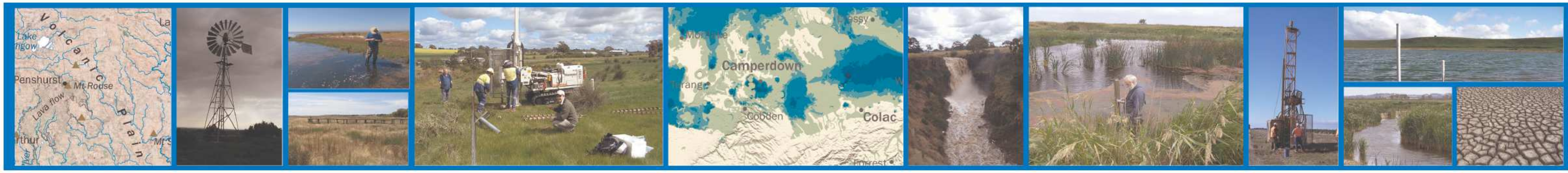
South West Victoria
Groundwater Atlas



South West Victoria Groundwater Atlas

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Australian Government
National Water Commission

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Foreword

Groundwater is a valuable resource but its great potential is hidden. It is complex, often described in unfamiliar technical language and hard to visualise. This atlas provides information in words and graphics that readers can understand – to help them develop their knowledge of this vital water resource.

The atlas describes the groundwater resources in South West Victoria: how much there is, where it is, how deep and thick it is, what it could be used for and how it is used now. We have presented the information as clearly as possible. It does not aim to be fully comprehensive, technically unchallengeable or academic. The maps are helpful for guidance on a regional scale but not suitable for making commercial decisions at a property level.

In developing the atlas, we drew information from a range of sources: from the collective understanding of our staff, industry experts and groundwater users in the region, and from key technical reports, maps and data. Importantly, the foundation for this work was the ability to describe the basic dimensions of aquifers. This was enabled through three-dimensional groundwater mapping developed by Southern Rural Water for its region. Combined with time series information including groundwater levels, usage and licences, we have a powerful way to present our knowledge.

On behalf of the Board I thank all members of the project team for their exhaustive efforts. General Manager Graham Hawke initiated and provided leadership to the project. Penny Winbanks managed the project and co-authored the atlas along with our team of hydrogeologists: Terry Flynn (technical leader and main author), Elissa McNamara and Liam Murphy. Eleanor Underwood led our consultation and, along with John Tilleard, contributed greatly to the design and shaping of the final product. We also appreciate the expertise of Spatial Vision who produced this publication.

The atlas project received significant financial support from the Australian Government through the National Water Commission's "Raising National Water Standards Program". I hope that our work will contribute to conversations that influence the way groundwater information is described and communicated on a national scale.

ACKNOWLEDGEMENTS

This atlas was developed by Southern Rural Water in consultation with a Stakeholder Reference Group who made significant contributions to its content and accuracy.

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Terry Burgi
CHAIRMAN, SOUTHERN RURAL WATER

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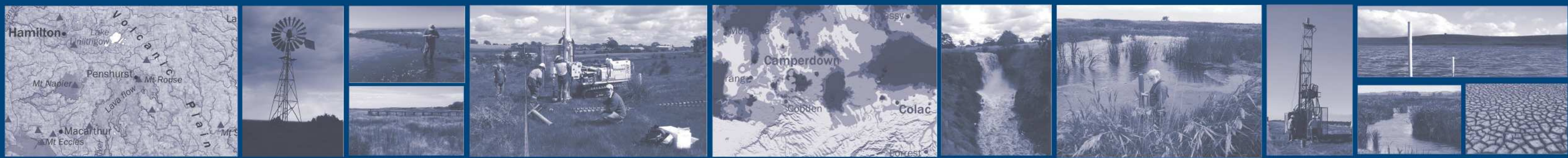
Chapter 1: Introduction



South West Victoria

This atlas describes the current understanding and use of groundwater resources in Victoria's South West Region. This is the area south of the Great Dividing Range stretching from Geelong to the South Australian border.

Landscape

The landscape of the region is made up of volcanic and coastal plains flanked by granite mountains, bedrock ridges and valleys. The Glenelg, Wannon and Hopkins Rivers rise in the Great Dividing Range in the west of the region and flow south across the volcanic and coastal plains to Bass Strait.

Volcanic activity has left its mark on the landscape – numerous cones, lakes such as Lake Corangamite, Lake Bolac and scoria mounds occur mostly across the southern areas. Limestone sink-holes and caves are found on the coastal plains from Port Campbell west to the border.

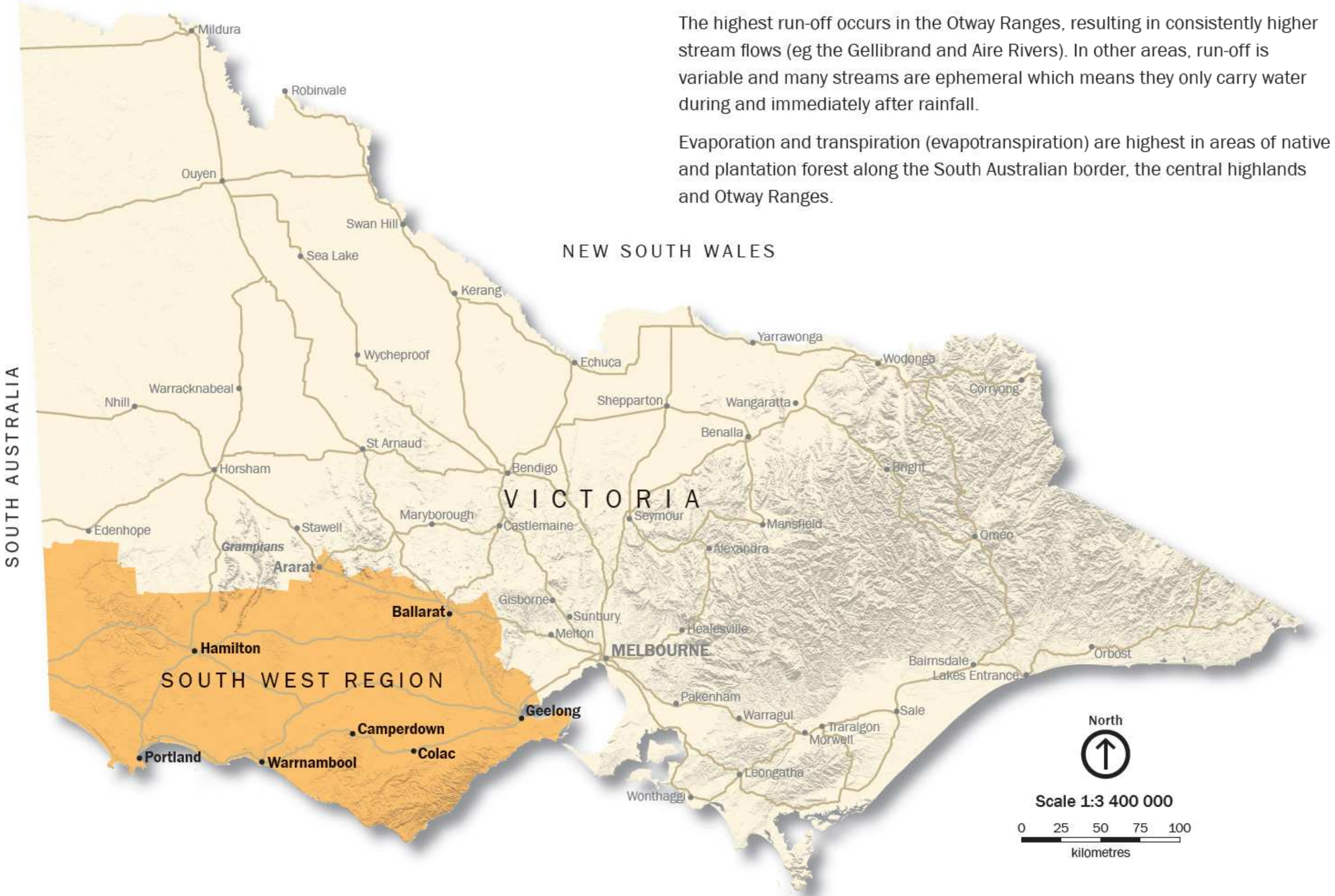
Before European settlement, grasslands dominated the volcanic plains and box ironbark, yellow gum woodlands and forests covered the uplands. Land clearing for farming developments followed the settlement. Over the last few decades extensive plantation forests have repopulated wooded vegetation particularly along the South Australian border.

Climate

Rainfall varies significantly across the region. The Otway Ranges is one of the wettest parts of Victoria, receiving more than 1,200 mm annually compared to the remaining areas of the region that generally receive less than 800mm annually.

The highest run-off occurs in the Otway Ranges, resulting in consistently higher stream flows (eg the Gellibrand and Aire Rivers). In other areas, run-off is variable and many streams are ephemeral which means they only carry water during and immediately after rainfall.

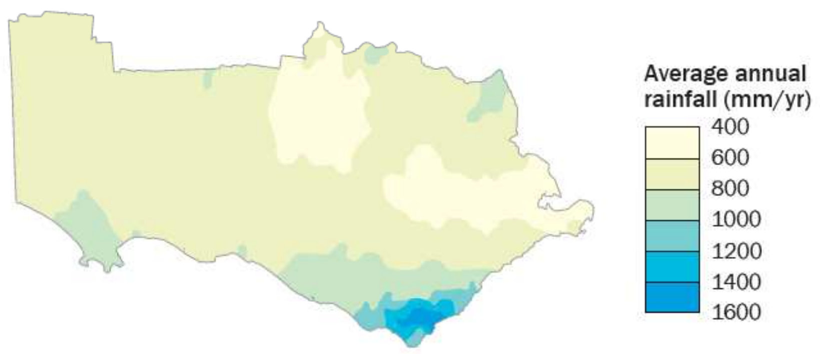
Evaporation and transpiration (evapotranspiration) are highest in areas of native and plantation forest along the South Australian border, the central highlands and Otway Ranges.



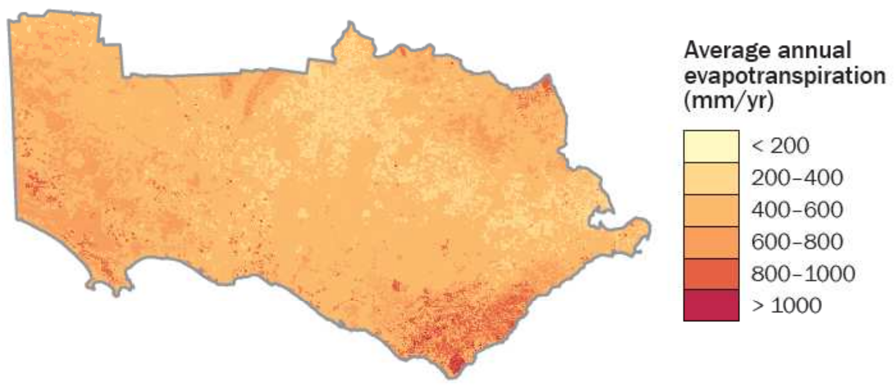
South West Region (Victoria)

(Top to bottom): a volcanic crater lake; the Grampians; volcanic plains

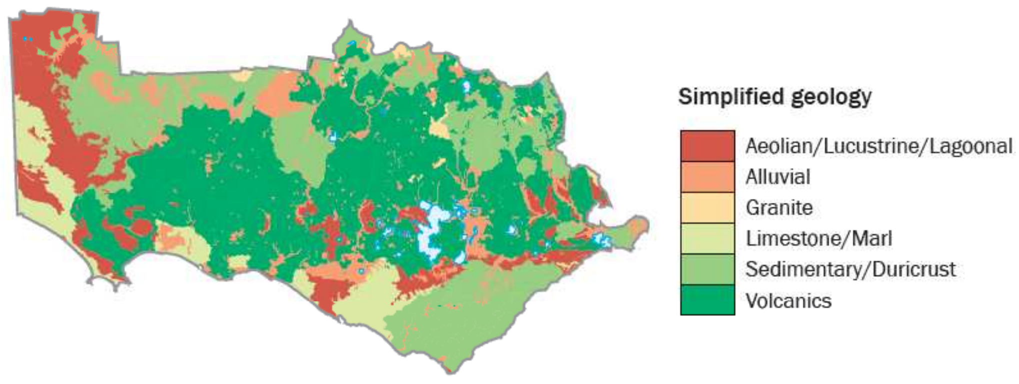
Landscape and climate



Average annual rainfall (mm/yr)
Recorded from 1980 to 1999 (Bureau of Meteorology)



Average annual evapotranspiration (mm/yr)
Modelled from 1958 to 2005, (DSE EnSysm project)



Simplified geology
Department of Primary Industries

Land cover
DSE 2000

Reading guide

Chapters 1, 2 and 3 introduce you to groundwater, the geological context, aquifer behaviour and groundwater use and management.

Chapters 4, 5 and 6 cover these topics in more detail for each group of aquifers in the region. Topics include:

- Geology
- Salinity and yield
- Movement of groundwater
- Groundwater and the environment
- Water balance
- Regional trends
- Users and usage
- Current and emerging issues

User groups

We have identified four groups of groundwater users based on their use, the type of aquifer they are most likely to access and the value of production (see table below for details).

We have not recognised plantations (that intercept groundwater), mines or quarries as user groups, but these are discussed in the atlas.

User group	Description of user groups	Type of aquifer accessed
Domestic and stock (D&S)	Includes all private right domestic and stock users in the region. These users are mainly rural, but also some private urban use for garden watering. Numerous users generally extracting quite small volumes. Also includes public emergency water supply use.	Mainly use upper aquifers.
Agribusiness	Includes those using groundwater for more intensive agricultural and horticultural purposes (including irrigating vegetables or pasture or for dairy-wash and other commercial activities (such as water bottling). Occurs mainly in the areas around Ballarat and Colac and along the coast from Warrnambool to South Australia. A smaller number of users; use higher volumes than the D&S user group.	Mainly use upper or middle aquifers.
Environment	Recognises that groundwater supports springs, streams, lakes, swamps and wetlands which all contribute to the environmental value of the region.	Mainly use upper aquifers, outcropping areas of lower aquifers or exposed basement.
Urban and industrial	Includes urban supplies drawn from groundwater (and then treated) for residential and commercial use as well as other industries such as refineries, smelters and processing plants. Mainly near the Otway Ranges and the coast.	Mainly use lower aquifers.

Aquifer groups

For the purpose of this atlas, we have identified three groups of aquifers (see table below) according to their depth and age (each type is colour-coded consistently throughout the atlas).

The depth of the aquifers corresponds to the order in time in which they were formed. For example the lower aquifers were formed first. In some cases an aquifer might be quite close to the surface but it has been grouped with the middle aquifers because of its geological age. The basement rock has been grouped with the lower aquifers.

The Victorian Aquifer Naming Framework groups hydrogeological units according to their geological age (see table below).

Aquifer and aquitard group	Aquifer and aquitard name	Geological age	Groundwater Management Units (GMUs)	Hydrogeological unit(s)
Upper	Upper tertiary/ quaternary basalt	0.01–5 million years	Bungaree, Cardigan, Glenelg, Glenormiston, Colongulac, Hawkesdale (part), Warrion, Yangery (part) (Hawkesdale and Warrion are part of Newer Volcanics)	Various quaternary deposits, Newer Volcanics, Bridgewater Formation
	Upper tertiary aquifer (fluvial)			Older sand aquifers: Moorabool Viaduct Formation, Hanson Plain Sand, Dorodong Sand, Grange Burn Sand
Middle	Upper middle tertiary aquifer	5–40 million years	Glenelg, Hawkesdale, Heywood, Nullawarre, Yangery	Port Campbell Limestone, Portland Limestone, Fyansford Formation, Batesford Limestone, Upper Gambier Limestone, Bochara Limestone, Duddo Limestone, Winnambool Formation
	Upper middle tertiary aquitard			Geera Clay, Gellibrand Marl, Newport Silt, Jan Juc Formation, Point Addis Limestone, Peubla Clay, Zeally Limestone, Maude Formation, Pintadeen Basalt
	Lower middle tertiary aquifer		Condah	Clifton Formation
	Lower middle tertiary aquitard			Lower Gambier Limestone, Wangoom Sand, Narrawaturk Marl, Demon's Bluff Group, Upper Mepunga Formation
Lower	Lower tertiary aquifer	40–65 million years	Dartmoor, Gellibrand, Gerangamete, Glenelg, Newlingrook, Paaratte, Portland, Jan Juc	Lower Mepunga Formation, Dilwyn Formation, Eastern View Formation, Pember Mudstone, Pebble Point Formation, Timboon Sand
	Cretaceous and Palaeozoic bedrock	65 – 545 million years		All Cretaceous and Palaeozoic basement rock

Reading guide

How to use the atlas

Read the introductory chapters first. They will give you an overview of the basic concepts so you can understand, interpret and analyse the text, data and maps throughout the atlas.

Use the tables on page 8 to identify which user group or aquifer group you are interested in. Chapters 4, 5 and 6 provide more detailed information on each of the three aquifer groups respectively: upper, middle and lower.

Example 1: A groundwater user near Warrnambool is interested in the Port Campbell Limestone. Using the table on page 8 they can see that this belongs to the middle aquifer group. This aquifer group is discussed in Chapter 5.

Example 2: A groundwater user in Ballarat is interested in the Bungaree Groundwater Management Unit (GMU). Using the table on page 8 they can see that this belongs to the upper aquifer group. This aquifer group is discussed in Chapter 4.

To provide readers with a starting point the tables below list some questions of interest and corresponding page references. These lists are not exhaustive and the atlas can be used to answer many more questions.

The following table lists some basic and commonly asked questions that may be of interest to readers.

	Background	Upper aquifers	Middle aquifers	Lower aquifers
Where are the different aquifers?	8	26	36 & 37	46
How much groundwater is there?	16	27	38	47
What can I use groundwater for?	11	27	38	47
How is groundwater monitored and what are the trends?	11 & 23	31	42	51
How is groundwater managed?	11, 20 & 21	33	44	53
Who uses groundwater in the South West region?	22	32	43	52

Examples of some of the more complex questions that can be answered using the atlas are listed below. In this instance, the page references should be used as a starting point only. Due to the complex nature of the questions information to support these questions can be found throughout the atlas.

	Background	Upper aquifers	Middle aquifers	Lower aquifers
How does groundwater replenish and move?	10, 14 & 16	28	39	48
What impacts groundwater levels?	17	30	41	50
How does groundwater interact with the surrounding environment?	10	29	40	49
Do different aquifers interact with each other?	17	30	41	50
Will the groundwater ever run out?	16	31 & 32	42 & 43	51 & 52

Limitations and assumptions

The groundwater mapping used in this atlas was prepared at a large scale of 1:250,000. The data used to create the maps varied in its spatial distribution so a moderate level of mathematical interpretation was required. For this reason, the data may not be suitable for use to identify availability, yield or quality of groundwater at a local or property level.

The content of the atlas is based on data sourced from various organisations and Southern Rural Water does not warrant the accuracy of the data supplied.

The licence data will change over time due to influences such as water trading and regulatory change such as the recent dairy amnesty. It should be used as a guide only.

The bore construction data is sourced from the State's Groundwater Management System and is not always reliable at a site specific level. Domestic and Stock (D&S) usage is estimated at 1.3 ML/yr per known bore.

Useful links

Further information not included in this atlas can be found about a range of groundwater related topics. Some selected links are shown below.

Information	Link
Climate	www.bom.gov.au/climate
Current entitlements	waterregister.vic.gov.au
Groundwater Dependent Ecosystems	www.nwc.gov.au/water-for-the-environment/groundwater-dependent-ecosystems
Groundwater data	www.vicwaterdata.net/vicwaterdata
Groundwater mapping	www.srw.com.au
Groundwater monitoring	www.water.vic.gov.au/monitoring/monthly/groundwater_levels gmu.geomatic.com.au www.ubspatial.com.au www.srw.com.au
Groundwater projects	www.nwc.gov.au/national-groundwater-action-plan/national-groundwater-action-plan-projects
Land use	www.dpi.vic.gov.au/vro
Licensing enquiries	www.srw.com.au
Minerals and energy	www.dpi.vic.gov.au/earth-resources
Western Region Sustainable Water Strategy	www.water.vic.gov.au/programs/sws/western
Secure Allocation Future Entitlements	www.water.vic.gov.au/environment/groundwater/management/secure-allocations,-future-entitlements
Understanding groundwater	www.nwc.gov.au/groundwater www.usgs.gov www.water.vic.gov.au/environment/groundwater/news-and-info
Using and managing groundwater	www.srw.com.au www.water.vic.gov.au/environment/groundwater/management

Common acronyms and units

D&S	Domestic and stock	GMU	Groundwater Management Unit
EC	Electrical Conductivity (a measure of salinity)	PCV	Permissible Consumptive Volume
GDE	Groundwater Dependent Ecosystem	TDS	Total Dissolved Solids (a measure of salinity)

ML = megalitre = 1,000,000 litres

GL = gigalitre = 1,000ML

ML/yr = megalitres per year

mAHD = metres above sea level (Australian Height Datum)

mg/L = milligrams per litre (used to measure TDS)

µS/cm = microsiemens per centimetre (used to measure EC)

Understanding groundwater

What is groundwater?

Groundwater is water that is found under the ground. It is stored in and can flow through discrete layers known as aquifers.

What is an aquifer?

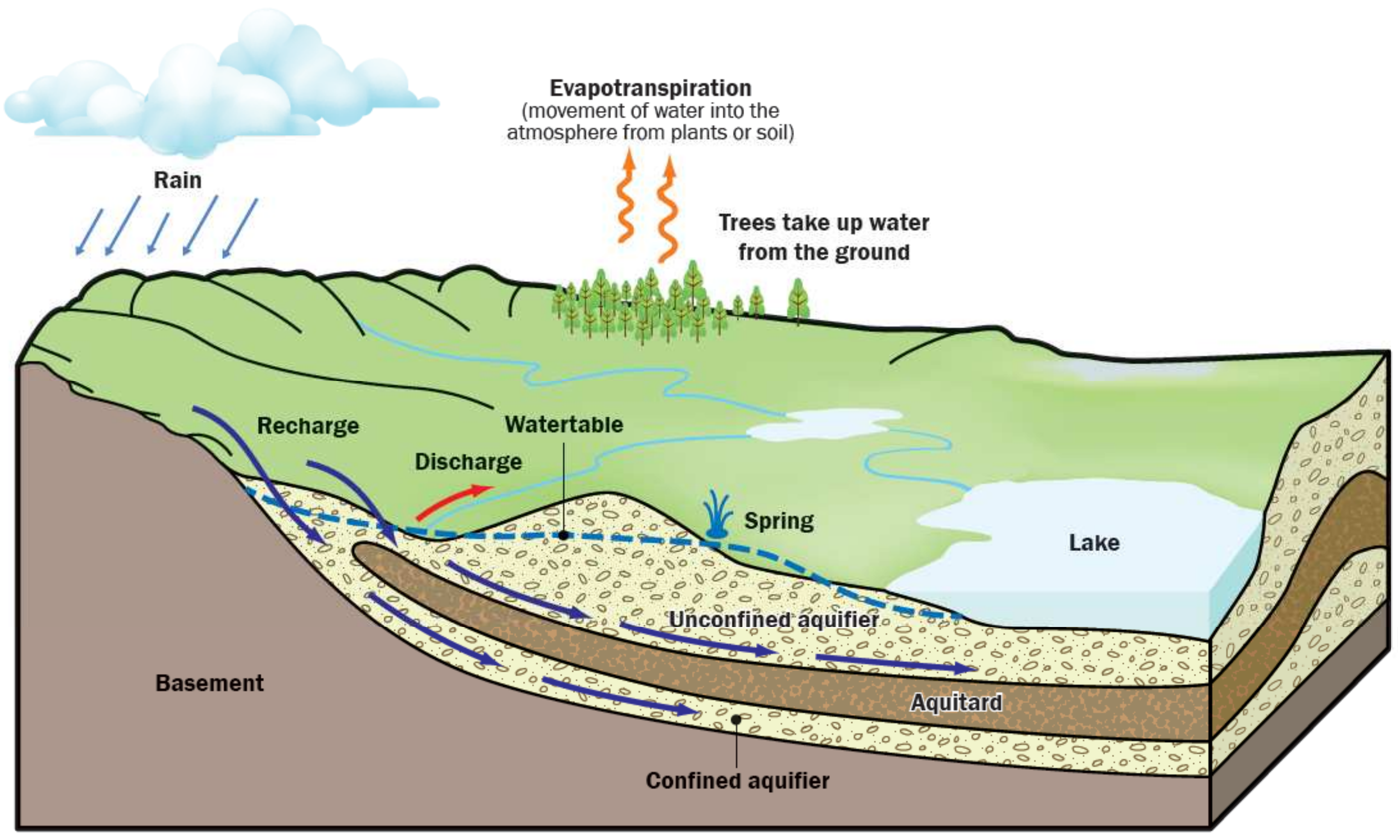
An aquifer is a discrete layer of fractured rock, gravel, sand or limestone below the ground that is porous enough to hold and convey groundwater.

Where does groundwater come from?

Surface water from rainfall or other water bodies percolates through the ground to the water table (**recharge**) where it is stored in an aquifer as groundwater. An aquifer can receive recharge directly from rainwater, from a surface water feature (such as a stream, lake or wetland) or from water stored in a neighbouring aquifer (alongside, above or below). Groundwater can be stored in an aquifer for thousands of years.

Where does groundwater go?

If it's close to the surface, groundwater can evaporate directly to the atmosphere or be used by vegetation. It can return (**discharge**) to the surface by seeping to surface water features such as springs, swamps, wetlands, rivers and creeks or it can flow to a neighbouring aquifer (alongside, above or below). It can also be extracted via a bore or a well.



How does groundwater move?

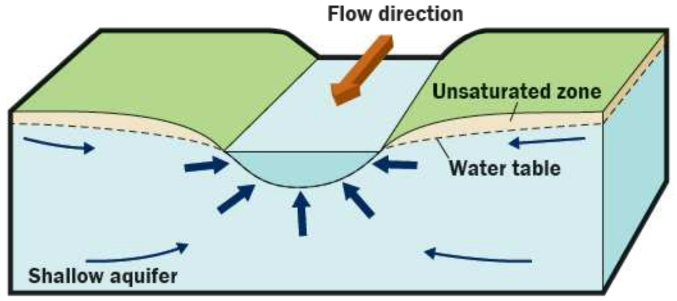
How groundwater moves through an aquifer and how much groundwater comes from a particular aquifer layer depends on the number of pores and fractures in the soil and rock and how well they are connected. Compared to stream flow, groundwater may take tens, hundreds or thousands of years to move the same distance through an aquifer.

What is the difference between an unconfined and a confined aquifer?

An **unconfined aquifer** is when the rock and soil between the groundwater and the surface of the ground is porous. A **confined aquifer** is when an aquifer is overlain by a layer of impermeable rock or clay (known as an **aquitard**). A confined aquifer can be under pressure. Artesian water is groundwater from a confined aquifer that is under sufficient pressure to allow the water to reach the surface without pumping. If this occurs naturally it forms a spring.

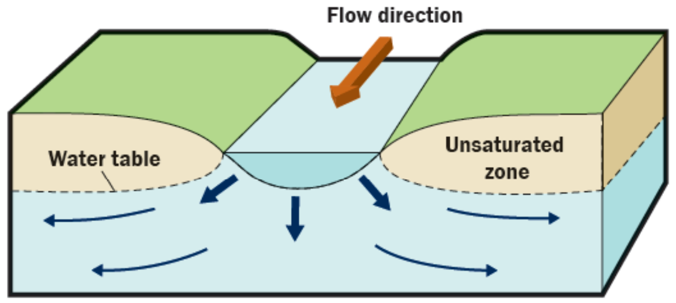
How does groundwater interact with streams, lakes and wetlands?

Water can move in both directions between an aquifer and surface water feature (eg wetlands, swamps, lakes and streams). Some surface water environments rely on recharge from groundwater, known as **baseflow**, to stay healthy and survive. These are known as Groundwater Dependent Ecosystems (GDE). The most commonly recognised GDEs include wetlands, river baseflows, vegetation, cave ecosystems and even the terrestrial animals that drink groundwater.



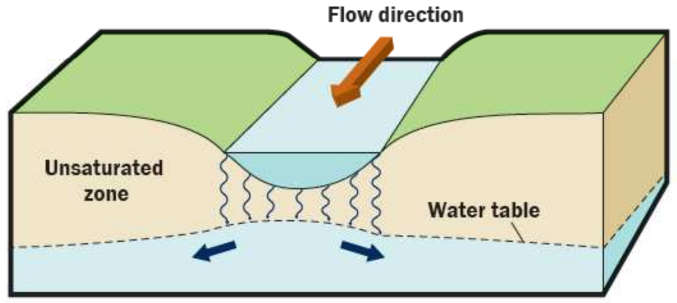
1. Gaining systems

If the water table is higher than the stream bed, groundwater can move through the ground into the stream (or other surface water environment).



2. Losing systems

If the stream flow is higher than the water table, the stream can lose water through the streambed into the aquifer.



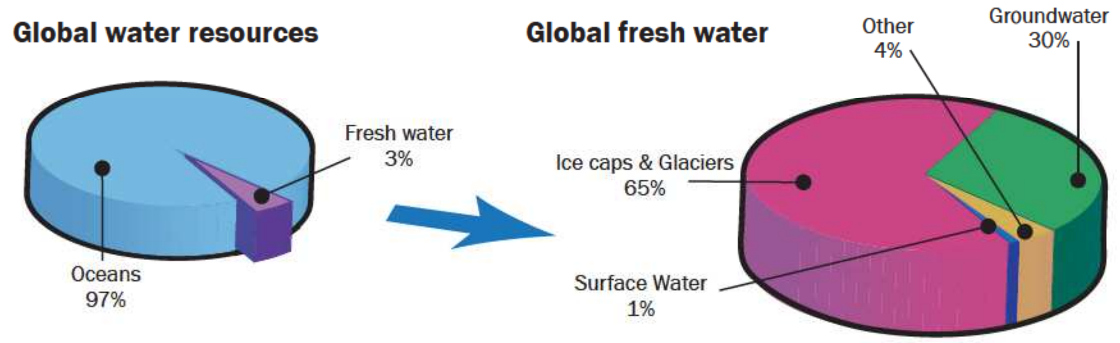
3. Partially disconnected systems

If the stream is separated from the water table by an unsaturated zone, there is still a weak connection. Pumping from a nearby bore will not impact on the stream flow but some leakage from the stream into the aquifer can occur.

Using and managing groundwater

How important is groundwater?

Groundwater is a significant global resource. It makes up about 30% of our fresh water resources while less than 1% occurs in our streams, rivers and other surface water environments.



How is groundwater accessed?

Vegetation can access groundwater directly or intercept water as it percolates through the ground. Some groundwater flows to the surface into springs, streams, wetlands, swamps or lakes. Shallow groundwater can be accessed by a well. Deeper groundwater can be accessed by drilling a bore (up to hundreds of metres deep) and pumping water from the aquifer to the surface using a windmill or powered pump.

What limits groundwater use?

Groundwater use for agricultural purposes is generally limited by water yield (availability) and quality. This table shows salinity limits for various agricultural uses:

Salinity EC µS/cm	Salinity TDS (mg/L)	Suitability for stock watering	Suitability for irrigation
<300	<180	Suitable for all stock.	Suitable for most crops and soil types.
300-800	180-480		Suitable for most crops (note: may require increased leaching for sensitive crops).
800-2500	480-1500		Suitable for some crops (note: requires adequate leaching and may be a problem if used on soils with restricted drainage and salt tolerance of plants must be considered).
2500-5800	1500-3480		Suitable only for salt tolerant crops on permeable, well drained soils (note: requires careful management).
5800-7500	3480-4500	Unsuitable for poultry.	Suitable only for highly salt tolerant crops on soil with excellent drainage and leaching potential (note: requires adequate winter rains to ensure excess salts are leached from the soil *and* requires careful management).
7500-8500	4500-5100	Unsuitable for poultry and pigs.	
8500-16500	5100-9900	Unsuitable for poultry and pigs. Generally unsuitable for lambs, calves and weaner stock. Suitable for dry mature sheep and cattle.	
16500-25000	9900-15000	Suitable only for dry mature sheep and cattle (note: requires caution for cattle unaccustomed to water with this salinity level).	
>25000	>15000	Unsuitable for all stock.	Generally considered too saline for irrigation.

The environment uses groundwater of varying salinity levels (from freshwater to hypersaline). Groundwater used for drinking supplies must be treated to make it suitable for human consumption, so while salinity is not critical to end use the cost implications of desalination must be considered.

Why is the use of groundwater managed?

Groundwater is not a limitless resource. Unsustainable development has been shown to result in declining groundwater levels and localised impacts can lead to interference between neighbouring bores. Consequently, groundwater use needs to be managed to ensure its sustainability and to limit any impact on other users.

How is the use of groundwater managed?

At a broad level, groundwater use is managed within Groundwater Management Units (GMU). These GMUs may be Water Supply Protection Areas (WSPA), Groundwater Management Areas (GMA) or Unincorporated Areas (UA). At an individual level, Southern Rural Water (SRW) regulates and manages groundwater use through issuing licences.

What licences are needed to access groundwater?

A 'works licence' is required to construct a bore (previously 'bore construction licence').

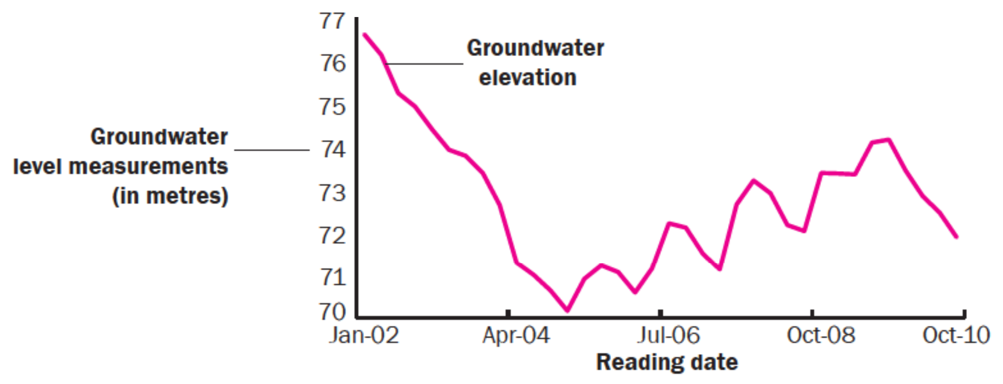
A 'take and use' licence is required to extract water from a bore, well, excavation or spring for any commercial purpose, including food and fibre production, industry or urban water supply.

No licence is required for landholders to extract groundwater on their own property for stock watering or domestic purposes such as watering a kitchen garden.

How is groundwater monitored?

SRW uses meters to monitor the amount of water taken from all new actively used commercial bores and from other commercial bores with entitlements over 10 ML or that lie within priority areas. Most licensed groundwater use is now metered.

Observation bores are used to collect groundwater level information which is measured in mAHD (metres above sea level). All new data is added to a database and analysed using hydrographs which show the fluctuations in groundwater levels over time (see example in graph below). Water quality information is also collected and recorded each time a new bore is drilled.



How are opportunities for additional groundwater entitlement identified?

The volume of water that can be allocated within a GMU is known as the Permissible Consumptive Volume (PCV) – previously Permissible Annual Volume (PAV). The PCV is calculated based on desktop assessments, licensed volumes and past usage patterns (see page 23 for a map showing GMUs).

1 Introduction

Chapter 2: Aquifers and groundwater

Groundwater movement through aquifers is driven by gravity and controlled by the materials it passes through. It is affected by changes that may be very distant or occurred at a much earlier time. This makes it very complex and difficult to understand.

This chapter discusses aquifer characteristics (such as groundwater movement, recharge, discharge, quality, yield, storage and resilience) to help explain how changes in groundwater levels affect users and the environment.

Aquifer systems

The aquifers described in this atlas occur predominantly in the Otway Basin. They are a system of sediments up to 1,000m thick, formed over the past 60 million years.

The most recent formations are the shallow volcanic, limestone and sand aquifers that can be found at the surface. The older sand aquifers are deeply buried under younger sediments and separated from each other by thick aquitards. Near the basin margin they come close to or outcrop at the surface. At the basin margin the various aquifers converge and may act as one unit (see diagram at right).

Aquifers are unconfined where they appear at the surface which means they can receive recharge directly from rainfall. Where they become buried under sediments they receive recharge more slowly by leakage.

The map below shows where the upper, middle and lower aquifers occur at the surface.

Flow systems

Rainfall percolates through the surface sediments until it reaches the water table where it flows under gravity through local, intermediate and regional flow systems within the aquifers.

Local flow systems have flow paths of less than 5 km and mostly occur in the upper aquifers. Groundwater in a local system has a relatively short residence time before it discharges to local streams. The aquifer responds quickly to change due to rainfall or extraction (see graph below right).

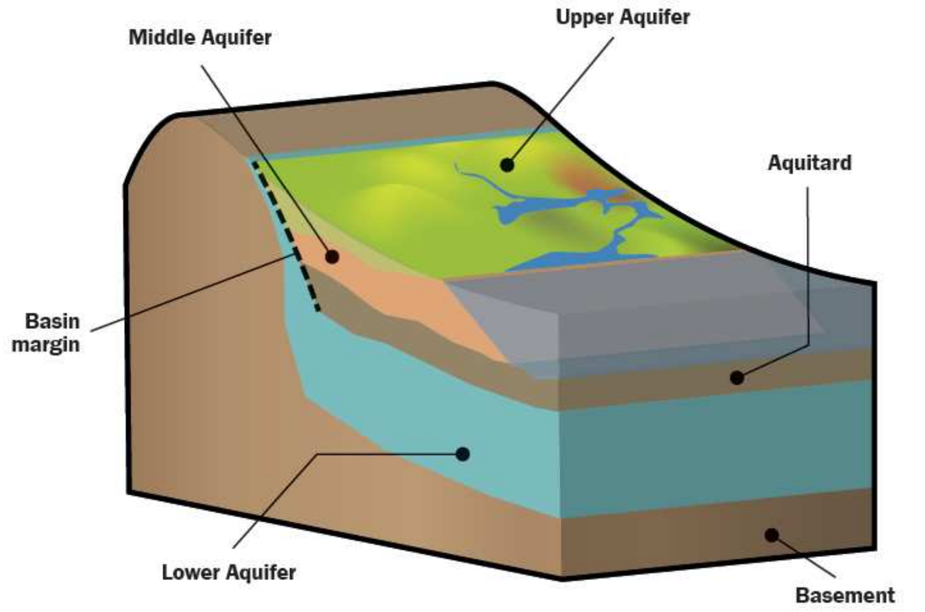
Intermediate flow systems have flow paths of up to 30 km and **regional flow systems** flow beyond 30 km. These systems are likely to be confined and rely primarily on leakage from overlying layers or deeper layers under pressure. They react more slowly to change than local systems. Groundwater in regional flow systems has a long residence time so the impact of a change in rainfall, extraction or land use may not be seen in a lifetime.

Observations

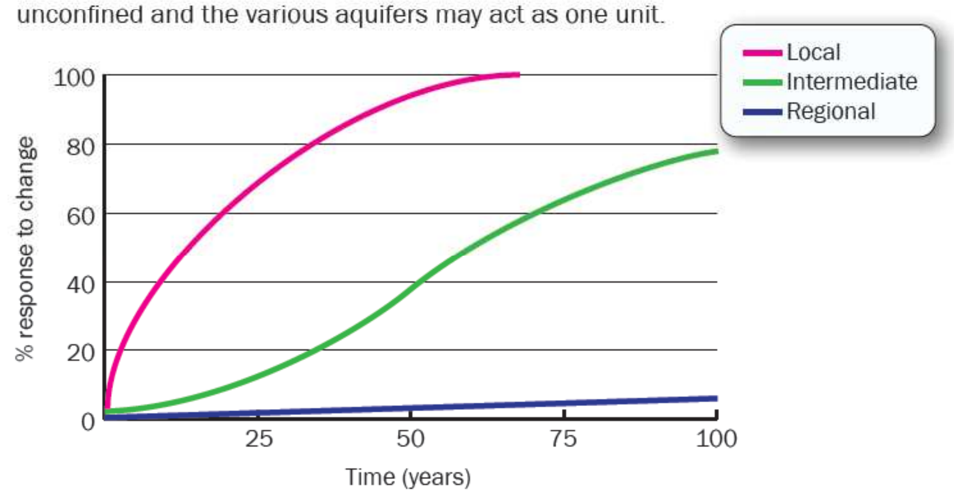
- Groundwater flow systems describe the cycle of groundwater from recharge to discharge within aquifers.
- There are three different types of flow systems: local, intermediate and regional, and many flow systems within aquifers.
- Local flow systems respond quickly to the impact of change in rainfall, extraction or land use; regional systems may take decades to respond.
- Upper aquifers are unconfined and receive recharge directly from rainfall; middle and lower aquifers are only unconfined near the basin margin and rely mainly on leakage from an overlying aquifer for recharge.

Aquifers recharge areas

(This map shows where aquifers occur at the surface – interpreted from surface geology)



This diagram shows that as the lower aquifer approaches the surface it becomes unconfined and the various aquifers may act as one unit.



This graph shows how groundwater responds to change in different flow systems over time.

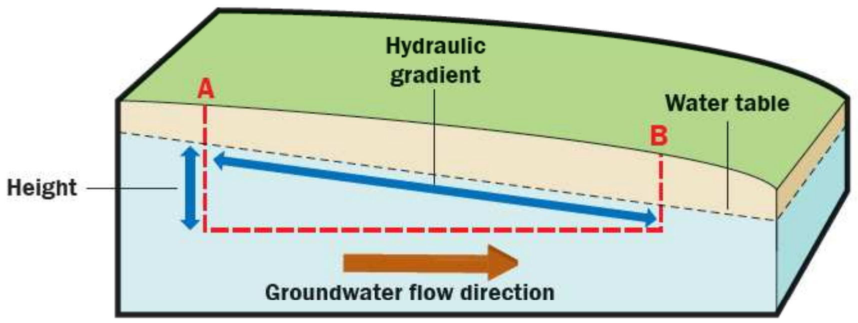
Movement of groundwater

How does groundwater move?

Two factors affect the ability of an aquifer to convey water: its hydraulic conductivity and hydraulic gradient (see diagram below).

Hydraulic conductivity describes how easily water can move through pore spaces within the aquifer. Sand aquifers tend to have a higher hydraulic conductivity than rock aquifers.

Hydraulic gradient describes the difference in height between two points. A steep gradient results in higher pressure, which means that the water can move more quickly through the particle spaces within the aquifer.



How long does it take for an aquifer to respond to change?

The lag in the way an aquifer responds to things like pumping, a change in weather or land use can take hours, weeks, years or even centuries. If the change is reversed, it can take decades for the aquifer to recover. This means that the groundwater levels we currently observe may be the result of change that occurred a long time ago – for example deforestation or high rainfall periods.

How does evapotranspiration affect groundwater systems?

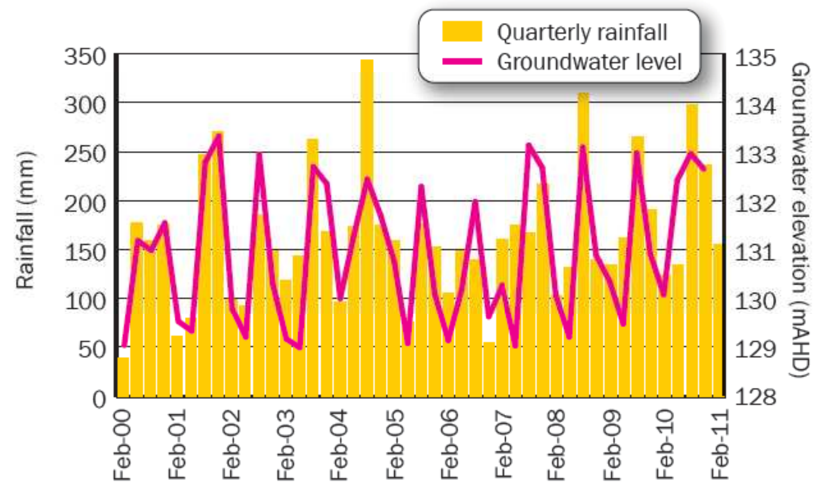
Vegetation draws groundwater if its roots can intercept a high water table (eg 5 metres from the surface). In expansive flat terrain, evapotranspiration is an important factor affecting the movement of groundwater. It is vital to the health of native landscapes, extracting more water than bores. Therefore land use significantly impacts the availability and movement of groundwater.

How does rainfall affect groundwater levels?

Different types of aquifers respond differently to rainfall patterns, depending on whether it is an unconfined upper, semi-confined middle or confined lower aquifer. The hydrographs below show examples of different types of aquifers in the region.

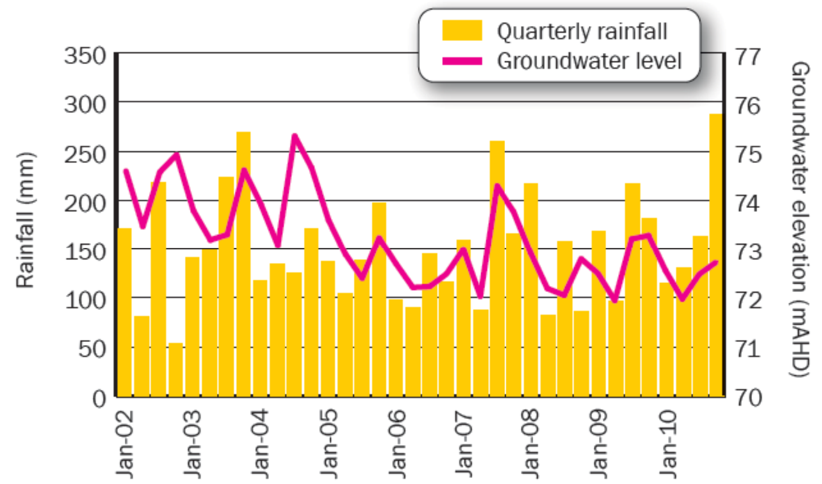
In unconfined upper aquifers, the groundwater level mimics the rainfall pattern and there is very little response time delay. These aquifers are highly reactive to rainfall.

Hawkesdale: unconfined upper aquifer



In middle aquifers, the groundwater level also tends to mimic the rainfall pattern, however the response time is delayed and more subdued than in the shallower aquifers – this reflects the additional time it takes for the rainwater to percolate down into the aquifer.

Condah: confined middle aquifer

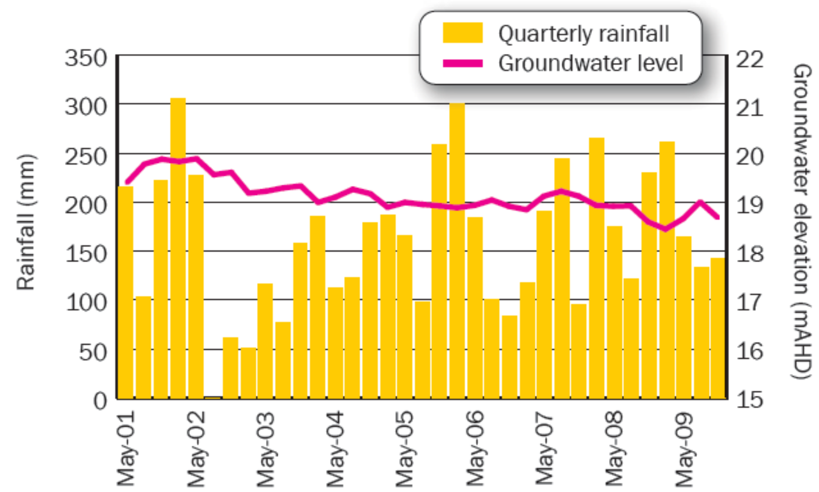


Observations

- The rate and direction of groundwater flow is driven mainly by gravity and how easily water can move through the aquifer material.
- Evapotranspiration significantly impacts the availability and movement of groundwater in flat terrain.
- Unconfined, semi-confined and confined aquifers respond differently to rainfall.
- The reliance of ecosystems on groundwater is variable and complex.

In confined lower aquifers, the lack of correlation between the groundwater level and the rainfall pattern shows that these aquifers do not react to rainfall or short-term climate variations.

Portland: confined lower aquifer



How much do ecosystems rely on groundwater?

Ecosystems may rely on groundwater entirely, partially or not at all. For example, a submerged cave has no other source of water and is therefore entirely dependent on groundwater. On the other hand, vegetation may draw more on groundwater to sustain growth in dry years however it would probably survive without it. Groundwater may support the health and survival of one species over another.

It is very difficult to know how much any ecosystem depends on groundwater. What we do know is that some level of dependence occurs when a high water table interacts with a surface ecosystem. For example where a high water table exists and streams, wetlands, vegetation or springs nearby persist during dry periods it's likely they depend on groundwater for their health.

Groundwater characteristics

Quality and yield

Groundwater **quality** varies according to the chemistry of the materials in the aquifer and how close the aquifer is to recharge points. Groundwater quality can be affected by temperature, pH levels, heavy metals and organic substances. Generally, we use salinity as an indicator of groundwater quality.

Evaporation of high water tables can concentrate the groundwater salinity in some areas or a change in groundwater levels can result in saline water being drawn into the aquifer.

Groundwater samples are taken from all new groundwater bores in the region and analysed for major ions, salinity, pH and temperature, but data showing a change in water quality over time is rare.

Yield is a measure of how much and how quickly groundwater can be extracted from an aquifer. Both volume and flow rates are greater in porous aquifers where there is plenty of space between the particles of sand, gravel or fractured rock.

While there are other factors that limit the potential uses of groundwater (such as the cost of drilling), quality and yield are the primary measures used to make decisions about using groundwater.

Storage and resilience

How much storage an aquifer has depends mainly on the pore space in the aquifer. This means that sand and limestone aquifers tend to have a greater storage capacity than fractured basalt aquifers.

The unconfined upper aquifers are exposed at or near the ground surface and can be quite thin with little storage. When it rains or rivers flood the aquifer's pore spaces fill quickly. This water is held in storage. When the aquifer becomes saturated the water spills into the surface drainage lines.

The behaviour of upper aquifers is seasonal. A period of dry weather or of extraction can substantially reduce water levels. However they can be replenished quickly from rainfall due to their exposure at the ground surface.

Recharge to lower aquifers comes from direct rainfall (where the aquifer is exposed at the surface) as well as from groundwater leaking from upper aquifers. Normally lower aquifers have more storage capacity than upper aquifers because they are generally much thicker and cover a greater area. In deeper formations it has been found that the storage volume of an aquifer can increase under pressure. If the pressure falls groundwater is released from storage. This acts to stabilise water levels.

Water takes much longer to leak into lower aquifers than upper aquifers.

Compared to the seasonal behaviour of upper aquifers, the storage capacity and resilience of lower aquifers mean that groundwater levels remain static and can rebound quickly after a period of sustained pumping or prolonged dry weather.

Observations

- **Yield and salinity limit the potential uses of groundwater.**
- **The rate at which groundwater levels drop when extraction occurs is related to how much is stored and how quickly it moves through the aquifer.**
- **An aquifer's storage capacity depends on its pore space (eg a sand aquifer has more space than a fractured rock aquifer) and the compressibility of the aquifer material in lower aquifers .**
- **Unconfined upper aquifers regularly fill and spill because they are exposed at the surface and their storage capacity is smaller than lower aquifers.**
- **Lower aquifers may take many decades to respond to changes in weather patterns, land use and pumping.**

How much groundwater can we access?

Most groundwater resources in Victoria are capped to protect existing users, the environment and potential users. The Permissible Consumptive Volume (PCV) in the South West Region is roughly equivalent to the estimated annual recharge amount. This cap aims to minimise any long-term risks associated with groundwater extraction. In some cases the PCV is an administrative cap on licensed entitlement. The diagram at right shows the proportion of groundwater stored in aquifers that is of suitable quality and accessible.

It is estimated that the volume of groundwater stored in the aquifers of South West Victoria is 300,000 GL.

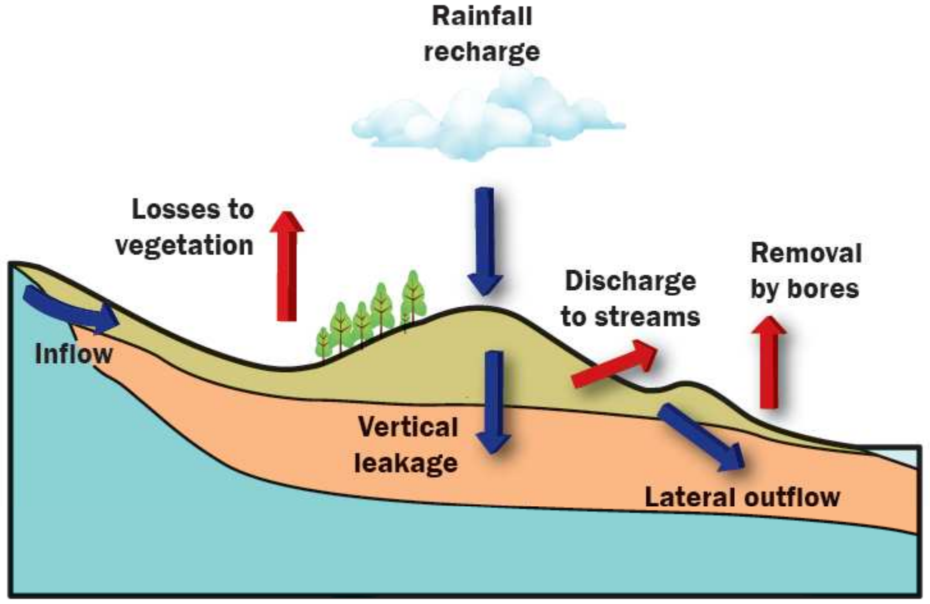
Taking into account water quality (salinity), only 50% is suitable for irrigation. Taking into further account bore yields and depth to groundwater, even less is practical for extraction.

The current allocation is capped at 241GL or 0.1% of the total groundwater in storage. This allows the aquifer to replenish. The volume in storage can be used during dry periods and replenished during wet periods.

Water balance

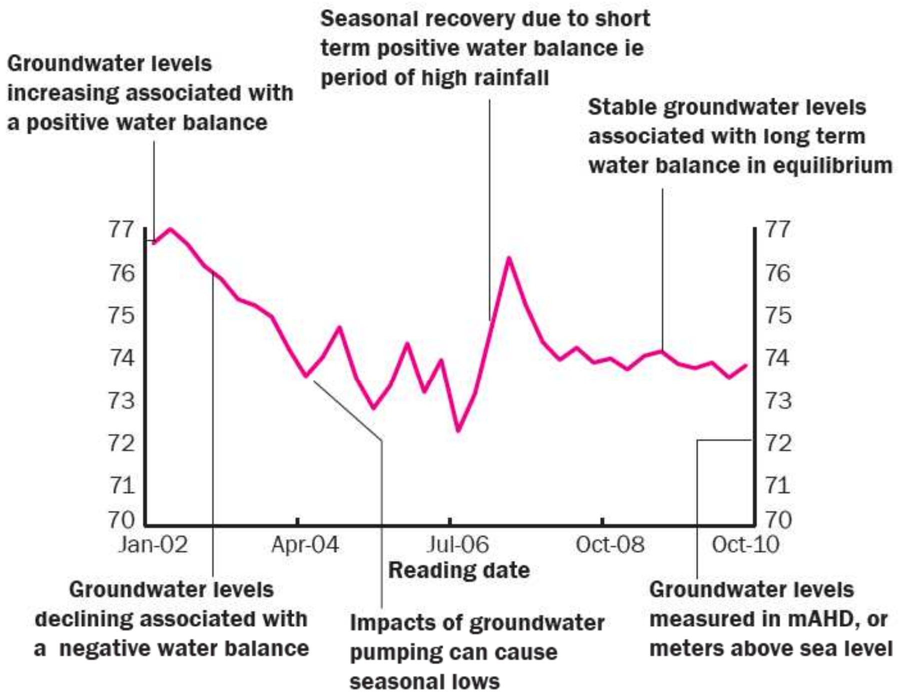
How do we estimate the water balance?

Water balance describes the relative importance of the inflows and outflows of an aquifer (see diagram below). It is based on estimates of recharge from rainfall, water removed by bores and vegetation, discharge to streams or leakage loss to deeper aquifers.



A water balance can be compared to hydrographs to see whether the observations from bores verify the balance.

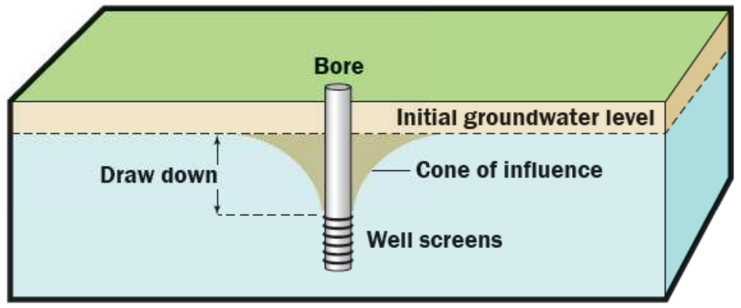
The graph below shows a sample hydrograph with simple explanations about the trends and how they can relate back to the water balance.



What happens when groundwater is extracted?

When a bore is pumped, it forms a cone of influence that extends out from the bore until pumping stops or until the cone extends to a point where the water being removed is in equilibrium with the water replacing it.

If rainfall recharge is higher than the rate at which groundwater is withdrawn and the aquifer has enough storage, groundwater levels should remain static over a region during dry seasons. Local issues such as increased extraction, changing water quality or changed land use will inevitably arise that may alter conditions for existing users.



Local bore interference occurs when bores are too close to each other. Pumping from one may create a cone of influence that can lower the water level in neighbouring bores. This can mean that when a neighbour begins to pump, there may not be enough water depth in your bore to achieve the usual yield.

When the total volume of groundwater pumped or intercepted in a region is greater than the volume that can be recharged, it can result in a regional groundwater decline. This leads to lower bore yields, higher pumping costs and other negative environmental impacts.

How does extraction impact the surface environment?

The impact of groundwater pumping on surface features can be difficult to measure or estimate. Some basic impacts are discussed below.

Reduction in stream flows can be can occur in two ways. **Interference** from a widening cone of influence can cause water to flow from the stream to the bore. This impacts the stream to varying degrees. If the bore is near the stream the impact may be obvious and immediate. If the bore is farther away the impact can take weeks, months or even years and is more subdued.

Interception occurs when any bore in an aquifer adjacent to the stream, no matter how far away, uses water that may otherwise contribute to baseflow into the stream at some point in time.

Observations

- **Water balance describes the balance between recharge and discharge of an aquifer as a whole or in part.**
- **When recharge exceeds discharge the water balance is positive. This means water can go to storage, groundwater levels can increase or groundwater can discharge to the surface.**
- **When discharge exceeds recharge the water balance is negative. This means water is released from storage, groundwater levels can fall or surface water can drain to groundwater.**
- **Groundwater extraction can contribute to local bore interference and a decline in regional levels.**
- **Declining groundwater levels can impact the surface environment by causing acid sulphate soils, subsidence and land salinisation.**

Acid Sulphate Soils (ASS) occur naturally in some inland and coastal regions. If left undisturbed these soils are harmless. However if the soil is drained and becomes dry, the iron sulphides in the soil react with the oxygen in the air to produce sulphuric acid. This can be harmful to the surrounding environment by contaminating surface water and is, therefore, potentially harmful to plants and animals.

Subsidence occurs when the ground surface drops due to changes occurring underground. This can be caused when large quantities of water are extracted leading to the compression of materials (such as clay) that support the aquifer or by the collapse of cavernous limestone or fractured basalt formations. This could have a negative impact on the environment in sensitive areas such as low-lying coastal land. It could also cause structural problems for buildings and other infrastructure.

Land salinisation occurs when high water tables evaporate and salt is left in the soil. This affects the productive capacity of land. Many areas in this region are at risk of dryland salinity. Much of this occurs naturally but it is also due to land clearing following European settlement. Reforestation and perennial pastures can help manage high water tables.

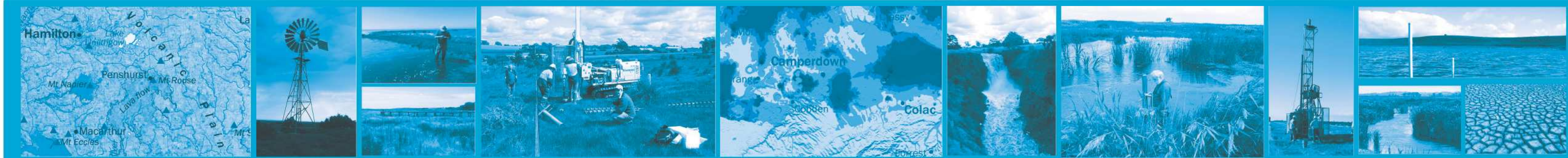
There may also be cases where irrigation contributes to high water tables, land salinisation or soil sodicity leading to erosion.

Chapter 3: Management and use

Groundwater is a resource shared by many users. In the South West Region it provides drinking water for about 20 towns including Geelong, Ballarat and Portland. It is also used for irrigating crops, for drinking water for stock and for industrial purposes. It plays an important role in sustaining the environment.

New systems of management have been introduced progressively as the value of groundwater has risen and its issues have escalated.

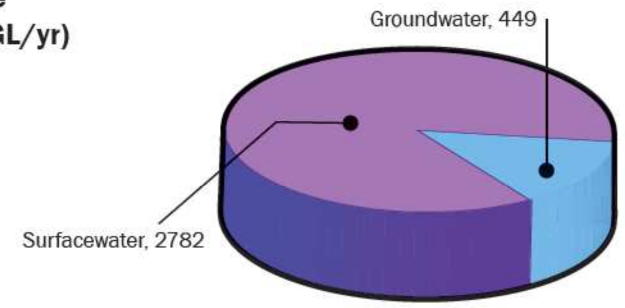
This chapter explains how groundwater usage and its systems of management have evolved.



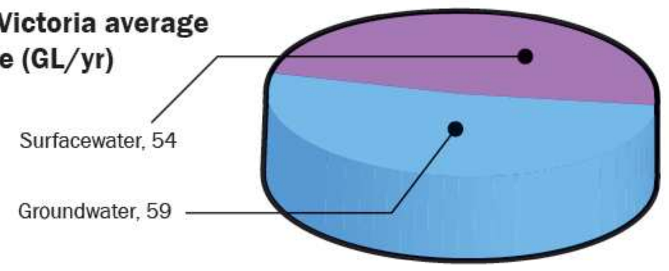
Early regulation

Groundwater is the major source of water in the region, in contrast to the rest of the state. Low stream flows and the generally flat topography mean that the region is not suited to diverting water from rivers and streams or constructing large water storages such as dams.

Victoria average annual usage (GL/yr)



South West Victoria average annual usage (GL/yr)



*These figures do not include estimates of small catchment dams.

The evolution of groundwater usage

Traditionally landholders had the right to extract any volume of groundwater on their property for any purpose.

Windmills were introduced during the late 1880s followed by mechanical bores. This meant that landowners had improved access to groundwater and they could extract greater volumes.

More sophisticated drilling and pumping equipment as well as greater demands for water from the growing dairy and potato industries led to an increase in bore construction, particularly during periods of drought notably in the 1970s and 1980s.

The Introduction of regulation

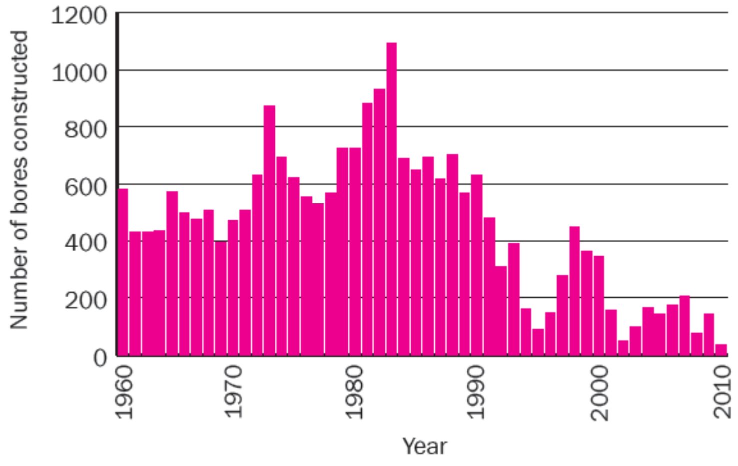
The increase in the use of groundwater led to the introduction of basic regulation by rural water corporations such as Southern Rural Water. Under authority of the Water Act, this includes a range of licences:

Works licence – a licence to construct, alter or decommission a bore for any purpose, including domestic and stock. This licence records the activity and ensures the construction is adequate.

Take and use licence – a licence to take and use groundwater for all commercial purposes other than domestic and stock. Unintentional water users such as the mining, minerals and energy sector also require a licence (excluding offshore operations as they are outside the State's control). Indirect or diffuse users such as the plantation industry do not require a licence.

Private right – a landowner has the right to take water for domestic and stock use from a bore on their property without requiring a take and use licence. However, they do need a works licence. Private rights are not formally issued and water use is not metered.

Bores constructed in South West Region



The region accounts for 40% of all groundwater bores across the state. This graph shows the number of licences issued to construct bores and bores registered post-construction. The highest number of bores were constructed through the 1970s and 1980s, particularly during periods of dry weather.

The increased access to and use of groundwater led to the need for formal regulation and management. The Groundwater Act was introduced in 1969 which required a 'works licence' to construct, alter or decommission bores and a 'take and use licence' to extract water for any commercial purpose (including irrigation and dairy washing).

TIMELINE

Pre 1880s
Wells were hand dug and lined with bricks or concrete, and water was lifted to the surface by buckets

Late 1880s
Advancements in drilling and pumping technology saw bores proliferate throughout the south west of Victoria

1969
The Groundwater Act was introduced

1969
The first Groundwater Conservation Area was established in Victoria at Koo Wee Rup

1970
The State Observation Bore Network was established

1983
The first major urban supply was established for Geelong

1985
Groundwater (Borders Agreement) Act was introduced between South Australia and Victoria

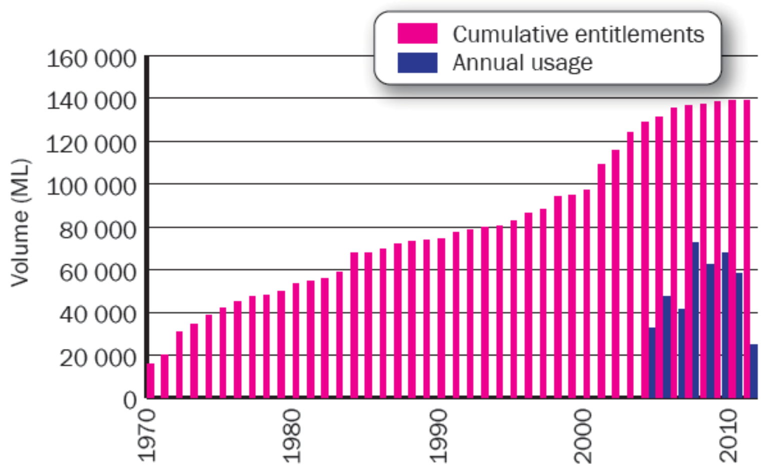
1989
Victorian Water Act was passed

Current management

In recent years, the regulation and management of groundwater resources has increased. This is in response to a greater dependence on groundwater combined with periods of low rainfall.

The growth in licence entitlements was consistent from 1969 (when licences were first issued) until 2000. Between 2000 and 2006 a steep increase occurred that coincided with a sustained period of dry weather. Since caps were introduced there has been little growth.

Growth of licences in south west Victoria



*data excludes undated licences and licences in unincorporated areas.

By 2003 most bores were metered. Usage is recorded by the end of each season on 30 June. Usage is normally less than 50% of the entitlement.

Groundwater Management Units (GMUs)

GMUs have generally been declared where there is a high concentration of licences. They are categorised by both their geographical boundary and their depth.

GMUs can be further categorised into Water Supply Protection Areas (WSPA), Groundwater Management Areas (GMA) and Unincorporated Areas (UA).

Permissive Consumptive Volume (PCV)

All WSPAs and GMAs have an allocation cap or PCV. The PCV regulates the volume of entitlements – it does not manage use. PCVs are mostly based on an estimate of the sustainable yield, taking into account existing users and the environment. If entitlements exceed the sustainable yield at the time of the estimate, the volume of entitlements is adopted as the cap. In other areas the PCV may be a precautionary cap that is below the estimated sustainable yield.

Water Supply Protection Areas (WSPAs) and Groundwater Management Plans (GMPs)

Once a WSPA has been declared, permanent transfers are not permitted until the Water Minister approves a GMP.

GMPs were originally intended to formalise metering and monitoring or to alter licence conditions where the need arose. In practice, the process of initiating WSPAs and granting approval for GMPs has taken much longer (several years) than originally expected (12 months).

Now that metering is mandatory, in most cases it is more efficient to manage groundwater without initiating the WSPA process and preparing a GMP. This is managed using a less formal means such as local management rules.

Observations

- The region's low stream flows and lack of topography suitable for dams has led to a high reliance on groundwater.
- The escalation in demand for groundwater use, particularly during dry periods, led to the need for regulation.
- Groundwater management is currently based on areas with a high concentration of licences (GMUs) and allocation caps (PCVs).
- Less formal means of management are now used to avoid the lengthy processes and restrictions that occurred with the WSPA and GMP processes.

The management of groundwater resources continues to evolve. The State has developed three key initiatives that will help shape the future:

The Western Region Sustainable Water Strategy aims to secure water supplies for towns and industry, encourage economically viable and sustainable agriculture and protect and improve the health of the environment.

The Water Register stores and reports water entitlement information, replacing an outdated paper-based system.

The Secure Allocation, Future Entitlement project (currently underway) provides an aquifer-based framework to regulate the allocation of groundwater.

1993
Victoria's first Groundwater Management Strategy was released

1997
Groundwater Management Areas and Permissible Annual Volumes were established

2002
The Water Act 1989 was amended to support the creation of Water Supply Protection Areas, and groundwater is formally recognised by the National Water Initiative and state policies

2002
Nullawarre and Yangery Groundwater Management Plans approved by the Minister

2006
Permissible Consumptive Volumes established incrementally across all defined Groundwater Management Units

2007
Three dimensional (3D) hydrogeological maps were produced for southern Victoria – this is a significant step in broadening our knowledge of groundwater

2010
Warrion Groundwater Management Plan approved by the Minister

Groundwater entitlements

Most bores are used for either domestic & stock (D&S) or for food production. Urban populations also rely on groundwater for their water supply and for industries that provide employment.

The table at right summarises the total volumes of water allocated and used in each of the aquifer groups. The map below shows the location and volume of entitlement by user group.

Aquifer group	PCV* (ML)	Entitlements (ML)	Metered usage (ML)**
Upper	63,044	68,855	18,819
Middle	67,481	79,398	24,081
Lower***	34,253	35,384	15,629

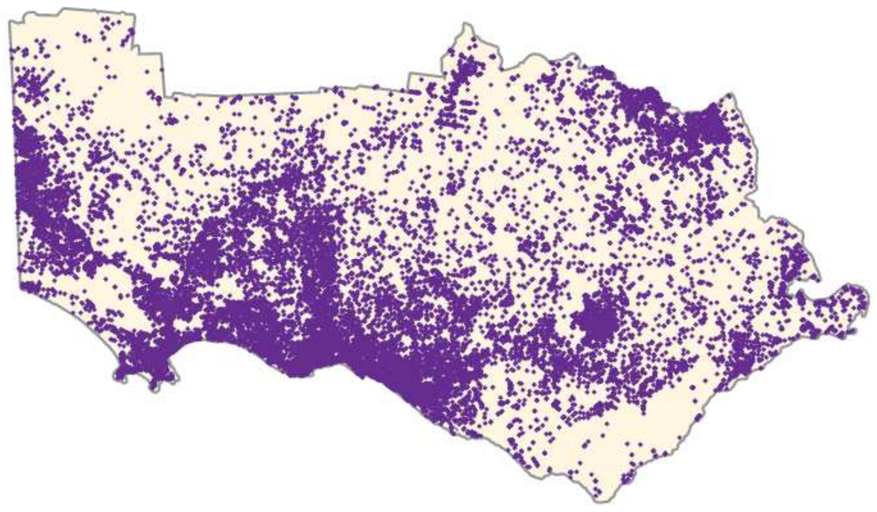
* PCVs listed are correct as at July 2011. It is likely PCVs will need to be amended to account for licences issued under the state-wide dairy amnesty.

** Average metered usage from 2004 until 2011 (does not include unlicensed D&S usage).

*** Entitlement appears to be higher than the PCV in the lower aquifer – this is due to special licence conditions for urban supply. See Chapter 6 for more information.

Urban and industrial licences generally have a higher volume and are spaced less densely than food production licences.

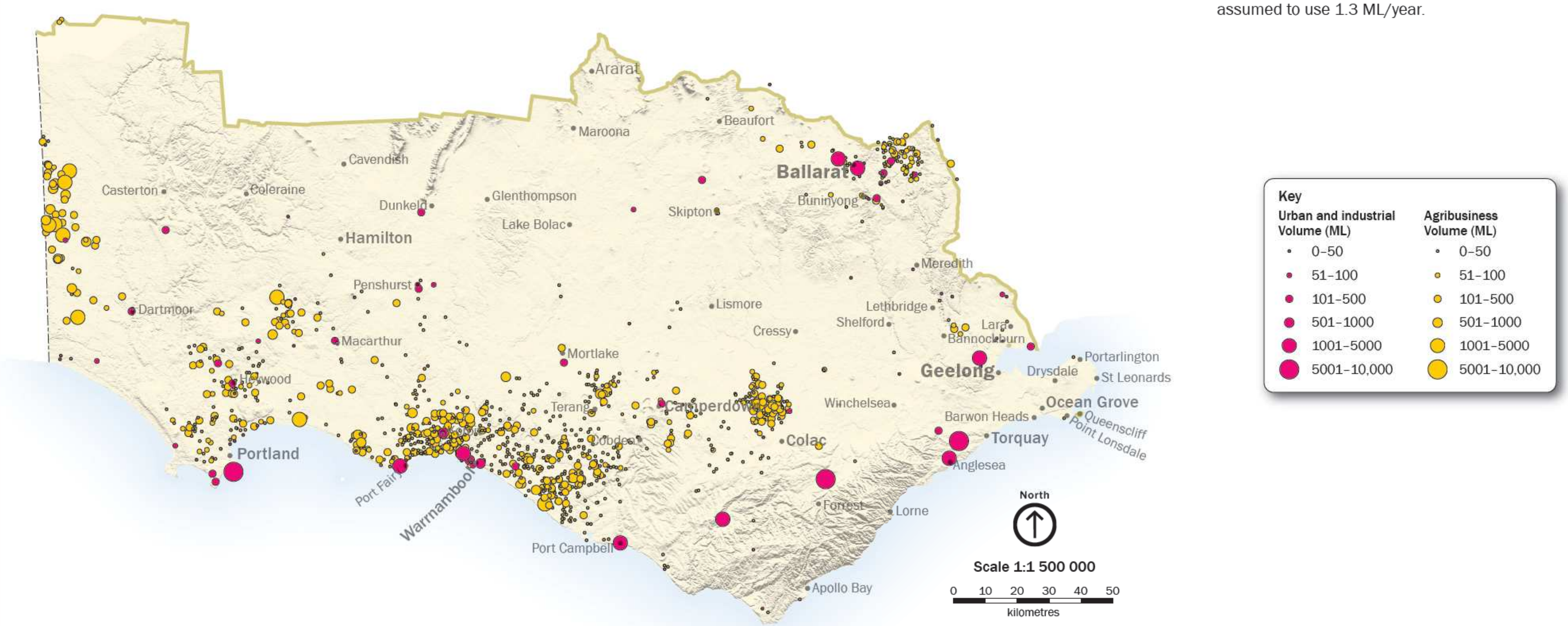
Most of the volume of entitlements is in the upper and middle aquifers. However usage figures suggest a higher proportion of reliance on using groundwater as a primary water source in the lower aquifer (see table above).



Active bores 2011

The map above shows all active groundwater bores, including D&S bores.

There are an estimated 16,000 D&S bores in the region. Each D&S bore is assumed to use 1.3 ML/year.



Groundwater licences and volumes

(Metered sites are shown – does not include inactive licences)

Groundwater monitoring

There are 660 observation bores across the region that form part of the State Observation Bore Network. The state government maintains these bores and uses them to monitor groundwater levels and sometimes salinity.

Groundwater level data is collected either monthly or quarterly and reviewed on a regular basis to assess trends. Salinity information is generally collected less frequently.

There is a high density of bores south of Colac. These are used to measure groundwater levels in the aquifer used for Geelong's town supply (Gerangamete GMU). Many of the bores not located in GMUs were drilled for geological investigations rather than groundwater management.

Most active bores are now metered (see page 11). This provides additional information on the volumes of water being extracted. This is used for water balance calculations and compliance activities.

Data is also collected from bore logs, weather stations and stream gauges. This can be used to help understand the extent, condition and behaviour of groundwater.

GMU boundaries

There are 17 declared GMUs in the region. The map below shows current GMU boundaries by aquifer group.

GMUs are categorised by their depth as well as their geographical boundaries (see page 21). This means that there may be more than one GMU in an area. For example Portland GMA is very deep and is overlain by Condah, Heywood, Hawkesdale and Yangery GMUs.

Observations

- Most groundwater development occurs along the coast and near major rural centres such as Ballarat, Colac and Warrnambool.
- GMUs cover areas with a high concentration of licences.
- Observation bores are used to measure groundwater levels and salinity to help safely manage the use of groundwater.

	Number of observation bores	
GMU name	Water level	Salinity
Bungaree	22	0
Cardigan	7	0
Warrion	30	18
Glenormiston	0	0
Colongulac	2	0
Nullawarre	23	4
Yangery	19	17
Hawkesdale	17	0
Heywood	1	0
Condah	9	4
Glenelg	45	0
Gerangamete	52	0
Jan Juc	10	0
Gellibrand	28	0
Newlingrook	19	0
Paaratte	18	0
Portland	9	0
Unincorporated areas	349	0

Groundwater observation bores and GMUs

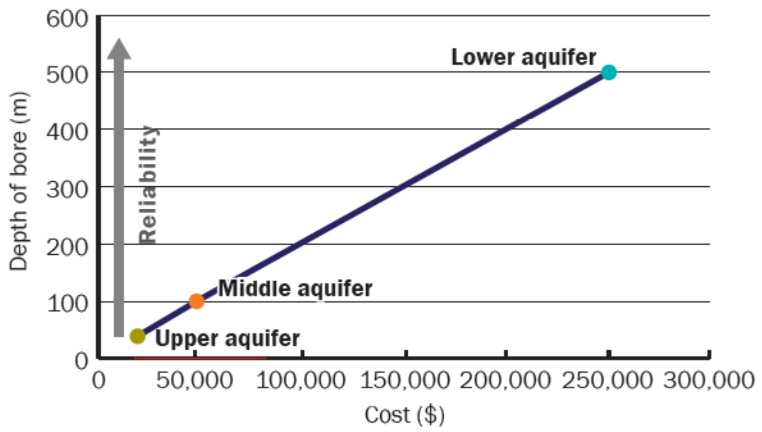
The value of groundwater

Users are interested in the reliability and security of groundwater and in turn, its value to them. A reliable bore is one that is always able to supply the rate and volume of water needed. Security relates to the certainty of a user's legal entitlement (specifically a licence or protection to access enabled by the Water Act).

Reliability

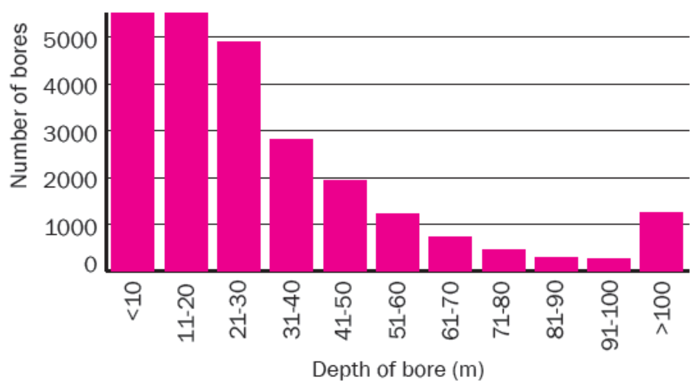
The reliability of a bore depends mainly on how deep it is. This means that deeper bores are usually more reliable. However they cost more to drill and to pump (see graph below).

Depth of bore versus cost to drill



Over 80% of active bores are less than 50 m deep.

Depth of bores (GMS 2011)



How willing a user is to pay for reliability is influenced by the value of production per megalitre of water. The table below shows the estimated total production value of the different user groups in the region.

Value of production

The total value of production for this region has been estimated as shown in the table below:

Value	Domestic and stock*	Agribusiness**	Urban and industrial***
$	15,280,000	46,757,000	73,018,000
$/ML (median)	900	1,400	3,500

Source: RMCG 2011

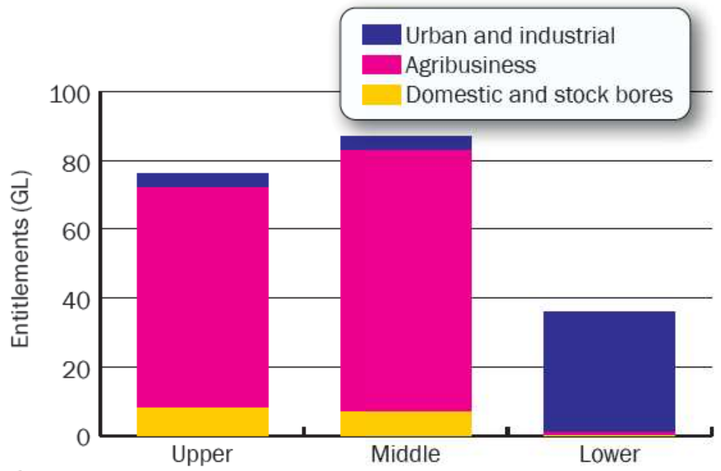
* Domestic and stock value is based on the annualised cost to replace a bore

** Agribusiness value is based on the additional production from using groundwater

*** Urban and industrial value is based on the cost of an alternative water supply

Urban water suppliers seek the greatest reliability. This has led to this user group drilling the deepest bores.

Entitlements by aquifer



Security

Most known groundwater sources are capped and fully allocated and it is becoming increasingly difficult to find new sources. However, users generally use less than 50% of their entitlement. This means there is scope for them to trade the balance of their entitlement.

Future development opportunities for new or existing groundwater users include:

Trading an existing entitlement – the price of traded groundwater is not fixed and is generally not reported. Anecdotally it costs approximately $1,000/ML for a permanent transfer and $100/ML for a temporary transfer.

Managed Aquifer Recharge (MAR) – this means taking a nearby surplus of surface water, storing it in an aquifer and extracting it when needed. This is an expensive option and is still in a developmental phase, so trading is generally a more attractive option.

Observations

- Users want a secure entitlement with a reliable supply at a cost they can afford.
- Users with higher value needs are willing to increase reliability by drilling deeper – this influences the distribution of users across aquifers.
- Although there is limited opportunity to obtain a new entitlement, a user who is seeking development opportunities may be able to access the unused proportion of entitlement. This can become active either for the current licence holder or by transfer to a new owner.

State observation bore drilling at Hawkesdale

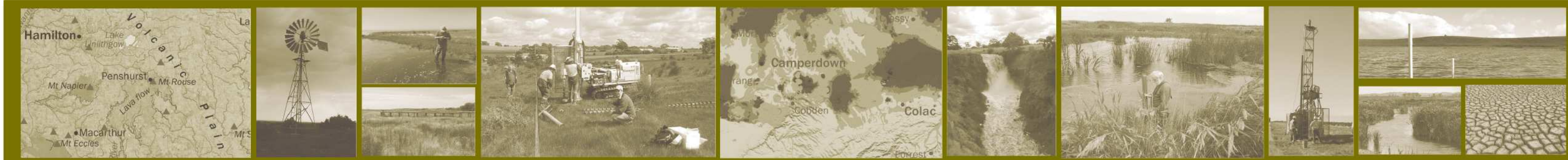
Chapter 4: Upper aquifers

Upper aquifers are located broadly across the South West Region. The most productive groundwater areas are found near Ballarat and Colac and from Casterton stretching north-west towards Edenhope and the South Australian border.

Upper aquifers occur within 100m of the surface so the water is easy to access. However yields are generally low and water quality is variable.

Upper aquifers interact closely with surface water environments such as rivers, creeks, drainage lines, wetlands, swamps and lakes. They receive direct recharge from rainfall and are strongly impacted by weather patterns and land use.

These aquifers are the region's primary source of groundwater for domestic and stock use. They are also used for irrigating crops in some areas or as a backup source during dry seasons.



4 Upper aquifers

Aquifer geology

The upper aquifers of the region include the Newer Volcanics and Bridgewater Formation and various older sand aquifers.

Newer Volcanics

The Newer Volcanics stretch from Ballarat to Portland. They were formed in the last 4 million years by over 400 volcanoes, fissures and vents producing scoria and fractured basalt.

These unconfined volcanic aquifers occur at the ground surface which means they can receive rainfall directly. They are mostly porous near the volcanic cones and are more likely to occur as confining layers of clay across the plains. These aquifers are thickest near Ballarat, Colac, Portland and south of Hamilton.

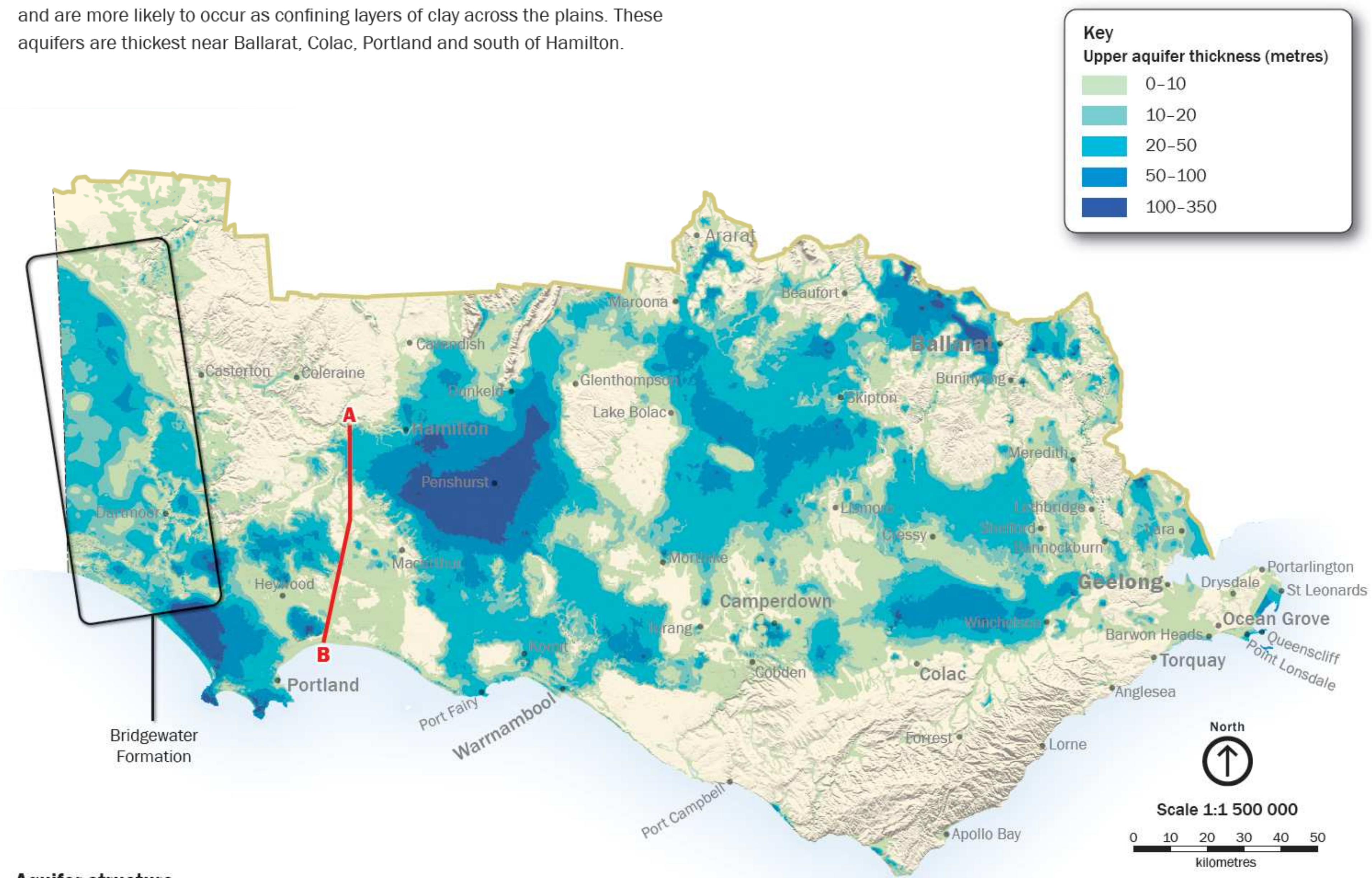
Bridgewater Formation

The Bridgewater Formation is an unconfined sand and limestone aquifer that occurs along the South Australian border. Bores can intercept porous water-bearing material at very shallow depths.

The older sand aquifers include the Hanson Plain Sands and Parilla Sand formations. These aquifers are most likely to be used for mineral production as their water quality is generally poor and not suitable for other uses.

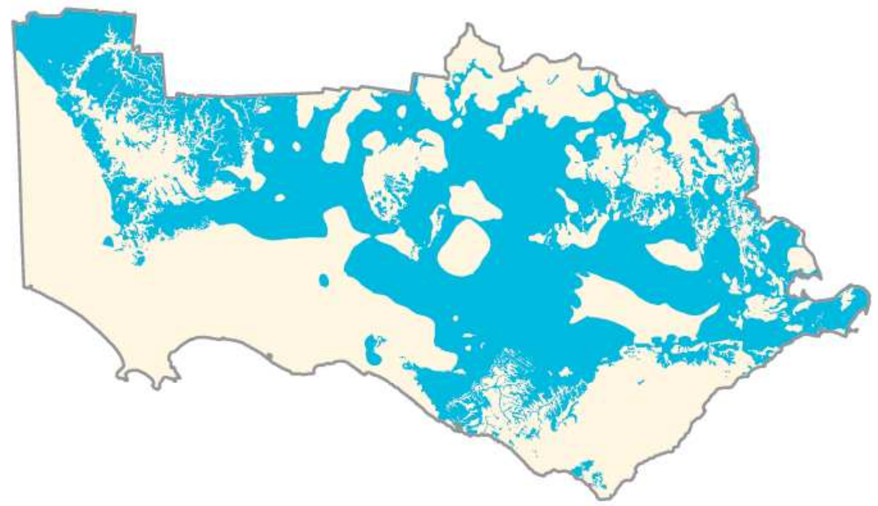
Observations

- **Unconfined volcanic upper aquifers occur at the ground surface which means they can receive rainfall directly.**
- **The region's upper aquifers are thickest near Ballarat, Colac, Portland and south of Hamilton.**
- **A significant sand and limestone aquifer occurs at shallow depths along the South Australian border.**

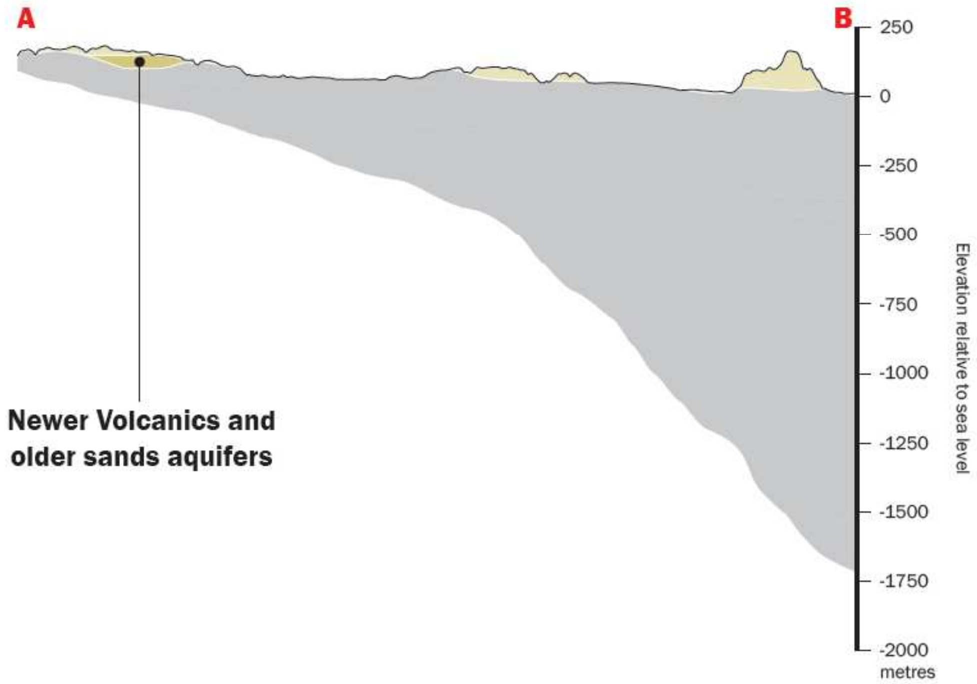


Aquifer structure
(Newer Volcanics and Bridgewater formation)

The map above shows the thickness of the aquifer. The upper part of the aquifer occurs at the ground surface. Light shading shows where the aquifers are thin and dark shading shows where they are thick.



Distribution of the older sand formations



Cross-section A-B
(Created from map on left)

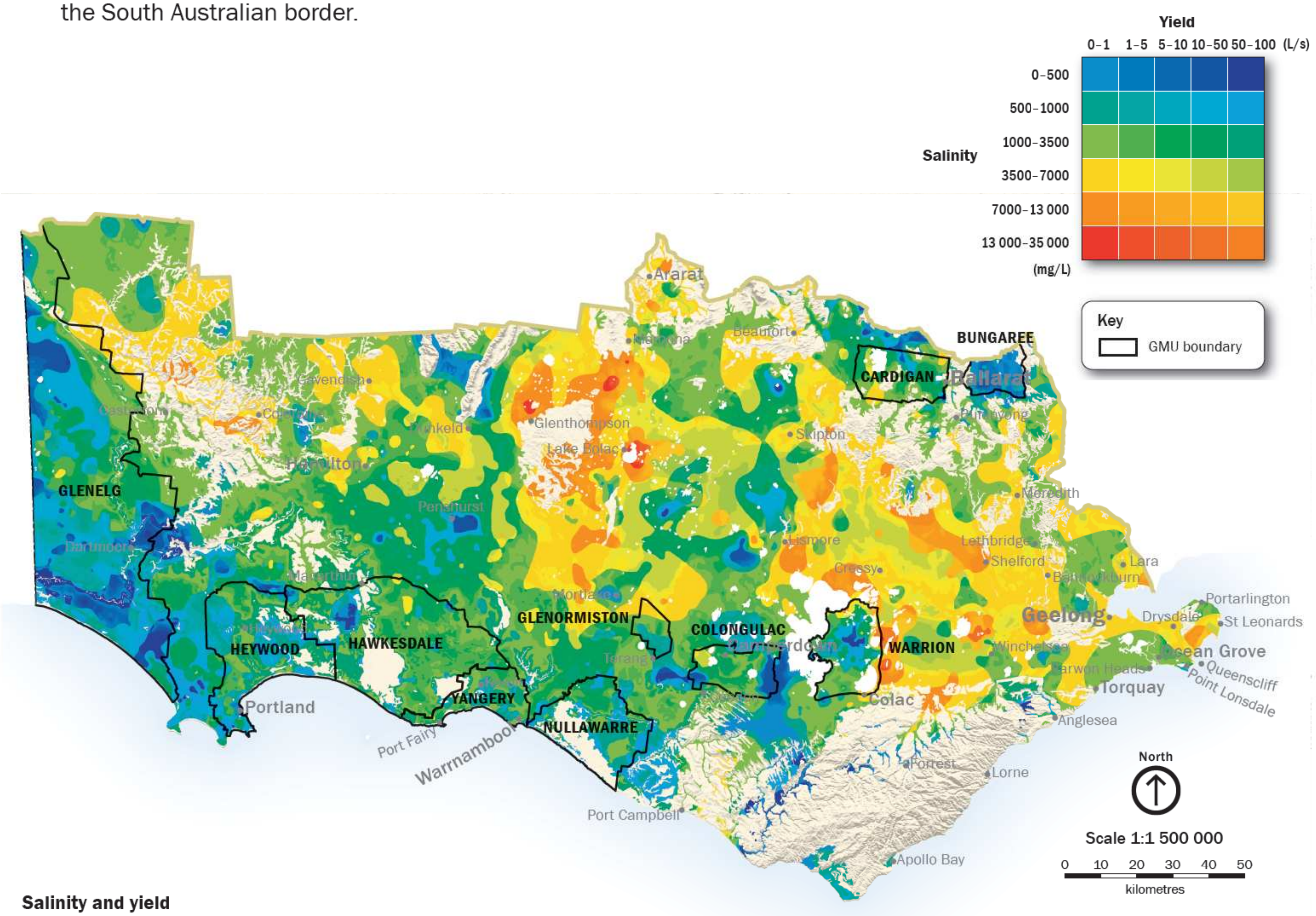
Salinity and yield

The upper aquifers near Ballarat and Colac provide high yielding and good salinity (quality) groundwater. This has led to significant development in these areas. Substantial development has also occurred around Lake Mundi near the South Australian border.

The total volume of the upper aquifers is approximately 30,000 GL. Not all of this can be used because it is either too saline for most uses or too low yielding.

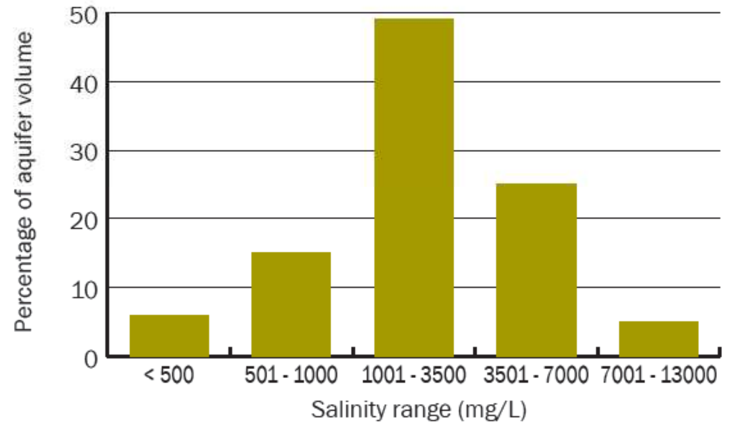
Observations

- **Most of the groundwater in the upper aquifers is either too saline or low yielding for commercial use.**
- **GMUs cover most of the high yielding, good quality groundwater areas.**
- **Due to the variability in salinity and yield, it is possible that isolated areas with good potential remain undeveloped.**



Salinity and yield
(Newer Volcanics, Bridgewater Formation and older sand aquifers)

The map above shows areas of low salinity and high yield (blue) and areas of high salinity and low yield (orange and red). Potential users need to consider whether the probable groundwater depth, salinity and yield are suitable for their needs before they invest. The map shows that salinity and yield are highly variable across the region and therefore it is not possible to know whether a bore location will be good or not before drilling. Potential users should seek information from hydrogeologists and drillers with expertise in the area as well as local information about existing bores.



Salinity by volume

The graph above shows the salinity distribution in the upper aquifers. The groundwater is more saline than in the lower aquifers with only 20% suitable for most uses.

Movement of groundwater

Flow systems

Local flow systems are common in the upper aquifers. The map below shows them by a high frequency of water level contours in elevated areas such as the Central Highlands near Ballarat and volcanic cones such as Warrion Hill. Here the flow path is steep and short before the water discharges from springs or intercepts the land surface in depressions and stream beds.

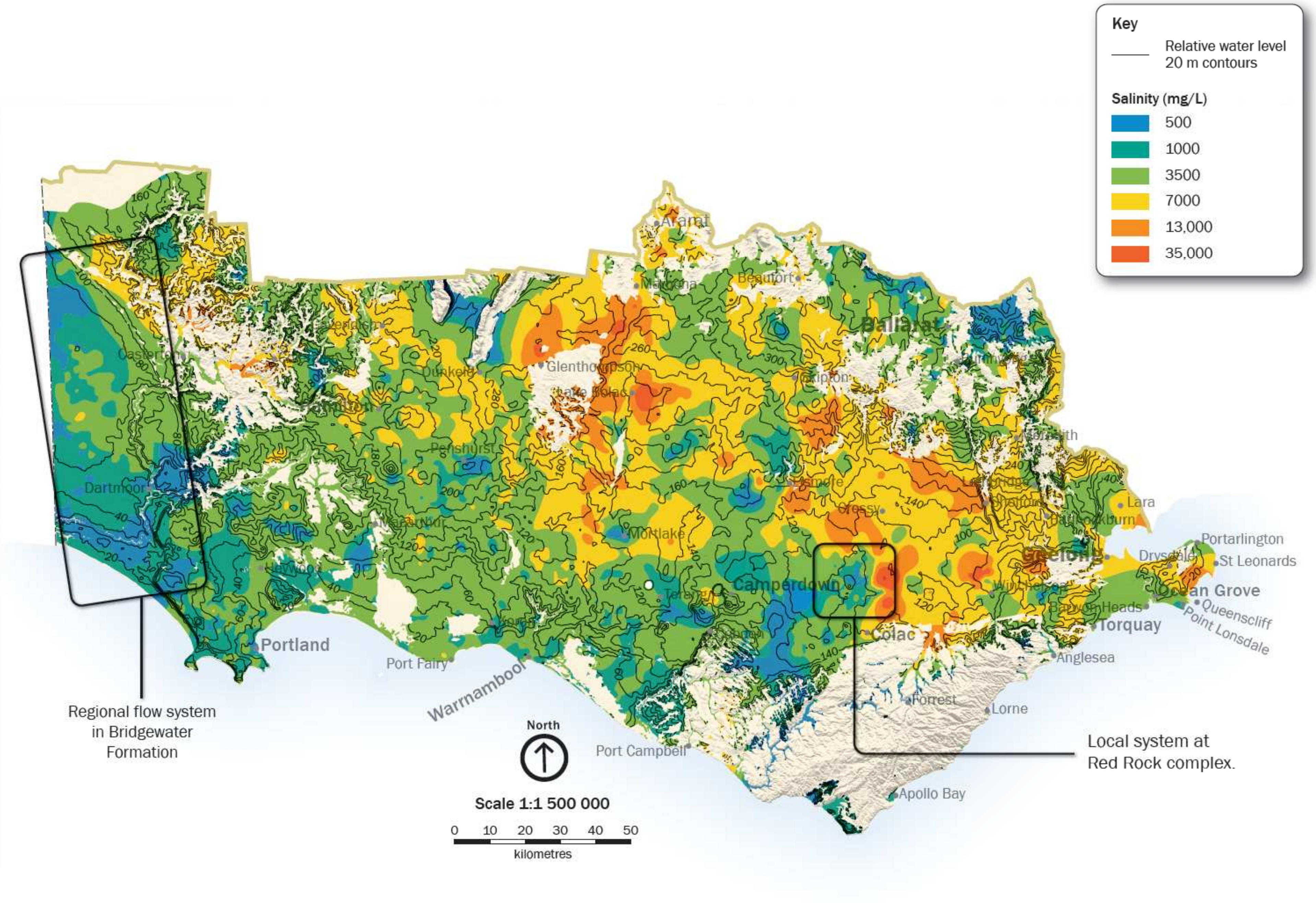
In contrast, the flatter gradients in the west of the region coincide with the regional flow system of the Bridgewater Formation where the groundwater moves slowly.

Interception

A bore anywhere along a flow system can intercept groundwater before it discharges to surface water environments such as streams or lakes. Local systems, such as in the hilly terrain around Bungaree, have bores that intercept groundwater that could otherwise contribute to stream flows. The impact of this interception is delayed if the bore is far away from the stream.

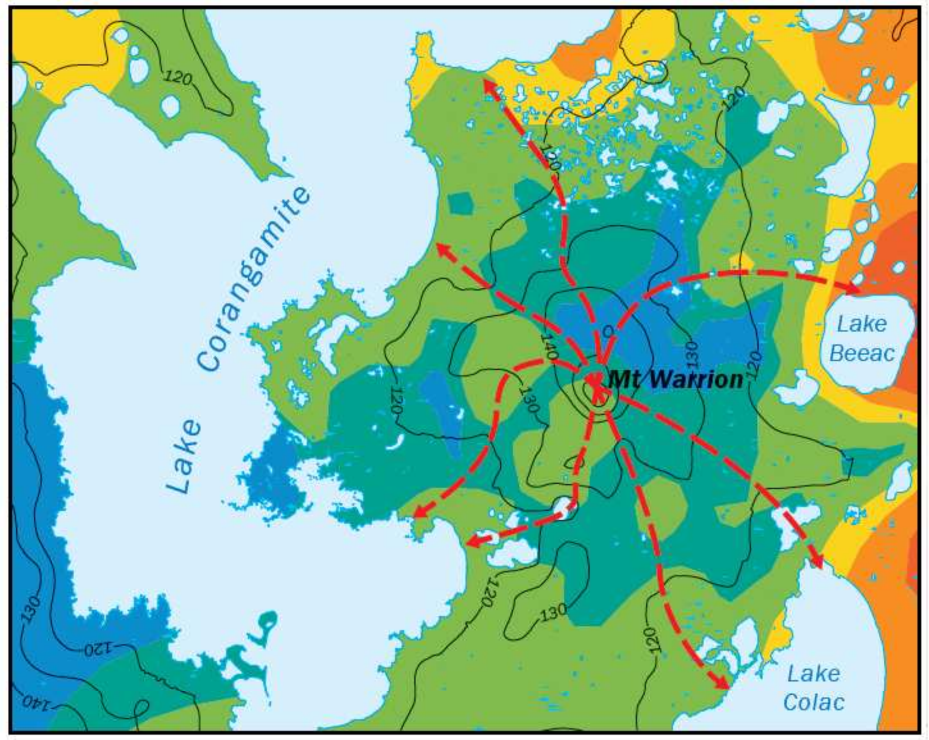
Observations

- **Local flow systems occur in the hilly terrain of the Bungaree, Colongulac, Glenormiston and Warrion GMUs where high yielding good quality upper aquifers occur.**
- **Regional flow systems occur in the flatter terrain in the west of the region, particularly in the Glenelg GMU.**
- **If groundwater is intercepted along a flow system it can affect the discharge to streams and other surface water environments.**
- **Salinity generally increases along a flow system.**



Groundwater flow systems

This map shows the salinity and groundwater elevation of the Newer Volcanics, Bridgewater Formations and older sand aquifers. A high frequency of contour lines indicates a steep gradient; as the landscape flattens contour lines are less frequent.



The map above shows the local flow system at Warrion Hill. Rainfall recharge enters the system on the scoria mounds and moves downhill to the local lakes where it discharges.

The water at the point of recharge on top of the hill is of higher quality. The water's salinity levels increase as it picks up salt along its flow path and becomes more concentrated as a result of evaporation when it reaches the discharge points.

Groundwater and the environment

Upper aquifers interact closely with surface water environments such as streams, lakes and wetlands. They help to support ecosystems and also provide a direct source of water for deep-rooted vegetation.

Groundwater Dependent Ecosystems (GDE)

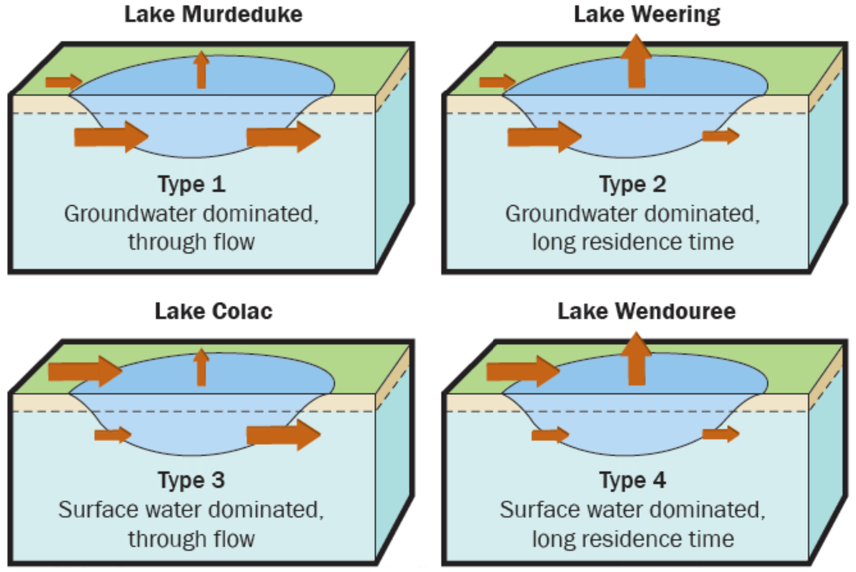
In the local flow systems, some potentially significant ecosystems rely on groundwater along the upper Eumeralla River and the lower Fitzroy River near Portland.

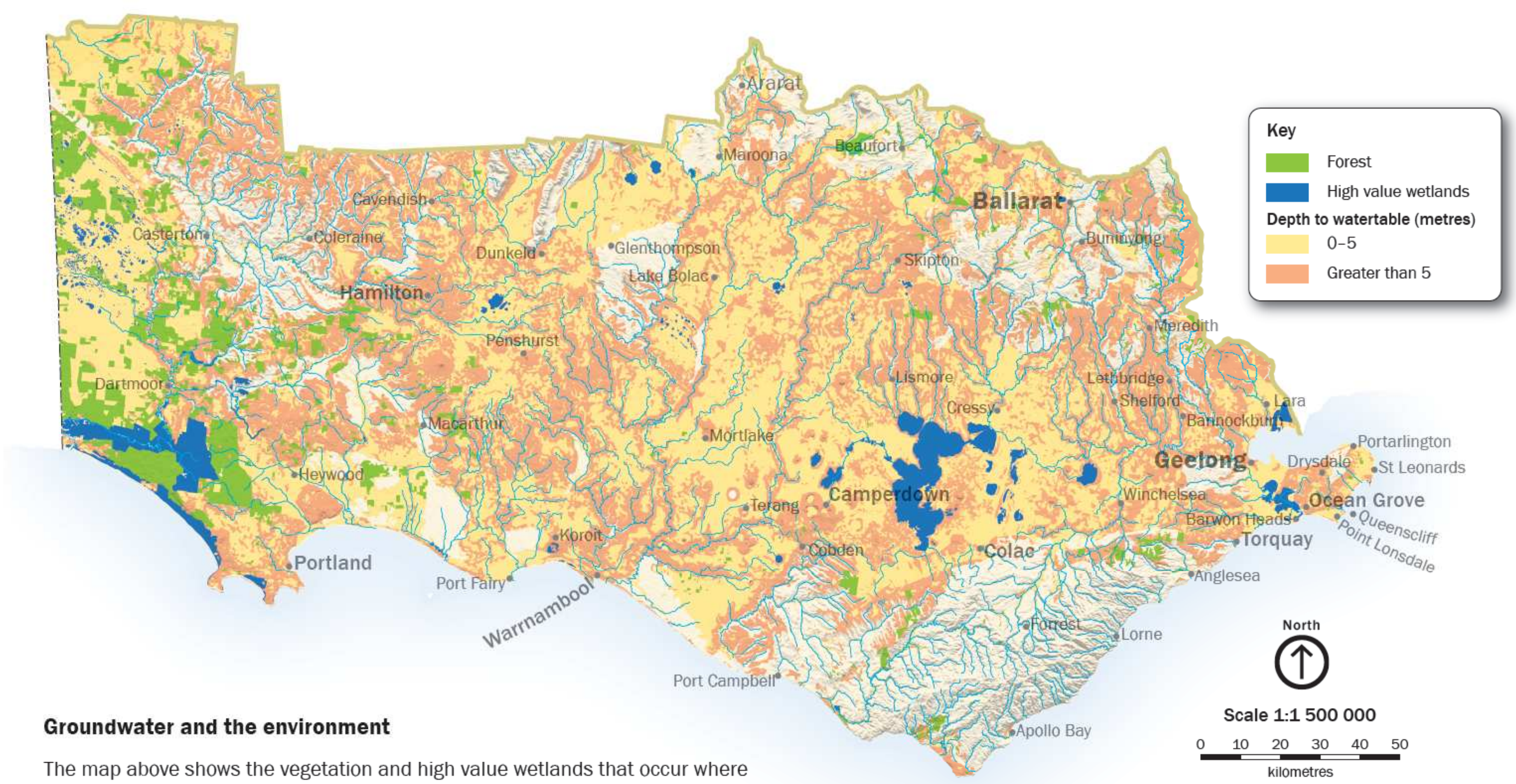
Some surface water environments with significant ecological value rely on groundwater. These include springs near volcanic cones such as Mt Warrenheip near Ballarat and the crater lakes surrounding the Red Rock complex near Colac.

In the intermediate and regional flow systems, where the movement of groundwater is very slow, the interaction is more likely to be as a saline discharge to a surface water feature, such as Lake Burrumbeet and Lake Bolac, or as evapotranspiration to vegetation.

Lake dynamics

The diagrams below show how the upper aquifers play an important role in supporting the regional lakes in the Corangamite region.





Groundwater and the environment

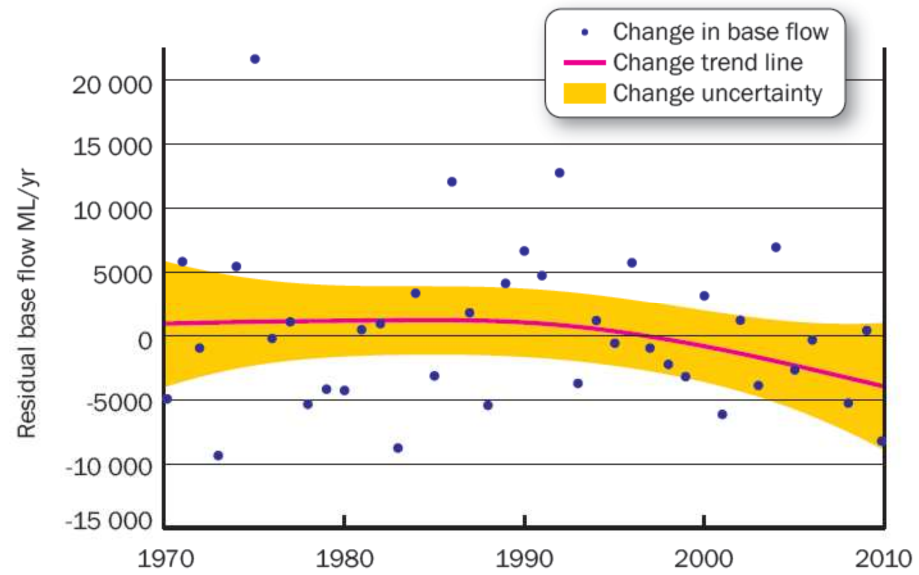
The map above shows the vegetation and high value wetlands that occur where the upper aquifers occur close to the ground surface.

Observations

- **Local systems in upper aquifers interact closely with streams and wetlands.**
- **GDEs are likely to occur in areas with shallow water tables such as the Red Rock complex and Lakes Burrumbeet and Bolac.**
- **Evapotranspiration of groundwater is important to the health of landscapes.**
- **Across large areas of the region, interception of groundwater from trees and other vegetation has more impact on stream flows than extraction.**

Baseflow to streams

Streams in the region between Warrnambool and Portland all show a declining baseflow over the past 40 years. This is mainly as a result of reduced rainfall. If the effect of rainfall is removed, the baseflow was reasonably consistent up to 1990 but has declined since. This could be because some of the rainfall that used to contribute to the baseflow has been intercepted. In this case, it is most likely that changes to land use have affected baseflow as there are few groundwater licences in the upper aquifer.



Baseflow to Fitzroy River

The figure above shows a change in baseflow over time in the Fitzroy River at Heywood after the effect of reduced rainfall is removed. The results are consistent with the 1997 Water and Land Use Change case study for the same area. It predicted a decline in baseflow and concluded that changes to land use had the biggest impact on baseflow.

Water balance

The amount of recharge and discharge in upper aquifers is complicated by the many flow systems. While we can broadly estimate the proportion of rainfall that enters an aquifer and how much that will contribute to streams, few detailed water balance studies have been conducted.

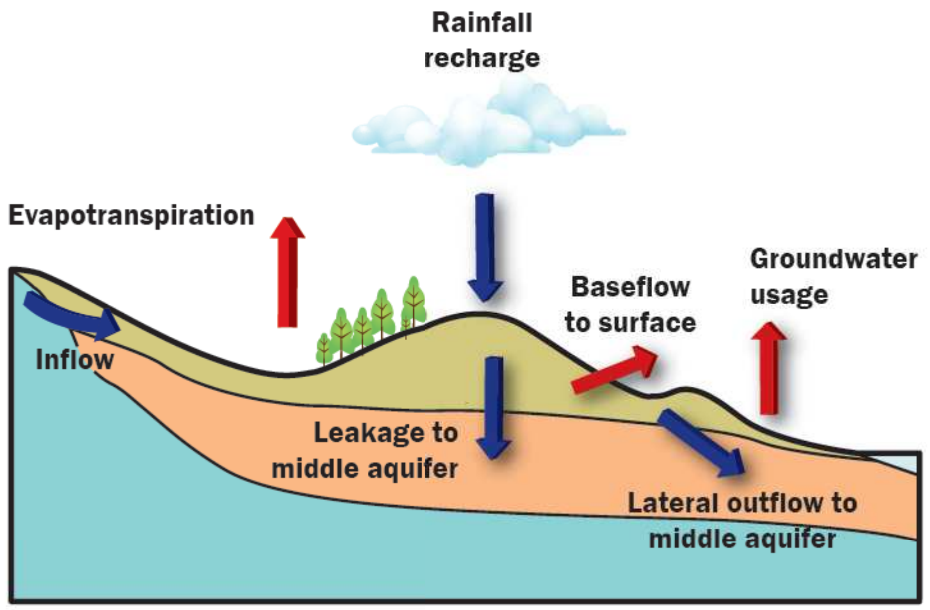
Hawkesdale case study

The Hawkesdale Groundwater Management Unit (GMU) covers the area from Lake Condah in the west to Woolsthorpe in the east. The fractured rock aquifer was formed by lava flows that are thickest around the volcanic cones and quite thin or not present elsewhere. Groundwater flows towards the coast and away from the higher terrain such as Mt Eccles.

There are relatively few groundwater licences for the upper aquifer at this location.

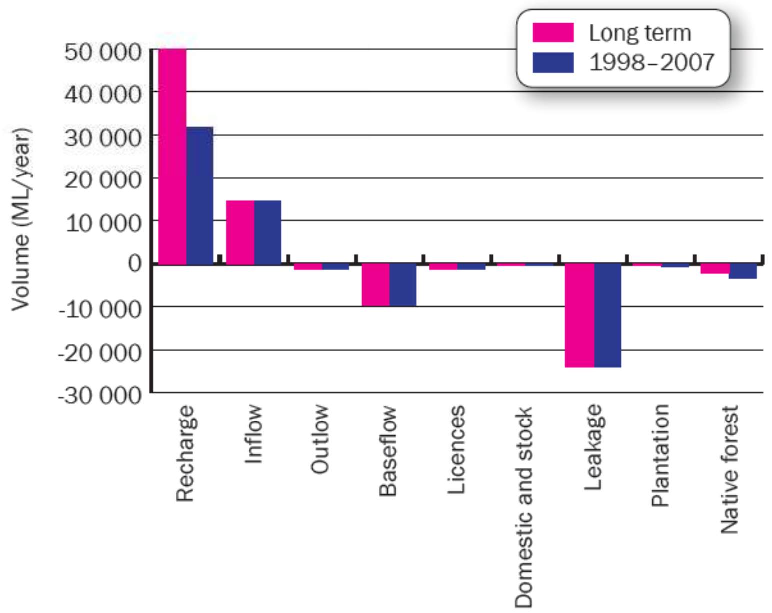
The diagram above shows the aquifer and relative groundwater level contours. The contours show the direction of flow from north to south. The absence of any aquifer through the central area of this GMU means it is separated into two regional flow systems.

The figure below shows the simple water balance model. Recharge is highest around the more porous volcanic cones. Discharge occurs in several ways: through baseflow to streams where the groundwater level is at the ground surface, through evapotranspiration, through lateral flow into the middle limestone aquifer and through leakage to deeper aquifers.



The graph below shows the estimated inputs and outputs to the water balance in the upper aquifer at Hawkesdale. It compares the long-term balance with the decade ending in 2007.

Hawkesdale water balance graph



Observations

- Unconfined upper aquifers get direct recharge from rainfall even during dry periods, as the Hawkesdale example shows.
- There is a substantial volume of leakage from the Hawkesdale aquifer that contributes to the middle aquifer and baseflow to streams.
- Compared to deeper aquifers, this aquifer is more sensitive to rainfall recharge and evapotranspiration.

Conclusions

The major input to the Hawkesdale system is through direct recharge from rainfall to the 1,400 km² catchment. The major output is through leakage from the upper aquifer to the middle aquifer. Another significant output is through baseflow to streams. Plantations and native forest cover 21% of the study area.

When comparing the long-term and the decade to 2007, direct recharge from rainfall accounted for the major change in the water balance. Importantly, the impact of rainfall was also greater than the combined impacts of pumping and plantations.

The net long-term water balance is estimated to be 25,000 ML/yr. This means that it has been gaining water in the long term and building storage. In the short term, it gained about 5,000 ML/yr. This means that it was still building storage even with land use change and lower than average rainfall. The method used average annual rainfall. In reality, intense rainfall quickly saturates the aquifer and then discharges or runs off to drainage. Therefore the volume going to storage is probably over-estimated.

This analysis is comparable to other regional flow systems in the upper aquifers which are also likely to be dominated by rainfall and evapotranspiration. The local flow systems are likely to be influenced by extraction and higher discharges to streams.

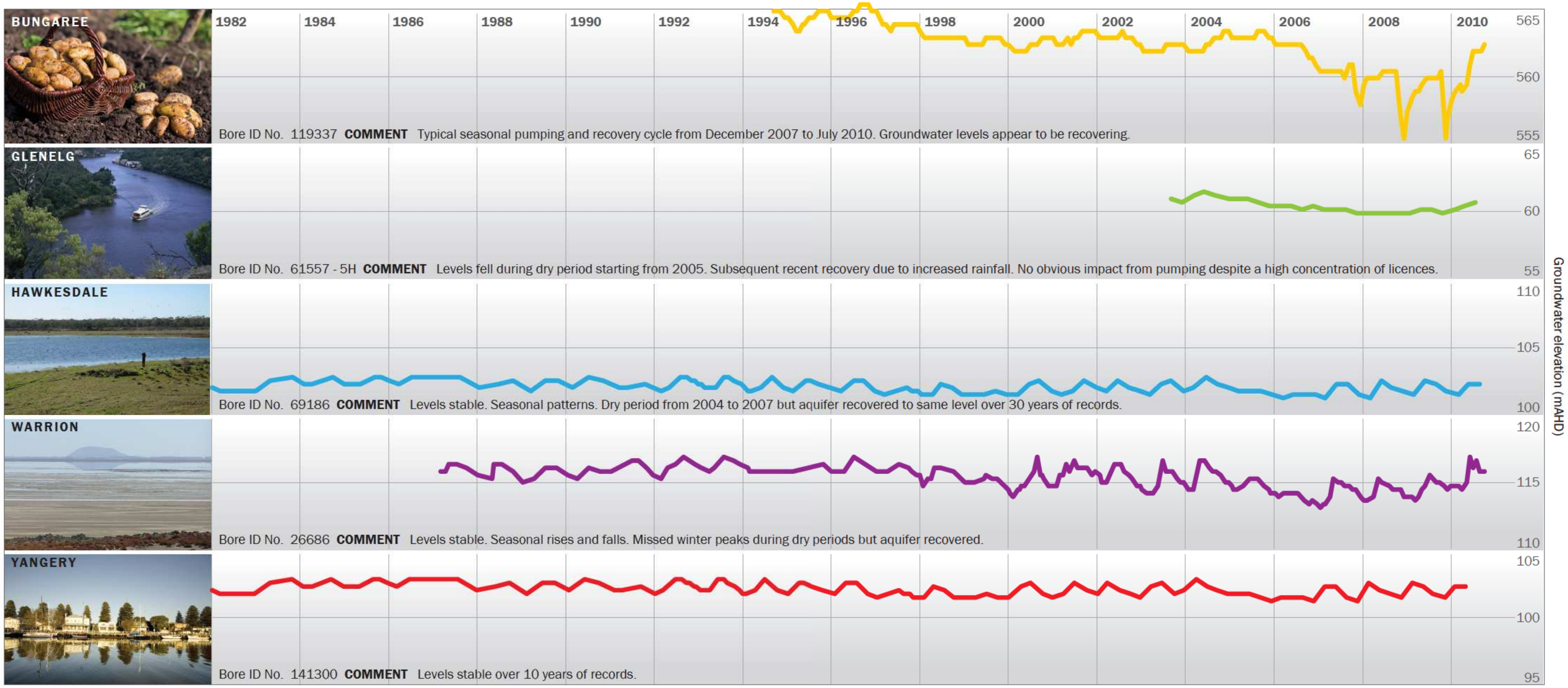
Regional trends

The hydrographs below show groundwater levels (relative to sea level) of several observation bores in the upper aquifers. These hydrographs represent the range of observed groundwater levels in the region.

Observations

- Groundwater levels in these aquifers vary seasonally depending on weather and the rate of pumping.
- Despite the seasonal variations or multi-year declines (in the case of Bungaree and Glenelg), groundwater levels recover if there is sufficient rainfall.
- By comparison to the aquifers in the volcanic formations, the groundwater behaviour in the sand and limestone aquifers at Glenelg is less seasonal. This indicates some level of confinement.
- Compared to the deeper aquifers, groundwater levels in these aquifers are seasonal and more sensitive to rainfall.

Location **Trend**



Groundwater levels shown are in metres relative to sea level. More hydrographs available from - www.srw.com.au

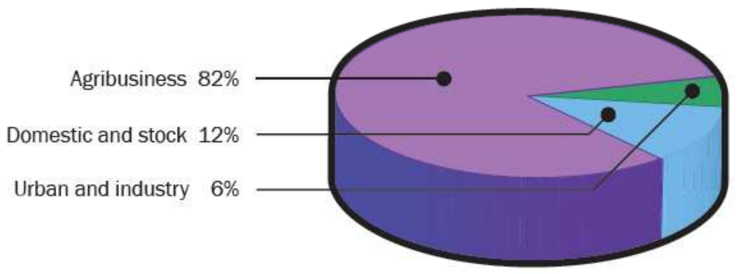
Users and usage

Usage from the upper aquifers is localised to areas where the yield and quality are adequate. This aquifer interacts closely with surface drainage systems and vegetation which means that the environment is a key user.

Licensed users

94% of licensed users are from the agribusiness group and domestic and stock group.

Distribution of entitlements by user



Glenelg GMU has a large volume of urban entitlement to service Casterton, Coleraine and Merino. Cardigan GMU has a large entitlement that was recently used to supplement Lake Wendouree. There are small entitlements in Unincorporated Areas to service Penshurst, Caramut and Darlington.

The average licence size in Glenelg is relatively high (413 ML/yr).

	Number of licences	Average (ML)	Largest (ML)
Bungaree	96	55	496
Cardigan	24	162	3,000
Colongulac	45	98	630
Glenelg	66	495	2,160
Glenormiston	32	83	634
Warrion	128	117	919
Unincorporated	130	38	450

There are over 8,000 registered domestic and stock bores that use approximately 11,000 ML/yr.

The environment and other users

The most significant user is the environment. Contributions to surface water and vegetation would be several orders of magnitude greater than the licensed usage. The plantation and other intensive land use industries also intercept a large volume of groundwater that is not readily accounted.

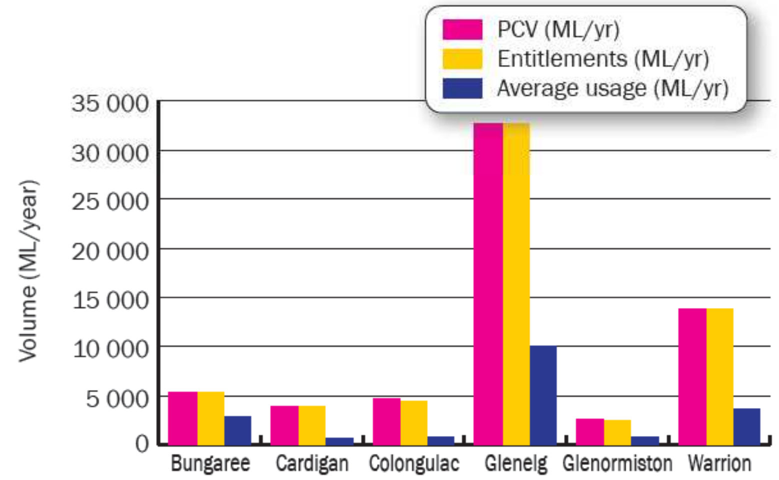
Licensed usage

The total licensed volume is close to the PCV cap. The average usage is around one third of the licensed volume.

	PCV	Entitlements	Average Usage
Totals (ML/yr)	63,044	*68,855	18,819

* Total entitlements exceed total PCV because there are licences in Unincorporated Areas (ie which do not have PCVs)

Bungaree has the highest proportion of usage (63% of entitlements). Colongulac has an average usage of 22% of entitlements and Warrion an average usage of 33%.



Sustainable usage

The upper aquifers are mainly thin and shallow and limited by depth. This means it is a seasonal resource (rather than a longer term resource) – it fills and spills during wet seasons and quickly declines during dry seasons.

Aquifer levels remained relatively stable during the recent prolonged dry period with only isolated reports of bore interference or bores running dry. This suggests that the current level of usage (one third of entitlements) is sustainable.

Compared to the lower aquifers this aquifer group is less reliable for long-term planning because of its short-term reliance on rainfall.

Value

This aquifer is cheap to access. Agribusiness users are located in areas of better quality water that coincide with rich soils. Potatoes at Bungaree and horticulture and dairy at Glenelg are prominent agricultural users. Compared to the deeper aquifers, domestic and stock users contribute a significant proportion of the value.

Observations

- **The upper volcanic aquifers are highly valued as a backup supply during dry seasons.**
- **This resource is less reliable than deeper aquifers because it is relatively thin and relies on rainfall to maintain groundwater levels.**
- **Estimates suggest domestic and stock usage accounts for about a third of the total usage.**
- **There is a substantial volume of unused entitlement that could be retained by licence holders as a backup during drought or traded to other users.**
- **If activated in highly developed areas the volume of unused entitlement could introduce stress.**

GMU	Domestic and stock ($)	Agribusiness ($)	Urban and industrial ($)
Bungaree	302,000	6,856,000	664,000
Cardigan	124,000	27,000	1,143,000
Colongulac	163,000	962,000	0
Glenelg	1,138,000	12,258,000	1,505,000
Glenormiston	139,000	451,000	137,000
Warrion	466,000	2,992,000	200,000
Other areas	5,668,000	2,357,000	2,109,000
TOTALS	8,000,000	25,903,000	5,758,000

Source: RMCG 2011

Future development

The usage data suggests there is a great deal of potential to develop the unused proportion of entitlement (70%). This is provided the yield and salinity are adequate to sustain this volume.

Licence holders place a value on sleeper (unused) entitlements to use during dry seasons or to grow their businesses.

The large areas of the aquifers that have poorer water quality could undergo a treatment process or be used as storage for managed aquifer recharge projects.

Current and emerging issues

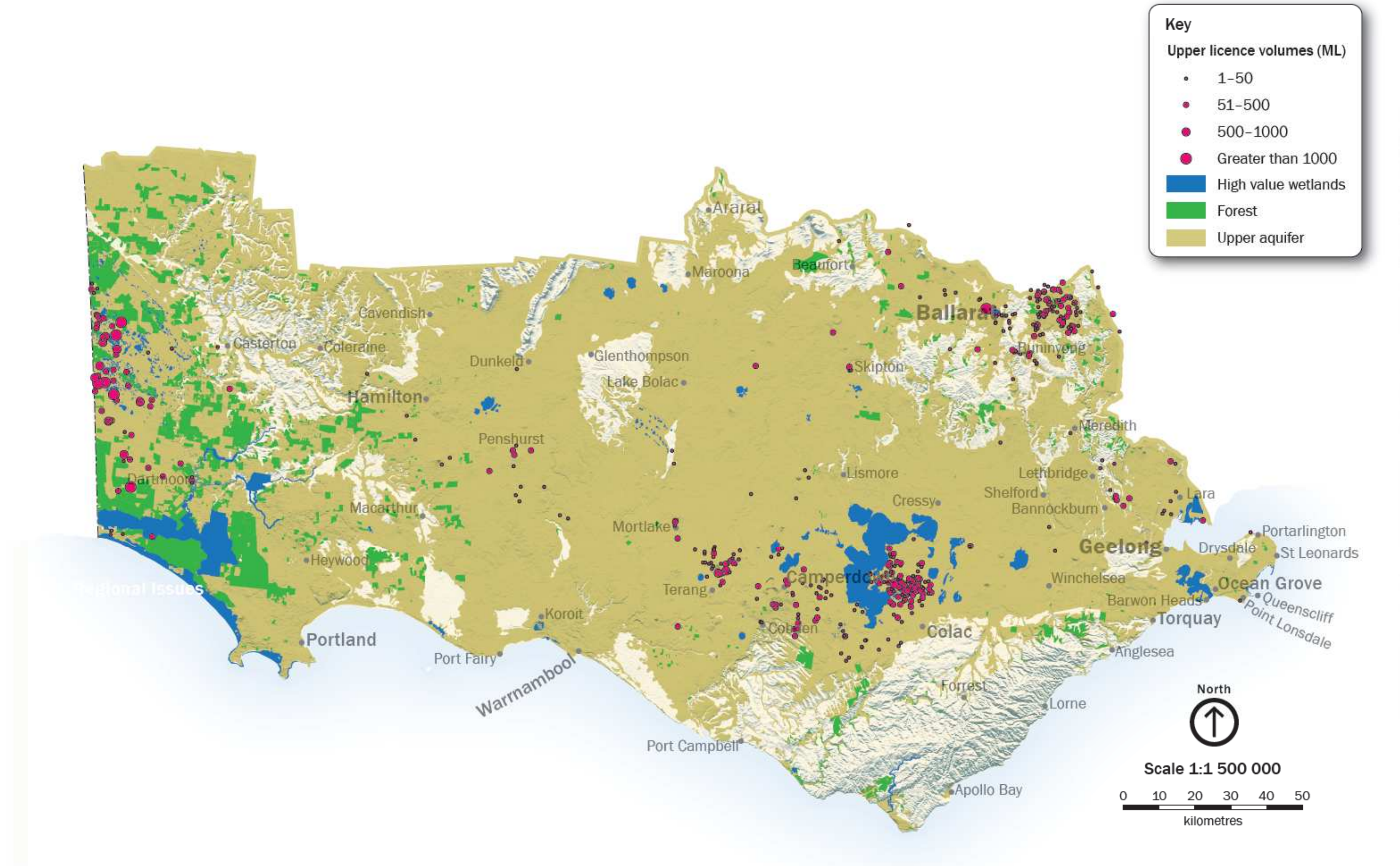
Managing upper aquifers is complex. There are many different stakeholders and user groups. There is also a significant level of value applied to groundwater by the community in general.

The upper aquifers serve an important purpose, providing a resource that can be accessed quickly and cheaply in times of need. They are also very important for the environment.

The map below shows the distribution of licences by size and the most likely Groundwater Dependent Ecosystems (GDEs), including tree plantations where they coincide with the upper aquifers.

Observations

- **Licences are located inland and localised in dense clusters.**
- **The clusters occur close to the potential GDEs near Colac, forests near Ballarat and along the South Australian border.**
- **While there appears to be large areas of undeveloped aquifers, few of these may have suitable quality and yield for most uses.**



Land use and licences

This map illustrates land use and licences overlying the upper aquifers.

Regional issues

- The management of competition for groundwater between the environment and other user groups.
- The impact of bore interference, particularly in bore clusters at Bungaree and Warrion.
- The potential for Acid Sulphate Soils (ASS) developing due to falling groundwater levels around lakes and along the coast.

Chapter 5: Middle aquifers

Middle aquifers occur across the southern part of the region, stretching from the South Australian border south of the Grampians to Port Campbell. These aquifers generally provide higher yields and better quality water than the shallower upper aquifers.

Most licences for these aquifers target the upper section (within 50 metres of the top of the aquifer) which provides good quality, high yielding water.

The highest yielding upper middle aquifers occur along the South Australian border. Entitlements here have a high percentage of usage and the water is generally used for agribusiness.

Towards the coast the limestone is noted for its “sinkholes” that drain surface water flow into the aquifer. These holes are even known to suck and blow air and are explored by cavers.

The lower middle Clifton Formation is a confined aquifer south of Hamilton. It is a high yielding aquifer suitable for urban supply and agribusiness. Bores near Condah Swamp have traditionally flowed without being pumped.

Aquifer geology

The middle aquifers in the region were formed 5 million to 30 million years ago. These aquifers extend across the South Australian border and directly underlie the shallow upper aquifers, except where they are absent near Warrnambool. There are two main aquifers known as the upper and lower middle aquifers.

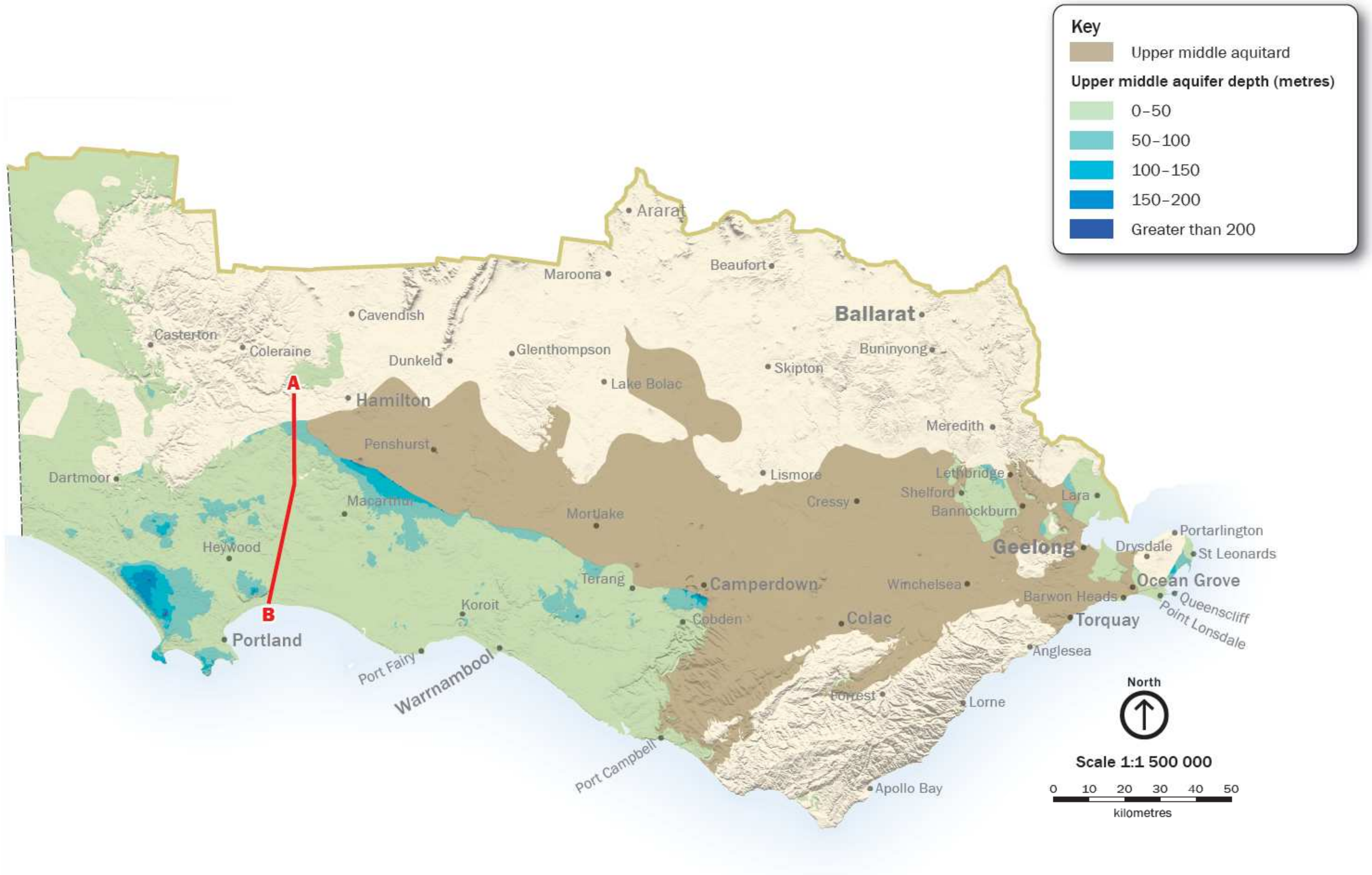
Upper middle aquifer

This includes the Port Campbell Limestone (except where it grades into the similar Gambier Limestone west of Portland). These limestone aquifers are up to 550 meters thick and are cavernous in parts. They are semi-confined by the overlying upper aquifers. It sometimes acts as one unit with the overlying Bridgewater Formation, which runs along the South Australian border.

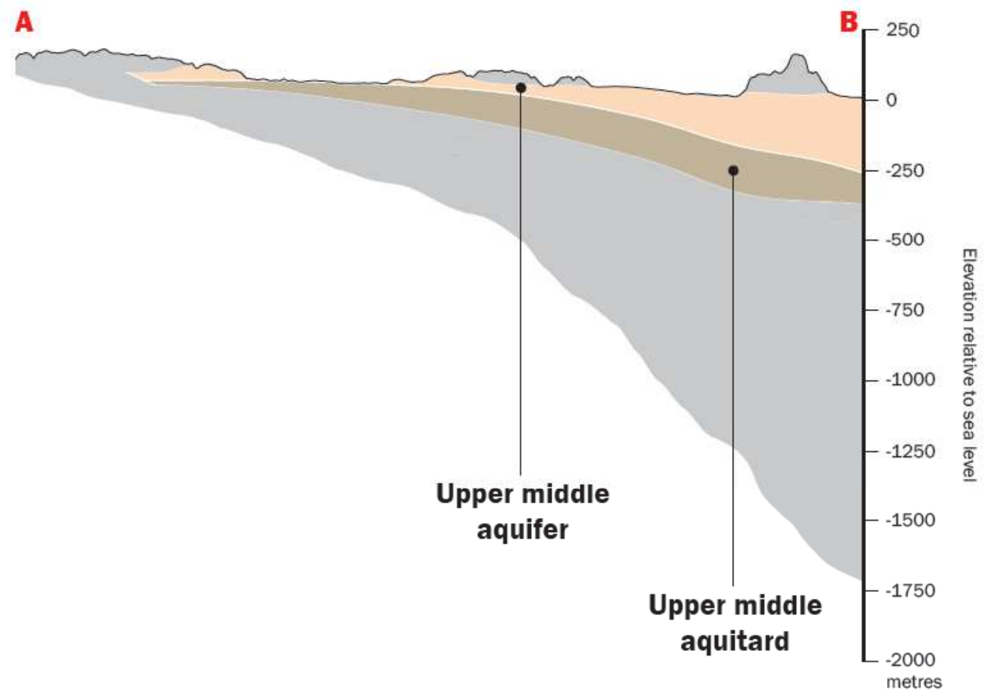
The upper middle aquifer is separated from the lower middle aquifer by the Gellibrand Marl. This is a thick aquitard made of impermeable silts and clays of marine origin.

Observations

- The upper middle aquifer is close to the ground surface and is semi-confined by the upper aquifer.
- It is confined from lower aquifers by a thick marl aquitard.
- It sometimes acts as one unit with the overlying Bridgewater Formation (an upper aquifer) along the South Australian border.



Upper middle aquitard



Aquifer structure

(Upper middle aquifer – limestone formations and underlaying aquitard)

The map above shows the distance from the ground surface to the lower aquifer. Light shading shows where the aquifers are at or near the surface and dark shading shows where they are deeper (eg overlain by other aquitards and aquifers).

Cross section A-B

(Created from map on left showing upper part)

Aquifer geology

Lower Middle Aquifer

The lower middle aquifer in the region is known as the Clifton Formation. It is older and deeper than the upper middle aquifer but not as extensive.

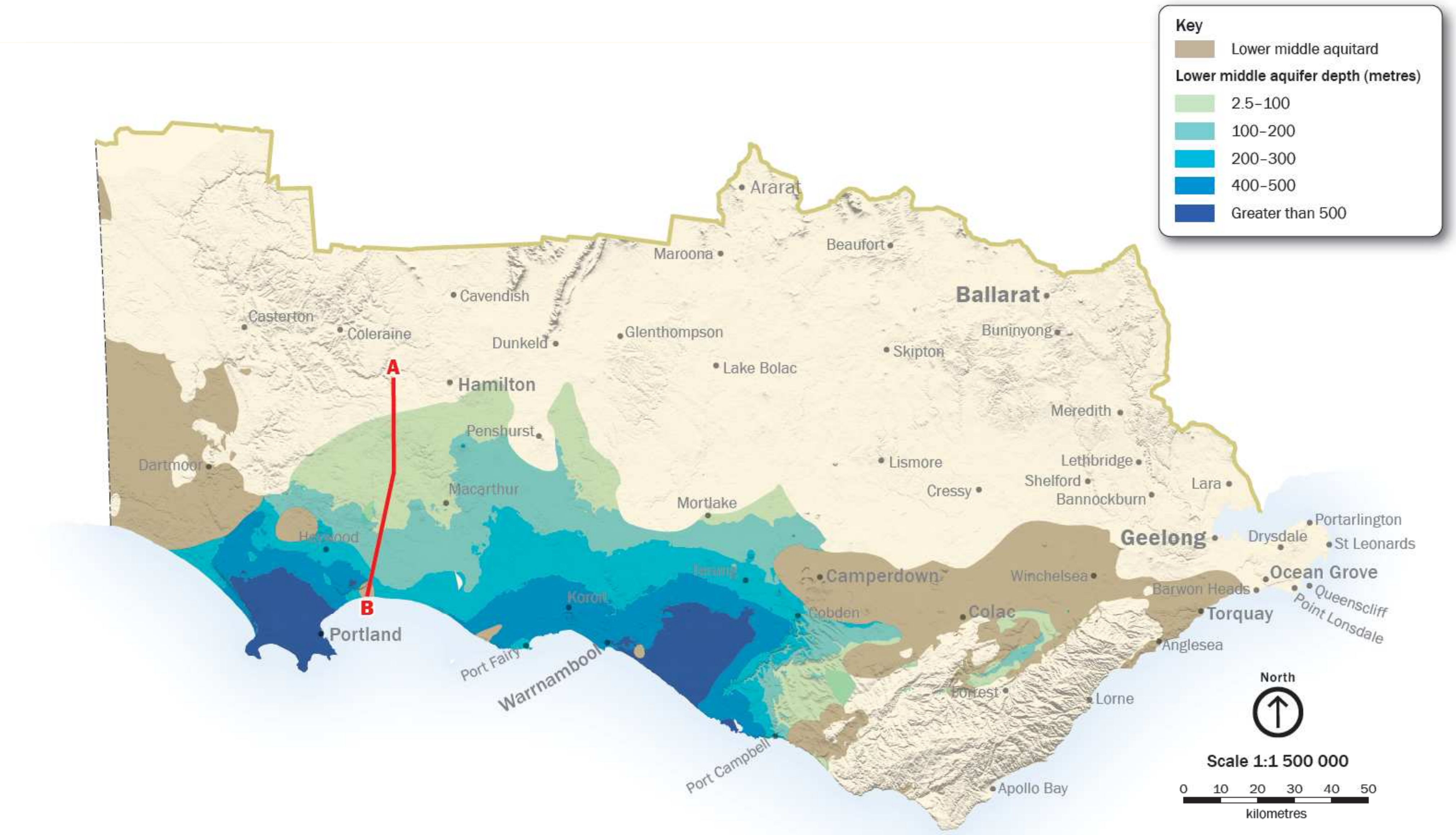
It is made of sandy limestone and marl of marine origin, making the Clifton Formation an aquifer in some areas and an aquitard in others.

Thick aquitards known as the Narrawaturk Marl and the Demon's Bluff formations underlie the Clifton Formation. These aquitards do not completely confine it from the lower aquifers.

The thickest part of the lower middle aquifer occurs where the upper part is very thin or absent.

Observations

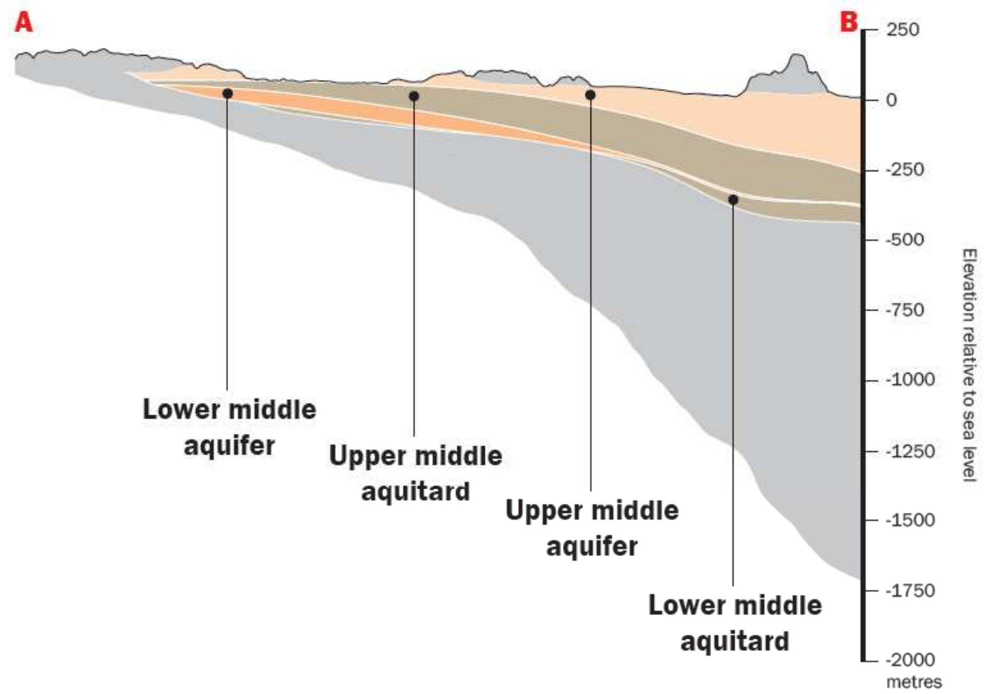
- **The lower middle aquifer is completely confined from the overlying layers by a thick aquitard.**
- **It is confined from lower aquifers by a thick marl aquitard, except along its northern reaches where it is connected to lower aquifers.**
- **It is thickest where the upper middle aquifer is very thin or absent.**



Aquifer structure

(Lower middle aquifer – Clifton formation and underlying aquitard)
The map above shows the depth from the ground surface to the lower aquifer. Light shading shows where the units are at or near the surface and dark shading shows where the units are deeper as they are buried by other aquitards and aquifers.

Lower middle aquitard



Cross section A-B
(Created from map on left showing the upper and lower parts)

Salinity and yield

Upper middle aquifer

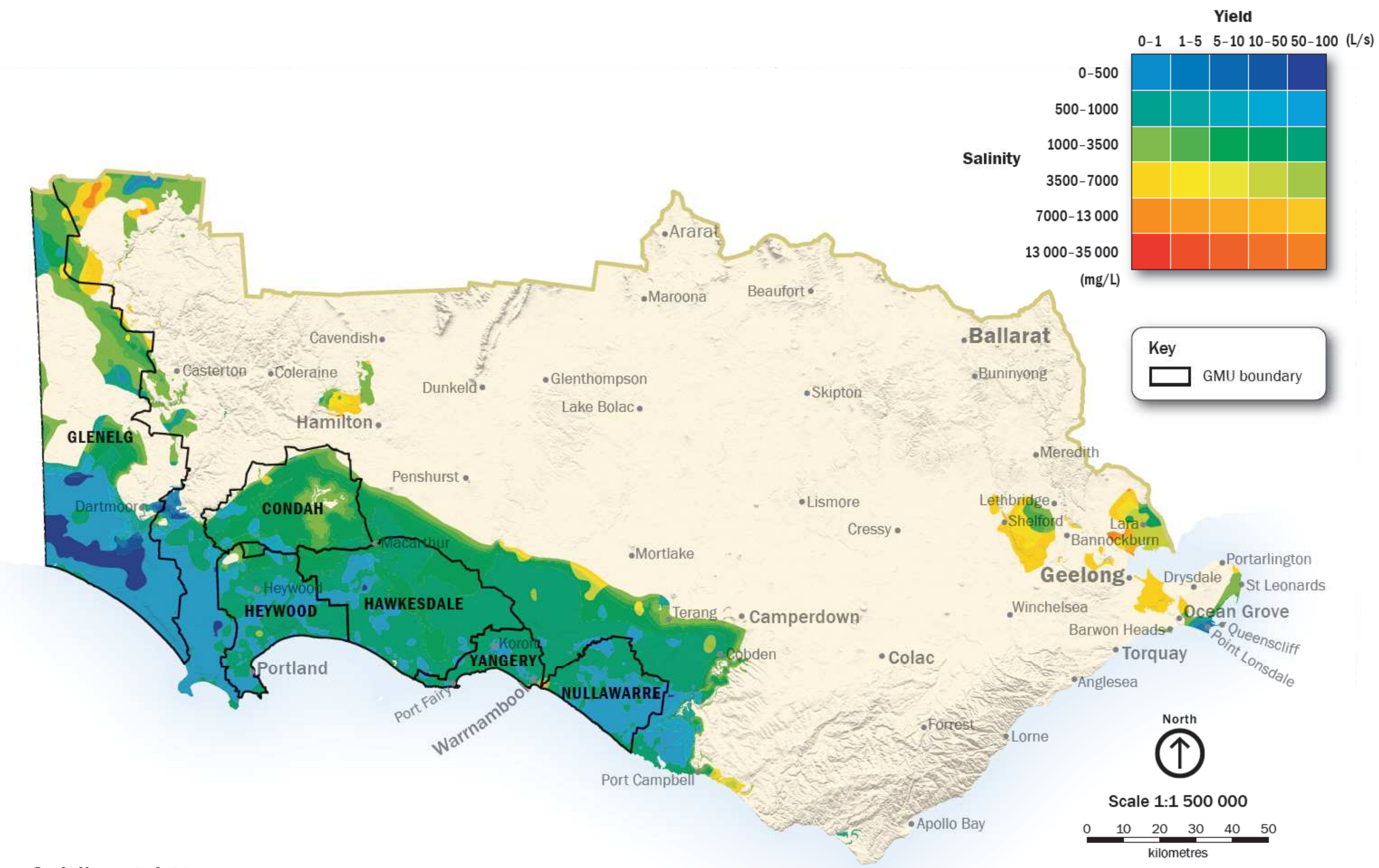
This aquifer is important because it is relatively shallow, high yielding, of good quality and underlies valuable farming land. The highest yields of 10 to 100 L/s occur near the South Australian border. Near Geelong the water quality is too poor for most uses – here the limestone is mined.

The total storage in this aquifer is approximately 50,000 GL. However only a percentage of this water can be used because most is too saline for most uses or too low yielding to extract.

This map does not include the salinity and yield for the lower middle aquifer as available data is limited. It is known to have good quality and yield in the Condah area shown by the small map below.

Observations

- **The upper middle aquifer has a very consistent rate of yield and salinity across most of its total area – this means that it is a very valuable aquifer.**
- **The lower middle aquifer around Condah is high yielding and has low salinity.**
- **GMUs cover the best areas of this aquifer.**

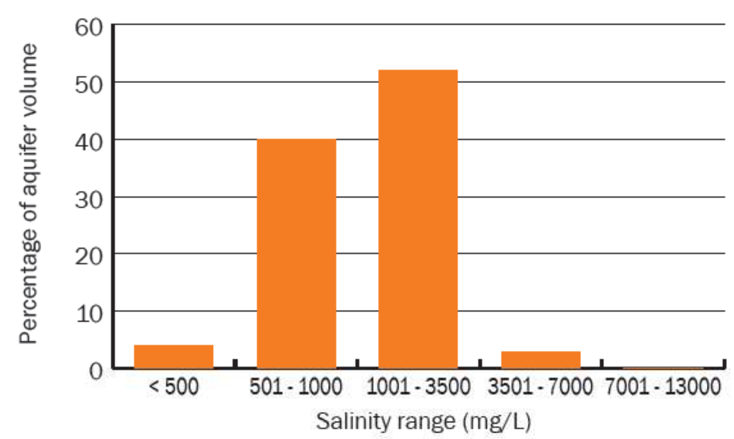


Salinity and yield

(Upper middle aquifer – Port Campbell Limestone and other limestone formations)

The map above shows areas of low salinity and high yield (blue) and areas of high salinity and low yield (orange and red). Potential users need to consider whether the probable groundwater depth, salinity and yield are suitable for their needs before they invest. The map shows that salinity and yield are highly variable across the region and therefore it is not possible to know whether a bore location will be good or not before drilling. Potential users should seek information from hydrogeologists and drillers with expertise in the area as well as local information about existing bores.

Salinity by volume



The graph above shows the salinity distribution in the aquifer. Approximately 45% of the groundwater has a salinity range suitable for most purposes.

Salinity and yield of lower middle aquifer

The area coloured blue indicates where the Clifton Formation (coloured brown) is high yielding and good quality (salinity range less than 1,000 mg/L) and is therefore suitable for most uses.

Movement of groundwater

Flow systems

The upper and lower middle aquifers have large regional flow systems. Recharge to the upper part (Port Campbell Limestone) comes from rainfall over a large area or leakage from the upper aquifer. Discharge is most likely to occur across the coast or into other formations as well as some surface discharge to swamps and leaks in low lying areas. The lower part (Clifton Formation) receives leakage from the upper formations and upward leakage from the lower aquifer.

Flow rate

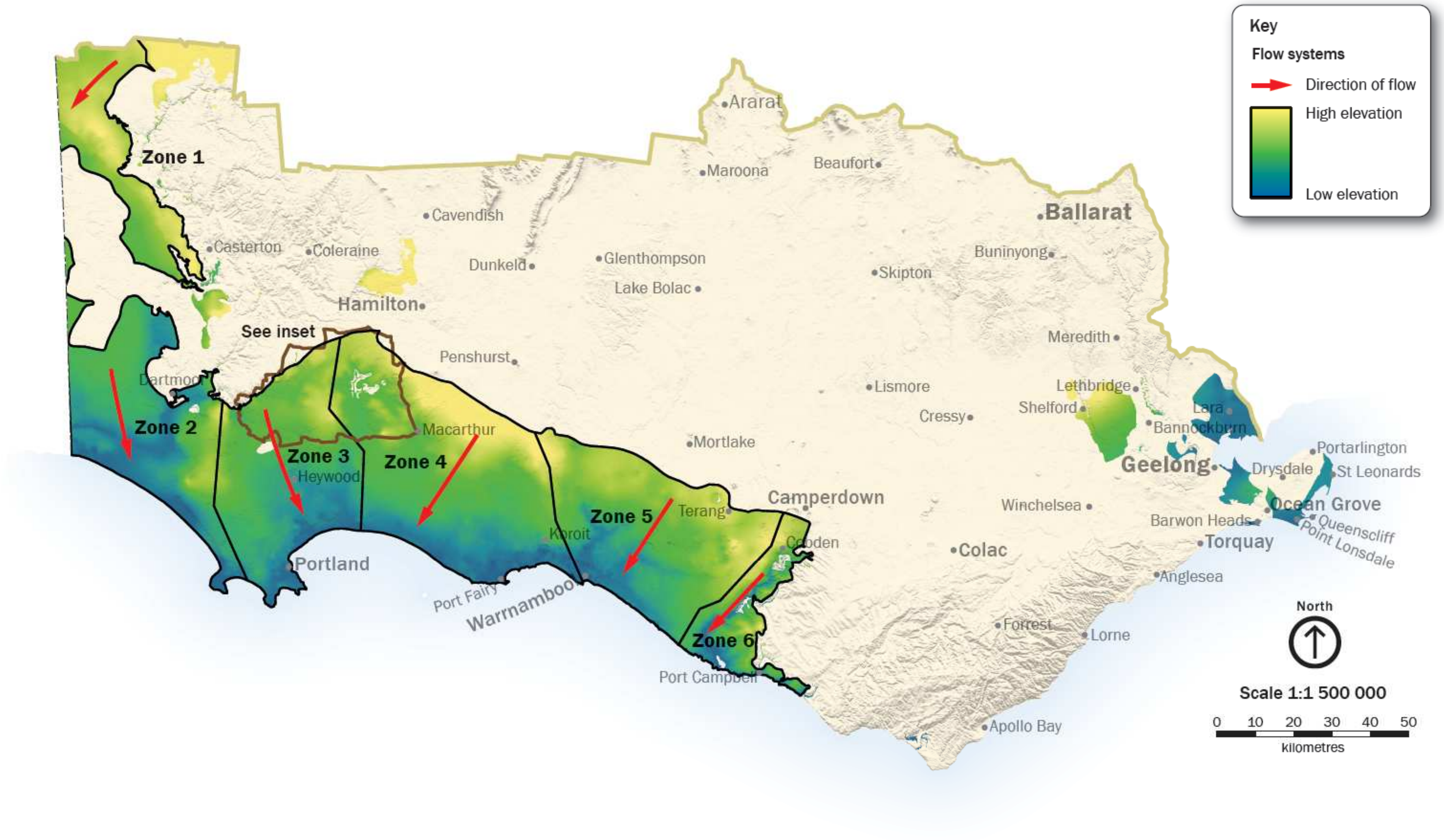
The flow in the upper and lower middle aquifers is lateral throughflow. This is because both parts are underlain by a very thick and relatively impermeable marl aquitard. The rate of flow is very slow. It may take groundwater from 200 to 500 years to travel 30km from the point of recharge to the point of discharge.

Pressure

The top of the Clifton Formation is at least 70 metres below the ground surface. It underlies a significant aquitard and is therefore very confined. Its groundwater pressure has a static level well above the top of the aquifer and is artesian near the Condah Swamp.

Observations

- **The upper middle aquifer recharges more directly from rainfall whereas the lower part relies on both downward and upward leakage from adjacent formations.**
- **Groundwater moves slowly through the middle aquifers in regional flow systems.**
- **The groundwater flows in large regional flow systems south to the coast**

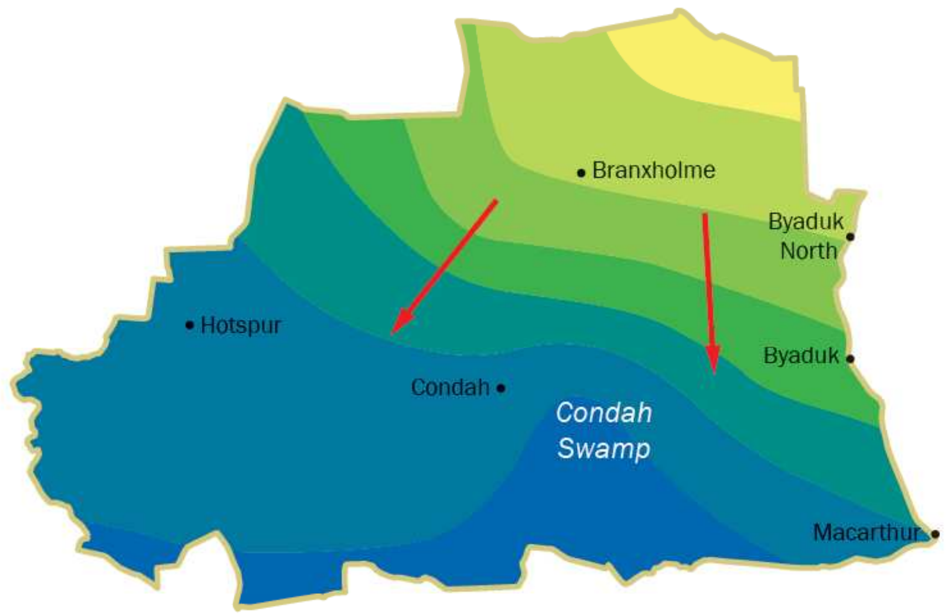


Groundwater flow systems

(Groundwater elevation - Port Campbell Limestone)

This map is made using the groundwater elevation of most of the upper middle aquifer. It is broken into six zones based on the groundwater elevations.

The map below shows the section of the Clifton Formation within the Condah WSPA boundary. There is no available data for groundwater levels outside this boundary.



Groundwater flow system of the Clifton Formation (lower middle aquifer)

5 Middle aquifers

Groundwater and the environment

The interaction of the middle aquifers with the surface environment is limited by the overlying upper aquifers.

Streams and ecosystems

The few streams that cross the limestone plains are ephemeral (flow only after rainfall) or estuarine. The reliance on groundwater is limited in these streams. The most likely reason is the presence of either an upper aquifer or a clay confining layer (aquitard) that blocks direct connection.

The limestone has developed cave-like features as a result of the dissolution of the limestone (known as karst). The karst absorbs local drainage and provides a subterranean environment for stygofauna (organisms that live in caves and aquifers). These occur in the area from Port Campbell to the South Australian border, particularly at Warrnambool and along the Glenelg River.

Vegetation found on the limestone plains can draw groundwater from the middle aquifers that occur near the surface. This is especially so where the upper basalt aquifer is absent in the far west of the region. Forest plantations thrive in this terrain, especially where their roots can access high water tables.

Interaction with other aquifers

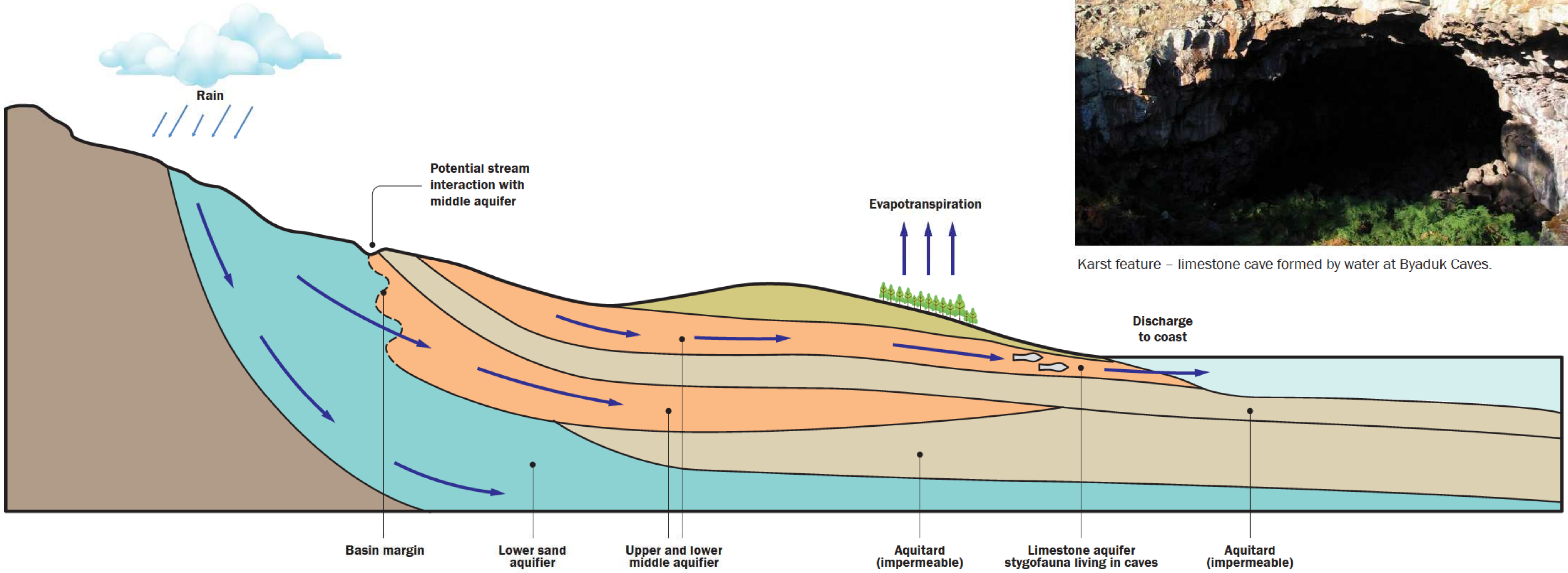
The limestone part of the upper middle aquifer is semi-confined by the overlying upper volcanic aquifer. The overlying Bridgewater Formation along the South Australian border is made of sand or limestone, meaning it is less confining and allows downward leakage.

It is essentially isolated except for where it has an interface with the lower aquifer along the basin margin. This shared margin is also where interaction with surface water features is possible notably along the Crawford River.

Observations

- **Interaction between the middle aquifers and surface water features is localised and mostly limited by an overlying confining layer.**
- **The upper and lower parts of the middle aquifers are isolated from each other by a thick aquitard.**
- **The lower middle aquifer is probably connected with the lower aquifers and with the Crawford River along the basin margin.**

Karst feature – limestone cave formed by water at Byaduk Caves.



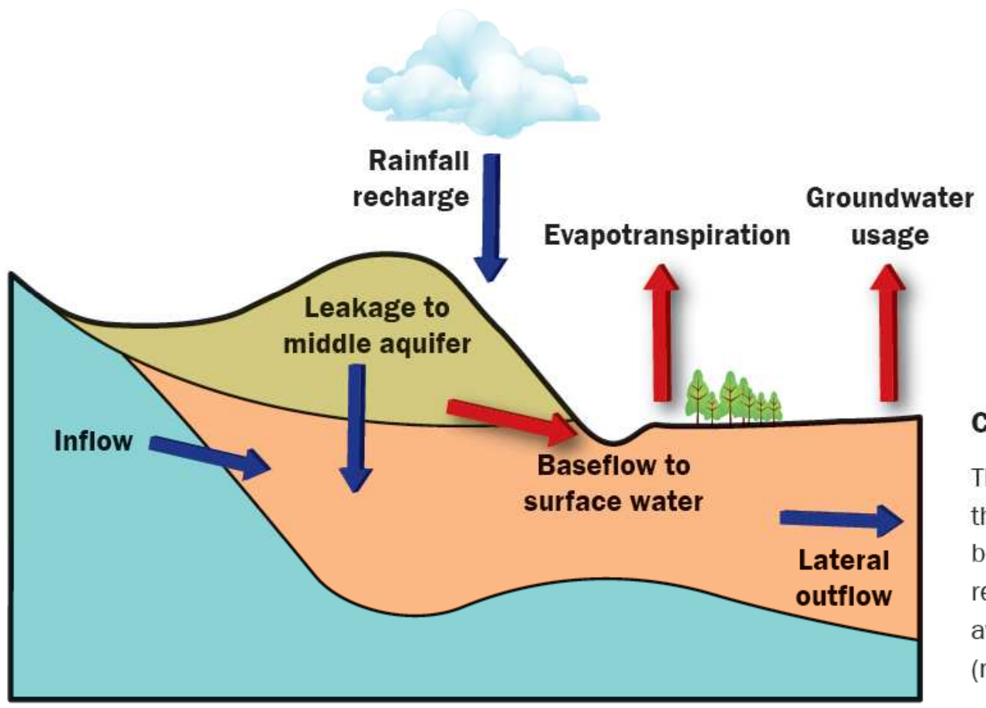
Water balance

While several desktop assessments of water balances in the middle aquifers have been completed, few have been done to a high level of detail.

Hawkesdale case study

The Hawkesdale Groundwater Resource Appraisal assessed the water balance in the upper middle aquifer in the Hawkesdale area (Zone 4 on the map showing movement of groundwater on page 39).

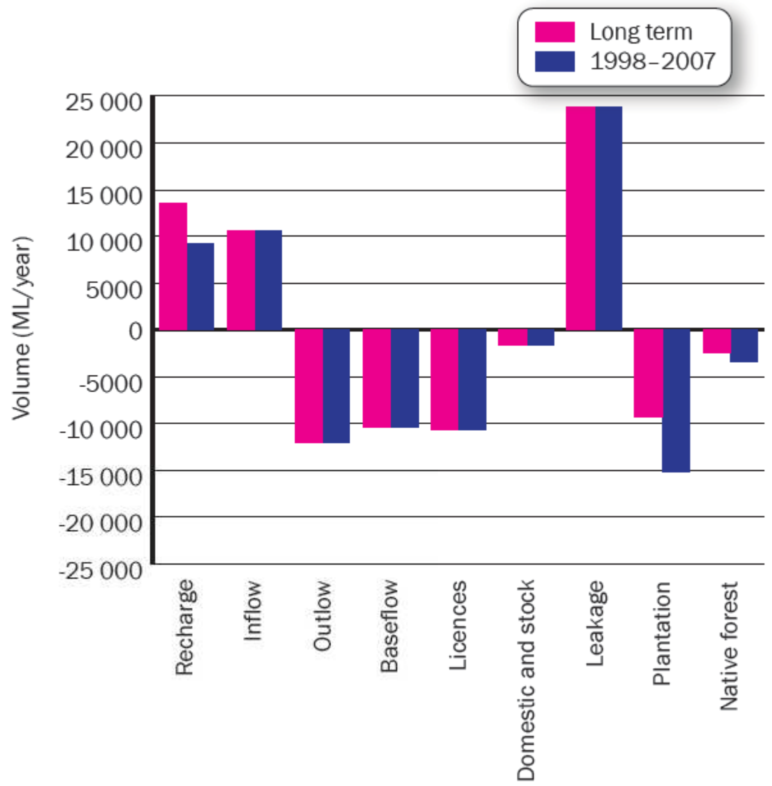
The figure below shows the water balance of the upper part of the middle aquifer.



The following graph compares the volume of the inputs and outputs to the water balance in the middle aquifer. This estimate was made in 2007 and contrasts the long-term balance with the previous decade.

It suggests that leakage from the overlying upper aquifer is the major input to the system in this area. The main factors influencing the difference in the water balance between the two periods are rainfall recharge and evapotranspiration from plantations.

Hawkesdale middle aquifer water balance



Conclusions

The net long-term water balance was estimated to be 1,600 ML/yr. This means the aquifer has been gaining water in the long-term which suggests it has been building storage. In the short term, it lost 10,000 ML/yr mostly because of reduced rainfall and change of land use. If rainfall levels return to the long-term average and land use does not change, the system will be close to equilibrium (neither gaining nor losing).

The results from this study are indicative of other parts of the upper middle aquifer, as the limestone formation and rainfall are relatively consistent across its total area. The major points of difference across the whole aquifer are the absence of a confining volcanic layer (west of Portland), density of groundwater licences (in its eastern parts) and plantations (in its western parts).

The lower middle aquifer (the Clifton Formation) is very confined. It is thought to receive inflow from where it interacts with the deeper Dilwyn Formation. It is estimated that the annual volume flowing through the Condah area is between 350 ML/yr and 5,000 ML/yr. The broad range in this estimate is due to the uncertainty of the data.

Observations

- **The water balance of the upper middle aquifer is influenced mostly by rainfall recharge and evapotranspiration (where the top of the aquifer occurs at or near the surface).**
- **This aquifer was losing water from 1998 to 2007. However it has maintained a positive long-term water balance even after several recent dry seasons.**
- **The reliance on rainfall highlights how it's not possible to reliably predict future balances and how important it is to understand the impact of land use and manage usage through licensing.**
- **Groundwater levels in the lower middle aquifer (Clifton Formation) are influenced by extraction at Condah and leakage into the lower aquifer.**

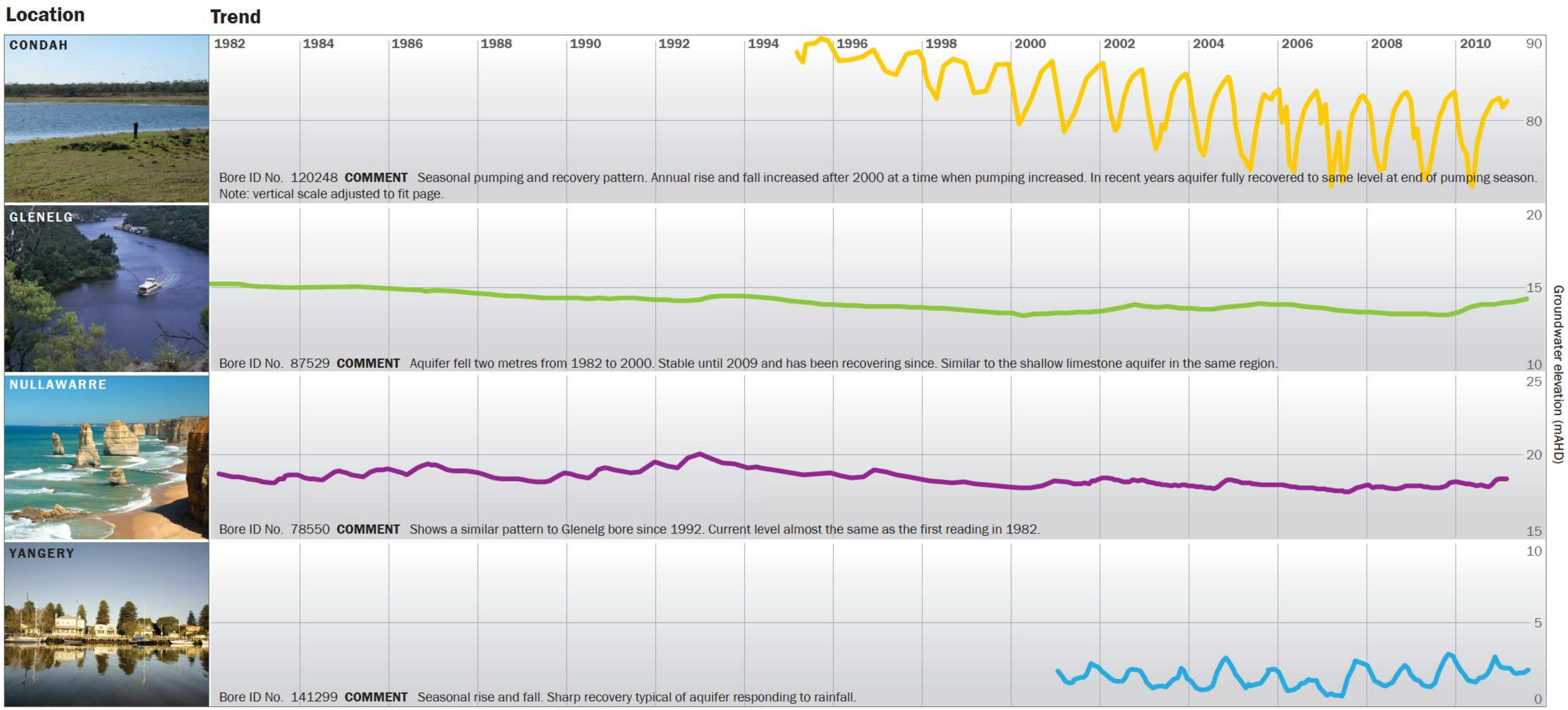
Regional trends

The hydrographs below show groundwater levels (relative to sea level) of several observation bores in the middle aquifers.

These hydrographs represent the range of observed groundwater levels in the region.

Observations

- **The upper and lower middle aquifers appear to have stable groundwater levels.**
- **The groundwater levels of the lower middle aquifer fall substantially during the summer months and recover during wet months.**
- **The pattern in Glenelg is not consistent with weather patterns or what was expected due to an increase in extraction. It may be affected by land use change.**



Groundwater levels shown are in metres relative to sea level. More hydrographs available from - www.srw.com.au

Users and usage

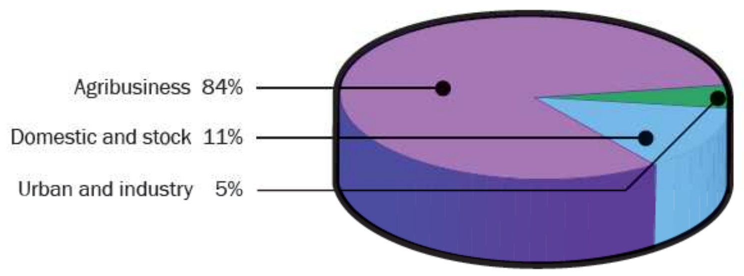
The middle aquifers are the most intensively developed of the aquifers. It is attractive because of its high yields, shallow depths and suitability for most uses.

Licensed users

95% of licensed users by number and volume are the agribusiness group and the domestic and stock group. Macarthur and Warrnambool also rely on the aquifer for urban supply.

The highest density of licences is along the coast from Warrnambool to Portland and in the Condah area.

Distribution of entitlements by user



	Number of licences	Average (ML)	Largest (ML)
Condah	39	193	2,160
Hawkesdale	108	127	901
Heywood	72	103	1,431
Nullawarre	180	156	614
Yangery	147	119	1,200
Unincorporated	225	51	2,000

There are approximately 7,500 domestic and stock bores that use approximately 10,000 ML/yr.

Licences in the Glenelg GMU have been accounted for in the upper aquifer, however some of these licences may also be in the middle aquifer.

The environment and other users

Groundwater Dependent Ecosystems (GDEs) are most likely to be deep-rooted vegetation, lakes in the Lake Mundi area and the lower reaches of streams from South Australia to Warrnambool.

The plains stretching from Portland into South Australia are ideal for plantation forestry because of the high rainfall and access to water from the middle aquifer in the root zone.

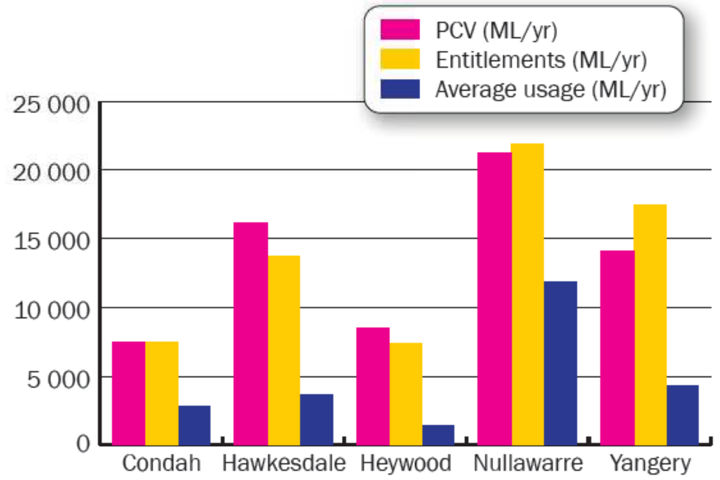
Licensed usage

Usage is 40% of entitlement. The highest usage was over 30 GL in 2006/07 during a dry year and the lowest around 17 GL in 2004/05 during a wetter year.

	PCV	Entitlements	Average Usage
TOTALS (ML/yr)	67,481	*79,398	24,081

*Entitlements exceed the PCV because of licences in unincorporated areas which do not have PCVs.

Nullawarre GMU recorded a high proportion of usage against entitlement but this may be distorted due to meters becoming clogged by iron bacteria. The relatively low usage in Hawkesdale is likely to increase as new developments become active.



*Hawkesdale GMU is capped at existing entitlements and the PCV is under review.

Sustainable usage

The limestone formations are extensive and continuous. Observation bores show that groundwater levels have remained stable during the run of dry seasons. The aquifers appear to be relatively confined by the overlying shallow volcanic aquifer and not in direct connection to lower aquifers. The connection with the upper Bridgewater Formation along the South Australian border is unknown. Current usage appears to be a relatively small component of the water balance. Rainfall and evapotranspiration appear to be more significant factors.

The aquifer is reliable because it extends over a large area, is at or near the surface where it receives rainfall recharge and has substantial storage.

The lower middle aquifer (the Clifton Formation) relies on the pressure in the lower aquifer to sustain its groundwater levels. Users need to factor in the possibility that changes in the lower aquifer may impact on the middle aquifer.

Observations

- **This is a highly reliable resource provided bores are drilled deep enough to allow for seasonal falls in groundwater levels.**
- **Usage is about 30% of entitlements. Estimates suggest domestic and stock usage accounts for a significant proportion of this.**
- **This aquifer appears well suited to a groundwater trading market because it is a relatively continuous system with a high number of entitlements and a substantial volume of unused entitlements.**

Value

Most of the water is used to irrigate pasture for dairy users. There are some large urban entitlements at Warrnambool and near Casterton. The value derived from the Unincorporated Area is abnormally high. This is because there are large urban and agribusinesses outside established GMUs.

Change to the groundwater economy in this area has been driven by the significant increase in dairy production in the past decade (causing a change from the traditional wool and beef production). This trend is highly likely to continue as dairy producers from northern Victoria seek a more secure water source.

GMU	Domestic and stock ($)	Agribusiness ($)	Urban and industrial ($)
Condah	41,000	1,488,000	530,000
Hawkesdale	1,256,000	2,857,000	871,000
Heywood	1,442,000	1,932,000	584,000
Nullawarre	1,085,000	7,396,000	2,165,000
Yangery	928,000	2,691,000	1,581,000
Other areas	2,371,000	2,357,000	2,109,000
TOTALS	7,123,000	18,721,000	7,840,000

Source: RMCG 2011

Future development

This aquifer has been particularly well developed where it occurs at or near the surface. It has also been significantly developed outside the GMU boundaries. There is a great deal of potential to develop the unused proportion of entitlement (60%). The data indicates that activation of the unused entitlement may be sustainable if it is well managed. Given the continuous nature of the aquifer and the high number of licences distributed across its total area, it would appear suited to a groundwater trading market if demand increases and regulation enables it to occur.

Current and emerging issues

The middle aquifers serve an important source of groundwater for agribusiness, urban and domestic and stock users. Groundwater levels have remained relatively stable. The most substantial changes affecting the management of the system are the influx of dairy users with large entitlements and the increase in plantations.

The map below shows the distribution of licences by size. There is a dense distribution of licences in the 101-200 ML range from Port Fairy to Port Campbell.

Many licences occur very close to the coast which increases the potential for seawater intrusion. Bores are measured to monitor whether salinity is increasing but no change has been detected.

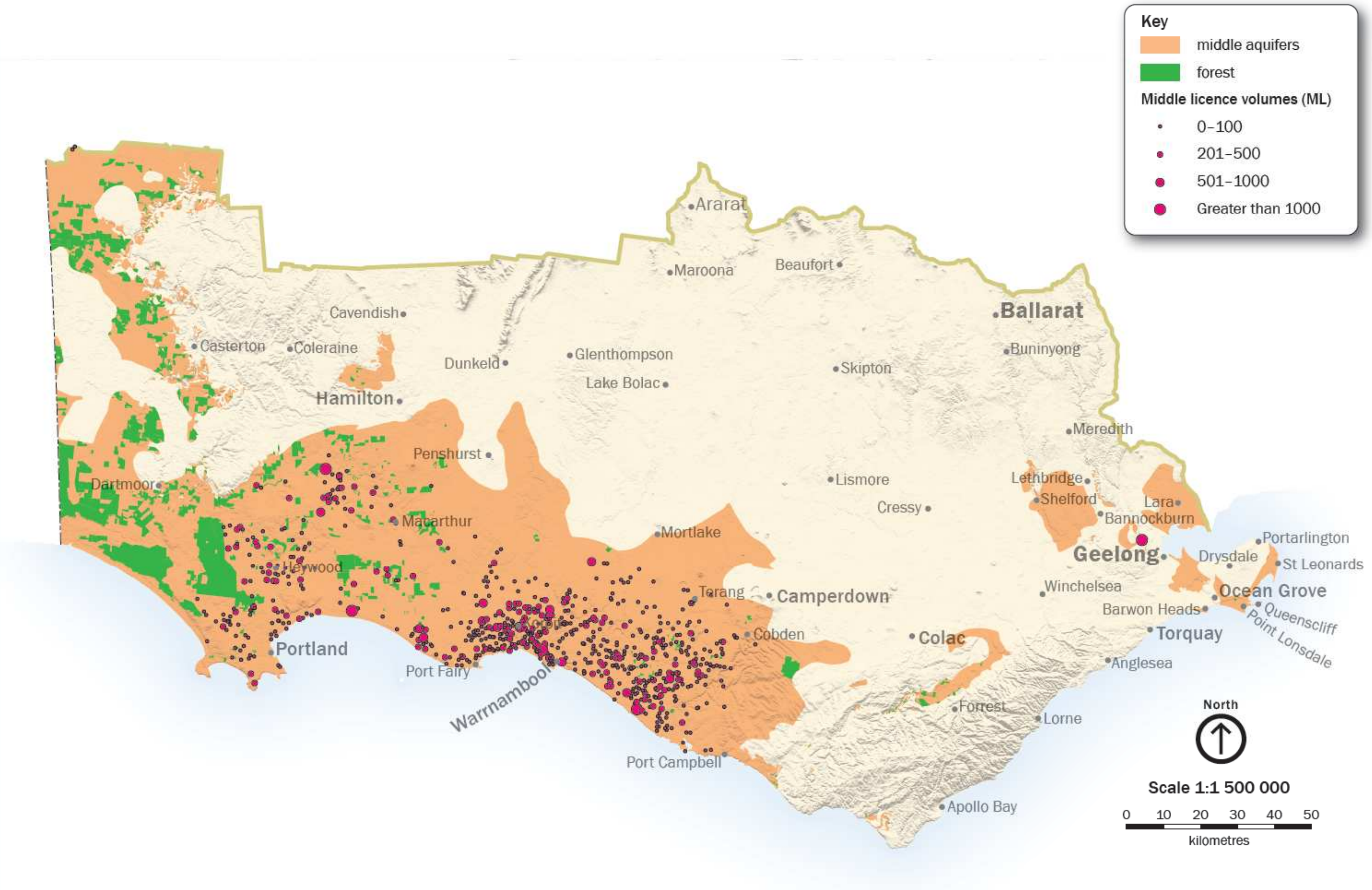
There is a cluster of large licences at Condah and a large outlying licence at Geelong used for dewatering at the Batesford quarry.

Observations

- **There is a dense distribution of licences from Port Fairy to Port Campbell.**
- **A large number of licences occur very close to the coast which increases the potential for seawater intrusion.**
- **There appears to be a large area of undeveloped aquifer in the west. However there is already a large number of licences in the upper aquifer that may also draw on the middle aquifer.**

Regional issues

- Reported bore interference by users in the upper aquifer from pumping in middle aquifer.
- The impact of interception by plantations in areas where there are shallow groundwater levels.
- The potential for saline intrusion along the coast.
- The decline of groundwater at Condah.
- The impact of iron bacteria fouling bores.
- The potential for Acid Sulfate Soils (ASS) developing as a result of groundwater declines near lakes and along the coast.



Land use and licences

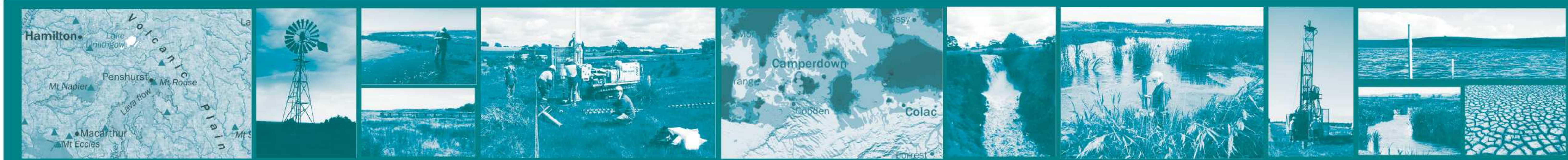
This map shows the distribution of licences and the land use where they coincide with the middle aquifers.

Chapter 6: Lower aquifers

The lower aquifers occur across the south of the region, stretching from the South Australian border south of the Grampians to Port Phillip Bay.

These aquifers are high yielding and have a relatively low salinity. They are used extensively for urban water supplies, including the cities of Geelong and Portland. They are generally too deep to be suitable for other users, except where they occur at or near the surface in the north of the region and around the Otway Ranges. Near the coast, the aquifers are under very high pressure caused by the weight of a large amount of overlying sediments and water. As a result of the pressure, the groundwater from these aquifers can reach temperatures of 50 - 60°C and flows freely from bores (artesian).

These aquifers are one of the most substantial and reliable water sources in Victoria due to their massive storage. However their relatively small annual recharge restricts their potential.



Aquifer geology

The lower aquifer systems of the region were formed about 60 million years ago. They are overlain by hundreds of metres of sediment and are underlain by the basement.

The lower aquifers extend over most of the Otway Basin. They are made up of the Dilwyn Formation, a major unit and the Eastern View Formation which occurs to the east of the Otway Ranges.

Dilwyn Formation

The Dilwyn Formation is made up of alternating layers of sand and clay.

In the Condah and Lake Mundi areas, the Dilwyn Formation is connected with the shallower Clifton Formation and limestone aquifers (from which most extraction occurs). This is because the aquitard separating them is thin or absent.

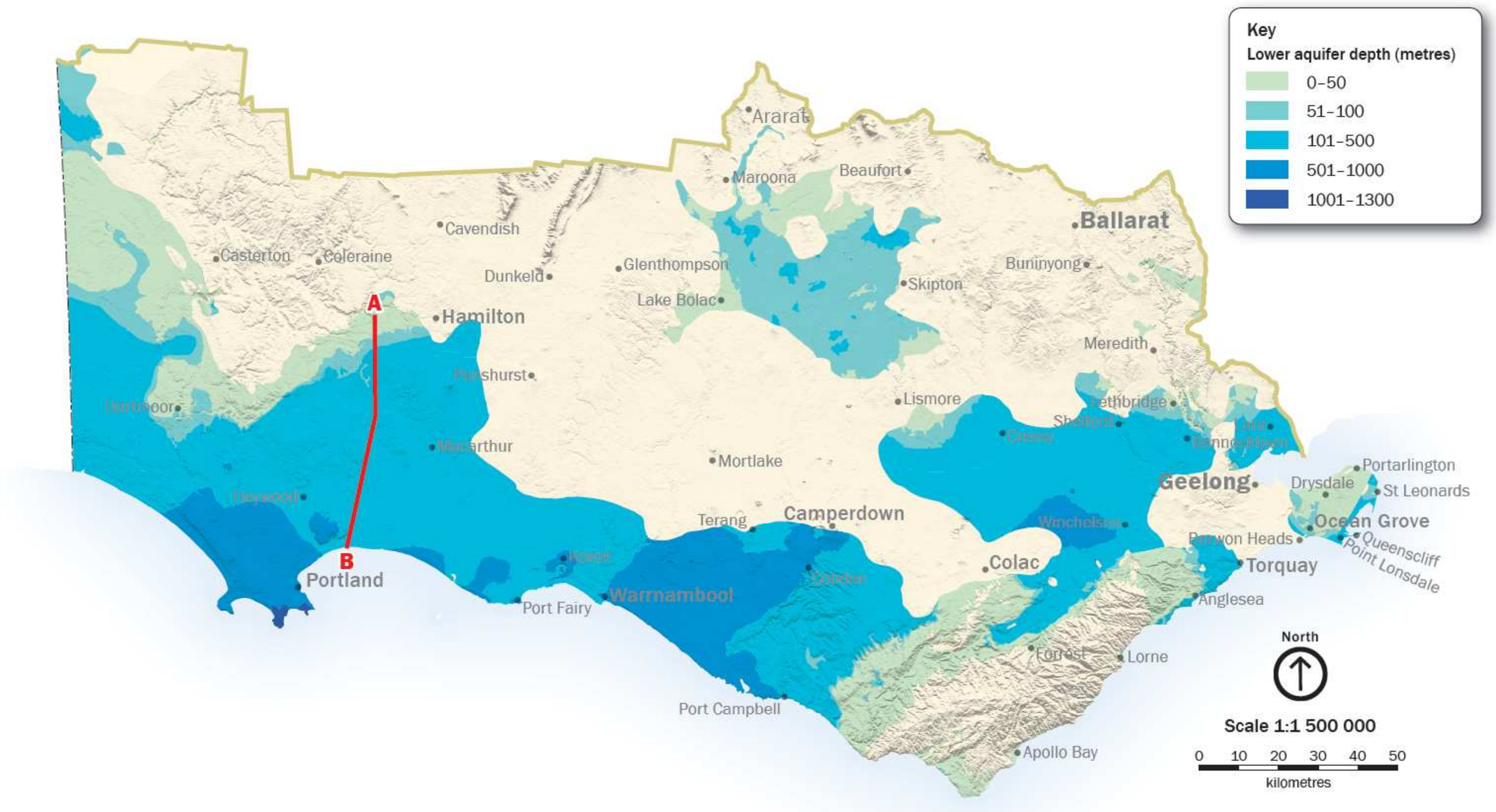
The basement is mainly siltstone with some fracturing and occurs at the surface around the basin margin forming the Grampians, Central Highlands and Otway Ranges. It deepens towards the coast where the overlying lower aquifer is much thicker. The basement only stores and transmits limited groundwater and effectively acts as an aquitard. However it is porous enough to hold water and fossil fuels and has high potential for gas development and geothermal energy.

Eastern View Formation

The Eastern View Formation is made up of mostly sand with minor amounts of silt and brown coal.

Observations

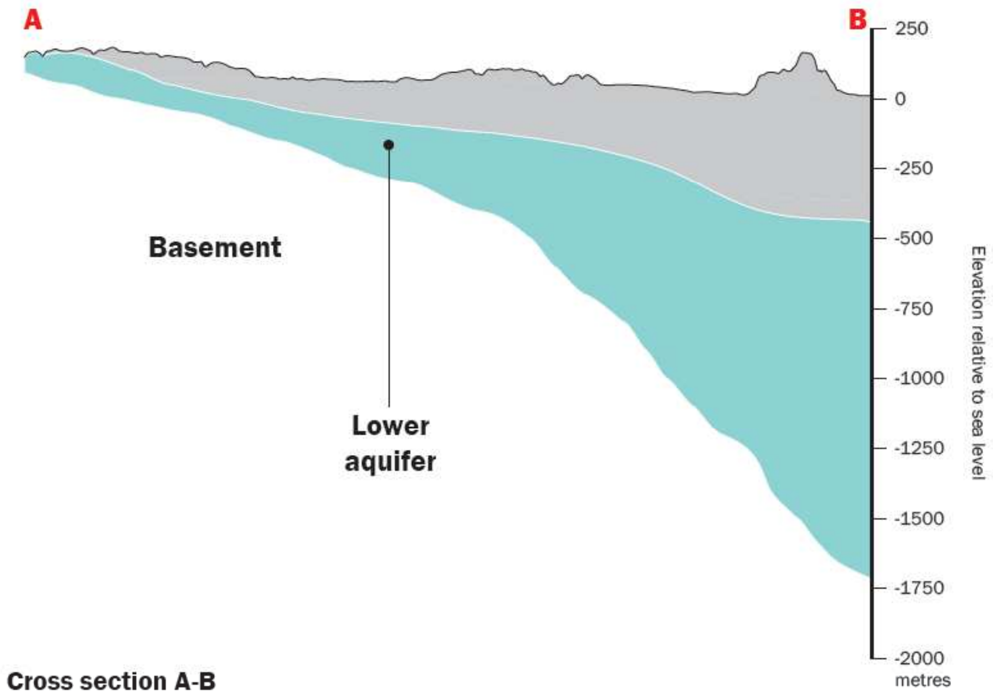
- **The lower aquifers occur at or near the surface west of Hamilton and around the Otway Ranges (where they are unconfined).**
- **Near the coast, the aquifers become much deeper and thicker (up to 1km).**
- **The basement is exposed at the surface around the basin margin forming the Grampians, Central Highlands and Otway Ranges.**
- **The basement is deeper near the coast, where it is overlain by the lower, middle and upper aquifers.**



Aquifer structure

(Dilwyn and Eastern View Formations)
The map above shows the depth from the ground surface to the lower aquifer. Light shading shows where the units occur at or near the surface and dark shading shows where the units are deeper as they are buried by other aquitards and aquifers.

Depth to basement from ground surface (metres)



Cross section A-B
(Created from map on left showing the lower aquifer and basement)

Salinity and yield

The lower aquifers near the coast (except around Warrnambool) have relatively low salinity water that is suitable for most uses.

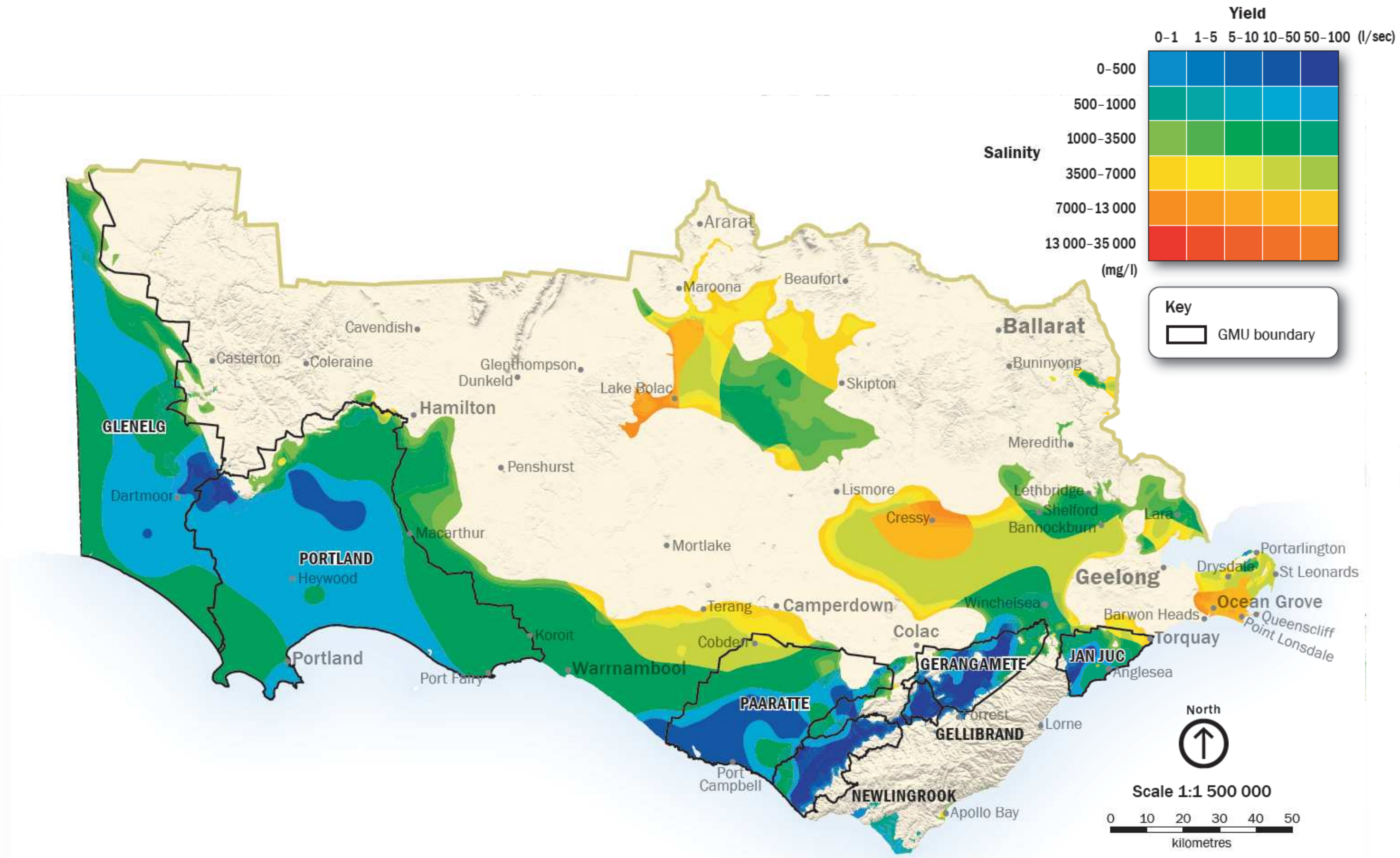
Where the aquifers are thickest at Portland, Port Campbell and Gerangamete, they are high yielding (in the range of 10-100 L/s). Salinity and yield are good in the Otway Ranges and west of Hamilton. Further inland, salinity is generally higher and yield is generally lower.

The total volume of these aquifers is approximately 250,000 GL. This is many times greater than the accessible volume because most of this water is too saline for most uses or too low yielding to extract.

Along the coast, the top of this aquifer occurs up to 1,000 m below the ground surface. This means it is under enormous pressure due to the weight of overlying sediments and water. Groundwater bores are often free-flowing (artesian) and groundwater can reach temperatures of 50 - 60°C. In the past, water from this aquifer was used to heat public buildings in Portland.

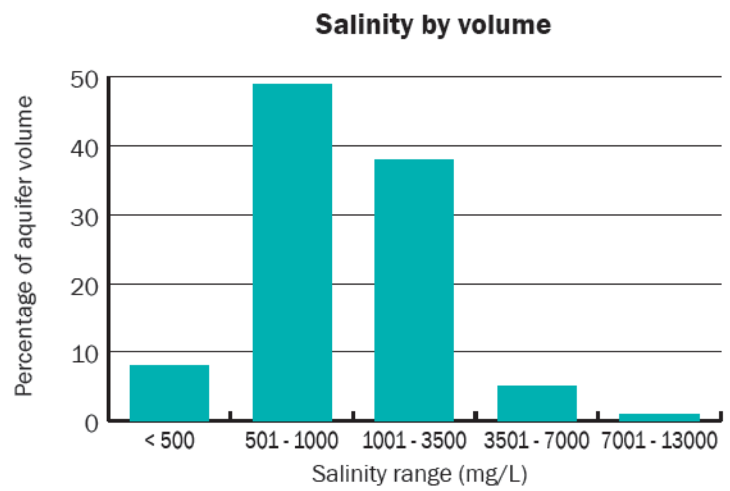
Observations

- **The lower aquifers have much greater storage and better quality water when compared to the upper aquifers.**
- **Yield and salinity are generally best close to the coast but are highly variable.**
- **Along the coast the aquifer is artesian and warm enough to heat buildings.**
- **The best areas for both salinity and yield are covered by GMUs.**

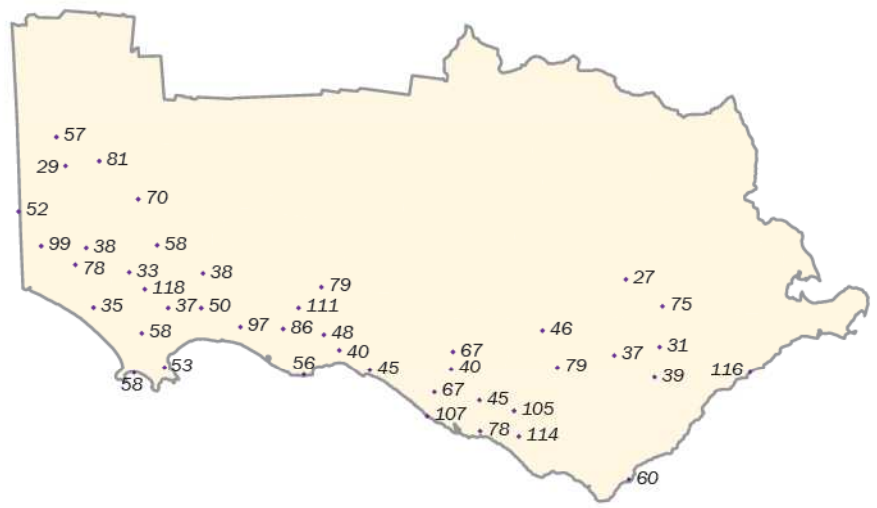


Salinity and yield

The map above shows areas of low salinity and high yield (in blue) and areas of high salinity and low yield (in orange and red). Potential users need to consider whether the probable groundwater depth, salinity and yield are suitable for their needs before they invest. The map shows that salinity and yield are highly variable across the region and therefore it is not possible to know whether a bore will be good or not before drilling. Potential users should seek information from hydrogeologists and drillers with expertise in the area as well as local information about existing bores.



The chart above shows the salinity distribution in the aquifer. Over 50% of the groundwater has a salinity range suitable for most purposes.



Basement temperature

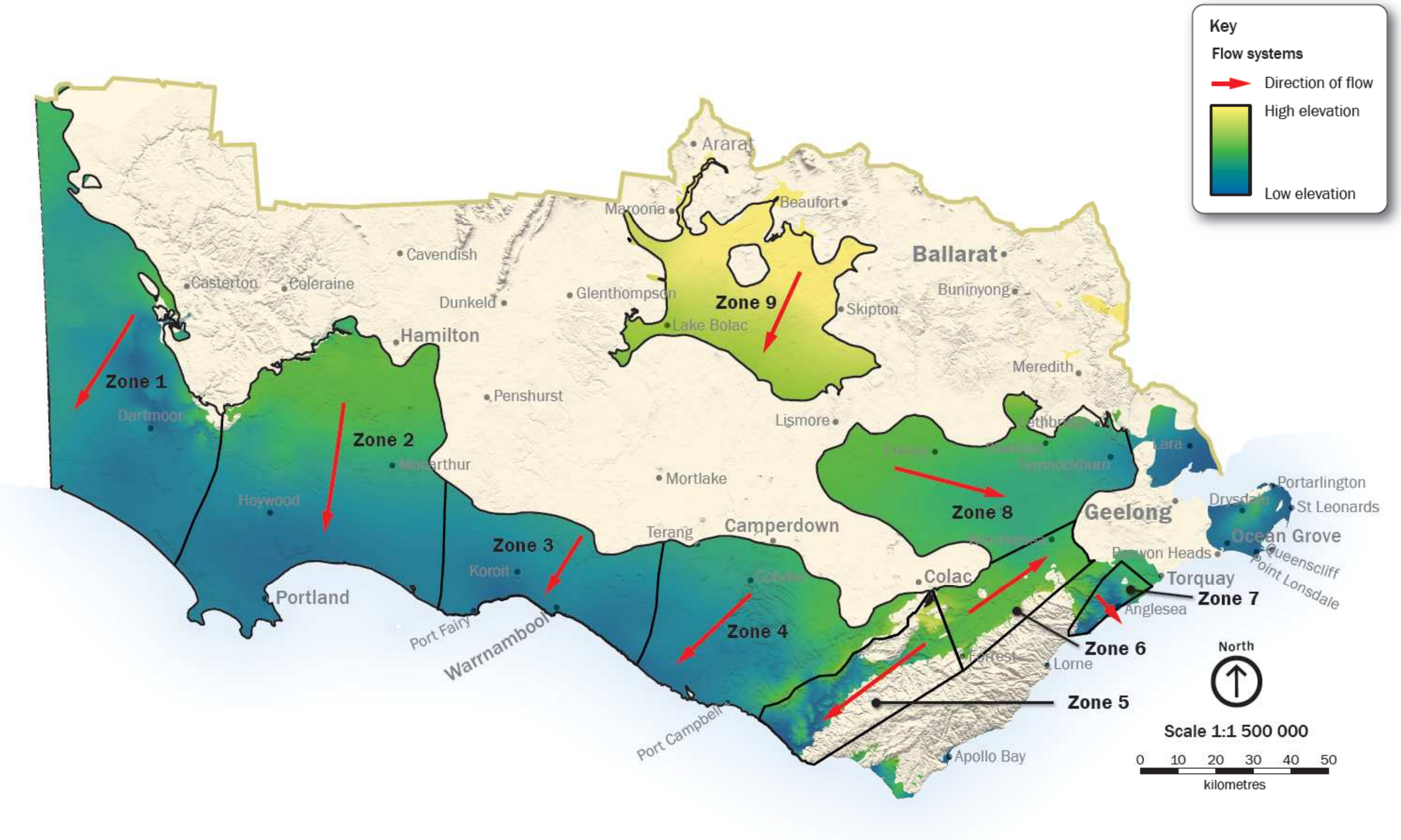
The map above shows groundwater temperatures (degrees Celsius) recorded in basement bores. The heat from the basement rocks causes a temperature gradient in the lower aquifers.

Movement of groundwater

Groundwater in the lower aquifers flows in nine separate flow systems, defined by the structure of the Otway Basin (zones are bounded by ridges in the underlying basement).

Five zones (Zones 1 to 5) are located to the west of the Otway Ranges and groundwater flows north-south across the coastline and it discharges well offshore. Basement ridges restrict flow in the east-west direction across zone boundaries.

East of the Otway Ranges, groundwater in Zones 6 and 7 flows east and eventually discharges offshore. Further inland, groundwater in Zones 8 and 9 flows south and discharges to other aquifers. Groundwater use is negligible in Zones 8 and 9 due to high salinity and low yield (see previous page).



Groundwater flow systems

(Groundwater elevations in the Dilwyn and Eastern View Formations)

The map above shows the groundwater flow systems of the lower aquifer. These zones were developed using the geological structure of the aquifer to identify aquifer compartments and the relative water levels were used to determine direction of flow. These zones are also referred to on pages 50 and 52.

Observations

- **Groundwater in the Dilwyn and Eastern View Formations flows in several zones (bounded by ridges in the underlying basement). The ridges restrict flow in the east-west direction across zone boundaries.**
- **Groundwater in Zones 1 to 5 (west of the Otway Ranges) flows from north to south across the coast where it discharges up to 50 km offshore.**
- **Groundwater in Zones 6 and 7 (to the north and east of the Otway Ranges) flows east and eventually discharges offshore.**
- **Further inland, groundwater in Zones 8 and 9 flows south and discharges to other aquifers.**

Flow systems

Local, intermediate and regional flow systems occur within all of the zones. Local and intermediate flow systems with travel distances of less than 30 km occur in several locations: where the aquifers are close to the ground surface; in the highlands where the lower aquifer outcrops (Zone 5 and northern parts of Zone 7); and at the recharge areas around Dartmoor in Zones 1 and 2.

Regional flow systems with long travel distances (greater than 30 km) occur where the Dilwyn and Eastern View Formations are deeper. Groundwater may be thousands of years old by the time it reaches the coast in Zones 1 to 4 (Glenelg, Portland, Warrnambool and Port Campbell). The regional flow systems of the aquifers become very confined by the surface close to the coast.

The fractured rock basement forms a very large regional flow system underlying the upper, middle and lower aquifers. Water moves very slowly through this system as it travels over 100 km from the highlands to the coast. Little groundwater is extracted from the basement as it is low yielding and generally high salinity.

Groundwater and the environment

The lower aquifers occur at or near the surface only in relatively small areas west of Hamilton and in the Otway Ranges (see map on page 46: Geology). The aquifers only receive direct rainfall recharge in these areas.

Effect of land use and rainfall on the aquifer

It can take hundreds or thousands of years for a change at the surface (such as rainfall or land use) to impact on the deeper, confined part of the aquifers near the coast (where most extraction occurs).This is due to the long travel times either from the inland recharge zones or downwards through all of the overlying aquifers and aquitards. Recent changes in land use or rainfall are unlikely to have impacted on the confined part of the lower aquifer west of the Otway Ranges. However it may still be responding to ancient climate changes.

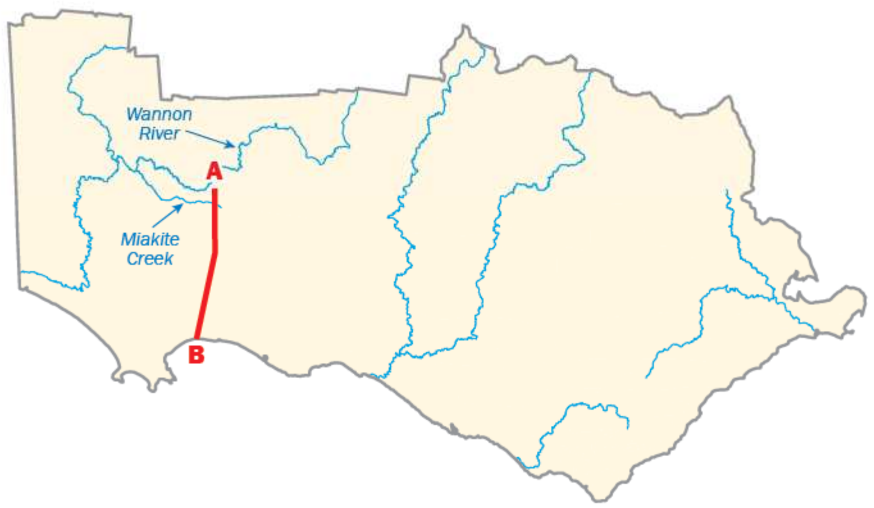
Effect of groundwater pumping on stream flows

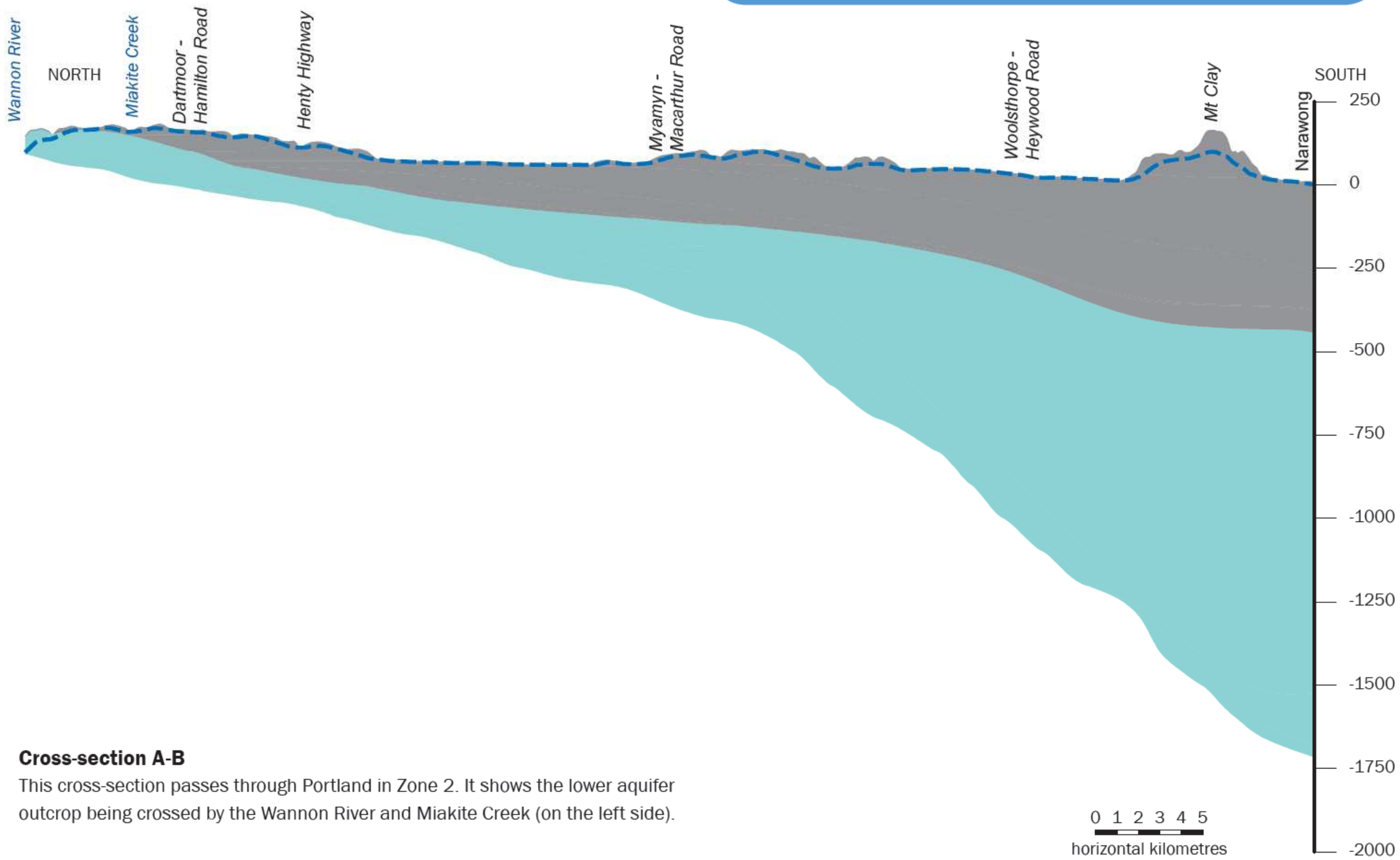
The lower aquifers interact with surface water where they occur at or near the surface. Parts of the Wannon River, Gellibrand River and Anglesea River (and their tributaries) cross lower aquifer outcrops and may gain flow from or lose flow to the lower aquifers. Groundwater extraction in these areas may significantly impact stream flows.

It is estimated to take as little as ten years for a pressure change (resulting from extraction from the deeper confined parts of the aquifer) to impact on distant connected streams. However this is difficult to measure or observe. This pressure change occurs much faster than the rate that groundwater travels the same distance. In contrast, it is estimated to take more than 100 years for extraction to have any impact on the shallower aquifers immediately above. This is due to the very slow travel times through the overlying aquitards.

Observations

- **Direct rainfall recharge occurs where the lower aquifers occur at or near the surface in small areas around the basin margins, particularly around Dartmoor and the Otway Ranges.**
- **The lower aquifers interact with surface water in several areas: the Wannon River north of Portland; the Gellibrand River; and the upper reaches of the Anglesea River near the Otway Ranges.**
- **Groundwater extraction or land uses such as plantation forestry in these areas may take from several months to several years to impact on surface water - how long depends on how close the extraction site is to the stream or river.**
- **Extraction from the confined section of the aquifers near the coast may also impact on waterways but this impact may be too small to be observed in a lifetime.**





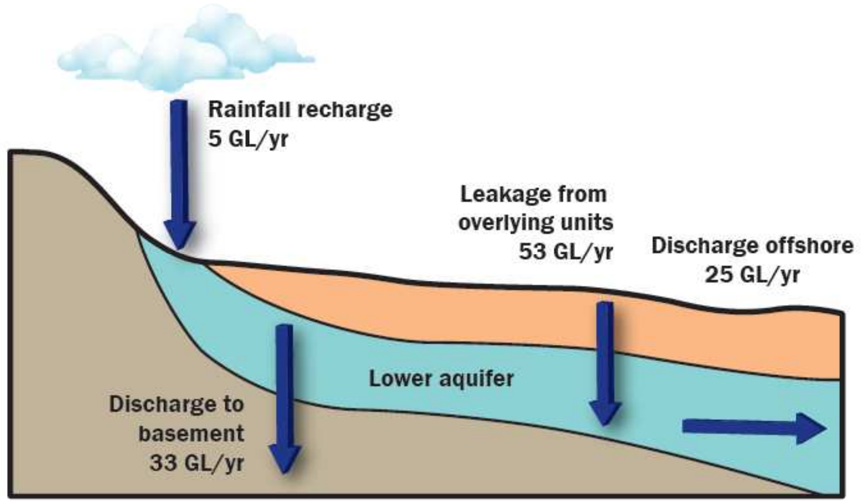
Cross-section A-B

This cross-section passes through Portland in Zone 2. It shows the lower aquifer outcrop being crossed by the Wannon River and Miakite Creek (on the left side).

Water balance

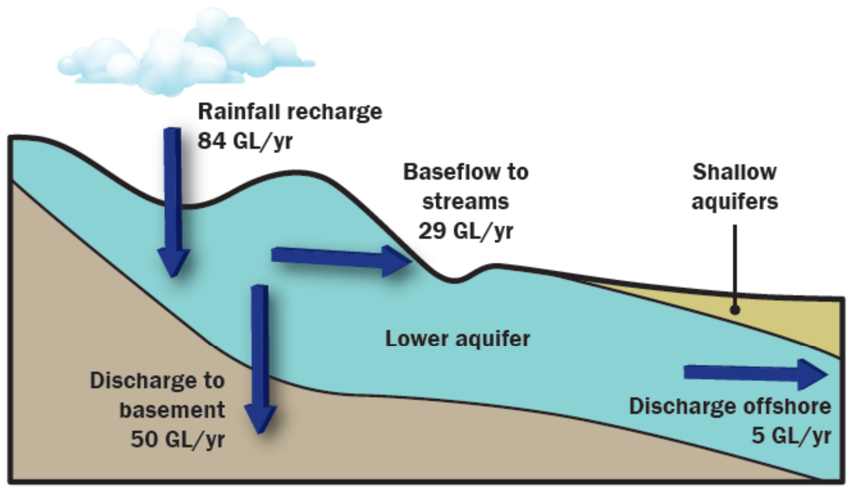
Water balances have been estimated for the seven zones identified in the movement of groundwater map along the south west coast and around the Otway Ranges.

The diagrams below compare a mostly confined zone in the west (Portland) with a mostly unconfined area in the Otway Ranges to the east (Newlingrook).



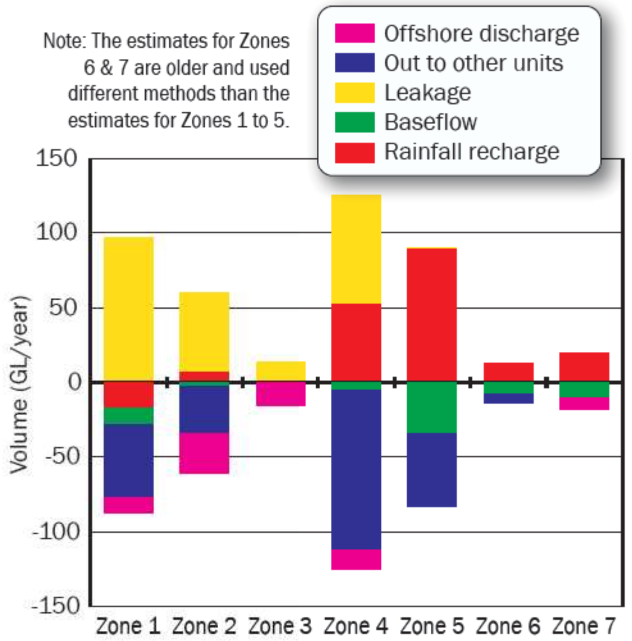
In **Zone 2** (around Portland) there is little direct recharge from rainfall because the lower aquifer is largely confined from the surface. The aquifer is strongly controlled by slow leakage from overlying formations that takes many decades to reach the aquifer.

The analysis shows that the net volumes of inputs and outputs are huge. Even though this may seem to be an infinite resource, each zone has different recharge and discharge characteristics that control how much and from where water can be taken.



In **Zone 5** (around Newlingrook) the main input is rainfall recharge because the aquifer occurs at the surface over a relatively large area. It discharges a large volume of baseflow to local streams, in particular the Gellibrand River. The aquifer is strongly controlled by recent rainfall.

The graph below shows the water balances for the lower aquifers west of the Otway Ranges.



Conclusions

Zone 4 (around Port Campbell) has the highest inputs and outputs. It is strongly controlled by throughflow. **Zone 3** (around Warrnambool) has very small inputs and outputs and is dominated by leakage from shallower aquifers and baseflow to streams. **Zones 1 and 2** (around Glenelg and Portland) are dominated by leakage from shallower aquifers and discharge to basement. Zone 1 (around Dartmoor) actually loses more water from evapotranspiration than it gains from rainfall. **Zone 5** (around Newlingrook) has a large recharge area in the Otway Ranges and substantial discharge as baseflow to streams. The estimates for **Zones 6** (around Gerangamete) and **7** (Angelsea) are based on older technical work and used different methods than the estimates for Zones 1 to 5. They show the relative size of the inputs (mainly rainfall recharge but probably including leakage from overlying formations) and outputs (baseflow to rivers and discharge).

This information shows the dynamics of each zone, including their strengths and vulnerabilities. The areas/zones that rely most heavily on rainfall for recharge occur in a high rainfall area around the Otway Ranges. If these aquifers were to be intensively pumped they are likely to recover because of the reliable rainfall. If there is a shift to long-term lower rainfall patterns, these aquifers are likely to decline more rapidly than the aquifers further west.

The aquifers to the west rely on leakage through overlying formations for recharge. This means the impact of rainfall is delayed by many years. These aquifers are more vulnerable to extraction than to rainfall changes. In the very long term, they are also vulnerable to extraction from shallower overlying aquifers that may intercept water that would otherwise leak through to these aquifers.

Observations

- **Each zone of the lower aquifers has a different water balance and its inputs and outputs are affected by different influences.**
- **The lower aquifers are mainly recharged from very slow downward leakage from the overlying aquifers and aquitards. The highest recharge rate occurs along the outcropping margin of the aquifer in high rainfall areas.**
- **It is important to balance extractions with periods of rainfall recharge in the eastern zones (Zones 6 and 7). This is to enable the resource to recover and sustain baseflow to dependent streams.**
- **It is important that caps set on allocations of overlying aquifers do not "double account" recharge from rainfall. Otherwise extraction from upper and middle aquifers will draw on the recharge assumed to be leaking through to the lower aquifers.**

Regional trends

The hydrographs below show groundwater levels (relative to sea level) of several observation bores in the lower aquifers.

These hydrographs represent the range of observed groundwater levels in the region.

Observations

- Groundwater levels are stable in most parts of the aquifers close to the coast because these aquifers are overlain by thick aquitards stretching across most of the basin and are insulated from recent rainfall or land use effects.
- The reaction to external influences is so slow that the aquifers in some areas may still be responding to rainfall and sea level changes from thousands of years ago.
- The aquifers in the east of the region are less confined than those in the west and have lower storage volumes. This makes them more sensitive to extraction and rainfall.
- Where overlying aquitards are thin or absent, the lower aquifer is influenced by extraction from the aquifers above.

Location **Trend**

Groundwater levels shown are in metres relative to sea level. More hydrographs available from - www.srw.com.au

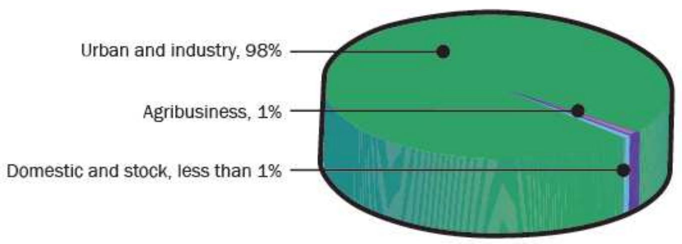
Users and usage

Groundwater from the lower aquifers provides the primary source of water supply to towns including Portland, Port Fairy, Heywood, and Timboon. It also provides a backup supply in towns and cities including Geelong and Warrnambool.

Licensed users

The main licensed users (98%) are urban water authorities and Alcoa. In Zone 1 (near Lake Mundi) the lower aquifer is relatively shallow inland and provides some use for agribusiness and domestic and stock users.

Distribution of entitlements by user



GMU	Number of licences	Average licence size (ML/yr)	Largest licence (ML/ yr)
Gellibrand	0	0	0
Gerangamete	1	8,000	8,000
Jan Juc	4	2,818	*7,000
Newlingrook	5	392	1,800
Paaratte	4	803	3,159
Portland	8	972	6,222
Unincorporated	14	226	2,920

*Includes Jan Juc Bulk Entitlement

Approximately 150 bores are registered for domestic and stock use which may use around 200 ML/yr.

Well over 3,000 domestic and stock bores occur in the middle and upper aquifers in residential areas of the major urban centres. These effectively supplement the town urban supply.

The environment and other users

There are very limited areas where the surface water environment and the lower aquifers interact. Given the remoteness of current significant pumping from these areas, the most influential factor on water for the environment is likely to be rainfall recharge and interception.

In the recharge areas around Dartmoor and to the west across the South Australian border, there are significant forest plantations which may impact on both groundwater recharge and surface water flows (see page 53: Current and emerging issues).

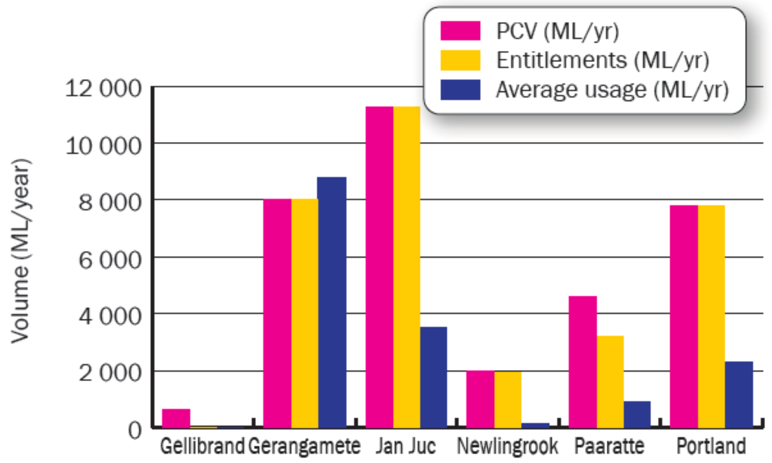
In human time frames, this could also affect the water supply for inland towns like Dartmoor but it will not have any measurable impact on groundwater extraction close to the coast, due to the very long time it takes for the groundwater to travel that distance through the aquifer.

Licensed usage

Usage is as high as 70% of entitlement where groundwater is the main urban water source. In towns where it supplements surface water sources, groundwater will probably not be used during wet seasons but could be highly used during dry seasons.

	PCV	Entitlements	Average usage
TOTALS (ML/yr)	34,253	35,384	15,629

The high proportion of usage at Gerangamete is a result of high usage in recent years for Geelong's town supply. The urban entitlements for Gerangamete and Jan Juc are based on long term average usages of 4,000 ML/yr and 7,000 ML/yr respectively, but allow for higher usage during droughts.



Sustainable extraction

The groundwater resource available in the lower aquifers is vast and the volume in storage is much greater than the total annual usage over many years. However there is uncertainty about the reliance of the lower aquifer on leakage from shallower aquifers for recharge. Extraction from shallower aquifers could intercept water that would otherwise contribute to this resource and this may impact on groundwater levels in the long term.

On the other hand, the Clifton Formation (the lower middle aquifer) appears to rely on pressure in the lower aquifer to maintain groundwater levels (see page 41 "Water balance")

In the eastern zones of the lower aquifers (Zones 6 and 7), pumping has been sufficient to stress the aquifer. Groundwater levels in Zone 6 have recovered following periods of pumping in the past and they are still recovering from the pumping period ending in 2010. Groundwater in Zone 7 is still being pumped and tested (see graphs on page 51).

Observations

- The great drilling depths mean that is it generally too expensive for users other than urban water authorities and industry.
- Groundwater from the lower aquifers is the main source of water supply for some towns and cities and supplements surface water sources in others.
- Opportunities to access new water by transfers from within the aquifer are limited as there are few existing entitlements and most of these are held by two water authorities. Further allocation is under review.

Value

The value estimated for the urban water supply in Gerangamete (Zone 6) is much greater than the other GMUs.

Good quality groundwater occurs at great depth in the areas west of the Otway Ranges. This means the cost of drilling or repairing bores is very high (up to $3 million). However, the large pressure along the coast and vast aquifer storage means bores should not be affected by significant groundwater declines within their effective life.

GMU	Domestic and stock ($)	Agribusiness ($)	Urban and industrial ($)
Gellibrand	2,000	0	0
Gerangamete	5,000	951,000	21,735,000
Jan Juc	3,000	1,126,000	26,818,000
Newlingrook	5,000	6,000	388,000
Paaratte	2,000	0	261,000
Portland	13,000	50,000	2,917,000
Other areas	131,000		7,300,000
TOTALS	161,000	2,133,000	59,420,000

Future development

The aquifers west of the Otway Ranges have high yield and water quality suitable for further development. Gellibrand GMU is yet to be developed although an investigation was undertaken by Barwon Water during 2007.

Technical work to support possible new allocation of entitlements is under way. Urban water suppliers and industry are likely to consider using groundwater more in the future to meet increasing demand.

Current and emerging issues

The map below shows current land uses where the lower aquifers and the basement outcrop. It includes active groundwater licences in the lower aquifers. The map on the right shows the total area of forest plantations where the lower aquifer outcrops and recharges around Dartmoor.

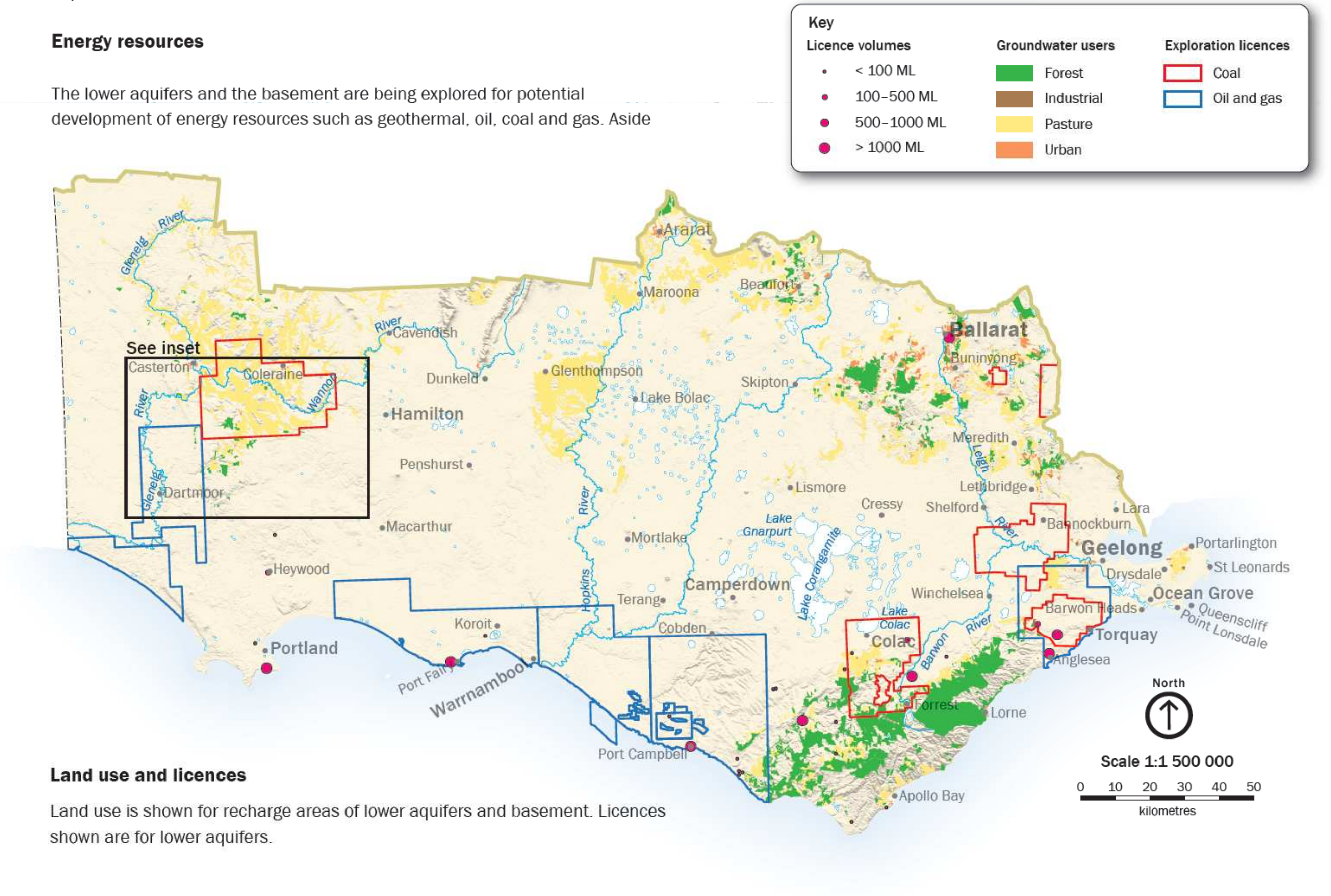
Stream interference

There is potential for groundwater extraction to impact on streams in recharge areas at the top of several river catchments (Crawford, Glenelg, Gellibrand, Anglesea and Barwon Rivers). Monitoring is being conducted in the Barwon and Anglesea River catchments to increase understanding and manage possible impacts.

Energy resources

The lower aquifers and the basement are being explored for potential development of energy resources such as geothermal, oil, coal and gas. Aside from coal, these explorations are all well separated from the aquifers used for urban water supply.

- Coal developments - open-cut and coal seam gas extraction, target inter-seams of the lower aquifers and may de-water the aquifer.
- The temperature of the basement rocks increases with depth. Geothermal projects extract the heat energy from the water in the "hot rock" for electricity generation or heat transfer.
- The porous basement formations are separated from the overlying lower aquifers by a very thick clay layer (more than 1 km thick). A small amount of offshore oil and gas extraction from the basement is under way near Port Campbell. On shore, these formations have also been tested for use as storage for carbon sequestration.

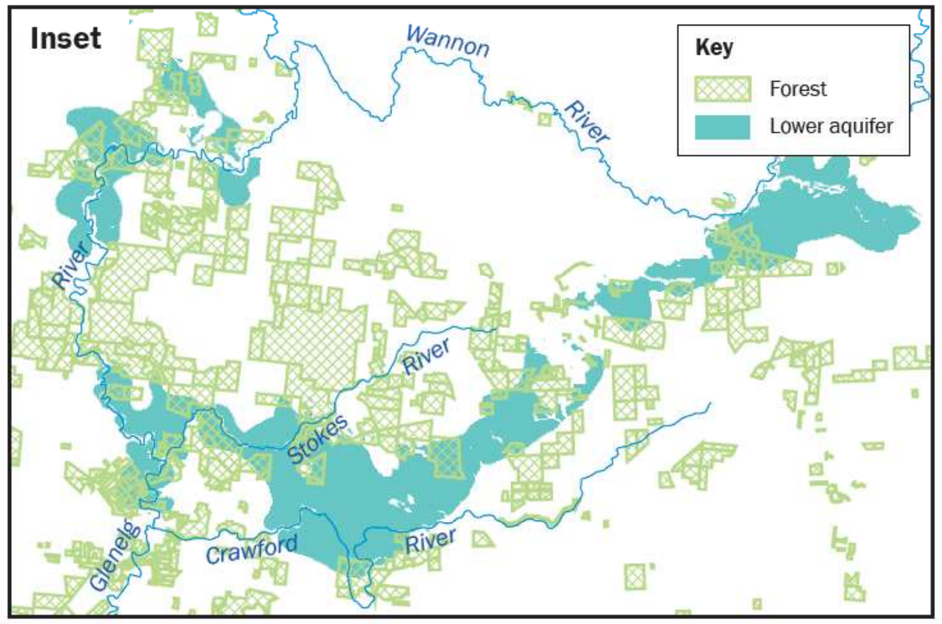


Land use and licences

Land use is shown for recharge areas of lower aquifers and basement. Licences shown are for lower aquifers.

Observations

- **There are some competing uses for groundwater from the lower aquifer in the recharge areas, but the area of impact is small relative to the total aquifer size.**
- **Stream interaction may occur in the recharge areas.**
- **Acid Sulphate Soils may be present and cause impact in the recharge areas.**
- **Much deeper aquifers and the basement are being explored for potential development of energy resources such as geothermal, oil, coal and gas. These are all well separated from the aquifers used for urban water supply.**



Plantations

Forest plantations can intercept water that would normally run off to surface water environments or recharge aquifers. This impact is likely to be insignificant close to the coast where most of the extraction occurs, because the lower aquifer recharge areas are very small relative to the large storage. Water tables could fall locally and impact on nearby users.

Acid Sulphate Soils

There is potential for Acid Sulphate Soils to impact in the recharge areas around the Otway Ranges. This occurs when certain soils are repeatedly wetted and dried out, causing the release of natural acids into the environment.

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