Port Phillip and Western Port Groundwater **Atlas**

Southern Rural Water

Managing Water. Serving Communities.

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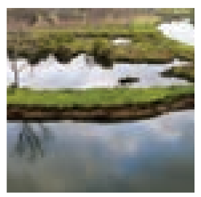
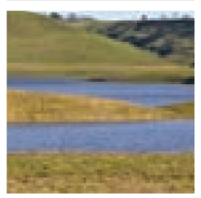
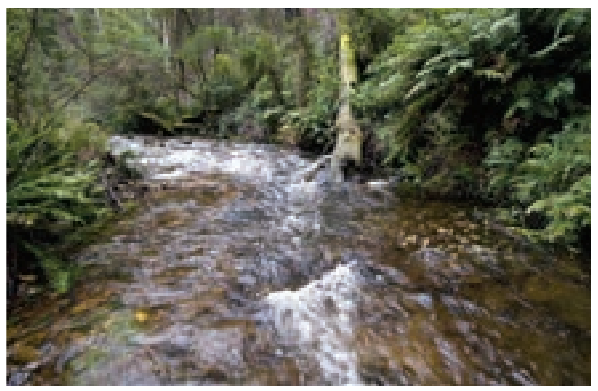
Port Phillip and Western Port

Groundwater Atlas





Foreword

Groundwater is a valuable water resource with great potential that is not well understood within the community. It is complex, hard to visualise and often described in unfamiliar technical language.

This atlas discusses the groundwater resources in the Port Phillip and Western Port region of Victoria, specifically how much there is, where it is, how deep it is, what it could be used for, what it is used for now and how it is regulated and managed.

This atlas provides information in words and graphics that are easy to understand to help readers develop their knowledge of this vital resource. It does not aim to be fully comprehensive, academic or technically perfect. Maps and data provide helpful guidance for users and potential users on a regional scale, however they are not suitable and should not be used for making commercial decisions at a property level.

In developing the atlas we drew information from a range of sources. These included the collective understanding of our staff, authorities responsible for the water resources in the region, industry experts and groundwater users across the region as well as from key technical reports, maps and data. This work was made possible by the important development of a new three-dimensional groundwater mapping tool by Southern Rural Water that gave us the ability to describe the dimensions of groundwater resources for the first time. We were then able to overlay our existing knowledge to achieve a much deeper understanding of groundwater than ever before.

This publication follows the *South West Victoria Groundwater Atlas* and the *Gippsland Groundwater Atlas* developed by Southern Rural Water in 2011 and 2012 respectively. In contrast to these two regions, Port Phillip and Western Port is far more urbanised and its aquifers store less fresh water. However, there is potential for aquifers and groundwater to play a more significant role in this region. I hope that our work will contribute to conversations at a national level that influence the way groundwater is understood.

Acknowledgements

On behalf of the Board I thank all members of the project team for their exhaustive efforts. Craig Parker (General Manager, Groundwater and Rivers) provided direction for the project. Penny Winbanks (Water Plans & Strategy) managed the project and co-authored the atlas with our team of hydrogeologists: Terry Flynn was the technical director, Elissa McNamara was the lead author and Liam Murphy was responsible for data and mapping. Eleanor Underwood chaired the Stakeholder Reference Group and was the engagement advisor. We also appreciate the expertise of Spatial Vision who produced the atlas.

The Stakeholder Reference Group collaborated with Southern Rural Water and made significant contributions to the content and accuracy of the atlas.

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Ian Anderson (Victorian Farmers Federation)
Chris Arabatzoudis (City West Water)
Simon Baker (Department of Environment and Primary Industries)
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Damien Connell (Smart Water Fund)
Matt Currell (RMIT University)
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Terry Burgi
CHAIRMAN, SOUTHERN RURAL WATER

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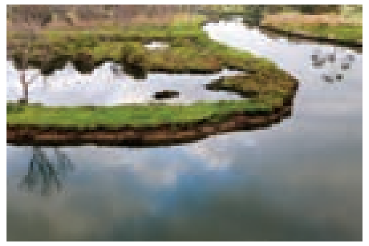
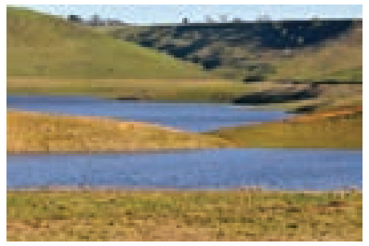
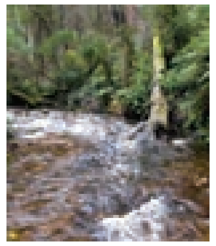






Reading guide

This Atlas provides introductory information on groundwater science, regulation and management. Atlases have also been produced for South West Victoria and Gippsland (see **www.srw.com.au**). The atlases do not provide detailed information suitable for use by technical professionals. Data for this purpose can be obtained by contacting Southern Rural Water.

Chapters 1, 2 and 3 introduce basic groundwater theory, geology and aquifer behaviour, as well as regulation, management and use.

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

- Geology
- Salinity and yield
- Movement of groundwater
- Environmental dependence
- Water balance
- Regional trends
- Users and usage
- Current and emerging issues

User groups

Four groups of groundwater users have been identified based on what they use groundwater for and the type of aquifer they are most likely to access (see table below).

User group	Description of user group	Type of aquifer accessed
Domestic and stock (D&S)	All private rights D&S users in the region: rural users and private urban users (garden watering). Many users who generally extract quite small volumes. Public emergency water supply use.	Mostly upper and middle aquifers
Environment	Springs, streams, lakes, swamps, wetlands and plants (which all contribute to the environmental value of the region). Total use across the region is thought to be large but cannot be quantified.	Mostly upper aquifers, outcropping areas of lower aquifers or exposed basement
Agribusiness	More intensive commercial, agricultural and horticultural purposes (including irrigating vegetables or pasture, dairy wash, water bottling and aquaculture). Occurs mainly in the areas south-east of Melbourne and in smaller pockets around Bacchus Marsh, Lancefield, Werribee and Wandin. A smaller number of users than the D&S user group who generally extract larger volumes.	All aquifers
Urban & Industrial	Some town supplies (the groundwater is treated when used for this purpose) for residential and other purposes. Industrial uses such as equipment cooling and Managed Aquifer Recharge (MAR). A small number of users who generally extract large volumes.	Mostly middle and lower aquifers

Aquifer groups

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

The aquifers are grouped according to when they were formed. For example, the basement and lower aquifers were formed first and the upper aquifers were formed last. In some cases an aquifer that occurs quite close to the surface has been grouped with the middle or lower aquifers because of its geological age. The basement rock has been grouped with the lower aquifers. In the table below there is an overlap in the age category between the middle and lower aquifers because different geological processes were occurring in the Port Phillip and Western Port Basins during those periods.

The aquifer groupings used in this atlas are generally consistent with those used in the Victorian Aquifer Naming Framework, however there are some differences (see table below).

Aquifer and aquitard group	Aquifer and aquitard name	Geological age	Groundwater Management Unit (GMU)	Hydrogeological unit
Upper	Quaternary aquifer and Upper Tertiary basalt aquifer	0.01-4 million years	Deutgam, Lancefield, Merrimu, Nepean	Recent sediments, Bridgewater Formation, Wannaneue Formation, Newer Volcanics
Middle	Upper Tertiary aquifer and Upper mid-Tertiary aquifer	4-38 million years	Frankston, Moorabbin, Koo Wee Rup	Moorabool Viaduct Formation, Brighton Group, Baxter Sandstone, Batesford Limestone, Sherwood Formation, Yallock Formation
	Upper mid-Tertiary aquitard and Lower mid-Tertiary aquitard			Fyansford Formation, Newport Silt, Maddingley Coal, Demons Bluff Group
Lower	Lower Tertiary basalt aquifer	19-65 million years	Wandin Yallock, Corinella	Mornington Volcanics, Older Volcanics
	Lower Tertiary aquifer		Cut Paw Paw, Parwan	Werribee Formation, Yaloak Formation, Childers Formation, Eastern View Formation
	Basement	65-545 million years		Permian glacial sediments and all cretaceous and palaeozoic basement rocks

The extent of each aquifer group and GMU boundaries are shown in chapters 4, 5 and 6 for the upper, middle and lower aquifers respectively.

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.

Then use the tables on page 4 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 is interested in the Newer Volcanics basalt aquifer in the western suburbs. Using the table on page 4 they can see that this belongs to the upper aquifer group. This aquifer group is discussed in chapter 4.
>
> **Example 2:** A groundwater user is interested in the Wandin Yallock Groundwater Management Unit (GMU). Using the table on page 4 they can see that this belongs to the lower aquifer group. This aquifer group is discussed in chapter 6.

Commonly asked questions

The atlas can be used to answer many other questions not listed here.

	Background	Upper aquifers	Middle aquifers	Lower aquifers
Where are the different aquifers?	4	34	44	54
How much groundwater is there?	16	35	45	55
What can groundwater be used for?	4, 11	35	45	55
How is groundwater monitored and what are the trends?	11, 25	39	49	59
How is groundwater managed?	11, 22, 23	40	50	60
Who uses groundwater in the Port Phillip and Western Port region?	4, 24	34, 40	44, 50	54, 60
What impact do urban areas have on groundwater recharge and use?	17, 28, 29	41	51	
How is groundwater pollution managed?	26, 27			
What are the economics of groundwater?	30, 31	40	50	60

More complex questions

The pages listed here should be used only as a starting point. Information relating to these questions can be found throughout the atlas.

	Background	Upper aquifers	Middle aquifers	Lower aquifers
How does groundwater replenish and move?	10, 14, 15, 17	36	46	56
What impacts groundwater levels?	10, 15	38	48	58
How does groundwater interact with the surrounding environment?	10, 18, 19	37	47	57
What are the current and emerging issues facing Port Phillip and Western Port?	18, 19, 26-29	41	51	61
Will the groundwater in the region ever run out?	16	38-40	48-50	58-60
What affects groundwater quality?	11, 16, 26, 27	35, 41	45, 51	55

Limitations and assumptions

The groundwater mapping used in this atlas was prepared at a scale of 1:250,000. The data used to create the maps varied in its distribution and some interpretation was required. For this reason the data is not suitable for identifying availability, yield or quality of groundwater at a local or property level.

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

The licence data provided will change over time due to regulatory changes, water trading, unrenewed licences and data verification.

The bore construction data is sourced from the Victorian Groundwater Management System database.

The locations and use of Domestic and Stock (D&S) bores are *estimated* throughout the atlas because these bores are private and therefore are not licensed or metered. D&S bores constructed prior to 1980 were not required to be registered, however they should be registered retrospectively. D&S bores constructed since 1980 were required to be registered in the Groundwater Management System. These bores are assumed to be actively used. In rural areas D&S use is estimated to be 1.3 ML/yr per known bore. This data is based on a number of studies. In urban areas with access to mains water supply D&S use is estimated to be 0.2 ML/yr per known bore. This data is based on the most recent available study. Actual use may vary significantly from these estimates.

The Lerderderg River

Glossary of common terms and units of measurement

Common terms	Acronym	Definition
Aquifer		A layer of fractured rock, gravel, sand or limestone below the ground that is porous enough to hold groundwater and allow it to flow
Aquitard		A layer of rock or clay below the ground that may hold some groundwater but is not porous enough to allow it to flow easily
Baseflow		The component of stream flow that is supplied by groundwater discharge
Bore		A vertical pipe that is drilled into the ground to access groundwater with openings for the water to flow into
Catchment Management Authority	**CMA**	An agency responsible for managing biodiversity and the health of waterways
Dairy wash		Water used to wash down farm dairies
Desalination		Removing salt from water sources
Dewatering		Removing water from an aquifer for mining, quarrying or construction purposes
Domestic and stock	**D&S**	Water used in households and by animals/livestock
Department of Environment and Primary Industries	**DEPI**	The Victorian Government department responsible for managing water and the environment
Entitlement		The total amount of groundwater authorised to be taken each year under a groundwater licence
Environment Protection Authority	**EPA**	The agency responsible for regulating environmental pollution
Evapotranspiration	**ET**	The loss of water to the atmosphere caused by the combined processes of evaporation from soils and transpiration through plants
Geothermal energy		Natural heat found underground
Groundwater		Water found under the ground that is stored in and flows through aquifers
Groundwater Dependent Ecosystem	**GDE**	Ecosystems such as wetlands, streams, estuaries or vegetation that rely totally or partially on groundwater to survive
Groundwater elevation		The height of groundwater relative to sea level (measured in mAHD)
Groundwater Management Unit	**GMU**	A Groundwater Management Area or Water Supply Protection Area declared under the Water Act to protect water resources
Imported water		Water that originates outside the Port Phillip and Western Port region such as water delivered to Melbourne from the Thomson Dam
Integrated Water Cycle Management	**IWCM**	A whole-system approach to water supply and waste water/stormwater management
Managed aquifer recharge (also Aquifer Storage and Recovery)	**MAR (ASR)**	The purposeful and actively managed recharge of water to aquifers for subsequent recovery and use or environmental benefit
Permissible Consumptive Volume	**PCV**	The volume of water permitted to be allocated (previously known as Permissible Annual Volume)
Ramsar		The International Convention on Wetlands that was signed in Ramsar (Iran) in 1971
Recharge (groundwater)		The process of aquifers being replenished by direct rainfall, seepage from surface water or leakage from neighbouring aquifers
Southern Rural Water	**SRW**	The rural water corporation of southern Victoria
Stygofauna		Microscopic animals that live within groundwater systems
Water table		The top of the groundwater level (also known as the saturated zone)
Well		A shaft that is sunk into the ground to access groundwater

Common units of measurement	
EC	Electrical Conductivity (used to measure salinity)
GL	Gigalitre or a billion litres (1,000,000,000 L)
L/s	Litres per second (used to measure yield)
mAHD	Metres above sea level (Australian Height Datum)
mg/L	Milligrams per litre (used to measure TDS)
ML	Megalitre or million litres (1,000,000 L)
ML/yr	Megalitres per year
mm/yr	Millimetres per year
µS/cm	Microsiemens per centimetre (used to measure EC)
TDS	Total Dissolved Solids (used to measure salinity)

Chapter 1: Introduction

Groundwater is a complex resource that can be difficult to understand. Building knowledge about groundwater is important because all water resources are valuable. Informed discussion relies on a base of reliable information.

This atlas discusses our understanding of groundwater in the Port Phillip and Western Port region. The information is based on aquifer mapping, groundwater licence information and the collective knowledge of a stakeholder reference group, verified and enriched through public consultation.

This chapter introduces the study area as well as background information on basic groundwater theory, regulation, management and use.

In this chapter you can find information on:

Port Phillip and Western Port region

The study area includes the majority of Port Phillip Basin and all of Western Port Basin. It extends from Little River in the south-west, Ballan in the west, the Great Dividing Range in the north, Drouin in the east and Phillip Island in the south-east.

Landscape

The region is made up of two bowl-shaped basins that drain into Port Phillip Bay and Western Port, divided by the highlands of the Mornington Peninsula.

The Werribee, Maribyrnong, Plenty, Yarra and Bunyip Rivers rise in the bordering hills and flow towards the bays. Volcanic plains extend west from the Plenty River to the You Yangs, Brisbane Ranges and Macedon Ranges. Sedimentary plains and rolling hills extend east of the Plenty River to the Yarra Ranges and Strzelecki Ranges.

The area around Koo Wee Rup was originally a swamp but has been drained for agriculture. The native grasslands and woodlands of the Port Phillip plains have mostly been cleared but natural forests remain in the State Parks.

Demographics

The Port Phillip and Western Port region includes the densely populated urban area of Melbourne, its sprawling outer suburbs, growth centres on urban fringe, rich rural land, parks and natural woodlands.

- Population: over 4 million – more than two thirds of Victoria's total population
- Dwellings: 1.4 million
- Business locations: 180,000
- Total area: 1.3 million hectares
- Land uses: approximately 13% urban, 45% rural farmland, 42% forest
- Agriculture: gross annual value of agricultural production is more than $1 billion (4,500 commercial agricultural holdings produce 15% of Victoria's gross value of agricultural production). The estimated value of groundwater supported production can be found on page 30.

Source: Port Phillip and Western Port Catchment Management Authority website

Natural values

The region has over 900 wetlands, including four of international significance (see also page 19). Parks, open spaces, waterways and wetlands contain significant remnant native vegetation and threatened flora and fauna species. Approximately 340 of the region's flora species and 200 animal, bird, fish and reptile species are considered under threat of local or total extinction. The region is home to Victorian emblems the Helmeted Honeyeater, Leadbeater's Possum and the Common (Pink) Heath.

Study area for this atlas—Port Phillip and Western Port region (Victoria)

This map shows the area discussed in this atlas (dark yellow shading). Groundwater atlases have also been prepared for South West Victoria and the Gippsland region (light yellow shading). Southern Rural Water is the authority responsible for groundwater resources in the total shaded area.

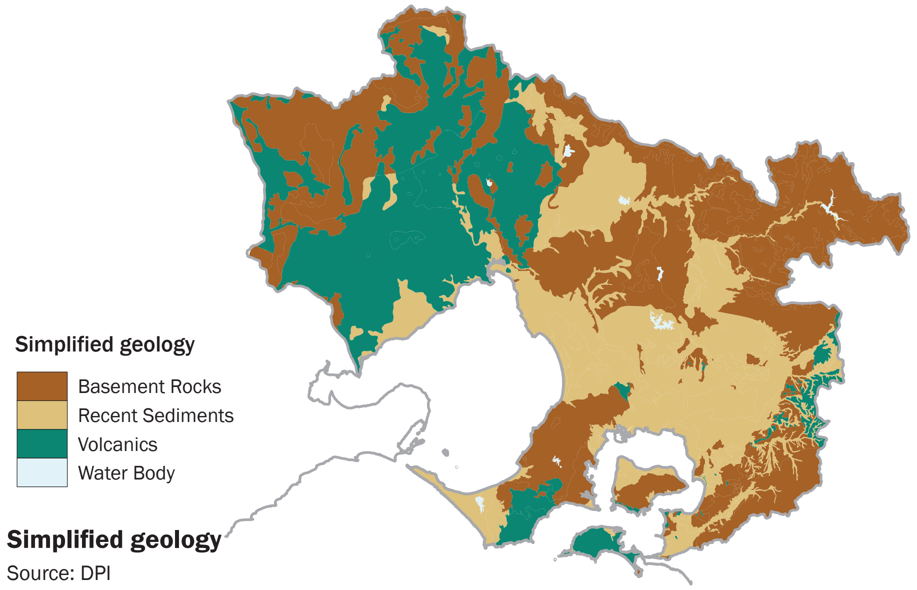
Farming land in Bacchus Marsh

Port Phillip and Western Port region

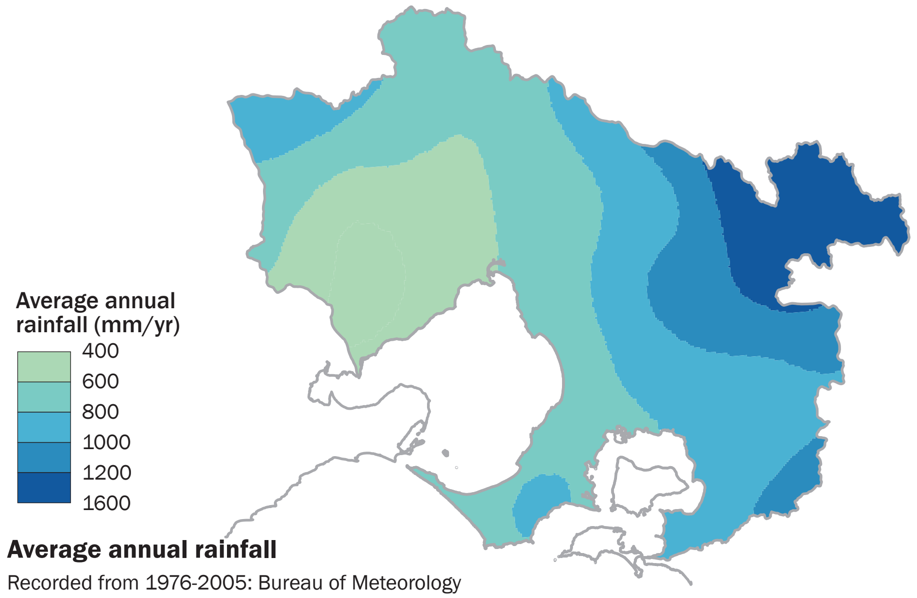
Climate

The average annual rainfall in this region is highest at the top of the Yarra River and Werribee River catchments. This contrasts with the drier basalt plains west of Melbourne.

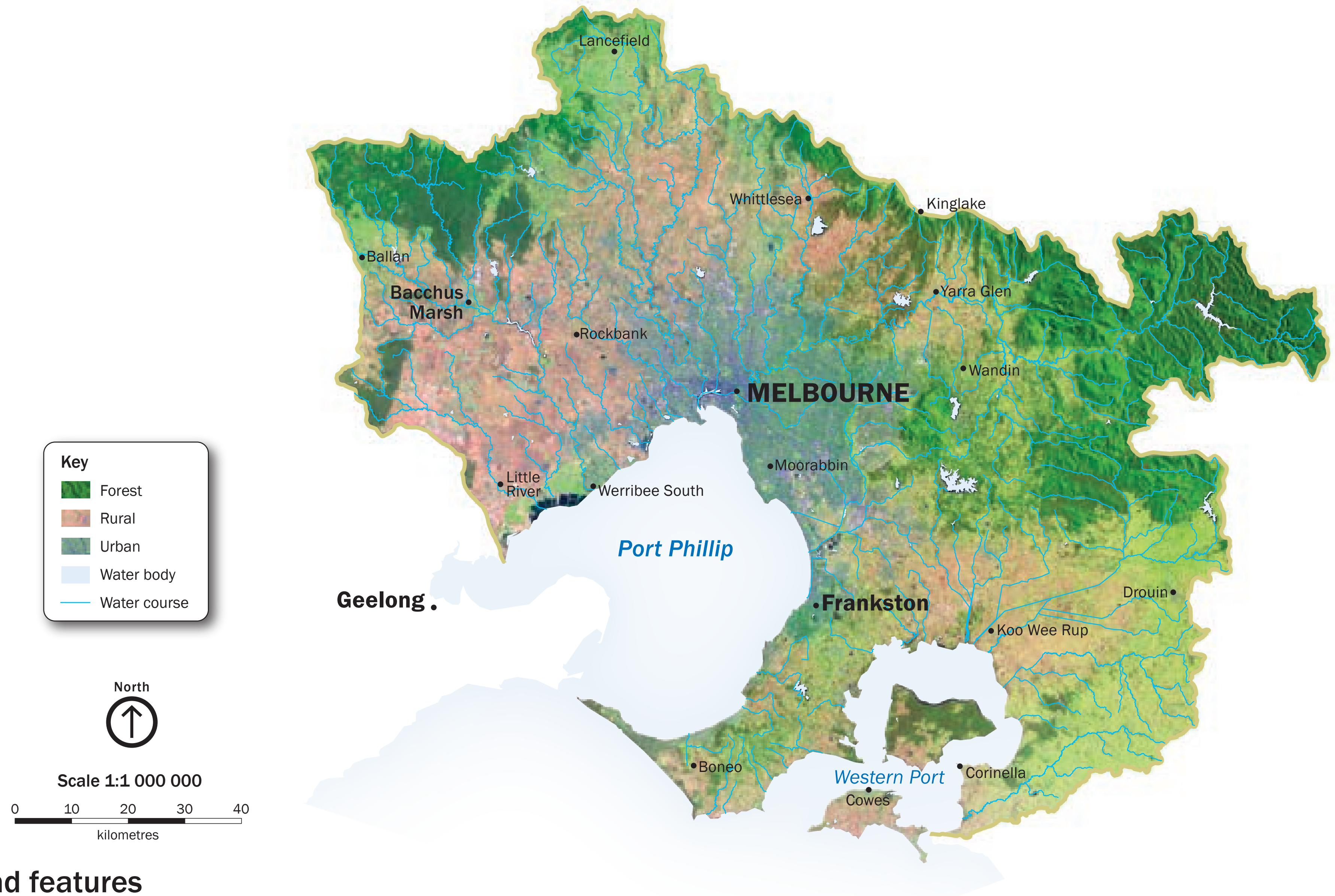
The highest evapotranspiration (evaporation plus water used by plants) occurs in the wooded areas of the ranges and where water tables are shallow such as in Werribee South. Run-off to rivers is also high in these areas. In the lower lying areas run-off is affected significantly by stormwater and drain networks.

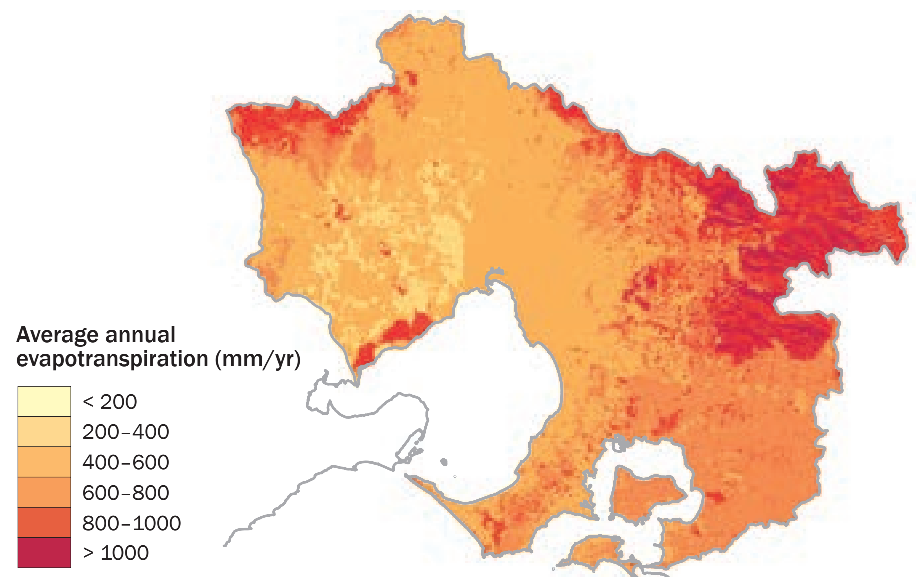


Simplified geology
Source: DPI



Average annual rainfall
Recorded from 1976-2005: Bureau of Meteorology





Average annual evapotranspiration (ET)
Modelled from 1958-2005: EnSysm project, DSE

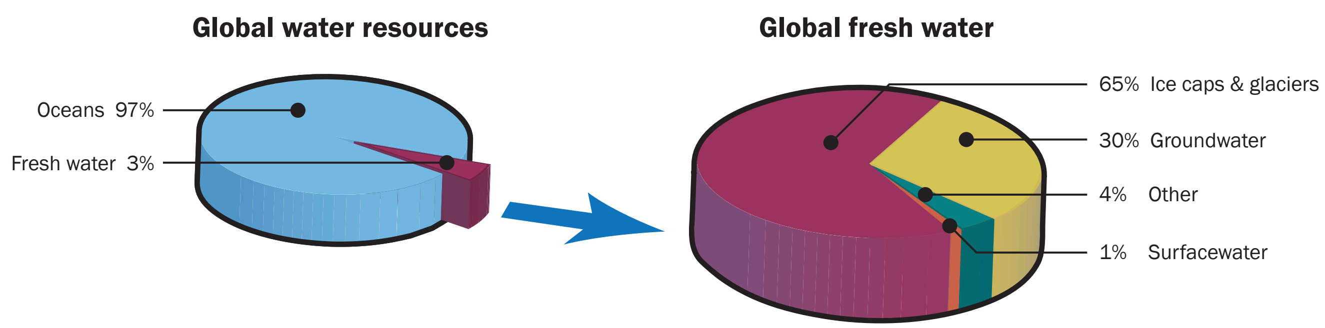
Land features

This map shows satellite imagery of the Port Phillip and Western Port region that highlights the major urban centres, geological features and water bodies.
Source: DSE Landsat 2000

Understanding groundwater

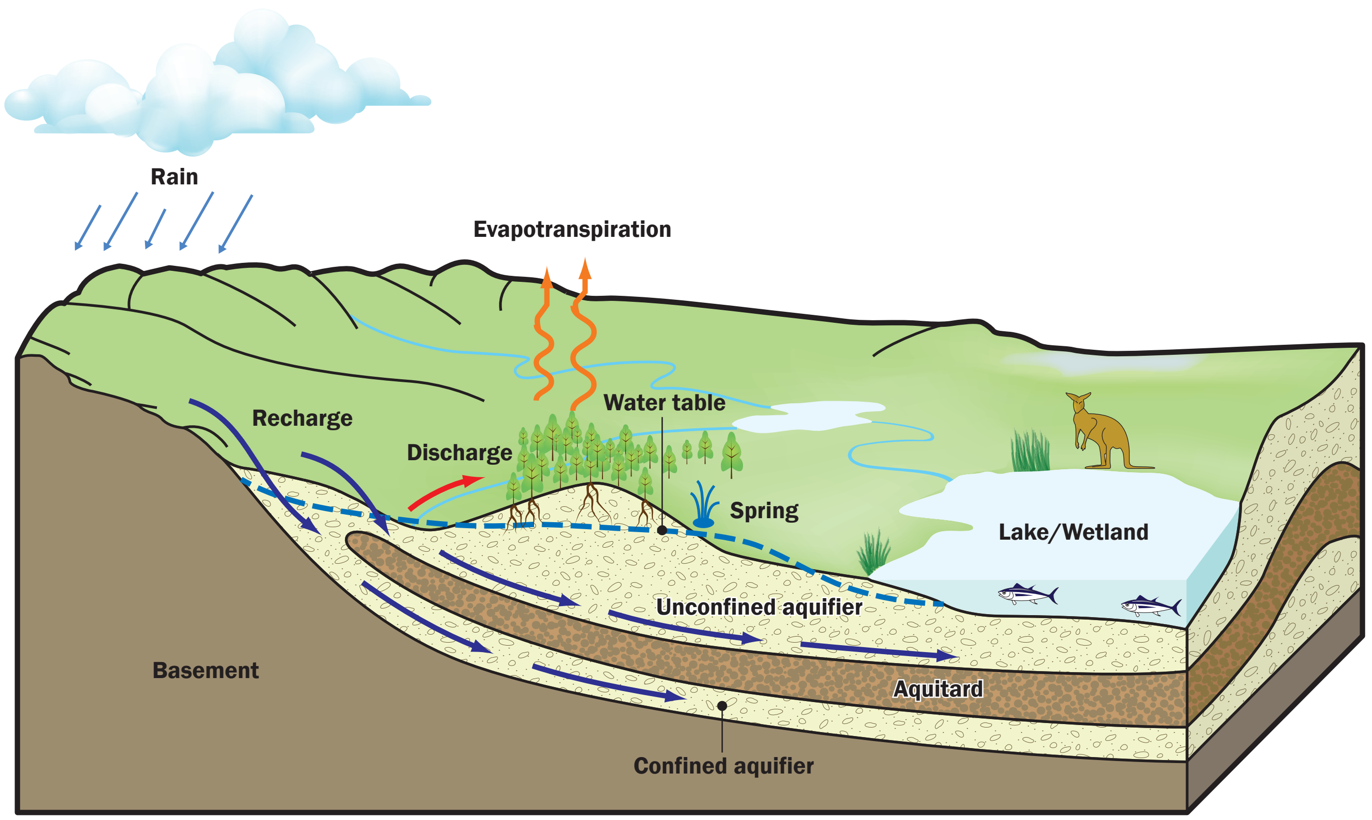
What is groundwater?

Groundwater is water that is found under the ground. It is stored in and can flow through layers known as aquifers. Groundwater is a significant global resource. About 30% of the world's fresh water resources is stored as groundwater while less than 1% is stored in our rivers and other surface water environments.



What are aquifers and aquitards?

An **aquifer** is a layer of fractured rock, gravel, sand or limestone below the ground that is porous enough to hold groundwater and allow it to flow. An **aquitard** is a layer of rock or clay that may hold some groundwater, however groundwater flow is very slow through an aquitard.



Where does groundwater come from?

Surface water from rainfall or surface water bodies can seep through the ground to the **water table** where it is stored in an aquifer as groundwater. This is called **recharge**. Deep aquifers can also receive recharge indirectly from overlying shallower aquifers via downward leakage and an aquifer can sometimes receive recharge via upward movement if the water in an underlying unit is under pressure. Groundwater may be stored in an aquifer for a few days or thousands of years.

Where does groundwater go?

If it is close to the surface groundwater can evaporate directly to the atmosphere or be used by vegetation and plants **(evapotranspiration)**. Where the **water table** intercepts the surface it can **discharge** as springs or as **baseflow** to surface water bodies such as swamps, wetlands, lakes, rivers and creeks. Groundwater can also flow to a neighbouring aquifer (alongside, above or below) or towards the ocean. It can also be extracted via pumping from a bore or a well.

How does groundwater move?

Differences in groundwater levels or pressure allow groundwater to move. The rate and volume at which it moves through an aquifer depends on aquifer material (soil, sand, gravel, rock, etc) and the connections between the pores or fractures (spaces) in the aquifer. Compared to stream flow, groundwater may take an extra few days or thousands of years to move the same distance.

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

An aquifer is **unconfined** when the material between the groundwater and the surface of the ground is porous such as sand, gravel or soil. An aquifer is **confined** when it is overlain by an aquitard which is formed by non-porous material such as rock or clay.

What is artesian water?

Artesian water is groundwater in a confined aquifer that is under enough pressure to force the water upward through the top of the aquifer. If pressure is high enough for the water to reach the surface without pumping from a bore it is known as **flowing artesian**. Where this occurs naturally it forms a **spring**.

How does the environment rely on groundwater?

Many surface environments rely on groundwater to survive and stay healthy. These are known as Groundwater Dependent Ecosystems (GDEs). GDEs include wetlands and river baseflows that depend on groundwater flowing (discharging) to the surface, vegetation using groundwater directly from shallow aquifers (evapotranspiration), cave ecosystems and even animals that drink groundwater or eat vegetation sustained by groundwater. Interaction between groundwater and surface environments varies greatly depending on the geology, topography and climate.

More information

All of the concepts introduced here are discussed in more detail in chapter 2. More information can also be found using the links on page 63**.**

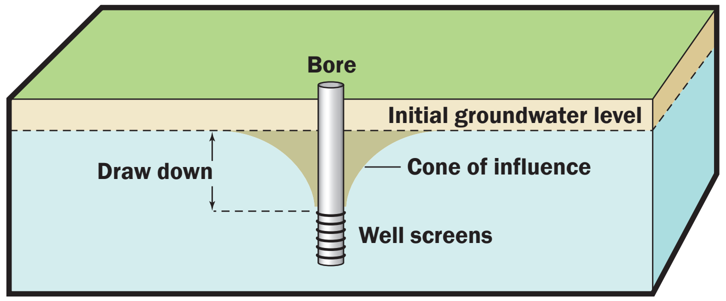
Using and managing groundwater

What is a bore?

A **bore** is a vertical pipe drilled into the ground with openings underground for groundwater to flow into (see diagram below). Groundwater can also be accessed by **wells** which are vertical shafts dug into the ground.

What happens when groundwater is pumped?

When groundwater is being pumped from a bore a **cone of influence** is formed that extends outwards from the bore. This can cause interference between bores. This means that when a neighbouring bore is being pumped there may not be enough groundwater in your bore to achieve the usual yield.



Pumping may also intercept the flow of groundwater to nearby springs and streams, however this impact may not be noticed for weeks, months or even years.

What happens when too much groundwater is pumped in an area?

When the total rate of groundwater pumped in a region is greater than the rate of recharge, regional groundwater levels will fall. This may lead to lower bore yields, higher pumping costs and environmental changes such as sea water intrusion (see page 36).

Why is groundwater use managed?

Groundwater is not a limitless resource. Groundwater use in Victoria is managed to monitor and protect groundwater levels and pressure and to ensure it is a sustainable long-term resource for all users, including the environment. More information on groundwater users can be found on page 24.

How is groundwater use regulated, managed and monitored?

Victorian groundwater use is regulated by the Water Act (1989). Southern Rural Water (SRW) is the authority responsible for all groundwater resources in southern Victoria. SRW manages access to and use of groundwater in accordance with the Water Act and policies developed by the Department of Environment and Primary Industries (DEPI) (see page 23). This includes ensuring compliance with the licensed use of bores, licensed volumes (through flow meters) and other licence conditions. Observation bores are used to monitor groundwater levels (see page 25) which provides important data about groundwater.

What licences are needed to access groundwater?

A **works licence** (previously known as a 'bore construction licence') is required to construct, alter or decommission any bore or well to ensure they are properly constructed to protect aquifers from contamination.

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

Private rights are not formally issued and water use is not metered. A landowner can take water from a bore or well on their property for domestic and stock (**D&S**) use without a **take and use licence**. However, they need a **works licence** to install or modify a bore or well. **Note:** D&S use includes drinking water for livestock and water for household purposes such as watering a kitchen garden.

What limits groundwater use?

Groundwater use is generally limited by factors such as yield, availability, costs such as drilling, and suitability for the purpose.

The table below shows salinity limits for various agricultural uses but many other factors influence water quality such as nutrients and metals). The State Environment Protection Policy (SEPP) for groundwater defines suitability for various uses according to salinity levels (see table below and see also links on page 63).

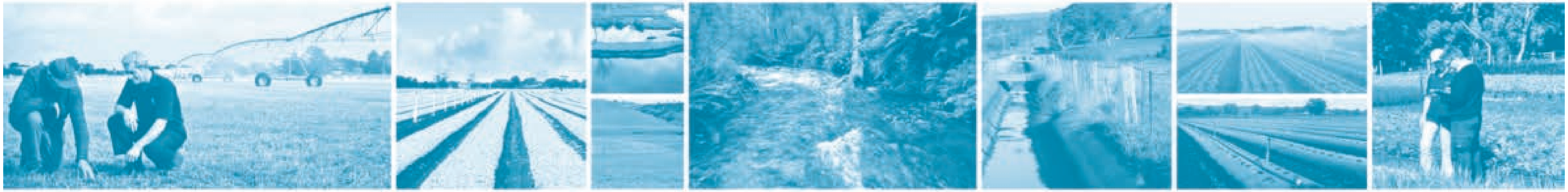
Where groundwater is used as a source for urban drinking supply and some industrial purposes it is treated to meet the high standards required.

The environment has adapted to groundwater of varying salinity levels. For example some ecosystems thrive in fresh water and some thrive in very salty water. This means that changes in salinity or other factors such as nutrients can significantly impact the environment.

IMPORTANT: Untreated groundwater is not recommended for human consumption. The quality of groundwater should be tested before use. Advice should be sought from the Department of Health and other experts. More information can be found using the links on page 63.

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).
800–2,500	480–1,500		Suitable for some crops (**note:** requires adequate leaching and may be a problem on soils with poor drainage. Salt tolerance of plants must be considered).
2,500–5,800	1,500–3,480		Suitable only for salt tolerant crops on permeable, well drained soils (**note:** requires careful management).
5,800–7,500	3,480–4,500	Unsuitable for poultry.	Suitable only for highly salt tolerant crops on soil with excellent drainage (**note:** requires adequate winter rains to leach excess salts from soils and careful management).
7,500–8,500	4,500–5,100	Unsuitable for poultry and pigs.	Generally considered too saline for any irrigation.
8,500–16,500	5,100–9,900	Unsuitable for poultry and pigs. Generally unsuitable for lambs, calves and weaner stock. Suitable for dry mature sheep and cattle.	
16,500–25,000	9,900–15,000	Suitable only for dry mature sheep and cattle (**note:** requires caution for cattle not used to water with this salinity level).	
>25,000	>15,000	Unsuitable for all stock.	

Source: DEPI, 2010



Chapter 2: Aquifers and groundwater

Groundwater movement through aquifers is driven by differences in groundwater levels or pressure and is controlled by the material that it passes through. Groundwater quality can vary greatly across an aquifer, through its profile and over time as a result of physical and chemical processes that change the temperature, salts and minerals within it.

This chapter explains how some changes in groundwater movement or quality are influenced by factors that have a relatively immediate impact. These are usually easy to understand. Other changes are influenced by factors that have occurred a long distance away or a long time ago. These are more complex and can be difficult to understand.

In this chapter you can find information on:

2 Aquifers and groundwater

Aquifer systems

Rainfall that seeps through the surface sediments and reaches the water table becomes what is known as groundwater. It then moves under gravity or pressure through local, intermediate and regional flow systems within the aquifers to its discharge point.

Local flow systems have flow paths of less than 5 km. They are found mostly in upper aquifers or where the lower aquifers and basement occur at the surface. These systems respond quickly to changes in rainfall, pumping and land use (see page 15). Groundwater may take from weeks to years to travel through a local flow system before reaches its discharge point.

Intermediate flow systems have flow paths of up to 30 km and **regional flow systems** are longer than 30 km. These systems are found mostly in confined middle and lower aquifers. They react more slowly to changes in rainfall, pumping and land use than local flow systems (see page 15). The impact of changes in regional flow systems may not be seen in a lifetime. Groundwater may take from decades to thousands of years to move through these systems before reaching its discharge point.

Aquifers in this region

The aquifers in the Port Phillip and Western Port Basins are a system of sediments and fractured rock up to 1,100m thick formed over the past 65 million years.

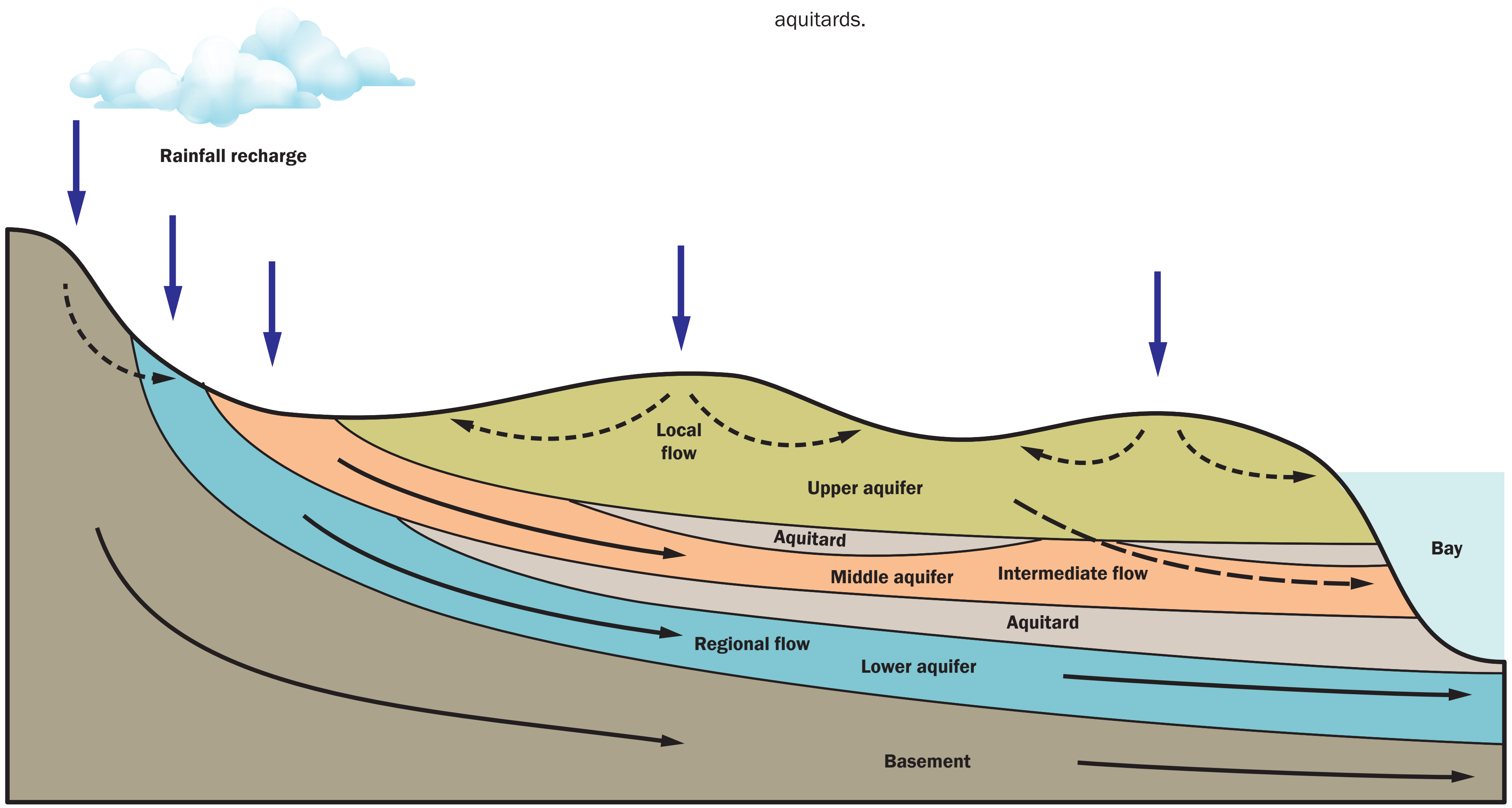
The youngest formations occur at the surface and are formed by sediments deposited by rivers, lakes and wind. Older sand, limestone and gravel aquifers are buried under younger sediments. Young volcanic formations occur at the surface north and west of Melbourne. Older volcanic formations occur east of Melbourne either at the surface such as in Wandin Yallock or deeply buried such as in Koo Wee Rup. The coal seams west of Melbourne form regional aquitards that confine the lower aquifers. The lower aquifers and basement are the oldest formations. Regional flow systems are found in these aquifers.

At the basin margin all aquifers occur close to or at the surface and may merge to act as one unit (see diagram below). This also occurs where there are no aquitards.

Observations

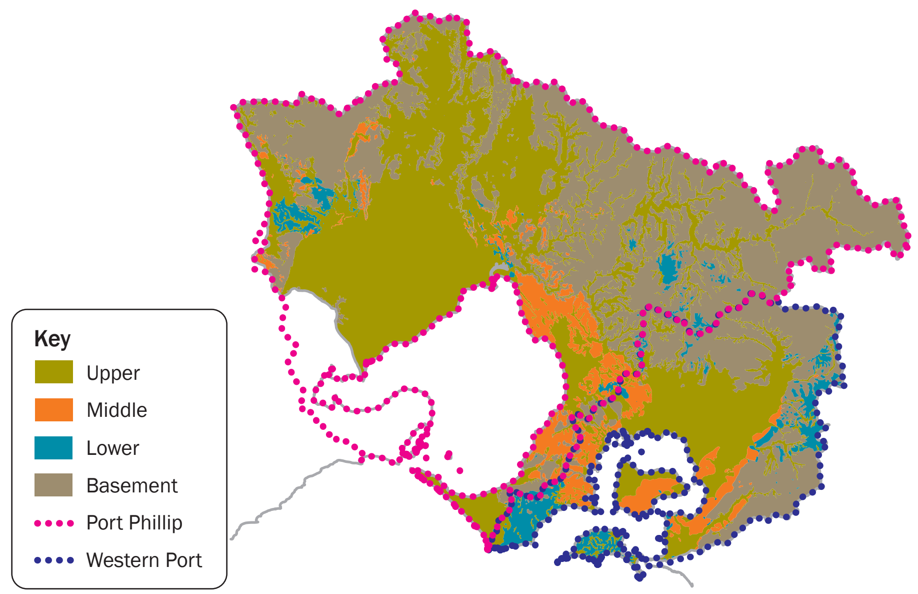
- Groundwater flow systems describe the movement of groundwater within aquifers from recharge point to discharge point.
- Groundwater flow systems may be local, intermediate or regional. Multiple flow systems may occur within an aquifer.
- Local flow systems respond quickly to changes in rainfall, pumping and 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 overlying aquifers for recharge.

Where aquifers occur at the surface they are unconfined (see map below). This means they can receive recharge directly from rainfall. Where aquifers are buried they receive recharge by slow leakage from overlying aquifers.



Groundwater flow systems

This diagram shows local, intermediate and regional flow systems. At the basin margin or where there are no aquitards the aquifers may merge to act as one unit.



Geological basins

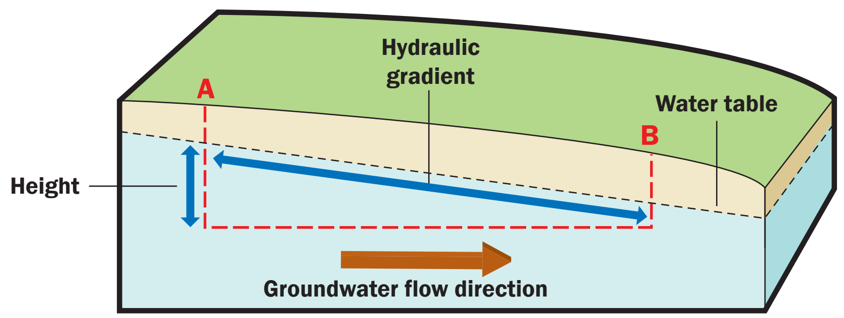
This map shows the extent of the Port Phillip and Western Port Basins and where the different aquifers – upper, middle, lower and basement – occur at the surface.

Interpreted from: surface geology

Movement of groundwater

How does groundwater move?

Two factors affect how water moves in an aquifer (see diagram below). **Hydraulic conductivity** describes how easily water can move through spaces within the aquifer. Sand aquifers usually have a higher hydraulic conductivity than rock aquifers. **Hydraulic gradient** describes the difference in groundwater height (pressure) between two points. A greater height or pressure difference between two points means a steeper gradient and so water will move more quickly through the aquifer.



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

It can take from hours to millions of years for an aquifer to respond to a change in rainfall, pumping or land use. If the change is reversed it can take as long as decades for the aquifer to respond. This means that the groundwater levels we observe now may be the result of changes that happened a long time ago such as forest clearing or high rainfall periods.

How does evapotranspiration affect groundwater systems?

Evapotranspiration is the combination of transpiration (groundwater use by plants) and evaporation of high water tables (where they occur less than 5 m from the surface). It is strongly affected by land use and geography.

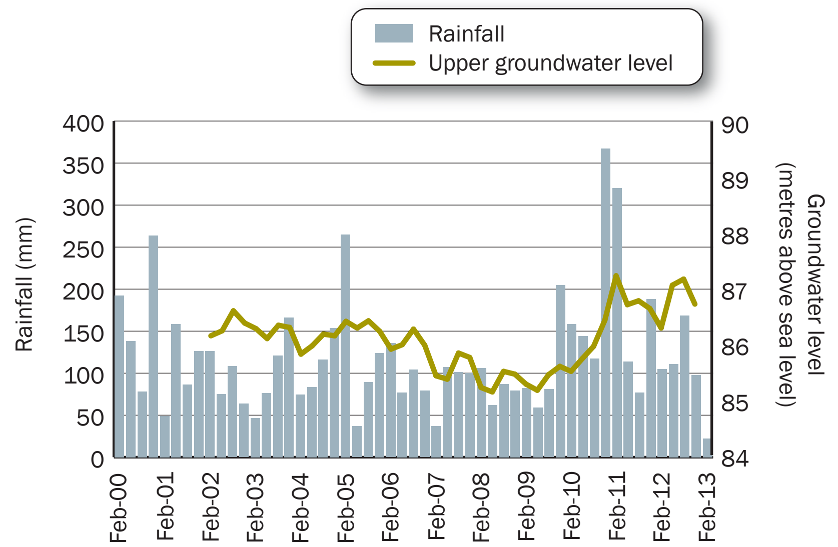
Evapotranspiration is vital to the health of many surface ecosystems and can account for more groundwater use than bores in some areas. In flat terrain it can significantly impact groundwater availability and movement. High densities of deep-rooted trees such as in thick forest or plantations can use large volumes of groundwater through evapotranspiration, **Note:** tree plantations are not currently a significant land use in the Port Phillip and Western Port region.

How do rainfall and pumping impact groundwater levels?

Unconfined upper, semi-confined middle and confined lower aquifers respond differently to rainfall and pumping (see hydrographs below for examples).

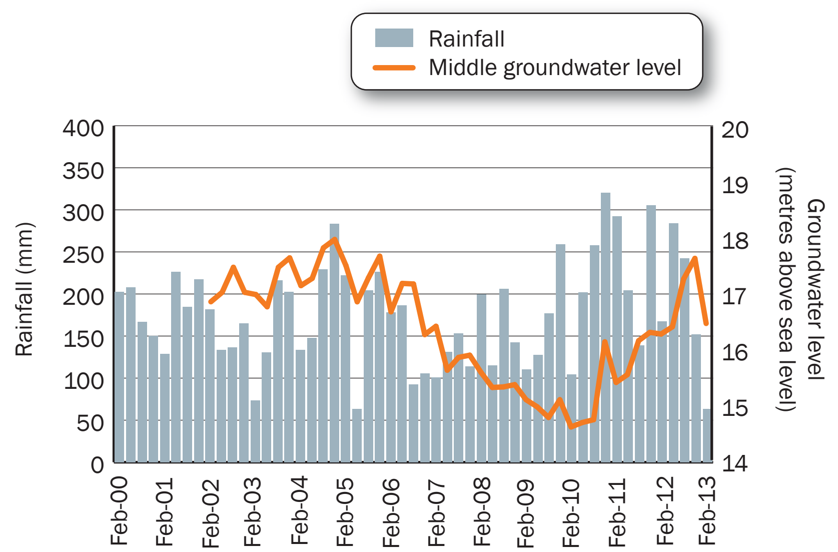
In unconfined upper aquifers the groundwater levels mimic rainfall and pumping patterns and there is little time delay. Recent sediment aquifers found in river valleys are also impacted by river levels.

Unconfined upper aquifer – Merrimu GMU at Bacchus Marsh



In semi-confined middle aquifers the groundwater levels mimic rainfall patterns but the response is delayed. This reflects the extra time it takes for rainwater to seep down into the aquifer. These aquifers still show an immediate response to pumping.

Semi-confined middle aquifer – Koo Wee Rup GMU

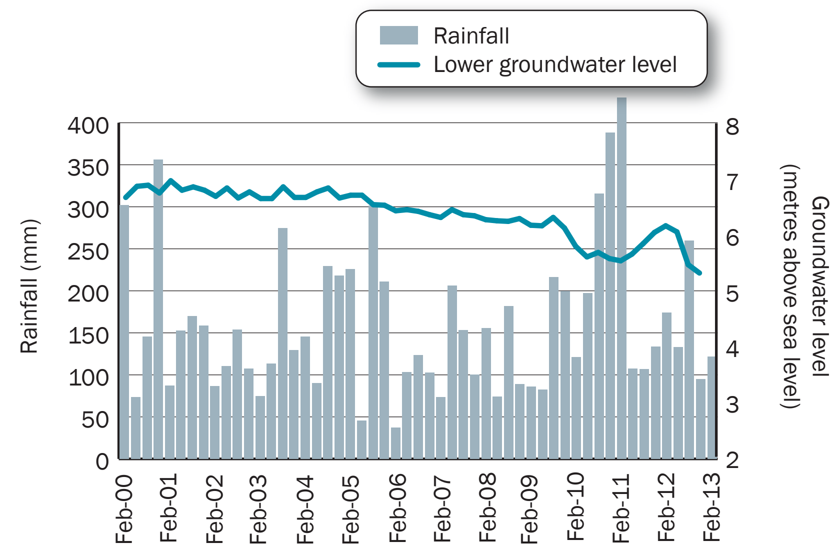


Observations

- **The rate and direction of groundwater flow is driven mainly by gravity and pressure as well as how easily water can move through the aquifer material.**
- **Evapotranspiration significantly impacts groundwater.**
- **Unconfined, semi-confined and confined aquifers respond differently to rainfall and pumping.**
- **Unconfined aquifers are very responsive to rainfall and pumping.**
- **Confined middle and lower aquifers respond very slowly to rainfall but may respond more quickly to pumping.**

Lower aquifers are generally buried under other aquifers and aquitards where they occur away from the basin margins. Groundwater levels in these confined aquifers do not show a relationship with rainfall patterns however they may respond to pumping. In the example below, nearby pumping has affected groundwater levels since 2009. Where lower aquifers occur at the basin margin they are unconfined and behave similarly to upper aquifers.

Confined lower aquifer – Boneo



Groundwater characteristics

Quality and yield are the main factors used to make decisions about the potential use of groundwater.

Other factors that influence decisions include aquifer storage and the cost of drilling (see page 30).

Quality

The main indicator of groundwater quality is salinity because it is simple to measure and compare between sites. Salinity is reported as Electrical Conductivity (EC) or Total Dissolved Solids (TDS) (see page 11).

There are many other indicators of groundwater quality that need to be considered according to the potential use or purpose (see pages 26 and 27).

Natural groundwater quality can vary greatly across an aquifer (horizontally and vertically) and over time. Physical and chemical processes occur underground that may affect salinity, temperature, pH (acidity), or the presence of heavy metals and organic substances, including:

- Rocks and minerals are dissolved, transported and redeposited as groundwater moves.
- Evaporation from high water tables causes minerals and salts to concentrate in groundwater.
- Changes in groundwater levels cause saline water to be drawn into an aquifer (see page 34).
- Reactions or heat sources such as volcanoes, hot rocks or the sun change the chemistry of groundwater.

Groundwater samples are taken from all new groundwater bores and analysed for major ions (used to indicate 'hardness' which affects soap lather), salinity, pH and temperature. Dissolved oxygen (DO) is important in environmental and contaminated site investigations. However, data is not collected regularly from the same locations so it is difficult to show changes in water quality over time.

Land use can affect both quality and yield. More discussion about groundwater pollution can be found on pages 26 and 27.

Yield

Yield measures how much (volume) and how quickly (flow rate) groundwater can be extracted from an aquifer. Extractable volume and flow rates are usually greater in aquifers where there are large and well-connected spaces within the aquifer material such as sand or gravel, in aquifers with high groundwater pressure and in larger aquifers with more storage.

Storage

The storage capacity of an aquifer depends mainly on the spaces within the aquifer material such as between grains or rocks and the aquifer's thickness. This means that a thick, sandy aquifer has more storage capacity than a fractured basalt aquifer.

Unconfined upper aquifers occur at or near the ground surface and can be quite thin with little storage. When it rains or a river floods the aquifer's pore spaces fill quickly and this water is held in storage as groundwater. When the aquifer becomes saturated the groundwater spills into surface drainage lines. The behaviour of upper aquifers is seasonal. Groundwater levels can fall substantially during a period of dry weather or increased pumping but can recover quickly when it rains (see page 15).

Observations

- **Groundwater quality and yield limit the potential uses of groundwater.**
- **Groundwater quality can be highly variable.**
- **Groundwater yield depends on the spaces within the aquifer material.**
- **An aquifer's storage capacity depends on the amount of space within the aquifer material and the aquifer's thickness (size).**

Recharge to middle and lower aquifers comes from leakage through overlying upper aquifers as well as from direct rainfall where the aquifer occurs at the surface. Lower aquifers typically have more storage capacity than upper aquifers because they are generally much thicker and cover a greater area. In deeper formations the aquifer's storage volume can increase because the groundwater is under great pressure. This means that groundwater levels can recover quickly after periods of pumping.

How much groundwater can we access?

The diagram at right shows the proportion of groundwater stored in the region's aquifers that is both accessible and suitable for use.

These aquifers receive deep recharge at a rate of 400,000 ML/yr after evapotranspiration (not including the basement). Of this, only about 100,000 ML/yr is received in areas where there is a high volume of pumping.

It is estimated that the volume of groundwater stored in the region's aquifers is 29,000,000 ML in the onshore part of the system (not including the basement).

Only 15% of the groundwater in storage (4,450,000 ML) is fresh water (less than 1,000 mg/L salinity) and suitable for most uses. The amount that can be extracted is further restricted by how much a bore can yield.

The average volume used is around 22,000 ML/yr but significantly more is licensed for extraction. The remaining groundwater is available for use by the environment.

Water balance

Water balances describe the flow of water into and out of a groundwater system.

The major components of a water balance in a groundwater system are:

- Rainfall recharge
- Evapotranspiration
- Recharge/discharge from/into streams, lakes and wetlands
- Leakage to underlying or overlying formations
- Groundwater use
- Throughflow to other aquifers
- Discharge offshore

Other potential components of the water balance in a groundwater system include recharge from septic tanks, irrigation leakage, leakage to and from pipe networks and groundwater extraction for infrastructure construction (roads and buildings) or quarry operation.

When recharge into an aquifer is greater than discharge the water balance is **positive:**

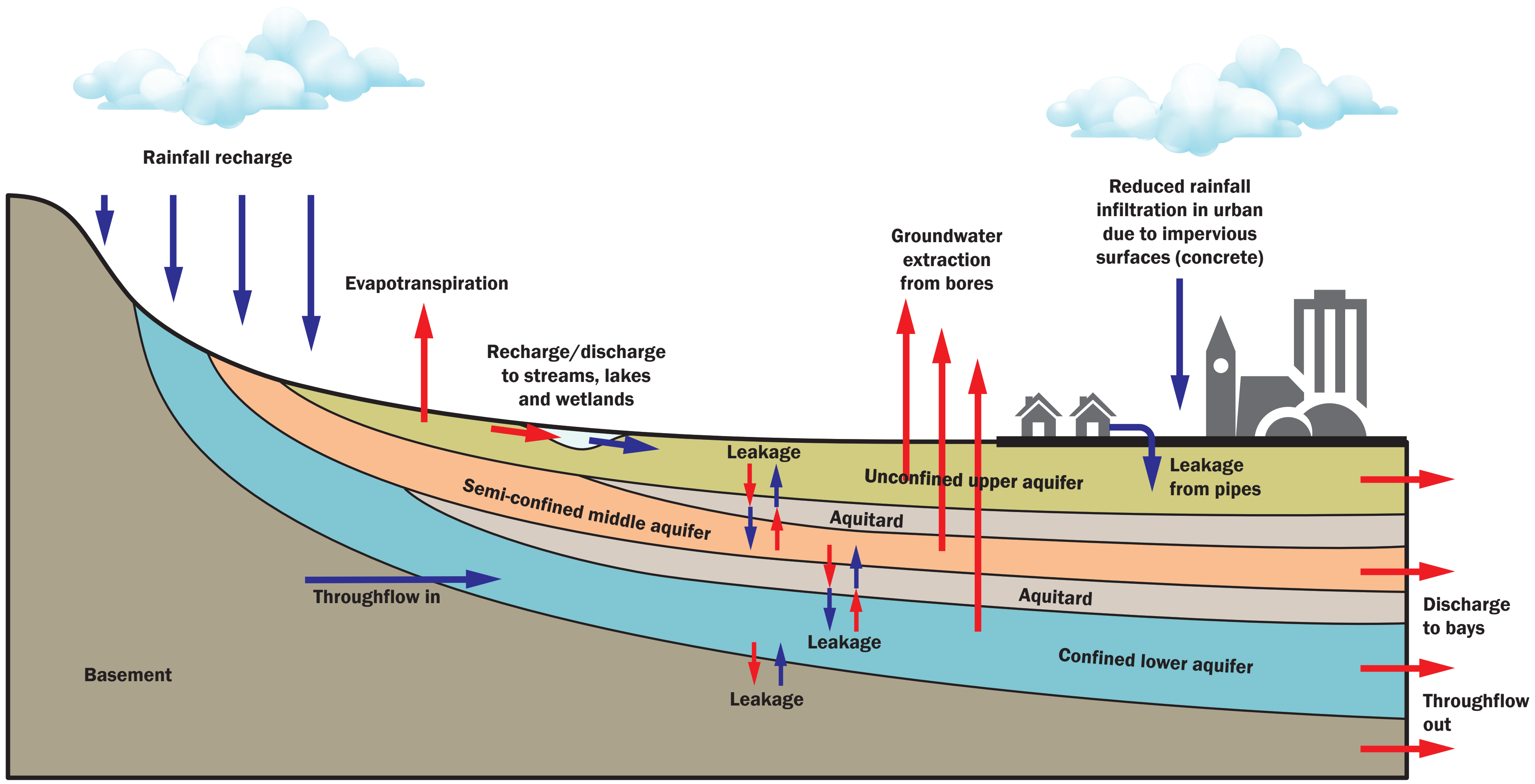
- Groundwater storage increases
- The water table rises
- Streams, lakes and wetlands may gain water

When discharge is greater than recharge the water balance is **negative:**

- Groundwater storage decreases
- The water table falls
- Streams, lakes and wetlands may lose water

The diagram below shows the major components of the water balance as well as inputs (recharge) and outputs (discharge) for each aquifer group: upper (unconfined), middle (semi-confined) and lower (confined).

Specific information on water balance in the upper, middle and lower aquifers in the region can be found in chapters 4, 5 and 6.



Major water balance components in groundwater systems

This diagram shows inputs (recharge) (blue arrows) and outputs (discharge) (red arrows).

Observations

- **Water balances helps us to understand what components of the water cycle contribute recharge or receive discharge from aquifers.**
- **Unconfined aquifers receive recharge mainly from rainfall. Semi-confined and confined aquifers rely mainly on leakage from surrounding formations.**
- **The water balance in urban areas differs significantly from rural areas because of large areas of hard surfaces that may prevent recharge from rainfall. The vast underground pipe networks may also interact with groundwater.**

Unconfined aquifers

The water balance in unconfined upper aquifers is mainly influenced by rainfall, evapotranspiration and pumping.

Other components include recharge from and discharge to streams, leakage to underlying formations, extraction for infrastructure construction and quarry operation, and discharge to the bays. In some areas septic tanks also provide significant recharge (see page 36).

Confined and semi-confined aquifers

The water balance in semi-confined middle aquifers and confined lower aquifers is mainly influenced by leakage from overlying formations and pumping.

Where these aquifers are deeper and have little or no connection with the surface, rainfall does not directly influence the water balance. Where they occur at the surface they receive some recharge from rainfall and may be influenced by evapotranspiration and stream interaction, however this is to a much smaller degree than unconfined upper aquifers.

These aquifers are also influenced by throughflow to other aquifers and discharge to the bays.

Urban water balances

The water balance in urban areas is different from and more complex than in rural areas. There are large areas of hard surfaces such as roads and buildings that prevent direct recharge of groundwater by rainfall.

Vast networks of underground pipes for water supply, stormwater and sewer systems may recharge groundwater via leakage or may be infiltrated by groundwater where they are damaged.

Infrastructure projects that extend below the ground surface such as tunnels and basements may need to be drained during or after construction. This may have a significant impact on local aquifers if there are large numbers of such projects.

Environmental dependence

The environment is a major user of groundwater. The volume used is difficult to measure but may be seen indirectly through observation of ecosystems that remain healthy during dry seasons.

Groundwater Dependent Ecosystems (GDEs)

GDEs can be made up of plants, animals or habitats that are dependent on groundwater. They can be grouped as:

- Surface water ecosystems that rely on groundwater discharge such as rivers, springs, wetlands and estuaries and the aquatic plants and animals that depend on these ecosystems
- Land-based ecosystems such as plants that draw on shallow groundwater through root systems and the animals that depend on them
- Underground ecosystems such as caves and pores in rocks and the often microscopic plants and animals that inhabit these places
- Ecosystems found in bays or the ocean that rely on groundwater discharge.

Levels of dependence

GDEs have varying levels of dependence on groundwater. They may be completely dependent, highly dependent or periodically dependent.

Completely dependent systems may not survive if even a slight change occurs in the groundwater they rely on. Periodically dependent systems may rely on groundwater during dry periods only.

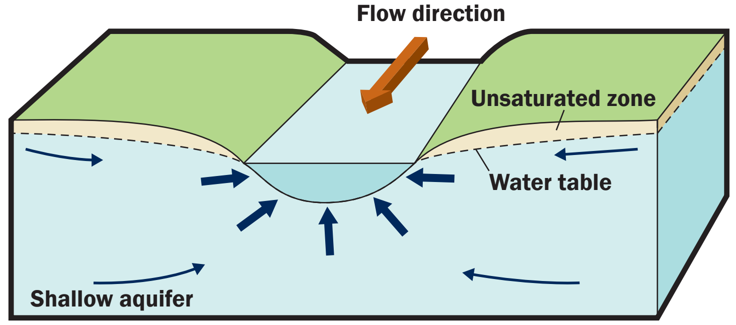
Aquifer and stream interaction

Unconfined aquifers and streams can be closely connected. The more an aquifer is confined the less likely it is to interact significantly with a nearby stream.

Water can move in both directions between aquifers and streams and the level and nature of the connection can change over distance and time.

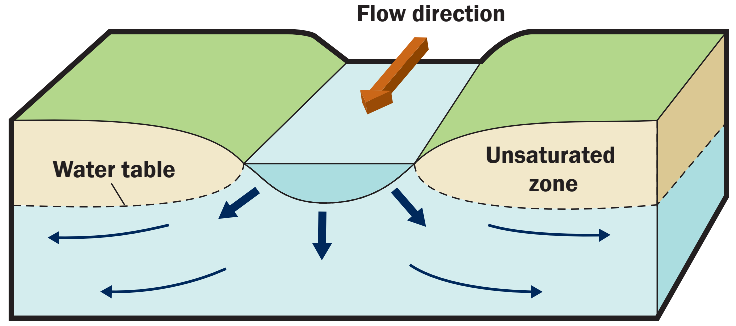
Interaction between aquifers and streams cannot be directly measured. Several estimation methods exist but the results of these may differ significantly.

Water flows from high to low elevation under gravity or pressure (see page 15). If the groundwater level is higher than the stream level, groundwater can discharge into a stream (see diagram below) or other surface water environment such as a lake or a wetland. This is known as a gaining water body.



A gaining stream

If a stream, lake or wetland's water level is higher than the groundwater level it can lose water to the aquifer (see diagram below). This may occur during a flood or if groundwater levels drop significantly due to pumping. This is known as a losing water body.



A losing stream

Interception

A bore anywhere along a flow system can intercept groundwater before it discharges to a surface water environment such as a waterway or wetland. For example, bores in local flow systems near highland waterways in the Yarra River catchment may intercept groundwater that could otherwise contribute to stream flows. The further a bore is from a stream the less impact it will have on groundwater discharges to the stream.

Observations

- GDEs can be surface water, land-based or underground ecosystems.
- If groundwater is intercepted by a bore, discharge to streams and other surface water environments may be impacted.
- Our understanding about the location and needs of GDEs is improving but there is still much to learn.
- The needs of the environment are considered when new groundwater licence applications are assessed.

Our understanding of GDEs

Since the mid-2000s our ability to identify and map potential GDEs has improved greatly. The National Water Commission has produced a GDE Atlas that identifies potential GDEs using satellite imagery, depth to groundwater maps, vegetation mapping and field surveys. However, unless this information is tested at the site it is likely to include many sites that are not GDEs. Potential GDEs across the region are mapped on page 19.

Research into underground ecosystems is currently under way in the Port Phillip and Western Port region. Microscopic animals called stygofauna can be found in shallow aquifers along current and prior streams.

The level of dependence by GDEs on groundwater is difficult to quantify. Some research has identified interaction between streams and groundwater, however this information is limited and does not provide insight into the dependence of other GDEs such as wetlands and vegetation. Melbourne Water and other organisations are currently conducting site-specific studies across the region to help us increase our understanding of groundwater and improve management of this important resource (see pages 37, 47 and 57).

Management

Groundwater pumping and its impact on groundwater levels is managed to protect discharge to streams and wetlands that are potential GDEs. When new groundwater licence applications are being assessed, key considerations are the needs of the environment, the combined allocation of surface water and groundwater and their level of interaction.

DEPI provides Ministerial guidelines to help authorities consider risks to GDEs when making licensing decisions. High value GDEs will be assessed site-by-site. These guidelines are outlined in the Gippsland Sustainable Water Strategy and apply to the entire State of Victoria. More information on these guidelines can be found using the links on page 63.

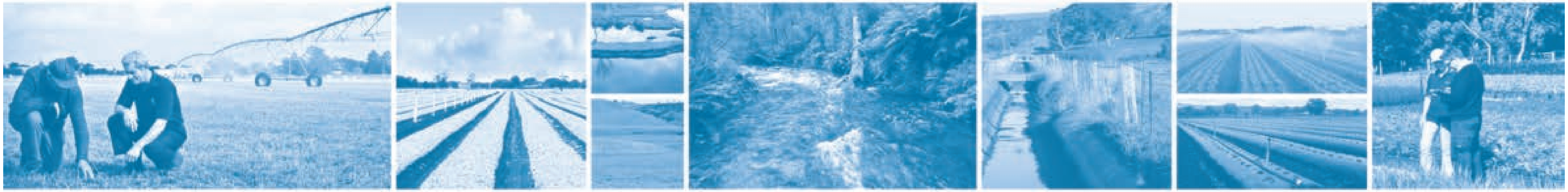
Environmental dependence

Potential Groundwater Dependent Ecosystems (GDEs)

This map shows potential GDEs. These areas are mainly associated with waterways, swamps and wetlands. The locations of GDE case studies from chapter 4, 5 and 6 are also shown.

Source: Melbourne Water, field surveys; National Water Commission, National GDE Atlas

2 Aquifers and groundwater



Chapter 3: Regulation, management and use

The value of groundwater has risen as demand has increased over time, leading to changes in its regulation and management.

The Port Phillip and Western Port region imports most of its drinking water from surface water systems in Gippsland. Groundwater is used mostly for agribusiness, domestic purposes, and as an important backup supply for some small towns.

Groundwater also plays an important role in sustaining environments around streams, lakes and wetlands.

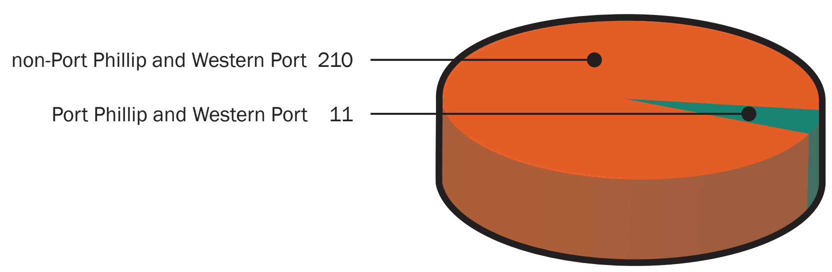
This chapter explains how the management and use of groundwater have evolved and provides context for some of the regional issues which are discussed in more detail in chapters 4, 5 and 6.

In this chapter you can find information on:

Early regulation

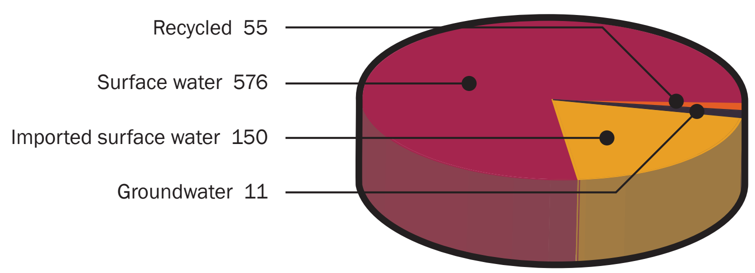
The Port Phillip and Western Port region accounts for only a small proportion of Victoria's total groundwater use. Groundwater accounts for only a small proportion of the total water use in the region.

Victorian groundwater usage 2010/11 (GL/yr)



The densely populated urban areas of Melbourne rely mostly on local and imported surface water such as from dams including the Thomson Dam which is outside the Port Phillip and Western Port region.

PWPP water usage 2010/11 (GL/yr)



Source: The data used to produce these two charts is taken from the 2010-11 State Water Accounts. Groundwater use during this period was low compared to average figures from 2004 onwards used in the rest of this document due to relatively high rainfall.

The evolution of groundwater use

Windmills that pumped groundwater from hand-dug wells were first used during the 1870s. The introduction of mechanical bore construction methods made drilling easier and gave landowners improved access to groundwater with deeper bores. Later, the use of centrifugal or turbine pumps meant landowners could extract greater volumes.

During the droughts in the 1960s and 1980s there was a greater demand for groundwater from agricultural users across the region. During the most recent drought in the 2000s there was high demand for groundwater for garden watering and domestic purposes. These dry periods led to further increases in bore construction and pumping.

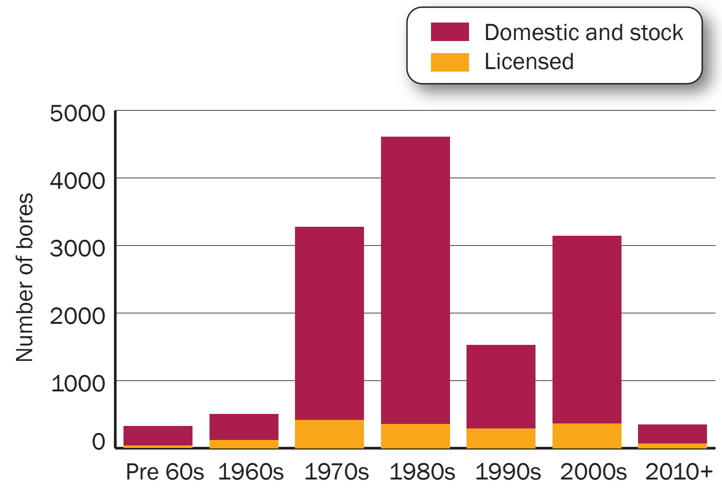
The introduction of regulation

Groundwater regulation in Victoria was influenced by two events: the failure of Nhill's town supply in 1967 and plunging groundwater levels near Western Port caused by pumping that led to concern about sea water intrusion.

The Groundwater Act was introduced in 1969 and was administered by the Department of Mines. In the early years allocation was based on the irrigated area and crop type. Sustainability was not taken into account. In the 1980s the number of licences around Koo Wee Rup was reduced to historical usage volumes to address concerns about over-allocation based on data collected from meters installed in the area during the 1970s.

Bore construction and licensing are now regulated under the Water Act which was introduced in 1989. Information on licence types can be found on page 11. Information on the need for bore construction licenses can be found on pages 26 and 27. More information on groundwater licensing requirements can be found using the links on page 63.

Number of bores constructed for groundwater extraction



This graph shows bores constructed for domestic and stock (D&S) and licensed (non D&S) purposes across the Port Phillip and Western Port region. Bores did not require a licence prior to 1969 and many were registered during the 1970s. The peaks during the 1980s and 2000s coincide with periods of drought. Bores with incomplete construction records are not included.

The region accounts for 30% of all groundwater bores across southern Victoria.

Timeline

1922
The first irrigation bore was sunk in Koo Wee Rup.

1946
Geological Survey of Victoria expanded their drilling program to search for groundwater and other resources.

1950s-60s
Extensive groundwater development around Koo Wee Rup led to loss of artesian pressure.

1969
The Groundwater Act was introduced. State Rivers and the Water Supply Commission became the authorities responsible for groundwater licensing.

1970
The State Observation Bore Network was established.

1971
The first Groundwater Conservation Area was established around Koo Wee Rup.

1985
Groundwater allocations were reduced in Koo Wee Rup.

1989
The Victorian Water Act was introduced, replacing the Groundwater Act.

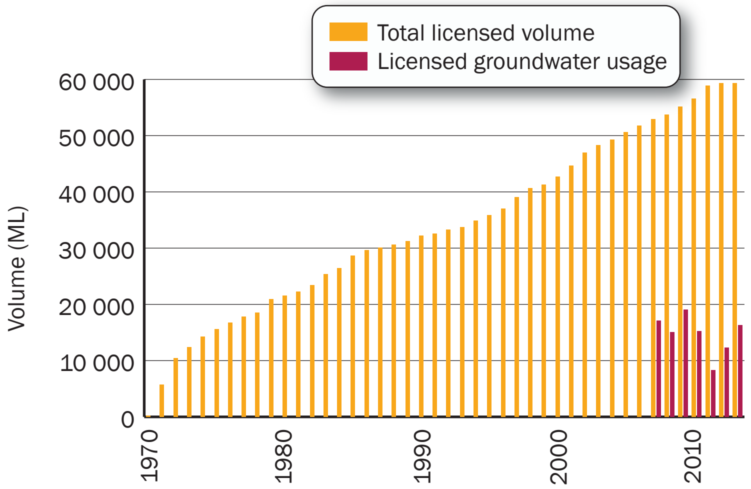
Current regulation and management

In recent years a greater demand for groundwater combined with periods of low rainfall has led to increased regulation and management of groundwater resources.

Allocation caps in intensively licensed areas were introduced in 1997 during a period of low rainfall. There was a high demand for the small volume of remaining entitlements, especially during the millennium drought. Water used for dairy wash purposes was licensed after 2010 which led to growth in licensed volume.

Growth of groundwater licences

The graph below shows the growth of groundwater licences across the region since 1969.



Metering commenced in 2004 except in the Koo Wee Rup GMU (see page 22). Since then all new licences are metered, regardless of their volume. Metering has been introduced progressively for existing licences, based on their volume.

This means that metering data is more complete from 2007. Use is typically less than 30% of total entitlement.

Note: data is collected at the end of each season on 30 June.

Current management

The Department of Environment and Primary Industries (DEPI) is the authority responsible for State policy, resource appraisals and the State Observation Bore Network. The Minister delegates licensing and resource management to rural water corporations such as Southern Rural Water (SRW).

DEPI has introduced three key reforms that drive management of groundwater resources:

- **Sustainable Water Strategies** aim to secure water supplies, encourage economically viable and sustainable agriculture and protect the health of the environment.
- The **Water Register** stores and reports water entitlement information. This replaces an outdated paper-based system.
- A framework of **groundwater management boundaries** (see below).

Groundwater management boundaries

DEPI has developed a new framework for groundwater management and reporting. This framework is based on:

- A **groundwater basin** contains one or more groundwater catchments within a geological basin and may extend offshore or across State boundaries. A basin may be broken into two or more sub-basins to reflect rural water corporation boundaries.
- A **groundwater catchment** contains a connected groundwater resource within a catchment area, including input (recharge) areas, use (demand) areas and output (discharge) areas.

Observations

- **An increased demand for groundwater during dry periods led to the introduction of regulation in 1969 and allocation caps in 1997.**
- **Groundwater management is now based on groundwater basins and catchments.**
- **Over the next few years local management plans or groundwater catchment statements will be developed to cover all areas in Victoria.**

Local Management Plans (LMPs) and **groundwater catchment statements** set out the rules that apply to groundwater catchments, including allocation limits, trading rules and restrictions. Over the next few years these will be developed for the entire State. They include Groundwater Management Plans (GMPs) that existed previously in some areas.

This new framework will incorporate areas of aquifers not previously managed by the system of Groundwater Management Areas (GMAs) and Water Supply Protection Areas (WSPAs), known collectively as Groundwater Management Units (GMUs). GMUs will be retained where appropriate but some changes to boundaries may be required.

GMUs are capped by a Permissible Consumptive Volume (PCV) that is determined by the Minister for Water. A PCV fixes the upper limit of entitlements. It is not a calculation of sustainable yield and does not manage use. PCVs were formerly known as Permissible Annual Volumes (PAVs).

Groundwater management continues to evolve with a major review of the Water Act taking place in 2014. More information, including a summary of recent State groundwater management policies and the new management boundaries, can be found using the links on page 63.

1993-95

Victoria's first Groundwater Management Strategy was released.

Regional water corporations, including Southern Rural Water, were established.

1997

GMUs and PAVs (now PCVs) were established.

2002

The Water Act (1989) was amended to include WSPAs. Groundwater was formally recognised by the National Water Initiative and State policies.

2003

A ban on groundwater use was declared in Deutgam to manage sea water intrusion.

2006

PCVs were declared for all GMUs by the Minister for Water.

The Central Region Sustainable Water Strategy was released.

2009

3D hydrogeological maps were produced for southern Victoria.

2010

The Koo Wee Rup GMP was approved by the Minister for Water.

The dairy wash program formalised the licensing of historical water use in dairies.

2012

Aquifer-based groundwater management was introduced and management planning was simplified.

2014

The Water Act (1989) is undergoing a major review.

Entitlements and usage

Most bores in the region are used for domestic and stock (D&S) or agribusiness. Groundwater is used for town supply during dry periods in a small number of towns such as Lancefield, Romsey and on Phillip Island.

The table at right summarises the total volume of water allocated and used annually in each of the aquifer groups. The large difference between entitlements and usage indicates that, although there are limited opportunities for new entitlements, there is significant potential for trading groundwater entitlements (see pages 40, 50 and 60).

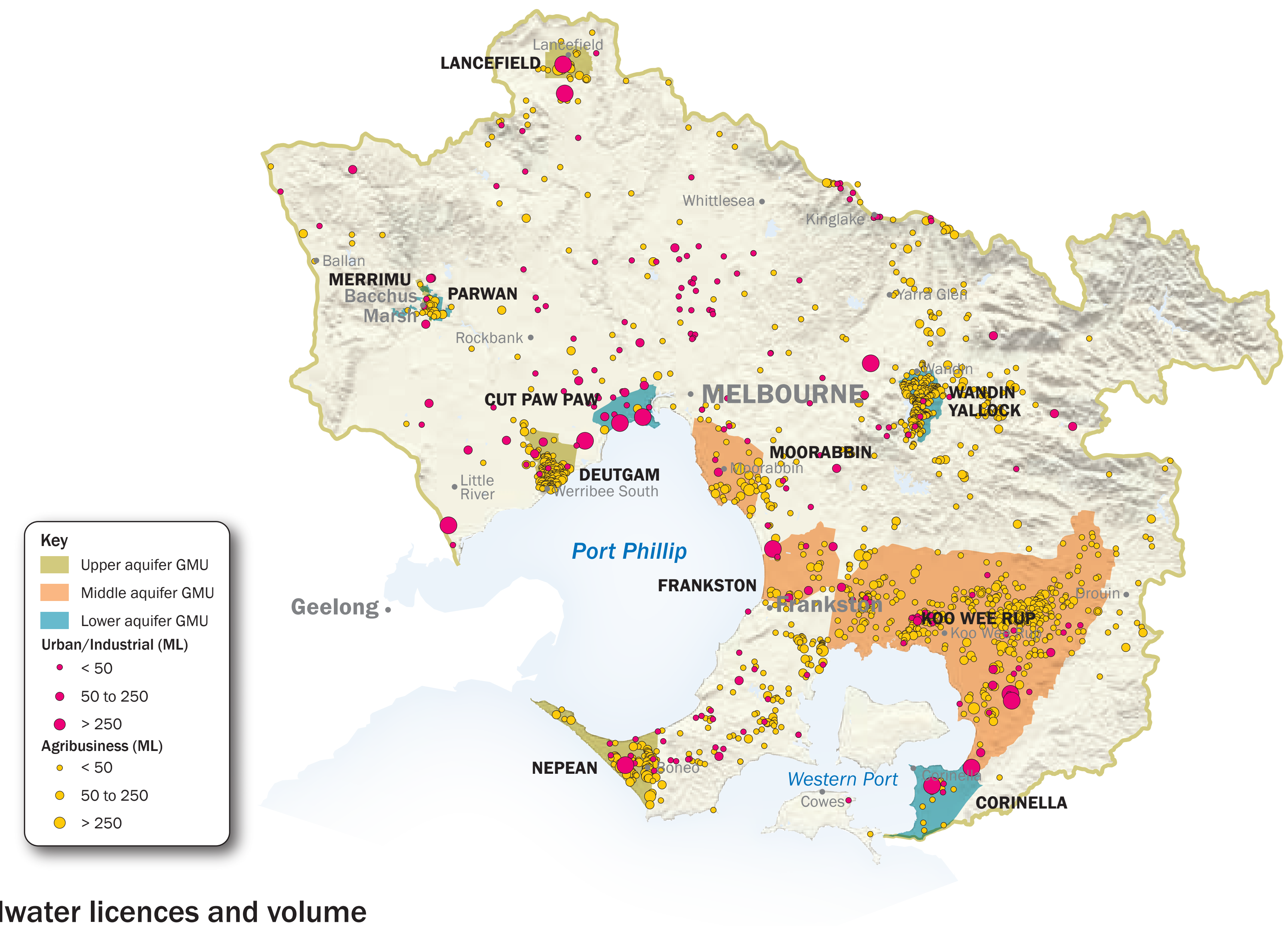
Aquifer group	Entitlement	Metered usage*	D&S usage**
Upper	19,532	7,716	3,064
Middle	20,388	5,634	1,377
Lower	15,453	2,360	2,121

* Due to data limitations metered usage has been estimated based on average usage within GMUs across the aquifer.

** D&S usage is estimated using only bores drilled since 1980. Annual usage for rural bores is 1.3 ML/yr and for urban bores is 0.2 ML/yr.

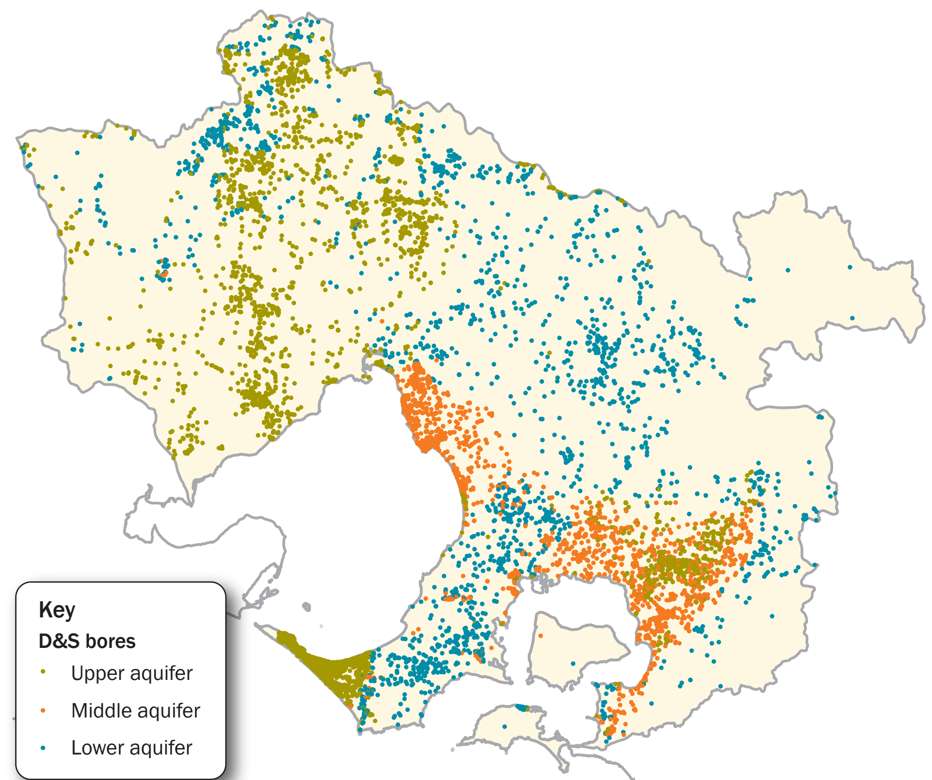
Observations

- **Groundwater use is concentrated in relatively small areas in the region.**
- **There is significant potential for trading groundwater entitlements but limited availability of new entitlements.**
- **Most bores in the region are used for D&S or agribusiness.**
- **Registered D&S bores in the region are estimated to use 6,500 ML/yr.**



Groundwater licences and volume

This map shows the location and volume of entitlement by user group. Industrial users include quarries.



Domestic & Stock

The map above shows all bores registered for D&S use in each aquifer group.

Under the Water Act the occupant of a property has a right to extract groundwater for D&S purposes, including:

- Household use
- Watering pets and livestock
- Watering a kitchen garden
- Watering a limited area around buildings for fire prevention

D&S rights under the Water Act exclude water for dairies, piggeries, feedlots, poultry and other intensive or commercial uses.

There are 8,546 D&S bores registered in the region since 1980, each estimated to use 1.3 ML/yr in rural areas and 0.2 ML/yr in urban areas. This amounts to a total D&S use across the region of approximately 6,500 ML/yr.

Monitoring

There are 229 observation bores that form part of the State Observation Bore Network (SOBN) across the region. The State Government maintains these bores and uses them to monitor groundwater levels and, in some cases, salinity.

Data on groundwater levels and salinity is collected monthly, quarterly or annually from the SOBN and reviewed on a regular basis to identify trends and inform management and allocation decisions. Monitoring programs are designed according to the level of risk to groundwater resources at each location. These are reviewed when conditions change.

GMU boundaries

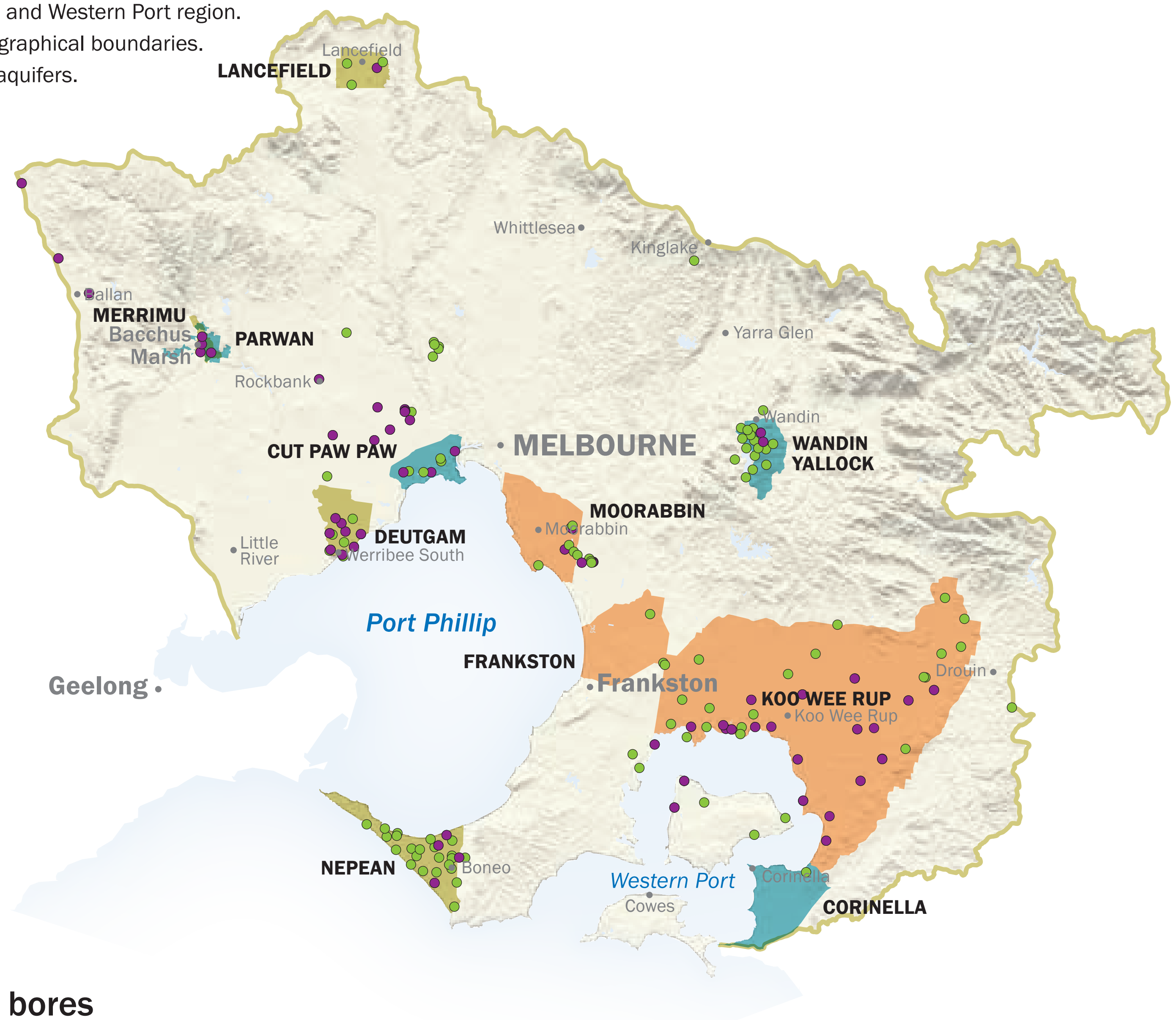
There are 11 GMUs within the Port Phillip and Western Port region. GMUs are defined by their depth and geographical boundaries. This means a GMU may include multiple aquifers.

The map below shows existing GMUs and the location of observation bores. More information about the SOBN can be found using the links on page 63.

Other monitoring

A large amount of groundwater data is collected from bores that are not part of the SOBN. It is collected for environmental, contaminated site and alternative water supply investigation purposes (see also pages 26, 27, 28, 37, 47 and 57).

Data is also collected from bore logs, pumping tests, weather stations, stream gauges and usage meters. This information is used to help us understand the extent, condition and behaviour of groundwater.



Groundwater observation bores

This map shows the location of State observation bores and GMU boundaries. The SOBN distribution does not necessarily match allocation or usage volumes.

Observations

- **Data collected from observation bores to measure groundwater levels and salinity is used by authorities to help regulate and manage groundwater use responsibly.**
- **A large amount of data is collected from bores that are not part of the SOBN and is used for environmental, contaminated site and alternative water supply investigation purposes.**
- **State Observation Bores are concentrated in GMUs but their distribution does not necessarily match licence or usage volumes.**

The table below lists the number of observation bores that are used to monitor groundwater levels and salinity (see also page 36).

Number of observation bores per GMU

This chart shows the different aquifer groups: upper (green), middle (orange) and lower (blue).

	Number of observation bores	
GMU name	**Water level**	**Salinity**
Deutgam	25	9
Lancefield	5	0
Merrimu	4	0
Nepean	26	8
Frankston	2	0
Koo Wee Rup	57	18
Moorabbin	11	1
Corinella	1	0
Cut Paw Paw	0	0
Parwan	4	0
Wandin Yallock	16	0
Outside GMUs	78	0
Total	229	36

Source: DSE and SRW monitoring records, 2013 and some private irrigation bores in Deutgam.

Groundwater level updates can be found using the links on page 63.

Groundwater protection

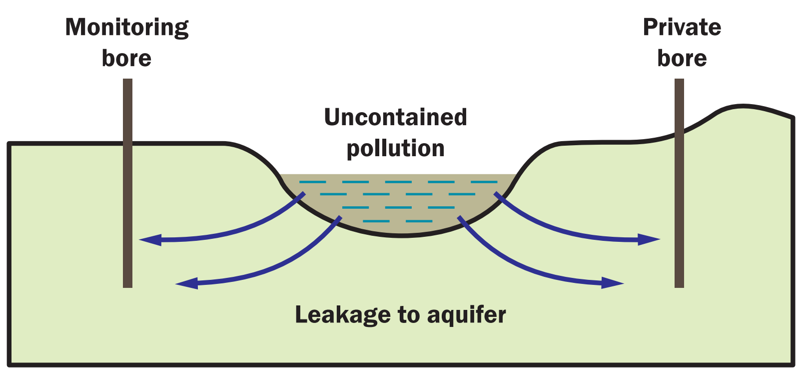
Protecting groundwater from pollution and degradation is a matter of public interest for reasons of human and environmental health.

Authorities responsible for protection of groundwater

Southern Rural Water (SRW) is the authority responsible for implementing legislation and several State Government policies in this area. SRW works closely with other agencies, industry and the community to achieve this. The Department of Environment and Primary Industries (DEPI) is the authority responsible for developing policy and legislation. The Environment Protection Authority (EPA) is the authority responsible for developing standards and enforcing regulation.

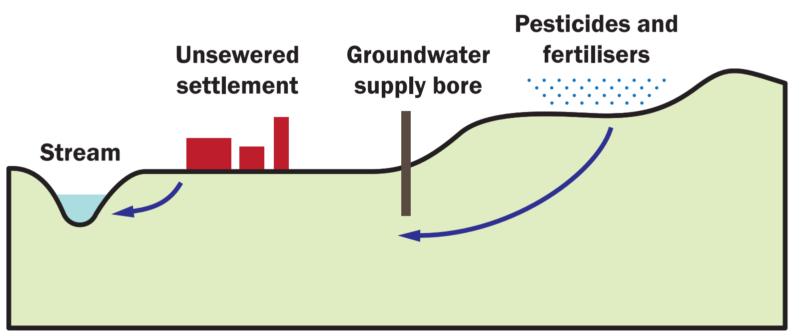
Types of pollution

Point source pollution refers to a single identifiable source of local pollution that may be very concentrated. Examples include landfill sites, industrial sites, intensive agricultural sites (eg feedlots), service stations and hazardous materials or waste storage areas.



Example of point source pollution

Diffuse pollution refers to regional pollution that occurs over a wide area and cannot be easily attributed to a single source. Many small sources can add up to have a significant impact on regional groundwater quality. Examples include agricultural chemicals (fertilisers, pesticides and herbicides), septic tanks and saltwater intrusion.



Examples of diffuse pollution

Policy and regulation

The main legislation and policy dealing with groundwater quality is the Environmental Protection Act (1970) and the *State Environment Protection Policy Groundwaters of Victoria (SEPP GoV). SEPP GoV* states that existing and potential beneficial uses of groundwater must be protected. Several authorities, including SRW, are responsible for upholding the *SEPP GoV* (see also links on page 63).

The **EPA:**

- Sets standards for groundwater quality and its management through *SEPP GoV*
- Supports business and industry to comply with *SEPP GoV* through relevant guidelines
- Regulates existing and potential **point source pollution** through licensing, clean-up notices and the Environmental Audit system
- Regulates pollution prevention, monitoring and clean-up
- Prosecutes offenders and manages reporting of polluted sites

A change of land use may trigger a site investigation or an environmental audit. This means that sites polluted before the introduction of strict regulation can be identified and managed.

Diffuse pollution is managed through:

- Standards such as objectives for groundwater quality listed in *SEPP GoV*
- Guidelines
- Codes of practice such as for chemical use and storage
- Education

As an example, local councils issue permits for the installation of EPA approved septic tanks in accordance with the EPA's Code of Practice for On-Site Wastewater Management which recommends a setback distance between septic tanks and bores.

SRW regulates "disposal of matter underground".

This includes licensing of activities such as:

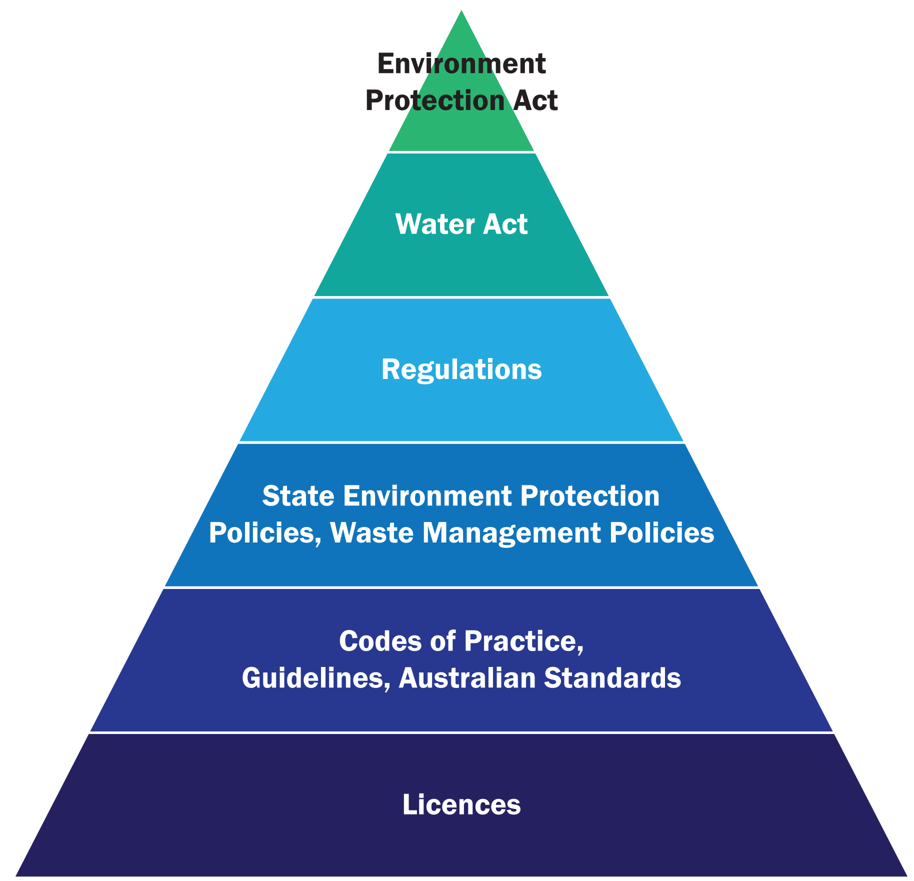
- Managed Aquifer Recharge (MAR) (see pages 28 and 29)
- Underground desalination (see page 27)
- The addition of compounds which help to clean up polluted groundwater

SRW also regulates bore construction. Bores can be drilled through more than one aquifer. If a bore is poorly constructed groundwater that is polluted or of a lower quality can pass from one aquifer into another.

Observations

- **Groundwater pollution is regulated and managed by multiple authorities including DEPI, SRW and the EPA.**
- **Groundwater pollution may be from point sources (local) or diffuse sources (regional).**
- **Groundwater pollution is regulated and managed by legislation, regulations, policies, guidelines, codes of practice and licensing.**

SRW also monitors compliance with bore construction licences (see also page 27). Bore construction licences have conditions relating to their maximum depth, minimum construction standards, decommissioning requirements and the qualifications required of drillers.



Hierarchy of groundwater protection legislation and regulations

Groundwater protection

Point source pollution across the region

A Groundwater Quality Restricted Use Zone (GQRUZ) is an area where there is residual groundwater pollution. It is usually caused by prior industrial activity. An area is identified as a GQRUZ when attempts have been made to clean up the groundwater and the EPA determines that restrictions should remain on how the water can be used without further treatment. In 2013 approximately 200 GQRUZs were listed across the Port Phillip and Western Port region. Known GQRUZ sites are mapped below.

Polluted sites may also be listed on the EPA's Priority Sites Register (PSR). The EPA is working with other authorities to identify and manage sites that may have been polluted by past practices.

Diffuse pollution across the region

Groundwater pollution from **septic tanks** may occur in unsewered areas such as the Nepean Peninsula where there were over 18,000 septic systems in 2013. Investigations have found bacteria and nitrate contamination in aquifers that are used for groundwater extraction by private bore owners.

Nutrient and chemical pollution may occur in agricultural areas due to the widespread application of fertilisers, pesticides and herbicides.

Underground desalination mini-plants are used by bore owners in some areas to reduce the salinity of groundwater before use. These plants treat the salty groundwater drawn from one aquifer and dispose the brine into another aquifer that is already salty, all within a single bore. State Government policies and guidelines are in place to monitor the individual and cumulative impact of these plants on the overall quality of groundwater in the area.

Groundwater user responsibility

There is no guarantee of groundwater quality for bore owners. They are responsible for assessing groundwater suitability for the intended purpose and for treating it if necessary. Bore owners should seek advice from the Department of Health and appropriate experts.

Bore owners are also responsible for making sure they use an appropriately qualified bore driller and that they comply with their bore construction licence (see page 26).

Monitoring

The *SEPP GoV* requires groundwater quality monitoring appropriate to the type of pollution. This is conducted by the Department of Environment and Primary Industries (DEPI).

Point source pollution is high risk and so it is regularly investigated and monitored to meet EPA requirements. Site-specific data is reported to the EPA.

The risks to groundwater quality from **diffuse pollution** do not justify regular sampling and analysis. DEPI takes a risk-based approach to its state-wide groundwater monitoring program for diffuse pollution. Monitoring is conducted to investigate specific areas or as a general review from time to time.

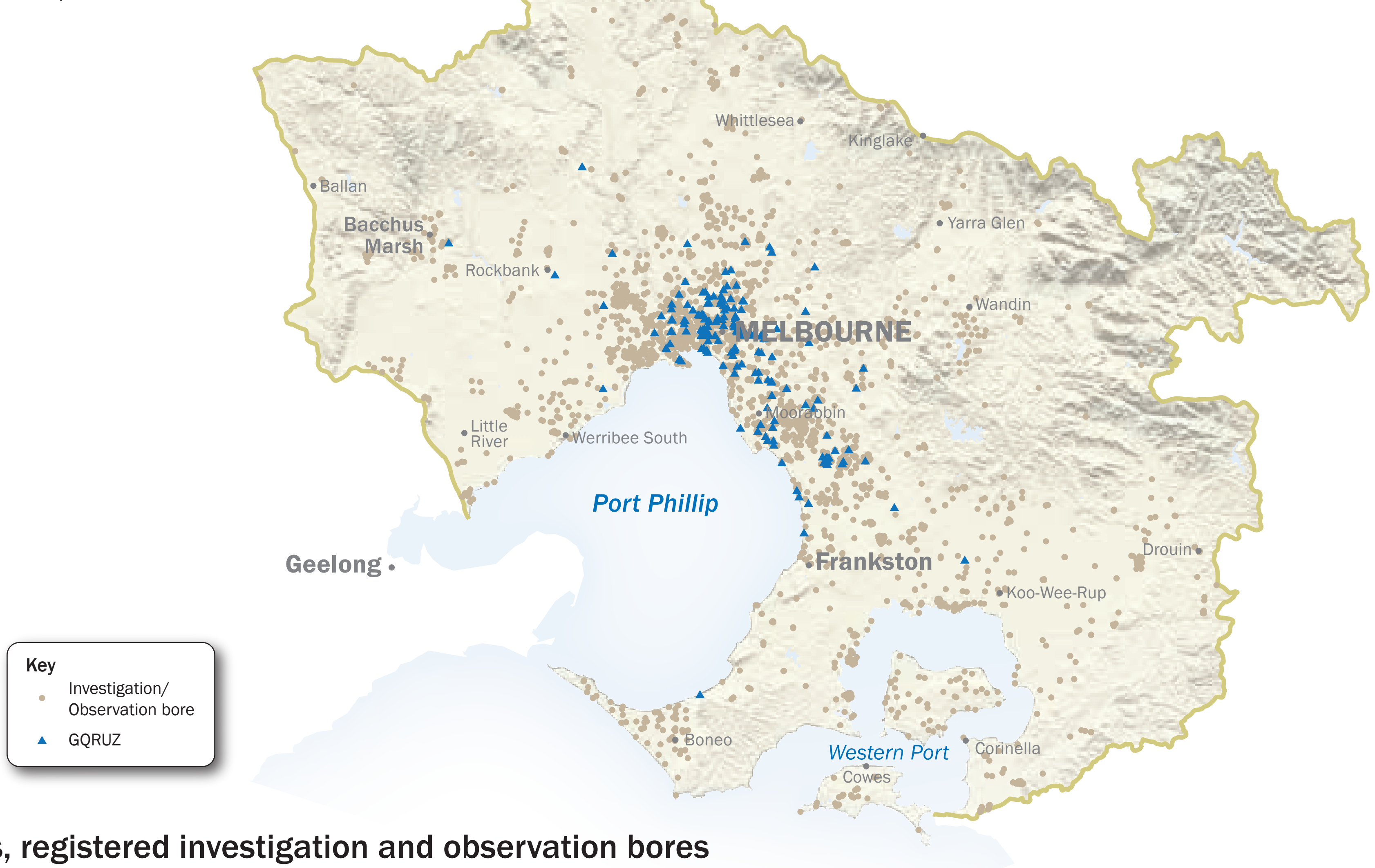
An example of such a general review took place in 2008 when groundwater quality across Victoria was analysed for pH, temperature, salinity, nutrients, metals, bacteria, pesticides and industrial chemicals. No pesticides, herbicides or industrial chemicals were detected in any bore sampled.

Salinity monitoring is conducted in areas at risk from sea water intrusion such as along the coast, including the Deutgam, Koo Wee Rup and Nepean GMUs (see pages 25 and 36). Groundwater restrictions have been enforced in the Deutgam GMU as necessary to limit sea water intrusion. No evidence of sea water intrusion has been detected in other areas to date.

Groundwater quality data collected by DEPI, rural water corporations and Melbourne Water is recorded on the Water Measurement Information System that is hosted by DEPI. More information can be found using the links on page 63.

Observations

- **Bore owners are responsible for ensuring that the groundwater they use is suitable for its purpose and for treating the water if necessary.**
- **Bore owners are responsible for complying with their bore construction licence and for having the work done by an appropriately qualified driller.**
- **High risk point source pollution is more highly regulated, monitored and reported than diffuse pollution.**
- **Groundwater salinity is monitored in areas at risk of sea water intrusion.**



GQRUZ sites, registered investigation and observation bores

This map shows the location of known GQRUZ sites, registered investigation and observation bores in the region. These bores are most commonly used for pollution investigation. Most were installed after 1990 when regulation and management of groundwater pollution increased.

Source: GQRUZ site locations from EPA (data correct as of October 2013)

Integrated water cycle management

By 2050 the population of Melbourne is projected to grow by over 3 million people to over 7 million. The current water supply will not meet the needs of this growth and, without alternative water supplies, the economy and environment will be impacted significantly. Groundwater is a potential supplementary water supply source and aquifers could be used for water storage.

Mains water is best used for purposes that require a high level of treatment such as drinking. However, the 374 GL used annually in greater Melbourne is mostly used for household washing and garden watering.

Alternatives to mains water are attractive if they are cost-effective, reliable and fit for purpose.

As part of the State Government's commitment to the reform of urban water supply and treatment, the Office of Living Victoria (OLV) was established to increase water security and efficiency while minimising water and energy use across Victoria.

Melbourne's Water Future strategy aims to optimise use of all available water sources through a whole-system approach to urban water needs. This includes drinking water, non-drinking water, waste water treatment, stormwater and water for the environment. **Integrated water cycle management** aims to reduce the need for costly transport of water supply and waste water through pipes and reduce the need for expensive treatment.

The role of groundwater and aquifers

Groundwater could be used as an alternative water supply for non-drinking uses including:

- Domestic use such garden watering, washing and toilet flushing – groundwater could be accessed through private bores
- Irrigation of sporting fields, schools and parks
- The operational needs of major infrastructure projects
- Dust suppression in quarries and landfills

Aquifers could be used as an alternative storage solution that could replace:

- Surface dams used for water storage – through Managed Aquifer Recharge
- Traditional piped stormwater systems – through Water Sensitive Urban Design

Domestic & stock (D&S) – private bores

Throughout the urban areas within the Port Phillip and Western Port region there are a large number of D&S bores on private properties (see map on page 29).

Groundwater is a more reliable source than surface water or rainfall run-off and is generally not restricted in urban areas as mains water is. Because of this, periods of low rainfall lead to an increase in bore construction in the 1980s and 2000s, especially D&S bores (see graph on page 22).

Since 1980 nearly 4,000 D&S bores have been registered in urban areas. Total usage from these bores is estimated to be 770 ML/yr*. More than half of these bores have been constructed since the year 2000.

Number of D&S bores registered since 1980

Council jurisdiction	Number of D&S bores
Bayside	172
Casey	341
Glen Eira	122
Melton	238
Mornington Peninsula	2870
Stonnington	77
Wyndham	381

* This assumes all bores constructed since 1980 are still active and that usage per site is similar to the average total metered use of households recorded by urban water authorities (0.2 ML/yr, Parsons Brinckerhoff 2010).

Many of these bores are located in older, established urban areas. Where infrastructure already exists D&S bores are a viable alternative for non-drinking purposes. Where there is no existing infrastructure the costs associated with drilling and operating a private bore would need to be considered.

Irrigation of green space and recreation

Some local councils, schools and golf courses rely on groundwater as their primary source of water for irrigating green space or as a back-up supply during dry years. This highlights the social value associated with this use of groundwater which is as important as any economic benefit.

Using groundwater as an alternative to mains supply for these purposes may be viable. The volumes used are reasonably low and some infiltration back into the aquifer occurs to partially offset its losses. Although the upfront costs to construct a bore are high, ongoing costs are reasonably low compared to accessing mains water. Groundwater is also less likely to be subject to restrictions.

During the millennium drought, the Swimming Pool and Spa Association of Victoria obtained a groundwater licence to safeguard its industry from restrictions to mains water. Groundwater was carted from its bore site to fill swimming pools.

Operational uses

Major infrastructure construction works intercept groundwater. Examples include road and rail tunnels, sewer and water supply mains, deep building foundations, marinas and even the dredging of Port Phillip Bay. In many cases the groundwater is disposed without being used for secondary purposes. In other cases mains water is injected into aquifers to stablise foundations around major infrastructure.

Quarries can also intercept groundwater as part of their operations. It is collected in sumps along with rainfall run-off. The water either evaporates or is used for dust suppression or product washing as a substitute for mains water. If groundwater is used for these purposes a licence is required. Currently many quarries rely on mains water for dust suppression.

In line with the National Water Initiative, the State Government is working to ensure that groundwater extraction for infrastructure construction and quarrying purposes is properly accounted for and to encourage appropriate use of this water.

Groundwater can also be used to heat buildings. A closed loop from a bore through the building and back to the aquifer can be used to cycle naturally warm groundwater through the building as a heat source.

Managed Aquifer Recharge (MAR)

MAR is the storage or disposal of water (usually stormwater, recycled water or river water) in aquifers for later extraction and use, or environmental benefit. It is also known as Aquifer Storage and Recovery (ASR). MAR is not a new water source.

Unlike dams, MAR avoids evaporation losses and is suited to urban areas because it uses little land. The stored water can be withdrawn from bores at multiple locations and may be cheaper than alternatives such as large desalination plants.

MAR is most suited to non-drinking uses such as toilet flushing, garden watering and irrigation. It works best in confined sand aquifers, preferably those that are naturally brackish and have few other users.

MAR may also be suitable for treating waste water. There is currently only limited recognition of this in Victoria.

MAR can also be used as an important source of water by the environment.

Risks to the environment and human health need to be considered in accordance with Victorian EPA and national guidelines. SRW regulates MAR schemes under the Water Act and State Environment Protection Policy (SEPP) (Groundwaters of Victoria) through licensing for bore construction, pumping water into aquifers and for extracting water as well as risk assessments and management plans.

Upfront investigation and infrastructure costs can be very high and projects normally involve a long trial and error phase. MAR schemes currently operating or being developed across the region are mapped on page 29.

More information about MAR, including guidelines, licensing requirements and potential MAR sites can be found using the links on page 63.

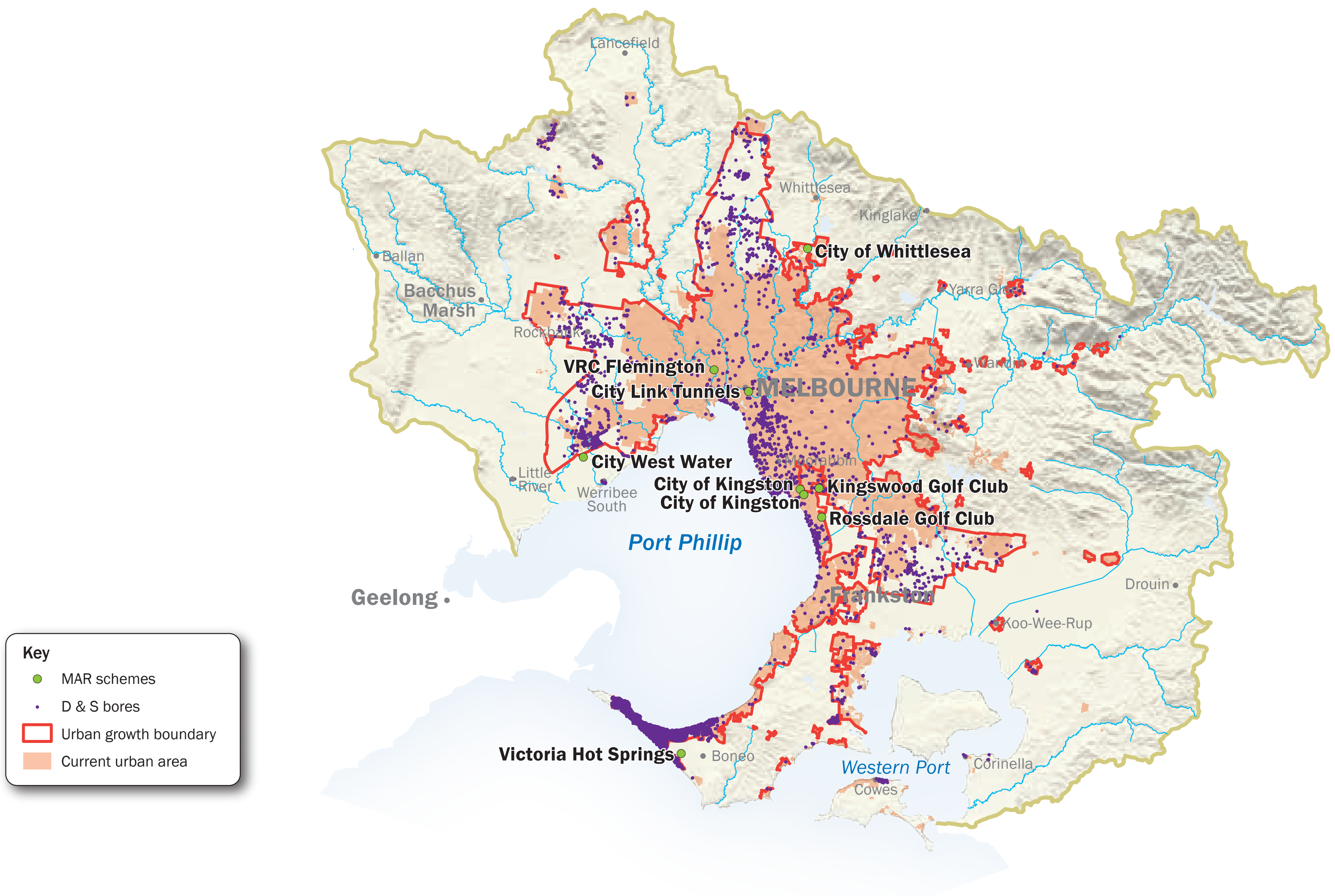
Integrated water cycle management

Stormwater management

Stormwater in the Port Phillip and Western Port region is managed by Melbourne Water and local councils. Using aquifers instead of traditional piped stormwater systems has the potential to reduce the risk of flash flooding, reduce the volume of run-off and increase the quality of discharges into our rivers, streams and bays. This can be achieved through active measures such as Water Sensitive Urban Design (WSUD) or in more passive ways which use the natural environment.

WSUD is about integrating whole-of-water cycle management into urban planning and design with the aim of mimicking the natural water cycle as closely as possible. Permeable paving, infiltration trenches and swales are examples of WSUD measures that encourage stormwater to infiltrate our aquifers as recharge instead of being lost as discharge directly into drains, rivers or the bay.

Councils and water authorities along the south-east margin of Port Phillip use the beach sands as a passive part of their stormwater systems. The stormwater seeps into the shallow sand aquifers and eventually discharges to the bay. This avoids the cost of disposal by pipes to ocean outfalls and reduces contamination in waterways.



Distribution of private D&S bores and MAR schemes

Observations

- **The Office of Living Victoria is working with water authorities, local government and developers to improve water management at all levels from households to city-wide.**
- **Restrictions and the expense of mains water have created interest in groundwater as a supply solution for individuals, businesses, industry and councils.**
- **Aquifers can be used for water storage and stormwater management.**
- **Policy reform could encourage innovative approaches to water management.**

Regulatory and management considerations

When considering the use of groundwater or aquifers as part of an integrated water cycle management approach, policy advisors, groundwater resource managers and end users need to consider:

- Where and when it is appropriate to add water to aquifers through MAR or WSUD, taking into account the surrounding environment
- How much groundwater can be sustainably extracted in total
- Whether the quality of groundwater is fit for purpose
- The impact on groundwater quality
- The monitoring and regulatory needs associated with changes
- The associated costs for infrastructure, water treatment etc
- The potential benefits

Many of the options discussed would require a take and use licence and other approvals. Policy reform could make an integrated water cycle management approach easier to implement by allowing special consideration under the regulatory framework for it to be used for specific purposes where it relieves pressure on mains supply.

Adopting an integrated water cycle management approach may lead to an increase in groundwater usage and subsequent changes to current water balances and the natural environment. Regulation and management would need to account for local and regional changes to groundwater recharge, discharge and quality. Changes to the groundwater monitoring network and program would also need to be considered.

The value of groundwater

Groundwater has great economic, environmental, and social and cultural value. Its value is protected by legislation and appropriate management.

Economic value of production

The willingness of a user to pay for groundwater depends on the return on investment and cost of an alternative water supply.

Groundwater production value of different user groups

Estimated total annual value by GMU			
GMU	D&S*	Agribusiness**	Urban & industrial***
Deutgam	$311,645	$1,991,860	–
Lancefield	$111,015	$510,228	$81,990
Merrimu	$21,401	$520,352	$12,069
Nepean	$3,072,313	$3,462,085	$6,131,764
Non-GMU Upper	$1,236,140	$810,855	$1,478,709
Frankston	$311,645	$30,862	$445,097
Koo Wee Rup	$1,995,599	$11,665,045	$1,147,857
Moorabbin	$559,089	$572,490	$2,462,444
Non-GMU Middle	$677,883	$ 444,662	$810,905
Corinella	$175,217	$95,657	$191,520
Cut Paw Paw	$50,826	–	$269,830
Parwan	–	$145,440	–
Wandin Yallock	$153,816	$1,619,065	–
Non-GMU Lower	$2,073,524	$1,360,145	$2,480,416
TOTAL	**$10,750,114**	**$23,535,831**	**$13,358,234**

This chart shows the different aquifer groups: upper (green), middle (orange) and lower (blue).

Source: RMCG 2011

* D&S value is based on the annualised cost to replace a bore and desalinate the water ($800/ML). Where garden watering is the primary use it could also be compared to the cost of mains water ($1,300 to $2,000/ML)

** Agribusiness value is based on the average additional production gained from using groundwater, depending on dominant agricultural land use and average bore depth in each area. The value could also be estimated by adding the cost of replacing bores (~$900-$3,000/ML)

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

Environmental value

Groundwater plays a major role in supporting the environment, particularly during dry periods. It supports the health of flora and fauna and maintains the balance between salt and freshwater systems (see page 36). To date, there have been no studies completed in the Port Phillip and Western Port region that assign a monetary amount to this value. Some studies have been completed in other areas of Australia and overseas that show people are willing to pay to protect Groundwater Dependent Environments (see also pages 18, 19, 37, 47 and 57).

Social and cultural value

Where groundwater interacts with surface water bodies such as springs, wetlands and waterways, the indigenous and wider communities place great value on these places for recreation, tourism, fishing and traditional activities such as ceremonies. The State Government has committed to increased consultation to preserve these values through its Sustainable Water Strategies (SWS). These policies apply right across Victoria (see Gippsland Region SWS actions 4.12 and 4.17; Western Region SWS policy 3.12 and section 3.5).

Alternative supply to mains water

Currently thousands of public parks, bowls clubs, turf clubs, schools etc across the region are irrigated using mains water. There is enormous potential to substitute this with alternative sources including groundwater. Integrated water management strategies developed by urban water authorities and local governments are addressing this issue (see pages 28 and 29). A good example is where 10 sports fields are being irrigated by the Mornington Peninsula Council using groundwater.

Aquifers for water storage

Confined aquifers that store water through Managed Aquifer Recharge (MAR) schemes have value. Where water is stored in aquifers less water is lost through evaporation and there is less impact on the land surface when compared to traditional dams. More information on MAR schemes can be found on pages 28 and 29.

Observations

- **Groundwater has significant economic value for users.**
- **Groundwater has significant non-monetary value for the environment and wider community.**
- **Users with higher value needs are willing to increase reliability by drilling deeper.**
- **Groundwater value is protected by legislation and appropriate management.**

Reliability and security

Groundwater is normally more reliable than surface water during dry periods. The **reliability** of a bore is determined by how long it can sustain the preferred pumping rate. Bores drilled into deep thick aquifers are usually more reliable than those in unconfined aquifers which can draw down quickly when pumped, particularly during dry periods. Reliability is not transferable – it varies from site to site and depends on the depth of the aquifer and the quality and condition of the bore and pump.

Security refers to the certainty a user has to access their entitlement according to their licence conditions such as volume, term, and restrictions. To some extent security is transferable as a licence can be traded even though conditions may apply to the transfer. Potential groundwater users should have a good understanding of their security before purchasing a licence or investing in infrastructure.

Protection of value

The value of groundwater resources is protected by legislation and appropriate management. This includes the value of its quality and quantity (see pages 23, 26 and 27).

SRW staff member Frank Crameri with a customer near Koo Wee Rup

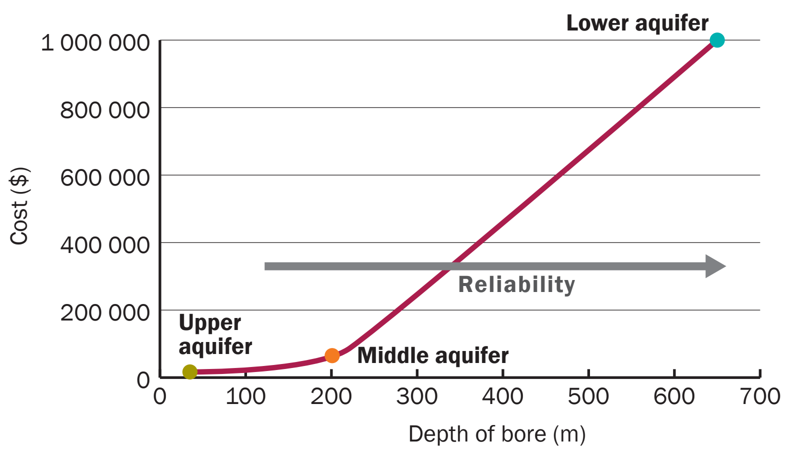
The cost of groundwater

Reliability and security strongly influence the price that users are willing to pay for groundwater.

Bore costs

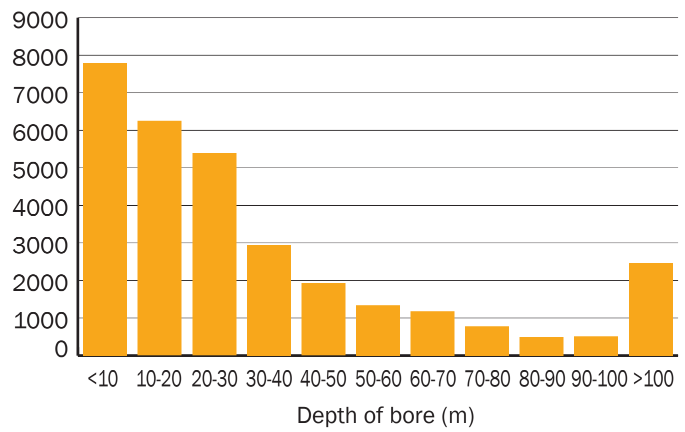
Bores drilled into deep thick aquifers usually have the highest reliability, however they cost more to construct (see graph below) and they are more expensive to maintain, repair and replace. As for all infrastructure, proper maintenance is required to maximise a bore's lifespan and efficiency. It may be necessary to drill multiple test bores before a good yielding bore can be installed. A shallow domestic and stock (D&S) bore may cost as little as $5,000 to construct. The cost of a lower or middle aquifer bore will depend on its depth.

Cost of drilling a bore at different aquifer depths



Almost 80% of registered bores in the region are less than 50 metres deep

Number of bores in region



Source: GMS 2013

Pumping costs

Pumping costs can vary widely, depending on:

- Groundwater level or pressure
- The type of pump used
- Peak versus off-peak use
- The type of energy used
- The pumping rate

Different solutions will be cost-effective in different situations.

Licensing fees

These are approved by the Essential Services Commission under Southern Rural Water's (SRW) five-year Water Plans.

An **application fee** is charged for new bores and groundwater licences to cover groundwater management costs. An investigation by a professional hydrogeologist may also be required to support the application.

An **annual licence fee** applies to all non-D&S use. This includes a fixed component and a charge per ML.

An **intensive management fee** may be applied where additional monitoring and management of a GMU is required to protect the resource. Licence holders in Deutgam and Koo Wee Rup GMUs currently pay an intensive management fee charged on a per ML basis.

Meters

All new non-D&S groundwater extraction is metered at the user's cost. All existing non-D&S use of 10ML/yr or more is metered (see also page 23).

Treatment costs

Where groundwater quality is not suitable for the proposed use additional treatment may be required. This may include desalination or other treatment to remove salts or potentially harmful substances.

Groundwater management costs

In line with the National Water Initiative, SRW operates on a cost recovery basis. Fees charged are used to cover groundwater management costs including monitoring.

In line with the State Government's Sustainable Water Strategies, groundwater monitoring costs for D&S users are paid by the State.

Observations

- **Users want a secure entitlement with a reliable supply at a cost they can afford.**
- **Bore construction, maintenance and pumping costs depend on the depth of the aquifer.**
- **Other upfront and ongoing costs need to be considered by potential users.**

Future development

Most known groundwater resources are fully allocated and capped and it is becoming increasingly difficult to find new sources. This may influence groundwater development costs. Future development opportunities for new or existing groundwater users include trading and MAR.

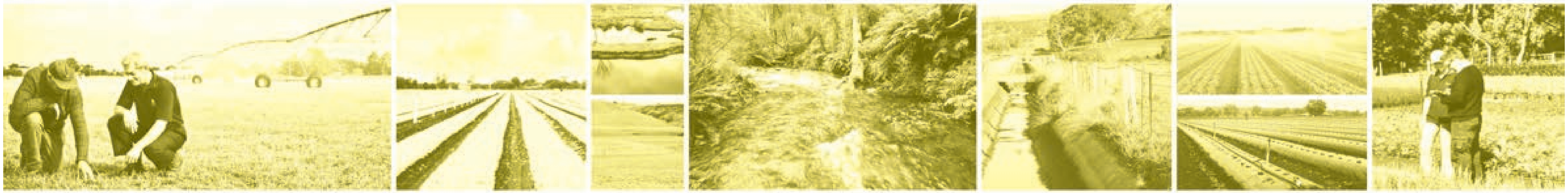
Trading an existing entitlement

Licensed users use approximately 30% of their entitlement on average. This means that there is potential for trading. Users who use all of their entitlement often secure additional water through trading. 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/yr for a temporary transfer. There are also application costs for trades. More information on this topic can be found using the links on page 63.

Managed Aquifer Recharge (MAR)

This means taking a nearby supply of stormwater, recycled water or river water, storing it in an aquifer and extracting it when needed (see pages 28 and 29). The cost of MAR schemes range from $1,000/ML to $3,000/ML when averaged over the project life. MAR schemes have high upfront infrastructure costs. Application fees also apply.

More information on SRW's fees and related costs can be found using the links on page 63.



Chapter 4: Upper aquifers

Upper aquifers occur along the river valleys, near the coast and on the plains west of Melbourne. They are thin and formed by sand and gravel sediments or basalts at shallow depths. They receive recharge directly from rainfall and discharge occurs to streams and the bays.

The better parts of these aquifers are high yielding and low salinity. This makes them suitable for uses such as agribusiness (pasture, dairy wash and horticulture), domestic and stock (D&S) and the backup town supply for Lancefield.

In this chapter you can find information on:

Aquifer geology

The upper aquifers in the region are formed by recent sediments, sands and basalt. They occur at the ground surface and receive recharge directly from rainfall.

Recent sediment aquifers

These aquifers consist of clay, sand and gravel along the river valleys, around Koo Wee Rup and in dune deposits near the coast (see soil map on page 35).

Sand and gravel aquifers underlie productive farmland along the river valleys and flood plains around Bacchus Marsh and Werribee and near Yarra Glen. They formed when soil and rocks eroded from the mountain ranges and were deposited by streams over the past 1 million years. Near Koo Wee Rup the upper aquifer is mostly clayey and acts as an aquitard (see also page 10) except in the south-eastern part of the GMU.

The Nepean Peninsula west of Boneo is covered by sand aquifers that can be more than 150 metres thick. These aquifers have been formed by deposits from the ocean and wind over the past 4 million years. Sandy dune deposits occur along the coast in the areas around Nepean and Koo Wee Rup and south-east of Melbourne.

Basalt aquifers

These aquifers are formed by numerous basalt flows due to volcanic activity over the past 4 million years and are known as the Newer Volcanics. They are most porous near the volcanic cones and are more clayey and act as confining layers across the plains west of Melbourne. They are thickest near the volcanic cones and where they flowed into and filled old river valleys such as south of Lancefield. The basalts occur at the surface where they are not covered by the recent sediments.

Observations

- **These aquifers receive recharge directly from rainfall.**
- **Sand and gravel deposits form localised but important aquifers along the river valleys, flood plains and near the coast.**
- **Basalt aquifers formed by volcanic activity exist to the north and west of Melbourne.**
- **Licences are concentrated in the best parts of these aquifers.**

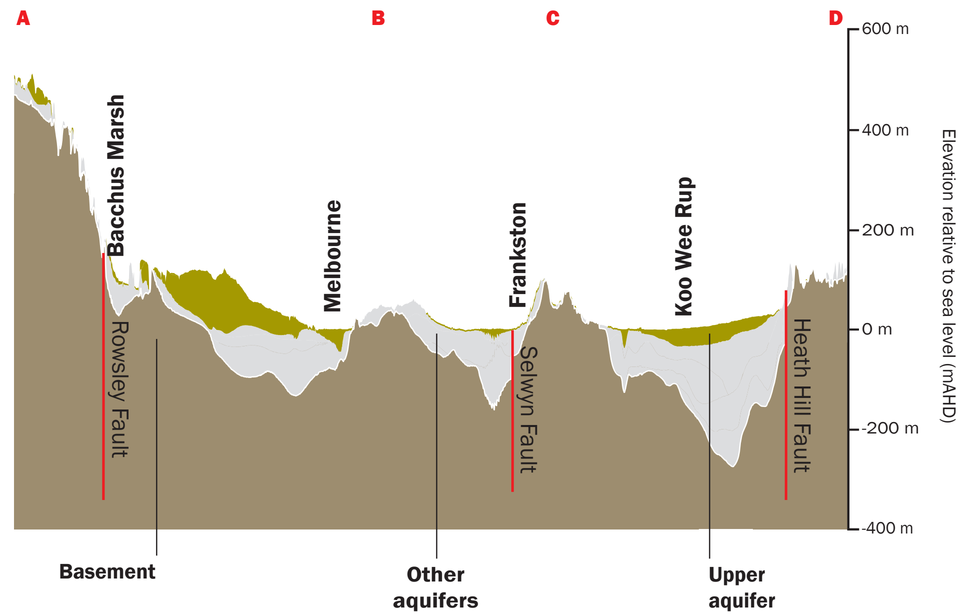
Upper aquifers: structure, thickness and licences

This map shows where the recent sediment aquifers are thin (light green shading) and where they are thicker (darker green shading). It also shows the extent of the basalt aquifers (orange). Groundwater licences are shown by user group. The location of major faults is shown.

Upper aquifer licences

The map on the left shows licensed groundwater entitlement by user group. Where the recent sediment aquifers are thickest around Werribee South and Boneo, there is a higher concentration of licences.

The cluster of licences around Lancefield indicates the low salinity and high yields of the basalt aquifer in this area (see also page 35). The lower concentration of licences in the basalt aquifers on the plains west of Melbourne and in the recent sediment aquifers to the north-east and south-east of Melbourne indicates the generally higher salinity and lower yields of groundwater in these areas.



Cross-section upper aquifers

This diagram shows the cross-section **A-B-C-D** taken from map on left

Note: horizontal and vertical scales are different.

Salinity and yield

Groundwater extraction from the upper aquifers is confined to isolated pockets where the yield is high and salinity is low. The best areas (those with the highest demand) are managed as GMUs. Groundwater salinity and yield depend on the soil and rock types as well as the aquifer thickness and depth.

Gravel and sandy soils

Where the soils are **gravelly or sandy** (see map below) there is more space between the soil particles and less salt than in clay soils, therefore groundwater flows quickly, picks up less salt and is stored in large volumes. In these areas yield is high and salinity is low.

Areas with gravelly or sandy soils used for irrigation and domestic and stock (D&S) supply are:

- Bacchus Marsh (Merrimu GMU)
- Werribee (Deutgam GMU)
- Nepean GMU
- South-east of Koo Wee Rup

Clay soils

Where the soils are **clayey** (see soil map below) groundwater yield is low and salinity is high. In clay soils water moves very slowly due to the extremely small amount of space between the particles. Clay soils also contain high salt levels which the groundwater picks up as it moves. These areas are effectively aquitards (see also page 10).

Basalt areas

In the **basalt** areas salinity and yield can be highly variable.

Near Lancefield the scoria and highly fractured basalt upper aquifer has a lot of space in the rock. Groundwater storage is relatively high and water flows relatively quickly resulting in low salinity and high yield.

The plains west of Melbourne between Bacchus Marsh and Werribee are covered with several basalt layers but the top layer has weathered to clay.

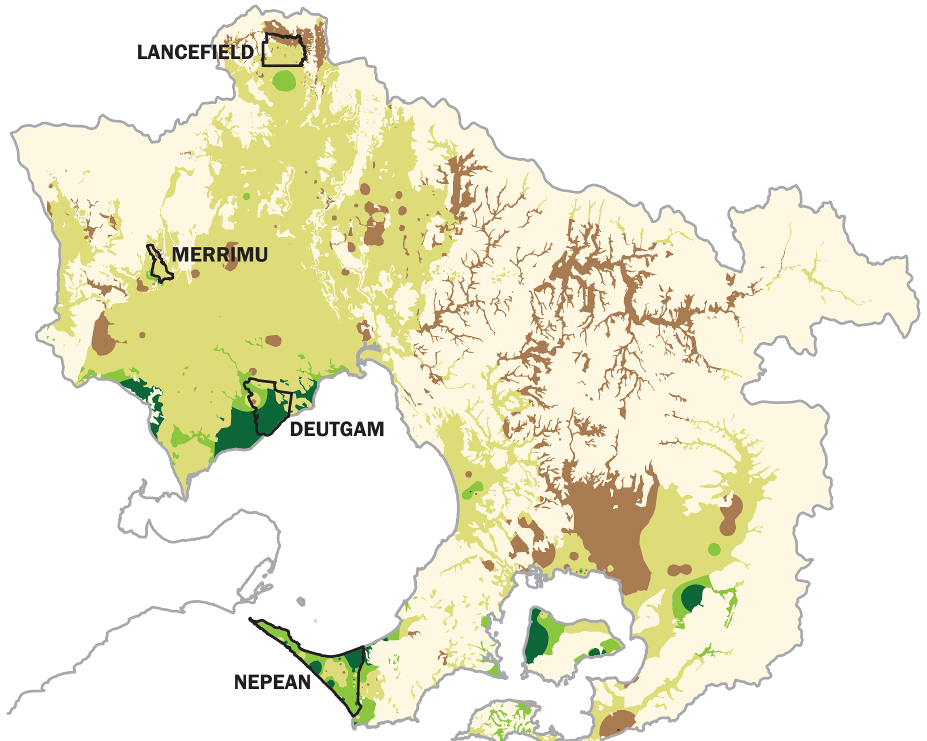
Observations

- **Groundwater extraction from these aquifers is confined to isolated pockets where the yield is high and salinity is low.**
- **Groundwater salinity and yield are highly variable in these aquifers and depend on the aquifer material, thickness and depth.**
- **The best areas of these aquifers are managed as GMUs.**

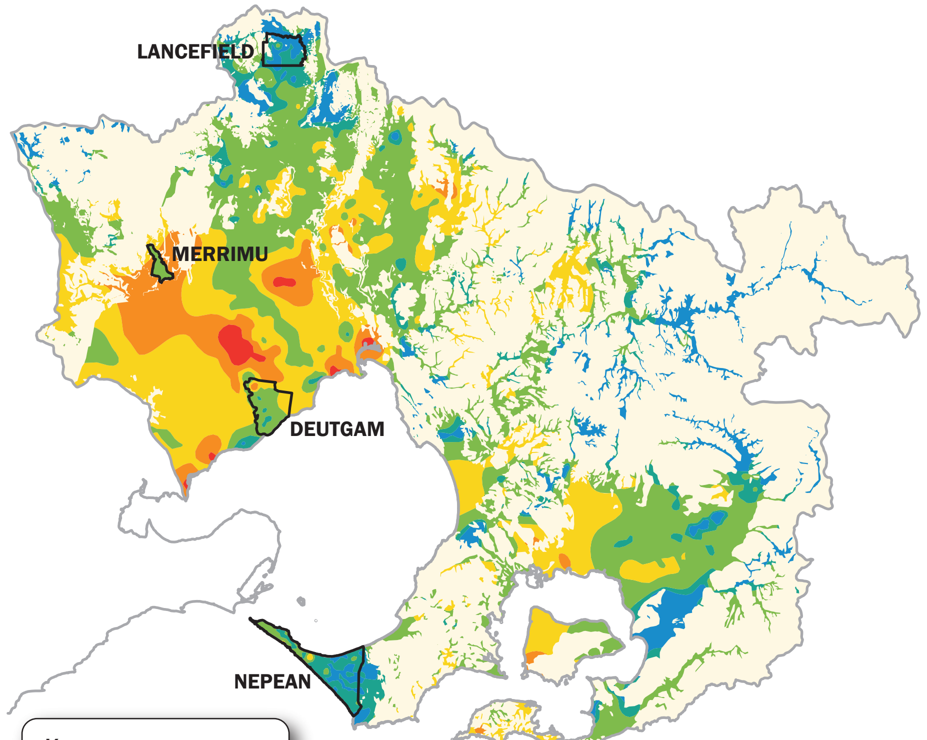
Groundwater moves more slowly across the flat terrain than it does in the highlands. Therefore, salinity is generally too high for most uses.

Volume of water in storage

It is estimated that 660 GL of fresh water (salinity less than1,000 mg/L) is stored in the upper aquifers.

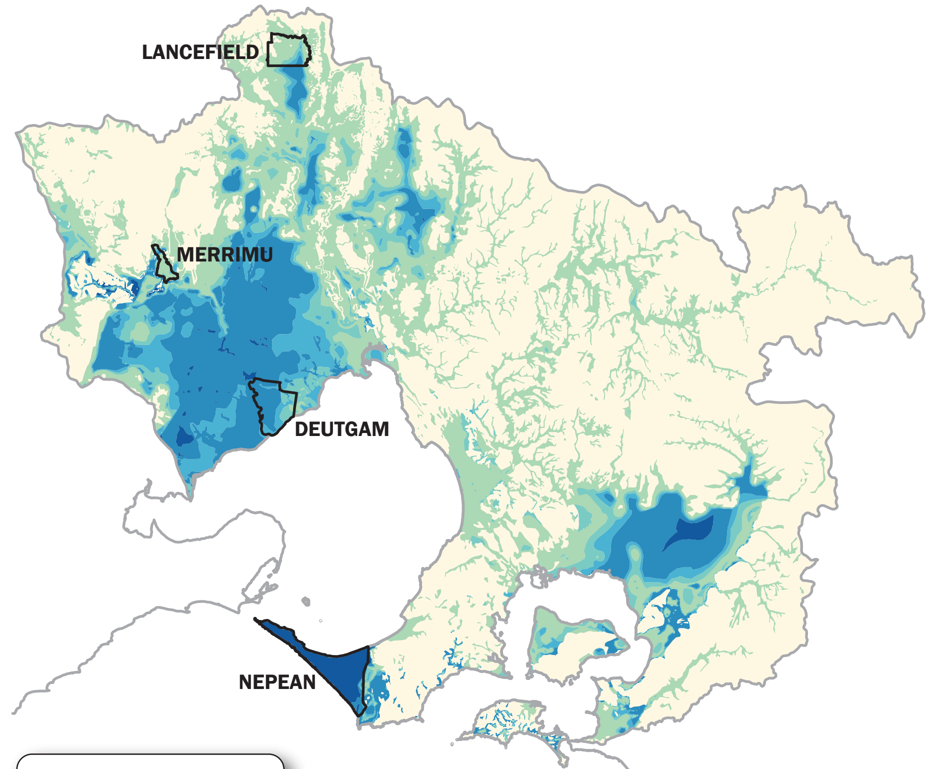


Soil and rock types of the upper aquifers



Salinity of the upper aquifers

Salinity data for Merrimu GMU has been amended from regional mapping using available local data. More information on irrigation and stock watering suitability can be found on page 11.



Yield of the upper aquifers

Movement of groundwater

Horizontal groundwater movement in the unconfined upper aquifers follows the structure of each aquifer from high to low elevation. Vertical movement through to the underlying formations also occurs.

General information on groundwater movement can be found on page 15.

Flow systems (horizontal movement)

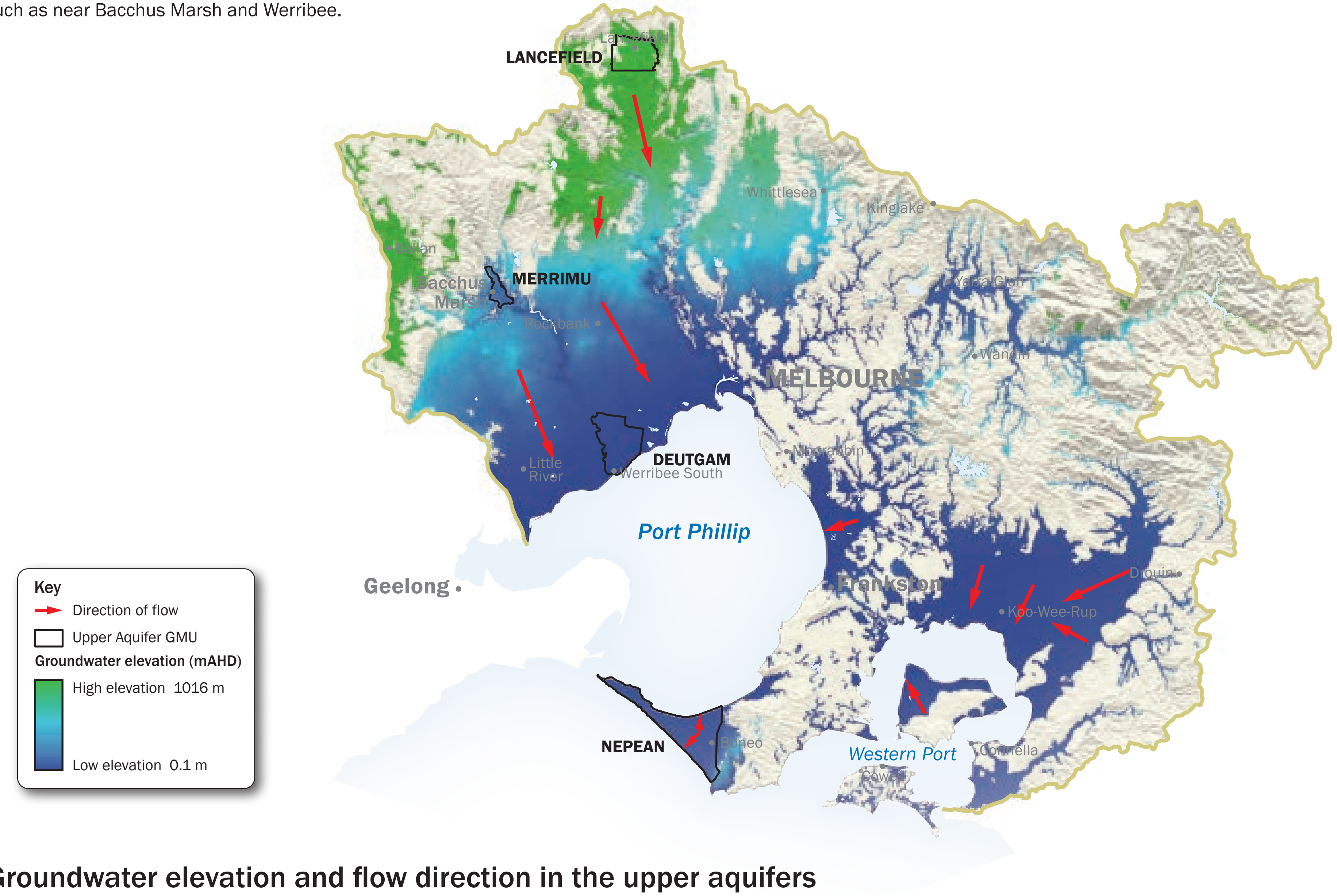
Local flow systems occur in fractured rock and recent sediments aquifers found in river valleys around the basin margins and along the flanks of the mountain ranges such as near Lancefield and Yarra Glen. Here the flow paths are steep and short before the water intercepts the ground surface in depressions and stream beds. These flow systems also occur along waterways within the basins such as near Bacchus Marsh and Werribee.

Intermediate and regional flow systems occur in the flatter terrain of the basalt plains such as west of Melbourne, on the flood plains around Koo Wee Rup and in the coastal sediments west of Boneo. In these systems shallow groundwater moves more slowly and discharges to the bays.

Vertical movement

Vertical movement is generally much slower than horizontal movement. This is due to occasional clay or peat layers which have low permeability compared to sand, gravel or fractured basalt.

The exceptions are in areas where clay and peat are not present and along fault lines. For example, faster recharge and vertical movement occurs in the sandy soils near Boneo, and slower recharge and vertical movement occurs in the clayey soils west of Melbourne and around Koo Wee Rup (see also page 33).

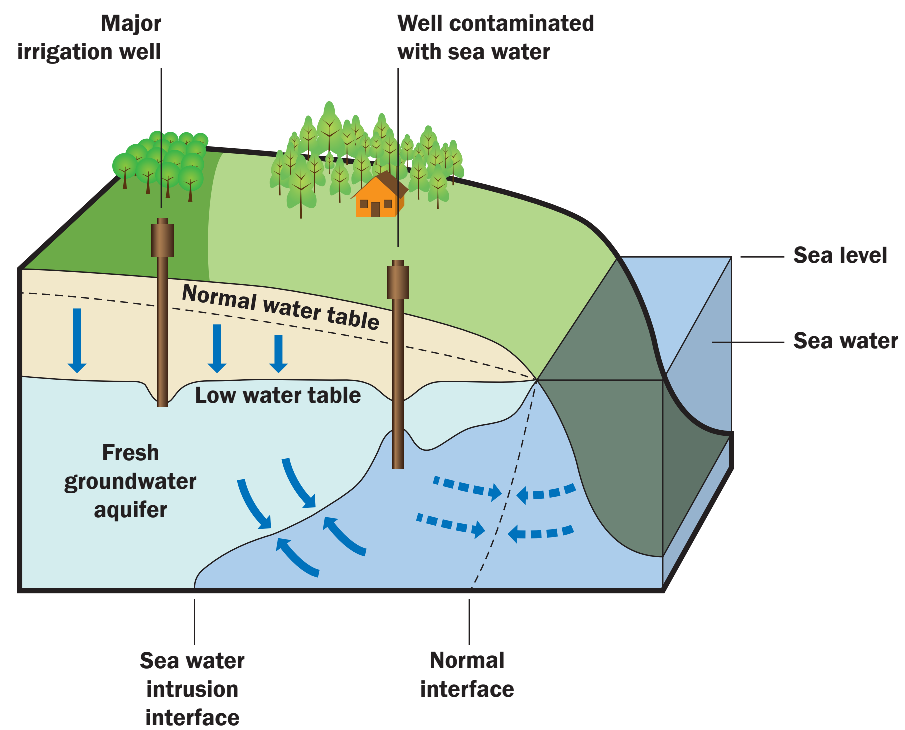


Groundwater elevation and flow direction in the upper aquifers

Groundwater flows from areas of high elevation (green) to areas of low elevation (dark blue).

Observations

- **Local flow systems occur in the fractured rock aquifers around the basin margins, along the mountain ranges and near waterways.**
- **Intermediate and regional flow systems occur on the basalt plains, on the flood plains and near the coast.**
- **Sea water intrusion can occur when excessive groundwater is pumped from aquifers connected to the ocean.**



Sea water intrusion

This diagram shows how sea water intrusion can occur in shallow coastal aquifers connected to the ocean. When too much fresh groundwater is pumped out of an aquifer the water table drops. This decreases the pressure of fresh water against sea water and allows the sea water to move inland.

Sea water intrusion is a potential problem and bores are monitored in:

- Deutgam GMU
- Koo Wee Rup GMU
- Nepean GMU
- The south-east suburban sandbelt (Moorabbin GMU)

A combination of groundwater levels falling below sea level and rising salinity levels in monitoring bores indicates that sea water intrusion may be occurring.

Environmental dependence

Upper aquifers interact closely with surface water environments such as streams, wetlands and the bays.

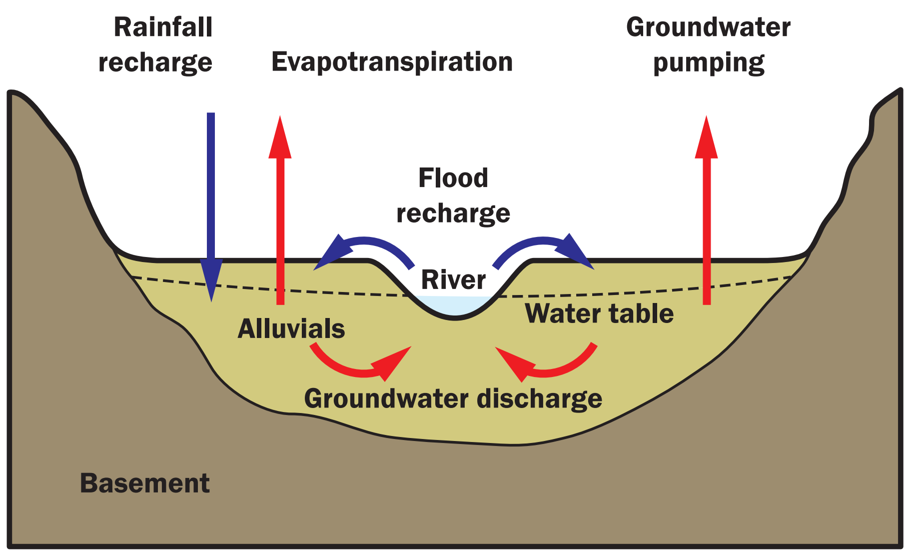
The examples on this page make the most of the few detailed studies available to show several different ways in which groundwater from the upper aquifers interacts with surface ecosystems. Information is provided in general terms only. Further general information and maps on the region's potential Groundwater Dependent Ecosystems (GDEs) can be found on pages 18 and 19. Specific examples of upper aquifer GDEs are provided on this page (see page 19 for locations).

Baseflow to rivers

Waterways interact with the upper aquifers across the region. Groundwater discharge into the waterways can make up a significant component of their flow during low flow periods in summer and autumn. It also supports drought refuges (permanent pools in waterways) when there is no flow.

In the highlands, groundwater discharges to waterways from springs, providing a baseflow.

On the plains and in the river valleys, waterways and billabongs may gain from or lose water to aquifers as groundwater levels rise and fall. Rivers gain groundwater during low flow periods and recharge the aquifers during floods (see diagram below). This switch from gaining to losing may occur many times each year or within close distances (see also page 18).



Groundwater interaction with waterways in the river valleys with recent sediment aquifers

Rivers are most likely to be affected by groundwater pumping in dry periods when river flows are low and pumping levels peak. This reduction in river flows happens with very little lag time where bores are located close to the river because groundwater moves quickly through the sand and gravel aquifers. However, aquifers with low salinity and high yields exist in small, isolated pockets, so the impact tends to be localised such as in the Yarra Valley.

Volcanic plains wetlands

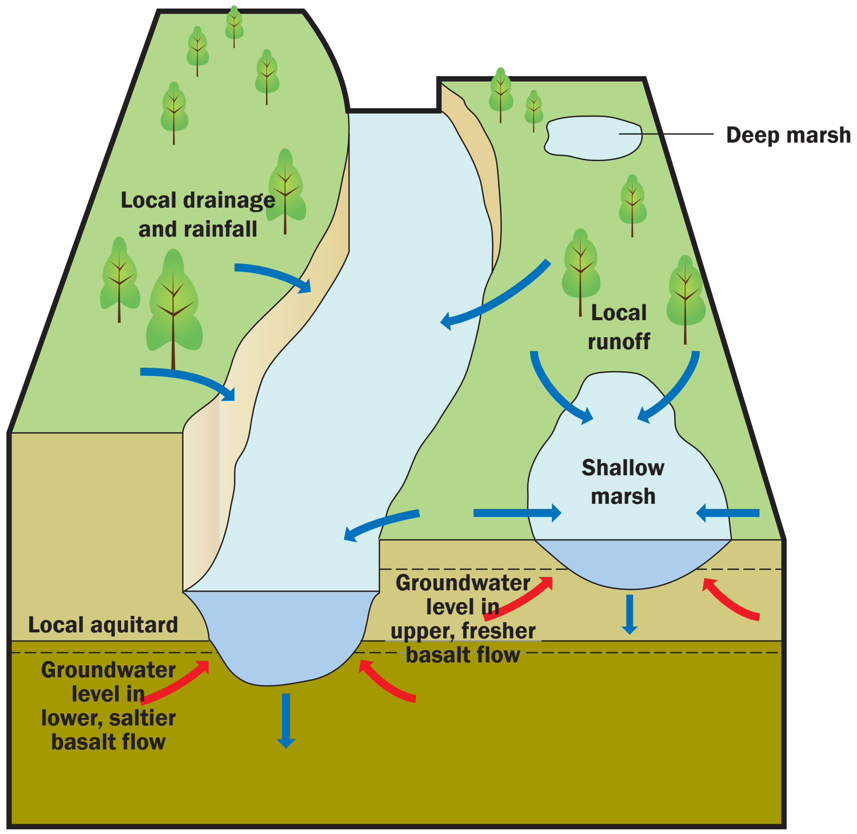
The volcanic plains west of Melbourne are home to numerous threatened and significant plants and animals.

The diagram below shows how streams and wetlands in this area depend on both surface water and groundwater. Examples include Deanside Wetlands at Rockbank and Kororoit Creek. Large old Red Gums in this area are also thought to use groundwater in dry periods.

Groundwater interactions on the volcanic plains are similar to those in the river valleys with recent sediment aquifers but they are more complex due to the multiple basalt layers. Each basalt layer can function as a separate aquifer with a very different flow rate and salinity. It is therefore common for fresh and saline ecosystems to exist very close to each other.

Deanside Wetlands is a freshwater marsh permanently connected to a low salinity shallow basalt aquifer layer. Numerous small, shallower wetlands are often disconnected from groundwater and mainly depend on run-off.

Kororoit Creek is connected to the deeper, saltier basalt aquifer layers, while its tributaries are connected to the fresher shallow layers. Interaction depends on groundwater levels which rise and fall with rainfall, so the creek gains groundwater in some areas and seasons and loses groundwater in others. Saline groundwater contributes to high salt levels in the lower reaches of Kororoit Creek and the plants in these areas are salt-tolerant.



Groundwater interaction with waterways on the volcanic plains

Source: SKM/Melbourne Water 2012

Observations

- **These aquifers interact closely with the environment in many areas.**
- **Surface water environments with significant ecological value may depend completely or partly on groundwater from these aquifers.**
- **Groundwater from these aquifers may contribute significantly to waterways during low or no flow periods in summer and autumn.**

Dune swamps

Tootgarook swamp is a dune swamp on the Mornington Peninsula (see map on page 19) and is a site of State biological significance. It is the largest remaining natural freshwater swamp in the Port Phillip & Western Port region and supports numerous endangered, threatened and vulnerable plants and animals as well as migratory birds. It also helps to limit flooding in nearby areas by providing some storage of stormwater.

The swamp is connected to the upper aquifer and plants in the swamp directly access the shallow water table. This aquifer is recharged by rainfall and stormwater run-off through the surrounding sandy soils and dunes. It also discharges groundwater to Chinaman's Creek (an artificial waterway also known as Boneo Drain).

The shallow groundwater maintains the swamp and its dependent habitat. It also prevents potential acid sulfate soils from drying and, therefore, prevents toxic discharges.

Tootgarook swamp may be sensitive to:

- Over-extraction of groundwater
- Urban development (which would reduce local recharge)
- Poor quality and potentially contaminated stormwater run-off
- Irrigation in the area that uses recycled water

Mornington Peninsula Shire Council is developing a management strategy for Tootgarook Swamp together with professional partners and stakeholders.

Source: Tootgarook Swamp information – SKM/Melbourne Water 2012

Water balance

The upper aquifers in the region are generally unconfined and often interact with local streams.

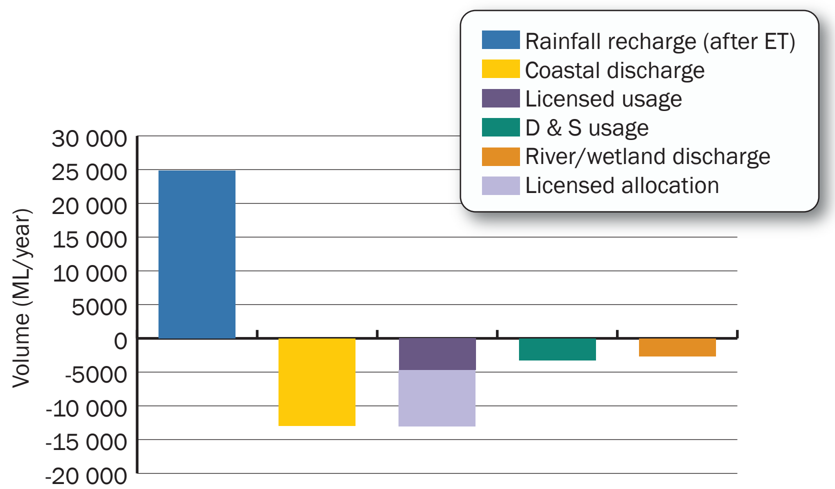
The information on this page makes the most of the few detailed studies available on water balance in the upper aquifers. General information about water balances can be found on page 17.

The main factors affecting the water balance in the upper aquifers are rainfall recharge, pumping and discharge to the bays, rivers and wetlands. Recharge is highest in the porous recent sediments aquifers (see also page 35). Discharge occurs as baseflow to streams, evapotranspiration, discharge to the bays, leakage to deeper aquifers and pumping.

The Bureau of Meteorology estimates that groundwater recharge across the region may be three to five times higher in wetter-than-average years (eg 2010-11) compared to drier-than-average years (eg 2006-07). The variation in recharge is greater than the variation in rainfall from year to year. More information about rainfall and recharge can be found using the links on page 63.

Extraction also varies from year to year. More information about average extraction and its range can be found on page 40.

Upper aquifer GMUs - combined water balance



Adapted from several reports (see page 62).

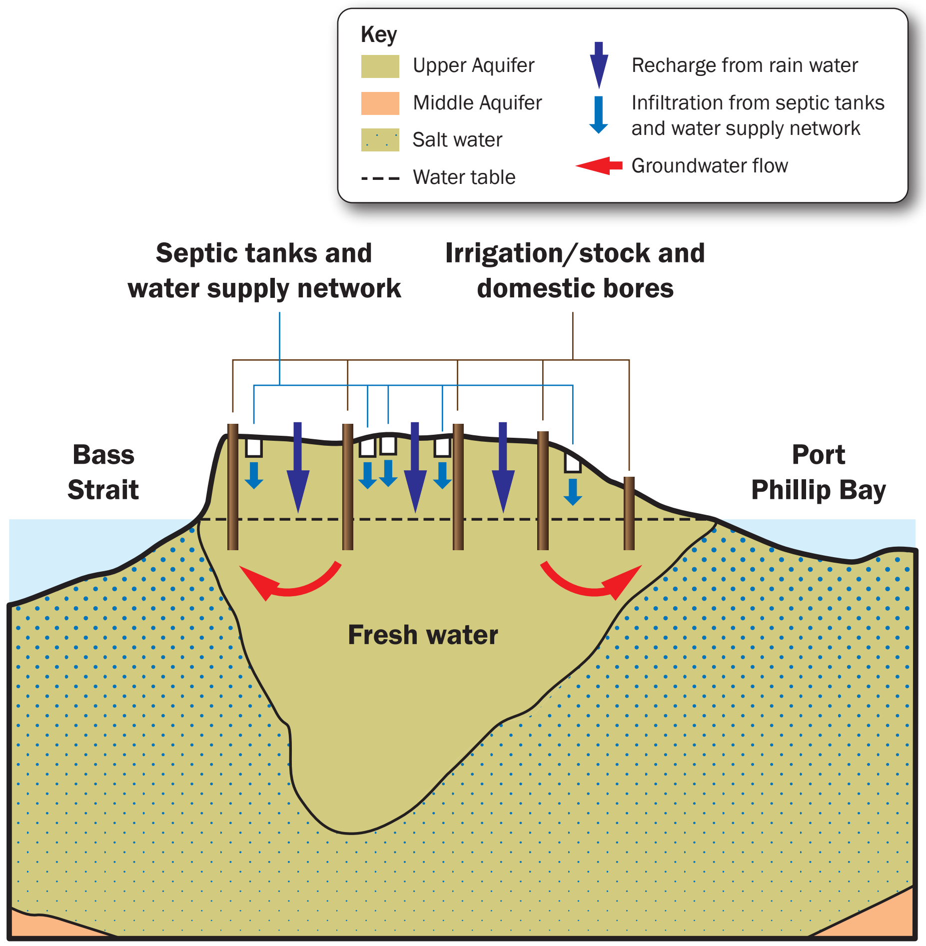
The graph (above) shows the estimated combined water balance of the upper aquifer GMUs at Lancefield, Deutgam, Merrimu and Nepean.

Averaged across all of the GMUs, the estimated total recharge is approximately equal to the estimated total discharge. If all licensed entitlements were used, discharge would be greater than recharge and coastal discharge would be affected. These estimates do not include the impact of evapotranspiration and land use; factors that are known to affect the water balance of upper aquifers elsewhere.

Nepean GMU

The Nepean Peninsula is covered by a thick sequence of sands. Groundwater use in this area is greatest for irrigation purposes in the hills around Boneo and there are numerous domestic and stock (D&S) bores in the coastal residential areas.

This cross-section shows how groundwater discharging to the ocean determines the position of the freshwater-sea water interface (see diagram above). If discharge were to decrease, the interface would move inland and the groundwater would become saltier. This impact would be felt first in bores closest to the ocean (see also page 36).



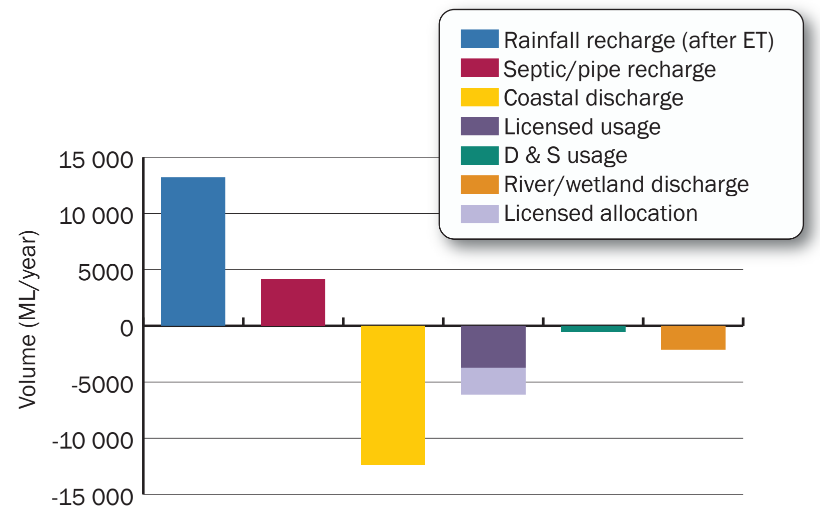
Adapted from: Parsons Brinckerhoff, 2010

Observations

- **The main factors affecting the water balance in these aquifers are rainfall recharge, pumping and discharge to the ocean.**
- **Rainfall recharge in these aquifers varies significantly from year to year.**
- **If all licensed entitlements were used, groundwater discharge to the bays, rivers and wetlands would be affected.**
- **Mains water from leaky pipes and septic systems adds to the water balance.**

The graph below shows the Nepean GMU water balance in 2009.

Nepean GMU water balance



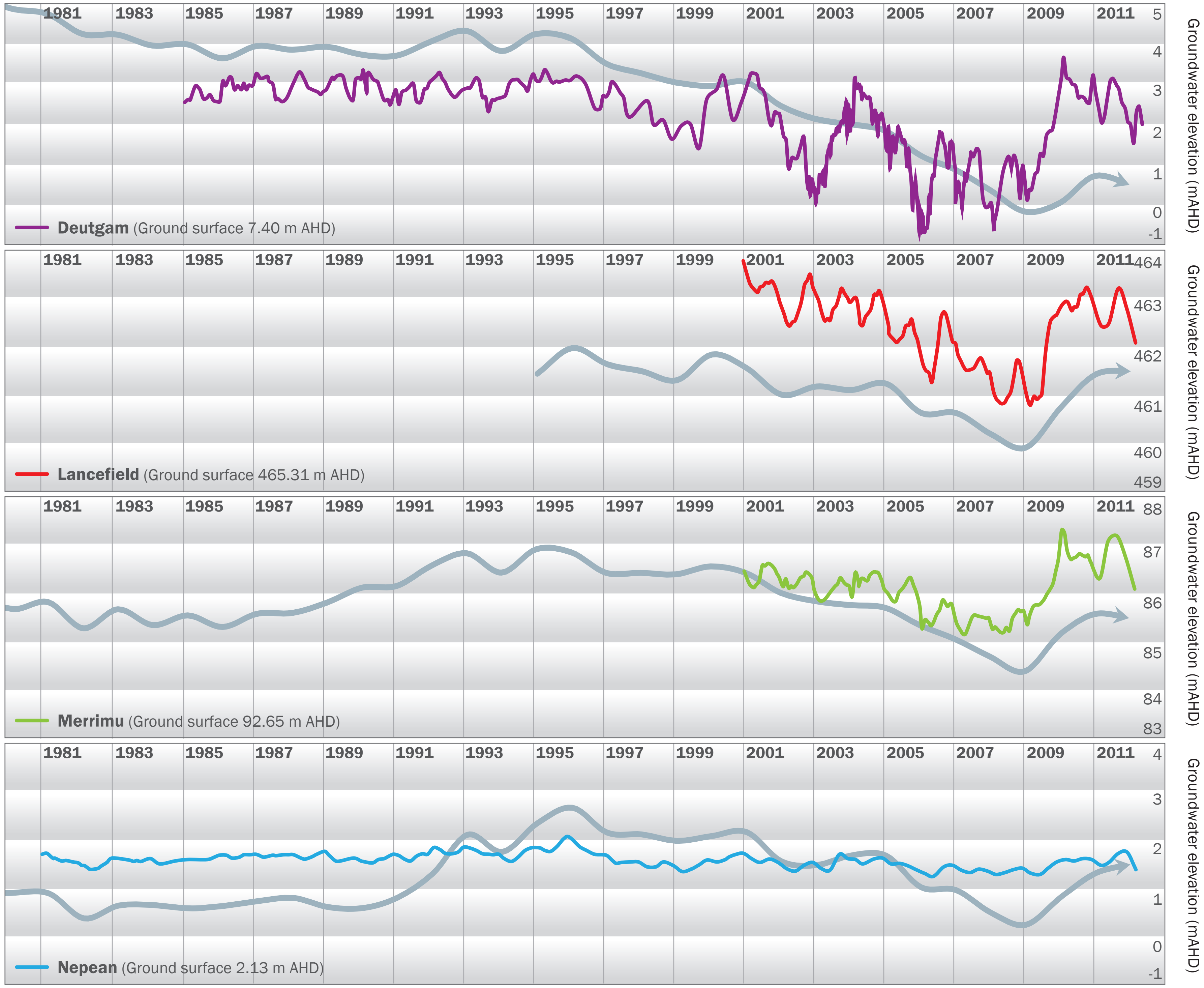
Adapted from: Parsons Brinckerhoff, 2010

Rainfall recharge through the sandy soils is high. However, it varies significantly from year to year and this affects discharge to rivers, wetlands and the ocean.

The Nepean Peninsula is densely populated and unsewered. Currently a large volume of mains water recharges groundwater through the pipe and septic systems. This influences the water balance. Sewering of the Peninsula is planned and groundwater recharge may be affected.

Southern Rural Water will continue to monitor pumping and groundwater levels to identify any changes early.

Regional trends



Groundwater levels and rainfall

The hydrographs above show groundwater levels (purple, red, green and yellow lines) relative to sea level in the upper aquifers at specific bore locations in the region. The level of the ground surface relative to sea level is also noted. The rainfall trend (grey line) is shown relative to the long-term average calculated since 1900. Where the rainfall trend line rises, rainfall is above the long-term average. Where the rainfall trend line falls, rainfall is below the long-term average. Where the rainfall trend line is flat, rainfall is equal to the long-term average.

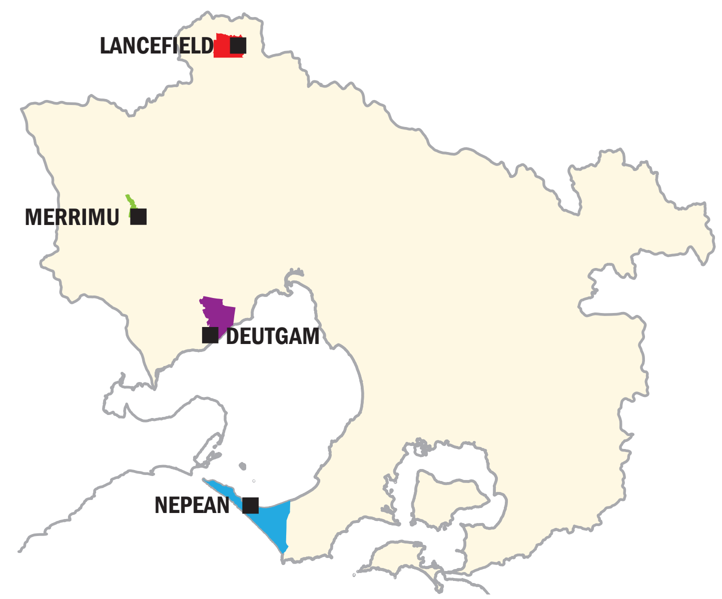
Note: mAHD = elevation in metres

Hydrographs from all monitored State Observation Bores can be found on the Southern Rural Water website www.srw.com.au.

Observations

- **Groundwater levels in these aquifers vary seasonally.**
- **The amount of seasonal fluctuation varies between bores and between GMUs.**
- **Groundwater level trends are fairly stable in all GMUs except Deutgam over the period of record keeping.**

Location of bores analysed in hydrographs at left



Rainfall trend

Deutgam GMU: Bore 59534 occurs in the recent sediments aquifer at the mouth of the Werribee River. Groundwater levels in this bore and across the GMU vary significantly and were below sea level in some bores at times during the millennium drought.

Lancefield GMU: Bore 144974 occurs in the shallowest part of the basalt aquifer in the eastern part of the GMU. Groundwater levels in this bore and across the GMU vary seasonally but the trend is fairly stable over the period of record keeping.

Merrimu GMU: Bore 144972 occurs in the recent sediments aquifer near the Werribee River. Groundwater levels in this bore and across the GMU vary seasonally but the trend is generally stable over the period of record keeping.

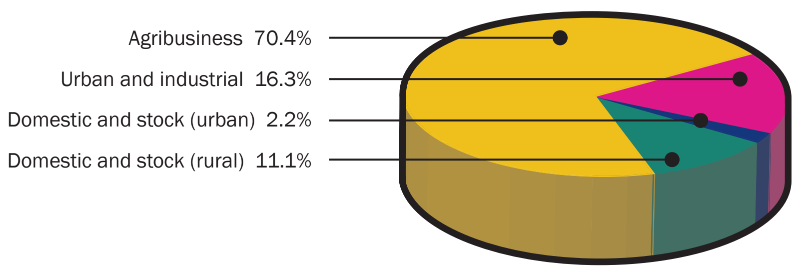
Nepean GMU: Bore 84892 occurs in the recent sediments aquifer close to Port Phillip Bay between Blairgowrie and Rye. While there is some seasonal fluctuation in this and other bores, the trend is fairly stable across the GMU since record keeping began in the 1980s.

Users and usage

Groundwater in the upper aquifers is best suited to agribusiness due to its yield and salinity. Agribusiness is the largest user group by volume throughout the region. These aquifers also interact closely with surface waterways and so the environment is also a significant user.

Most groundwater is licensed for agribusiness and industrial users (including sand and basalt quarries – 257 ML/yr total) (see pie graph below). There are also urban licences near Romsey and Lancefield.

Domestic and stock (D&S) users are not licensed but their estimated usage is shown. There are about 4,500 registered D&S bores in the upper aquifers (see map on page 24). Approximately 2,500 of these are in urban areas and estimated to use 0.2 ML/yr/bore (a total of 510 ML/yr). There are almost 2,000 D&S bores registered in rural areas. These are estimated to use 1.3 ML/bore/yr (a total of 2,600 ML/yr). The total D&S usage from the upper aquifers is therefore estimated to be approximately 3,000 ML/yr.



Breakdown of potential use in the upper aquifers

Deutgam, Lancefield, Merrimu and Nepean GMUs have most of the licence allocation with average volumes of 34 to 99 ML/yr (see table below).

Non-GMU areas account for almost half of the licences, mostly in the basalt plains north-west of Melbourne and along river valleys in the Yarra Ranges and Yarra Valley. However the concentration of licences is low.

GMU	Number of licences	Average licence size (ML/yr)	Largest licence (ML/yr)
Deutgam	143	34	204
Lancefield	13	105	294
Merrimu	10	34	65
Nepean	73	78	720
Non-GMUs	164	37	500

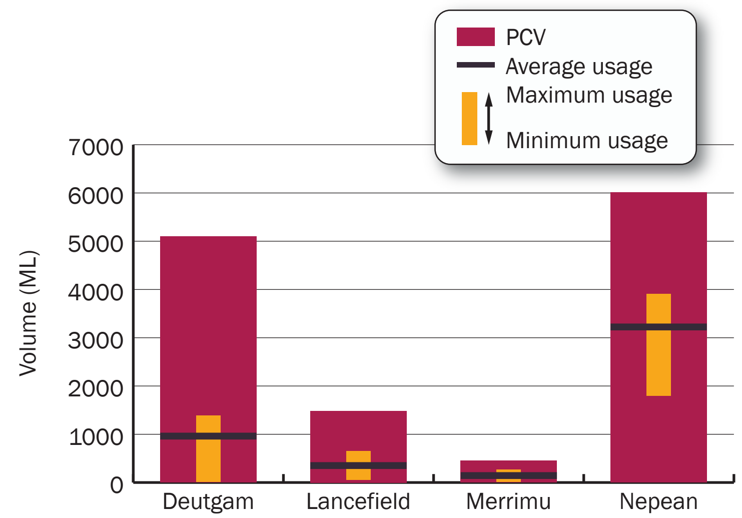
Licensed usage by GMU

The average licensed usage is approximately one third of total entitlements.

	PCV (ML/yr)	Entitlements (ML/yr)	Average licensed use (ML/yr)
Deutgam	5,100	5,082	978
Lancefield	1,485	1,378	336
Merrimu	451	440	126
Nepean	6,110	6,110	3,210
Non-GMUs	N/A	6,523	3,066
Total	**N/A**	**19,532**	**7,716**

Although there is a small difference between total entitlement and the PCV in some management areas, SRW have capped entitlement at current levels.

Average, minimum and maximum metered usage by GMU



Nepean GMU has the highest proportion of usage (53% of entitlements). Deutgam has the lowest (19%) but this is influenced by several years of groundwater restrictions. Lancefield and Merrimu GMUs use an average of 25% and 31% of their entitlements respectively. Average usage in non-GMU areas is 47%. Note: this data has been collected since 2003-04.

The environment

These aquifers interact strongly with surface water features and some vegetation relies on shallow water tables. Therefore use of groundwater by the environment is significant. However, it is not currently possible to quantify this usage. Groundwater use by plants from shallow water tables (evapotranspiration) varies depending on the plant type and climatic conditions (see also pages 18, 19 and 37).

Observations

- **Most groundwater is licensed for agribusiness users. Most bores are used for D&S purposes.**
- **Entitlement is capped in the upper aquifer GMUs.**
- **There is a substantial volume of unused entitlements that could be retained by licence holders as a backup during dry periods or traded to other users.**

Sustainable use

Because of their reliance on rainfall recharge and their small storage capacity and low yields, these aquifers drain rapidly during dry seasons and recover in the wet seasons. This occurred even during the millennium drought (see page 39). This suggests that the current level of use is sustainable with current rainfall patterns.

Deutgam GMU is the only area where groundwater restrictions have been enforced to minimise risk to the aquifer. The combined impact of the millennium drought and groundwater pumping caused groundwater levels to drop below sea level and this led to sea water intrusion (see page 36). Most licensed groundwater users have not experienced significant increases in salinity increases to date as most bores are shallow and distant from the river and coast. However, significant salinity increases have been observed in deeper bores along the coast and the Werribee River and sea water intrusion has been confirmed through detailed chemical analysis (DPI, 2011). Data collected since the millennium drought indicates that groundwater salinity along the Werribee River and coast has returned to normal as groundwater levels have recovered. Soil salinity is also monitored in this area.

Value

The economic value of groundwater in the upper aquifers is approximately $20 million/yr. Groundwater also has significant environmental, social and cultural value. Therefore groundwater reliability and security is very important for our wider community. More discussion about the value of groundwater can be found on page 30.

Future development

Entitlements in the upper aquifer GMUs are capped and new entitlements can only be obtained through trading. New entitlements may be available in some non-GMU areas, however a rigorous application process applies to protect the overall sustainability of the aquifers.

There is potential to develop unused entitlements (68%) provided that yield and salinity are adequate and that the impact on other users (including the environment) is acceptable. Licence holders value their unused entitlements to use during dry seasons or to expand their businesses.

Areas of the aquifers with poorer water quality but reasonable yield may be suitable for some uses after treatment.

Current and emerging issues

The upper aquifers are important sources of groundwater because they can be accessed quickly and cheaply. They also support deep-rooted vegetation and wetlands and provide stream baseflows, which is particularly important during dry periods. They are also subject to additional demand by domestic and stock (D&S) users when mains supply is restricted.

Regional issues

- Competition for groundwater resources
- Urban expansion
- D&S use
- Groundwater pollution, including sea water intrusion

Competition for groundwater resources

Because of the low storage and isolated nature of the upper aquifers (see pages 34 and 35) there is strong competition for groundwater resources from:

- The environment (discussion about the value of groundwater to the environment and other users can be found on page 30)
- The public
- Private economic interests such as agribusiness, quarries and other industrial users. More information about licensed entitlement for these activities is shown on page 40

Competition between users, including the environment, is managed by Southern Rural Water (SRW) in consultation with stakeholders through the Water Act and management plans or rules (see page 23).

Urban growth, environmental assets and quarries across the upper aquifer

The map above shows the extent of the upper aquifers, current and future urban boundaries for Melbourne, major rivers and wetlands which may be dependent on groundwater and quarries which may intercept groundwater.

Observations

- **There is strong competition for limited groundwater resources in these aquifers and management of this resource needs to take into account the strong relationship between rainfall, land use and groundwater use.**
- **Urban expansion can impact groundwater recharge and use.**
- **Upper aquifers are vulnerable to pollution, including sea water intrusion.**

Urban expansion

Where planned urban growth overlies the upper aquifers (see map below left) groundwater recharge may be affected (see also page 17). SRW is working with the Office of Living Victoria, Melbourne Water, urban water retailers, local councils and developers to identify urban growth areas which may impact on groundwater resources or Groundwater Dependent Ecosystems (GDEs) and put in place appropriate management measures. These may include enhanced stormwater recharge to aquifers. Changes in water supply policy may also lead to increased use of groundwater (see also pages 28 and 29). Also, areas at risk from soil and shallow groundwater salinity in urban growth areas also need to be considered (see links on page 63).

D&S use

There is uncertainty around the number of D&S bores that are used and the volume of groundwater that is extracted (see page 5). Registered D&S bores are highly concentrated in some areas (see map on page 24). Also applications for D&S bore construction rise dramatically during dry periods (see page 22), including in urban areas.

The impact of D&S use on the environment and other users can be estimated using data collected from SRW's monitoring bores (see page 25). D&S use can only be restricted by the Minister for Water not through local management plans or rules.

Groundwater pollution

Because they occur at the surface, upper aquifers are vulnerable to pollution from current and historical industrial sites, agricultural chemicals and septic tanks (see pages 26 and 27). Where groundwater use is concentrated in shallow aquifers close to the coast, sea water intrusion can also lead to salt pollution (see page 36).

If urban water authorities, Councils and the EPA determine that high concentrations of septic tanks pose a risk to human or environmental health, programs are put in place to build sewerage infrastructure such as on the Nepean Peninsula and in Warrandyte, Macedon, Nyora and Silverleaves on Phillip Island. The most significant of these programs is on the Nepean Peninsula where there are over 18,000 septic systems. Sewerage programs will improve groundwater quality for D&S and other users including the environment in these areas but may also reduce groundwater recharge (see page 38).

Chapter 5: Middle aquifers

Middle aquifers cover a large part of the Port Phillip and Western Port region. They are thickest near Koo Wee Rup and are mostly buried, except on the eastern edge of Port Phillip Bay where they occur at the surface. Where they are buried, recharge occurs from leakage through the overlying sediments. Where they occur at the surface, they receive recharge directly from rainfall.

Groundwater use is concentrated near Koo Wee Rup where salinity is low and yields are high. The main use in this area is agribusiness. There is also some use on the eastern edge of Port Phillip Bay for irrigation of green spaces. Domestic and stock (D&S) use is also extensive in these areas.

In this chapter you can find information on:

Aquifer geology

The middle aquifers in the region were formed between 4 million and 38 million years ago. They are mostly buried and confined by the upper aquifers. However, they occur at the surface and are unconfined on the eastern side of Port Phillip Bay. They are made up of several formations which are connected and act as one aquifer in each basin.

The basin boundaries are shown on page 14.

Port Phillip Basin

The middle aquifers in this basin are made up of the Moorabool Viaduct Formation, Batesford Limestone and Brighton Group. These aquifers are generally less than 50 metres thick and vary from fine sands and clay to coarse sand and gravel in some areas, as well as limestone (see also page 45). It is confined in the west. In the east where it is unconfined there is a concentration of licences.

Western Port Basin

The middle aquifer in this basin is known as the Western Port Group and is made up of the Baxter Sandstone, the Sherwood Formation and the Yallock Formation. It is confined by the upper aquifer and is over 150 metres thick to the south of Koo Wee Rup. Most of the licences are within the Koo Wee Rup GMU where the aquifer is thickest and relatively shallow (see maps below).

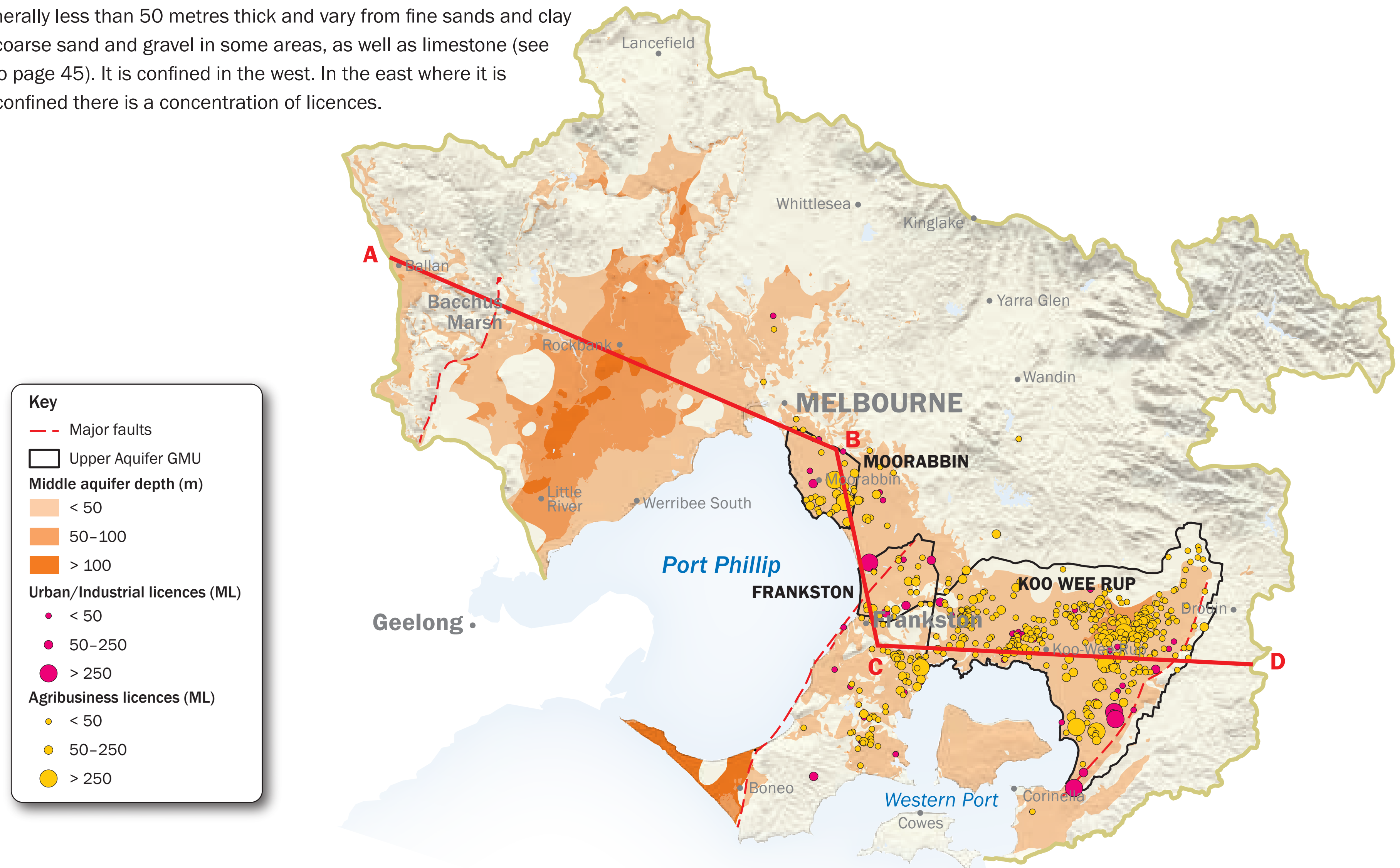
This aquifer varies from fine sand and clay in the upper western part of the basin to coarse sands, gravel, shells and limestone in the lower eastern part of the basin (see also page 45).

Middle aquitard

The middle aquifers are partially underlain by the middle aquitard (see cross-section below right and page 54). The aquitard is formed of mainly coal and silt.

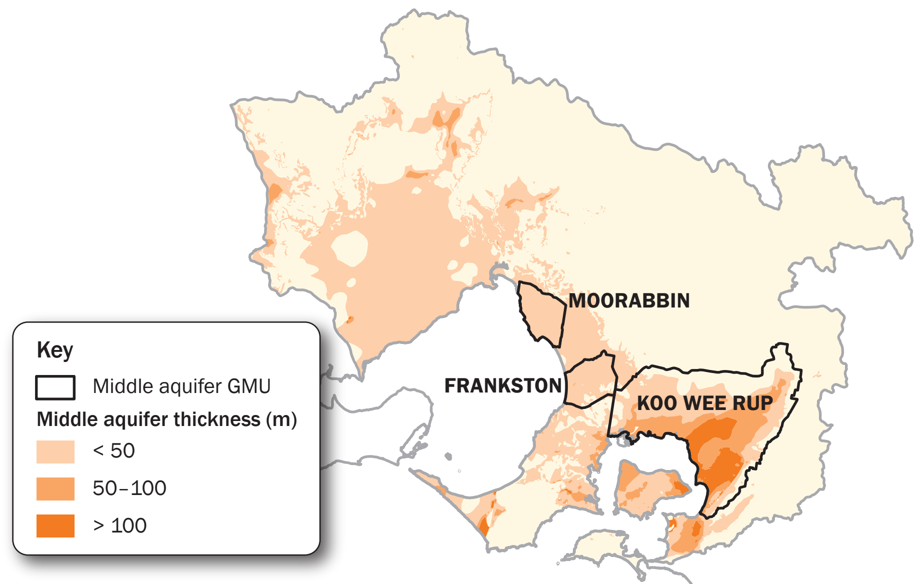
Observations

- These aquifers are buried and confined by the upper aquifers except on the eastern side of Port Phillip Bay.
- Most of the groundwater licences are concentrated in the Western Port Basin where these aquifers are thickest.
- These aquifers are mostly sand.



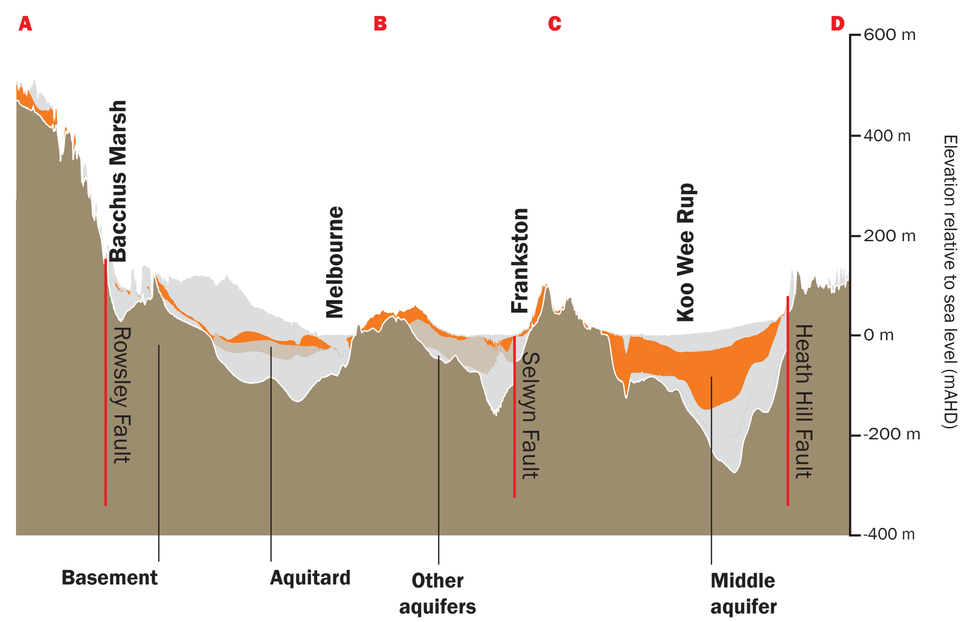
Middle aquifers: depth to the top of the aquifers and licences

This map shows where the middle aquifer occurs close to the surface (light orange shading) and where it is deeply buried (dark shading). Groundwater licences are shown by user group. Major faults are shown.



Thickness of the middle aquifer

This map shows where the middle aquifer is thin (light shading) and where it is thicker (dark shading).



Cross-section middle aquifer and aquitards

This diagram shows the cross-section **A-B-C-D** taken from map on left

Note: horizontal and vertical scales are different.

Salinity and yield

Groundwater use in the middle aquifers occurs mainly in areas with both high yield and low salinity. The best areas (those with the highest demand) are managed as GMUs. Groundwater salinity and yield depend on the soil and rock types as well as the aquifer thickness.

Where the aquifer material is **clay** or **silt** to the west of Melbourne and south of Frankston, groundwater moves slowly and picks up salt from the clay particles. In these areas salinity is high and yield is low.

The middle aquifer to the south-east of Melbourne is **sandy** with some **gravel** around Koo Wee Rup. In these areas, groundwater flows more quickly, is stored in greater volumes and picks up less salt as it moves. Therefore salinity is low and yield is high.

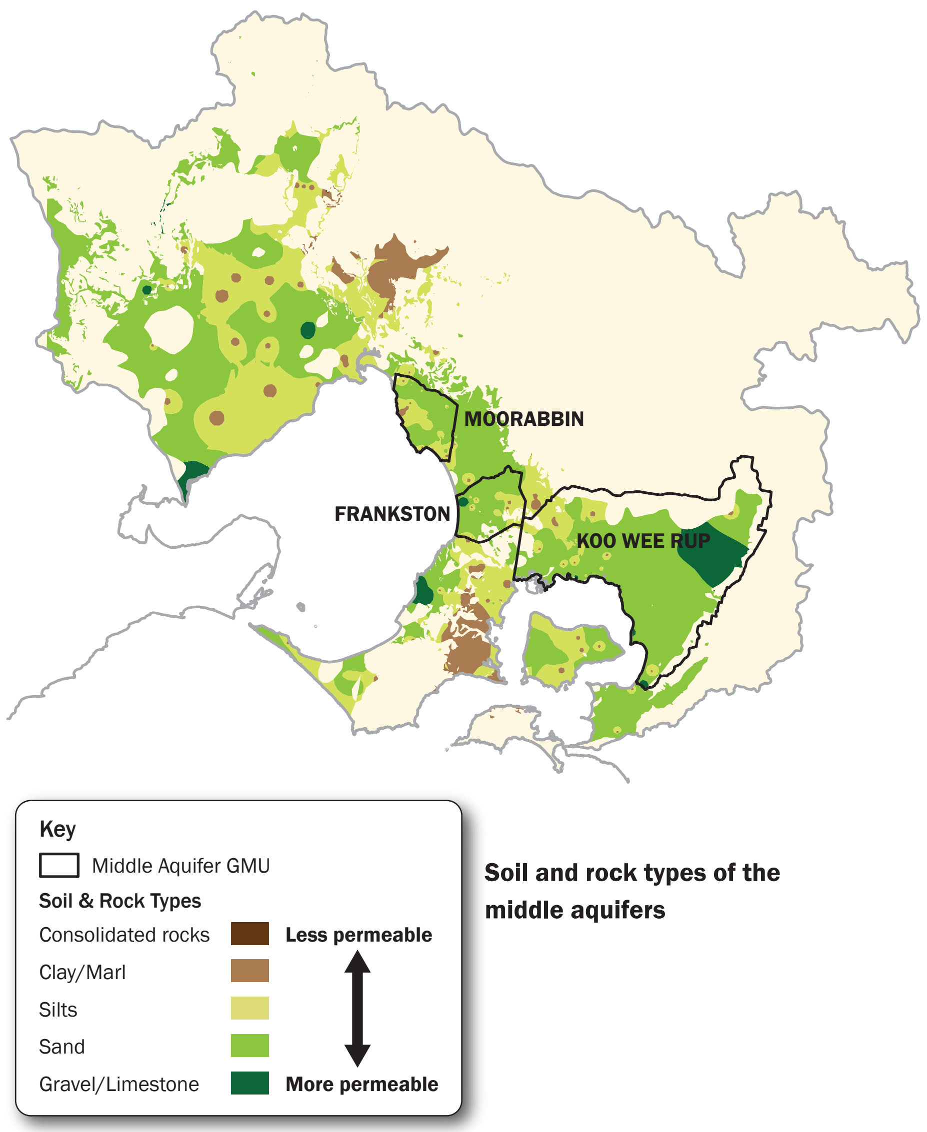
Although the middle aquifer is sandy to the west of Melbourne, it is thin and confined by the upper aquifers (see page 44) so salinity is high and yield is low.

The middle aquifer in the Koo Wee Rup GMU provides an important supply of high yielding, low salinity water for irrigation of farmland. Some irrigation also occurs in the Moorabbin and Frankston GMUs but yields are lower than around Koo Wee Rup. This is because the aquifers are thinner in the Port Phillip Basin than in the Western Port Basin (see page 44).

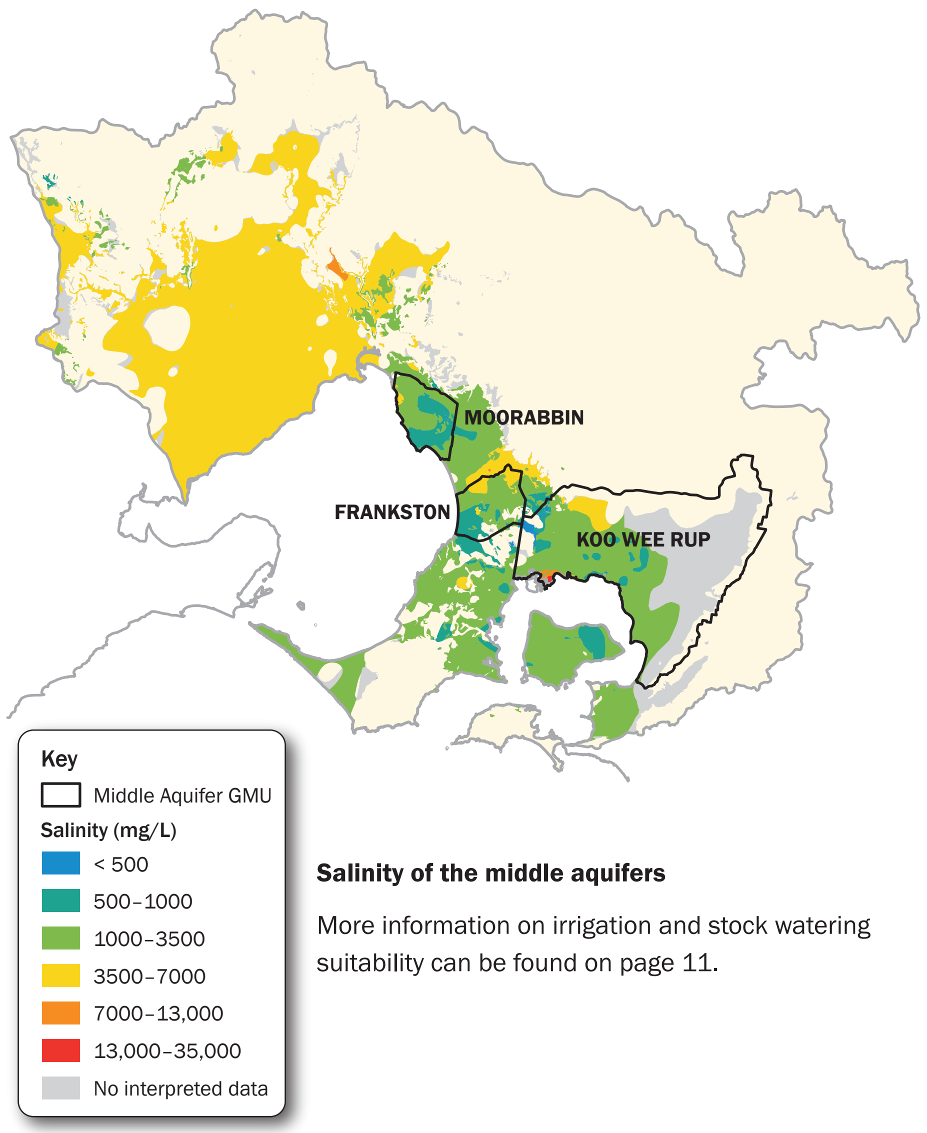
It is estimated that approximately 1,000 GL of fresh water (salinity less than 1,000 mg/L) is stored in the middle aquifers across the region.

Observations

- **Groundwater salinity is best south-east of Melbourne, and yield is best near Koo Wee Rup where the aquifer is thick.**
- **The best areas of these aquifers are managed as GMUs.**
- **Most groundwater use is concentrated in the GMUs.**

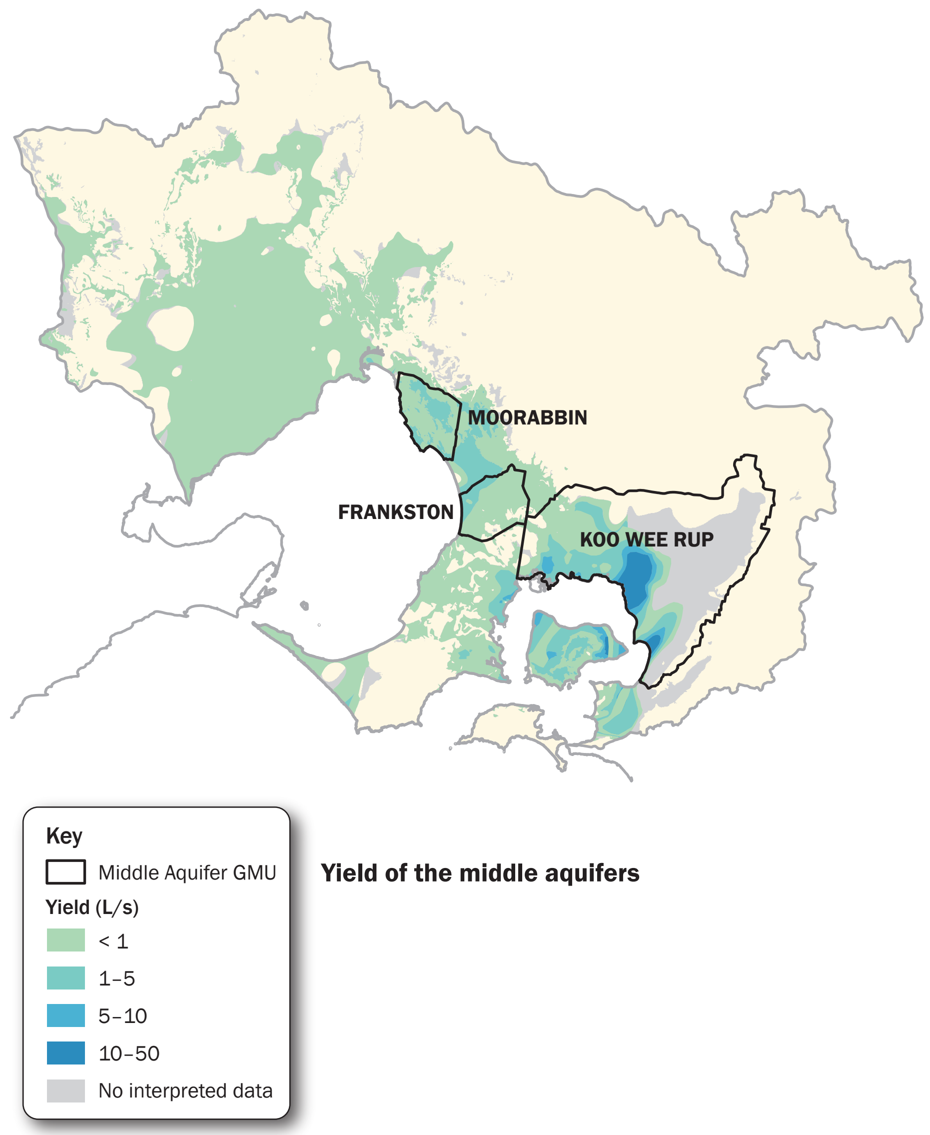


Soil and rock types of the middle aquifers



Salinity of the middle aquifers

More information on irrigation and stock watering suitability can be found on page 11.



Yield of the middle aquifers

Movement of groundwater

Groundwater in the middle aquifers moves mainly through large regional flow systems. Some local flow systems also exist where the middle aquifer occurs at the surface between Moorabbin and Frankston.

Groundwater flow

In the middle aquifers groundwater flow is mainly horizontal from high to low elevation. Vertical movement also occurs between the underlying and overlying formations, across fault lines and where there are no aquitards or clayey soils (see also pages 35 and 56). The natural direction of flow is from the basin margins where water enters the aquifers towards the bays.

The rate of flow in the regional systems is very slow. It may take groundwater thousands of years to travel tens of kilometres.

Recharge

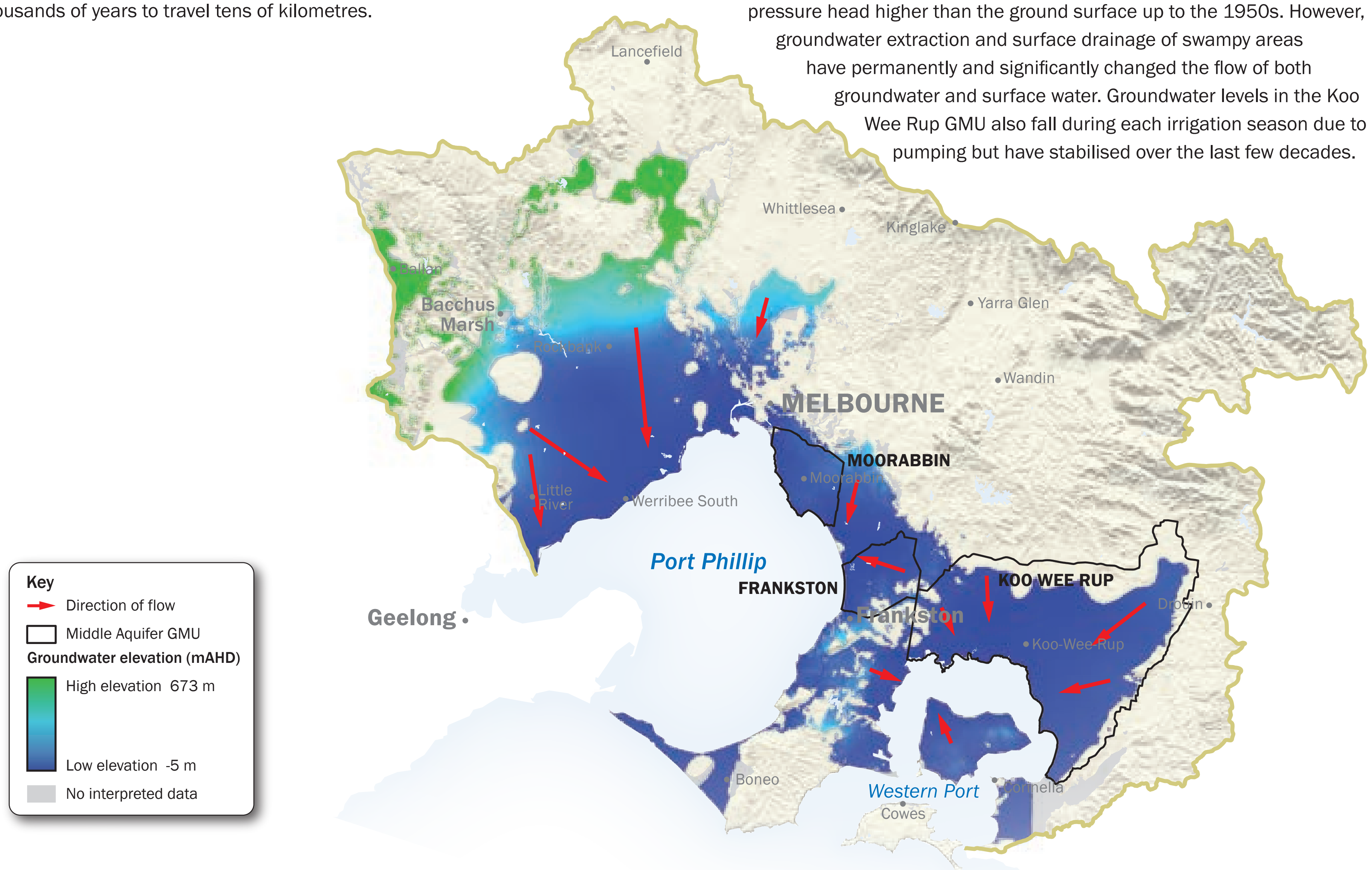
The middle aquifer outcrops between Moorabbin and Frankston. It is recharged directly from rainfall in this area.

In the Koo Wee Rup GMU and north-west of Melbourne, there are small areas where the middle aquifer outcrops and receives direct rainfall recharge. However, most of the aquifers in these areas are buried and receive recharge as leakage through the overlying aquifers.

Pressure

West of Melbourne, west of Boneo and within the Koo Wee Rup GMU, the middle aquifers are under pressure from the weight of overlying aquifers.

In the Koo Wee Rup GMU groundwater flowed freely from bores with a pressure head higher than the ground surface up to the 1950s. However, groundwater extraction and surface drainage of swampy areas have permanently and significantly changed the flow of both groundwater and surface water. Groundwater levels in the Koo Wee Rup GMU also fall during each irrigation season due to pumping but have stabilised over the last few decades.

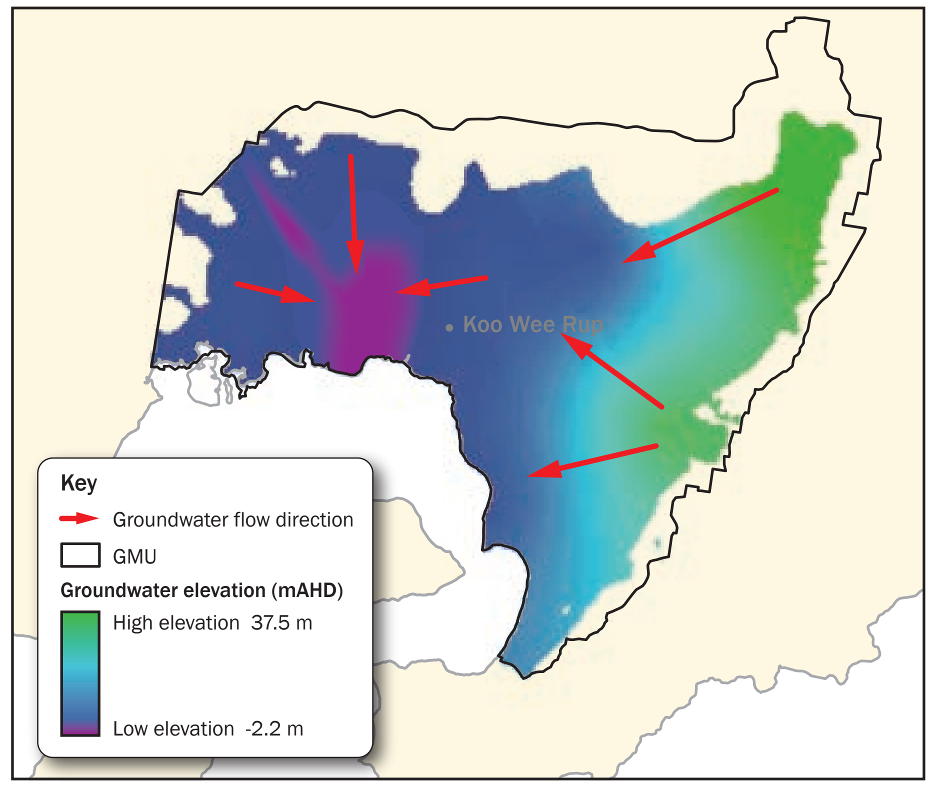


Groundwater elevation and flow direction in the middle aquifers

Groundwater flows towards the bays from areas of high elevation (green) to areas of low elevation (blue).

Observations

- Groundwater moves slowly in regional flow systems through the middle aquifers but some local flow systems also exist.
- Where these aquifers occur at the surface between Moorabbin and Boneo recharge occurs directly from rainfall.
- Where these aquifers are buried recharge occurs as leakage through upper aquifers.
- Significant loss of groundwater pressure occurred in the Koo Wee Rup GMU up to the 1950s but groundwater levels have now stabilised.



Groundwater elevation and flow direction in Koo Wee Rup GMU, October 2006

The overall direction of groundwater flow across this GMU is towards Western Port (from areas of green shading to areas of dark blue). However, in the area where use is concentrated, groundwater levels drop below sea level each irrigation season which affects the local groundwater flow direction (area shown in purple). There is not enough data to show whether seasonal behaviour in the middle aquifers also affects the overlying upper aquifers.

Environmental dependence

Across most of the region, interaction between the middle aquifers and surface ecosystems is limited by the overlying upper aquifers. Where the aquifer occurs at or close to the surface there is more potential for interaction.

The examples on this page make the most of the few detailed studies available to show different ways in which groundwater from the middle aquifers interact with surface ecosystems. Information is provided in general terms only. Further general information and maps on the region's potential Groundwater Dependent Ecosystems (GDEs) can be found on pages 18 and 19.

Streams and wetlands

The middle aquifers are buried by the upper aquifers across most of the region (see page 34) but they occur at or close to the surface between Moorabbin and Boneo (see page 44).

Groundwater from the middle aquifers may interact with streams and wetlands between Moorabbin and Boneo, however available data is limited. One study estimated that the total groundwater discharge to streams and wetlands in these areas is 33,000 ML/yr (Parsons Brinckerhoff, 2010).

The Ramsar-listed Edithvale and Seaford wetlands are potential GDEs. They may be supported by groundwater from the middle aquifers discharging through the overlying upper aquifers (see diagram below).

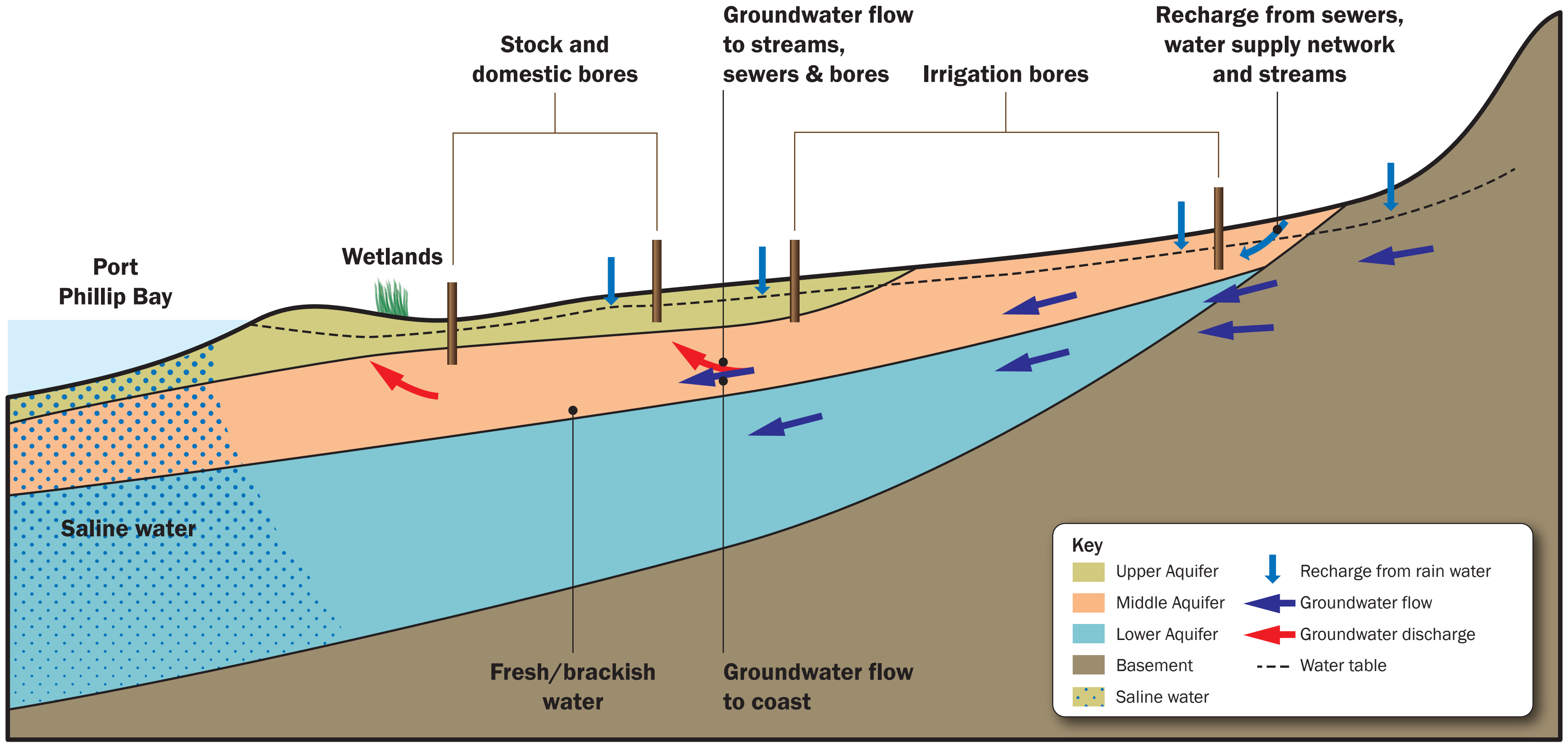
Bays

There is potential for sea water from the bays to enter the middle aquifers if pressure falls below sea level (see also page 36). To protect against this groundwater salinity is monitored in the Moorabbin and Koo Wee Rup GMUs. No sea water intrusion has been detected to date.

The Ramsar-listed sea grass beds in Western Port are potential GDEs, however the flow of groundwater into and under Western Port is poorly understood. Further research is being conducted.

Observations

- **Where these aquifers occur at or close to the surface, there is the greatest potential for groundwater interaction with surface environments.**
- **Where these aquifers are buried, there is limited potential for groundwater interaction with surface environments.**
- **These aquifers may interact with the Edithvale and Seaford wetlands and with Western Port however this is poorly understood and more research is needed.**
- **Interaction with other aquifers is greatest in the Koo Wee Rup GMU.**



Environmental dependence on the middle aquifer — Frankston area

Source: Parsons Brinckerhoff, 2010

Interaction with other aquifers

The middle aquifers are semi-confined or confined where the overlying shallow aquifers are silt or clay. In these areas they receive recharge via leakage through the upper units. Downward leakage is greater where the overlying soils are sandy or gravelly such as in the south-eastern part of the Koo Wee Rup GMU (see page 35).

In the Koo Wee Rup GMU, groundwater pressure in the middle aquifer may be higher than in the overlying shallow aquifers and so upward leakage may also occur. There may also be leakage between the middle and lower aquifers in both directions. Vertical groundwater flow is greater where there is no aquitard between aquifers (see page 56). In the Koo Wee Rup GMU, the middle and lower aquifers act as one unit because there is no aquitard between them.

5 Middle aquifers

Water balance

The most significant parts of the middle aquifers occur along the eastern shore of Port Phillip Bay and around Western Port Bay.

It is for these parts of the middle aquifers only that detailed water balance studies have been completed.

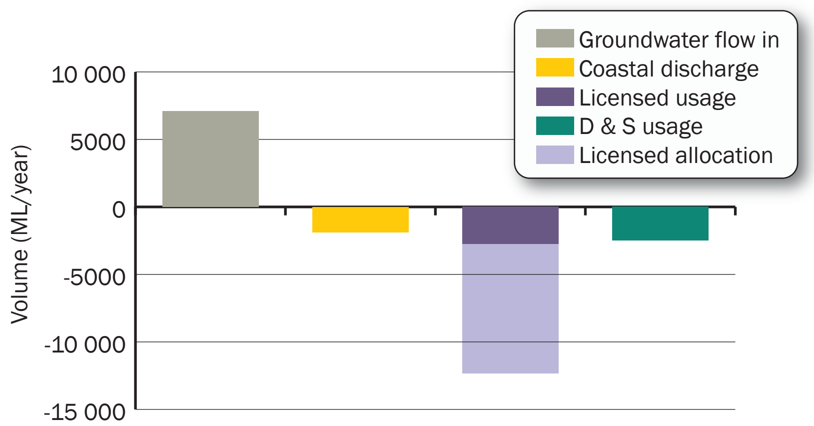
Further general information on water balances can be found on page 17.

One of the major factors affecting the water balance in the middle aquifers is recharge via downward leakage from the overlying aquifers as they receive little direct rainfall recharge. Other major factors are pumping and discharge to coastal wetlands or off the coast.

Western Port Basin

Downward leakage (recharge) from the overlying units is likely to be highest in the sandy soils on the eastern side of the basin (see also page 34). As there is no significant aquitard between the middle and lower aquifers in this basin (see page 56) there is also leakage (discharge) to the underlying units.

The graph below shows the estimated water balance for the middle aquifers of the Koo Wee Rup GMU. It shows that groundwater pumping and coastal discharge from the middle aquifers are balanced by recharge from leakage through the overlying units and groundwater stored in the middle aquifers. If all licensed groundwater allocations were extracted, the water balance would be negative and groundwater levels would probably drop.



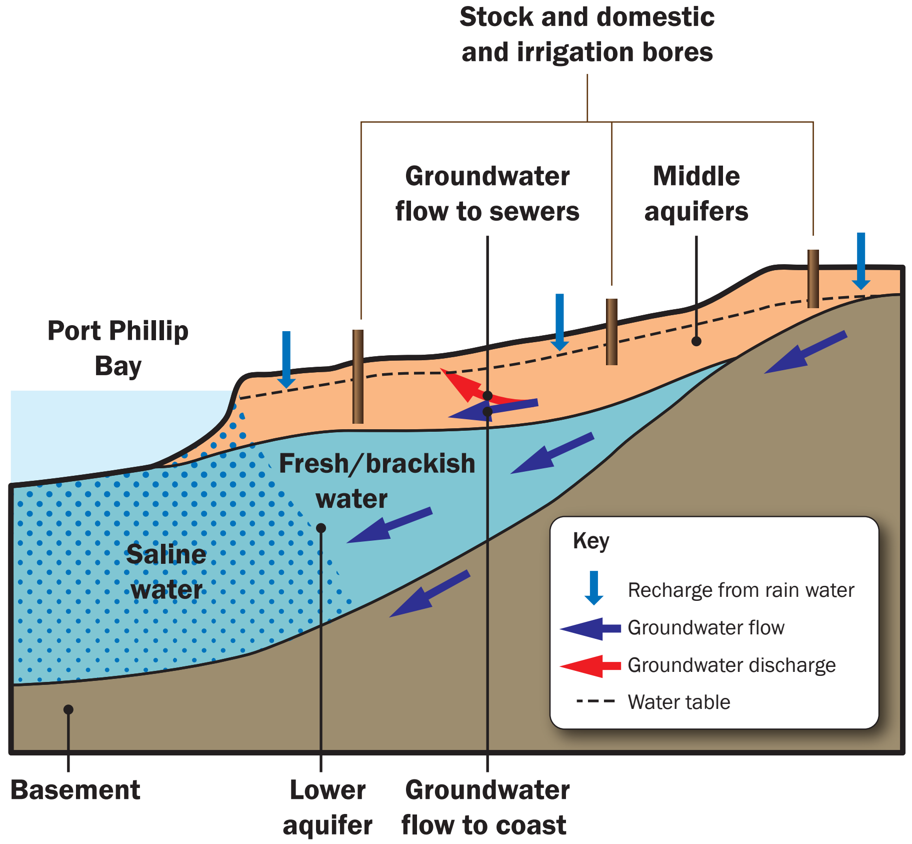
Adapted from: SKM, 2001

Port Phillip Basin

Between Moorabbin and Boneo, south-east of Melbourne along the eastern shore of Port Phillip Bay, the middle aquifers occur at or close to the surface (see also page 44). They are dominated by the Brighton Group and include the Frankston and Moorabbin GMUs.

The cross-section below shows water movement into and out of the middle aquifer in the Moorabbin area. This is similar for all areas between Moorabbin and Boneo except around Frankston where the middle aquifer is partly buried by the upper aquifer (see also pages 34 and 47). Recharge is mainly from rainfall through the sandy soils (see also page 45).

Conceptual cross-section of the Moorabbin study area

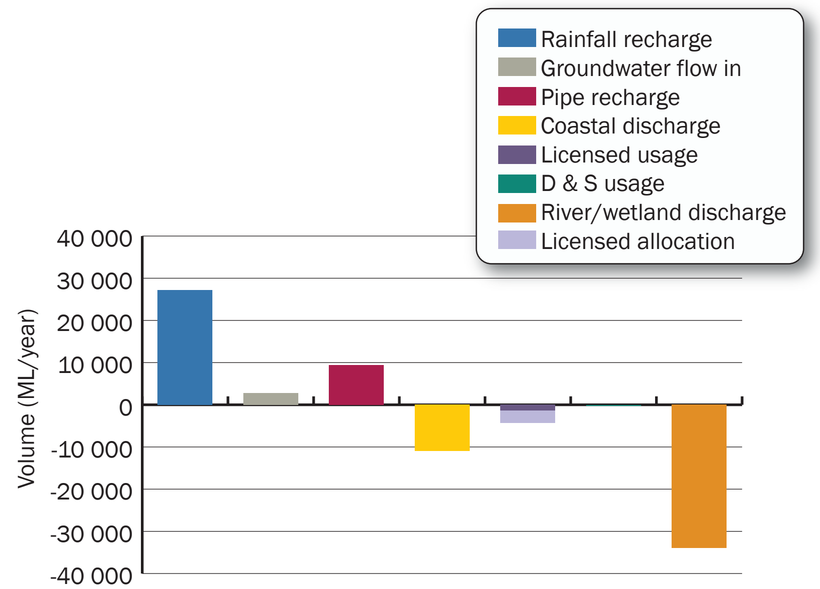


Source: Parsons Brinckerhoff, 2010

Observations

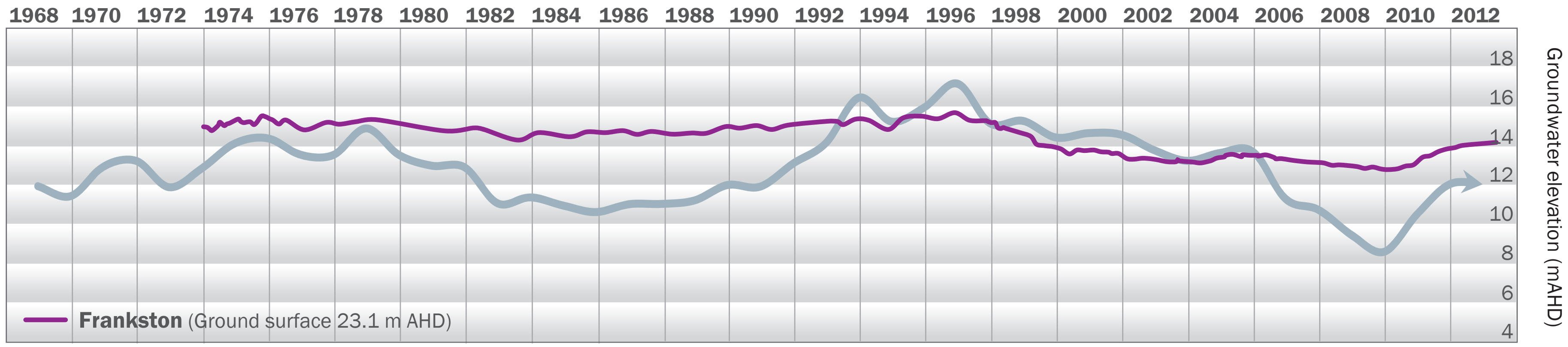
- **In the Western Port Basin, the main factors affecting the water balance are recharge via leakage from the overlying units and discharge via pumping.**
- **In the Port Phillip Basin, the main factors affecting the water balance are recharge directly from rainfall and discharge to rivers, wetlands and offshore.**

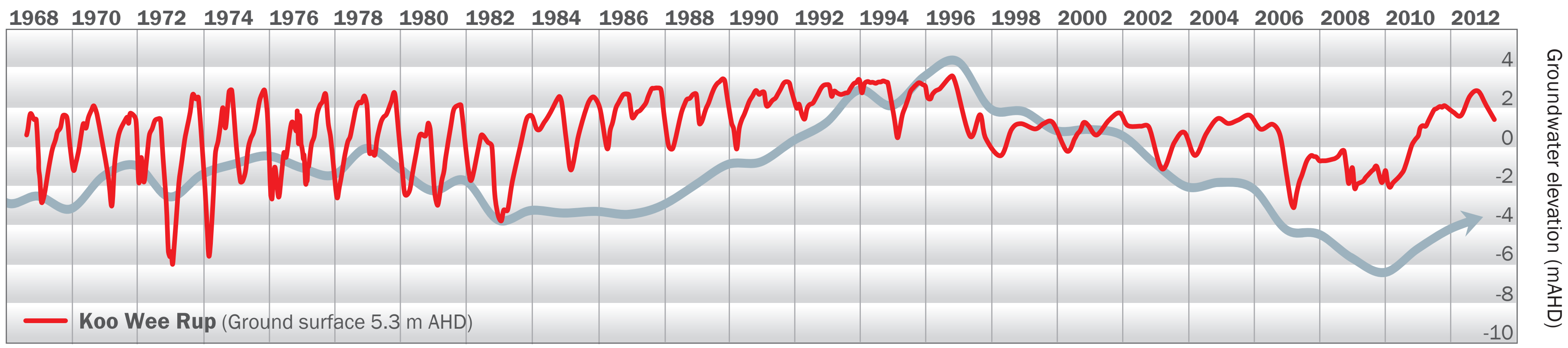
The graph below shows the estimated major inputs and outputs to the Brighton Group middle aquifer between Moorabbin and Boneo. Recharge from rainfall is estimated after evapotranspiration. Groundwater allocation and use is low so discharge is mainly to rivers and wetlands and offshore.

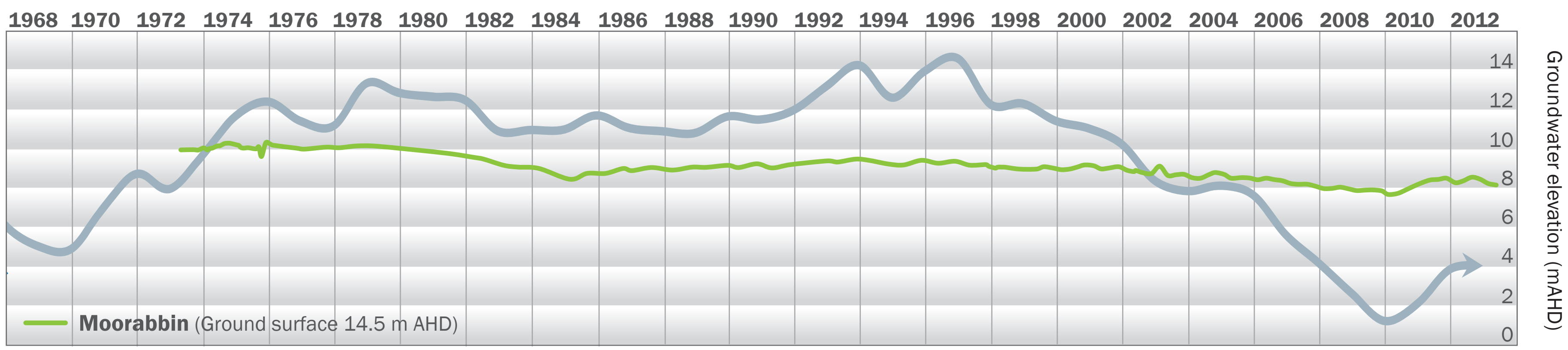


Adapted from: Parsons Brinckerhoff, 2010

Regional trends







Groundwater levels and rainfall

The hydrographs above show groundwater levels (purple, red, green and yellow lines) relative to sea level in the middle aquifers at specific bore locations in the region. The level of the ground surface relative to sea level is also noted. The rainfall trend (grey line) is shown relative to the long-term average calculated since 1900. Where the rainfall trend line rises, rainfall is above the long-term average. Where the rainfall trend line falls, rainfall is below the long-term average. Where the rainfall trend line is flat, rainfall is equal to the long-term average.

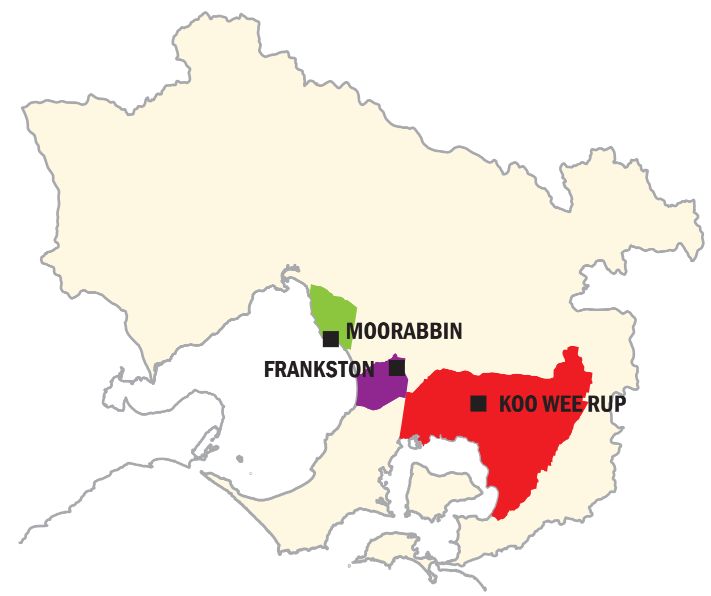
Note: mAHD = elevation in metres

Hydrographs from all monitored State Observation Bores can be found on the Southern Rural Water website www.srw.com.au.

Observations

- **Some seasonal fluctuation occurs in all GMUs.**
- **Seasonal fluctuation of groundwater levels is greatest in the Koo Wee Rup GMU where the middle aquifer is confined.**
- **Groundwater level trends are generally stable over the period of record keeping.**

Location of bores analysed in hydrographs at left



Rainfall trend

Frankston GMU: Bore 62949 occurs inland in the north-eastern part of the GMU. In this bore and across the GMU there is some seasonal fluctuation but the trend is stable over the long-term.

Koo Wee Rup GMU: Bore 71184 occurs in the centre of the GMU where the middle aquifer is confined. There is significant seasonal fluctuation in the area where extraction is concentrated (see page 46). However, across the entire GMU, seasonal fluctuation has lessened and levels have stabilised overall in recent decades. The trend is therefore stable over the period of record keeping.

Moorabbin GMU: Bore 80245 occurs near the coast in the southern part of the GMU. In this bore and across the GMU there is some seasonal fluctuation and the trend is an overall decline of about 1 metre.

Users and usage

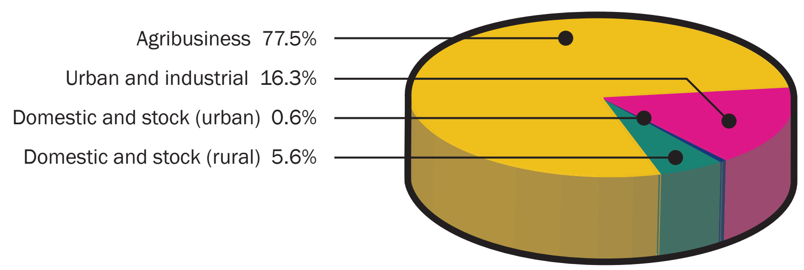
Groundwater in the middle aquifers is attractive to users in the Koo Wee Rup GMU and on the eastern side of Port Phillip Bay because of its high yield, relatively shallow depth and suitability for most uses. Most use occurs in these areas.

Users

As in the upper aquifers, agribusiness users hold most of the licensed volume in the middle aquifers. Most of the licensed volume is in the Koo Wee Rup GMU (see also page 44).

Urban and industrial users also account for a significant proportion of entitlement. This group includes quarries with a total entitlement of 2,184 ML/yr.

Domestic and stock (D&S) users are not licensed but their estimated usage is shown. There are just over 1,600 registered D&S bores in the middle aquifers (see map on page 24). Approximately 650 of these are in urban areas and estimated to use 0.2 ML/yr/bore (a total of 130 ML/yr). There are approximately 950 D&S bores registered in rural areas. These are estimated to use 1.3 ML/bore/yr (a total of almost 1,250 ML/yr). The total D&S usage from the middle aquifers is therefore estimated to be approximately 1,380 ML/yr.



Breakdown of potential groundwater use in the middle aquifers

GMU	Number of licences	Average licence size (ML/yr)	Largest licence (ML/yr)
Frankston	23	70	400
Moorabbin	30	69	312
Koo Wee Rup	362	34	986
Non-GMU	100	35	350

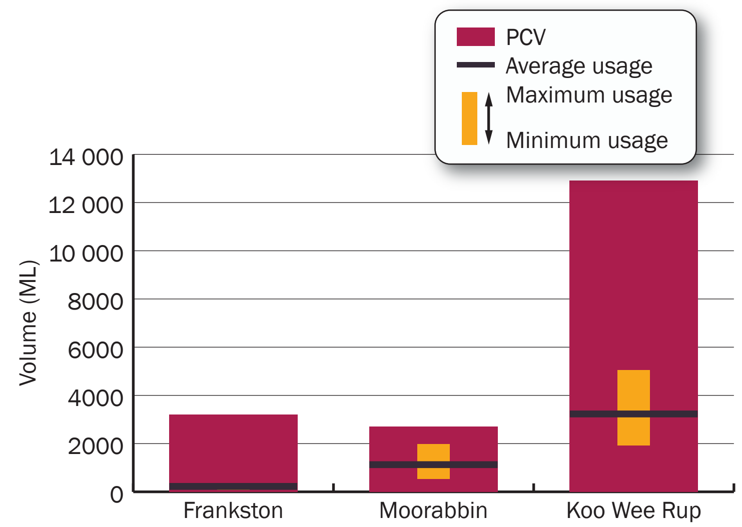
Licensed usage by GMU

Average total usage is 28% of total entitlements.

	PCV (ML/yr)	Entitlements (ML/yr)	Average licensed usage (ML/yr)
Frankston	3,200	1,671	186
Moorabbin	2,700	2,614	1,143
Koo Wee Rup	12,915	12,612	3,328
Non-GMU	N/A	3,491	977
Total	**N/A**	**20,388**	**5,634**

Although there is a difference between the volume of entitlements and the Permissive Consumptive Volume (PCV) in some GMUs, entitlement has been capped based on the findings of several technical studies. New aquifer-based planning is under way and limited entitlements may be available in specific aquifers or GMUs once this is complete.

Average, minimum and maximum metered usage by GMU



Average usage across the GMUs is highest in the Koo Wee Rup GMU where users rely heavily on groundwater for irrigation of crops. However it is still relatively low at 25% of total entitlements. The maximum and average usage shown for the Koo Wee Rup GMU is similar to usage over the whole period of record keeping dating from the 1970s.

Note: this data has been collected since 2003-04

The environment

The middle aquifers are unconfined between Moorabbin and Boneo and the discharge volume to coastal waterways and wetlands has been estimated at 33,000 ML/yr (see page 47). Where these aquifers are confined across all other areas of the region interaction with surface environments is very low.

Observations

- **Agribusiness is the largest user group by volume but most registered bores are for D&S use.**
- **Entitlement is capped in the middle aquifer GMUs.**
- **There is a substantial volume of unused entitlements that could be retained by licence holders as a backup during dry periods or traded to other users.**
- **Any significant increase in usage of unused entitlements in some GMUs may require additional management to ensure sustainable usage.**

Sustainable use

In the Koo Wee Rup GMU a massive increase in groundwater use in the 1950s and 1960s led to loss of natural artesian pressures. As a result groundwater licensing was introduced and entitlements were reduced by the State Government in an effort to stabilise groundwater levels and ensure that extraction was sustainable (see also page 22). Current groundwater levels remain lower than they were prior to the 1950s but have stabilised over the long-term (see page 47). Monitoring data shows that a seasonal cone of depression develops each year in the centre of the GMU where usage is concentrated (see page 46).

Licensed usage is much lower than the volume of entitlements, however D&S usage is estimated to be significant. If usage rises additional measures may be required to manage the potential impact on other groundwater users and the environment.

Less data is available for the Port Phillip Basin than the Koo Wee Rup GMU. There are no indications so far that current levels of use in this area are unsustainable.

Value

The economic value of groundwater in the middle aquifers is approximately $21 million. Groundwater also has significant environmental, social and cultural value. Therefore groundwater reliability and security is very important for our wider community. More discussion about the value of groundwater can be found on page 30.

Future development

Although entitlements in most of the middle aquifers are now capped, there is a great deal of potential to develop the unused proportion of entitlements (72%). However, the data indicates that widespread activation of the unused entitlements in the Koo Wee Rup GMU may require additional management.

Current and emerging issues

The middle aquifers are important sources of groundwater because they support a variety of users, including the environment in a number of areas. They are also subject to additional demand by domestic and stock (D&S) users during dry periods.

Regional issues

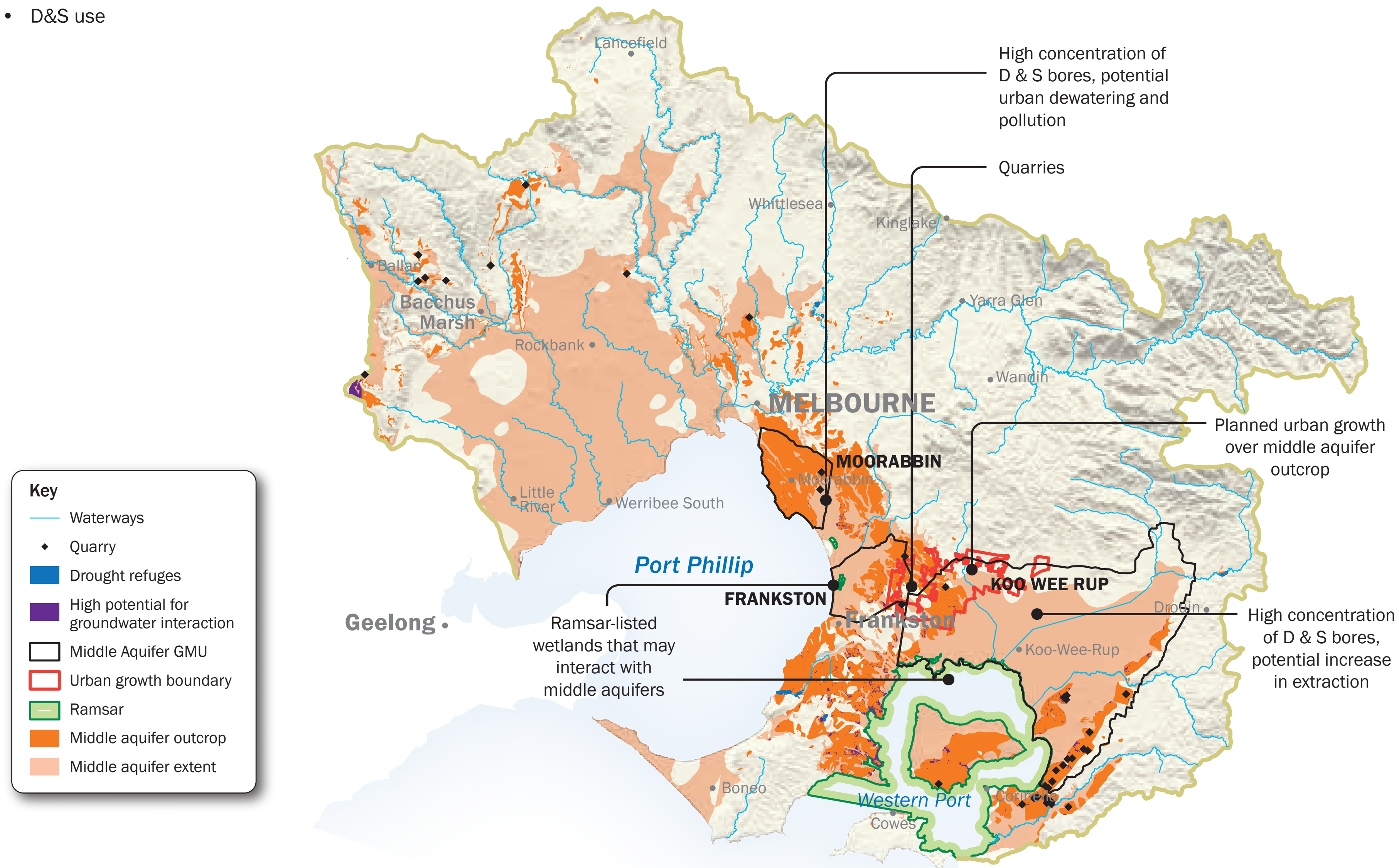
- Potential for increased groundwater extraction
- Dewatering for urban developments and quarries
- Urban expansion
- Groundwater pollution, including sea water intrusion
- D&S use

Increased groundwater extraction

There is significant potential for increased extraction from existing entitlements in the Koo Wee Rup GMU (see also page 50). Southern Rural Water (SRW) will continue to monitor groundwater levels and usage to identify any potential issues early that may require additional management (see also pages 42 and 48).

Dewatering

Where the water table is shallow groundwater extraction may be required for quarry operations or urban development (see also page 28). Quarries exist across the middle aquifers and their licensed entitlement is shown on page 50. Underground urban development is particularly relevant to the middle aquifer between Melbourne and Frankston.



Urban growth, environmental assets and quarries across the middle aquifers

The map above shows the extent of the middle aquifers including where they outcrop (they may be affected by planned urban growth or interact with rivers and wetlands) and quarries which may intercept groundwater from the middle aquifers.

Observations

- **Any increase in usage of existing unused entitlements may need to be managed.**
- **Dewatering for urban development and quarry operation may be significant in some areas.**
- **Urban expansion and pollution may impact these aquifers.**

Urban expansion

Densely populated urban areas can impact groundwater (see also page 17). SRW is working with the Office of Living Victoria, Melbourne Water, urban water retailers, local councils and developers to ensure that groundwater resources and Groundwater Dependent Ecosystems (GDEs) are protected as the urban area expands (see also pages 28 and 29). It is important to consider areas at risk from soil and shallow groundwater salinity in urban growth areas (see links on page 63).

Planned urban growth west of the Koo Wee Rup GMU may impact the recharge area in these aquifers (see map at left). SRW has identified this potential threat and has initiated research in partnership with RMIT and Melbourne Water.

Groundwater pollution

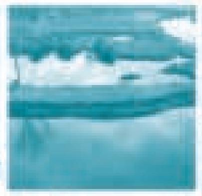
The middle aquifers occur at the surface between Melbourne and Dromana and are vulnerable to pollution from current and historical industrial sites as well as from chemicals including fertilisers (see also pages 26 and 27). Where groundwater use is concentrated in shallow aquifers close to the coast, sea water intrusion can lead to salt pollution (see page 36).

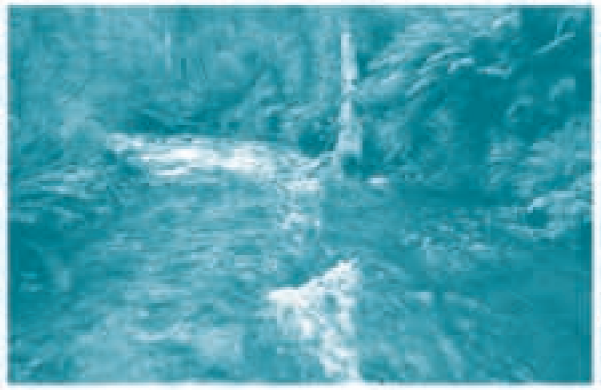
D&S use

There is uncertainty around the number of D&S bores that are used and the volume of groundwater that is extracted (see page 5). Registered D&S bores are highly concentrated in some areas (see map on page 24). Also applications for D&S bore construction increase dramatically during dry periods (see page 22) including in urban areas.

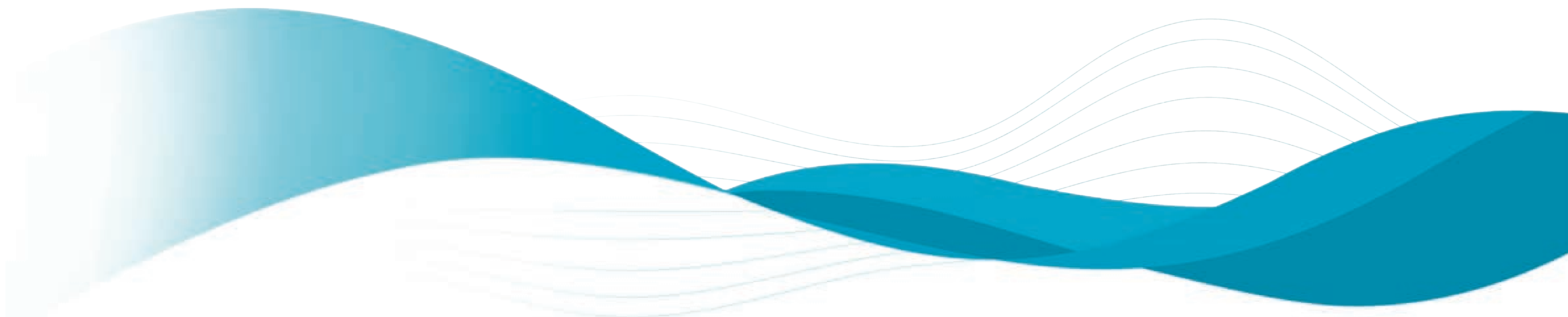
The impacts of D&S use on the environment and other users can be estimated using data collected from SRW's monitoring bores (see page 25). D&S use can only be restricted by the Minister for Water not through local management plans or rules.









Chapter 6: Lower aquifers and basement

Lower aquifers extend across the region and are formed by sand, sandstone and basalt. They occur at or close to the surface in a small number of areas and are very deep along the coast. Basement rocks occur at the surface in the highlands and are buried under the lower aquifers along the coast. Recharge occurs directly from rainfall where the lower aquifers and basement occur at the surface and by downward leakage where they are buried. Discharge occurs offshore into Bass Strait.

The lower aquifers are used for agribusiness, to supplement town supplies on Phillip Island and for industrial purposes. Although the basement acts mainly as an aquitard, it provides significant baseflows to streams in the highlands. It has sufficient yield and quality to support a number of agribusiness and industrial users and is an important water supply for rural domestic and stock (D&S) users.

In this chapter you can find information on:

Aquifer geology

The lower aquifers in the region were formed between 19 and 65 million years ago. They are overlain by the upper and middle aquifers and aquitards and are underlain by the basement which was formed between 65 and 545 million years ago.

Werribee and Childers Formations

The most widespread formation of the lower aquifers is the Werribee Formation. It is mainly sand and has clay and coal layers within it that act as aquitards. It occurs at the surface near Bacchus Marsh but is mostly buried deeply. It is thickest south-west of Melbourne and on the Nepean Peninsula and is very thin between Moorabbin and Frankston.

The Childers Formation exists within the Western Port Basin. It is mainly sand with some coal and is deeply buried.

Licences are concentrated where the lower aquifers are shallow near Bacchus Marsh and Boneo.

Older Volcanics

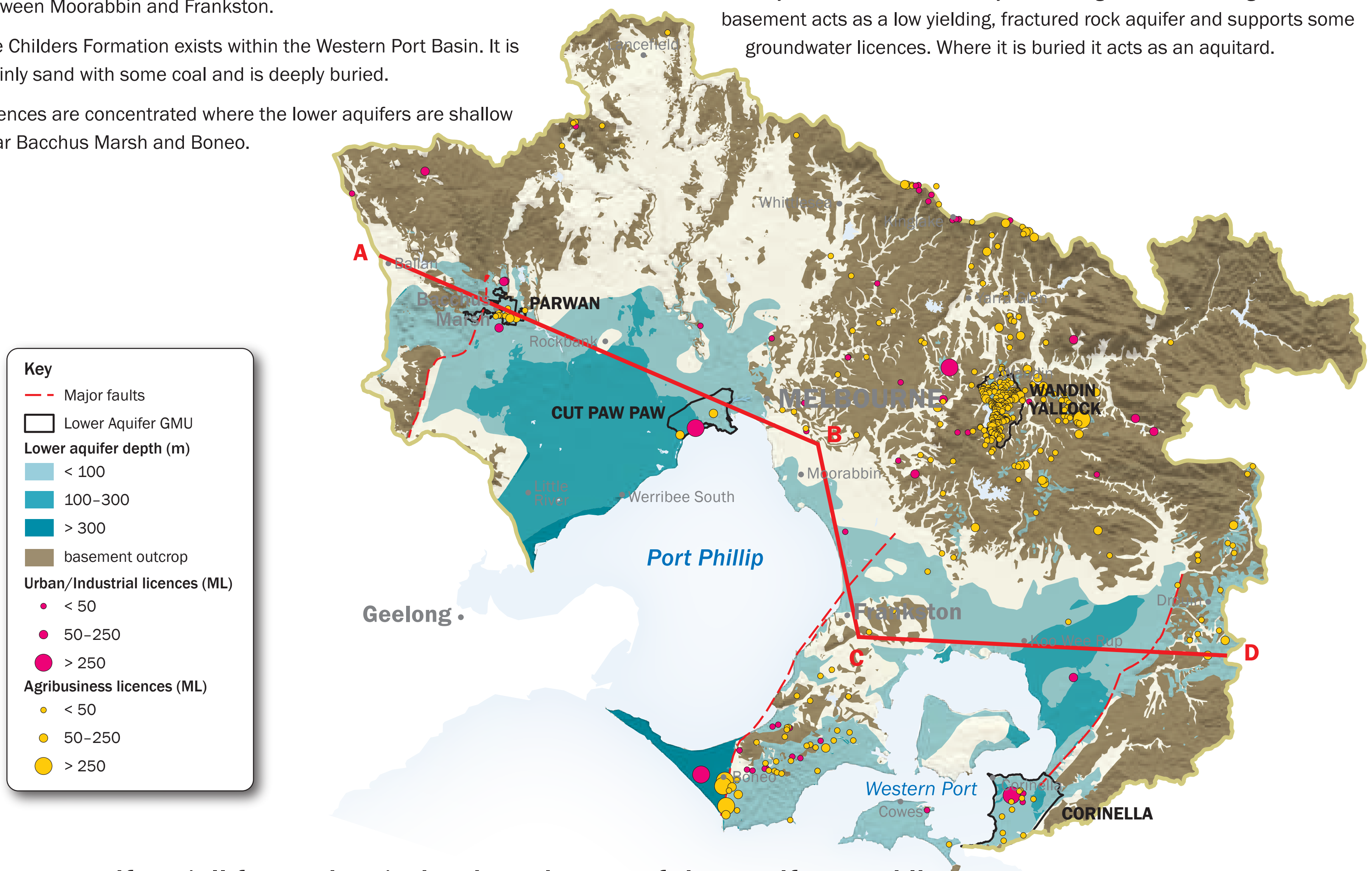
The fractured basalt Older Volcanics aquifers occur in scattered highland areas and beneath the Childers Formation in the Western Port Basin (see map below right). Groundwater does not flow between the separated areas of these aquifers. Where the aquifers occur at or near the surface they receive direct recharge from rainfall. This aquifer is mainly used for groundwater supply near Wandin.

Basement

The basement occurs at the surface around the basin margins, forming the Great Dividing Range, Mornington Peninsula Highlands and Strzelecki Ranges. It is mainly siltstone, sandstone, claystone and granite. In the ranges the basement acts as a low yielding, fractured rock aquifer and supports some groundwater licences. Where it is buried it acts as an aquitard.

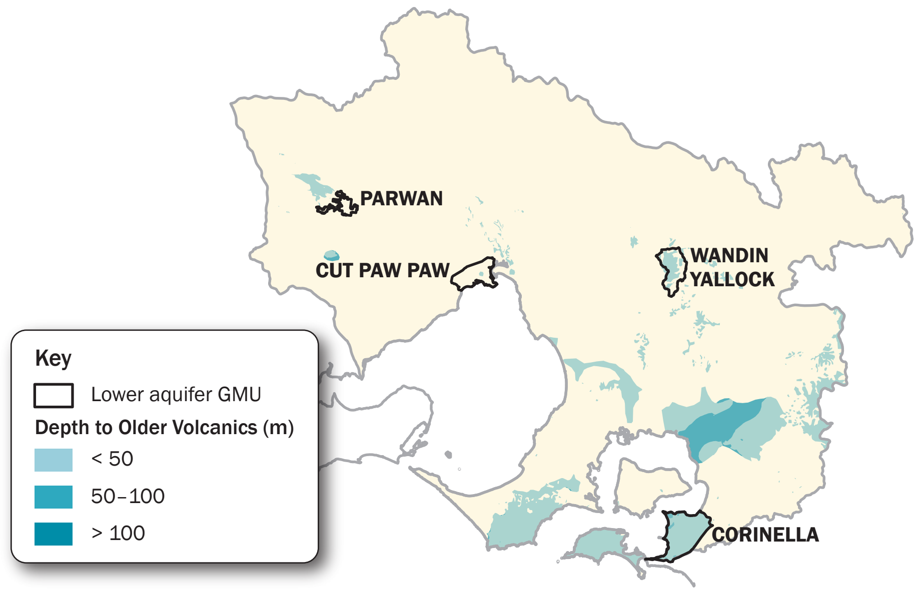
Observations

- The lower aquifers occur at the surface in only in small areas. The basement occurs at the surface around the basin margins.
- Where these aquifers and basement occur at the surface they receive recharge directly from rainfall. Elsewhere, they receive recharge via leakage.
- Groundwater licences are concentrated where these aquifers occur close to the surface.

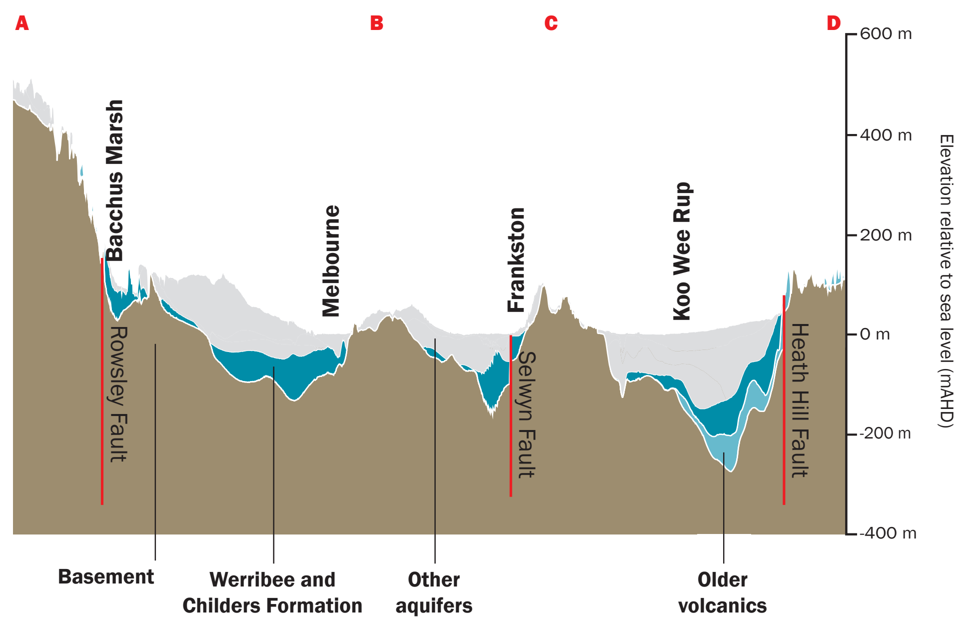


Lower aquifers (all formations): depth to the top of the aquifers and licences

This map shows where the lower aquifers occur at or near the surface (light blue shading) and where it is buried (dark blue shading). It also shows where the basement occurs at the surface (brown areas) and where it is buried by the upper and middle aquifers (beige areas). Groundwater licences are shown by user group. Major faults are shown.



Depth to the top of the Older Volcanics



Cross-section lower aquifers

This diagram shows the cross-section **A-B-C-D** taken from map on left

Note: horizontal and vertical scales are different.

Salinity and yield

Groundwater use from the lower aquifers and basement occurs mainly in areas with both high yield and low salinity. The best areas (those with the highest demand) are managed as GMUs. Groundwater salinity and yield depend on the soil and rock types as well as the aquifer thickness and depth.

Where the aquifer contains **clay** or **coal** (see map below), groundwater moves slowly and picks up salt from the clay particles, therefore salinity is high and yield is low. The limited available data indicates that groundwater salinity in the coal seam near Bacchus Marsh is between 2,000 mg/L and 3,500 mg/L.

The aquifer south-east of Melbourne is **sandy** with some **gravel** around Koo Wee Rup. Groundwater flows more quickly, is stored in greater volumes and picks up less salt as it moves. Therefore salinity is low and yield is high.

The aquifer to the west of Melbourne is sandy but is confined by the upper aquifers. It receives recharge as leakage through the overlying aquifers and so salinity is high. However, yield is high in this area as the aquifer is thick and under high pressure.

The basalts of Wandin Yallock occur at the surface and are recharged directly by rainfall so salinity is very low. Yield is low to moderate because fractures in the rock only store small amounts of groundwater compared to a sandy aquifer.

In the highlands where the basement occurs at the surface, salinity is low because of the direct rainfall recharge and short groundwater flow paths. However, yield is low because of low groundwater storage in the rock fractures. Where there are very few fractures the basement acts as an aquitard.

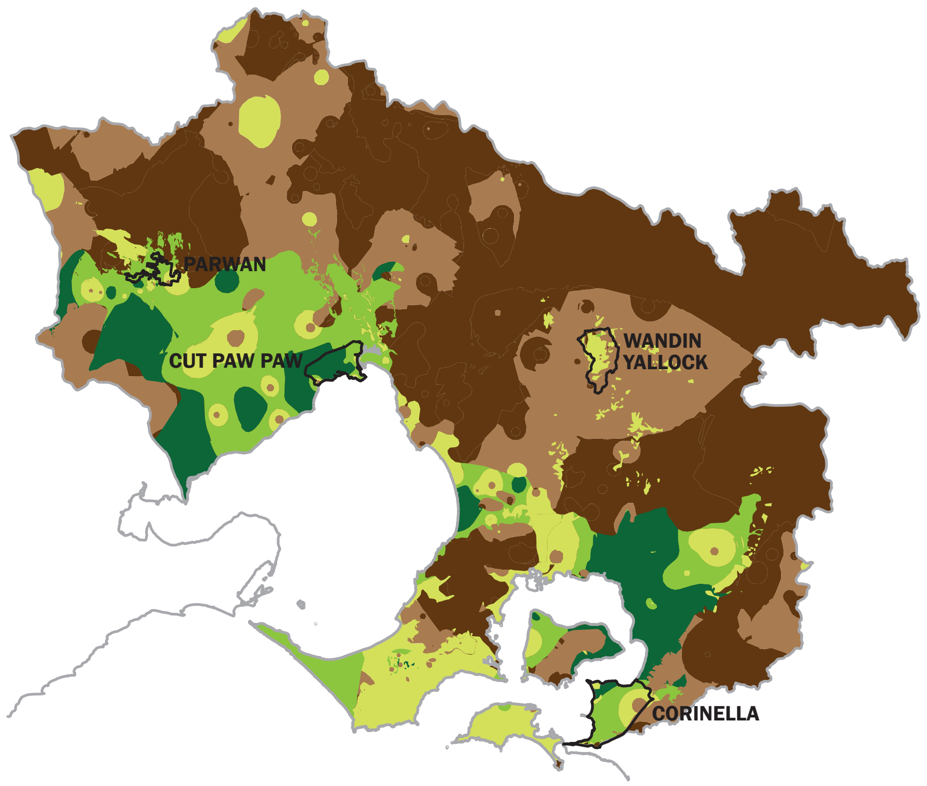
There is some irrigation use from the lower aquifers near Boneo and Bacchus Marsh where the aquifers are relatively shallow, high-yielding and low salinity (see map on page 54).

Observations

- **Salinity is best in the Wandin Yallock GMU, the area south-east of Melbourne and near Koo Wee Rup.**
- **Yield is best in the areas west, south and south-east of Melbourne.**
- **The basement is low salinity and low yielding and acts mainly as an aquitard.**

The lower aquifer is also used for backup urban supply at Lang Lang near Koo Wee Rup. Cut Paw Paw was declared as a GMU to manage potential industrial demand in the area but uptake of entitlements has been low.

It is estimated that 2000 GL of fresh water (salinity less than 1,000 mg/L) is stored in the lower aquifers across the region. Estimates of fresh water in storage in the basement are not available.



Key

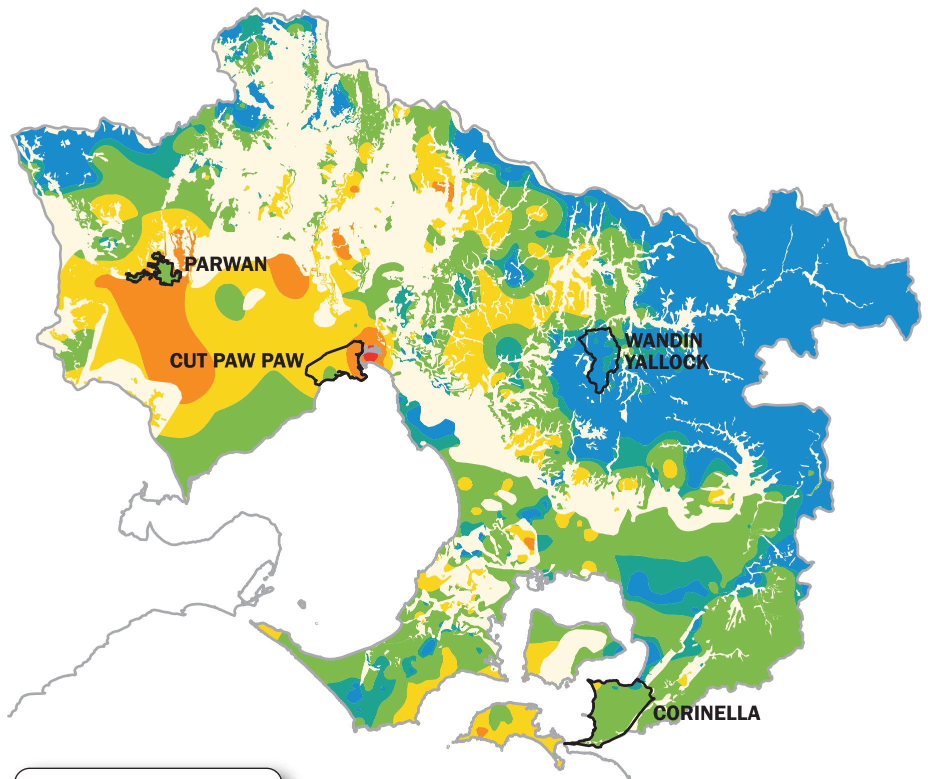
- Lower Aquifer GMU

Soil & Rock Types

- Mudstone/Siltstone/Granite — **Less permeable**
- Clay/Minor coal
- Weathered Basalt/Sandstone
- Basalt/Weathered Sandstone
- Sand — **More permeable**

Soil and rock types of the lower aquifers and basement

See maps on page 54 for lower aquifer and basement areas.



Key

- Lower Aquifer GMU

Salinity (mg/L)

- < 500
- 500–1000
- 1000–3500
- 3500–7000
- 7000–13,000
- 13,000–35,000

Salinity of the lower aquifers and basement

See maps on page 54 for lower aquifer and basement areas. Salinity data for Parwan GMU has been amended from regional mapping using available local data. More information on irrigation and stock watering suitability can be found on page 11.

Key

- Lower Aquifer GMU

Yield (L/s)

- < 1
- 1–5
- 5–10
- 10–50
- > 50

Yield of the lower aquifers and basement

See maps on page 54 for lower aquifer and basement areas.

Movement of groundwater

Groundwater in the lower aquifers and basement flows from areas of high elevation around the basin margin towards the bays.

Flow systems

Local and intermediate flow systems with travel distances of less than 30 km exist where the Older Volcanics occur at the surface around Wandin and where the basement occurs at the surface in the highlands in the Great Dividing Range (see map on page 52). In these areas groundwater discharges to springs and feeds streams.

Regional flow systems with long travel distances of greater than 30 km occur where the lower aquifers (mainly the Werribee and Childers formations) and basement are deeper. This groundwater may take thousands of years to discharge offshore (see also water balance on page 58).

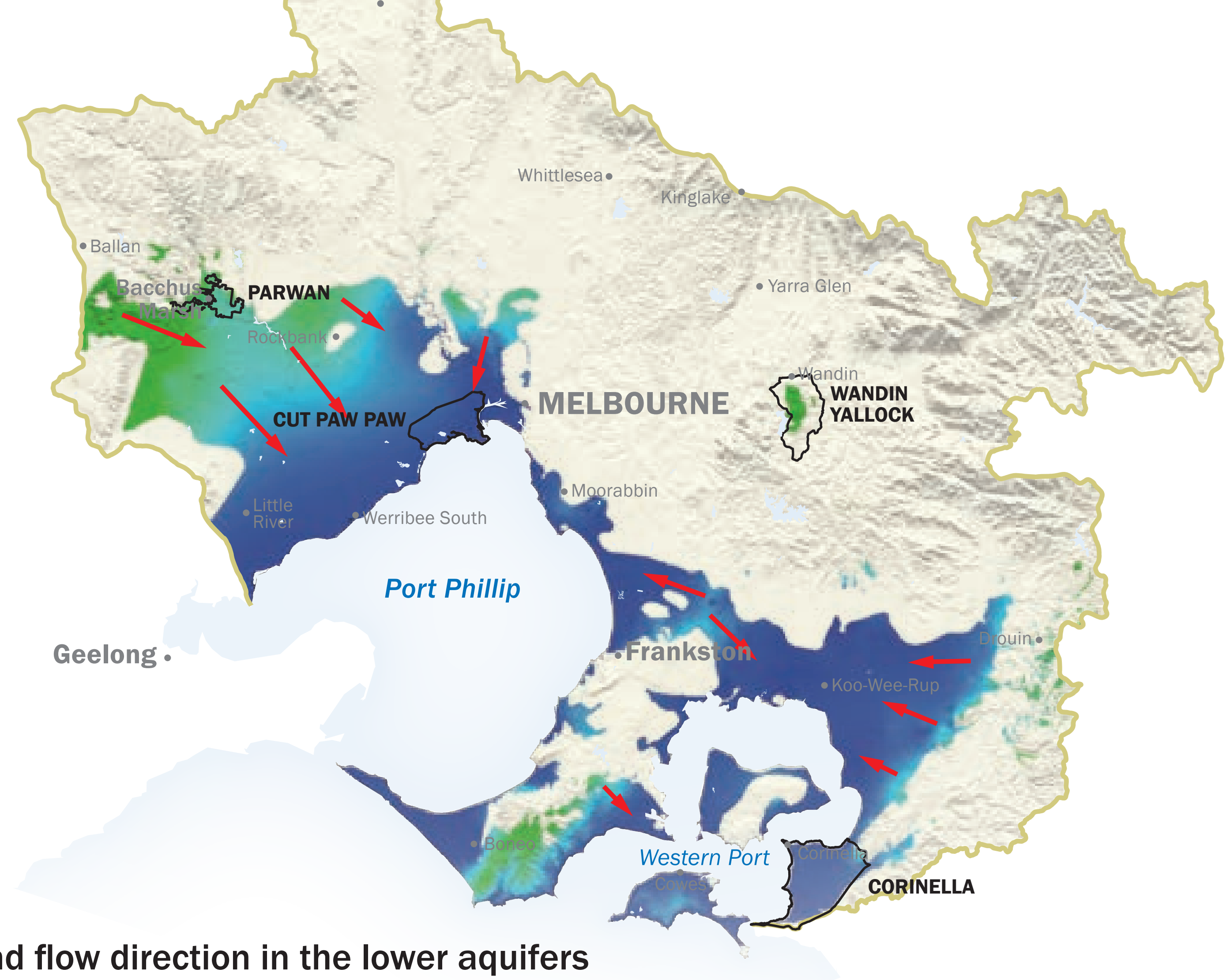
The basement is mostly low yielding and acts as an aquitard. It contains groundwater that moves very slowly in a regional flow system. However, in the highlands around the basin margins it acts as a fractured rock aquifer and yield is higher.

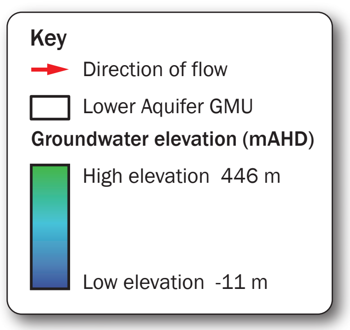
Recharge

Around the basin margins where the lower aquifers and basement occur at the surface, they receive recharge mainly from rainfall and stream leakage. Where they are buried, they receive recharge as leakage from overlying aquifers and aquitards.

Observations

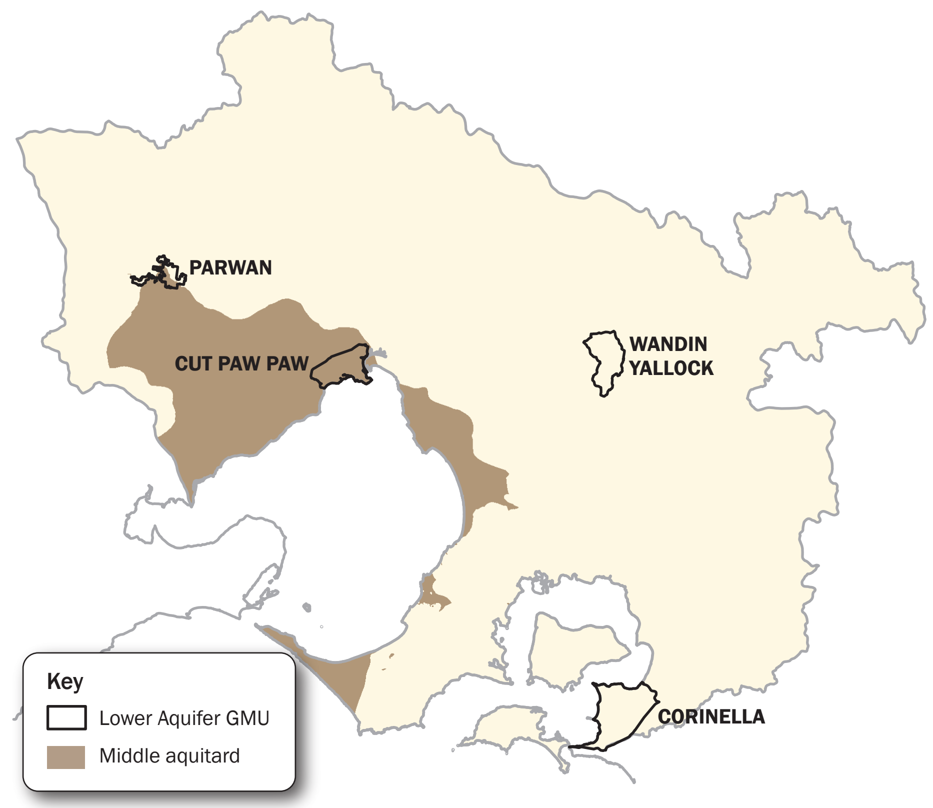
- **Groundwater in the lower aquifers and basement flows from the highlands and basin margins towards the bays.**
- **Local and intermediate flow systems exist where the lower aquifers and basement occur at or near the surface. These systems discharge to rivers and streams.**
- **Regional flow systems occur where the lower aquifers and basement are buried deeper. These systems discharge offshore.**
- **Where the lower aquifers are confined by the middle aquitard the groundwater is under pressure from overlying units.**





Groundwater elevation and flow direction in the lower aquifers

Groundwater flows from areas of higher elevation or higher pressure (green) to areas of lower elevation or lower pressure (blue). Data for the Wandin Yallock GMU is shown where the monitoring network exists in the Older Volcanics basalt aquifers.



Extent of middle aquitards

This map shows where aquitards of mainly silt and coal lie between the middle and lower aquifers (brown) (see also cross-section on page 44).

Where an aquitard exists there is little groundwater flow between aquifers and the lower aquifer is under pressure from overlying units. Between Bacchus Marsh and Werribee South and near Boneo, groundwater is forced upwards towards the surface by pressure in the lower aquifers.

Where there is no aquitard the middle and lower aquifers act as one unit such as around Koo Wee Rup.

Environmental dependence

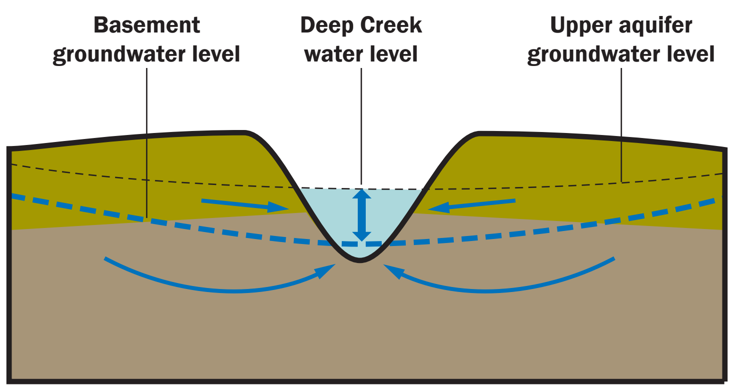
In the highlands around the basin margins, groundwater in the lower aquifers and basement exists in unconfined, fractured rock systems and interacts strongly with streams. The lower sand aquifer (Werribee Formation) interacts with streams where it rises to the surface in only a very small number of areas.

The examples on this page make the most of the few detailed studies available to show different aspects of how the lower aquifers and basement interact with surface ecosystems. Information is provided in general terms only. Further general information and maps on the region's potential Groundwater Dependent Ecosystems (GDEs) can be found on pages 18 and 19.

Baseflow GDEs

Spring flows from the fractured rock basement and Older Volcanics aquifers contribute to streams across the highlands such as Deep Creek near Lancefield. Groundwater discharge also contributes to drought refuges (permanent pools in waterways) when there is no flow and supports endangered species such as the Yarra Pygmy Perch. Melbourne Water has mapped these drought refuges (see page 19) and their groundwater catchments.

The diagram below shows how drought refuges in Deep Creek near Lancefield receive groundwater from the basement as well as from the upper aquifers. This means that the water level rises and falls with groundwater levels.



Groundwater flows to drought refuges

Modified from: SKM/Melbourne Water, 2012

Groundwater pumping

Groundwater extraction can affect stream flows across the highlands. Bore construction is not permitted immediately adjacent to streams so that the impact can be managed.

In the Woori Yallock Creek catchment (which includes most of the Wandin Yallock GMU), water from streams, dams and rainwater tanks is used for irrigation and domestic and stock (D&S) purposes. The volume taken from streams is actually greater than that taken from bores (RMCG, 2011), however groundwater supply is more reliable than surface water supply. If all licensed groundwater entitlements were used as well as registered D&S bores, the total depletion in summer could be as high as 11% of the stream's flow (SKM, 2009).

Southern Rural Water (the authority responsible for groundwater resources in the region) is working with Melbourne Water (the authority responsible for surface water resources in some parts of the region) to investigate whether it may be beneficial to co-manage groundwater and surface water resources where they interact strongly.

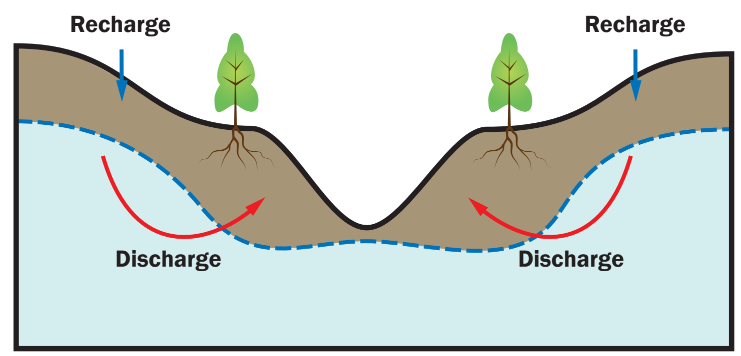
Evapotranspiration

Evapotranspiration refers to water being used directly by plants and may occur where groundwater is close to the surface. While this is difficult to quantify directly, it can sometimes be observed indirectly.

An example of this occurred in the days following the Black Saturday bushfires in 2009. Locals observed significantly increased flows in the upper reaches of Diamond Creek south of Kinglake. A study commissioned by Melbourne Water found that the sudden and dramatic decrease in evapotranspiration due to the destruction of a trees and plants in the bushfires allowed an increase in discharge of groundwater to waterways (see diagram to the right). It is also likely that there was a significant increase in run-off after the bushfires that would also contribute to increased stream flows. There is no available long-term data or analysis of stream flows in the area during the period of bush regrowth and regeneration since 2009.

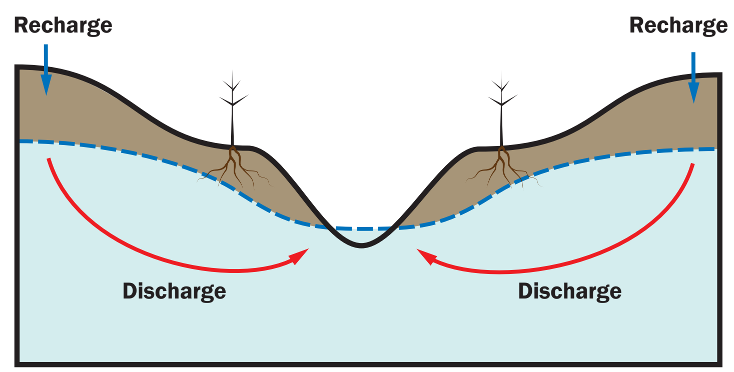
Observations

- **Groundwater from the lower aquifers and basement contributes to stream flows and drought refuges in the highlands.**
- **It may be beneficial to co-manage groundwater and surface water resources where they interact strongly.**
- **The effect of evapotranspiration can be indirectly observed through the changes in highland stream flows after a large bushfire.**



Undisturbed system with ET from groundwater.

All recharge discharges to ET with groundwater levels at stream depressed.



Post bushfire system without ET from groundwater.

Some of the recharge that would have discharged to ET now discharges to the stream.

Source: GHD, 2012

Water balance

Water balances have been estimated for the Werribee Formation that extends across the Port Phillip Basin and the Older Volcanics in the Wandin Yallock GMU.

Further general information on water balance can be found on page 17.

Where the lower aquifers and basement occur at the surface in the highlands and around the basin margin they receive direct rainfall recharge (see map on page 54). Where they are buried there is likely to be some leakage to and from the shallower formations but the rate is uncertain. Some horizontal groundwater flow between the basement, lower and shallower aquifers is also likely at the basin margin where the aquifers may act as one unit (see diagram on page 14).

Werribee Formation

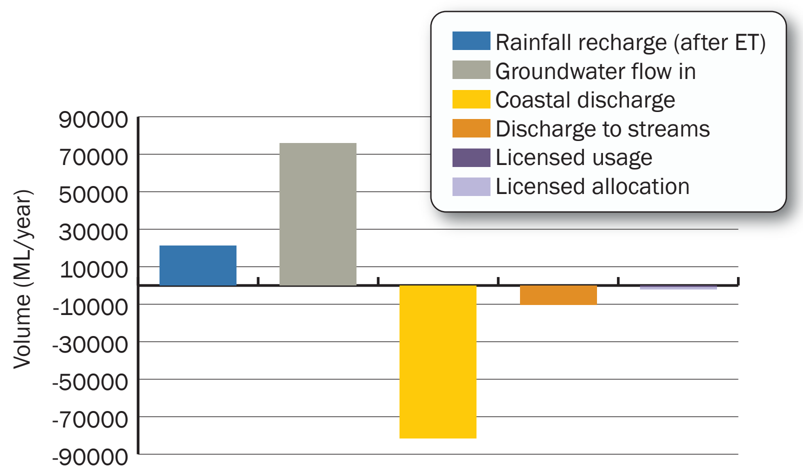
The Werribee Formation is the most extensive unit of the lower aquifers within the Port Phillip Basin.

It is mostly buried by other aquifers and the middle aquitard (see page 54). Therefore, recharge is received mainly as leakage from the overlying units. Direct rainfall recharge occurs in small areas where it occurs at the surface and is shown in the graph below after evapotranspiration. It interacts with streams only in small areas where it occurs at the surface.

Use of groundwater from this aquifer is relatively low due to its depth and salinity (see page 55). Discharge occurs under Port Phillip Bay where groundwater from the Werribee Formation is forced upwards into overlying formations by sea water pressure and out into Bass Strait. This is shown in the graph below as "coastal discharge".

The total flows into and out of the aquifer are approximately equal.

Werribee Formation water balance



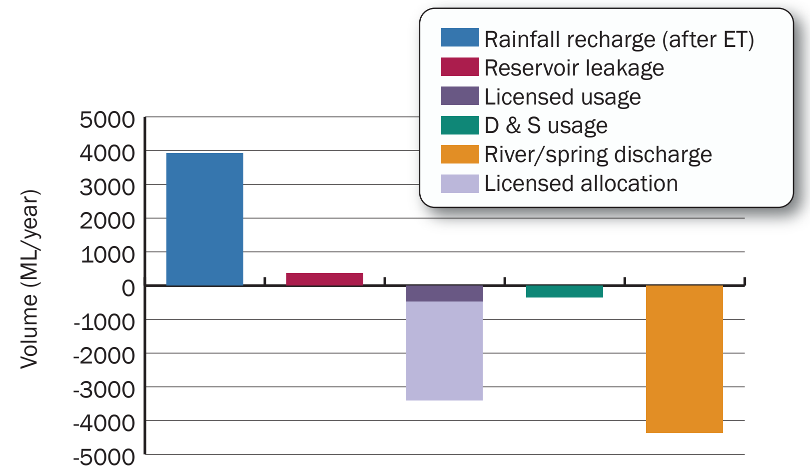
Modified from: GHD, 2011

Wandin Yallock GMU

The most intensive use of groundwater from the lower aquifers across the region is from the Older Volcanics in the Wandin Yallock GMU (see page 54).

In contrast to the Werribee Formation, the Older Volcanics occur close to the surface and are not extensive. It is recharged directly by rainfall and interacts strongly with streams along short flow paths.

Wandin Yallock GMU water balance



Modified from: SKM, 2013

Rainfall recharge after evapotranspiration is the major source of recharge with some contribution from irrigation leakage. Evapotransipration is relatively low because groundwater occurs more than 20 m below the surface across most of the GMU. There is also some recharge via leakage from the adjacent Silvan Reservoir. Discharge occurs mostly as baseflow to streams. Groundwater extraction is very small compared to recharge by rainfall and discharge to streams.

This is a preliminary estimate only of the water balance. The data presented suggests that there is a negative water balance in this GMU. However, the available monitoring data indicates that groundwater levels are fairly stable over the long term (see also page 59).

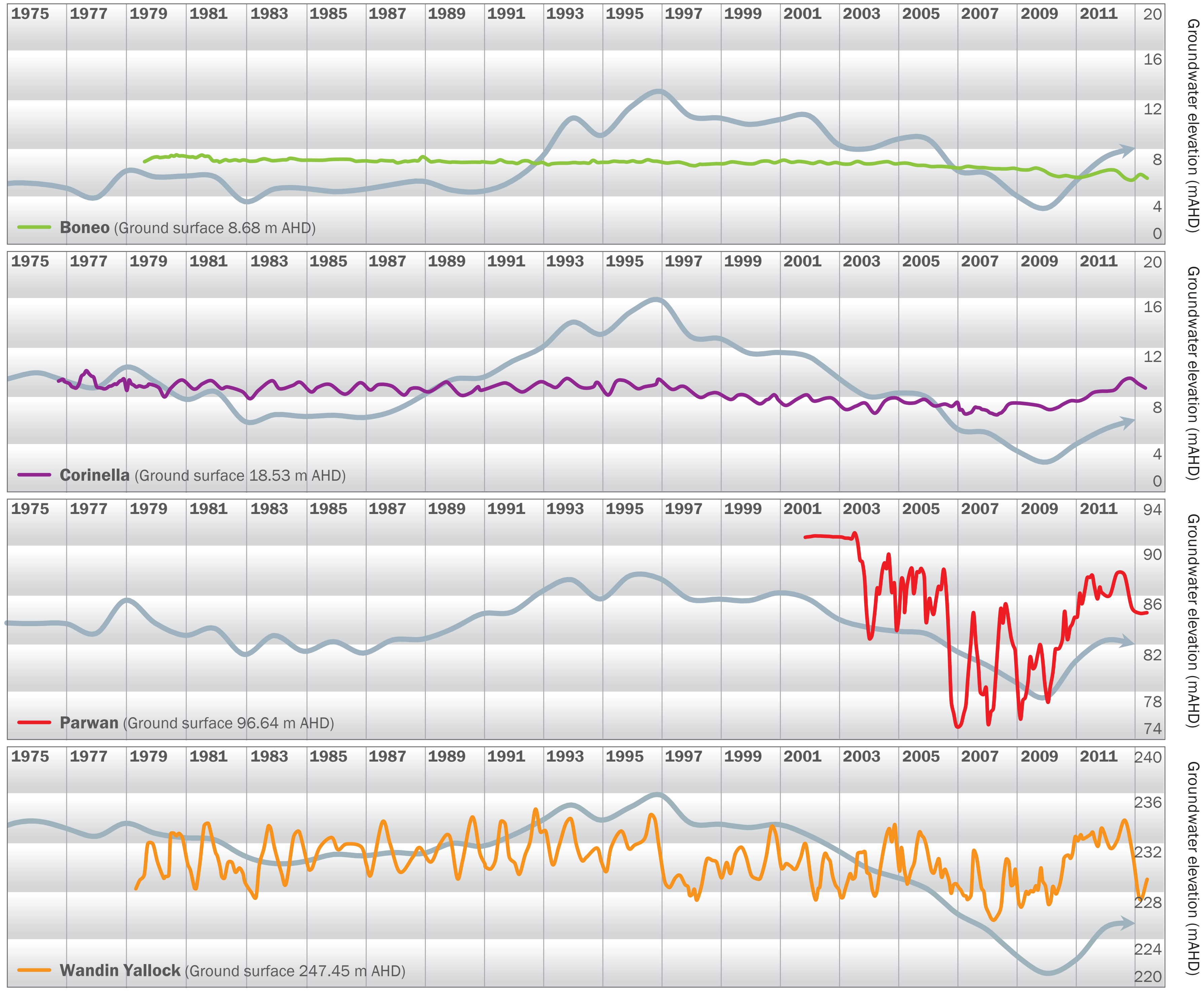
NOTE: The water balance graphs on this page are not directly comparable as they were completed for different purposes using different methods. However, they are useful for comparing the relative sizes of each component within a GMU or aquifer.

Observations

- **Water balances have only been completed for selected parts of the lower aquifers. None are available for the basement.**
- **The Werribee Formation in the Port Phillip Basin is mostly buried. Recharge occurs mostly as leakage from the overlying units and discharge is mostly to Port Phillip Bay and Bass Strait.**
- **The Older Volcanics in the Wandin Yallock GMU occurs at the surface. Recharge is mostly from rainfall and discharge is mostly to streams.**

Groundwater-irrigated crops in Wandin Yallock GMU

Regional trends



Groundwater levels and rainfall

The hydrographs above show groundwater levels (purple, red, green and orange lines) relative to sea level in the lower aquifers at specific bore locations in the region. The level of the ground surface relative to sea level is also noted. The rainfall trend (grey line) is shown relative to the long-term average calculated since 1900. Where the rainfall trend line rises, rainfall is above the long-term average. Where the rainfall trend line falls, rainfall is below the long-term average. Where the rainfall trend line is flat, rainfall is equal to the long-term average.

Note: mAHD = elevation in metres

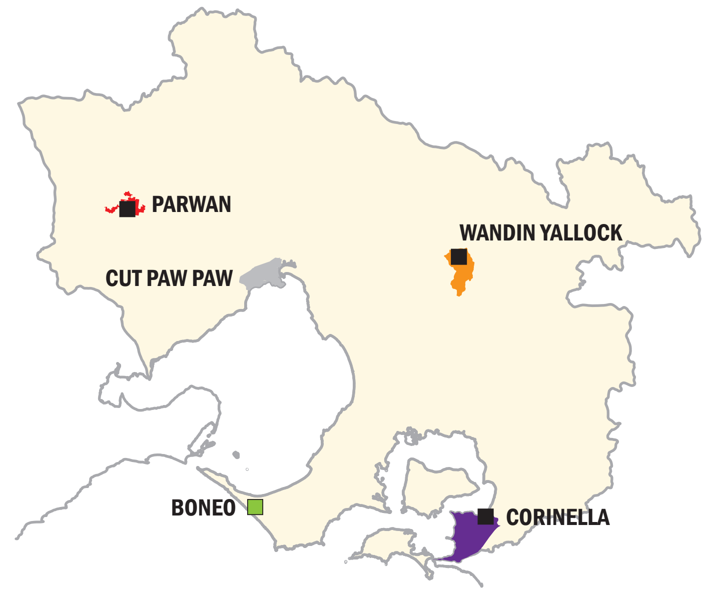
Hydrographs from all monitored State Observation Bores can be found on the Southern Rural Water website www.srw.com.au.

Observations

- Groundwater level trends in the lower aquifers are fairly stable overall.
- The amount of fluctuation is affected by how confined the aquifer is and the volume of groundwater use.
- Groundwater levels are influenced directly by rainfall only where the lower aquifers occur at the surface.

Location of bores analysed in hydrographs at left

There are no monitoring bores in the Cut Paw Paw GMU.



Rainfall trend

Boneo (non-GMU): Bore 84887. This bore occurs in the Werribee Formation which is a confined lower aquifer. The levels in this bore show very little seasonal fluctuation. Other bores in the area which are closer to extraction points are more affected by pumping. The trend in this bore and across the GMU is stable over the long term.

Corinella GMU: Bore 56922. This bore occurs in the Older Volcanics aquifer which occurs at the surface and is unconfined. Levels in this bore fluctuate slightly but are stable overall. There is only one SOBN bore in this GMU.

Parwan GMU: Bore 144963. This bore occurs in the Werribee Formation which is a confined lower aquifer and has been influenced by pumping for irrigation since 2003. Levels in this bore and across the GMU fluctuate seasonally but there is a slight downward trend overall

Wandin Yallock GMU: Bore 98404. This bore occurs in the Older Volcanics aquifer which is unconfined and occurs at the surface. It is influenced by climate and irrigation. Levels in this bore and across the GMU fluctuate seasonally but the trend is fairly stable over the long term.

Users and usage

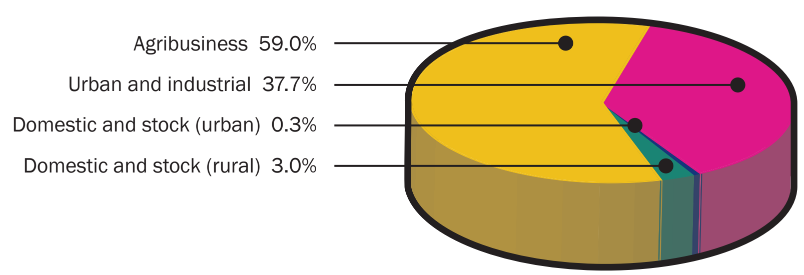
Agribusiness is the largest user group of groundwater in the lower aquifers and basement by volume. Domestic and stock (D&S) is the largest user group in the basement.

Users

The graphs below show groundwater user groups in the lower aquifers and basement. Total licensed volume is shown for agribusiness and urban/industrial. Estimated usage for D&S is shown at 1.3 ML/bore/yr in rural areas and 0.2 ML/bore/yr in urban areas (see map on page 24). There are 415 bores registered for D&S use since 1980 in the lower aquifers with total estimated usage of 349 ML/yr. There are 1,649 bores registered for D&S use since 1980 in the basement with total estimated usage of 1,772 ML/yr. D&S users access the lower aquifers and basement where the aquifers occur at the surface (see map on page 54). Total D&S use in the lower aquifers and basement is just over 2,000 ML/yr.

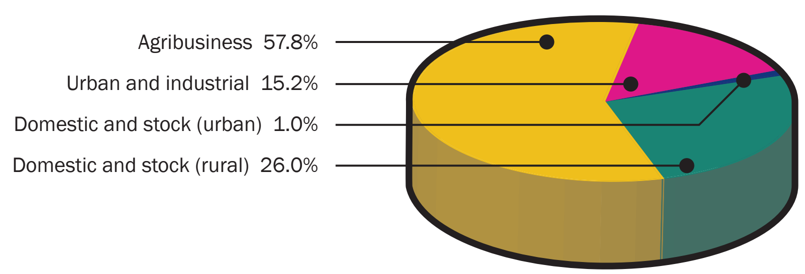
Industrial users include mines and quarries with a total allocation of 1,436.8 ML/yr. There are urban licences in Corinella and near Koo Wee Rup. The Corinella licence is used to supplement surface water supplies around Phillip Island.

Lower



Breakdown of potential groundwater use in the lower aquifers

Basement



Breakdown of potential groundwater use in the basement

The table below shows the number of licences, average licence size and the largest licence size for the lower aquifers and basement.

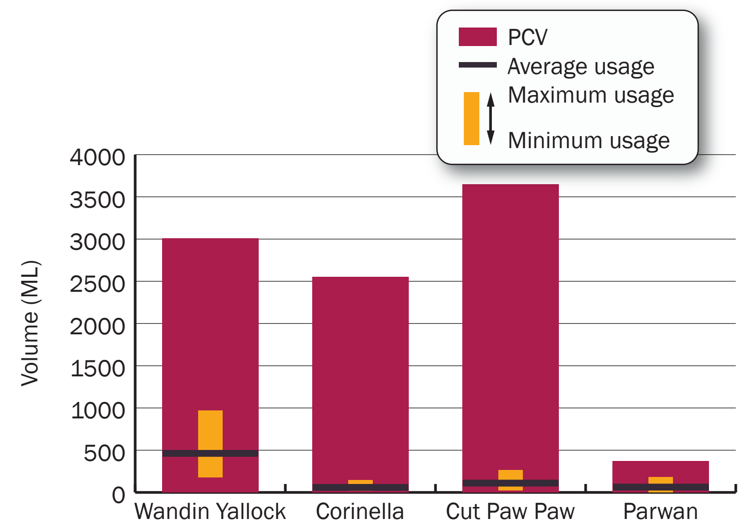
GMU	Number of licences	Average licence size (ML/yr)	Largest licence (ML/yr)
Corinella	13	48	490
Cut Paw Paw	3	170	342
Parwan	9	40	138
Wandin Yallock	185	16	78
Non-GMU	223	46	1825

Licensed usage by GMU

The table below shows the Permissive Consumptive Volume (PCV), entitlements and average metered usage for the lower aquifers and basement. Average licensed usage is 16% of total entitlements.

	PCV (ML/yr)	Entitlements (ML/yr)	Average licensed usage (ML/yr)
Corinella	2,550	662	67
Cut Paw Paw	3,650	514	109
Parwan	371	371	58
Wandin Yallock	3,008	3,005	473
Non-GMU	N/A	10,901	1,744
Total	**N/A**	**15,453**	**2,360**

Average, minimum and maximum metered usage by GMU



Note: this data has been collected since 2003-04

Note: Parwan GMU has an allocation cap imposed by Southern Rural Water, not a PCV.

Observations

- **Agribusiness is the largest user group of groundwater in the lower aquifers and basement by volume.**
- **D&S users are a large user group in the basement.**
- **There is potential to access the unused proportion of existing entitlements through trading and new allocations may be available in some areas.**

The environment

Where the lower aquifers and basement occur close to the surface groundwater supports stream flows, drought refuges and other Groundwater Dependent Ecosystems (GDEs) including trees. Environmental use of groundwater from these aquifers has not been quantified but more discussion about this topic can be found on page 57.

Sustainable use

The available data from across the lower aquifers and basement does not indicate that unsustainable groundwater use is occurring. However, there is minimal or no groundwater monitoring in some areas with little or no extraction such as the Cut Paw Paw GMU.

Value

The economic value of groundwater use in the lower aquifers and basement is approximately $8 million per year. Groundwater also has significant environmental, social and cultural value. Therefore groundwater reliability and security is very important for our wider community. More discussion about the value of groundwater can be found on page 30.

Future development

Entitlements are currently available under the PCVs in the Corinella and Cut Paw Paw GMUs. There are *no* remaining entitlements under the PCVs in the Parwan and Wandin Yallock GMUs. There may be potential for new entitlements in the non-GMU areas. For all new allocation and trading applications, Southern Rural Water must be satisfied that the overall aquifer sustainability is maintained and that the impact on other users and potential GDEs is acceptable.

There is potential to access the significant unused proportion of entitlements in all GMUs and non-GMU areas (84% of total entitlements). This could occur through trading between users or by existing license holders using any unused entitlements for purposes such as business expansion.

Current and emerging issues

Groundwater from the lower aquifers and basement has lower levels of extraction than water from the middle and upper aquifers. However, it interacts strongly with surface water in the highlands leading to significant use by the environment. These units also contain mineral and energy deposits and there is potential demand for these resources.

Regional issues

- Environmental dependence
- Combined management of groundwater and surface water
- Potential mineral and energy extraction

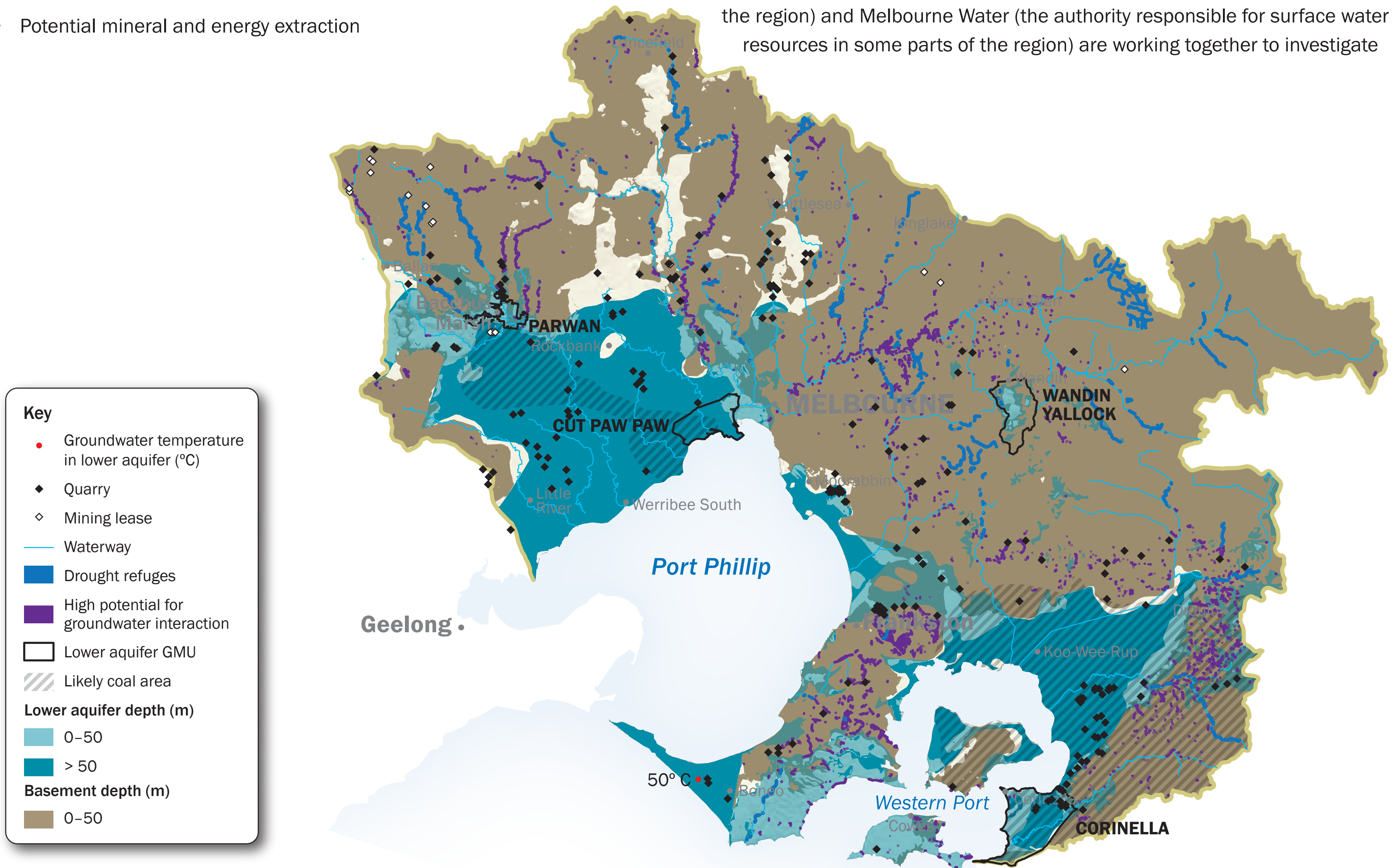
Environmental dependence

Groundwater from these units interacts strongly with surface water in the highlands around the basin margins. It provides spring and baseflows to streams and also maintains drought refuges during periods of low or no stream flow. Trees may also access groundwater directly through their deep root systems (see also pages 18, 19 and 57).

Combined groundwater and surface water management

Strong interactions between surface water and groundwater from the lower aquifers and basement have been found in areas including Deep Creek and Wandin Yallock GMU (see also page 57).

Southern Rural Water (the authority responsible for groundwater resources in the region) and Melbourne Water (the authority responsible for surface water resources in some parts of the region) are working together to investigate whether it may be beneficial to co-manage groundwater and surface water resources where they interact strongly.



Aquifer extent, groundwater temperature, environmental assets and potential energy development

This map shows the where the lower aquifers and basement are close to the surface and interact with the environment. Likely coal areas and groundwater temperature in the lower aquifer are also shown.

Observations

- **Where the lower aquifers and basement interact strongly with surface environments in the highlands the environment is a significant groundwater user.**
- **It may be beneficial to co-manage groundwater and surface water resources where they interact strongly.**
- **Extraction of mineral and energy deposits in the lower aquifers and basement is regulated by multiple agencies.**

Energy, minerals and geothermal development

Mining, quarrying, gas extraction and geothermal energy development may all interact with groundwater. These operations are regulated by the Department of State Development, Business and Innovation. Associated groundwater extraction and injection of water or other substances is regulated by SRW. Additional environmental approvals may be required from DEPI and the EPA.

Mining and quarrying operations may intercept groundwater. Extraction or management of groundwater required for operations may require licensing by SRW. There are several small (less than 5 hectare) mining or “prospecting” licences in the basement, mainly for gold. There is a small coal mine operating in Bacchus Marsh. There are no large mines operating in the region. Several quarries extract materials including basalt. Current groundwater allocation from the lower aquifers and basement for mining and quarrying is discussed on the previous page.

Coal seams exist in the middle aquitard and lower aquifers (see map). Coal can be mined and used for electricity or chemical production. The coal seams also hold natural gas (methane), which can be pumped out for use in electricity production, heating or manufacturing. In some areas, low methane content in the coal presents technical and economic challenges to gas extraction.

The basement has confined reservoirs of hot water and gas several kilometres below the ground. These are potential targets for geothermal energy and gas extraction. The likely impact of these activities on the overlying aquifers is limited by their great depth. Groundwater management boundaries and PCVs are being revised so that the very deep reservoirs can be managed separately to shallower aquifers.

Where the aquifers are deep, groundwater temperatures are relatively high (see map) and can be used for public recreation and heating. There is currently a recreational “hot spring” development near Boneo.

Sources

Source	Topic	Chapter
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*Bartley Consulting, 2010, *Water Users Surveys in the Condah and Glenelg Water Supply Protection Areas*	Domestic and stock (D&S) use in rural areas	3, 4, 5, 6
Bureau of Meteorology	Climate	1
Bureau of Meteorology, 2012, *National Atlas of Groundwater Dependent Ecosystems*	Environment	4
Coffey, 2008, *Groundwater Snapshot - Southern Victoria*	Groundwater protection	3
DEPI (Dept of Environment and Primary Industries), 2012, *Secure Allocation, Future Entitlement*	Groundwater management framework	3
DEPI, 2012, *Victorian Sate Water Accounts 2010-11*	Groundwater usage	3
DEPI, 2013, Groundwater management system database (water measurement information system)	Registered bores	3, 4, 5, 6
DPCD (Dept of Planning and Community Development)	Urban growth boundaries	4, 5
DPI (Dept of Primary Industries)	D&S use in rural areas	3, 4, 5, 6
DPI, Land use data	Land use	1, 4, 5, 6
DPI website, *Water Quality for Farm Water Supplies*	Beneficial uses	1
DPI, **http://vro.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/lwm_connecting_landscapes_groundwater**	Environmental dependence	2
DSE (Dept of Sustainability and Environment) & SKM 2009, *Victorian Aquifer Naming Framework*	Aquifer grouping	Reading guide
DSE, 2000, Landsat	Land cover	1
DSE, 2010, GDE mapping	Environment	2, 4, 5, 6
DSE, *Ensym (Environmental Systems Modelling)* project	Evapotranspiration	1
DSE, 2011, *Gippsland Sustainable Water Strategy*	GDE policy, groundwater value	2, 3
DSE, 2011, *Western Region Sustainable Water Strategy*	Groundwater value	3
*DSE, 2011, *Reasonable Stock and Domestic Guidelines for Rural Residential Properties*	D&S use in rural areas	3, 4, 5, 6
EPA (Environment Protection Authority)	Groundwater protection	3
Groundwater Online (**http://groundwater.geomatic.com.au/Main.aspx**)	Groundwater monitoring	3
GHD, 2011, *Lower Tertiary Aquifer, Port Phillip Basin, Groundwater Resource Appraisal*	Water balance	6
GHD, 2012, *Upper Diamond Creek Groundwater – Surface Water Investigation*	Environmental dependence	6
Gleick, PH (editor), 1993, *Water in Crisis: A Guide to the World's Freshwater Resources*	Global groundwater resources	3
holytrinity.faithweb.com/p-on-Ecology/w03-water-B.htm	Sea water intrusion	4
Larsen et al, 2013 *Estimating Stock and Domestic Water Use to Improve Catchment Water Management Outcomes*	D&S use in rural areas	3, 4, 5, 6
Melbourne Water, 2012, *Drought refuge mapping*	GDEs	2, 4, 5, 6
Office of Living Victoria (OLV)	Integrated Water Cycle Management	3
Parsons Brinckerhoff, 2010, *South-East Melbourne Sandbelt Groundwater Resource Appraisal*	Water balance, environmental dependence, D&S use in urban areas	3, 4, 5, 6
RMCG 2011, *Value of Services to Southern Victoria*	Economics	3, 4, 5 & 6
RMCG, 2011, *Stock and Domestic Water use in the Woori Yallock Catchment*	Environmental dependence	6
SKM, 1998, various *Permissible Annual Volume* reports (Lancefield, Merrimu)	Water balance	4, 5, & 6
SKM, 2001, *Koo Wee Rup, Dalmore and Lang Lang report on modelling of potential groundwater use and implications for PAV*	Water balance	5
SKM, 2005, *Werribee Irrigation District – final report on groundwater model*	Water balance	4
SKM & GHD, 2009 (updated 2012), *Hydrogeological mapping of southern Victoria*	Geology, salinity, yield and movement	2, 4, 5 & 6
SKM, 2009, *Woori Yallock Creek Catchment hydrogeological Characterisation – Estimation of Surface Water Depletion*	Environmental dependence	6
SKM and Melbourne Water, 2012, *Conceptualisation of Key GDEs in Melbourne Water Catchments*	Environmental dependence	4, 5, 6
SKM, 2013, *Wandin Yallock WSPA Water Balance*		
Southern Rural Water	Metered usage data	3, 4, 5, 6
University of New South Wales, **https://www.connectedwaters.unsw.edu.au/resources/resources_home.html**	Environmental dependence	2
Water Register, 2013	Groundwater entitlements	3, 4, 5 & 6

* Indicates multiple sources for D&S use estimates in rural areas

Photography courtesy of: Alison Pouliot, Gino LaMorticella and cover imagery by Andrew Samson (Image and Light Photography).

For more information on...

USING GROUNDWATER

Applying for a licence or drilling a bore
Southern Rural Water (SRW)
1300 139 510
www.srw.com.au

Groundwater in your area
Department of Environment and Primary Industries (DEPI) – Groundwater resource reports
http://www.depi.vic.gov.au/water/groundwater/groundwater-resource-reports

Visualising Victoria's Groundwater
www.vvg.org.au

Using groundwater around your property
Department of Health, Environmental Health Unit – Groundwater use around the house
1300 761 874
http://www.water.vic.gov.au/__data/assets/pdf_file/0012/741/your_private_drinking_water_supply.pdf
http://www.health.vic.gov.au/water/drinkingwater/faqs.htm

DEPI – Groundwater use for agriculture
http://www.depi.vic.gov.au/agriculture-and-food/farm-management/managing-dams/water-quality-for-farm-water-supplies

Trading water
SRW, *WaterMatch*
www.srw.com.au/watermatch

HOW GROUNDWATER IS MANAGED

Legislation, regulation and management
Water Act 1989 – Legislation
http://www.legislation.vic.gov.au/Domino/Web_Notes/LDMS/LTObject_Store/LTObjSt5.nsf/DDE300B846EED9C7CA257616000A3571/F8DBB7E6417A03EDCA2577CB00024075/$FILE/89-80a099B.pdf

DEPI – State-wide framework
http://www.depi.vic.gov.au/water/governing-water-resources
http://www.depi.vic.gov.au/water/groundwater/managing-groundwater

SRW – Groundwater Management Plans and Local Management Plans
http://www.srw.com.au/Page/Page.asp?Page_Id=170&h=0

Groundwater quality and pollution
Environmental Protection Authority
1300 372 842
www.epa.vic.gov.au/your-environment/water/protecting-victorias-waters

Policy and strategy
Sustainable Water Strategies
http://www.depi.vic.gov.au/water/governing-water-resources/sustainable-water-strategies

Land and groundwater legislation
http://www.epa.vic.gov.au/about-us/legislation/land-and-groundwater-legislation
State Environment Protection Policy (Groundwaters of Victoria)
http://www.epa.vic.gov.au/about-us/legislation/land-and-groundwater-legislation#sepp_groundwaters

Groundwater entitlement
Victorian Water Register
http://waterregister.vic.gov.au/Public/GroundWater.aspx

All links are correct as at May 2014

Catchment and land management
Port Phillip & Westernport Catchment Management Authority
03 8781 7900
www.ppwcma.vic.gov.au

Melbourne Water
131 722
www.melbournewater.com.au/

TECHNICAL INFORMATION

Groundwater monitoring data
DEPI – State monitoring data
http://data.water.vic.gov.au/monitoring.htm

SRW – Groundwater levels
http://www.srw.com.au/Page/Page.asp?Page_Id=737&h=0

Development of groundwater maps
SRW, *Hydrogeological Mapping Report*
http://www.srw.com.au/Files/groundwater_maps/Hydrogeological_Mapping_Report.pdf

Land use data
DEPI, Victorian Resources Online
http://vro.depi.vic.gov.au/dpi/vro/vrosite.nsf/pages/vrohome

Climate data
Bureau of Meteorology
www.bom.gov.au

General groundwater facts and information
National Water Commission, *Groundwater Essential* booklet
http://archive.nwc.gov.au/library/topic/groundwater/groundwater-essentials

Wikipedia
http://en.wikipedia.org/wiki/Hydrogeology

US Geological Survey – Groundwater information (basic concepts)
http://water.usgs.gov/ogw/

HOT TOPICS

Coal seam gas
http://www.srw.com.au/Page/Page.asp?Page_Id=910&h=0

Groundwater Dependent Ecosystems
Bureau of Meteorology, *National GDE Atlas*
http://www.bom.gov.au/water/groundwater/gde/

Managed Aquifer Recharge (MAR) and Aquifer Storage and Recovery (ASR)
http://www.csiro.au/Portals/Publications/Brochures--Fact-Sheets/MAR-FAQ.aspx
http://www.srw.com.au/Page/page.asp?Page_Id=1056&h=0

Integrated Water Cycle Management
Office of Living Victoria
http://www.livingvictoria.vic.gov.au/planning

Minerals and energy
Department of State Development, Business and Innovation
http://dsdbi.vic.gov.au/what-we-do/support-energy-and-earth-resources

Soil salinity
Port Phillip and Western Port Salinity Report, 2010
http://www.ppwcma.vic.gov.au/Resources/PublicationDocuments/69/PPW%20Salinity%20Report_Section%201-3.pdf

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