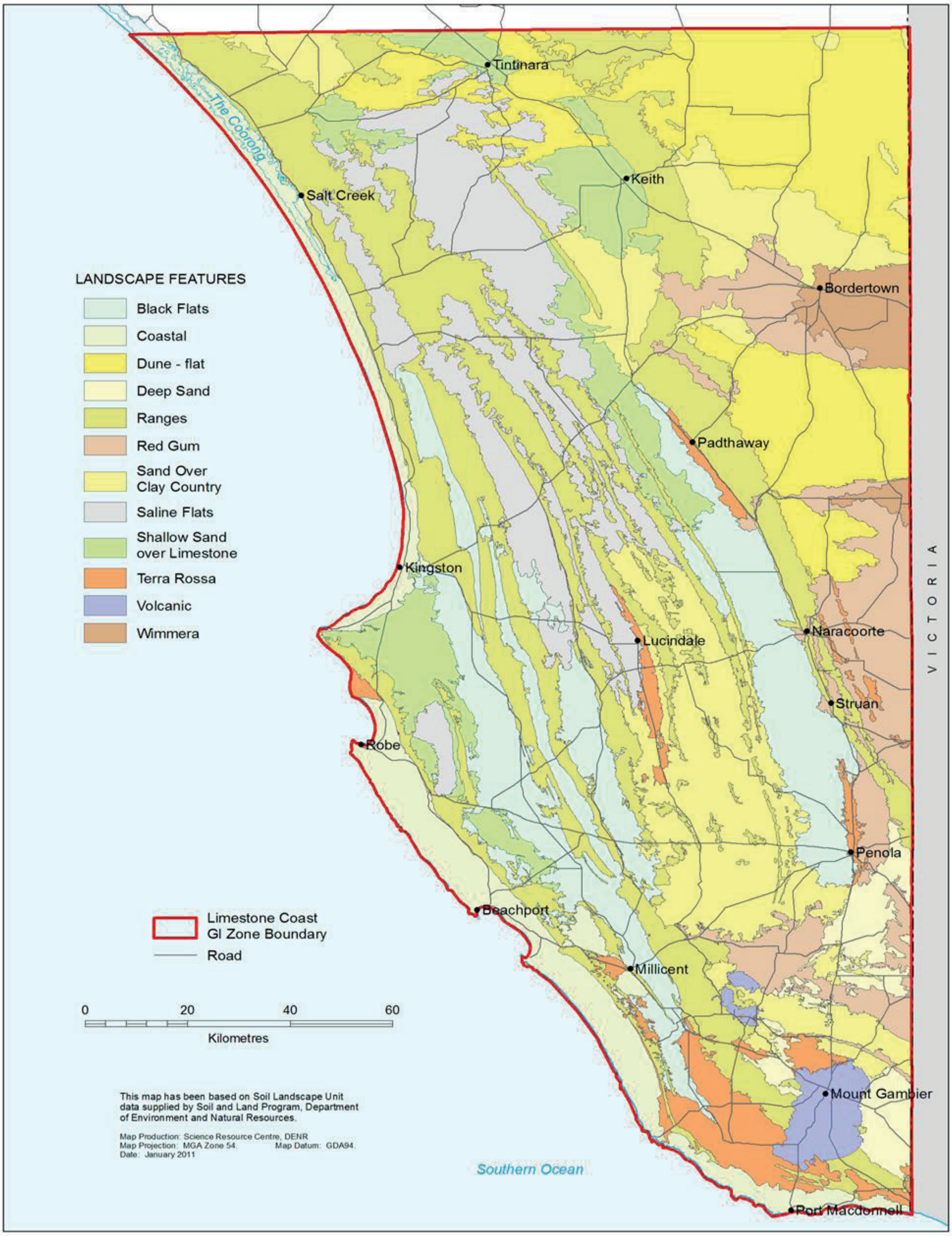

Figure 5.3. Landscape surface Features of the Limestone Coast Wine Zone.

Introduction

A land surface of low relief and generally subtle undulating features obscures the extensive geological history of the Limestone Coast region. From the northern areas, exposed basement granites give way to terrestrial and marine sedimentary deposits in the south. These sediments have been variably 'worked' by subsequent geological processes, including volcanics, to give a complexity of surface and near surface expressions.

Significantly, this has resulted also in the development of well utilised aquifer systems. The expansive and heterogeneous nature of the landscape provides ample opportunity to explore some of the important aspects of this setting that make it one of Australia's premium wine regions.

5.1 Dune Systems

In a pass from the S-W coastal zone northwards, the first obvious feature is the series of 'dune ranges' that lie approximately parallel to the coast, forming a somewhat gentle series of hills and inter-dune valleys (Figure 5.1). These extend well inland and mark the high sea levels related to global climate over the last 900,000.

As many as 30 sea level oscillations within the Limestone Coast wine zone are recorded in these stranded beach dunes. They provide evidence of the cyclic nature of past climates in the region. Each of the dunes is separated in time by an average of around 20,000 years, the older dunes lie north of Keith, and the most recent (~20,000 years old) lies in 50 -100m of water offshore (~100km).

Slightly curved in appearance they tend to merge with one another in the coastal zone and can be seen as sets of dunes. Sprigg (1979) describes these as 'abandoned Coorongs' and places them in 2 major groups, with the more landward set containing higher amounts of quartz sand and the coastal ranges comprised of more limestone deposits. The coastal dunes are termed 'Bridgewater type' and inland they are termed 'Wimmera type'. Topographically, they are separated by about 100m of relief. Inland of these sea-beach dunes, the wind blown component of coastal dusts has contributed to the calcreted and lime rich soils of the mallee.

Calcrete caps developed during soil formation trail to the leeward side and this has helped to preserve the original structure of the dunes. The lack of any significant surface drainage also helped, that is, the landscape just did not have the potential (relief with direct passage seaward) to erode and transport away any great amount of the built up dunes. Further, continent uplift (mostly across the Mt Gambier area), has enhanced the preservation of many kilometers of these ubiquitous deposits. More detail on these dune systems is provided in the geology section.

5.2 Lunettes, Lakes and Lagoons

As a result of the strong influence wind has on coastal sediment redistribution, lunette systems have developed across the existing beach dune systems (noted offshore also). Landward, these lunettes are sub-circular to crescent shaped. In the topographic lows between these dunes, lakes and lagoons, often ephemeral, act as sediment traps and natural wetland settings.

Drainage is a common feature of the region and an idea of the general layout of surface cuttings to allow it can be seen in Figures 7.1a, 7.2a, 7.9a. Two important features should be noted in this regard; the first is that drainage is north-westward into the Coorong as well as south-westward through cuttings into coastal waters and the second is that the dune systems (in particular the Woakwine ridge) act as significant barriers to southward drainage of surface waters.

5.3 More Landward Dunes – The Avenues

Of all these ancient beach dunes, the Woakwine Range is by far the the largest and most complex (internally). Landward beyond the Woakwine lies the west and east Dairy ranges, these pass south eastward becoming the Millicent, Kongorong and McDonnell ranges. Further inland are two more groups of dunes (3 beaches each) Murrabinna, Reedy Creek, West Avenue and then East Avenue, Ardune and Baker (400,000 years old and and 520,000 years old respectively).

Still eastward, the Peacock, Woolumbool, Stewarts and Harpers ranges are buried a bit deeper into the landscape, they are aged at between 560,000 years old and 630,000 years old), after this and further eastwards a wide "corridor' lies between the Harpers and Naracoorte – Black range. Black range is aged at about 680,000 years. At Hynam, east of Naracoorte, the next beach stand dune sits at higher elevation and around Keith 6 more dunes that may be associated deposits are dated at between 795,000 and 895,000 years old. Dune systems are shown in figure 6.5b and their elevation and age are shown in figure 6.5c.

5.4 Escarpment

In the Naracoorte area, we see evidence of the last significant faulting expressed at the surface. This, the Kanawinka fault (Figures 6.2a and 6.2b), running N-W to S-E (also parallel to the coast) has produced a visible fault escarpment of around 20m, although total vertical displacement is around 40m. The fault is down-thrown on the S-W side, lies between the east and west Naracoorte ranges, and is somewhat obscured by the dune systems, which add a further 40m to local relief. Since this major faulting event, subsequent earthquakes have not produced any further vertical displacement. The overlying beach stand dune and river deposits are not faulted. Rather, it is the preceding Gambier limestone deposits that have been displaced and then somewhat covered by later sedimentation.

Throughout much of the region (mostly S-W of the Kanawinka fault), where the surface has fallen into shallow cavities (roof collapse), sinkholes may act as windows into the groundwater, or, if above the water table, open caves. They can also be a trap for the unwary, as many a fossil deposit attests. The Limestone Coast wine zone is famous for its cave complexes formed within limestones. A visit to the World Heritage listed Naracoorte Caves Conservation Park (NCCP) will give insight into both the underground nature of the region and the past habitats and wildlife of the area.

5.5 Volcanics

Although much of the Limestone Coast wine zone is of low relief, it is noted for several surface expressions of relatively recent volcanic activity (newer volcanics). In Mt Gambier, roadside cuttings show the texture of the ash deposits from the last explosive eruption. They present as surge beds with volcanic 'bombs', including large and small clasts of olivine basalt, limestone, and clay bed material (Figure 6.5b). These types of volcanoes (maars) are formed through explosive reactions of magma with groundwater. Ash deposits are noted for a radius of about 8km around this regional centre (max. elev. ~ 160m).

The Mt. Gambier complex is only one of 20 or more volcanic sites across two zones in this part of South Australia, along with Mount Gambier Gambier is Mt. Schank (14km S of Mount Gambier), this volcano differs through having a dry base in its two main craters. Regionally separated and N-W of Mount Gambier lay a series of three vaguely linear expressions of eruptions, these occurred along fissures in the crust. They provide local topographic highs and have been partly covered by dune formation. Lakes Leake and Edward occur in craters formed by these eruptions.

As continental uplift continues and a strong thermal gradient exists in the region, these volcanics are not considered extinct, merely dormant. The most recent activity is believed to be around 4,600 years ago (carbon dating of organic inclusions in ash beds), this sits well within the timeframe of human occupation and legitimises the dreamtime legends of local aboriginal tribes that speak of doused campfires and the moaning voices of bird spirits. Incidentally, the occurrence of high temperature rocks at relatively shallow depths is also a source of interest to geothermal energy prospectors (Panax, 2009).

5.6 Northern Margins

The onshore margins of the area are fringed by the Padthaway ridge in the N-W, running approximately from Cape Jaffa through to Naracoorte, the Kanawinka fault, extending from approximately Naracoorte towards the S-E and beyond the Victorian border and the Dundas plateau, also eastward over the state boundary (Figure 6.2a).

Although granites are exposed right across the ridge zone from Kingston to Keith, the best and greater proportion of outcrops are seen just north of the Padthaway wine region boundary. The Padthaway green granite (geologically the Marcollat granite) is a Cambro-Ordovician intrusion (~480 million – 440 million years ago) that is mostly obscured by sediments of the Murray basin. This ridge separates the Murray Basin from the southerly Otway basin, within which, much of the Limestone Coast wine zone lies. To the south of the Padthaway ridge major sequences of sediment have been deposited over these basement rocks.

Subsequent weathering and erosion has contributed to down-slope sedimentary basin infill and therefore, modern soil formation. Soils of the more northerly parts of the Limestone Coast wine zone are sandier as a result of weathering of granites in this region (Landscape surfaces are shown in figure 5.3).

5.7 References

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Mount Benson Wine Region

Wrattonbully Wine Region

Geology

6

Markus Pichler

Introduction

Geological processes determine the way landscape is expressed in terms of topography, rock types, soils, drainage, infiltration, runoff, recharge and groundwater characteristics. Large and small scale geological processes impact on viticulture, consider slope and soil type as the result of these processes.

The Limestone Coast wine zone of south east South Australia hosts a landscape derived from the break-up of Gondwanaland, whereby the separation and movement of the Australian continent away from the Antarctic continent (Figure 6.1) produced a seaway (the Southern Ocean) Basins associated with this new continental margin became subject to sedimentary infilling. It is upon these varied deposits that the Limestone Coast wine zone has developed. Central to this area is the Otway basin, more specifically the westernmost portion, termed the Gambier Embayment (Figure 6.2a) (Love, 1993; Tyler et al. 1995). The timing of continental separation is generally agreed to have been initiated around 158 million years ago (Norvick and Smith, 2001). This tectonic process is referred to as the rifting, drifting and drying of the Australian continent.

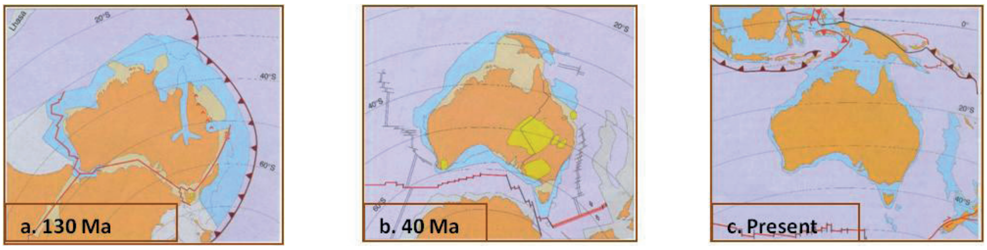

Figure 6.1. Development of the Otway basin, within which the Limestone Coast Wine Zone lies, is initiated about 158 million years ago (a) and is linked to global climate changes. Land contact is maintained with Antarctica until around 40 Million years ago even though rifting (splitting) was well developed(b). After this, the sea floor spreading rate increased and the southern seaway opened up. This allowed the development of the Westerly circumpolar current, the isolation of Antarctic climate and a twin hemispherical global climate regime(c). To this day the Australian continent moves northward at a rate of about 8cm /yr. (Li and Powell 2001). Image courtesy of Elsevier Publishing.

6.1. Basin boundaries

The onshore northern margin of the Otway basin is marked by the Padthaway ridge (Figure 6.2a), situated from Cape Jaffa through to Naracoorte. The deeply eroded granite of this ridge provides a boundary to the thick sediments deposited to the south (Morton, J. 1995). These igneous rocks (about 500 million years old) present as attractive green granite suitable for decorative building purposes and are well exposed in the Padthaway region.

Southwards from Keith, major sequences of sedimentary deposits lay over the top of these granites and associated metamorphic rocks (rock altered by pressure and temperature during the granite formation and upwelling). In the north and to the east these rocks are exposed as the Padthaway ridge (Figure 6.2a) and the Dundas plateau (Victoria).

Granite, as a relatively harder rock, often stands above surrounding countryside that is underlain by deposits more subject to weathering and erosion, and so throughout the north-western part of the Limestone Coast wine zone, outcrops of granite can appear as 'whalebacks' (see surface geology map Appendix G). During earlier geological periods, when sea level was much higher these intrusions formed a series of granitic islands, an archipelago if you like, which probably served as a barrier between the Southern Ocean and the coast. Sediments that were already in place were metamorphosed as these granites pushed their way up from deeper in the earth. The resultant rocks (Kanmantoo group) are often expressed as micaceous schists (flakey minerals in a wavy textured and layered rock, often derived from mudstones) and these can be recognised in deeper drill holes of the northern parts of the Limestone Coast wine zone.

6.2. Faulting

The lower south east has undergone different episodes of faulting. Seismic studies show a complexity of step-like structures (half graben) that extend well offshore (Panax, 2009; Norvick and Smith, 2001), and which reflect the stresses that this part of the crust was under during periods of sediment accumulation as continental separation continued. In addition, stresses and faults were associated with the Australian continent as it was 'added to' on its eastern margin, and later, as regional thermal uplifting occurred. Thermal uplift is a well recognised feature of the geology of the south east of Australia. In many places, the crust is relatively warm at shallow depths (a steep thermal gradient); this comes about through crustal thinning during continental separation and the persistence of volcanics in the region (discussed later) over recent geological time. Some parts of the Limestone Coast wine zone are more buoyant and slowly rise in relation to the surrounding countryside.

Kanawinka Fault and karst development

The Kanawinka Fault (Figures 6.2a, 6.2b) gives the Gambier Embayment its present north eastern boundary and topographic high. Oriented N-W to S-E, and nearly parallel to the coast, this fault had its last significant movement before the stranded beach dunes were formed and before the deposition of Pliocene sands (around 2 – 5 million years ago). These sands present as a thin veneer around Naracoorte, where (to the east) they form a layer between 2cm. and 1m thick. Below these, the Gambier limestone is markedly faulted. Pliocene tectonic activity (regional uplifting and fault development occurred in conjunction with continental compression during this time) would likely have provided more gradient (tilt) to the S-W, assisting the delivery of Murray basin sediments from a topographic high to the north-west, into this part of the Otway basin. Movement since this last major event has not produced any further vertical displacement, probably because of the broadly regional thermal up-warping centred south and east of the Kanawinka faultline.

The Gambier limestone (described later), along the Kanawinka fault, contains many kilometres of cave complexes that have formed as a result of dissolution by groundwater (White, S. 2005). Development of caves, conduits and other variously shaped cavities are controlled by groundwater movement, and the groundwaters physical and chemical characteristics.

Over time, weak organic acids leach into the porous rock and dissolve the calcium carbonate (limestone), where passage is available; the dissolved load is transported away, leaving behind a cavity. These take many shapes and come in many sizes, from multi-level cave systems and chambers to channels and conduits 4 km long. They form no distinct regional network as their occurrence is likely to reflect rock/water interactions (preferential chemical weathering along fractures and the more porous parts of the formation) and changes in the water potential (head difference) which controls the rate and direction of groundwater movement.

As regional uplift occurred and relative sea level fell, what is now Mosquito Creek, eventually cut through the west Naracoorte Range and the cave systems drained. Where the surface has fallen into shallow cavities (roof collapse) sinkholes may act as windows into the groundwater, or if above the water table, pitfalls and caves. These landscapes of cavernous limestone are termed 'karst'.

The town of Naracoorte lies on the Kanawinka fault and the nearby World Heritage listed Naracoorte Caves complex gives visitors the opportunity to see some of the karst nature of the sub-surface in this area. This site has been widely recognised for the extensive sediments and fossil deposits which record the change in landscape, biology and climate during the more recent geological past.

Tartwaup fault

The Tartwaup fault trends approximately WNW – ESE along a line just north of Mt. Gambier (Figures 6.2a and 6.2b.). In fact, it is a series of fault complexes which have in more recent times been noted to extend further westwards and well offshore. The Tartwaup fault zone has been described as a 'hinge' zone, or axis, with structures and deposits either side differing, in particular, sediment thickness is markedly different either side of the fault zone. In figure 6.2b it can be seen that the major faulting must have occurred after the deposition of the Dilwyn formation (discussed later in this section), in this situation the up-faulted northern block becomes subject to increased erosion and sedimentary deposit thinning, particularly adjacent to the fault. Further seaward, the overlying Gambier limestone attains greater thickness as the marginal setting provides more opportunity for the accumulation of marine deposits. Faults in the northern part of the basin tend NW to SE (with the lower 'down thrown' side towards the SW) but southward of and including the Tartwaup, faults tend to have their down thrown sides towards the south (SSW).

Figure 6.2a. – Limits of the Otway basin Gambier embayment (Drexel and Preiss, 1995). Of note here are the major faults Kanawinka and Tartwaup, the Padthaway Ridge, exploratory drillhole locations and the line A – A which marks the location of the cross section shown in figure 6.2b.

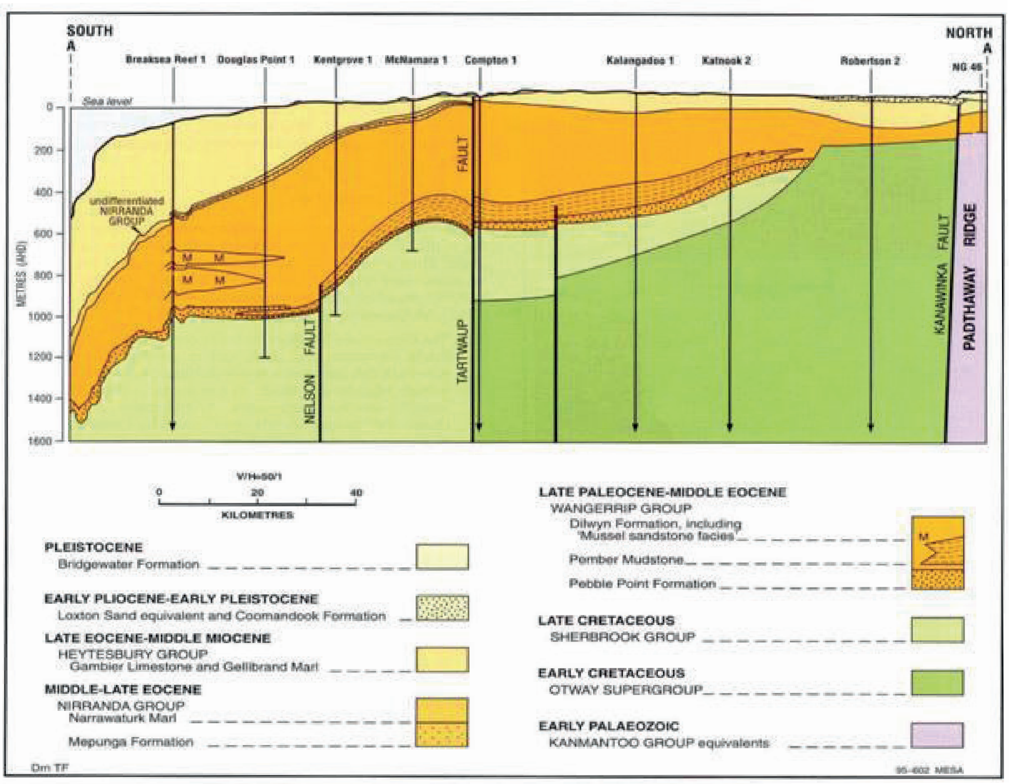

Figure 6.2b. North to South geological cross section of the Gambier embayment. Either side of the Tartwaup fault a change in the thickness of deposits occurs. (Drexel and Preiss, 1995). The line of this cross section is shown in the previous image. Image courtesy of Primary Industries and Resources South Australia.

6.3. Major Depositional Events

The basement rocks of the northern part of the Limestone Coast wine zone have an abrupt upper contact, suggestive of a significant erosional period before the first of the Otway basin group of sediments were laid down. These erosional contacts between depositional events, or unconformities, occur frequently within the stratigraphy of the region.

Cretaceous deposits
(145 to 65 million years ago)

Cretaceous deposits of the Limestone Coast wine zone can be described in two stages, those that occurred during separation of continents and those that were laid down after separation (Morton 1995). These stages are separated by the Tartwaup fault zone; this fault marks the boundary between the northern sub-basin (Penola) and the southern sub-basin (Mount Gambier). Although this is a somewhat simplistic explanation for what is quite a complex sequence of events that occurred over millions of years (for more detail, see DRET, 2011 and Panax, 2009). Of the two sequences, the Otway supergroup was laid down first and over that, the Sherbrook group. In their own right, these sandstone, siltstone, mudstones and shales form the lowest (and likely the most saline) of the Limestone Coast wine zone aquifer/aquitard systems. They reflect a depositional environment of rivers and lakes, then deltas with increasing influence from the coastal setting (stronger and more persistent winds and increasing deposition of marine sediments).

Tertiary deposits
(65 to ~ 2 million years ago)

The first of the Tertiary sediments are a continuation of deltaic mudstones which underlie the Wangerrip group (see geological stratigraphy in appendix G and margin figure 6.3a). Pember mudstone and Pebble Point formations provide a base for the important Dilwyn formation; it is this sequence of inter-bedded sands, gravels and clays that provides the region with an extensive confined aquifer system, the Tertiary Confined Sand Aquifer (TCSA).

The Dilwyn Formation

(55 to 48 Million years ago)

In broad terms, the Dilwyn formation (denoted by red bracket area of adjacent figure 6.3a) changes from more consistently sandy deposits inland to somewhat mixed sand and silt deposits in the coastal regions. The sandy type is often ferruginous (iron stained / cemented) and contains an iron sulphide mineral (pyrite). Inter-bedded within the Dilwyn formation are layers of carbonaceous and silicate muds and silts, glauconite pellets and rarely, shelly fossils. Around Kingston, coal seams also reside in this formation. The environment of deposition is suggested to be that of a riverine setting such as a delta that allowed discharge of this sediment to sea.

Seaward, the formation was deposited in a setting where the delta is extended into coastal bays. Distinctly sandy intervals occur within coastal Dilwyn formation ('Mussel sandstone'); these are the remnants of 'barrier bars' the same as exist in offshore environments today. The Dilwyn formation is exposed at 'Allen's' quarry NW of Mt Gambier alongside the Tartwaup fault (Figure 6.2a).

Above the Dilwyn formation lie the Mepunga sands (in green brackets of adjacent figure) and Narrawaturk marls that form the division between the Wangerrip group and the Heytesbury group (appendix G and adjacent figure), and also the confining layer for the Dilwyn formation, that is, the upper boundary of the TCSA. These marls and sands of the region are often associated with the mineral glauconite, notably green; it is a result of the diagenesis (mineral changes) of iron micas in a continental shelf environment. Glauconite can be found in sediments across a wide range of the Limestone Coast wine zone, quite simply because much of the geology is deposited in a transient marginal setting. As the sedimentary deposits have formed the greater part of groundwater resource in the Limestone Coast wine zone; it follows that Glauconite can be found in many of the drill-holes installed to access this water.

So far, in this section, we have moved upward from basement rocks through Cretaceous deposits and we are now well into the Tertiary age deposits (those that occurred after 65 million years ago). We move on now into what is the most significant of these more recent deposits.

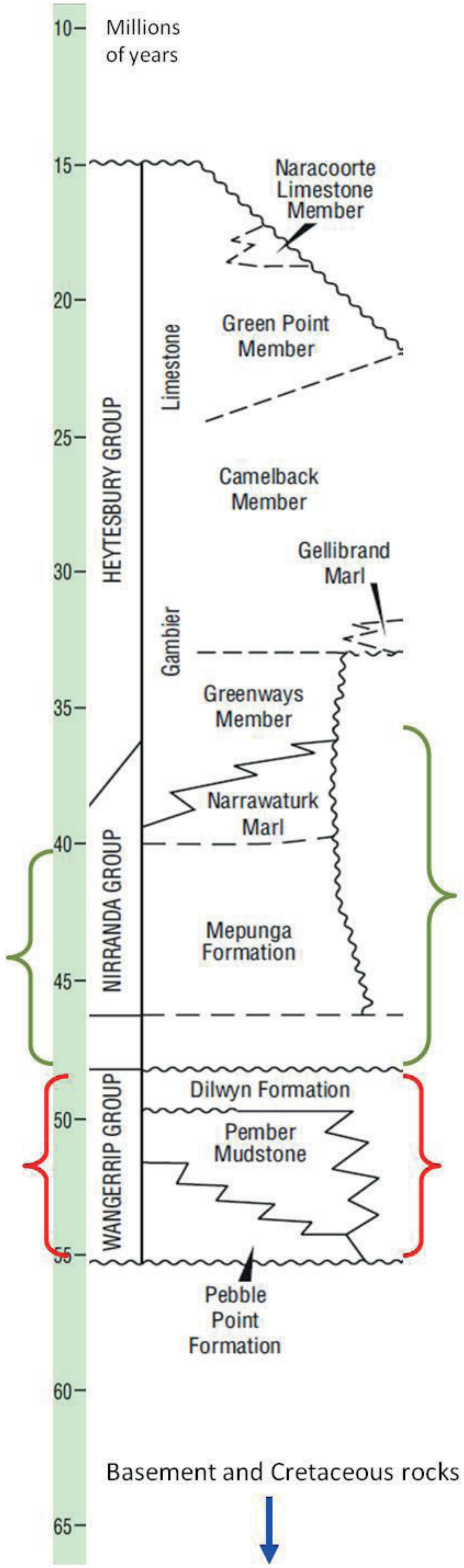

Figure 6.3a. Stratigraphy of the Tertiary deposits of the Limestone Coast Wine Zone (from White, M. 1996). Featuring the Dilwyn Formation. Further stratigraphy is available in the Hydrostratigraphic chart, Appendix G. Image courtesy of Primary Industries and Resources South Australia, MESA journal.

The Gambier Limestone (38 – 15 million years ago)

The Gambier Limestone is the major deposit that is synonymous with the Limestone Coast wine zone. The highly fossiliferous calcium carbonate unit is extensive throughout the region and varies in thickness and composition (noted in blue brackets in adjacent figure 6.3b). It is of high importance first as the prime source of shallow groundwater and then as a building material. In some zones associated with major faults, the limestone has become dolomitized (some of the calcium in the limestone has been replaced by magnesium) and this is used as a high grade magnesium supply for glass making, and as a sculpting medium.

White (1996) provides an excellent description of the Gambier Limestone and relates / compares it to previous studies. This work utilises the lithology of 26 petroleum exploration wells, and is quite detailed in its descriptions of, and the spatial extent of the three primary sub-divisions (Figure 6.3f and adjacent figure 6.3b).

The Greenways Member (shaded green in figure 6.3c) is named after the location used to describe it (Greenways 1 – SW of Lucindale, figure 6.3f), and is composed of lower and upper sections. The lower section is grey limestone/ marly limestone / marl with glauconite. In some locations this lower section may present as a more muddy brown limestone. Both sections are replete with marine fossils including, urchins, lace corals, snails and sponges, as well as quartz and chert. Some of the smaller fossil components of the upper section differ from that of the lower section and the mineralogy includes pyrite. The thickness of the Greenways member in Reedy Ck 1 (Figure 6.3f) is about 36m and offshore from Pt MacDonnell (Breaksea Reef 1) is about 128m. It sits atop the Narrawaturk marl with no erosional event between them (it's conformable), and they share similar characteristics and age, as well as grading into each other. They can be distinguished from one another by the Narrawaturk having a more grey / green colour tone. Both are likely to have been deposited in an inner to middle continental shelf position.

Usually, but not always, the Greenways member lies conformably under the Camelback member.

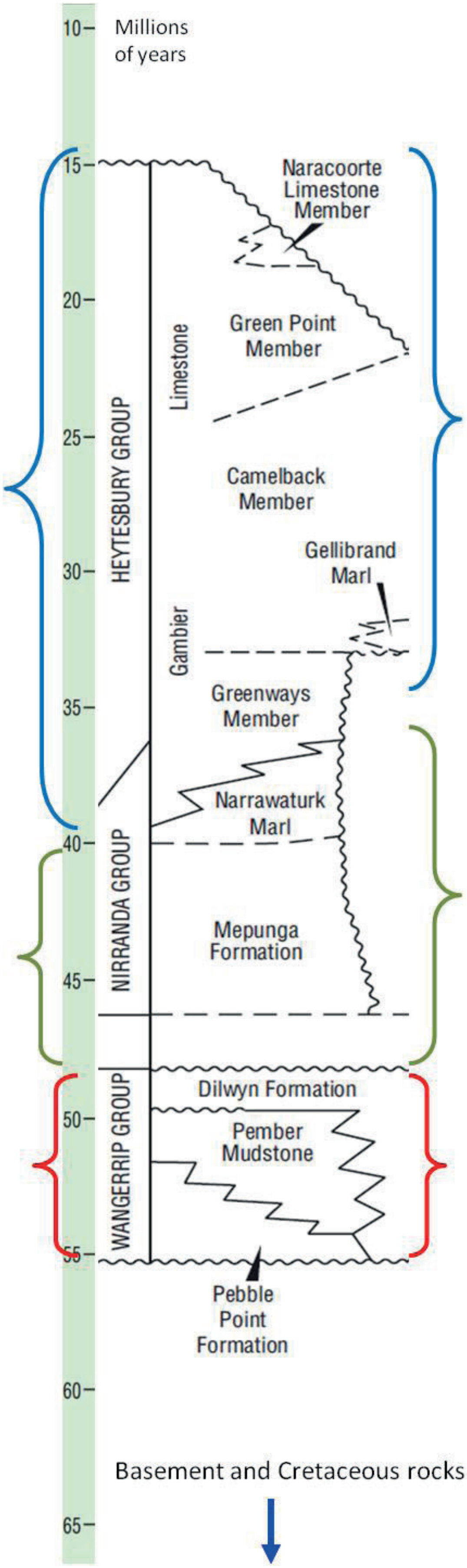

Figure 6.3b. Stratigraphy of the Tertiary deposits of the LCWR (from White 1996). Featuring the Gambier Limestone. Further stratigraphy is available in the Hydrostratigraphic chart, Appendix G. Image courtesy of Primary Industries and Resources South Australia, MESA journal.

The Camelback member (shaded brown area of adjacent figure 6.3.c) is named after the drillhole that contains one of the better representations of it (Camelback 1, near Lucindale, figure 6.3f). It is widespread and extends northwards into the Murray basin; White (1996) states that it is equivalent to the Clifton formation in Victoria. This member contains abundant lace coral fossils as well as clams, snails, sea urchins and corals. Wood, quartz, chert, glauconite and rock fragments are also noted.

Mostly, the Camelback is a seen as a white / off white or fawn coloured limestone, occasionally, grey. In some locations the base of the Camelback has a conglomerate/ coarse sand texture, but only where the Greenways is not present. That is to say, the Camelback lies unconformably on top of much older sediments (Figure 6.3d adjacent), or, to put it another way, the deposit that should have been between them is absent because it was eroded away before the Camelback was deposited. The Camelback varies in thickness from about 10m in Camelback 1 (Figure 6.3f) up to about 250m WNW of Mt Gambier in Burrungule 1 (Figure 6.3f), and like the Greenways, is suggested to have formed in an inner to middle continental shelf environment, excepting the conglomerate / sandstone base (deposited as sea moved up onto land). Often, the Camelback is the latest of the Gambier limestone depositional events, but it can also have another member lying over the top of it.

The Green Point member (shaded red area of adjacent figure 6.3.d) is named after the most eastern occurrence of it (Figure 6.3f). The member is rarely seen at depth, but crops out at locations between Bucks Bay and Green Point at the southern coastal extremities of the Limestone Coast wine zone. It's a grey limestone containing chert as well as lace coral, urchins, clams, glauconite, quartz and pyrite. White (1996) is tentative in descriptions of sediment thickness, presumably because of its limited extent. At its 'type' location, it is about 200m thick and lies over the Camelback member with no erosional event between. White also suggests that the Green Point has some characteristics similar to that of the Naracoorte limestone member discussed further on).

In Geltwood Beach 1, SW of Millicent (Figure 6.3f), the Green Point member lies over an eroded base of Greenways member. Evidently, a time break and erosion occurred between these depositional

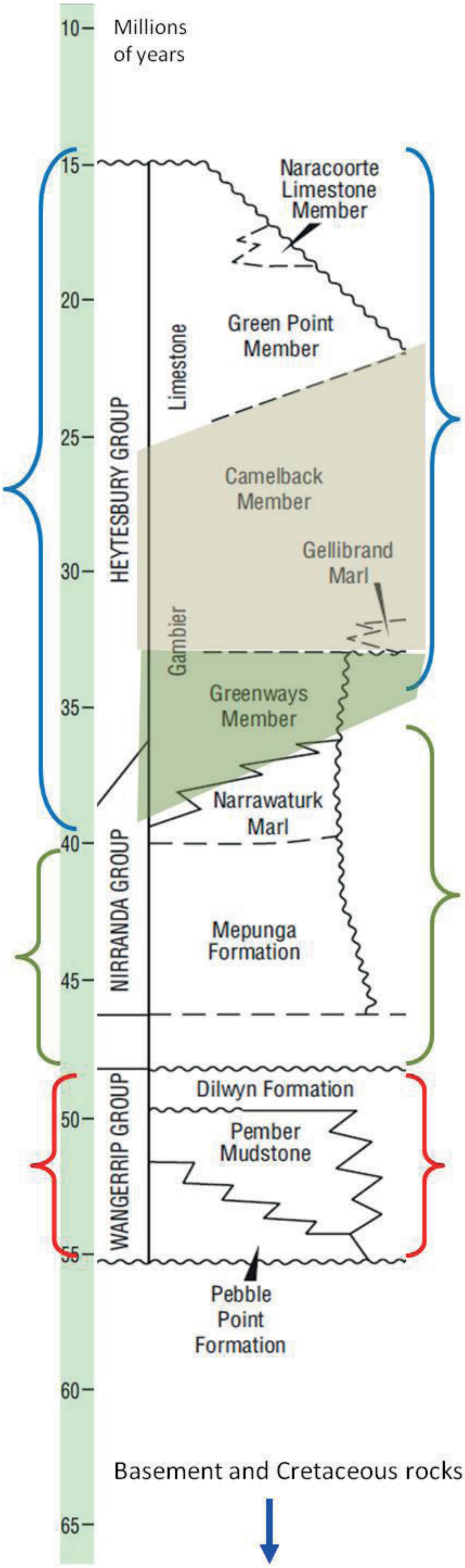

Figure 6.3c. Stratigraphy of the Tertiary deposits of the LCWR (from White 1996). Featuring the Greenways and Camelback members. Further stratigraphy is available in the Hydrostratigraphic chart, Appendix G. Image courtesy of Primary Industries and Resources South Australia, MESA journal.

events, said to have been in a setting that covered the whole continental shelf. North of Mt Gambier, the Green Point member is usually absent, it is not noted in the Naracoorte area, instead; the Naracoorte limestone member lies directly on top of the Camelback member.

The Naracoorte Limestone Member lies within the upper part of the Gambier limestone (denoted by purple shaded area within Green Point member, adjacent figure 6.3e), is about 6m thick and is found only in the northern parts of the basin (Drexel and Preiss, 1995). It's a coarse-grained, rubble dominated limestone that has been leached out through solution processes (such as described previously in cave formation along the Kanawinka fault) and contains many casts and moulds of molluscs and sea urchins.

The lateral shift of coastal environments during the deposition of the various elements of the Gambier limestone occurred over long periods of time and many changes in global climate and sea-level changes. At times this has been concurrent with tectonic and volcanic events, faulting / slumping and thermal uplift of the region. It should come as no surprise therefore, that the associated deposits are variable according to the sources of sediment, their modes of transport and the influences noted above. This has resulted in stratigraphic relationships that change markedly across the 20,000 km2 of the Limestone Coast wine zone.

It has been noted by drillers and land managers interested in Limestone Coast wine zone groundwater resources, that at times there appears to be systems of groundwater 'perched' above the usual water table depth. This is not surprising given the variable nature of the Gambier limestone (in all three physical dimensions). Less pervious layers exist within it, and at times these can retain some water above the usual water table depth. These systems are often temporary. It is likely that the resource users at close hand to their own particular site and with their own unique experiences are best suited to comment on the location and temporal occurrence of these perched systems. The broad nature of this study does not have the capacity to define their location or extent. Those wishing to install new bore holes are suggested to work closely with locally experienced drillers, previous land managers and adjacent landowners as well as the Department for Water.

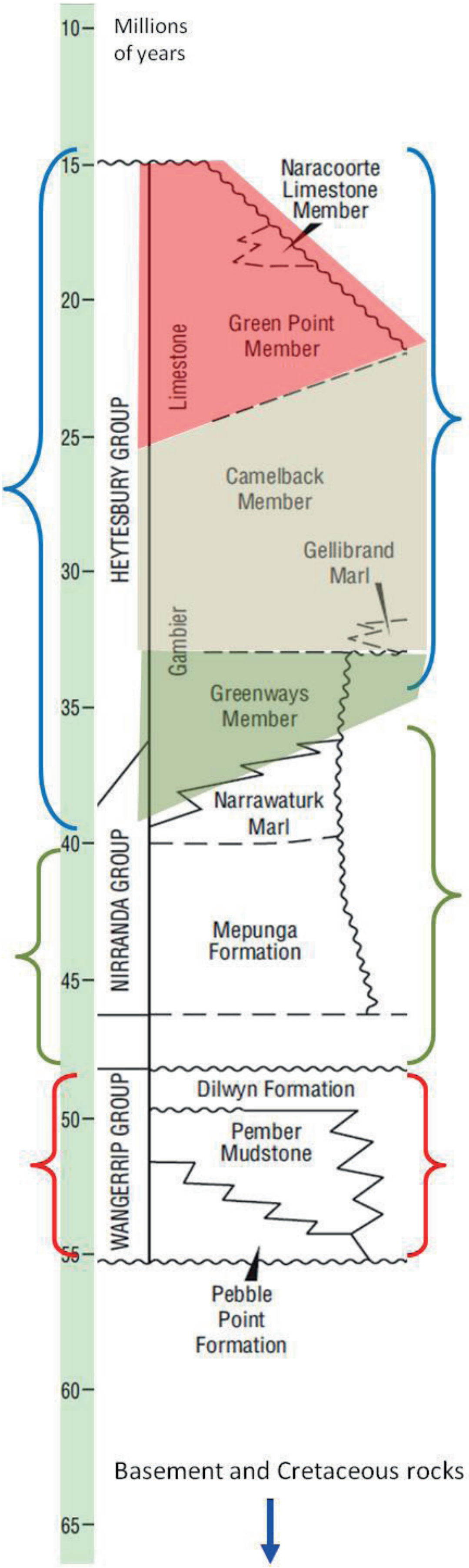

Figure 6.3d. Stratigraphy of the Tertiary deposits of the LCWR (from White 1996). Featuring the Camelback and Green Point members. Further stratigraphy is available in the Hydrostratigraphic chart, Appendix G. Image courtesy of Primary Industries and Resources South Australia, MESA journal.

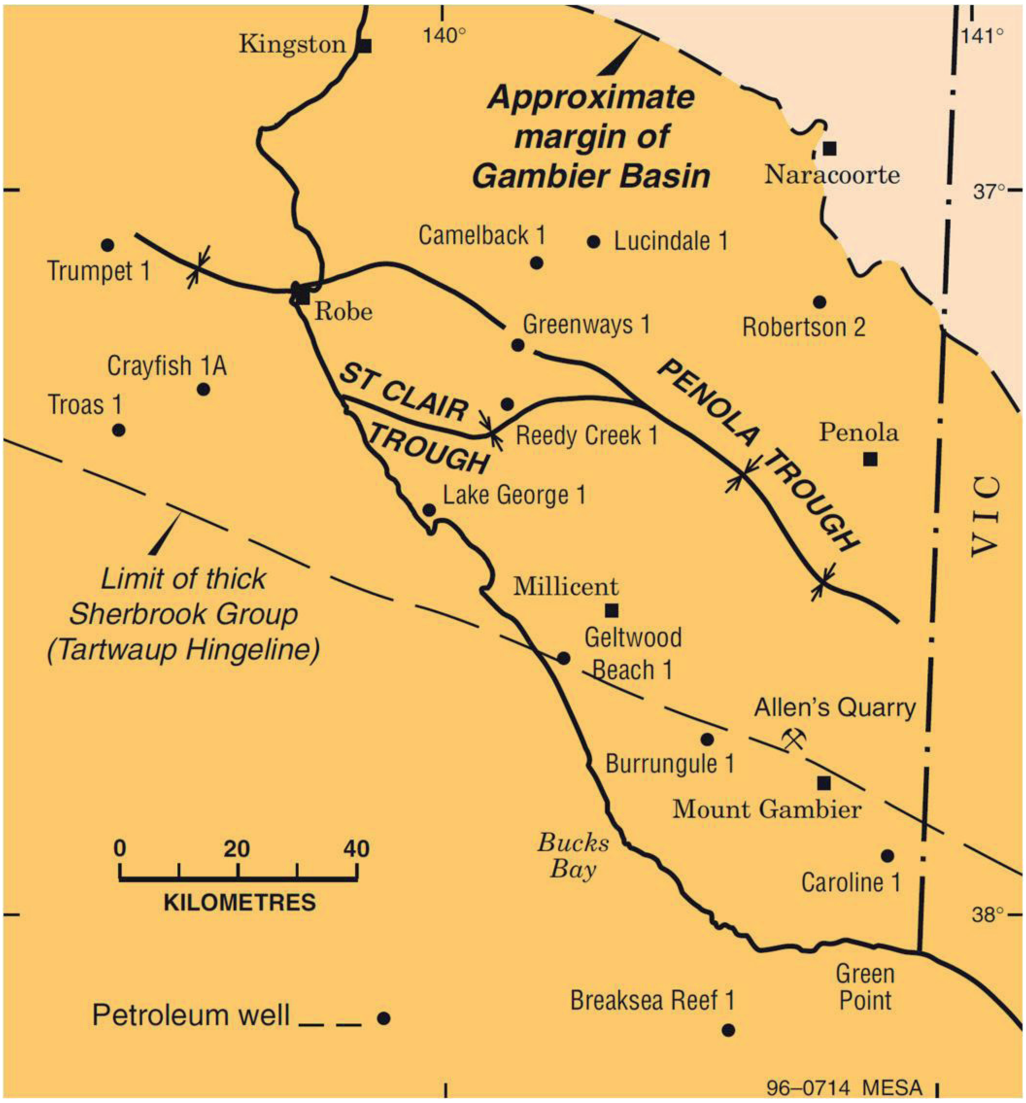

Figure 6.3f. Locality map for White, M. 1996. Showing petroleum exploration drillhole locations used for determining the depth and spatial extent of the Gambier Limestone (White 1996). Also shown are the locations and extent of the 2 main linear geological depressions (troughs). Image courtesy of Primary Industries and Resources South Australia, MESA journal.

6.4. Volcanics

Gentle uplifting of the region as a result of relatively recent volcanics has occurred (Quaternary newer volcanics – 2,000,000 to 4,000 years ago). Volcanic activity is now dormant, but because of continued continental uplift and a strong thermal gradient (high temperatures at shallow depth) in the region, these volcanics are not considered extinct.

Volcanic outbursts occurred in two stages; the first, at around 1.5 million years ago, resulted in the somewhat linear complex of fissure eruptions located to the north west of Mount Gambier (Figure 6.5b). Fissure eruptions discharge lava lengthwise along crustal fracture zones rather than from a localised point (as was the case for Mt Schank and Mount Gambier). The second stage has been dated at around 4,600 years (at Mt Schank) (PIRSA, 2002).

The Limestone Coast wine zone hosts two types of volcanic eruptions and one of these types has produced the region's most significant landmark and surface water feature, Mount Gambier and it's cobalt 'Blue Lake'.

The Blue Lake (Figure 6.4a) has been shown to be accumulating sediments for the last 28,000 years (Leaney et al, 1995), but dates based on isotope ratios of these sediments conflict with dates obtained from carbon dating the organic inclusions in the ash beds (on the volcano flanks). Leaney et al (1995) suggests there is a tendency for lake sediments to pre-date the eruptive phases that deposited the ash beds. The system is perhaps not so simple or easy to date definitively, as the conflicting information suggests. Refinement of methodology and extent of sampling as well as development of dating techniques is progressing and a more definitive set or sets of dates can be expected over time.

Still, this eruption period is very recent in geological terms, and well within the time frame of human occupation. Dreamtime legends of the local indigenous peoples include mentions of tribal relocation because of volcanic activity (PIRSA, 2002). Although it may not be possible to predict further eruptions, there are more recently recorded instances of earthquake activity that are likely to be associated with magmatic movements and the crustal adjustments that go along with its upwelling.

In 1897, a large earthquake resulted in spouts of water and quicksand eruptions from beaches in Kingston, Beachport and Robe, aftershocks persisted for months. Another significant earthquake occurred in the Robe region in 1948. Smaller earthquakes have happened since then, but a study of temperature below the surface suggests no large body of hot magma is ready to erupt. However, a resource exploration well near Mount Gambier has recently been used to study rare gases that reside at about 2,500m depth; they are suggested to be of volcanic origin. Given this, the classification of dormant, not extinct, seems quite reasonable.

Eruptions at Mount Gambier produced dark lava rich in magnesium and iron (basaltic) and at later stages ash and scoria. In the case of Mount Gambier, initial flows moved upward through the Gambier limestone and smaller explosive activities produced small maars (explosion craters), followed by lava flows and then a quiet period before groundwater found its way down into volcanic conduits and made contact with hot magma. This water became superheated and a large head of steam provided the pressure that led to larger explosions. These larger explosions and eruptive phases are what led to the large craters and ash deposits that are Mount Gambier and Mt Schank. The force of these explosions was large enough to rip up previous basalt flows and other surrounding rock, blast it upward and outward, the rocks landed in and became a part of the surrounding ash beds, these missiles are known as volcanic 'bombs' (Figure 6.4b). Sometimes these bombs are just a few centimetres in size and their innards contain attractive green crystals of olivine; sometimes they are just a piece of mudstone or limestone. Ejection of 'bombs' weighing up to 20 tonnes are noted. The beds of ash that contain these often present as a surge of layered ash that has hardened and fixed a flow-like texture, they are termed, surge beds.

Now, the Mount Gambier crater complex is both a window into the water table and a reliable source of potable water, as well a valuable tourism asset due to its locally high relief (mostly ~ 60m above the surrounds) and the changing colour of its Blue Lake. The 'sister' volcano to Mount Gambier is Mt Schank, and the eruption crater here presents quite differently to Mount Gambier as its base is dry. The floor of Mt Schank crater is above the water table.

Fallout from the volcanics (as ash) contributes to further complexity of stratigraphy in some regions of the Limestone Coast wine zone. It has also led to the development of remarkably productive soils. The radial extent of most of the ash fallout around Blue Lake is 8km.

Incidentally, it may be worth noting that as climate change raises sea levels, in the Limestone Coast wine zone, this is occurring in conjunction with land surface rise due to thermal uplift, so the rate of sea influx over land is different (less) than in many other places of the world.

Figure 6.4a. Blue Lake lies within the crater of Mt. Gambier and acts like a window into the groundwater. Different ash bed layers can be seen in the flanks of the 'maar' type crater. Image – Diceman 2004.

Figure 6.4b. Volcanic ash 'surge beds' containing 'bombs' and showing a flow-like texture. Road cutting in Mt. Gambier. Image M. Pichler 2011

6.5. Dune Systems – stranded beaches and lunettes.

Throughout the Limestone Coast wine zone, many low elevation linear hills are encountered, these are the result of sea-level high stands and their associated coastal deposits; they are stranded beach dunes, left behind as sea levels retreated and are commonly termed the Bridgewater formation.

These stranded beaches are set in 2 zones; inland, at higher elevations (and extending far beyond the Limestone Coast wine zone) is found a more silicate set of sedimentary deposits and at lower elevations (more coastal) the calcareous aeolianites (rocks derived of windblown dune sands) of the Bridgewater formation. These two zones are separated by about 100 – 120m of elevation. Most, excepting those around the Mt Gambier region, are slightly curved in shape. The coastal set has **10 groups of ridges** with all but the upper and lower most formed from multiple beach dunes (2-6). The dune formed during the last glacial period (~20,000 years ago) can be located offshore in about 50 -100m of water. Sprigg (1979) states as many as 50 of these stranded beaches remain as records of sea-level change, some well east and north of the Limestone Coast wine zone and many offshore. At Hynam, they are about 940,000 years old. Climate change and the linear stranded beach dunes relate well to each other through the Milankovitch cycles and the timing of these deposits can seen in the following figure (Figure 6.5a). Milankovitch cycles result from the combined effects of the earth's movement in relation to the sun. They have a significant effect on the amount of solar radiation that the earth recieves. Factors which combine to produce these cycles are the eccentricity, precession and axial tilt of the earth's orbit. Milankovitch cycles can be related to major climate cycles over recent geological history.

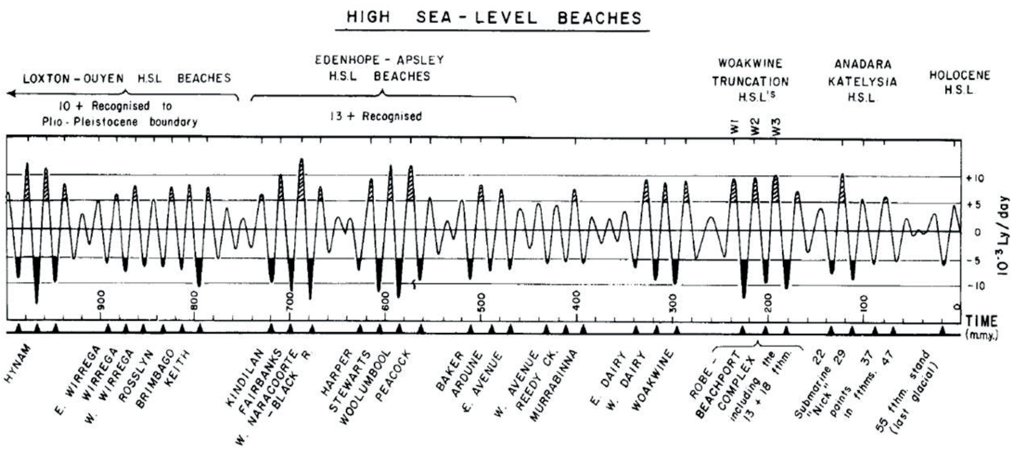

Figure 6.5a. Timing of the formation of the stranded beach dunes and intensity of solar radiation correlate well, low radiation levels match dune formation and glaciation. The more inland the dune, the older it is. Image from Sprigg (1979).

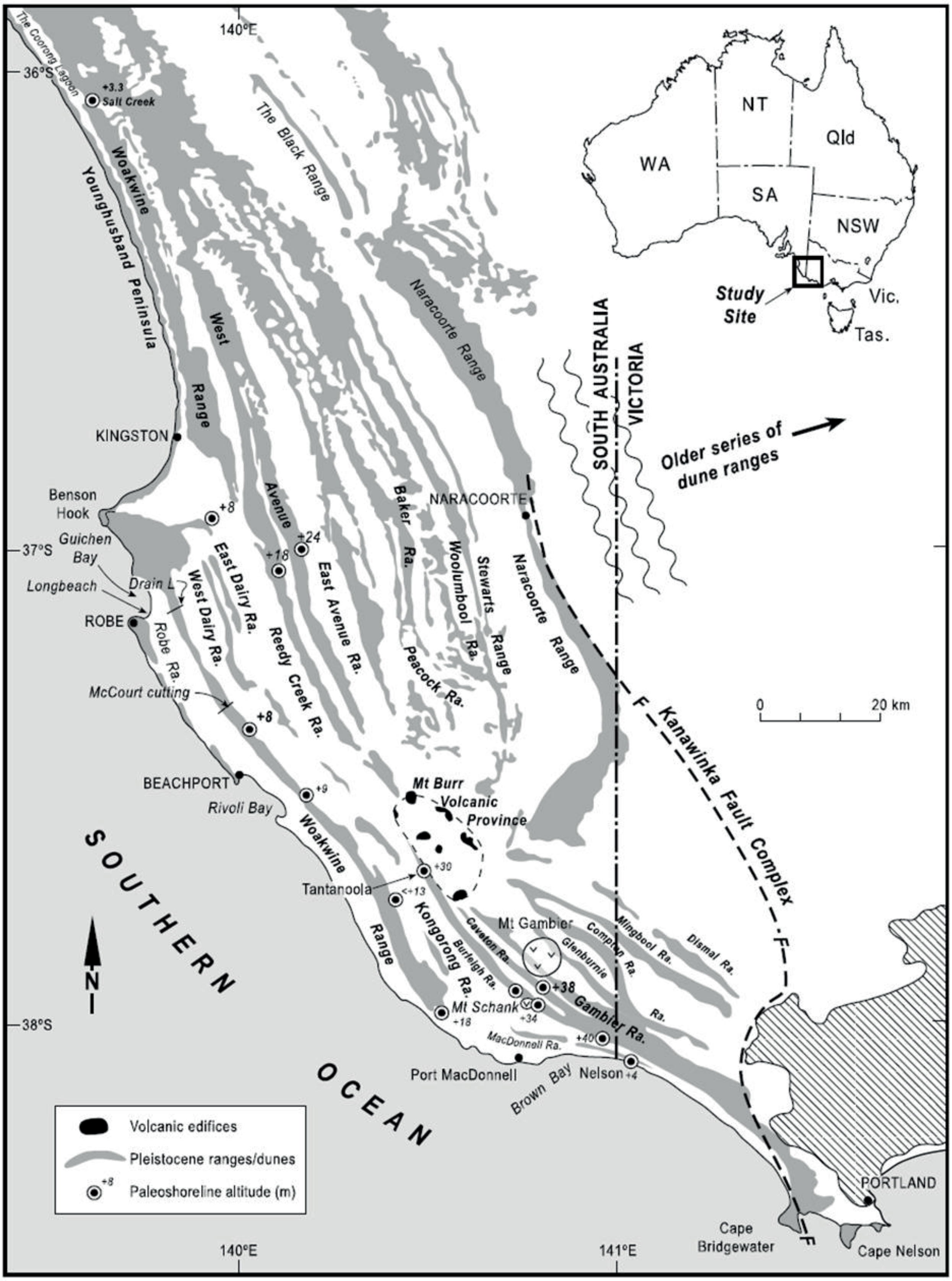

Figure 6.5b. Main dune ranges of the Limestone Coast Wine Zone. Murray-Wallace 2002. Image courtesy of John Wiley and Sons Publishing.

Since deposition and consolidation, the lower (younger) set has been covered in seawater when more recent global climates have resulted in higher sea levels. This has not markedly changed the nature of them. But more inland beach stands have been re-worked by subsequent sea level changes, they are older and have had more opportunity to weather and be redistributed by wind and wave action.

The higher level stands are ridgedwind blown deposits, comprised of sand, silt and clay, with occasional small amounts of marine mollusc. The lower set of beach stands is far more influenced by coastal deposition, they are cross bedded, whereby sediment is deposited on the slopes of dunes and as the dune moves /grows in a direction, subsequent sediment layers are not laid down parallel to older sediments, rather they are at angles to each other. They are also subject to erosion by strong winds and in places show evidence of slippage (avalanches). These lower dunes are quite shelly and sandy, with the seaward faces often more shelly. Frequently, the stands are fronted by 'bars' as can be seen in near shore settings today.

Bridgewater formation development was enhanced by glacial conditions, which produce drier and windier climates with lower sea levels. A significant component of the beach dunes is silicate sand, blown eastward from lower reaches of the Murray River, and from exposed sea floor and eroded beaches, this sandy component reduces south eastward and the more calcareous deposits harden into aeolianite. That is, the dunes become hardened towards the south east of the Limestone Coast wine zone as the sediments contain more limestone fragments of marine fossils that can be dissolved and re-precipitated around the grains that make up the dunes.

These drifting sheets of sands incorporated into the dunes show periods of accumulation that are presumed to match the cool, dry and windy phases of increased glaciation. The winds are likened to the westerlies which now occur in Patagonia. Changing weather patterns resulted in intensified south westerlies and associated wave activity during cold fronts, this increased erosion of sea floor and coastal deposits, allowing more sediment to be blown into dune systems. This aspect of sedimentation highlights the role of atmospheric / climatic conditions on the development of stratigraphy in the Limestone Coast wine zone.

Other dune systems merge with the linear stranded beaches; these are lunette (sub-circular) shaped aeolian (wind-blown) deposits. These dunes reflect the cyclicity of strong westerly winds and so can often be seen as extensions to the sides of major dunes systems, somewhat perpendicular to the main dune trend (some indication of this can be seen in figures 6.5.b and 6.5f. During dry times these westerlies also played a significant role in the deposition of related longitudinal dunes of the Lower Murray basin (immeadiately N-NE and in hydrogeologic contact with Gambier embayment of the Otway basin), which also supplied riverine sands under windy conditions.

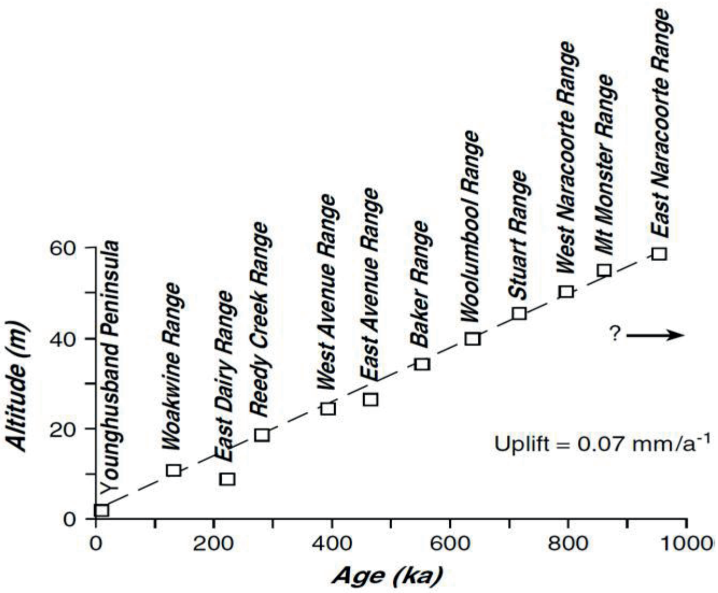

Figure 6.5c. Main dune ranges with ages and point elevations from Murray - Wallace 2002. See preceding image for locations of elevations recorded for each range. Image courtesy of John Wiley and Sons Publishing.

Lunettes can present as a complex resulting from periods of growth and erosion, as well as periods of neither. They can have internal zones of relict soil layers (palaeosols), and show periods of accelerated growth as well as containing lunette within lunette structures. Sprigg (1979) points to their development contemporaneously with the major dune systems. Their structure reflects a cold desert setting with high velocity prevailing winds, as is the case during times of peri-glacial climate. That is, the climate you might expect when situated close to the edge of glaciation (extending from the South Polar region). Lunettes are also found in offshore waters.

Landward, these lunettes are sub-circular and promote the development of ephemeral lakes, lagoons (recharge zones), claypans and siltbeds. Between and within many of these dune systems the lake systems act to retain sediment and this provides further variation in soil types, as the wet settings trap finer minerals (clays and silts) and organic sediments. Over the last few decades, many of these wet depressions have been drained by cuttings.

The Woakwine ridge (Figure 6.5b) represents one of the major barriers to surface discharge to sea and in order to provide more agricultural land, cuttings have been made through the ridge in order to drain the wetlands (see landscape section for image of drainage system); secondarily this is likely to have resulted in reduced recharge to groundwaters and a subsequent lowering of the water table. Inter-dune zones/avenues are also areas where emergent groundwaters and high evaporation rates can lead to highly saline land surfaces.

Over the last few million years the land surface has been uplifted by around 200m (particularly around Mt Gambier,), this has allowed the sequential preservation of thousands of kilometres of these linear dune/lunette systems. The lack of significant regional relief has meant also that surface drainage is reduced and the capacity for sediment removal minimised. Further protection and preservation of the dunes is enabled through the development of calcrete 'caps' formed during soil formation, these caps trail to the leeward side (inland side). Calcrete forms as acids of soils and rainfall dissolve particulate calcium carbonate (also within the soil), this dissolved material passes downwards through the soil profile and precipitates out to form layers at shallow depths. Often, these layers can be seen as bands on the margins of uprooted paddock limestone. This is a second type of limestone in the Limestone Coast wine zone, those which are formed through the accumulation of marine organic matter, like the Gambier limestone and to some degree the Bridgewater formation, are termed 'biogenic' (made of biological matter). Limestones formed in soil zone are termed 'pedogenic' (made in the soil of soil matter – and a 'ped' is an individually discernable small clump of soil).

Dune system stratigraphy (from drainage cuttings) reveal as many as 20 sequences of calcreted palaeosols (ancient soils); between these fossil soil layers are cross bedded sands, fine silt layers and beds of uniform fine calcareous loess (wind blown limestone silt). Each of these layers has been truncated (thinned through weathering and erosion) before the next soil layer is formed over it. Also noted in the cross sections are highly fossiliferous layers reflecting intermittent submersion and shallow water marine deposition. This submersion has added layers of biogenic material to the complex cross sections of these dunes (Figures 6.5d and 6.5e).

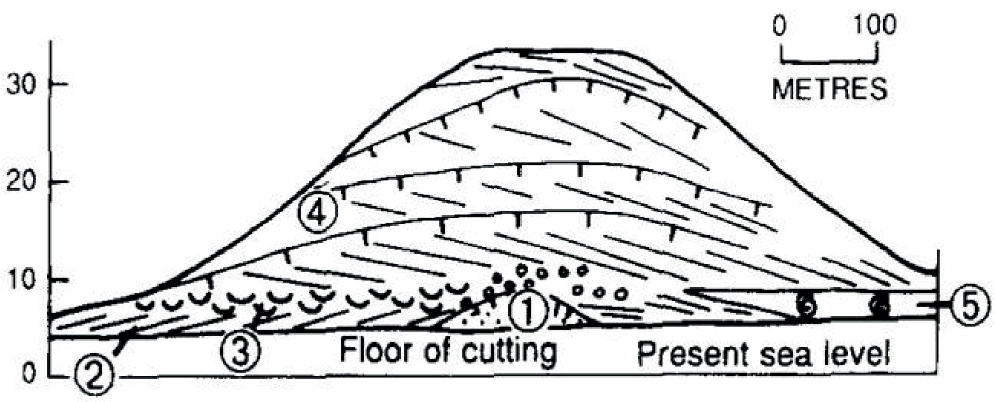

Figure 6.5d. Woakwine Ridge – simplified cross-section sketch – 1. Calcreted zone at depth. 2. Shallow Marine deposits. 3. Littoral facies. 4. Transgressive dune sequence. 5. Back barrier lagoon deposits. Image – Murray Wallace, 2010. Image courtesy of Elsevier Publishing.

The Woakwine Range has at least three of these shelly layers. The Robe dune also shows a series of truncated and calcreted palaeosol horizons, but Sprigg (1979) noted that the shelly dune layers were were yet to be recognized in here. Of all the aeolianite beach dunes, the Woakwine Range is by far the the largest and most complex (internally).

Using beach stand elevations, and given sea level oscillations of 120m., Sprigg (1979) determined uplift in the Gambier zone during deposition of the greater part of the beach stands. At around 700,000 years ago (between deposition of east and west Naracoorte Ranges, uplift was around 0.75mm/yr, at about 400,000 years ago (around Reedy Creek range deposition time) this rate had doubled to 1.5mm/yr, by the time the Woakwine Range was deposited, the rate had increased to ~ 8mm/yr. The continuation of uplift to the present is supported by knowledge of the seismic activity in the Beachport/Millicent region. Although later work by Belperio (1995) gives an uplift in the Guichen Bay area of only 0.07 mm/yr. So although the notion of uplift in the region is agreed upon, there are significant differences in the estimates of the rate of uplift in different zones of the Limestone Coast wine zone.

Since the separation of the Australian and Antarctic continents, deposition of coastal and shelf sediments between the northern and southern parts of the Limestone Coast wine zone has differed in terms of thickness, depositional timing, secondary basin faulting and their response to climate and sea level changes. These sediments along with local volcanic rock and ash deposits, sediments delivered from topographic highs in the east and wind-blown sediments from the west have also become sources of and locations of soil development, as well as storage zones, pathways and boundaries for groundwater.

Figure 6.5e. Shallow marine deposits within the Woakwine Ridge. Image - Belperio et al. (1995). Image courtesy of Elsevier Publishing.

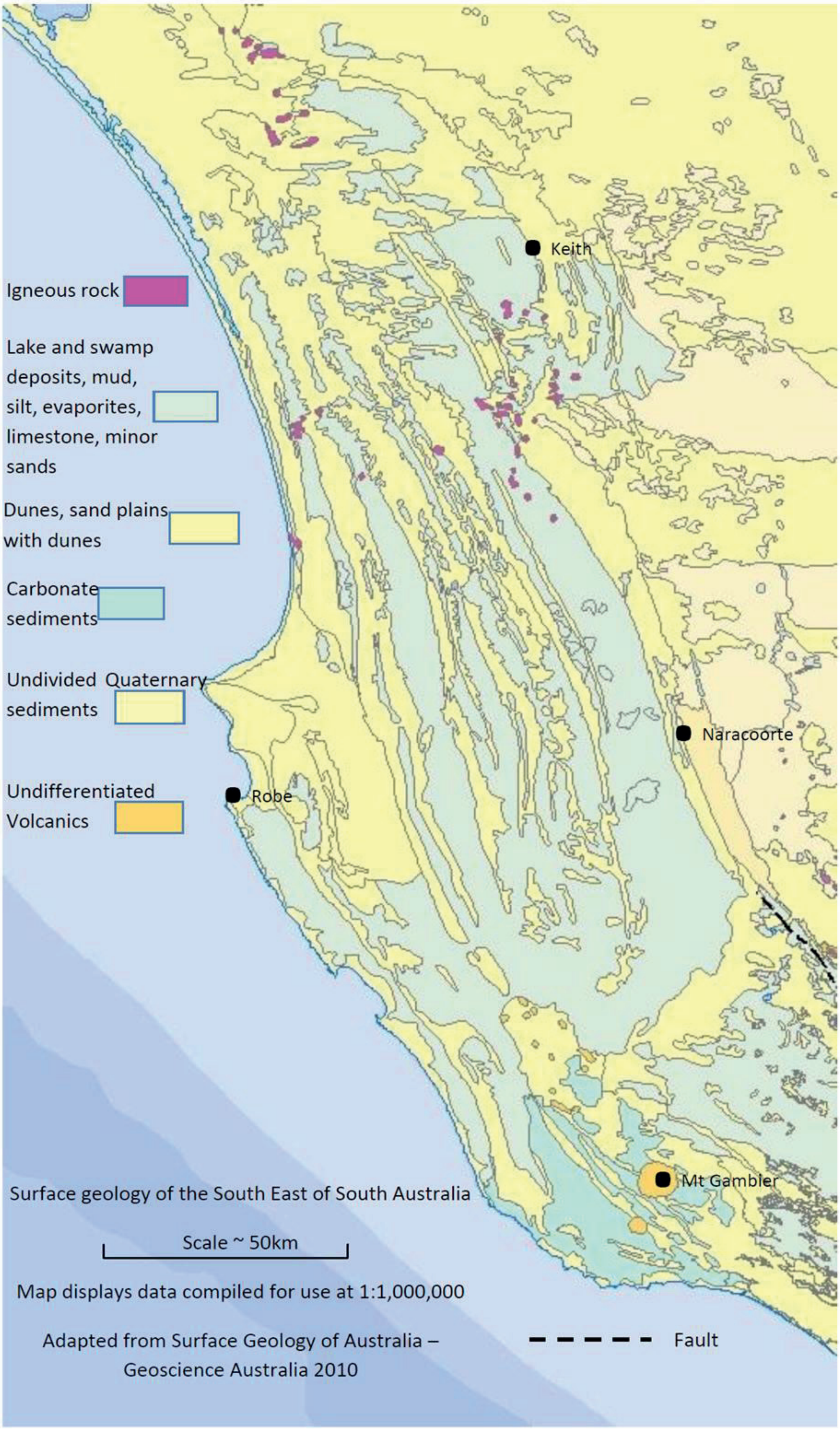

Figure 6.5f. Surface geology of the South East of South Australia. Image courtesy of Geoscience Australia.

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Hydrology

7

Markus Pichler

7.1. Natural Surface Flows

In the section describing major landscape features, it was noted that the Limestone Coast wine zone is of low relief, with only gentle gradients across the undulating surface. Along with highly permeable sediments and soils, this reduces the tendency for surface runoff. Further, the stranded beach dune ridges tend to act as barriers to seaward surface flow (to the southwest). Consequently, few natural surface waters flow through the region, despite annual rainfalls exceeding 800mm in the southern Limestone Coast wine zone.

The main streams of the region include Mosquito Creek Naracoorte Creek and Morambro Creek (Figure 7.1a); all have their origins to the east in Victoria. In 1941, L. K. Ward reviewed the underground water resources of the area and in doing so provided a description of the surface drainage provided by these streams, even at this time, installed drainage had altered what would have occurred naturally.

Morambro Creek was said to have filled Lake Cadnite near Frances (32 km NE of Naracoorte) then spread out into marshy land that has been cut to allow drainage into the unconfined aquifer through limestone sinkholes. Downstream and further westward the stream channel becomes more defined, passes through the Naracoorte range and directs flow to Cockatoo Lake, south of Keppoch. Beyond here Morambro Creek is described as being lost within lakes and swamps around Lake Roy (6km W of Keppoch). When rainfall was exceptionally high, runoff made it into Drain E of the South East Drainage Network (Figure 7.2a).

Mosquito Creek crosses the Naracoorte Range near Struan (12 km S of Naracoorte) after which the watercourse becomes less clearly defined, it then passes into Bool Lagoon and onward to join up with the Naracoorte Creek west of Lake Ormerod. The combined streams then move through Carey's Swamp (15km WNW of Naracoorte) and then onto Drain E according to Ward (1941), however Holmes and Waterhouse (1983), and the Dept. for Water (2010) show Bool Lagoon passing into drain M. A more complete and more modern perspective of the integration of natural and artificial surface flows can be gained through viewing a layout of the hydrologic monitoring network, (Figure 7.1a).

The natural surface drainage of smaller and more transient creeks and streams tends to be into the many swamps and lakes of the corridors between dunes. Before artificial drainage networks were instigated, these waters slowly drained towards the north west into the lower Coorong. Many of these swamps and marshes remain wet all year round; others dry up completely in summer, the natural persistence of marshy ground in many areas provides a habitat for wildlife, but this has been at odds with the opening up of agricultural lands through wetland drainage.

Figure 7.1b Bool Lagoon, source waters for this important wetland complex are provided through Mosquito Creek (DWLBC 2007).

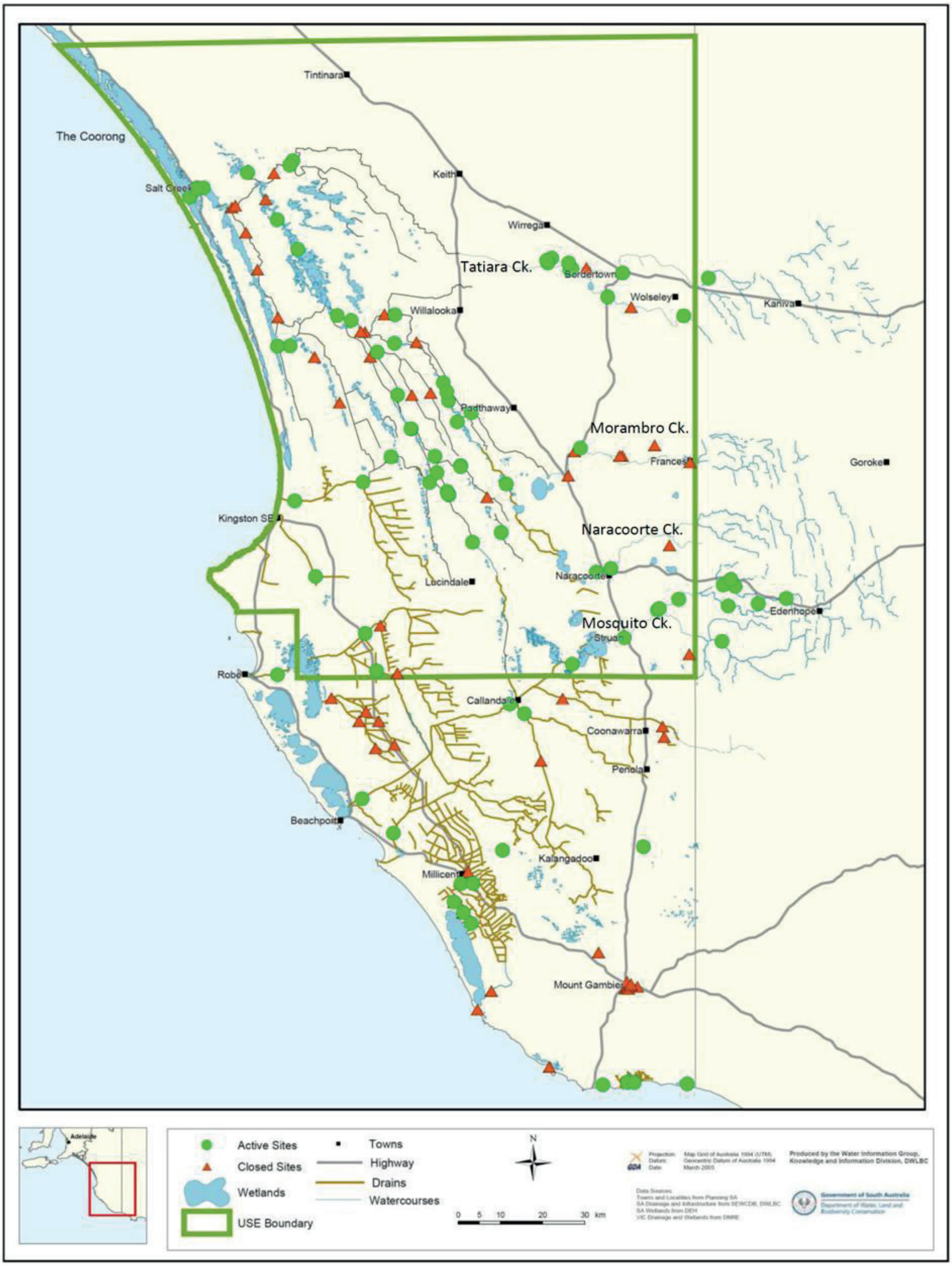

Figure 7.1a. Hydrologic monitoring network of the South East Region. The surface drainage network shows a complex of natural waterways and unnatural cuttings. These form an intricate network of south/southwest-ward drainage through the dune barriers and north-westward drainage along inter-dunal corridors that slowly drain into the southern Coorong (Stace, P. 2005). Image courtesy of Department for Water.

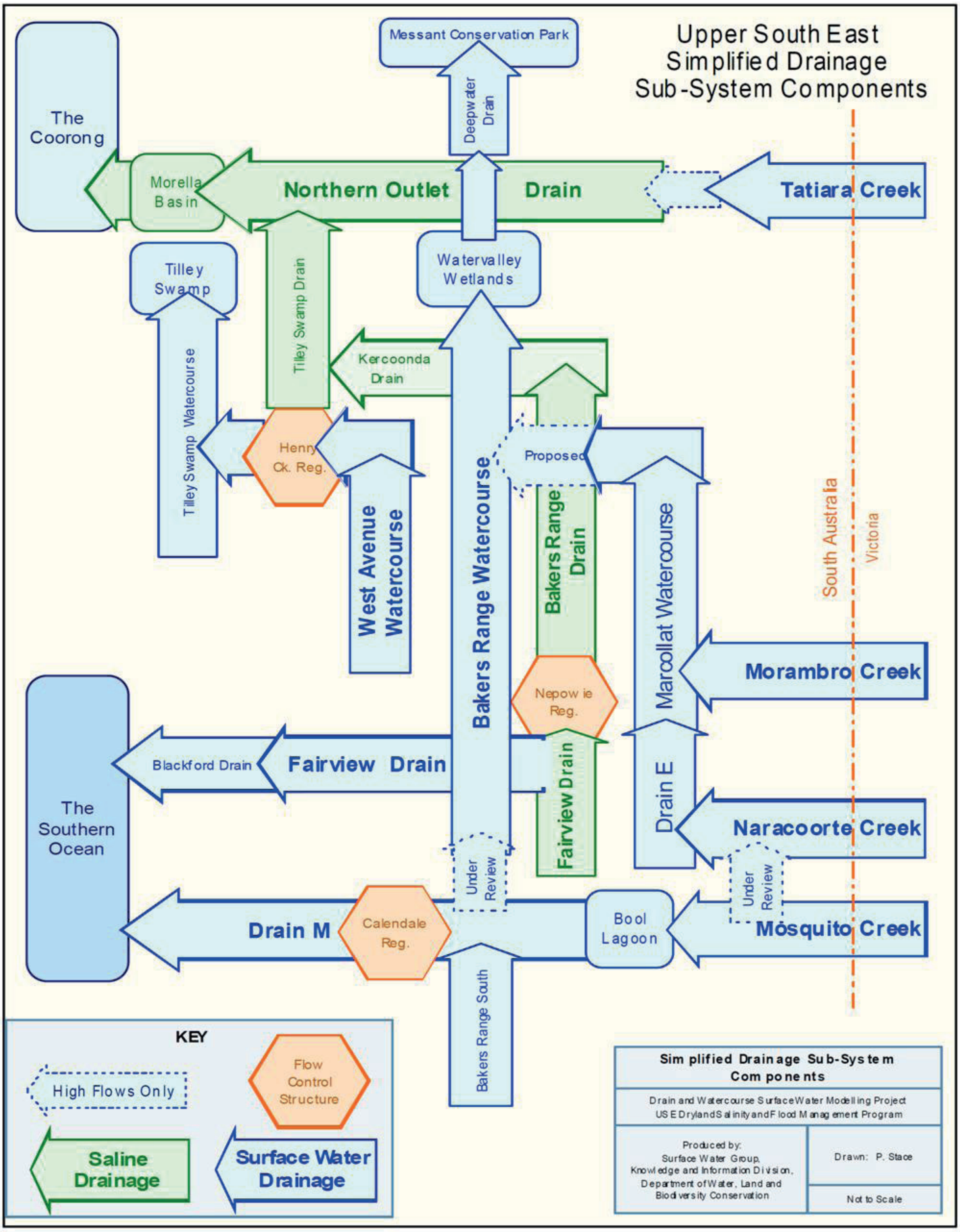

Figure 7.2. A simplified layout of the Upper South East drainage network. The system incorporates natural and installed drainage, and considers wetland maintenance as well as the need for flood mitigation. Department for Water, 2010. Image courtesy of Department for Water.

7.2. The Drainage Network

The apparent origins of the drainage of the south east region occur around 1860 (Holmes and Waterhouse, 1983), yet it was not until the 1940's that a concerted and collaborative approach to drainage was attempted. Natural drainage lines between ranges were enhanced and connected with new cuttings; the result has been described as a success in terms of reducing water-logged and seasonally inundated land, thereby increasing the available pasture. Much of the drainage network was developed between 1944 and 1970 under the supervision of the South East Drainage Board.

Several consequences arise out of the drainage program, of note are:

1. Increase in pasture
2. Flushing of salty waters from surface and soils
3. Reduction in natural wetlands and biodiversity
4. Reduced evaporation of standing waters (which concentrates salts)
5. Lowering of the water table
6. Reduced recharge to groundwaters
7. Recognition of the loss to sea of large volumes of resource waters (average ~ 160 billion litres a year since 1970)

As stated previously, the drainage network is extensive and complex, management of the land and water resources as well as wetland biodiversity is now enabled through drainage controls. Successful administration must consider the variable nature of rainfall and evaporation as well as groundwater levels and gradients. The complexity of the system is seen in virtually any image of the network (Figure 7.9a), however a schematic of the sub-system components, for the Upper South East Drainage System, provides a simplified example of the network (Figure 7.2).

7.3. Groundwaters of the Limestone Coast Wine Zone

Groundwater supplies are an integral part of life in the Limestone Coast wine zone; they are used to supply homes, townships, industry and irrigation. The extensive nature of the two primary aquifers means that supply is generally reliable; however increasing demand and competition for the resource suggests that management and monitoring programs will become more important in the future.

The geology section outlines some of the attributes of these aquifers and a stratigraphic column is located in figure 7.8d. Through geological descriptions one might determine where a particular formation is more or less likely to contain water. In basic hydrogeology, we learn that sands gravels and many types of limestone are very capable transmitters of water and therefore make good aquifers, whilst clays and marls along with bedrock become the layers above and below, through which little if any water can move, they retard groundwater flow (aquitards). Aquitards confine the aquifers below them and in the case of the Limestone Coast wine zone; a complicated sequence forms the aquitard that separates the two primary systems, the unconfined Tertiary Limestone Aquifer (TLA) and the Tertiary Confined Sand Aquifer (TCSA). Some idea of the depths of these formations can be found at the end of this section where Hydrogeological cross-sections for the 6 main zones of viticulture in the Limestone Coast wine zone are provided (Figures 7.9b to g).

Because water flow is from high head to low head, the flow directions of both systems are determined by the mapping of water levels, that is, the water-table for the TLA and the potentiometric surface of the TCSA. The potentiometric surface is that level up to which confined water will rise when it has been intersected by a well. So we have two sets of groundwater flow generally similar when considered on a regional scale, but each which its own smaller scale characteristics (Figures 7.4 and 7.7.).For both systems groundwater flow is directed radially in a west to southerly swathe.

7.4 The Tertiary Limestone Aquifer

So named because of the variable limestones that it is made of and the time period over which much of it was formed, it is the unconfined system that is wide spread across the region. Being unconfined, it has a water-table, which is usually at quite shallow depths (Figure 7.4). The shallow water-table means that well installations are less costly, but flow rates may be improved with deeper well constructions. Love (1991), suggests as much as 350 million mega-litres are stored in this aquifer, which is used extensively for industry and irrigation, however salinity is variable and where high recharge occurs the water may be subject to contamination. The water quality of both aquifers is discussed in the section (8) dealing with management of water resources.

Lithologically (in terms of rock and sediment types), the TLA incorporates the Gambier limestone and all deposits above this, including the Quaternary (2.6 million years ago to the present) Padthaway, Coomandook and Bridgewater formations. These later units tend to form smaller superficial and surficial aquifers that lay over but are in hydraulic contact with the underlying Gambier limestone. The Gambier unit is by far the largest of the TLA's hydro-geological features. The Padthaway formation occurs in the topographic lows between the dunes, and the Bridgewater formation is the dunes themselves. These upper parts of the TLA are used extensively for irrigation in the northern parts of the Limestone Coast wine zone (i.e. around Keith and Padthaway).

The sequence of rock types in the TLA ranges from grey / white quartz and limestone sands and clay with fossil remnants (Padthaway) to less hardened peat, sand, sandy clay and silt deposits. In the northern regions the sequence is less consolidated, quite fossiliferous and glauconitic, whereas in the southern regions the more consolidated deposits contain zones of fossiliferous and un-fossiliferous material as well as dolomites and chert. Overall, the sequence has a tendency to be more marly and dolomitic towards the base.

Towards the southwest of the region, within the TLA, a marly horizon acts as a leaky barrier to an underlying semi-confined system, but the extent and continuity of this hydrogeological feature is poorly understood.

Where the TLA makes contact with the Murray Basin (through the Murray group limestones) in the north east, the two systems are hydraulically connected, despite the unconfined system being thinner to the north and east than it is in the south. To the north of Mt. Gambier the TLA is thinner because of geologically recent sea-level rise, thermal uplift and subsequent 're-working' of the upper section.

The Gambier limestone can be described as a dual porosity medium, meaning that some of the porosity is a result of the initial deposition (primary porosity) and some is due to alterations since deposition (secondary). The primary porosity comes about because the original deposit was skeletal and provided large void space, but this has been variably reduced through carbonate cementation. Zones of inter-particle porosity also result from carbonate sand inclusions; these are likely to be the result of the re-worked (weathered and eroded) skeletal limestone.

Secondary porosity is a most interesting feature of the Limestone Coast wine zone hydrogeology generally. Fractures in the rock that occur along structurally weak zones cause preferential flow paths to develop, further dissolution of the limestone occurs as a result of weak acids in the water and the outcome is that the hydraulic properties are widely variable in this karst zone. Porosity of the aquifer taken from borehole samples ranges from 30% to 50%, but where it crops out at the surface and is somewhat weathered, porosity ranges from 49% to 61%.

Porosity is a measure of the aquifers ability to hold water, but transmissivity tells us about the capacity of the aquifer to allow water to move through it, which is more useful in practical terms. Pump tests have shown the transmissivity in these karst zones to range from 200 m^3/ day^{-1}/ m^{-1} up to 10,000 m^3/ day^{-1}/ m^{-1}.

Despite being an ostensibly karst environment, the conduits through which much groundwater is able to move, do not form the sort of network that surface drainage systems often develop into. That is to say that there is no structured pattern of increasing channel size and water flow towards a common exit, recognised.

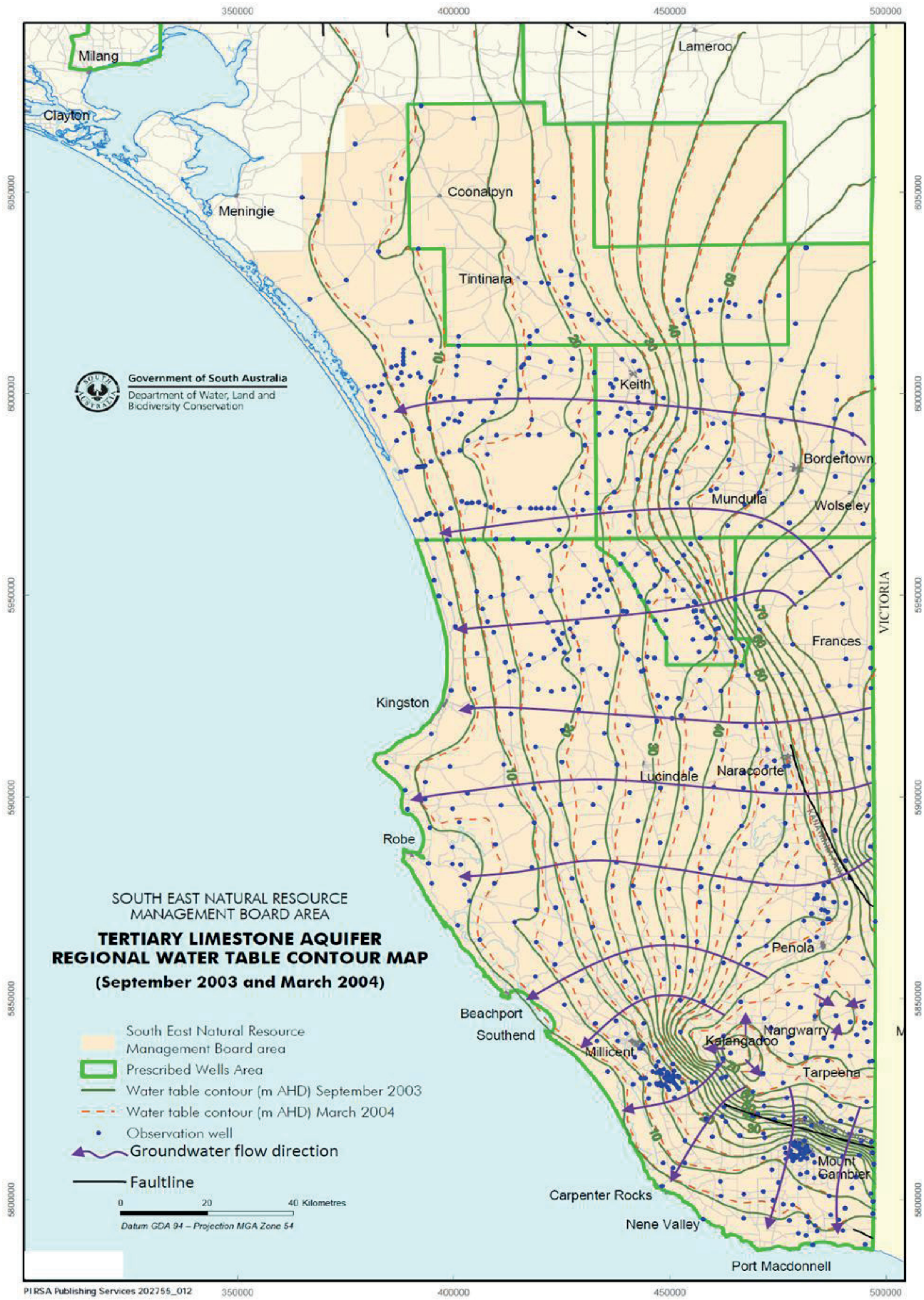

Figure 7.4. Watertable contours and flow directions of the TLA. Also noted is the lateral extent to which levels change between the end of the dry season and spring. Like the TCSA, this unconfined system shows steep gradients around fault zones. Adapted from DWLBC (2006). Image courtesy of Department for Water.

7.5. Recharge and groundwater movement in the TLA

Two primary modes of recharge to the unconfined aquifer are recognised;

1. Diffuse recharge through the soil matrix.
2. Localised point source recharge through the numerous sinkholes of the karst landscape, and through the base of standing water bodies such as lakes, lagoons and swamps.

These recharge modes may be direct and relatively rapid or delayed and somewhat slower (Figure 7.5b. for illustration of the various modes). Diffuse recharge is dependent on soil characteristics and so will be variable throughout the region. Generally, those soils which have high clay content will hold water for extended periods, but percolation into deeper zones is restricted. Sandier soils allow for a much greater infiltration rate and therefore more rapid recharge, with less standing water and runoff. Recharge through soils has been estimated using several techniques and has been found to be quite wide ranging, this is not surprising given the variable nature of soils. In the northern regions, estimates of mean annual diffuse recharge vary between 2mm/yr and 40mm/yr. In the lower regions, where annual precipitation is higher, estimates range from 47mm/yr to 270mm/yr.

Figure 7.5a. An exposure shows the contact between the overlying soils and the unconfined TLA, solution pipes extending well into the unconfined system make for an intimate yet extremely heterogeneous contact. Infiltration rate of rainfall and therefore recharge rate of groundwater through this diffuse mode is dependent on soil characteristics (Gartner's Quarry, near Penola).

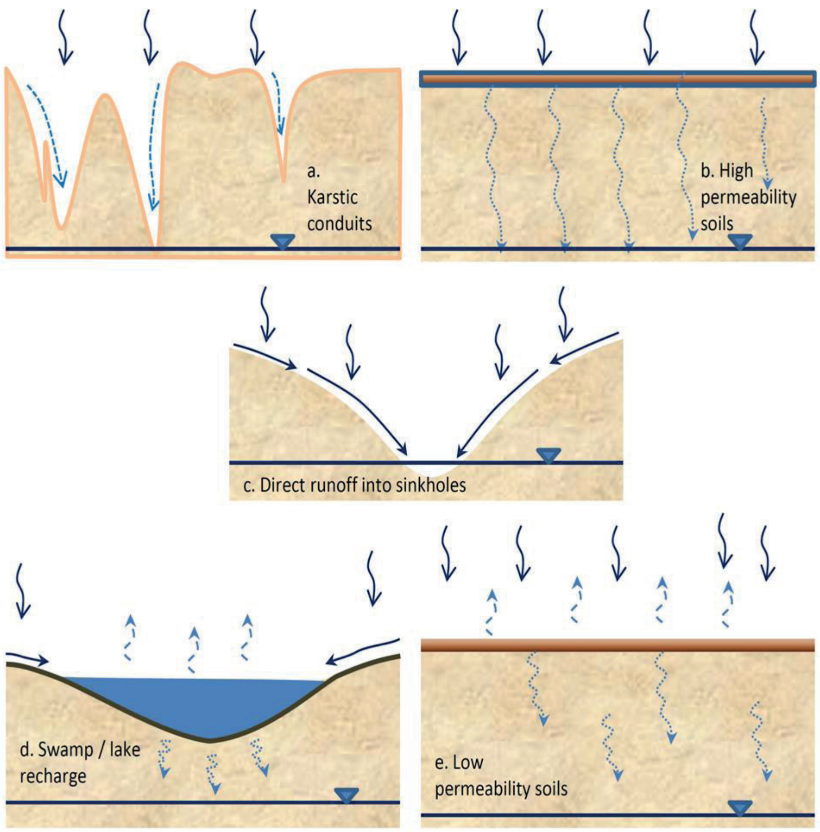

Figure 7.5b. Recharge mechanisms for the Limestone Coast Wine Zone groundwaters. Direct through mechanisms a, b & c. Delayed through mechanisms d & e. In (a), the Gambier Limestone outcrops and directly receives surface waters, in (b) highly permeable soils allow rapid infiltration and time in the unsaturated zone is brief therefore evaporation and salt concentration is reduced, in (c) surface water runoff is directed into sinkholes, in (d) surface water collecting in swamps and lakes passes slowly into the saturated zone because underlying sediments in these settings are fine and act to retard infiltration, similar to the low permeability soils in example (e) where the surface and unsaturated zone may stay moist and evaporation leads to salt concentration. Adapted from Love (1991).

Groundwater recharge is increased through land clearance, the interception and transpiration by vegetation is virtually removed from the water budget leaving more capacity for infiltration. Before european settlement, recharge was only about 40% of what occurs currently.

Contour maps are used to assess changes in groundwater levels and flow directions are inferred from these (Figure 7.4 and 7.7), where contour lines are close together, the gradient of the water surface is steeper and so the potential exists for faster flow in these zones. The two main areas of steep gradients around Naracoorte and north of Mt Gambier are associated with major fault zones. In the Mt Gambier zone the unconfined aquifer is thinner and has been lifted, creating a groundwater 'divide' (groundwater flows away on both sides) and east of Nangwarry, the water table is depressed, suggesting that this area may be a recharge zone for the lower confined aquifer. An idealised conception of the TLA can be seen in figure 7.5c.

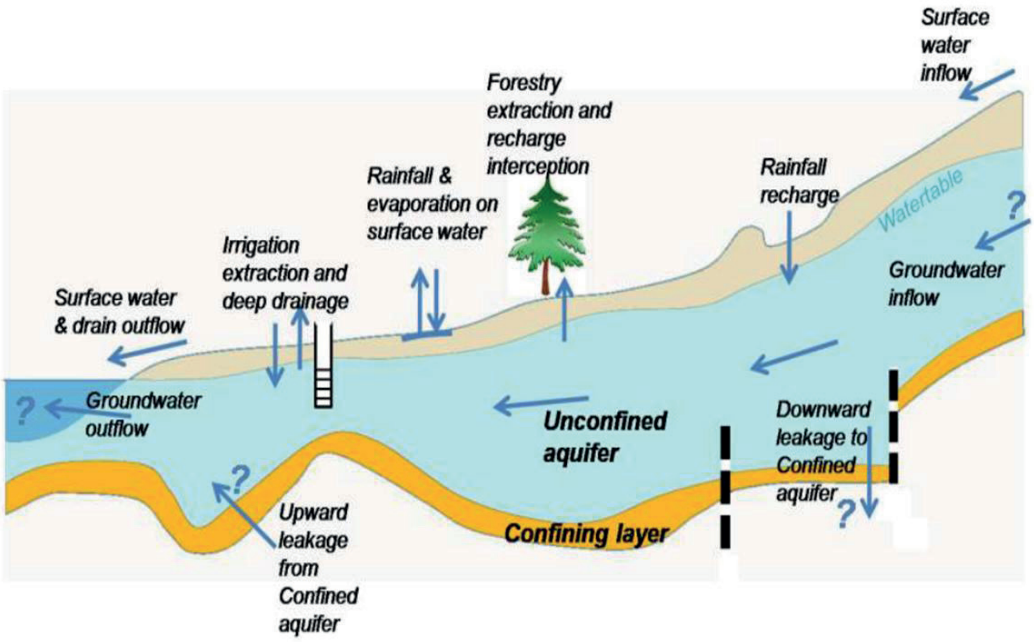

Figure 7.5c. Conceptualisation of important features of the TLA (Woods 2010). Note, there is both upward and downward leakage between the confined / unconfined systems, and thinning / uplift of the confining layer and aquifer. Image courtesy of Department for Water.

Because soils of the region are mostly quite permeable and the water table is shallow (usually <10m between dunes), the unconfined aquifer is quite responsive to local rainfall and rebounds well after winter rains, even where extraction is high. Seasonal watertable fluctuation is in the order of 2m in many areas.

Currently topical, is the incorporation of forestry practices into the water accounting of the region. Timber plantations greatly reduce or negate altogether, recharge of groundwaters through the soils they stand in. Where the water table is shallow (<6m) uptake of water by tree roots can be considered a direct extraction from the resource and so needs to be considered in broad scale management planning. The reduced recharge in areas of plantation, particularly in the southern Limestone Coast wine zone, has been noted as long ago as 1991 (Stadter & Stewart), and is associated with long term falls in groundwater level that extend well beyond the plantation area.

7.6. The Tertiary Aquitard

As previously stated, the sequence which forms the division between the upper unconfined and the confined aquifers is a complex of clays and marls, often glauconitic and containing fossils, this is the Mepunga formation and Narrawaturk marl (Figure 7.8d). They can be difficult to distinguish from one another because of their variable nature and the way that the different facies extend laterally into adjacent deposits (interfingering).

The aquitard extends upward into the Gambier limestone, where marly boundaries are noted, but are not continuous, and into the underlying Dilwyn formation whose upper parts contain very dark clay and lignite horizons.

Towards the northern extent of the Limestone Coast wine zone this aquitard thins out to less than 10m in depth where basement rock is at relatively shallow depths, but in most of the region thickness ranges between 20 metres and 40 metres.

Hydraulic conductivity is a measure of a mediums capacity to pass fluid and so is used to determine how well an aquitard is 'sealed', because in fact many confining boundaries do not completely seal off. Where these layers are not very effective, they may be termed 'leaky layers'. For a confining layer to be effective it must be of low conductivity in a vertical sense, that is, it must resist the upward or downward movement of water. Vertical hydraulic conductivity of the tertiary aquitard in the Lucindale region has been measured and shown to be variable between 10^{-3} and 10^{-7} metres a day.

7.7 The Tertiary Confined Sand Aquifer

This lower confined aquifer system is comprised of unconsolidated sands, gravels and clay layers of the Dilwyn formation and to a lesser extent, the sands of the Mepunga formation (see Hydrostratigraphic column in figure 7.8d). It is described as a multi-aquifer groundwater system (Brown et al, 2002), but is treated as single system on a regional scale. Very little is understood about the hydraulic interconnections between the sub-aquifers. Most wells utilising this aquifer only penetrate to less than 30 metres below the base of the upper unconfined aquifer.

Like the unconfined aquifer, the TCSA is also thinner to the northern and north-eastern margins, increasing in thickness towards the south, to as much as 800 metres offshore. Also like the TLA and the tertiary aquitard, the hydrogeological sequence is elevated around the structural high of the Mount Gambier region, in the vicinity of Nangwarry (Figure 7.7).

Like all geological deposits of the region, the TCSA is variable, in the northern areas it contains more sand and gravel than clay, and the clay does not form continuous layers. The extent and characteristics of these confining layers are one of the areas of enquiry which are likely to lead to a better understanding of the aquifer system as a whole. It is these layers which will define the extent of the poorly understood sub-systems. What we do know is that in the southern areas there is a higher proportion of clay, and that these beds can be continuous over sub-regions but the basin wide correlation of them is not yet clear.

Information regarding the hydraulic properties of the TCSA is less abundant than is available for the TLA, and what there is tends to be less variable than the TLA. Transmissivity values range from 200 to 1600 cubic metres a day and porosity determined from bore-hole logs varies from 20 – 30 percent.

Figure 7.7. TCSA contours and flow direction. Where the contours are close together the surface is steeper and the potential for faster flow exists. The line of Zero Head Difference (between the TCSA and the TLA) is not a fixed feature, but moves laterally with changes in water level, an elevated groundwater 'divide' west of Nangwarry drives flows both towards the N/NW and S/SW (adapted from DWLBC 2006 and Love et al 1993). Image courtesy of Department for Water.

7.8. Recharge and groundwater movement in the TCSA

Potentiometric surfaces of the confined aquifer system are shown in figure 7.7, like the TLA, groundwater movement generally tends to the west, south-west and south. The closeness of contour lines (indicating a steep gradient) occurs in the fault zones (also like TLA). The steep gradients associated with the TCSA in these areas are suspected be the result of a number of factors. Around the Kanawinka fault, on the up-thrown (north) side of it, the aquifer may be less conductive than on the down-thrown side, causing a 'build up' of water on the upper side and therefore a steeper gradient. It is possible that this feature is caused by aquifer thinning, but according to Love (1991), there does not seem to be any rapid changes in thickness of the aquifer across the fault.

The closeness of potentiometric surfaces around the Tartwaup fault in the south is said to be a result of aquifer thinning on the up-thrown side of this fault, aquifer thinning results in reduced transmissivity values, and in this case a steepening of the hydraulic gradient. The 'divide' just north of Mount Gambier (Figure 7.7) gives potential for flow to the north-west, west and south. As noted previously, both the TLA and the TCSA are closer to the surface in this region.

Significantly, a 'mound' of groundwater sits atop the divide zone (just west of Nangwarry); this mound corresponds with the groundwater 'sink' of the TLA (Figure 7.4). Put more simply, the unconfined aquifer appears to drain downwards here, whilst the confined system is built up. The location of these corresponding features is seen as being strongly suggestive of a recharge zone for the TCSA, especially in light of the closeness to the surface of both aquifers and the thinner nature of the confining layer between the systems, in this region.

Nearby (12km SW of Nangwarry), two wells adjacent to one another, one in the confined and one in the unconfined, show very different seasonal fluctuations in water level. Whilst the unconfined system levels change markedly between summer and winter (~2m difference), the confined system remains relatively stable with oscillations in the order of 100 – 200mm over a ten year period. Consider; the upper unconfined system shows rapid response to recharge through infiltration of winter rains, but the confined system being 'fed' by the unconfined is much less reactive, even though the supply available for recharging the confined system is greater. The implication here is that the recharge to the confined TCSA (in this area at least), is diffuse, not direct. The aquitard is a leaky layer, rather than a layer with occasional gaps that would provide more direct hydraulic connection.

As the Dilwyn formation crops out at the surface only rarely (some in Victoria, but the best local example is probably a few kilometres north-west of Mt. Gambier), most recharge to the confined system will be via the unconfined system 'pushing' water downward through the confining layers. The potential for this downward vertical recharge can only exist where the difference in head between the systems is positive with respect to the unconfined TLA (Figure 7.8a). Generally, these conditions exist only in the eastern portion of the Limestone Coast wine zone.

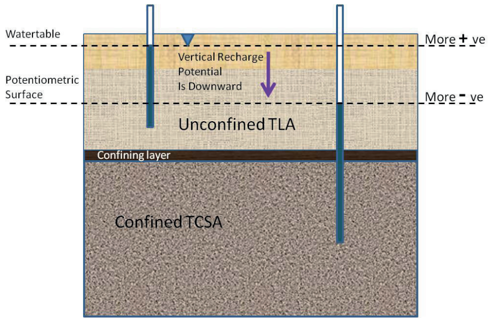

Figure 7.8a. Recharge of the TCSA downwards through the unconfined system. Head level of the unconfined system is above the level to which the confined system will reach if penetrated by a well, so potential for recharge is downward into TCSA. Image M. Pichler 2011

In the western portion of the Limestone Coast wine zone, the potential exists for upward recharge to the unconfined system. In this case the potentiometric surface of the confined system must be above the watertable (Figure 7.8b).

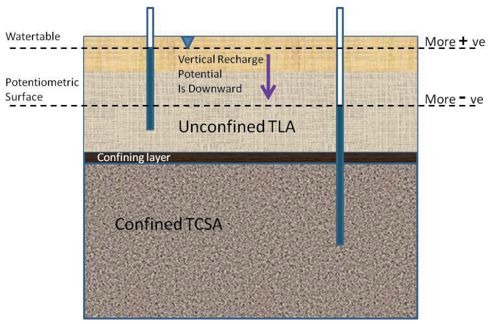

Figure 7.8b. Recharge of the TLA upward through the confining layer, from the TCSA. The head level of the confined system is above the level of the unconfined system. So potential for recharge is upwards through the confining layer into the TLA. Image M. Pichler 2011

downward from the TLA to the TCSA, or vice versa, depending on location, there must be a line where the difference between heads is zero. This is termed the line of Zero Head Difference (ZHD) (Figure 7.7). Along this line no potential for vertical recharge to either of the two main aquifers exists.

There is however, the potential for upward leakage into the confined system via an even deeper aquifer system. This is the Cretaceous system, which is not utilised because of its depth and the poorer water quality. Why drill through two much better systems to get to salty water? In any case there is as yet no evidence for a hydraulic connection between the deeper confined systems.

Aquifers do not end at the shoreline, and many will discharge waters into the sea at a distance from the shore or at the shoreline, given the extent of the coastline of the region, the groundwater flow direction implied by contour maps and the spatial variation in the aquifer material and confining layers, it would be reasonable to expect this also occurs along the Limestone Coast. Although no direct evidence exists, there is some likelihood that the unconfined system is actually recharged through upward movement of water from the TCSA, offshore.

Between Kingston and Robe, artesian expression of the TCSA results in easy access to irrigation water. Artesian waters are those which will rise above the surface from a confined system, this minimises pump requirements for irrigation. The area has a significant seasonal variation in water level and Love (1991) noted that the recovered level after winter rains was in long term decline, most likely due to increasing use of the resource. Love et al. (1993) marked out the area of artesian irrigation using data from the late 1980's and early 90's (Figure 7.7), whilst the general location may be reasonable, it is likely to change seasonally and over extended periods. Consequently, the amount of natural groundwater discharge at any location in the artesian expression zone is also likely to be variable, because it is related to the lateral shift of potentiometric contours.

Together, the TLA and the TCSA might be considered a somewhat integrated system variable within each aquifer and between sub-aquifer units. A simplified broad 3D image of the lower part of the Limestone Coast wine zone (Figure 7.8c), and the hydrostratigraphic profile (Figure 7.8d) should help to visualise some of the concepts discussed in text.

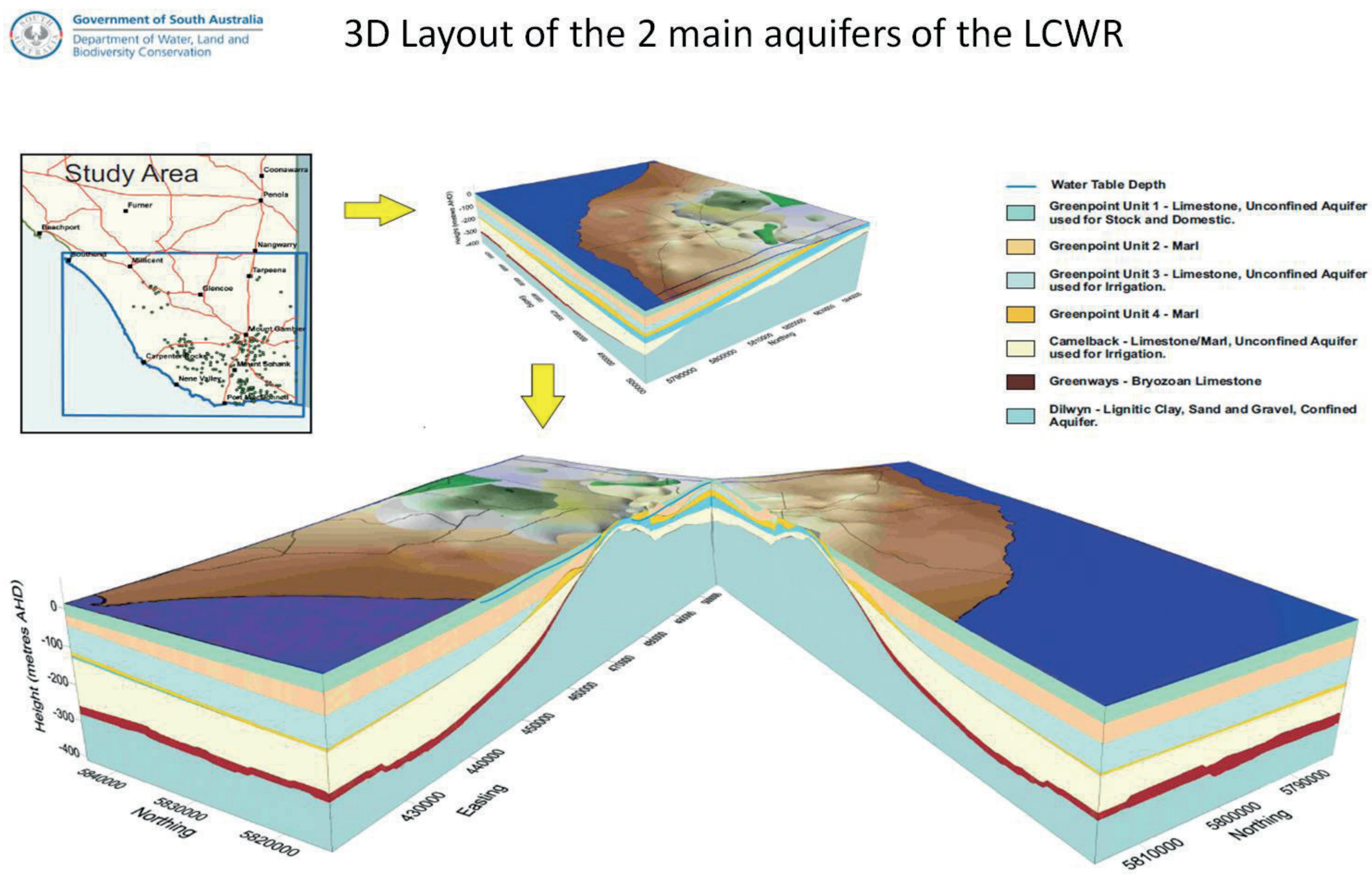

Figure 7.8c. Broad scale Hydrogeological features of the Lower Limestone Coast. 3 sub-aquifer systems are used to illustrate the unconfined system; the confining layers between these are not continuous across all of the Limestone Coast Wine Zone. The confined system extends down to basement rock. Both systems are elevated in the Mt. Gambier region. (Source, P. O'Connor, Dept Water, Mt. Gambier)

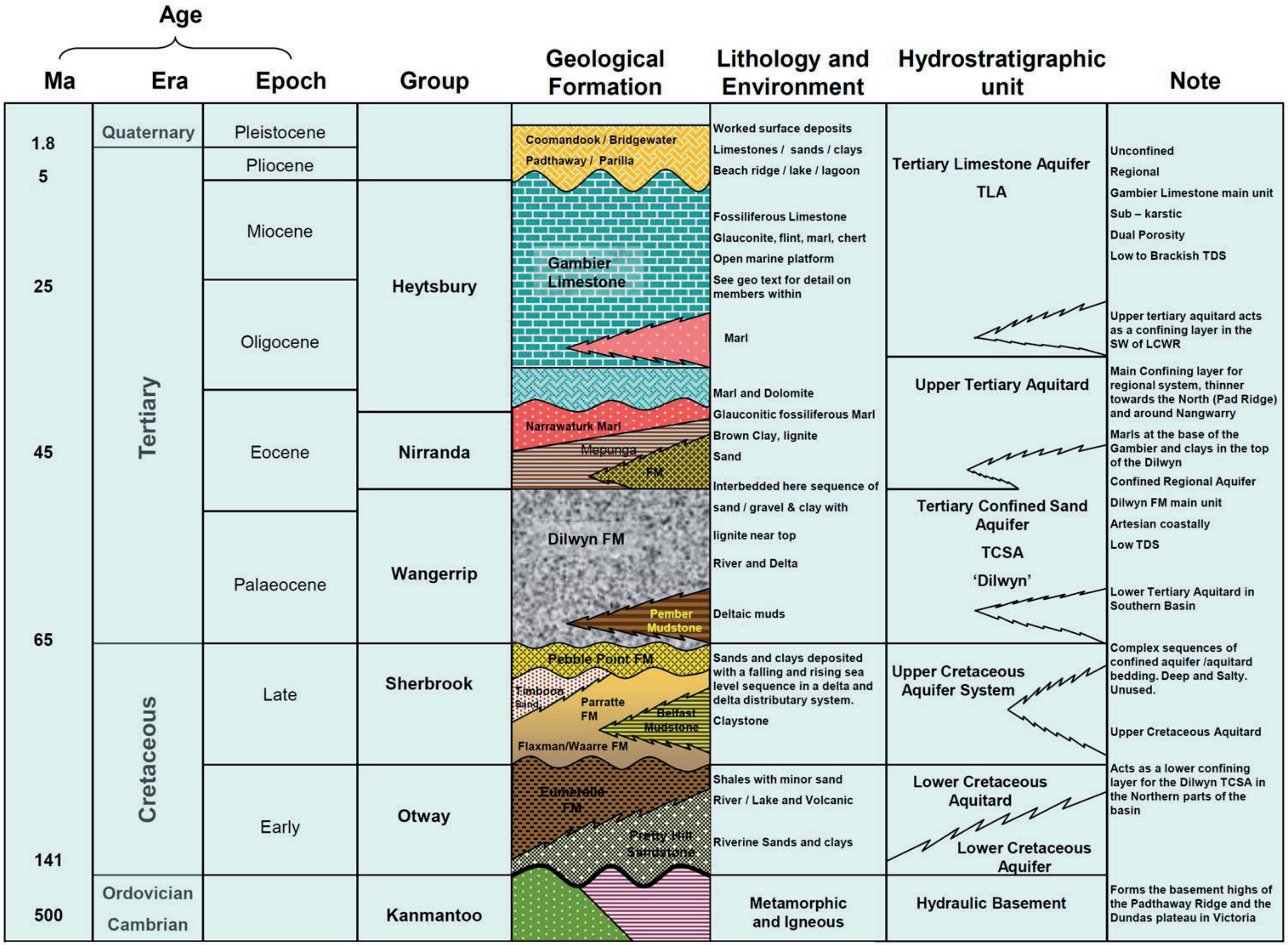

Figure 7.8d. Hydrostratigraphy of the Limestone Coast Wine Zone. Adapted from Love et al, 1993.

7.9. Hydrogeological Cross-sections

These cross sections are developed using SARIG drill-hole data, they are idealised, and intended to provide a general description only. Figure 7.9a shows locations of cross sections for each of the wine regions. Drill holes providing sufficient depth are limited in some areas. Cross sections should be used in conjunction with the knowledge that significant smaller scale variation exists.

Those intending to further develop groundwater resources should consult closely with drillers, preferably those with regional experience and neighbours; it would be wise to keep their own records wherever possible. Retained drill-hole samples with associated depths recorded may be of benefit in the long term.

The Department of Water can also provide information, and accessing 'Obswell' online data will give further details including trends in water level and quality.

The SARIG data base (PIRSA) is freely accessible for drill-hole enquiry, further, PIRSA also provide a library of retained drill cores and samples for viewing by arrangement.

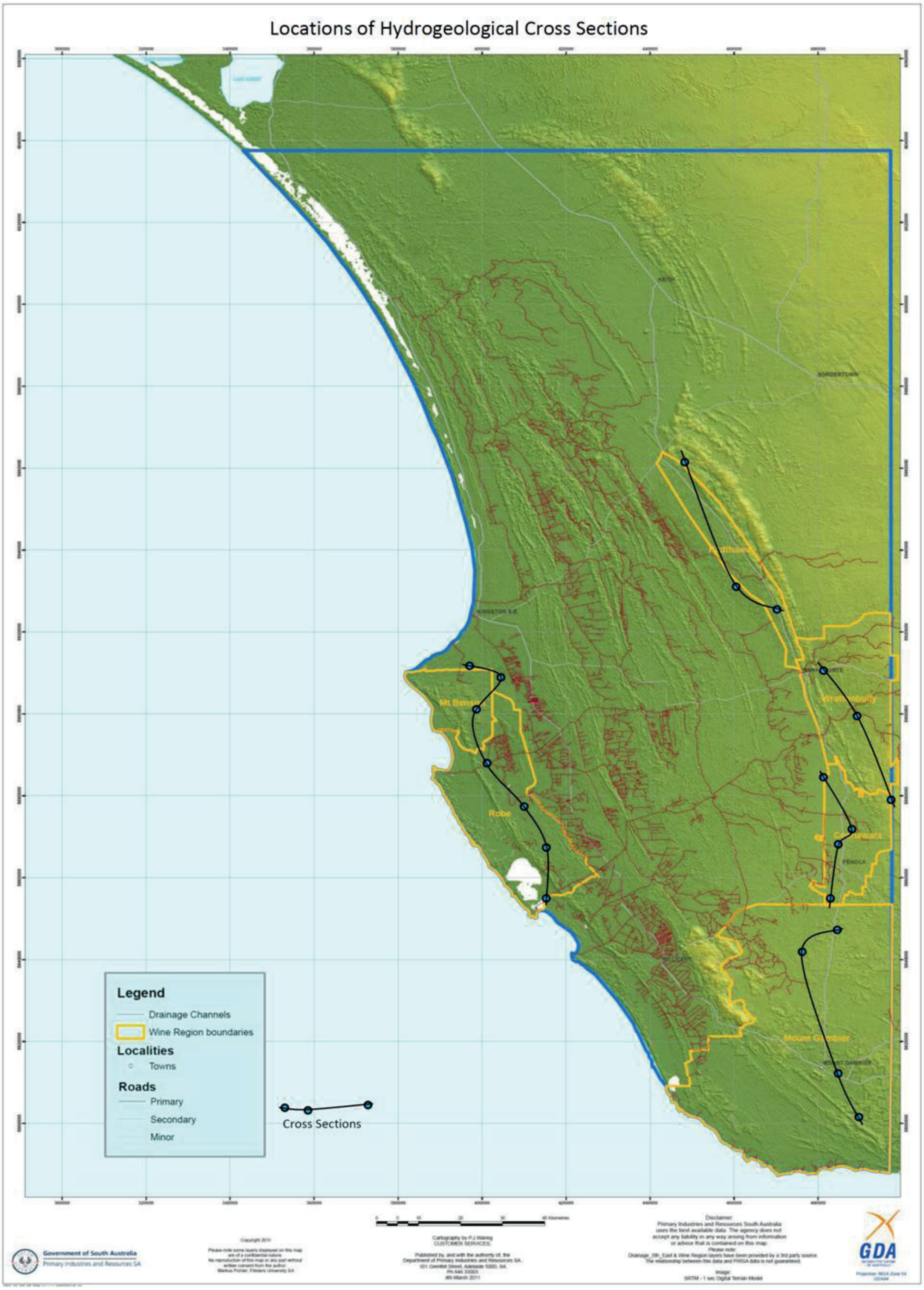

Figure 7.9a. Locations of Hydrogeological Cross-Sections (in black), inferred from SARIG drill-hole data. Also shown is the surface drainage network (red). Base image and drainage from PIRSA (2011), wine regions from Phylloxera and Grape Industry Board of South Australia (2011).

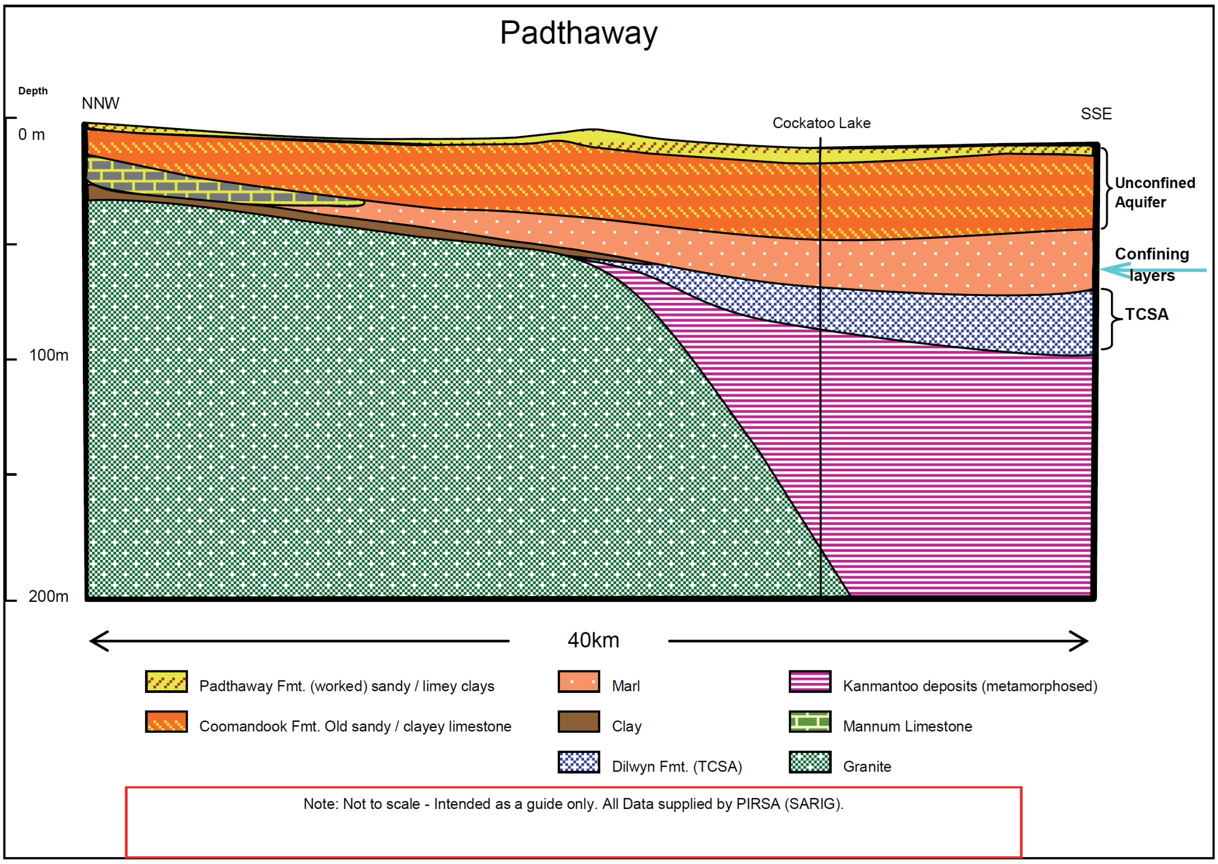

Figure 7.9b. Hydrogeological cross-section of the Padthaway area, for location refer to figure 7.9a. Image M. Pichler 2011.

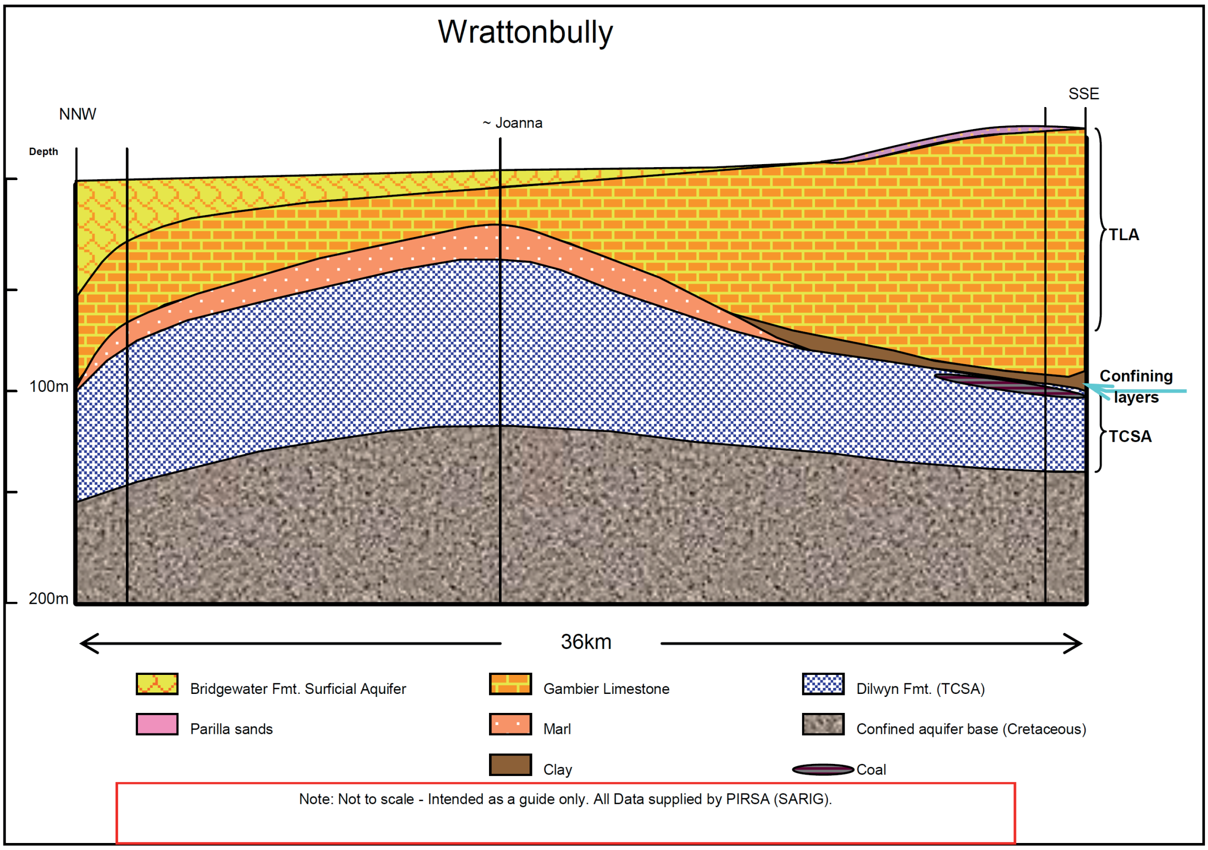

Figure 7.9c. Hydrogeological cross-section of the Wrattonbully area, for location refer to figure 7.9a. Image M. Pichler 2011.

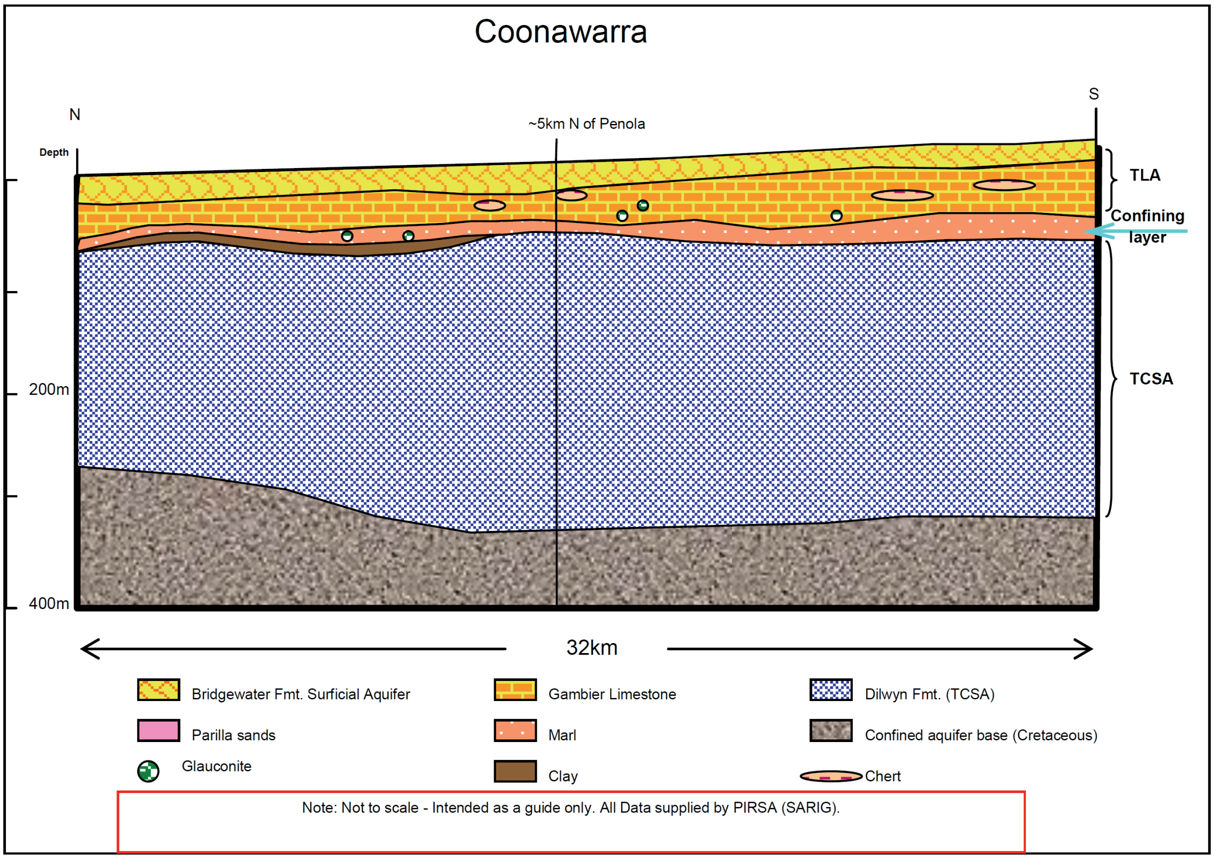

Figure 7.9d. Hydrogeological cross-section of the Coonawarra area, for location refer to figure 7.9a. Image M. Pichler 2011.

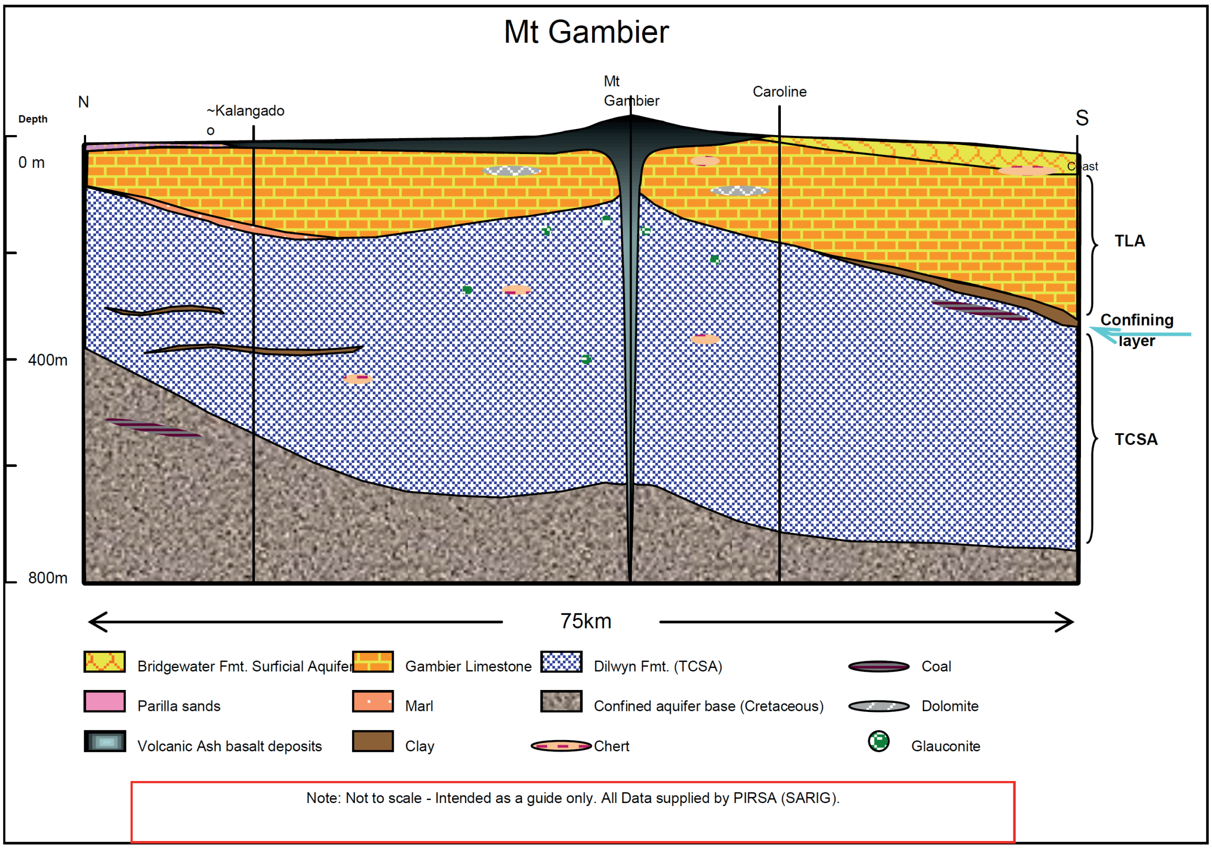

Figure 7.9e. Hydrogeological cross-section of the Mt. Gambier area, for location refer to figure 7.9a. Image M. Pichler 2011.

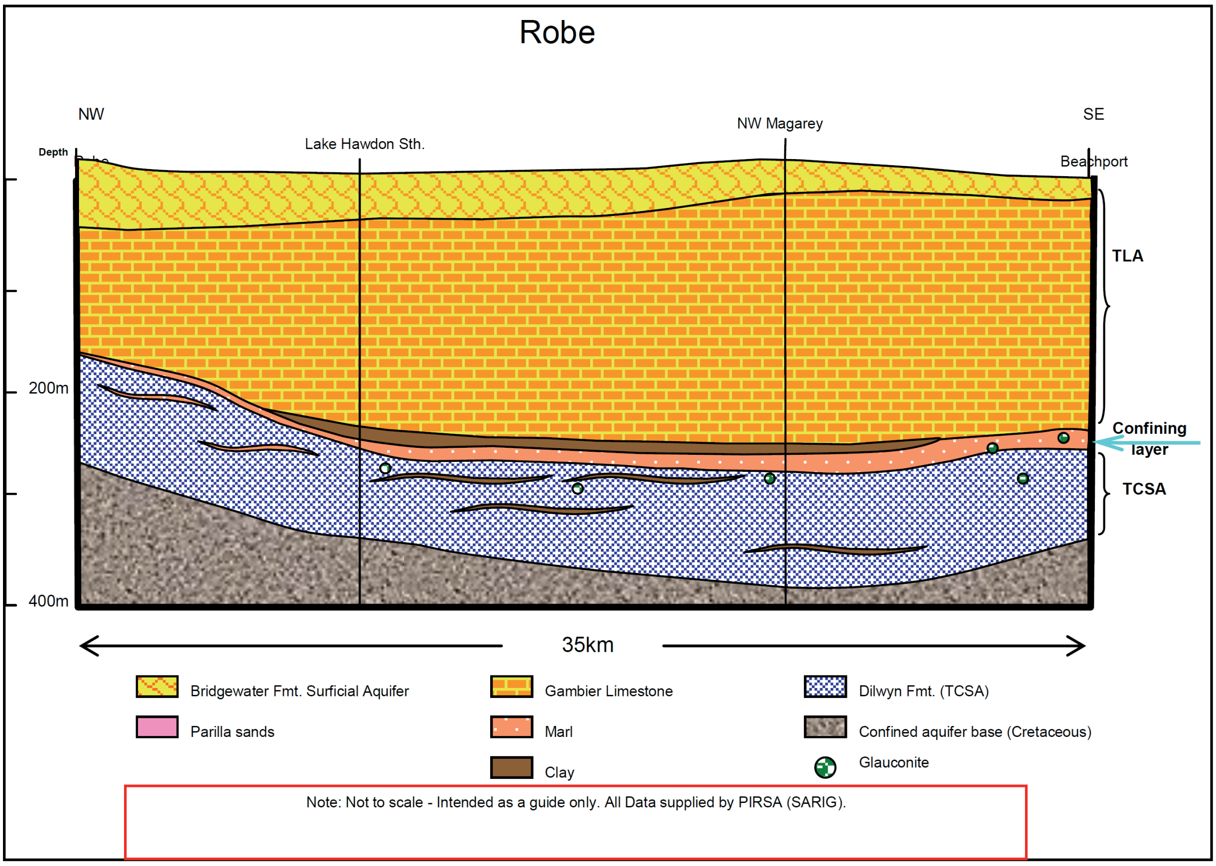

Figure 7.9f. Hydrogeological cross-section of the Robe area, for location refer to figure 7.9a. Image M. Pichler 2011.

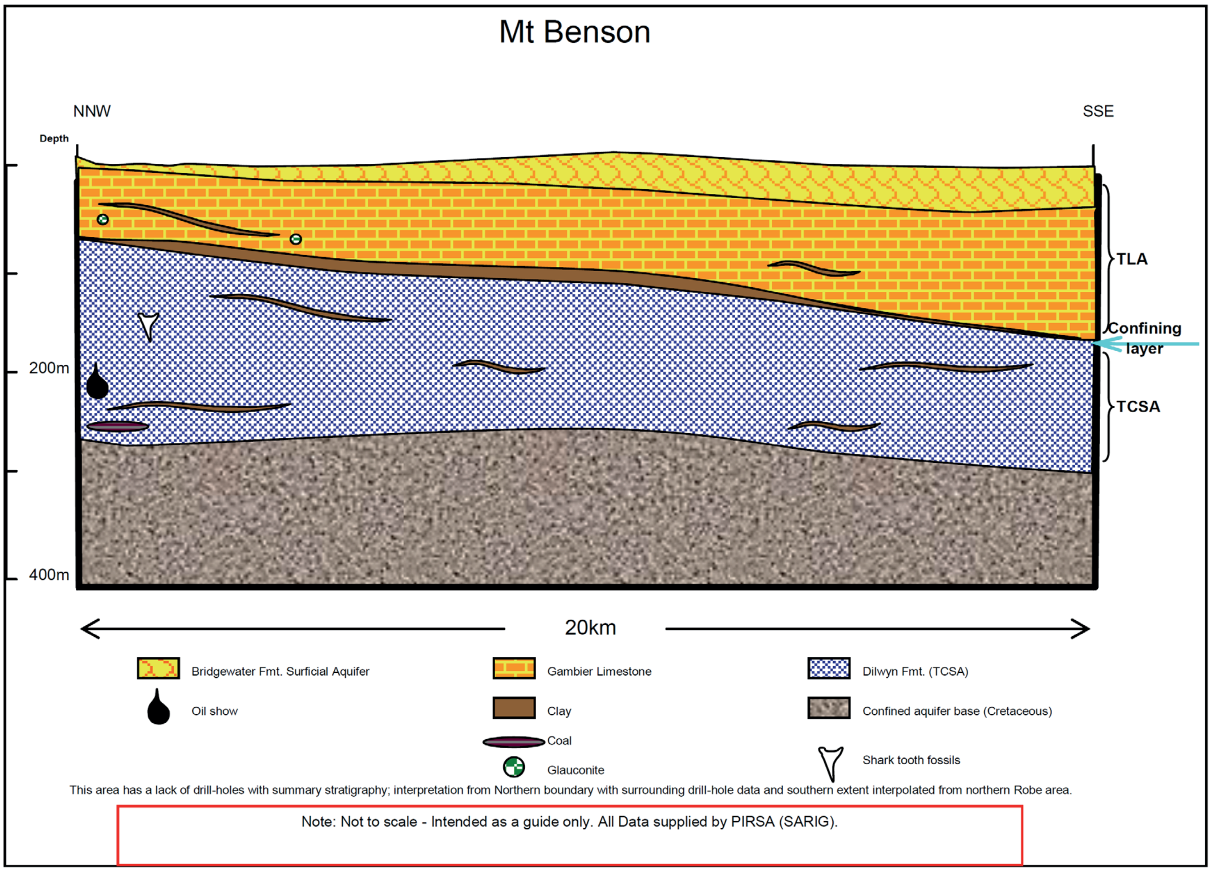

Figure 7.9g Hydrogeological cross-section of the Mt. Benson region, for location refer to figure 7.9a. Image M. Pichler 2011.

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Environment & Water Resource Management
8

Markus Pichler

8.1. The Nature of the Environment Of The Limestone Coast Wine Zone

Having developed throughout such a large area, across two degrees of latitude and under the climatic influence of the Southern Ocean, the Limestone Coast wine zone hosts a wide range of environmental settings.

In the coastal zone, cliffs, reefs, long sandy beaches and drifting dunes are set against a spectacular and seasonally variable Southern Ocean. A little inland, dense coastal shrublands on ancient dunes look over the lakes and lagoons that lay between them and, protected from the full force of the coastal influence, flowered heathlands lay across low lying areas. Further inland, natural forests / woodlands, wetlands and grasslands are set upon and between landscape undulations.

Mallee to the north and coast to the west and south, provide natural boundaries to the environmental layout of the Limestone Coast wine zone. This generally corresponds to what might be considered the north-western extent of a 'south east Australian environment'. Robinson and Rowberry in their chapter on the National Parks of the South East of South Australia (Tyler et al. 1995) point to this regional environmental position in terms of the distribution of nature reserves in the area. Some of these reserves and their features are summarised in the following paragraphs.

Penola Conservation Park conserves a wide range of habitat and vegetation types across a range of landforms, dunes swales and swamps. The park is covered by open stringybark forest and redgum woodland and the understory throughout much of this park is seasonally inundated. The park covers around 220 hectares and the swampy ground is a recognised habitat for smaller native mammals and tiger snakes. Drier parts of the park support populations of kangaroos and wallabies and during winter and the area receives an influx of water-birds.

Piccaninnie Ponds Conservation Park – this attractively named site is recognised for its variation in coastal vegetation types and for the rare species of water plants associated with the clear and deep (60 metres) permanent surface waters. Originally, these ponds drained eastward over the state boundary, but before the second world war, drain cuttings re-directed outflow seaward and reduced the standing water level. The park is located 32km SE of Mount Gambier (Figure 8.1).

Figure 8.1. Piccaninnie Ponds (image - NRM, 2010)

Dingly Dell Conservation Park (adjacent to Piccaninnie Ponds) contains one of the last remaining stands of the macrocarpa variant of the blue gum.

Tantanoola and Naracoorte Caves Conservation Parks (NCCP) – (30km NE of Mt. Gambier and 10 km SE of Naracoorte respectively) provide good access to fossil deposits, the palaeontological investigations associated with these sites allow a reconstruction of past environments of the region. Both sites deliver significant benefits to tourism, but particularly, the NCCP has excellent descriptions and displays of the past flora and fauna of the region. Both permit a more intimate view of the nature of the karst sub-surface, that is, the dissolved limestone geology recognised throughout much of the Limestone Coast wine zone. Caves provide a curious aspect to the environmental diversity of the region, through preservation of the past and conservation of the present.

Gower Conservation Park (located about 20 km SE of Millicent) contains relatively undisturbed stands of closed canopy Eucalyptus forest, representative of much of the dune system vegetation, with an understory of yakka and bracken.

Reedy Creek Conservation Park the reserves here (7 sites – located on the south end of the Reedy Creek range, from 12 to 35 km N – NE of Millicent) protect a small amount of open redgum forest across a creek bed setting. Drainage works have reduced the wetland area.

Furner Conservation Park is located about 25 km NE of Millicent, this is a relatively undisturbed open forest on the NW slopes of the Reedy Creek range. The ridge tops and lower parts of the slopes have different vegetation communities and both provide habitat for a small population of the red-necked wallaby. This park has few very large specimens of eucalyptus oblique, some of which have trunk diameters in excess of 3m.

Bool Lagoon Game Reserve and Hacks Lagoon Conservation Park is a biologically diverse area about 16 km south of Naracoorte is one of the most important and largest freshwater lagoon systems in southern Australia (Figure 8.2). The wetland complex is an aggregation of semi-circular lunettes that provide saucer shaped embankments surrounded with rushes and reeds. Water birds (~ 75 species) feature prominently in the faunal lists, and the wetlands perform an important role in the provision of refuge during times of drought. At least 47 species of water-birds breed here, and during particularly wet winters, these may include as many as 10,000 Ibis. It is suggested that this is probably the last place in South Australia where the Brolga may be seen (Tyler et al. 1995).

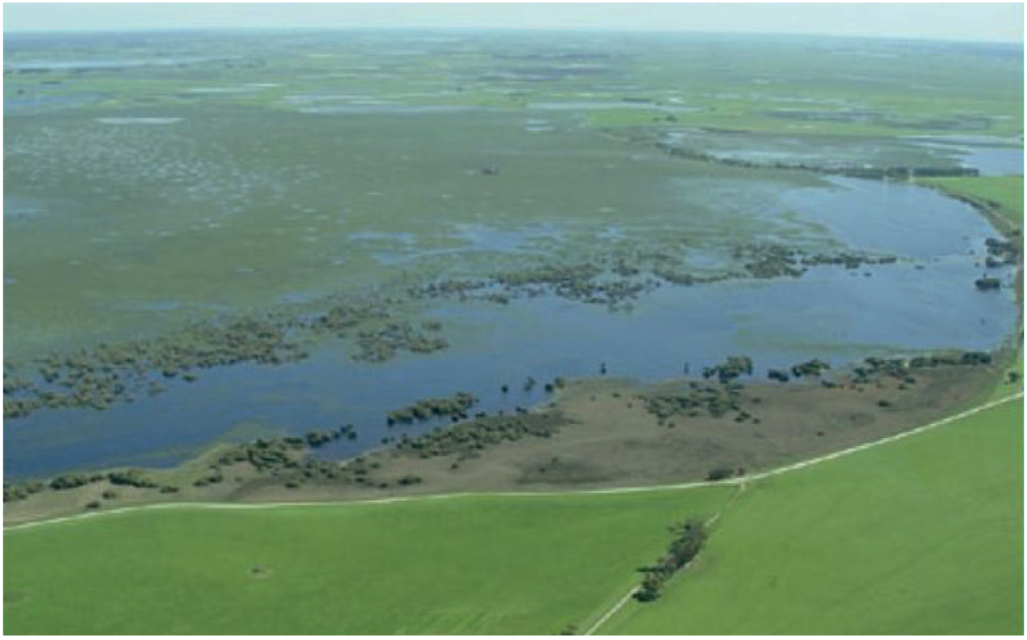

Figure 8.2. Bool lagoon; A Ramsar listed wetlands of international significance, covers an area of nearly 2700ha and is an important refuge for waterbirds in particular. Image courtesy of Department for Water.

Swamps and wetlands have been very much reduced since european settlement, but well managed drainage networks may enhance some aspects of the persistence of aquatic life (REFLOWS 2008), through provision of permanent pools, relocation opportunities for aquatic species via the network and the ability of flow regulators to maintain water levels in localised areas.

In general terms the coastal environments are best represented and the zones of high soil fertility associated with volcanic ash fallout are least represented.

In recent years it has been recognised that many surface-water bodies and their associated environments are intrinsically linked to groundwater because the surface water is a result of interaction between the aquifer and the surface (SENRM 2007). These zones, of which the Limestone Coast wine zone has many, are termed 'Groundwater Dependant Ecosystems'. The more recognised areas of their occurrence are shown in Figure 8.3. The conservation of these zones is somewhat problematic because of their interaction with the groundwater resource.

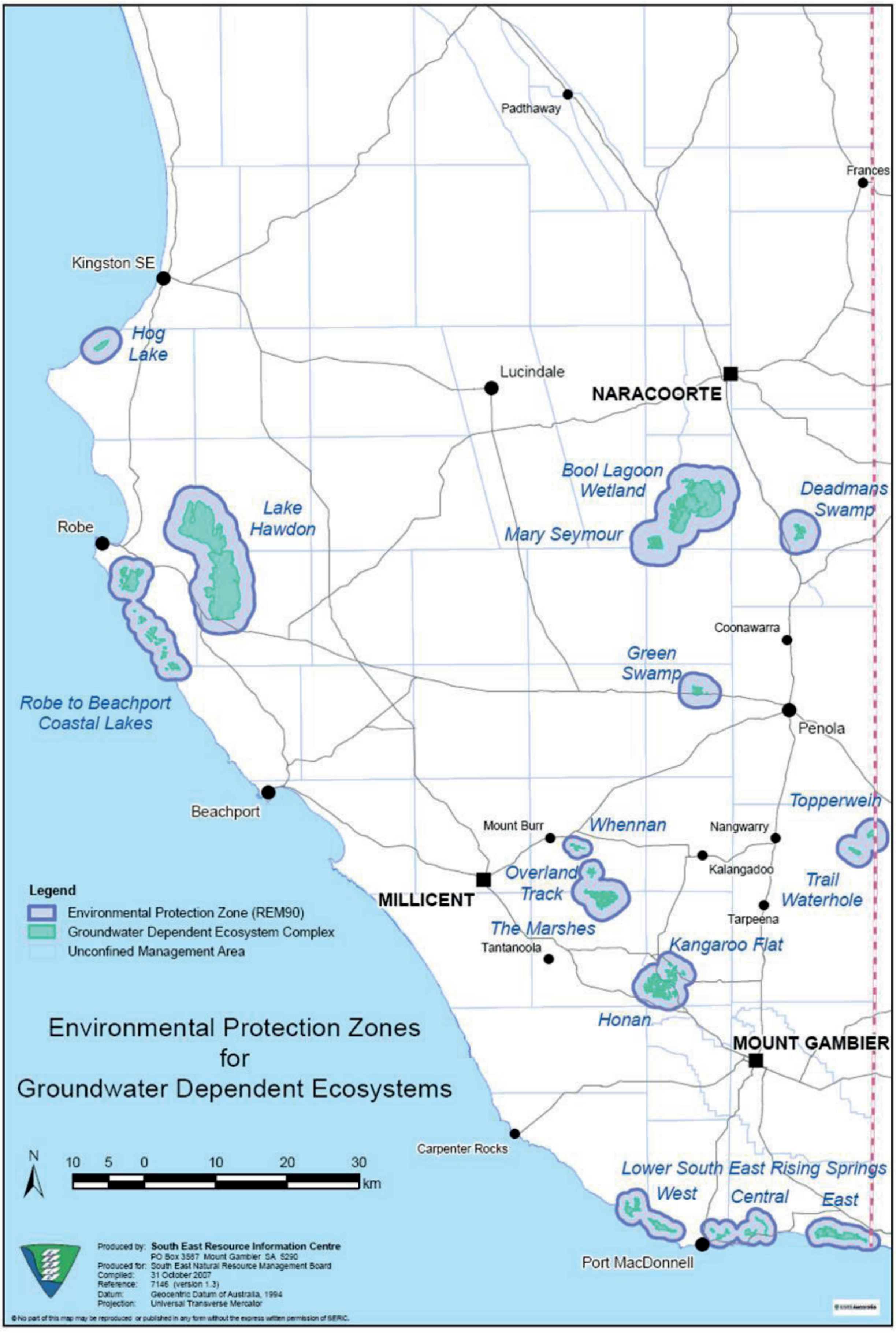

Figure 8.3. Recognition of the interaction between surface and groundwater is vital in the conservation of Groundwater Dependant Ecosystems of the Limestone Coast Wine Zone. (Image – SENRM 2007).

8.2 Groundwater Dependant Ecosystems of the Limestone Coast Wine Zone

Across the Limestone Coast wine zone there are thousands of sites of environmental importance. In order to present the locations more clearly, two maps of the zones have been developed (Figure 8.4 and Figure 8.5). Public access to these types of maps is freely available online at the Department of Environment and Natural Resources website 'Nature Maps'. The interface is easy to use and the layers of information available cover many aspects of the environment.

The nature maps on the next pages are separated into upper and lower sections and highlight various aspects of interest such as, reserves under management by National Parks and Wildlife, sites of significance for their flora and fauna and the state of habitats within the region. Also presented (Figure 8.6) is a map describing the types of wetland environments of the Limestone Coast wine zone. This aspect is also considered in conservation measures because wetland type will determine habitat. Consider the differences in fauna between a freshwater lake setting and saltwater lagoon.

Generally, settlement and the development of primary production occur in the most suitable places, the most fertile landscapes, where water is accessible and where transport corridors are available. The last places to be placed under production are usually the least suitable for agriculture and so tend to be the best represented areas of past environments.

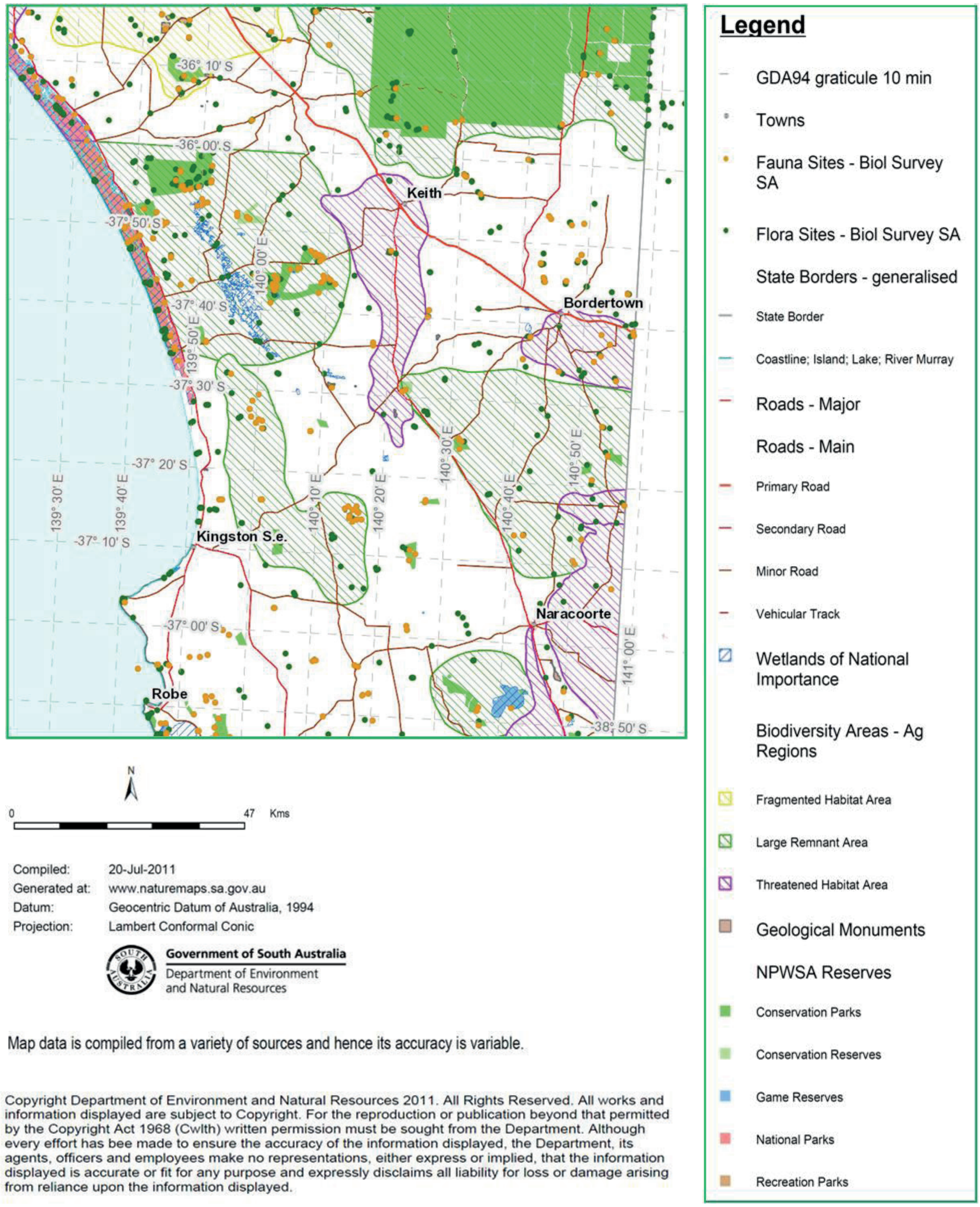

Figure 8.4. Upper LCWR nature map highlights NPW reserves, habitat condition and sites of interest. (Image DENR 2011)

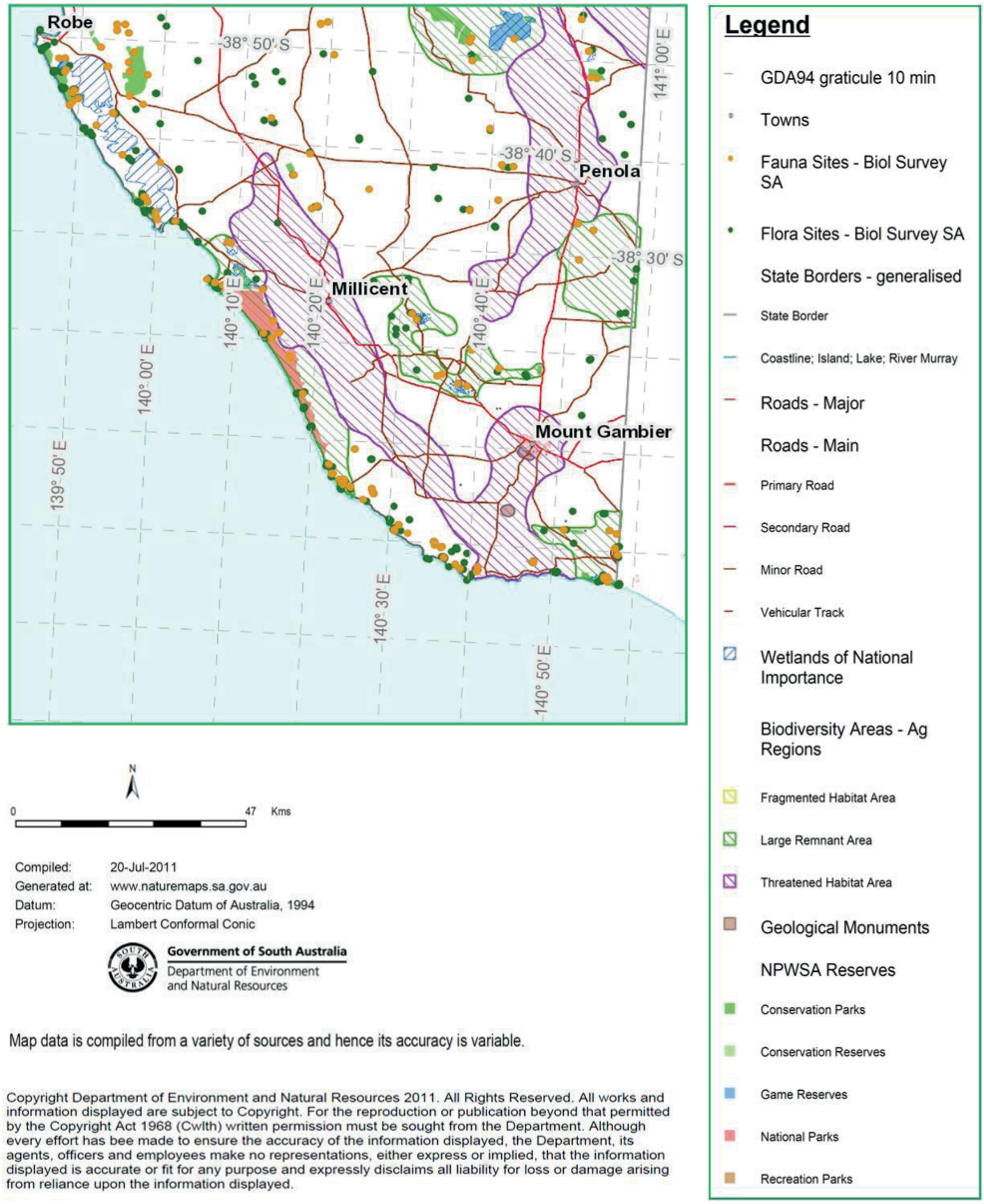

Figure 8.5. Lower LCWR nature map highlights NPW reserves, habitat condition and sites of interest. (Image DENR 2011)

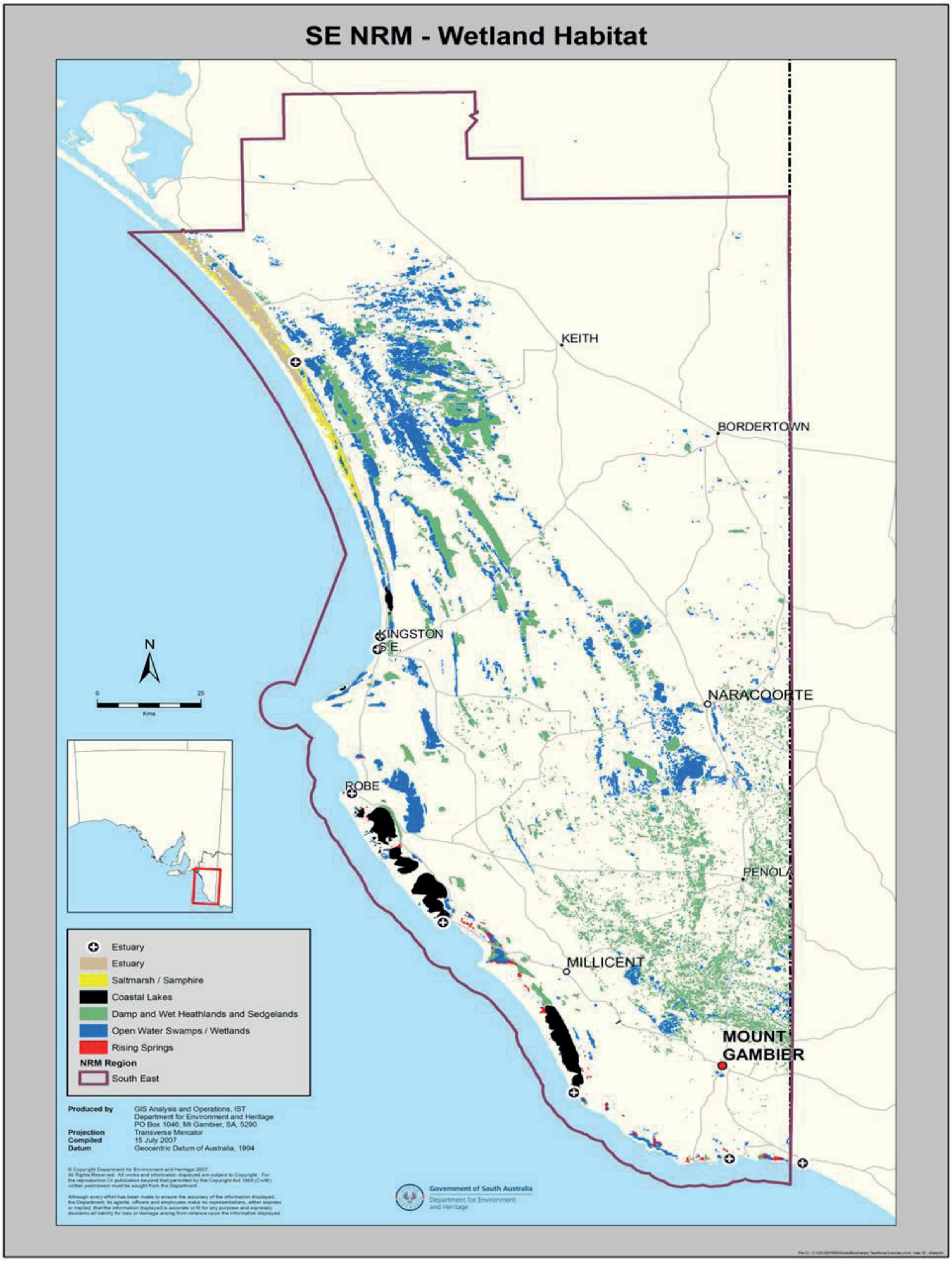

Figure 8.6. Types of wetland habitat across the LCWR range from saline to fresh water systems, they include those that are groundwater dependant and those that are maintained by surface water flow. (Image – DEH 2007).

8.3 Water Resource Management and Condition

Linked through their common need for water, the conservation of biodiversity and utilisation of the water resource for irrigation, industry, town and domestic supply, as well as stock watering, gives the management of water resources in the Limestone Coast wine zone its own particular requirements and difficulties.

Of most significance is the sheer size of the area and the need to balance the requirements of differing interests in different areas, against the likelihood that sufficient recharge will enable a reliable and sustainable supply of water, keeping in mind that the quality of the water must also be considered. Where supply is assured, long term irrigation/water use programs can be developed with more certainty. In terms of viticulture and the development of recognizable regional characteristics over long time frames, this aspect of surety and ability to plan, is vital.

The Department for Water is continually developing a better understanding of the resource through scientific investigation and using improved information to more sustainably allocate water across the 74 management areas (Figure 8.7) of the unconfined tertiary limestone aquifer (TLA) and the fewer but larger management areas of the confined tertiary sand aquifer (TCSA) (Figure 8.8). The increase in monitoring data enables interactions at smaller scales to be more clearly understood and factored into management. Of recent note is the improvement in knowledge of the effects of different land-uses on recharge.

Forestry practice (prevalent throughout much of the Limestone Coast wine zone) and its relationship to water resource use in the region is topical and recent work has shown forestry is a significant user of water through the prevention of infiltration for recharge (plantations are often at elevation and associated with high rainfall zones). Forestry also affects groundwater levels directly through groundwater extraction from the aquifer, where the water table is deemed to be shallow enough (6 – 8 meters) (Department for Water 2010).

Currently, water allocation is in a state of changeover from area/land use based principles that use proportions of Mean Annual Recharge (MAR), to volume based criteria. A detailed explanation of this extensive departmental document can be viewed in the freely available online, 'South East Water Science Review, Lower Limestone Coast Water Allocation Plan Taskforce, 2010'.

The key points in regard to water resources of the region are;

1. An estimated 93% of available water is used by agriculture and natural processes such as evaporation and spring seepage.
2. Long term declines in water level result from reduced rainfall and recharge as well as changes in land use practice.
3. The unique ecological character and biodiversity of the region are strongly linked to groundwater and are affected by land-use.
4. Wetland extent is 6% of pre-European area, of this only 10% is considered intact.
5. That forestry, in particular, blue gum plantations, directly result in reduced groundwater levels and are associated with regional 'cones of depression' and an alteration/deterioration of groundwater dependant ecosystems.
6. That current knowledge is in-sufficient to provide reasonable certainty to sustainable levels of extractions from the resource.

There is a close relationship between the resource, natural environments, forestry practices and agriculture. The water resources of the Limestone Coast wine zone are used extensively and are approaching maximum possible extraction. This justifies close and careful management based on the principles of improved science and data collection.

As the resource is well utilised, the balance between interests is critical, management practices need to be adaptive to changing needs and land-use. More specific allocation of resources and the feedback of resources (i.e. recharge of irrigation water over land) will be considered in budgeting. Losses of water through evaporation and the delivery system are considered, as well as the interaction of groundwater bodies between management zones. Some zones may be able to extract large volumes of water without affecting neighbouring properties; others might only be able to extract small amounts before significantly affecting water use on adjacent landholdings. Newer management principles attempt to address issues of volume and quality at a smaller more integrated scale (Department for Water, 2010). The surety of supply over the long term is important to all irrigators.

Figure 8.7. TLA groundwater management areas of the Limestone Coast Wine Zone interact with border zones and each other, sustainable practices aim to incorporate this interaction and allocate the resource accordingly. (Image – SENRM 2011)

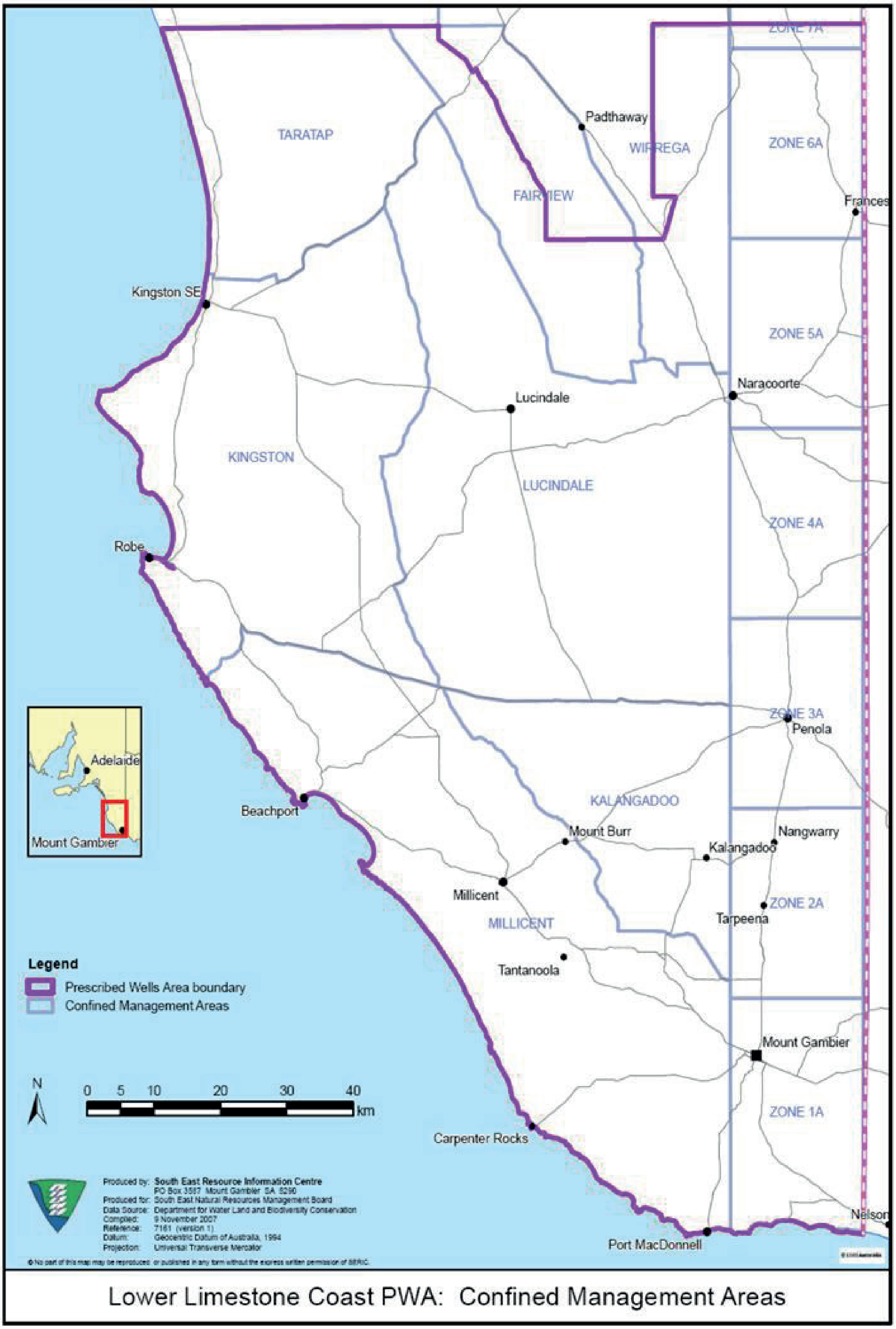

Figure 8.8. Like that of the TLA, management areas of the TCSA for the greater part of the Limestone Coast Wine Zone reflect interaction with border zones. Generally, zones are much larger and fewer in number than those used for the management of the TLA. (Image SENRM 2011)

If we consider briefly and simply that the primary water supply is a dual aquifer groundwater system, then monitoring the level of the watertable/potentiometric surface over time is the obvious way to observe impacts on resource storage. This is especially useful for sustainable management if good information is available for extractions, land-use and evapotranspiration.

In terms of viticulture the quality of the water within which the roots reside is paramount. Uptake of nutrients occurs from a solution across the root wall /soil interface so what is available to the vine depends on how the soil and water interact to determine the nature of that solution. Salt concentration in groundwater is dependent on many factors, initially it is a result of the quality of the water recharging the system and the length of time it has in contact with the aquifer substrate, but it can also be severely affected by evaporative processes when the water table is at or near the surface and through flushing of high salinity waters into zones where it can percolate into aquifers. In some instances groundwater can become contaminated by nutrient flushing in agricultural areas. Water quality is as important as assured volumes.

Water levels and salinity for the two groundwater systems of the Limestone Coast wine zone are depicted in following images.

8.4 The Unconfined Tertiary Limestone Aquifer – Water Levels and Salinity

The level of the watertable has changed over the entire record of measurement (time frame not noted in map - presumably some decades) (Figure 8.9). In this image the areas of orange /red indicate where the level has fallen and the green/yellow tones indicate where there is a rise. Red zones are of concern and bear closer scrutiny; these are most evident in the area south of Keith and around Mount Gambier.

Over extraction can cause changes in the groundwater flow direction, reduce the capacity of the wells in adjacent landholdings and can lead to decreased water quality.

Although the quality of the image in Figure 8.10 is reduced, the layout of shaded zones clearly shows areas of concern similar to Figure 8.9. Over the more recent short term (5 years 2004 – 2009), it appears that the fall in the level of the water table has been slightly lower. However this is likely to be an artifact of the map construction, note the value of colour ranges used to show level changes. In Figure 8.9 the strong red tone indicates a change of between -0.1 to -0.4 m/yr (at a point) and in Figure 8.10 the same colour indicates a change in level of greater than -0.7 m/yr (over an area). It is possible that the resource store diminishes at a faster rate in the Mt. Gambier region than in the Keith region.

The long-term salinity of the tertiary limestone aquifer (TLA) is shown in Figure 8.11; significant increases (above 5mg/L/yr) are noted throughout the area around Keith and extending south eastward through Padthaway, Naracoorte, Coonawarra and towards Penola. The recent salinity of the TLA is shown in Figure 8.12. In this image both the TLA and surface wetlands are incorporated as management recognises the dependence of many wetlands on natural groundwater discharge, and the capacity for recharge of groundwater through wetlands.

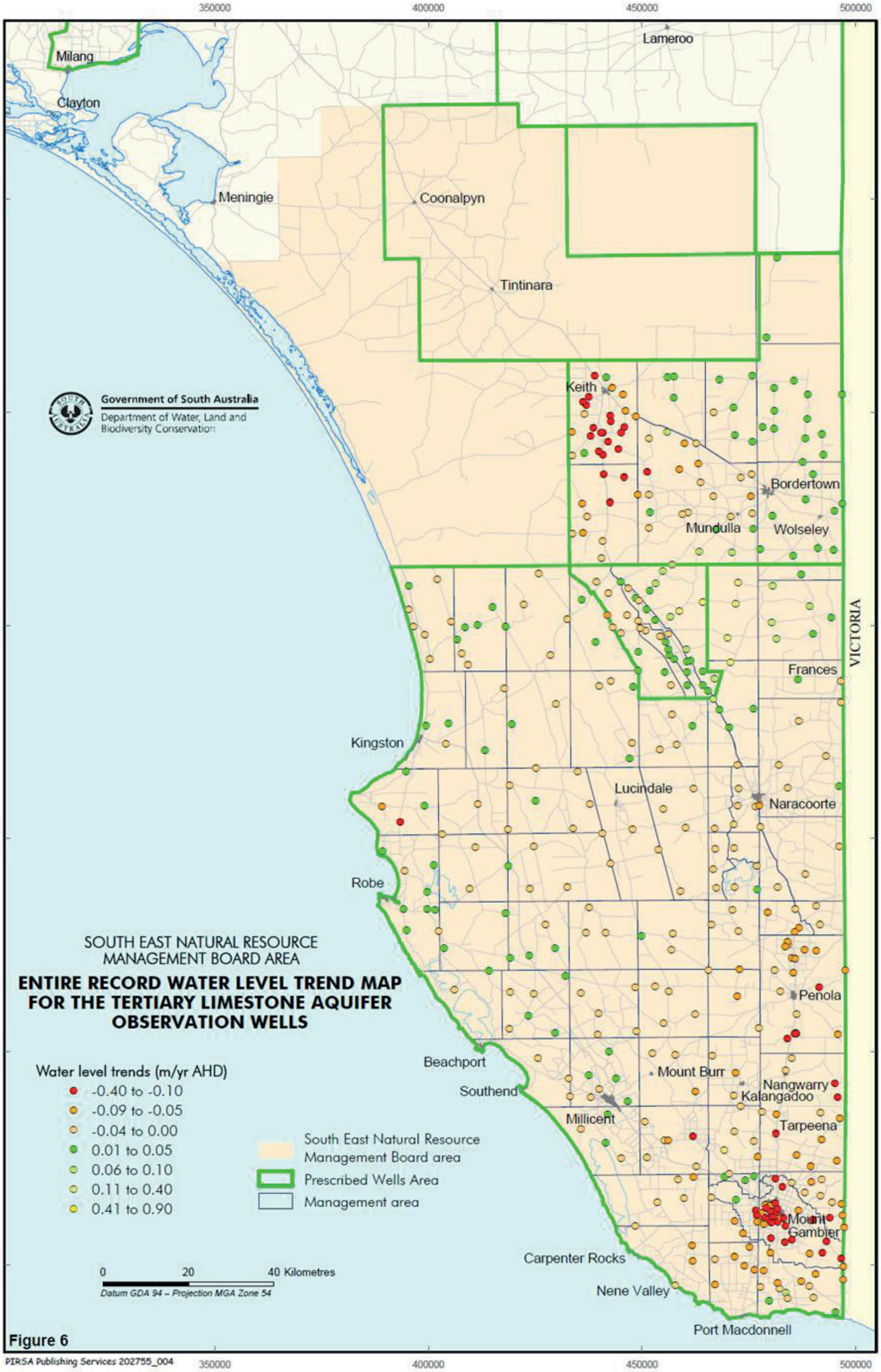

Figure 8.9. Trends in watertable levels for all data in the Limestone Coast Wine Zone, units are metres of change per year, referenced against the Australian Height Datum (AHD). Image courtesy of the Department for Water.

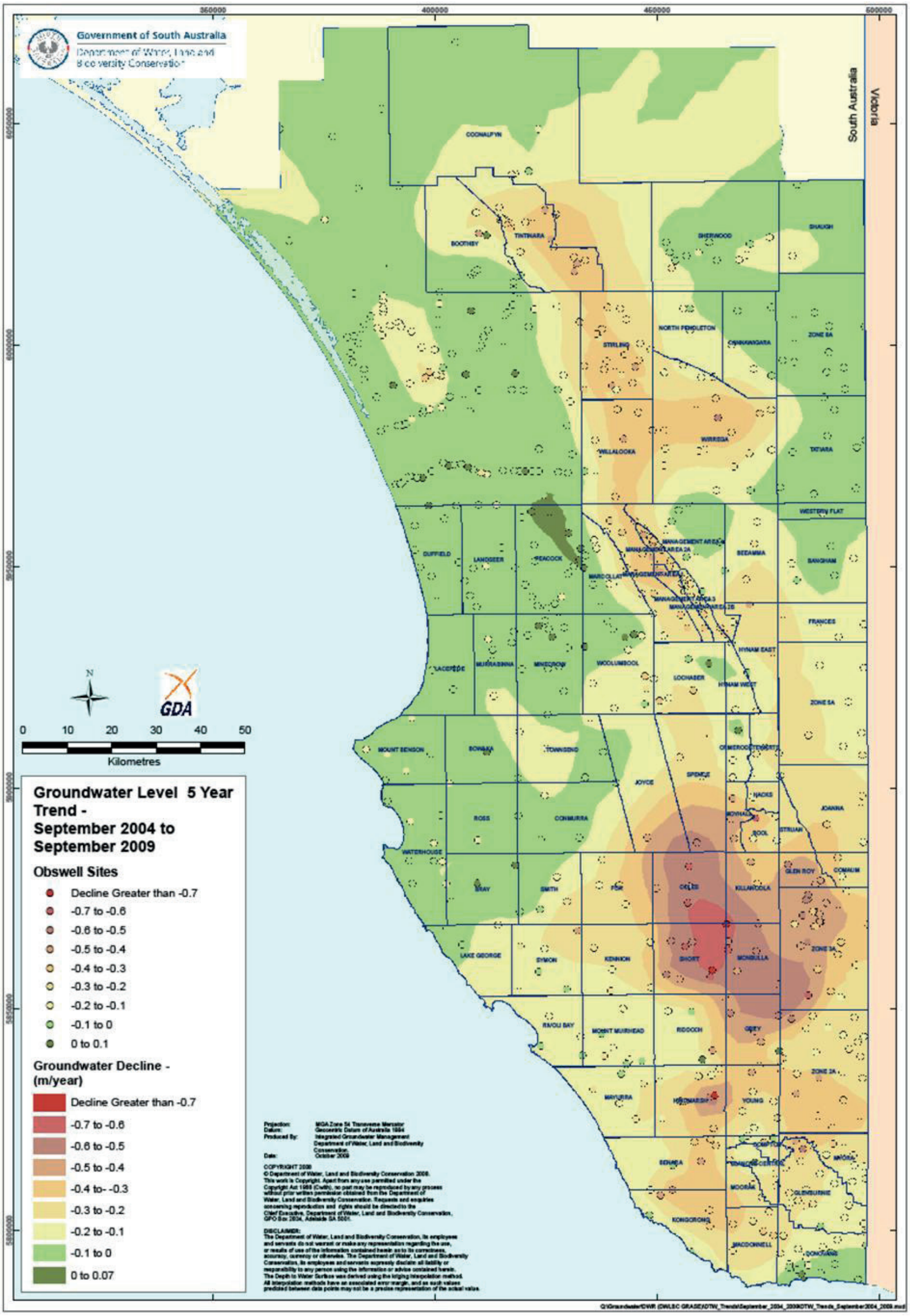

Figure 8.10. Generalised trend in water level of the TLA over the period 2004 – 2009. This short term trend map uses different values for the same colour range as figure 8.b.2; take care with comparisons and interpretation. Image courtesy of Department for Water.

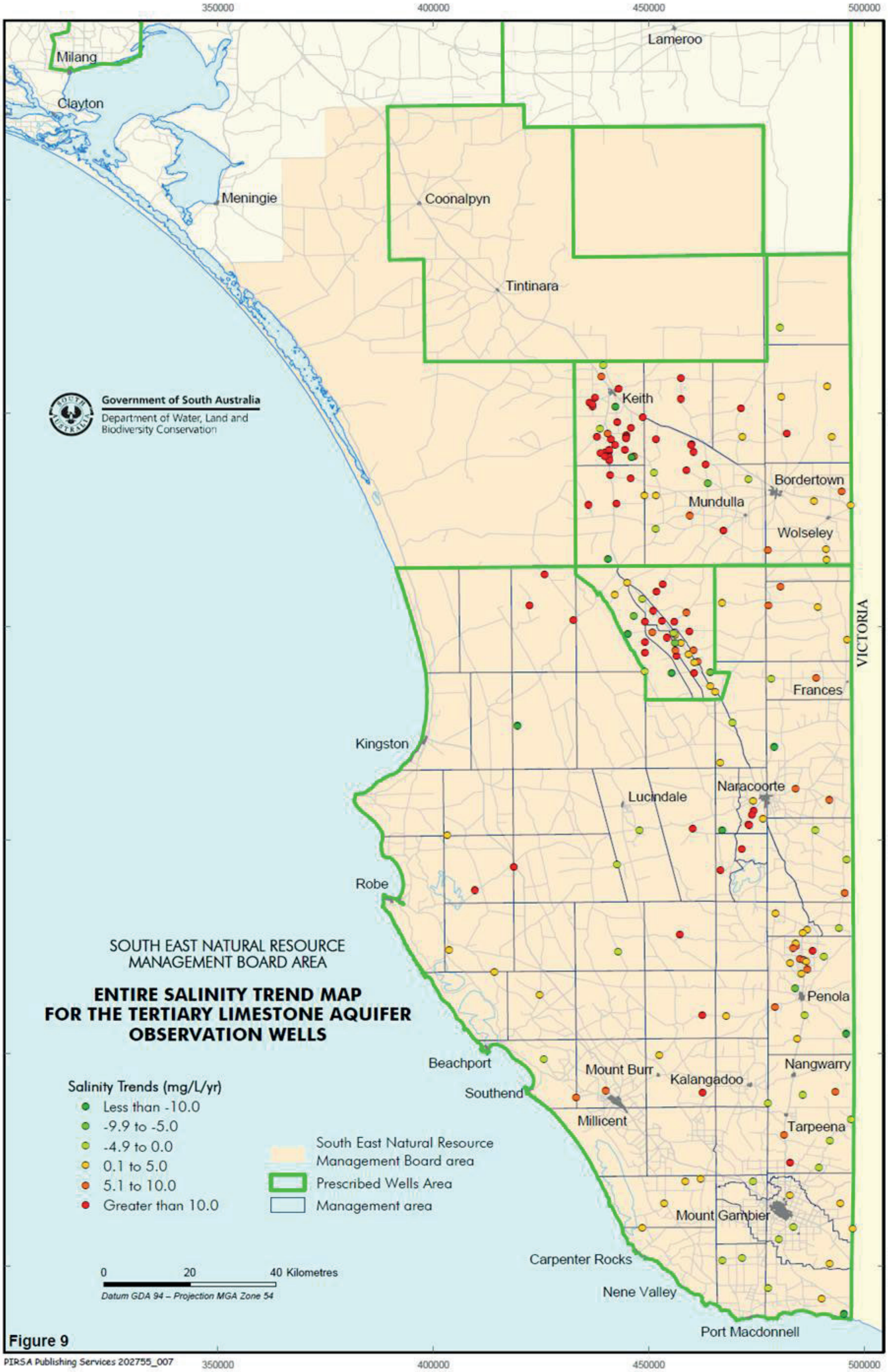

Figure 8.11. Trends in salinity of the TLA for all data in the Limestone Coast Wine Zone, units are in milligrams per litre per year. Of most concern are the areas between Keith and Penola. Image courtesy of Department for Water.

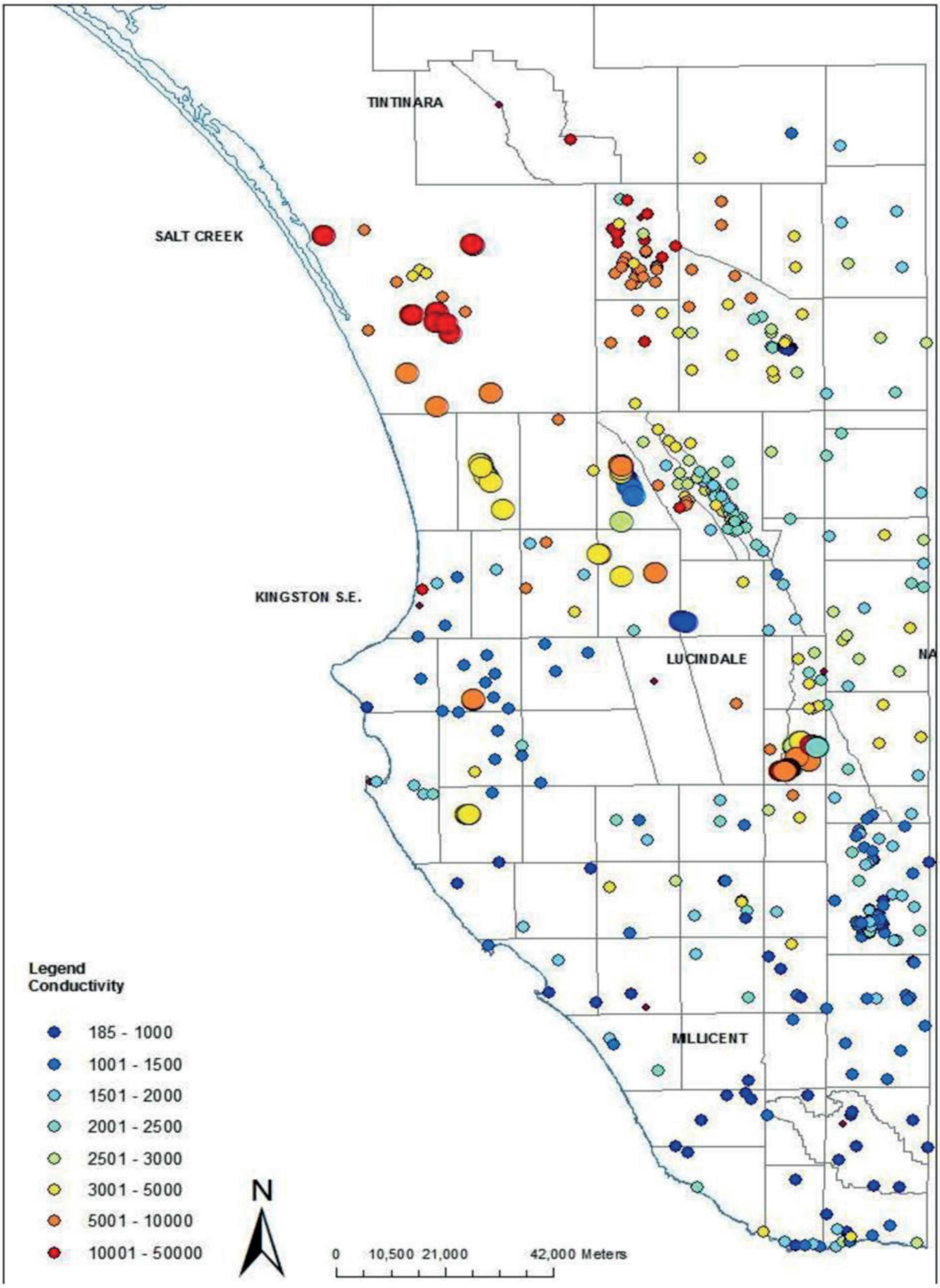

Figure 8.12. The primary water quality issue is salinity; the proxy used in this image is Electrical Conductivity (EC) in units of micro Siemens/cm-1. Salinity is the primary indicator of the suitability of water for different agricultural uses. Larger circles are wetlands and smaller circles represent salinity of the unconfined Tertiary Limestone Aquifer. Data used is from 2009. Image courtesy of Department for Water.

8.5 The Tertiary Confined Sand Aquifer – Water Levels and Salinity

Although less heavily used than the TLA the tertiary confined sand aquifer (TCSA) requires monitoring and management because it is recharged through the overlying TLA as well as through interactions with bordering aquifers in the north and across the eastern state boundary. Confined aquifers such as this do not react in the same manner as un-confined aquifers to local rainfall.

The trends in the level of the potentiometric surface of the confined aquifer and the apparent salinity trends of those waters are shown in Figure 8.13 and Figure 8.14. In these images the areas of orange / red indicate areas of concern either through increasing salination or through lowering of the potentiometric surface (the potentiometric surface is the level up to which water will rise from a confined aquifer – somewhat analogous to the water-table in an unconfined system).

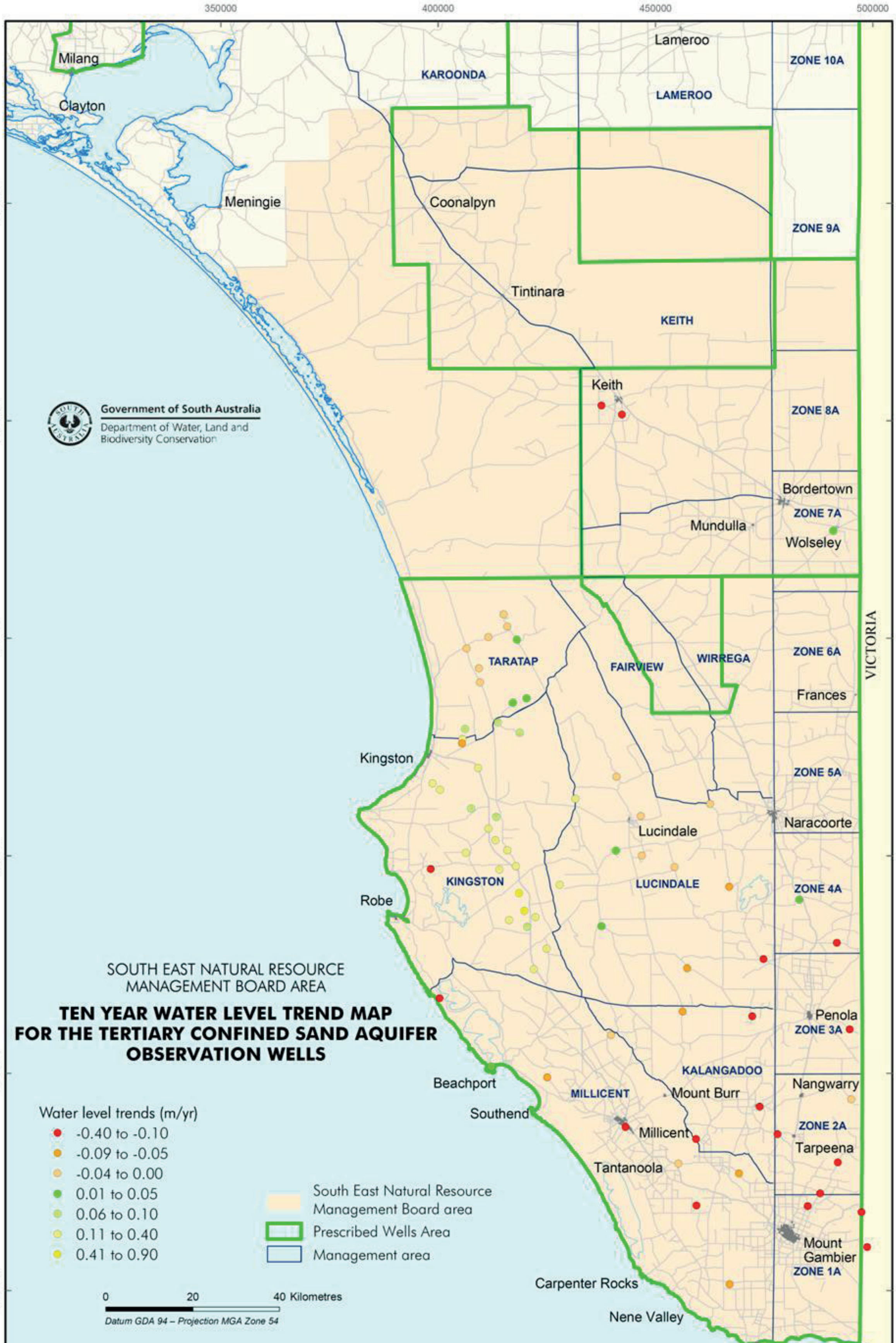

Figure 8.13. The changes in water level of the TCSA are most marked in the lower part of the Limestone Coast Wine Zone, areas around Keith and Kingston also bear close monitoring. Image is from DWLBC report of 2006, so years are most likely from 1996 – 2005.

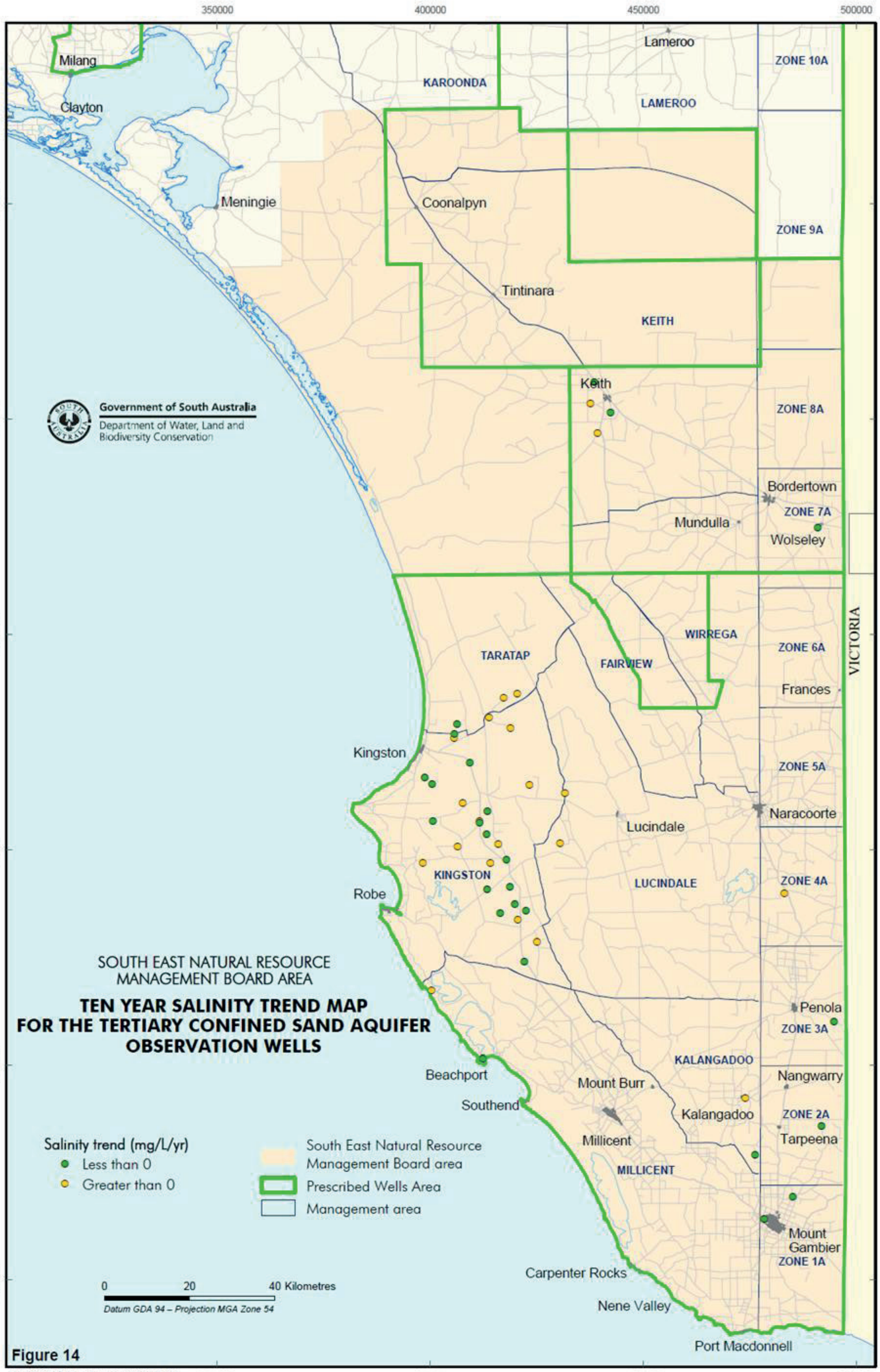

Figure 8.14. Detrimental changes in salinity of the TCSA are indicated by the yellow / orange spots. The data extent is limited and uneven but most concern appears to be in the central western part of the Limestone Coast Wine Zone. Image is from DWLBC report of 2006, so years are most likely from 1996 – 2005.

8.6 An Example Of The Management Of Combined Interests of the Limestone Coast Wine Zone

The instigation of a surface drainage re-use program in 2006 aims to implement the inter-connected network to provide more surety of water supply to wetlands(REFLOWS 2008). Funded to the tune of $14 million in 2007 and submitted for planning approval and public consult in 2008, this program will direct water destined for discharge to sea, back to the upper south east flow system. This is likely to provide better opportunities for wetlands management and the control of dry-land salinity, as well as continuing to provide mitigation of flooding.

Further benefits expected are an improvement in water quality and an increase in the capacity for recreational use in many areas. Target zones for the REFLOWS project are shown in figure Figure 8.15.

The project includes agreements with landholders and is expected to involve the restoration of flows across 70,000 Ha of the Limestone Coast wine zone. As could be expected, a program such as this involves cutting new drains and flood-ways that must be incorporated into the existing network.

Waters from the Mosquito, Morambro and Naracoorte creeks as well as from the Bool Lagoon area will be directed towards the Marcollat watercourse (west of Padthaway). In particularly wet years, surplus flow will pass onto Bakers Range north and the capacity for inter-catchment transfers allows movement of water into the West Avenue waterway and Tilley swamp. Extreme flow may result in fresher water discharge into the southern lagoon of the Coorong (DWLBC 2008). No mention is made of further opportunities to store surface waters in 'reservoirs', but it can be presumed that more surface water is likely to lead to increased recharge of groundwaters, at least in some areas.

The water resources throughout the Limestone Coast wine zone are predominantly below the surface, this hidden nature of groundwater makes it easy to overlook, until an issue arises. Once groundwater issues develop, they can be difficult to turn around, consider what the influence of increasing salinity may have on long term agriculture. Management of the water resource throughout the Limestone Coast wine zone is critical in terms of the prosperity of the region and the posterity of its biodiversity.

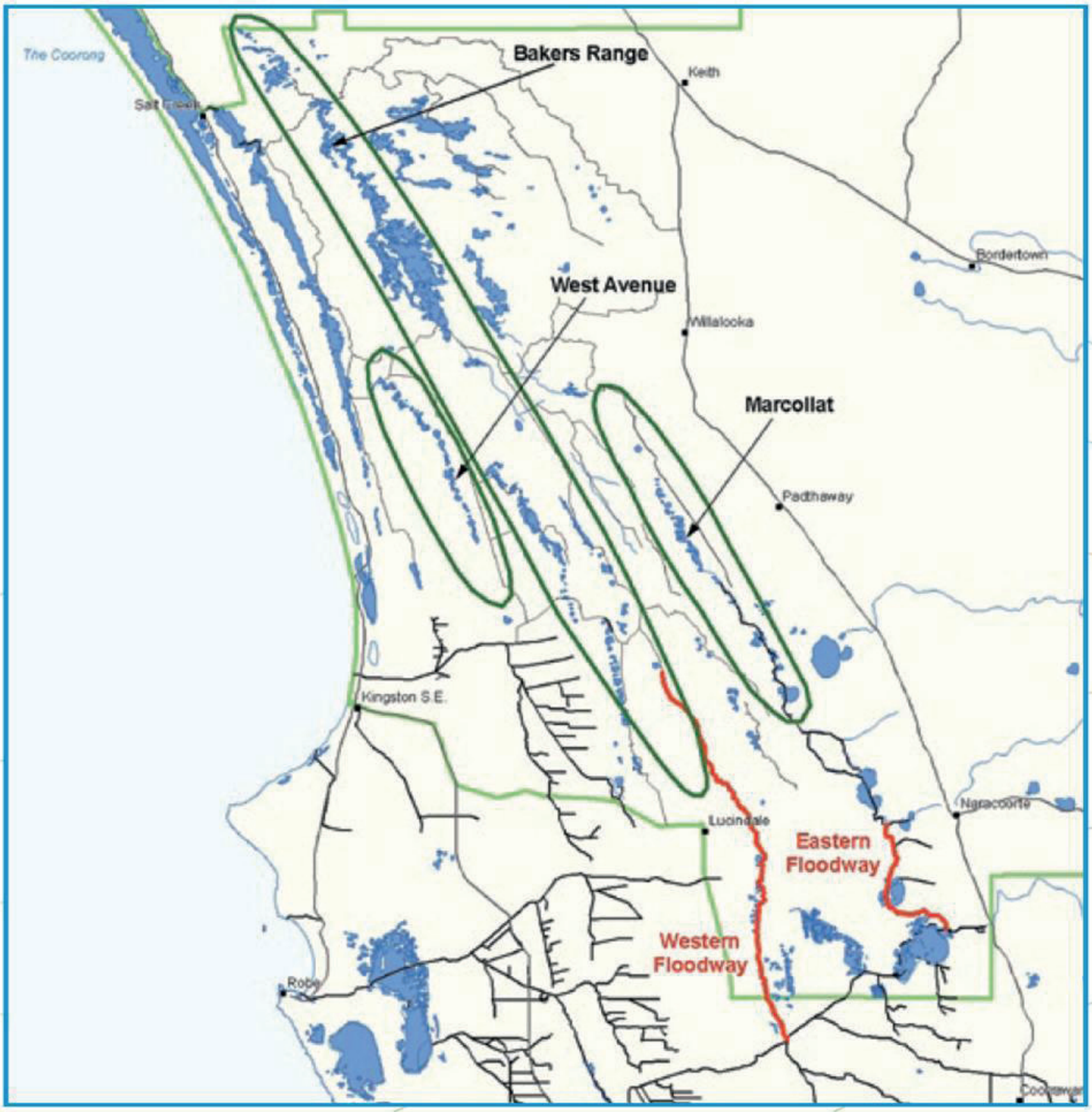

Figure 8.15. Target areas of the REFLOWS program utilising surface drainage to maintain ecologically significant wetlands and water courses. Image courtesy of Department for Water.

8.7 References

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Appendices
9

Monthly Climate Statistics for 'COONAWARRA' [026091]

Created on [26 Jan 2011 14:10:52 GMT+00:00]

Commenced: 1985

Last Record: 2010

Latitude: 37.29 Degrees South

Longitude: 140.83 Degrees East

Elevation: 57 m

State: SA

Statistic Element	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Mean maximum temperature (Degrees C)	27.1	27.4	25	21	17.2	14.5	13.8	14.8	16.8	19.3	22.5	24.7	20.3
Highest temperature (Degrees C)	44.5	43	40.8	35.1	29.9	23.2	23.2	25.5	31.2	35.8	37.6	42.8	44.5
Date of Highest temperature	28-Jan-09	14-Feb-04	6-Mar-86	9-Apr-05	4-May-90	8-Jun-05	6-Jul-88	20-Aug-95	26-Sep-87	12-Oct-06	30-Nov-06	31-Dec-07	28-Jan-09
Mean number of days >= 35 Degrees C	3.5	3.5	1.8	0	0	0	0	0	0	0	0.8	1.9	11.5
Mean number of days >= 40 Degrees C	0.7	0.3	0	0	0	0	0	0	0	0	0	0.1	1.1
Mean minimum temperature (Degrees C)	11.4	11.6	10	7.7	6.8	5.4	5	5.3	6.4	7.1	8.8	10.1	8
Lowest temperature (Degrees C)	0.2	2.5	0	-2.2	-3	-3	-3.3	-3.6	-2.6	-2.2	0	0.5	-3.6
Date of Lowest temperature	9-Jan-87	25-Feb-92	26-Mar-05	24-Apr-99	24-May-06	7-Jun-06	10-Jul-97	3-Aug-97	7-Sep-94	12-Oct-87	28-Nov-86	1-Dec-94	3-Aug-97
Mean number of days <= 2 Degrees C	0.2	0	0.6	2.7	4.2	5.7	5.8	5.2	3	2.8	0.9	0.3	31.4
Mean number of days <= 0 Degrees C	0	0	0	0.5	1.7	2.6	2.1	1.8	0.4	0.4	0	0	9.5
Mean rainfall (mm)	26.1	17.8	27.3	36.5	51.6	75.1	77.8	80.7	64.2	46.4	35.7	40.2	576.4
Decile 5 (median) monthly rainfall (mm)	19.2	17.6	21.4	29	49.2	68.8	76.5	76.8	63.3	46.5	32.1	26.8	601
Mean daily sunshine (hours)													
Mean daily evaporation (mm)	7.3	6.8	5.3	3.3	1.9	1.4	1.5	2.1	2.8	4.2	5.3	6.4	4
Mean 9am relative humidity (%)	62	65	69	70	83	87	85	81	74	66	65	62	72
Mean 3pm relative humidity (%)	38	38	40	50	63	70	69	64	60	55	48	44	53
Mean 3pm wind speed (km/h)	20.1	19.9	18.7	17.5	16.3	17.8	19.6	22	22.5	22.3	21.3	21.5	20

Glossary

10

Aquifer
A body of underground rock/sediment, from which useful quantities of water can be extracted.

Cretaceous
Time Period; from about 145 Mya to about 65 Mya (named after the extensive chalk (calcium carbonate) deposits laid down during this time.

Delamerian
Mostly used to describe a significant period of mountain building in South Australia from about 514 Mya to about 500 Mya, even older sediments (~ 900 Mya) were metamorphosed, buckled, faulted, folded and intruded by granites.

Geomorphology
The science dealing with landform/land surface and its genesis in relation to the underlying geology.

Horst and Graben
These are opposing terms that describing landforms associated with faulting that produce a topographic low between opposing faults (Graben) or a topographic high between opposing faults (Horst), related to rifting process. Half Graben describes that situation where only one side of the opposing faults are expressed or described.

Jurassic
Time Period; from about 200Mya to about 145 Mya (Age of Reptiles).

ka
An interval of a thousand years.

Karst
A geomorphological structure formed as a result of preferential dissolution of limestone. Giving rise to caves, tunnels, pitfalls for animals and preferential flow-paths for underground waters, common features throughout the SE of SA.

kya
Thousand years ago.

LGM
Last Glacial Maximum was a period of globally reduced temperatures during the last glacial cycle between 30 and 18 thousand years ago

Ma
An interval of a million years

Marl
Loose earth or stone comprised of clay and calcium carbonate, these two fine grained materials are usually in a well mixed deposit of somewhere around 40 – 60% clay and 40 – 60% calcium carbonate.

Mya
Million years ago.

Mesozoic
A Geological Era; from about 250 Mya to about 65 Mya (Age of Dinosaurs).

Ordovician
Time Period; from about 488 Mya to about 444 Mya (First jawed Fishes).

Palaeozoic
Geological Era; from about 542 Mya to about 251 Mya (meaning – 'old life').

Pleistocene
Geological Epoch; lasting from 2.6 million to 10 thousand years before present.

Quaternary
Geological Period; from about 2.6 Ma to present, encompassing the Pleistocene and Holocene epochs.

Rift
Extensional tectonic term describing separation of lithospheric plates, usually along mid-ocean ridges, often result in continental genesis and demarcation.