Groundwater

Terms and definitions

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1 Groundwater occurrence

1.1 Water cycle

The water cycle is the perpetual movement of water on earth (Figure 1). The suns heat evaporates water from open water bodies and land. Water vapour rises into the atmosphere and condenses to form clouds with lower air temperature.

Precipitation falls back down to earth under gravity as rain, hail or snow. Precipitation may:

- return to the atmosphere through evaporation;
- contribute directly to surface water bodies, glaciers or snow;
- fall on the landscape and run-off into streams and rivers that feed into the ocean;
- infiltrate the soil and be taken up by plants and returned to the atmosphere through transpiration; and
- enter the ground to recharge groundwater systems.

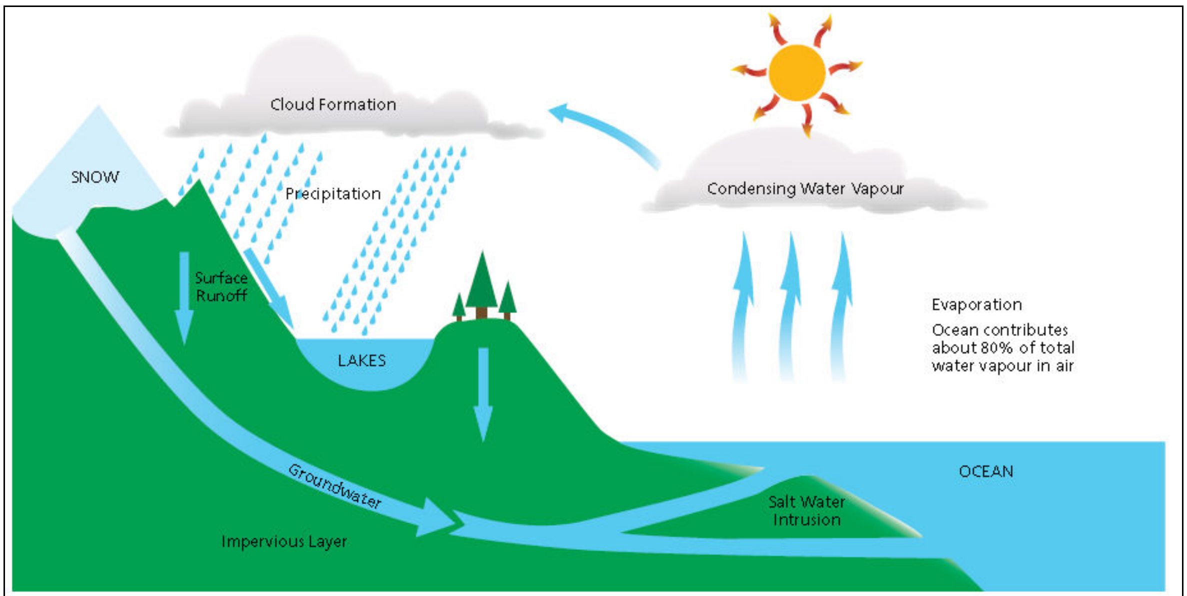


Figure 1 Water Cycle (DSE 2009)

1.2 Groundwater

Groundwater is water beneath the earth's surface in pores and fractures of soil and rocks (Figure 2).

Groundwater is also water that drains through the unsaturated soil to a saturated zone where pores and fractures can store water.

Groundwater supports a significant amount of agricultural activity, provides urban supplies to a number of towns across Victoria, and is an essential source of water for domestic and stock supply.

Groundwater is also an important environmental asset that provides base flow to streams and supports wetlands and other groundwater dependent ecosystems (definition provided in section 4.6).

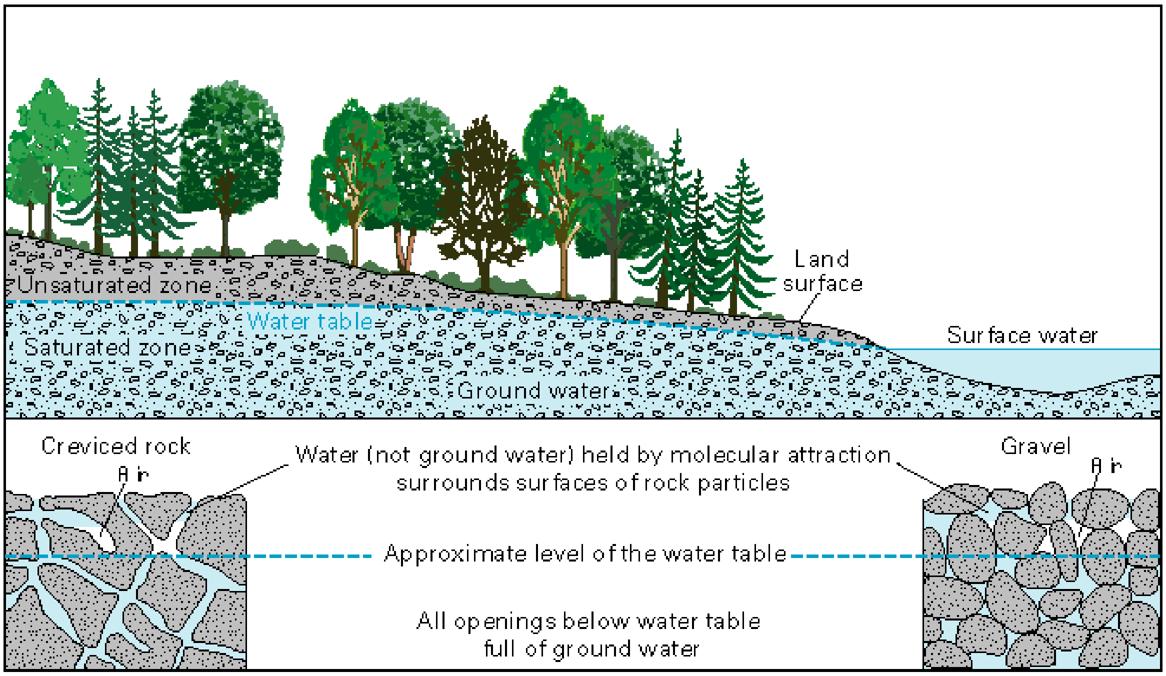


Figure 2 Groundwater occurrence (Ghost Watershed Alliance Society 2015)

2 Aquifer types

2.1 Aquifer

An aquifer may be broadly described as saturated fractured rock or sand from which usable volumes of groundwater can be pumped.

2.2 Aquitard

An aquitard restricts the flow of water from one aquifer to another, for example a clay layer or solid rock.

2.3 Unconfined aquifer

An unconfined aquifer is a section of rock or sand that does not have a confining layer (e.g. clay aquitard) on top of it (Figure 3).

An unconfined aquifer is often shallow.

The top of an unconfined aquifer is the watertable.

An unconfined aquifer acts similar to a sponge, in that the watertable surface can fluctuate up and down depending on the recharge and discharge rate.

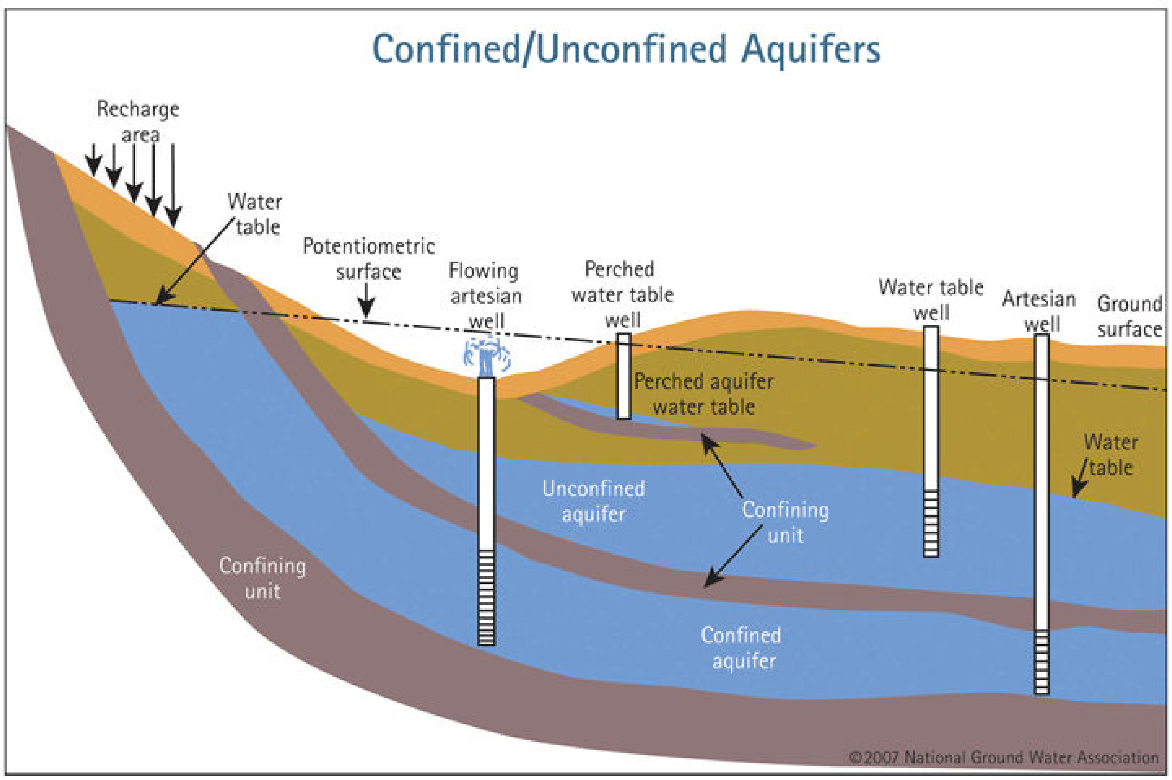


Figure 3 Aquifer types (National Groundwater Association 2007)

2.4 Confined aquifer

A confined aquifer is a section of rock or sand that is overlain by a confining layer (e.g. clay aquitard on top) that restricts movement of water into another aquifer (Figure 3)

Groundwater in confined aquifers can be under high pressure because of the confining layer on top of the aquifer and the recharge zone is higher in the catchment.

In a confined aquifer the water level in a bore will rise to a level higher than the top of the aquifer because of the high pressure. This is referred to as the potentiometric surface and is similar to squeezing a juice box with a straw in it, casuing the juice to rise up the straw.

In some bores the water level may be above the ground surface in which case it is called artesian.

2.4.1 Deep lead

A deep lead is an ancient river bed (paleochannel) that has been buried by sediment or basalt resulting from volcanic lava flows. Deep lead aquifers usually store and transmit large volumes of water.

2.5 Perched aquifer

Perched aquifers occur where groundwater is located above unsaturated rock formations as a result of a discontinuous impermeable layer (Figure 4).

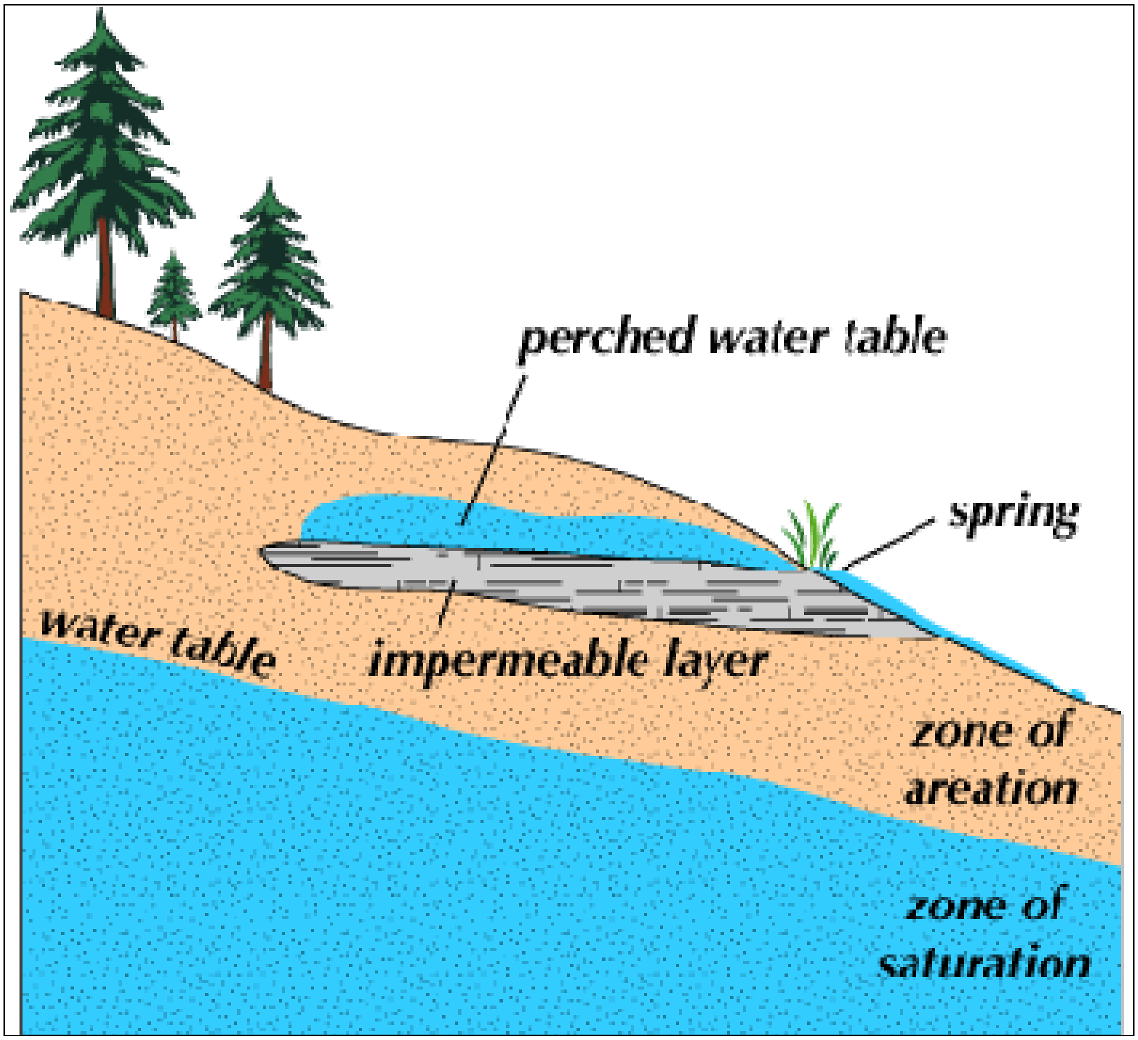


Figure 4 Perched aquifer (Arizona State University, date unknown)

3 Aquifer properties

3.1 Hydraulic head

Hydraulic head is the height to which water will rise in a bore. It is the resting groundwater level.

The hydraulic head may be measured as the depth below natural surface (Figure 5).

The hydraulic head may also be measured against sea level (surveyed reduced water level to Australian height datum) to compare between different bores.

Groundwater will always move from high to low hydraulic head.

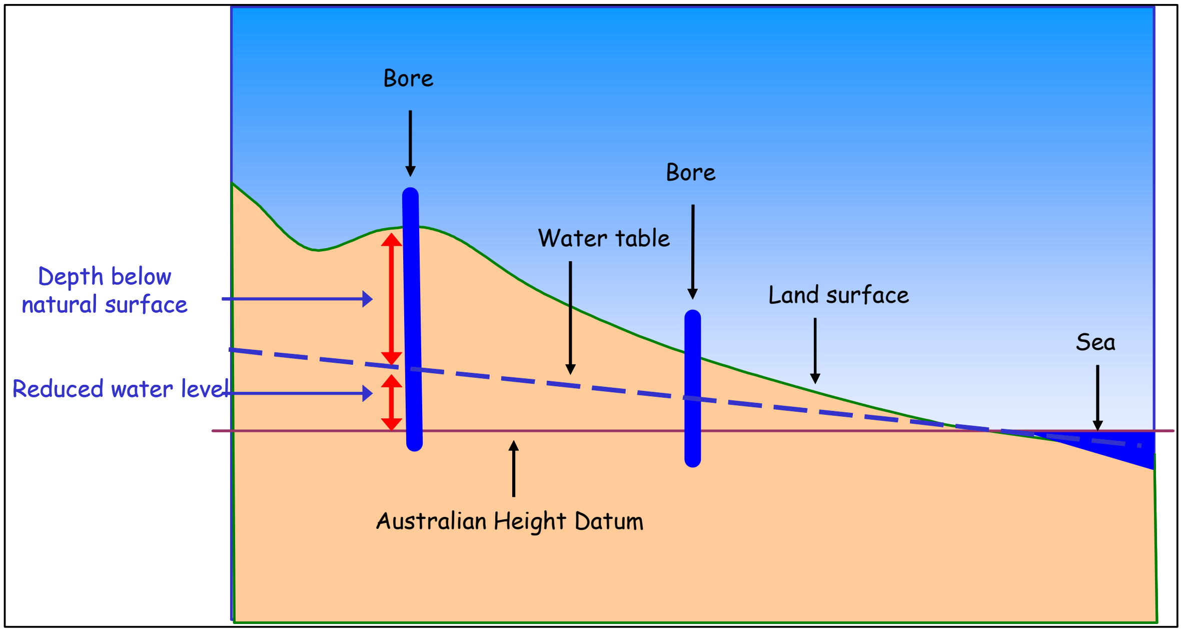


Figure 5 Measures of groundwater level depth below natural surface and against the Australian height datum

3.2 Hydraulic gradient

A hydraulic gradient is the difference between the hydraulic head measured at two points in an aquifer divided by the distance between them (Figure 6).

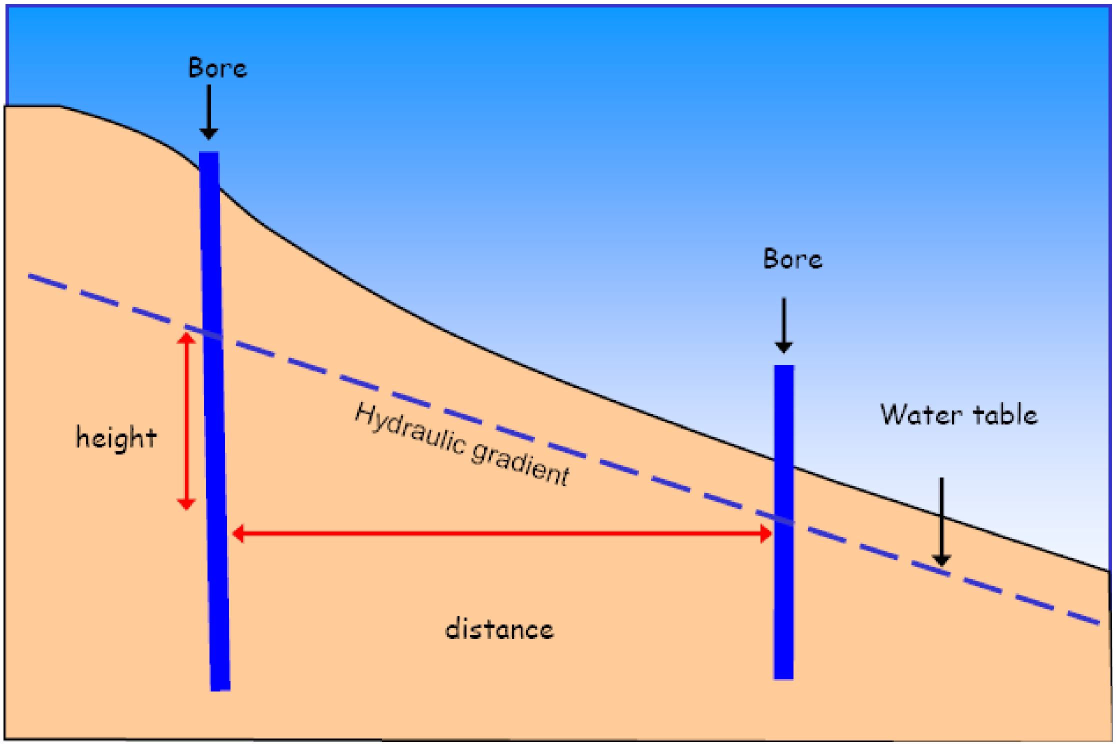


Figure 6: Hydraulic gradient slope between two bores

3.3 Transmissivity (T)

Transmissivity describes the ability of the aquifer to transmit groundwater throughout its entire saturated thickness (Figure 7).

Transmissivity is measured as the rate at which groundwater can flow through an aquifer section of unit width under a unit hydraulic gradient.

Transmissivity can be determined from a pumping test using the levels of drawdown over time pumped.

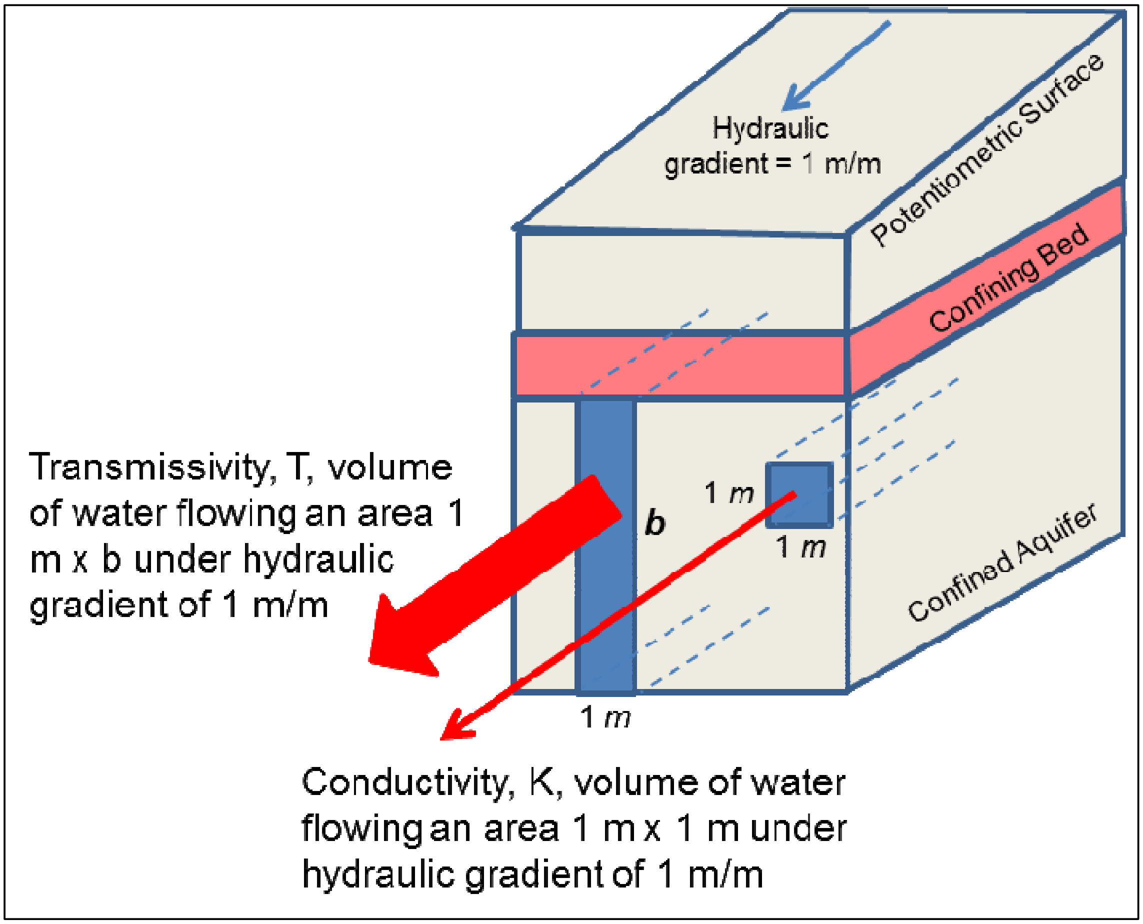


Figure 7 Aquifer transmissivity and hydraulic conductivity (McKinney, 2015)

3.4 Hydraulic conductivity (K)

Hydraulic conductivity is the ease with which water can move through an aquifer.

Hydraulic conductivity can be determined by dividing the transmissivity of the aquifer by the aquifer thickness (Figure 7).

The hydraulic conductivity can vary in a geological unit over relatively short distances, particularly in fractured rock aquifers.

Typical values for hydraulic conductivity are:

Table 1 Typical hydraulic conductivity of geological units (adapted from Domenico and Schwartz 1990)

Geological unit	Hydraulic conductivity (m/d)
Fine sand	0.02 to 17
Coarse sand	0.08 to 520
Gravel	26 to 2,592
Shale	8×10^{-9} to 2×10^{-4}
Sandstone	3×10^{-5} to 0.5
Permeable basalt	0.03 to 1,728

3.5 Storage coefficient (S)

The storage coefficient or storativity is the volume of water released from storage with respect to the change in head (water level) and surface area of the aquifer.

The value of the storage coefficient is dependent upon whether the aquifer is unconfined or confined.

3.5.1 Unconfined aquifer

In an unconfined aquifer, the predominant source of water is from gravity drainage as the aquifer materials are dewatered during pumping.

The storage coefficient is approximately the same as the percentage of pore space in the aquifer. The storage coefficient for an unconfined aquifer ranges from 0.01 to 0.30.

Unconfined aquifers can produce more water for a smaller change in head compared to confined aquifers (Figure 8).

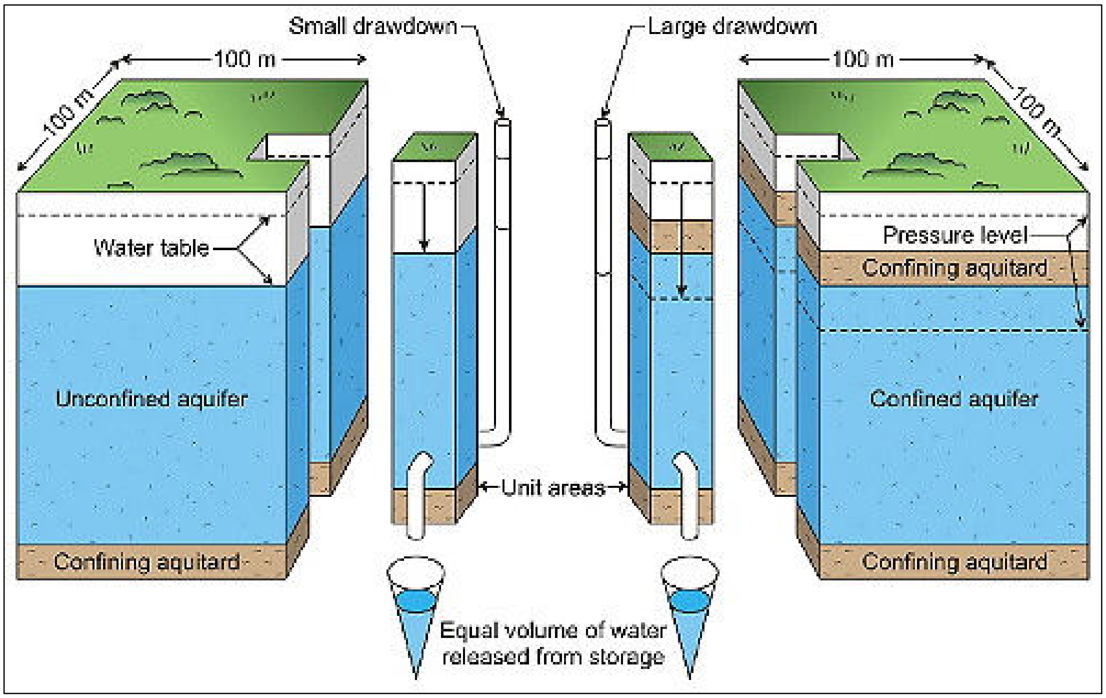


Figure 8 Larger drawdown in confined aquifer compared to unconfined aquifer (Connected Waters Initiative 2013)

3.5.2 Confined aquifer

Water released from storage in a confined aquifer is from compression of the aquifer and expansion of the water when pumped.

During pumping, the pressure is reduced in a confined aquifer, but the aquifer is not dewatered. The storage coefficient in confined aquifers ranges from 1×10^{-5} to 1×10^{-3}.

4 Groundwater flow

4.1 Groundwater flow

Groundwater flows from recharge to discharge areas through pores and fractures in sediment and rock in the zone of saturation (Figure 9).

Groundwater flows from high elevation to low elevation and from high pressure to low pressure.

There are local, intermediate and regional groundwater flow systems. Groundwater residence times may range from tens to tens of thousands of years.

The rate of groundwater flow is dependent on the hydraulic conductivity and hydraulic gradient. The greater the hydraulic conductivity or the greater the hydraulic gradient the more rapid groundwater flows.

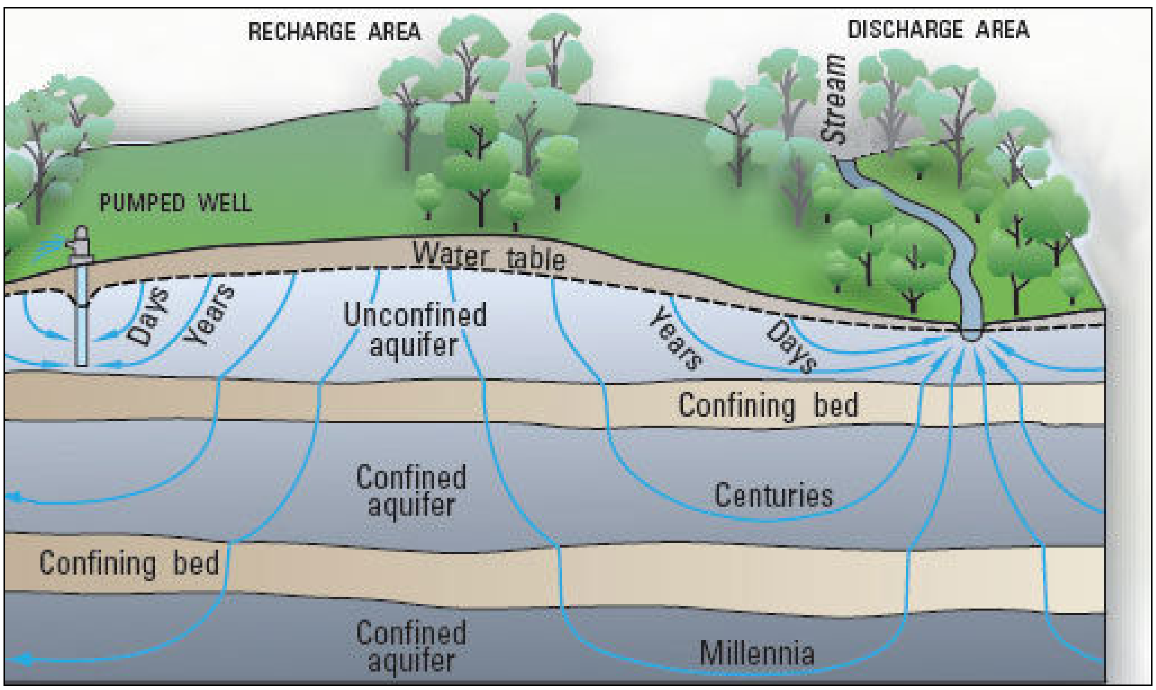


Figure 9 Groundwater flow (USGS 2015)

4.2 Recharge

Recharge is the process whereby groundwater is replenished by water entering the groundwater system (Figure 10). Recharge does not include water held in the soil in the unsaturated zone that may be evaporated, taken up by plants, or discharge at topographic lows.

Groundwater can be recharged from rainfall, irrigation infiltration or leakage from surface water bodies (e.g. stream, channel, lake).

Recharge to unconfined aquifers occurs over a wide area directly above the aquifer.

Recharge to confined aquifers occurs where the aquifer is exposed at the surface, or from leakage through confining layers. Recharge to confined aquifers can occur directly where it outcrops (i.e. typically at a higher elevation many kilometres away where it is unconfined) or via slow downward seepage through an overlying leaky aquitard.

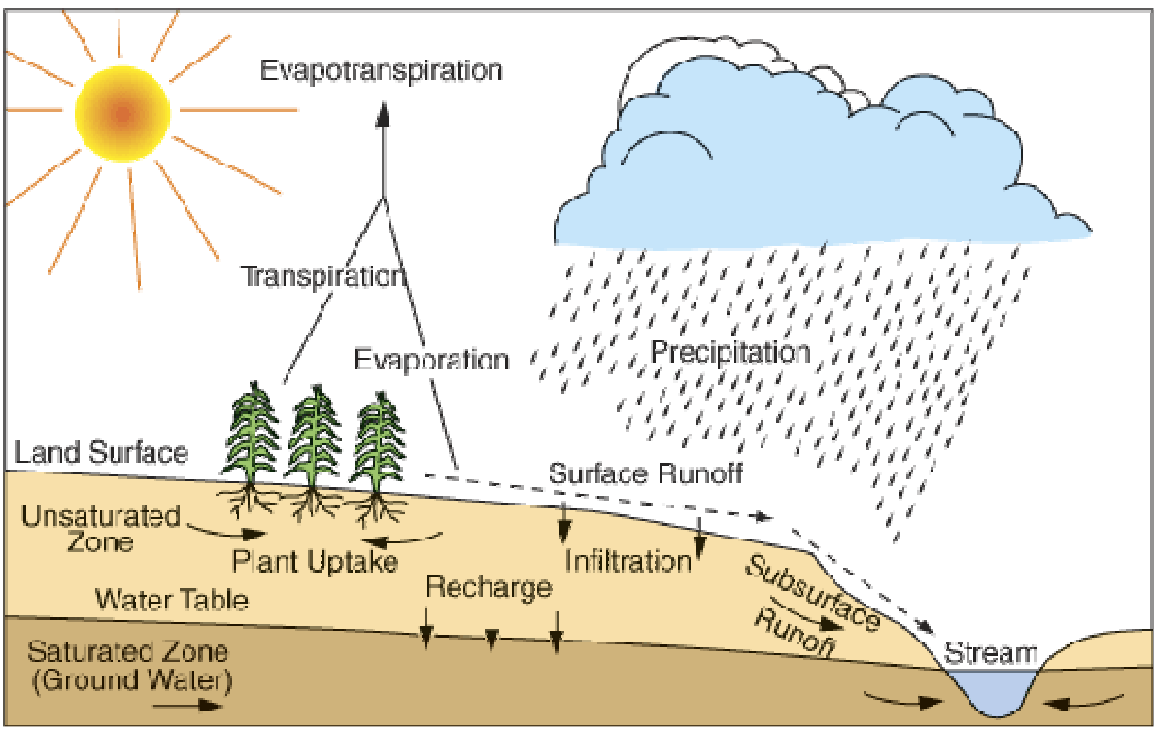


Figure 10 Groundwater recharge to unconfined aquifer (Kansas Geological Survey 2003)

4.3 Discharge

Discharge is when groundwater leaves the aquifer.

Discharge can occur through groundwater pumping, leakage to surface water bodies (e.g. base flow), or spring seepage (Figure 11).

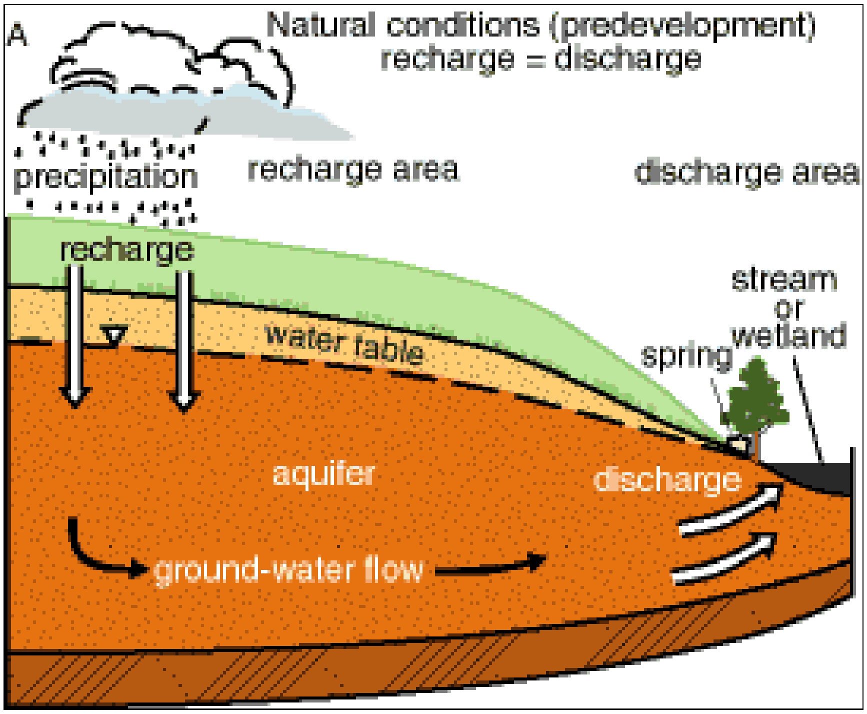


Figure 11 Groundwater discharge (Kansas Geological Survey 1998)

4.4 Spring

Springs exist where the watertable intersects the land surface and water flows out of the ground (Figure 12)

Springs can occur in the following settings:

1. low parts of the landscape
2. where a high permeability rock overlies a low permeability rock
3. where faults or fractures provide preferred pathways for groundwater flow

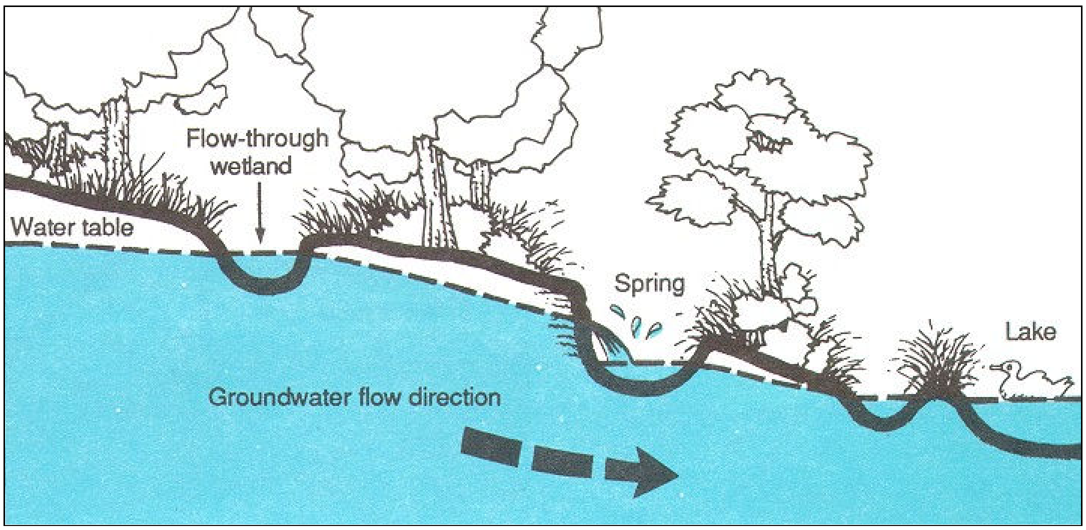


Figure 12 Spring occurrence (Raymond 1988)

4.5 Groundwater interaction with surface water

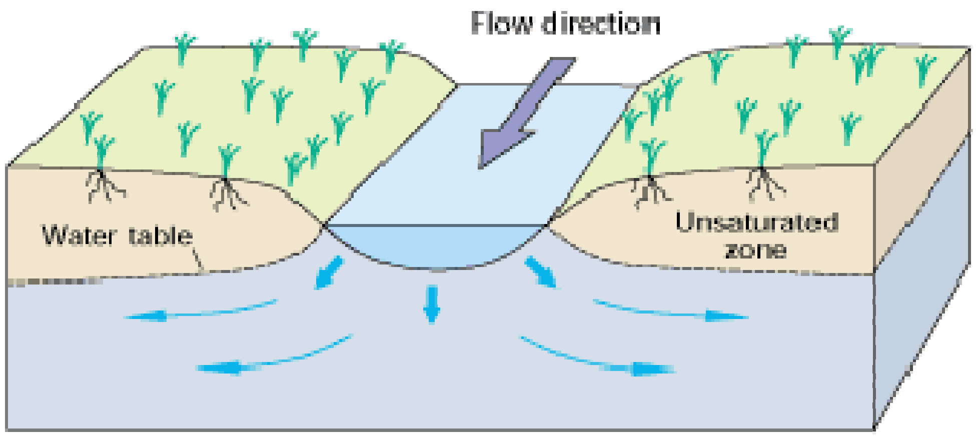
Where the groundwater level is higher than the surface water level groundwater can discharge into a stream (called a gaining stream) (Figure 13).

Where the surface water level is higher than the groundwater level the river can leak to recharge the groundwater system (losing stream).

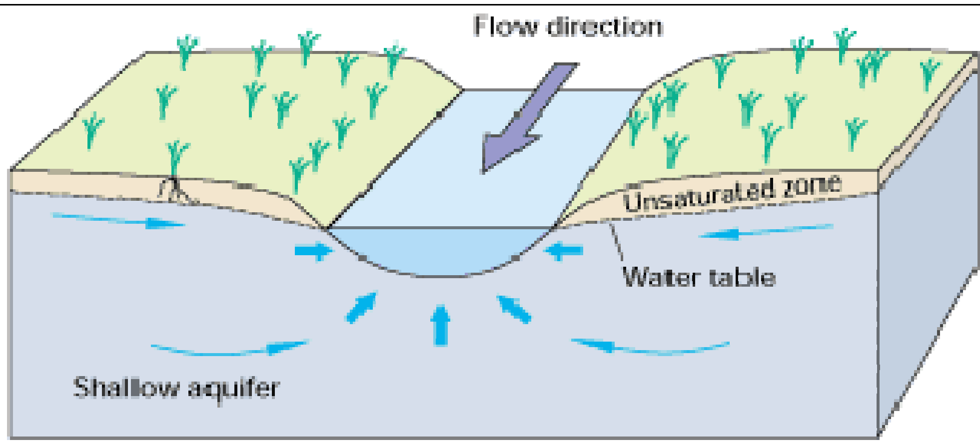
Groundwater can discharge to a stream in some places and leak back into the groundwater system in others.

The flow of water between the surface water and the aquifer is called the seepage flux.

Seepage flux is largely controlled by the hydraulic gradient between the surface water level and the groundwater level and the hydraulic properties of the aquifer, as well as the geological material separating the aquifer from the surface water feature.



a) losing stream



b) gaining stream

Figure 13: surface water-groundwater interactions (Winter, Harvey, Franke & Alley 1998)

4.6 Groundwater dependent ecosystem

A groundwater dependent ecosystem (GDE) is an ecosystem that relies on groundwater, to some degree, for its survival (Figure 14).

Types of groundwater dependent ecosystems include:

1. aquifer and cave ecosystems including stygofauna (fauna that live in groundwater) in fractured rock aquifers
2. ecosystems dependent on surface expression of groundwater including base flow (e.g. fish in remnant aquatic pools), wetlands, mound springs and sea grass beds
3. ecosystems dependent on subsurface presence of groundwater where roots tap into the groundwater system e.g. red gums

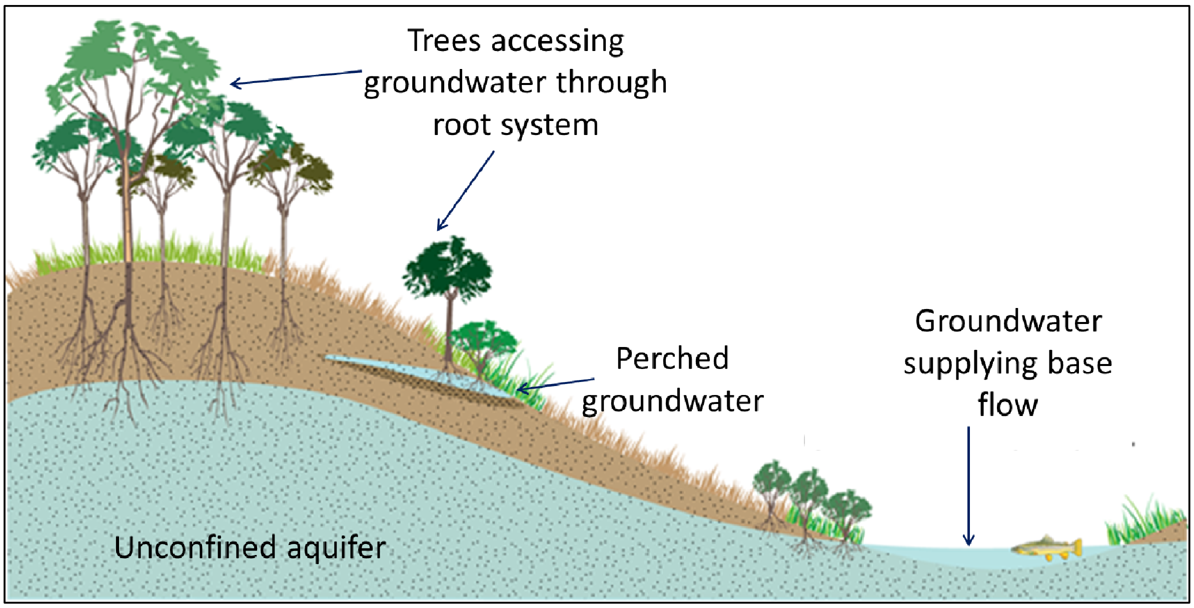


Figure 14 Examples of groundwater dependent ecosystems (modified from Texas A&M University 2013)

5 Groundwater pumping

5.1 Pumping test

A pumping test is a test where water is pumped from a bore over a period of time at a known rate.

During operation of the pump the groundwater levels decline. When the pump is switched off the groundwater levels recover.

The drawdown is measured in the pumping bore, and any surrounding monitoring bores, over the duration of the pumping test (Figure 15).

The time versus drawdown data can be used to determine aquifer transmissivity and storativity.

A pumping test can also inform the optimum pumping rates from the bore.

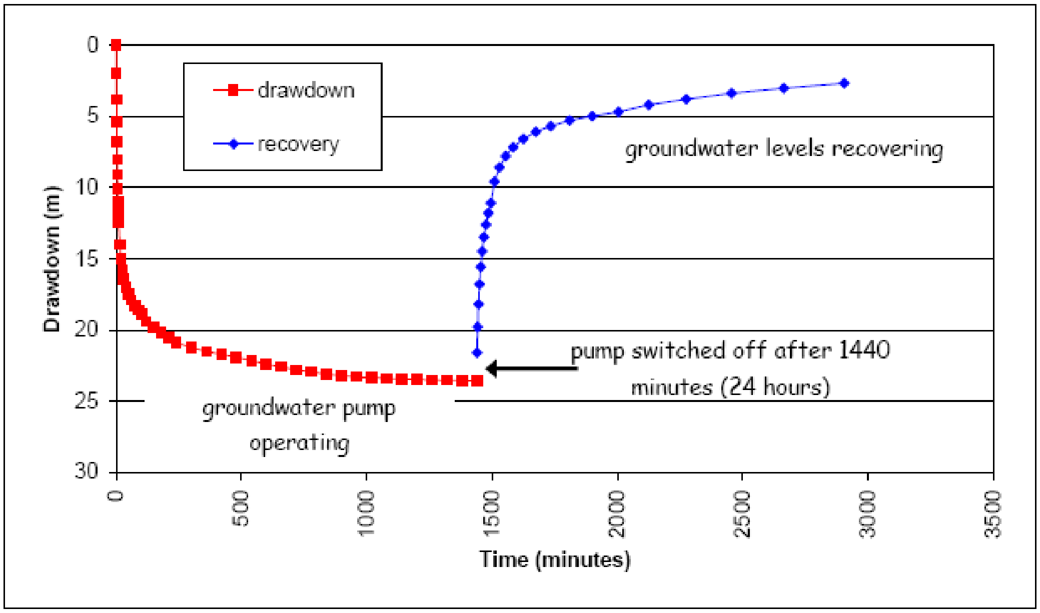


Figure 15 Pumping test time-drawdown data

5.2 Cone of depression

Groundwater pumping creates a cone of depression (drawdown) of the watertable or potentiometric surface surrounding the pumped bore.

The distance the drawdown cone extends depends primarily on the nature of the aquifer, the pumping rate and the pumping period.

Aquifers with lower storativity create deeper and wider cones than aquifers with higher storativity (Figure 16).

Aquifers with low transmissivity develop deep and narrow cones of depression whereas aquifers with high transmissivity are characterized by shallow and wide cones.

In a confined aquifer, the potentiometric surface is lowered in the cone of depression but the aquifer always remains saturated.

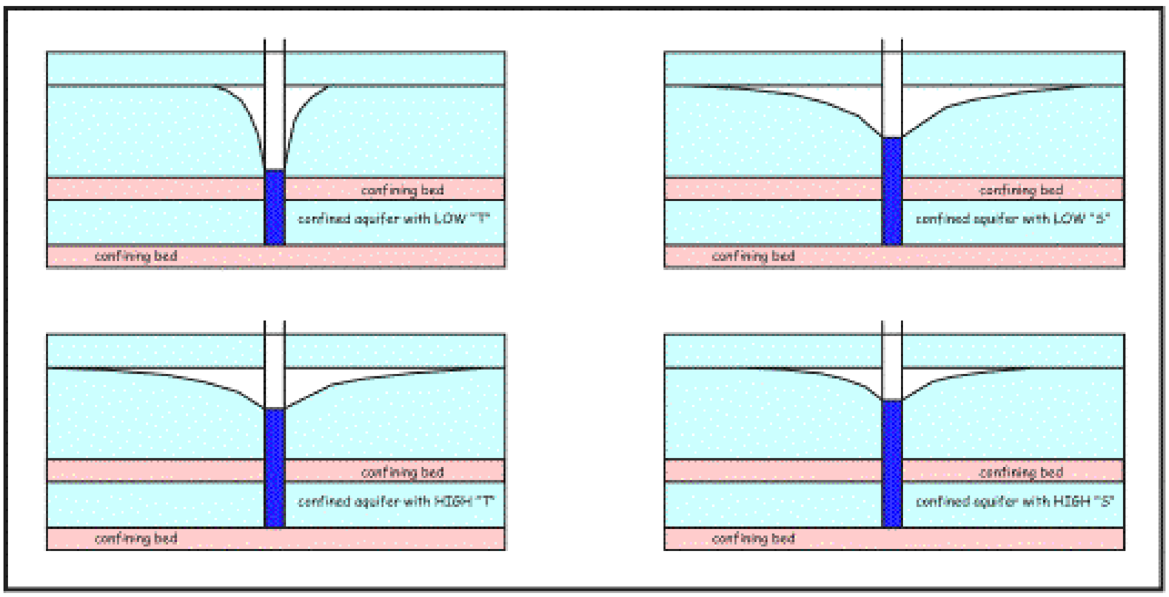


Figure 16 Cone of depression for various confined aquifer characteristics (modified from Freeze and Cherry 1979 by Utah Division of Water Rights, date unknown)

5.3 Bore construction

A borehole when drilled may intersect multiple aquifers.

A bore casing and screen (slotted casing) are placed into the borehole.

Gravel pack may be placed in the annulus (space between the drilled bore hole and the bore casing e.g. PVC) around the screen, or the natural formation may be used.

Bentonite is a type of clay used to seal aquifers and avoid cross contamination.

Borehole is cemented at the surface to avoid contaminants entering groundwater systems.

An example bore construction is shown in Figure 17.

Guidelines for Minimum Construction Requirements for Water Bores in Australia are available through the Australian Drilling Industry Association: http://www.adia.com.au/wp-content/pdf/MCR3RD2012B.pdf

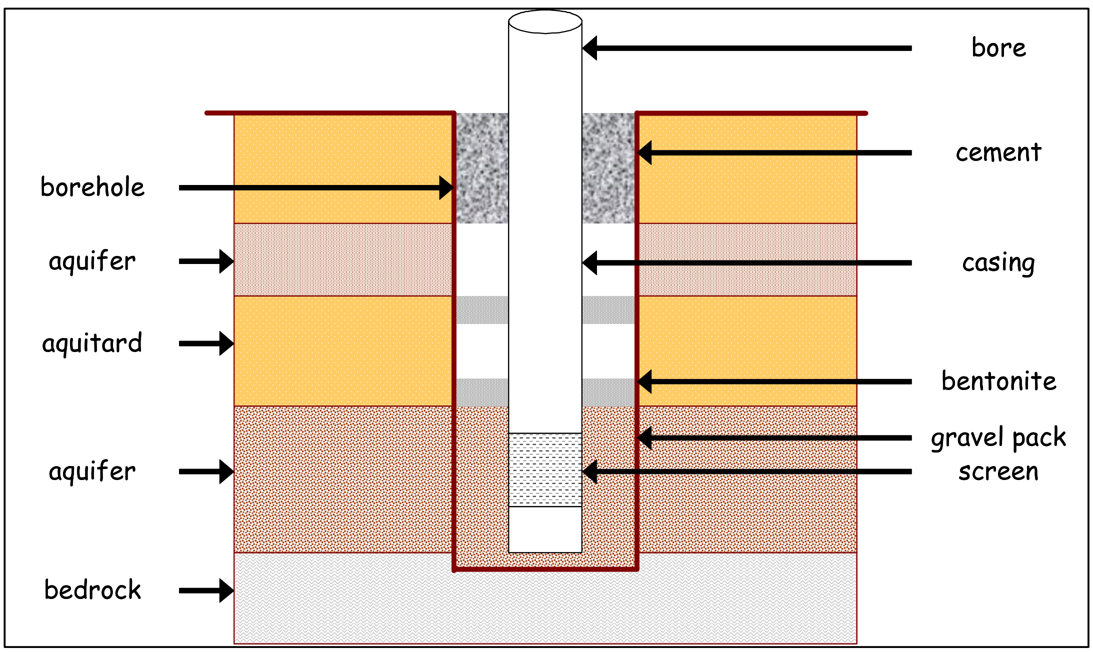


Figure 17: Example Bore Construction

5.4 Pumping interference

Pumping interference occurs when the drawdown cone resulting from the pumping of one bore impacts on the available drawdown in a neighbouring bore or an environmental feature (e.g. stream) (Figure 18).

The available drawdown is the height of water in a bore above the pump that may be displaced due to pumping. A reduction in the available drawdown can reduce the bore yield.

Where the drawdown cone intercepts a stream, it can cause the stream to lose water to the groundwater system.

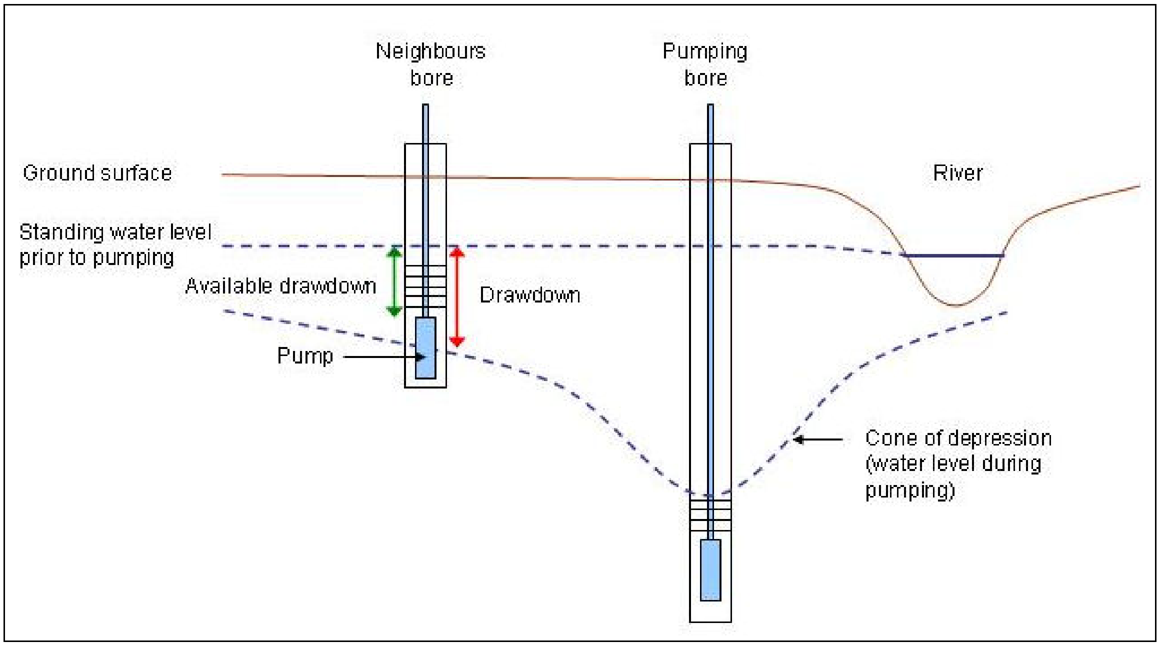


Figure 18: Pumping interference to neighbouring bore and stream

5.5 Entitlement

Entitlement is the volume of groundwater licence that may be extracted in a year subject to licence conditions.

The Victorian *Water Act 1989* governs groundwater licensing in Victoria. A licence to take and use groundwater under section 51 of the Victorian *Water Act 1989* is required for any purpose other than domestic and stock use.

5.6 Allocation

An allocation is a percentage of licence entitlement that is permitted to be pumped in a water year.

For example, a groundwater licence with 100 ML/year entitlement where a 70% allocation has been announced may only extract up to 70 ML in that water year.

A water year, sometimes referred to as a season, is a period of 12 months commencing 1 July.

6 Groundwater monitoring

6.1 Groundwater monitoring

Monitoring of groundwater levels is undertaken to observe changes in groundwater levels over time to support resource planning and management.

The State Observation Bore Network (SOBN) comprises strategically located bores owned and monitored by the Department of Environment, Land, Water and Planning (DELWP) (Figure 19).

Groundwater levels are monitored by DELWP quarterly. Groundwater levels are monitored monthly in key bores by Goulburn-Murray Water.

Figure 19 State observation bores

6.2 Water measurement information system (WMIS)

When a bore is drilled by a licensed driller, the driller must submit a bore completion report to Goulburn-Murray Water which captures information on bore location, lithology (description of rock or sand formation), construction and yield.

The state water measurement information system (WMIS) is an online database where bore information is stored.

Groundwater level and quality information from the State Observation Bore Network is also stored on the WMIS.

Groundwater information is publicly available and can be retrieved from the WMIS at the following web address:

http://data.water.vic.gov.au/monitoring.htm

6.3 Hydrograph

A hydrograph is a plot of groundwater level trends over time (Figure 20).

Hydrographs can be used to interpret seasonal influences on groundwater levels such as climate such as seasonal rainfall, floods, drought and climate change.

Hydrographs can also be used to interpret aquifer response to groundwater pumping (i.e. when groundwater is pumped) and applied irrigation.

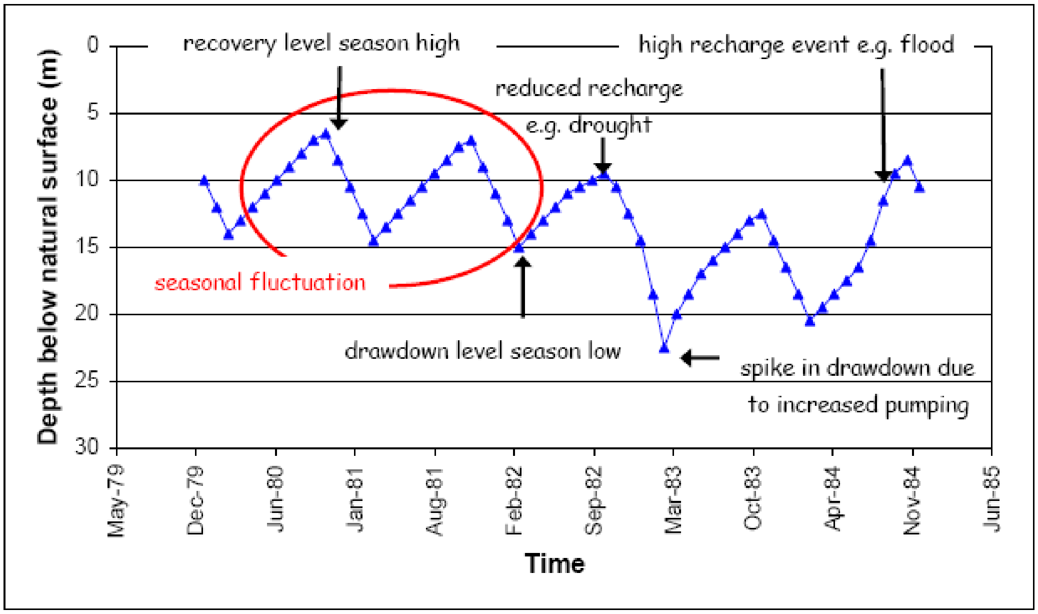


Figure 20 Example of a groundwater hydrograph

6.4 Recovery level

The recovery level is the level to which groundwater will recover or rise in a bore (Figure 20).

Regionally, groundwater recovery occurs in response to seasonal recharge (i.e. winter and spring rainfall).

Locally, groundwater recovery in a pumping bore occurs when a groundwater pump is switched off.

6.5 Drawdown level

The drawdown level is the level to which groundwater is lowered in a bore due to pumping (Figure 18 & Figure 20)

Drawdown occurs in response to:

1. pumping from the bore
2. interference from a neighbouring pumping bore
3. in response to local, intensive groundwater pumping
4. regional seasonal decline due to discharge in excess of recharge

6.6 Nested monitoring bores

At some locations there are multiple monitoring bores which are screened at different depths to observe the relationship between different aquifers such as their connection, response to pumping, recharge mechanisms, and the potential direction of vertical groundwater flow (Figure 21 & Figure **22**).

In areas where the shallow monitored bore groundwater levels are higher than the deeper bore, there is potential for downward movement of groundwater.

In areas where the deeper monitored bore groundwater levels are higher than the shallow bore, there is potential for upward movement of groundwater.

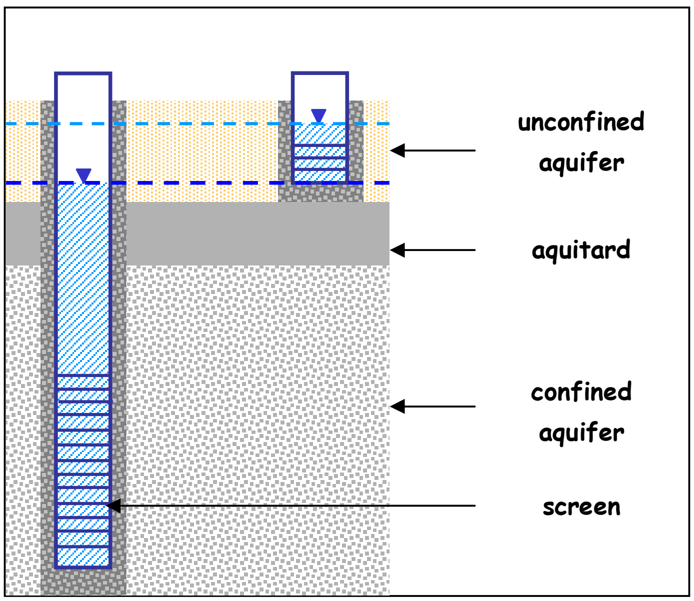


Figure 21 Nested monitoring bores in cross-section

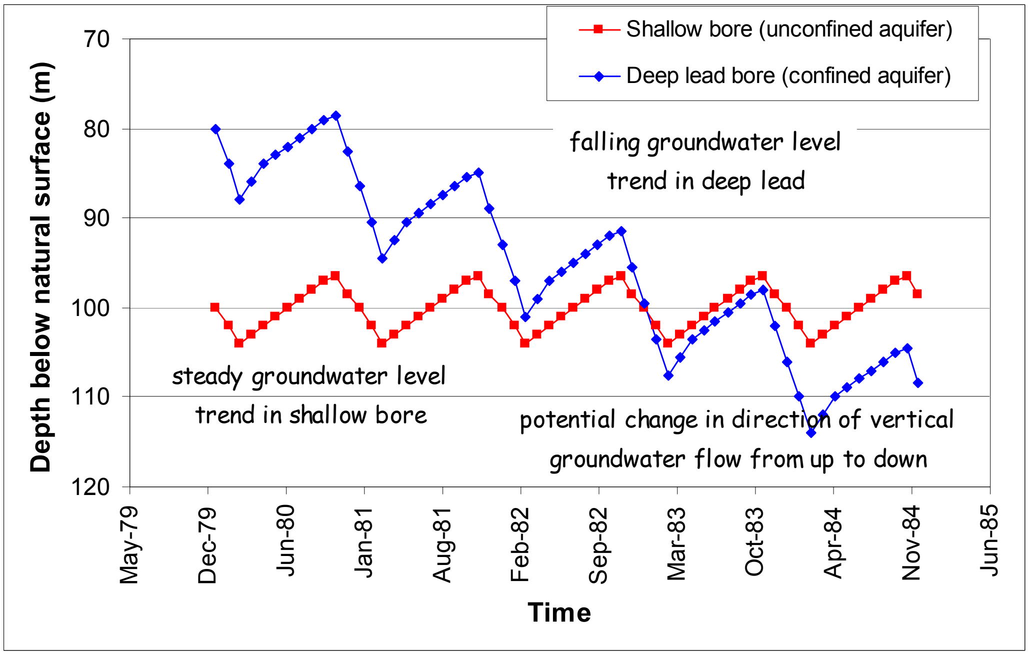


Figure 22 Example of a hydrograph for nested monitoring bores

6.7 Water table

The watertable is the surface between the saturated and unsaturated zones. It is the top of an unconfined aquifer (Figure 23).

The watertable moves up and down on a seasonal basis. It is generally highest during winter/spring owing to higher recharge and reduced pumping and lowest during the summer/autumn because of limited recharge and increased pumping.

Contouring the groundwater levels from bores in an unconfined aquifer produces a watertable map.

Watertable maps indicate groundwater flow direction.

A watertable map can be used to identify areas of high watertable that might result in waterlogging or land salinity.

Watertable maps can also be used to identify areas of an aquifer under stress from pumping.

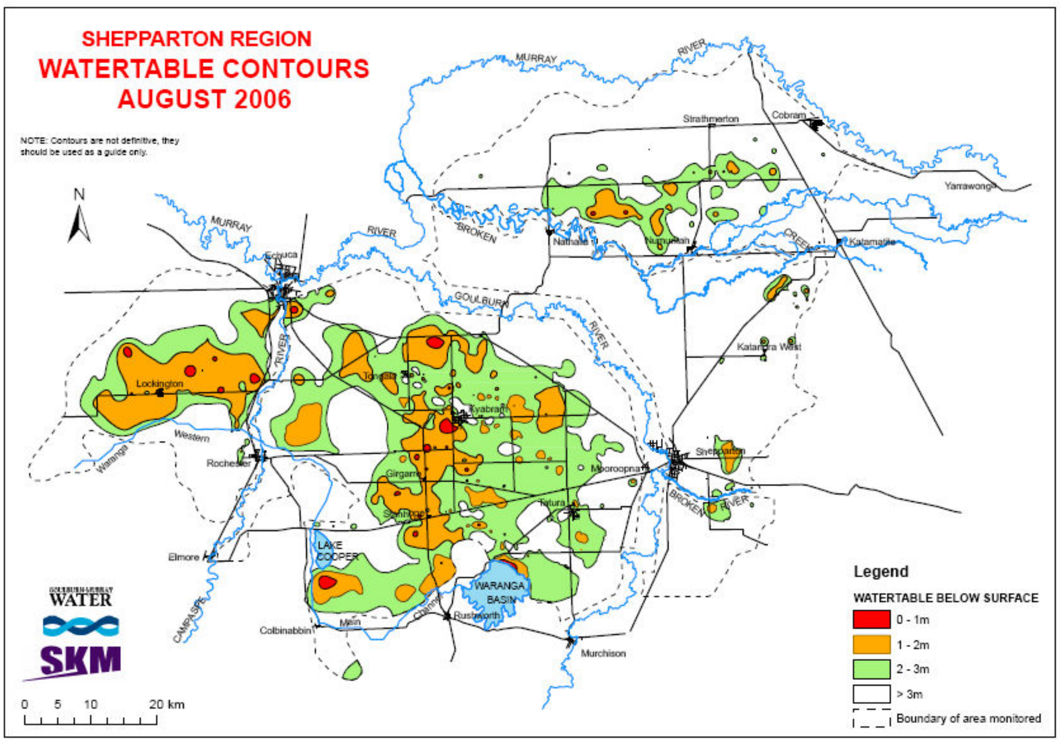


Figure 23 Shepparton Irrigation Region watertable map August 2006

6.8 Potentiometric surface

In confined aquifers, the level that the water rises to in a bore is the potentiometric level.

Contouring the potentiometric levels creates a potentiome.tric surface for the confined aquifer (Figure 24). This is similar to the watertable for an unconfined aquifer.

The potentiometric surface provides an indication of the level to which water will rise in a bore screened in a confined aquifer.

The potentiometric surface indicates the groundwater flow direction.

The potentiometric surface can be used to identify areas of the aquifer under stress from pumping.

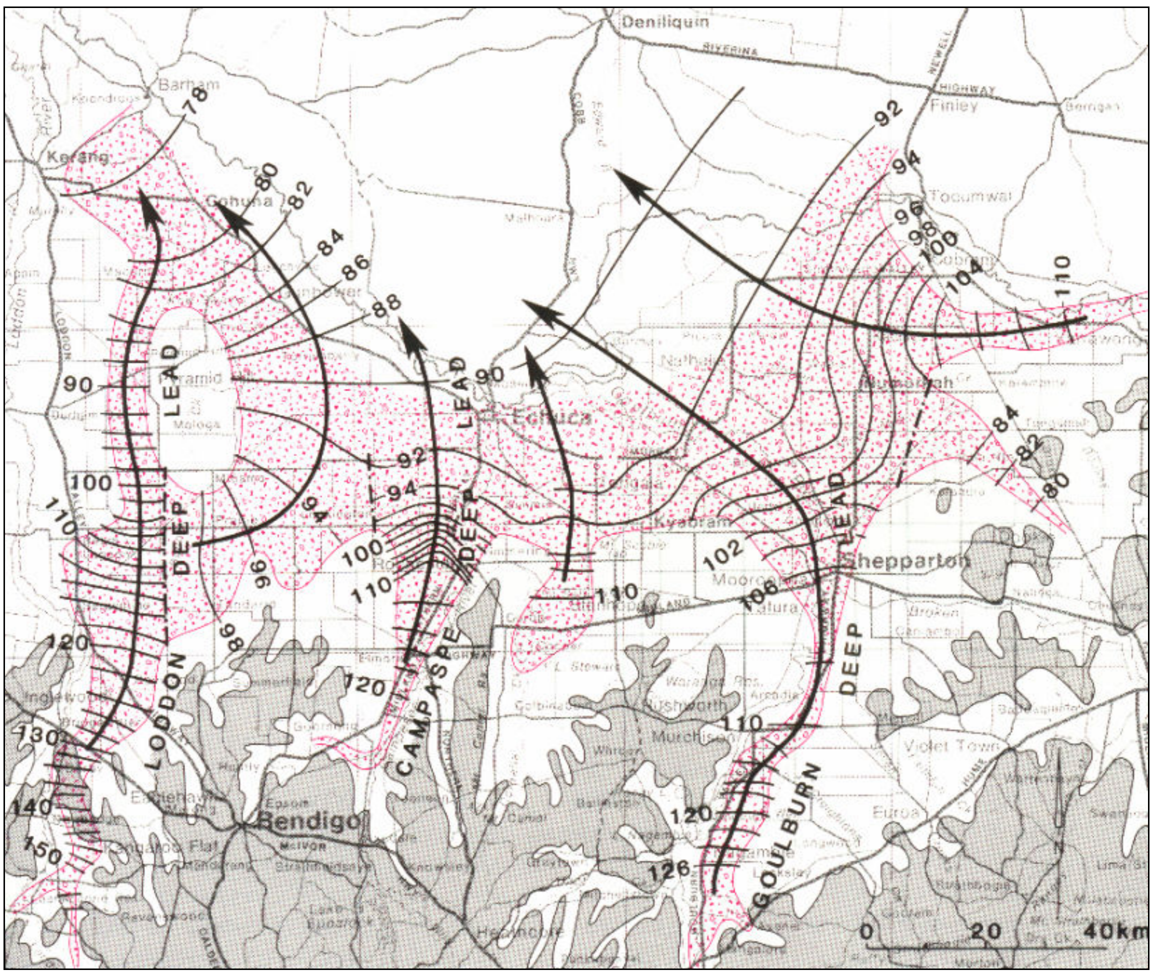


Figure 24: Potentiometric surface of the deep lead system of Northern Victoria – August 1981 illustrating northward groundwater flow (Macumber, 1991)

6.9 Groundwater quality

Groundwater quality can vary within and between aquifers. Factors such as recharge, discharge, land use, groundwater level and origin influence groundwater quality.

Groundwater chemistry can be used to determine groundwater flow paths and relative age. Groundwater protection legislation in Victoria is based on the concept of Beneficial Use, which identifies categories of groundwater based on water quality criteria.

Total Dissolved Solids concentration (a measure of salinity in mg/L) is used to determine the highest beneficial use category for groundwater (Table 2).

Table 2 Beneficial Use classifications (EPA 1997)

	Segments (mg/L TDS)				
Beneficial Uses	**A1** (0-500)	**A2** (501-1,000)	**B** (1,001-3,500)	**C** (3,501-13,000)	**D** (greater than 13,000)
1. Maintenance of ecosystems	✓	✓	✓	✓	✓
2. Potable water supply:					
desirable	✓				
acceptable		✓			
3. Potable mineral water supply	✓	✓	✓		
4. Agriculture, parks and gardens	✓	✓	✓		
5. Stock watering	✓	✓	✓	✓	
6. Industrial water use	✓	✓	✓	✓	✓
7. Primary contact recreation (e.g. bathing, swimming)	✓	✓	✓	✓	
8. Buildings and structures	✓	✓	✓	✓	✓

7 References

Arizona State University. (Date unknown). Introduction to hydrology. [WWW document] https://www.asu.edu/courses/gph111/Hydrology/HydrologyOutline.html (accessed 23/11/2015)

Connected Waters Initiative (2013). Groundwater levels and aquifer storage. [WWW document] http://www.connectedwaters.unsw.edu.au/schools-resources/fact-sheets/groundwater-levels-and-aquifer-storage (accessed 23/11/2015)

Department of Sustainability and Environment (DSE). (2009). Groundwater Notes 1. Melbourne, State of Victoria Department of Sustainability and Environment.

Domenico, P.A., and Schwartz, F.W. (1990). Physical and Chemical Hydrogeology. United States of America, John Wiley & Sons, Inc.

Driscoll, F.D. ed. 1986. Groundwater and wells. St Paul, MN: Johnson Screens

Environment Protection Authority (EPA). (1997). State Environment Protection Policy (Groundwaters of Victoria). Victoria Government Gazette, S 160. [WWW document]. http://www.epa.vic.gov.au/~/media/Publications/S160.pdf (accessed 24/11/15)

Fetter, C.W. 2001. Applied hydrogeology. 4th ed. Upper Saddle River, NJ: Prentice-Hall

Freeze, R.A., and Cherry, J. A. 1979. Groundwater, Englewood Cliffs, NJ: Prentice-Hall

Ghost Watershed Alliance Society. (2015). What are groundwater aquifers? [WWW document] http://www.ghostwatershed.ca/GWAS/Aquifers.html (accessed 23/11/2015).

Kansas Geological Survey (2003). Factors influencing recharge. [WWW document]. http://www.kgs.ku.edu/Publications/pic22/pic22_2.html (accessed 23/11/2015)

Kansas Geological Survey. (1998). Stream-aquifer interaction. [WWW document]. http://www.kgs.ku.edu/Publications/pic9/pic9_2.html (accessed 23/11/2015)

Macumber, P.G. (1991). Interaction between groundwater and surface systems in northern Victoria. Department of Conservation and Environment, Victoria

McKinney, D.C. (2015). Groundwater flow equations – groundwater hydraulics presentation. [WWW document] http://slideplayer.com/slide/2328551/ (accessed 23/11/2015)

National Groundwater Association. (2007). Confined/unconfined aquifers. [WWW document] http://www.ngwa.org/Fundamentals/use/PublishingImages/aquifer_types.gif (accessed 23/11/2015)

Raymond, L.S. (1988). What is Groundwater?, New York State Water Resources Institute Bulletin No.1, Cornell University.[Accessed via WWW document: *Groundwater: Myths or Facts?* Michigan Technological University http://cseo.mtu.edu/community/groundwater/GWmyths.htm (accessed 23/11/2015)

Texas A&M University. (2013). Current and recent research. [WWW document] https://ceprofs.civil.tamu.edu/gmiller/research.html (accessed 23/11/2015)

United States Geological Survey (USGS). (2015). Groundwater discharge – the water cycle. [WWW document]. http://water.usgs.gov/edu/watercyclegwdischarge.html (accessed 23/11/2015)

Utah Division of Water Rights. (date unknown). Groundwater, aquifers and confining beds. [WWW document] http://www.waterrights.utah.gov/wellinfo/theis/hydrogeology_discussion.asp (accessed 24/11/2015)

Winter T.C., Harvey J.W., Franke O.L. and Alley W.M. (1998). Ground water and surface water; a single resource. USGS Circular 1139. US Geological Survey, Denver, Colorado. http://pubs.er.usgs.gov/usgspubs/cir/cir1139