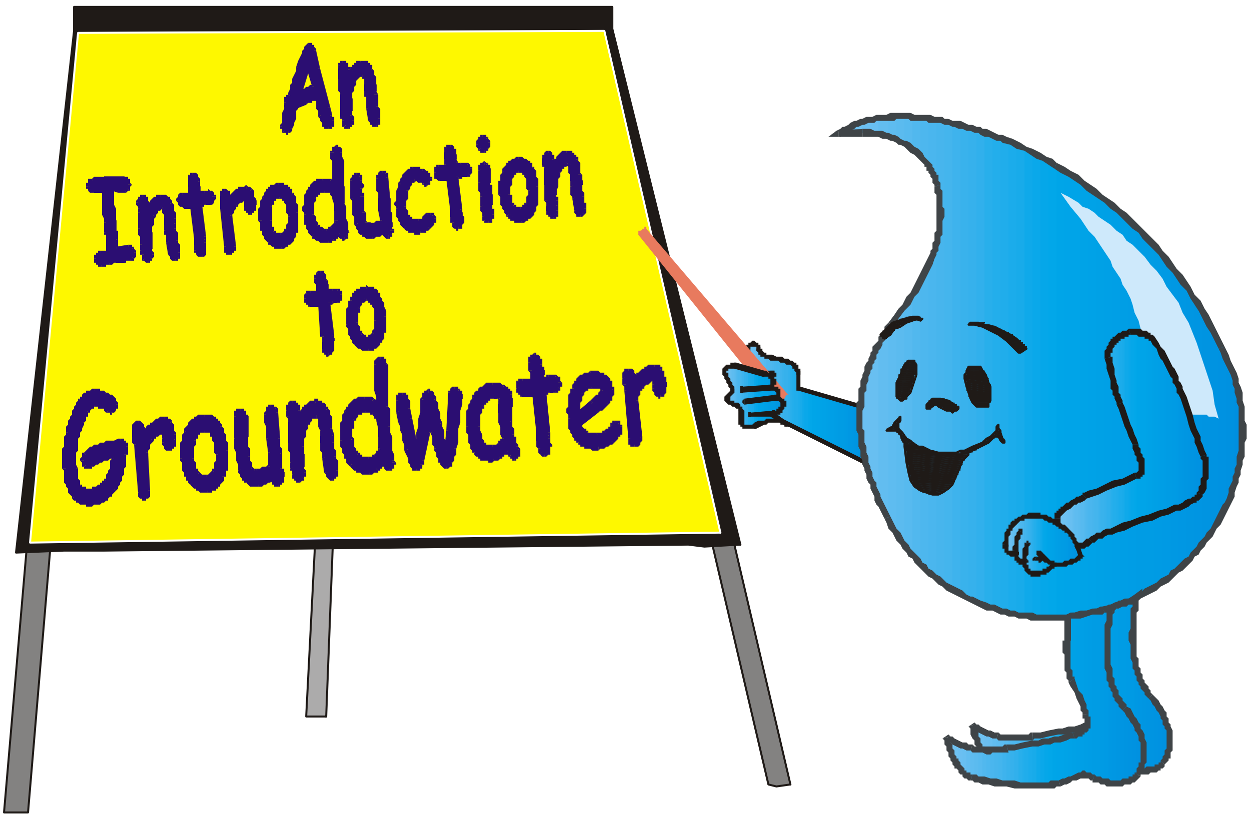
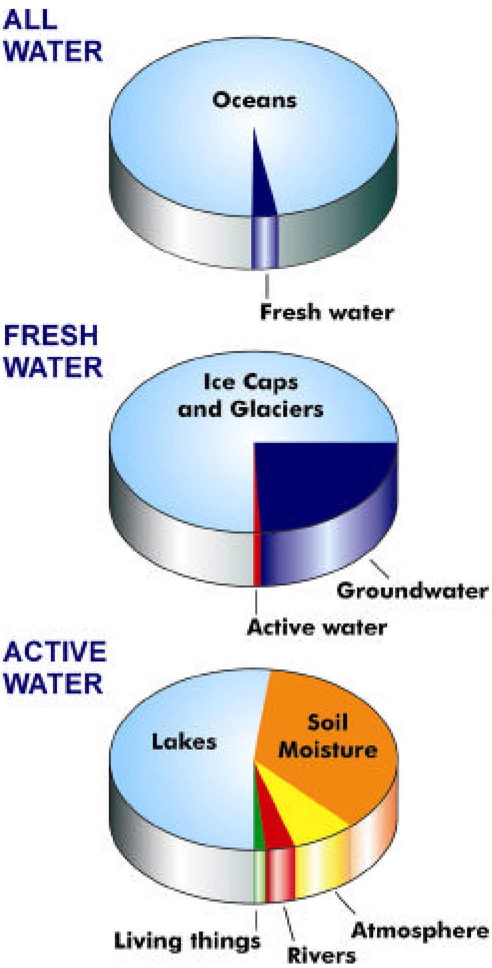

An
Introduction
to
Groundwater

Why is Groundwater Important?

When many Australians think of water, they tend to think of surface water and issues such as river salinity. Surface water in reservoirs is probably the water that most people are conscious of in their everyday lives and most capital cities in Australia are reliant on surface catchments for their daily water. There is however another water resource that is just as vital but not as visible, this is groundwater. In Australia use has increased by 40% since 1983, and in NSW, Victoria and Western Australia by over 200% over this period Many people in regional areas depend on groundwater for stock and domestic uses.



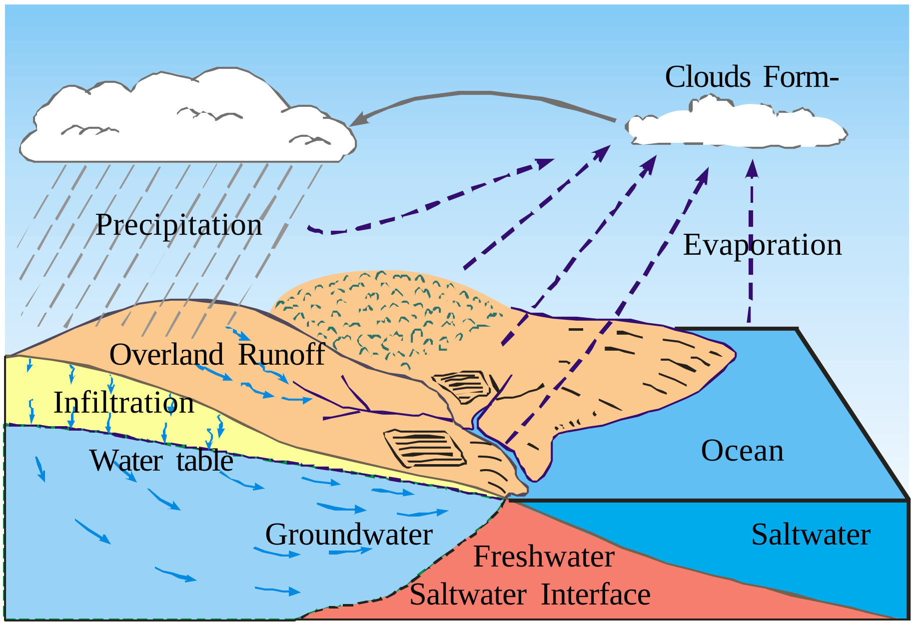
Approximately 97% of water on Earth is found within the oceans. Of the world's freshwater, approximately 75% is frozen in ice-caps and glaciers, while approximately 25% is stored as groundwater. Surface water represents less than 1% of the world's fresh water.

If all groundwater was removed from under the surface and placed on the face of the Earth, it would cover the land to a depth of 300 metres.

To almost every individual in Australia, groundwater is the closest free water. In Australia only 37% of our fresh and marginal water supplies and 14% of water use is from groundwater. Groundwater resources are under exploited in comparison to surface water resources, with only 3% of the available groundwater used, compared with 13% of surface water. However, our semi-arid climate has resulted in much of our groundwater being too saline to use.

The Hydrological Cycle

Groundwater is an integral part of the hydrological cycle. The hydrologic cycle is the endless movement of water from the atmosphere to the earth and back again. Water can exist as clouds, rain, hail, snow, groundwater, river water, in the ocean, as steam, as fog or in living things.



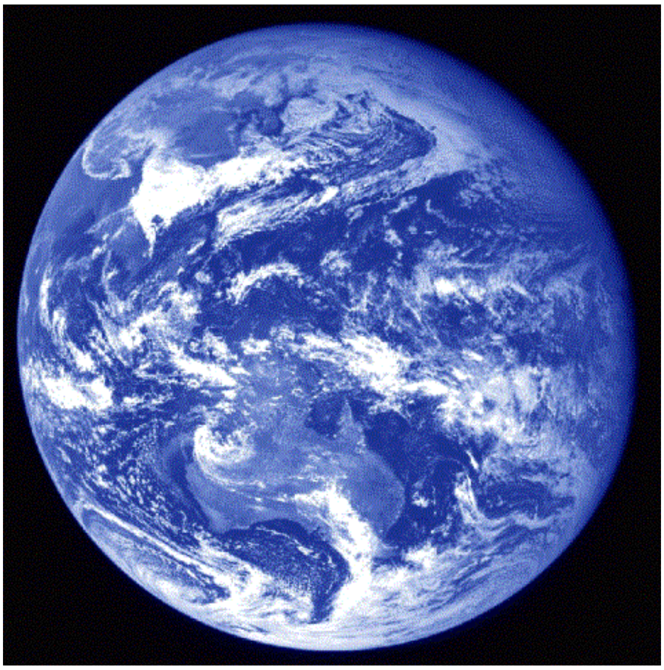
The continuation of the hydrological cycle depends on the energy supplied by the sun and the rotation of the Earth. The energy that is absorbed and released during the various stages of the hydrologic cycle helps drive the Earth's weather systems. This energy allows water to change states from liquid to vapour in a process known as evaporation. Evaporation occurs from rivers, creeks, lakes, dams, ponds and the soil, with the majority of evaporation occurring in the ocean.

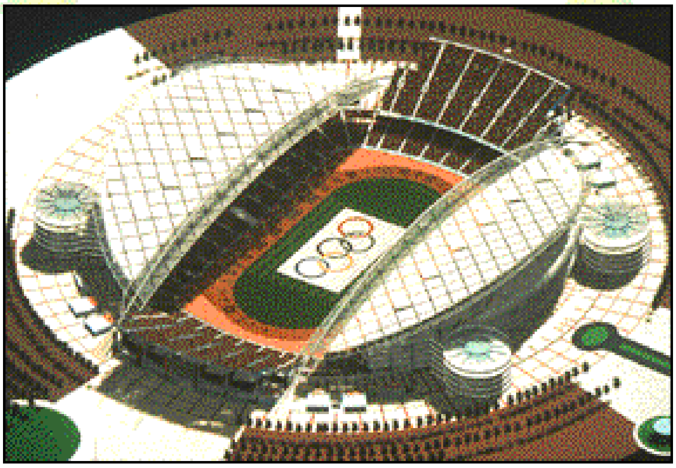
Water is returned to the Earth's surface as precipitation with the help of energy from the sun that converts vapour to liquid. Not all precipitation over land reaches the surface, with some evaporated as it falls and some intercepted by vegetation. Water that does reach the earth may also be evaporated through the process of evapotranspiration. Transpiration is the process where water is absorbed through the roots of plants and moves through the plant to its leaves where it is evaporated.

Once on the surface, water that is not evaporated from the surface can proceed in two ways. It can soak into the ground, fall into a body of water or it can runoff over land. Water soaks into the soil in a process known as infiltration. Water that is not evaporated in the soil zone will move through the subsurface to the watertable where it will travel as groundwater to rivers, creeks, lakes, springs, wells or the ocean. Runoff is surface water that can be evaporated or move overland to rivers, creeks, lakes, dams and the ocean. The amount of runoff depends on the slope of the land surface and the porosity of the surface.

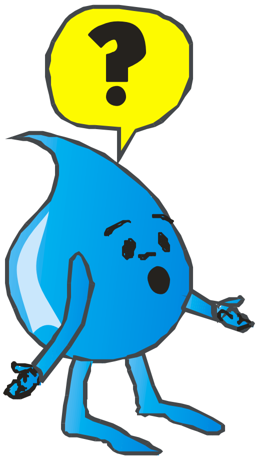
In terms of water, this planet is a closed system.

The water that is available to our planet now is the same water that was available three billion years ago, and the only water that will be available in the future. We depend on water to survive. The population of Earth is expanding rapidly and so are the demands on water, but our supply of water does not expand. This is why there is a need to conserve water and keep it clean.





The total amount of water in the hydrologic cycle has been estimated as over one billion cubic kilometres. To gain some idea of how immense this volume is, one cubic kilometre would fill 300 Olympic stadiums (Environment Canada).



What Is Groundwater?

We have already seen that groundwater is the worlds largest freshwater resource. Its volume eclipses polar icecaps and is more than two hundred times that of lakes and rivers combined. In large parts of Australia it is the only sustaining source of watersupporting towns, mines, livestock and irrigation. So what exactly is it?

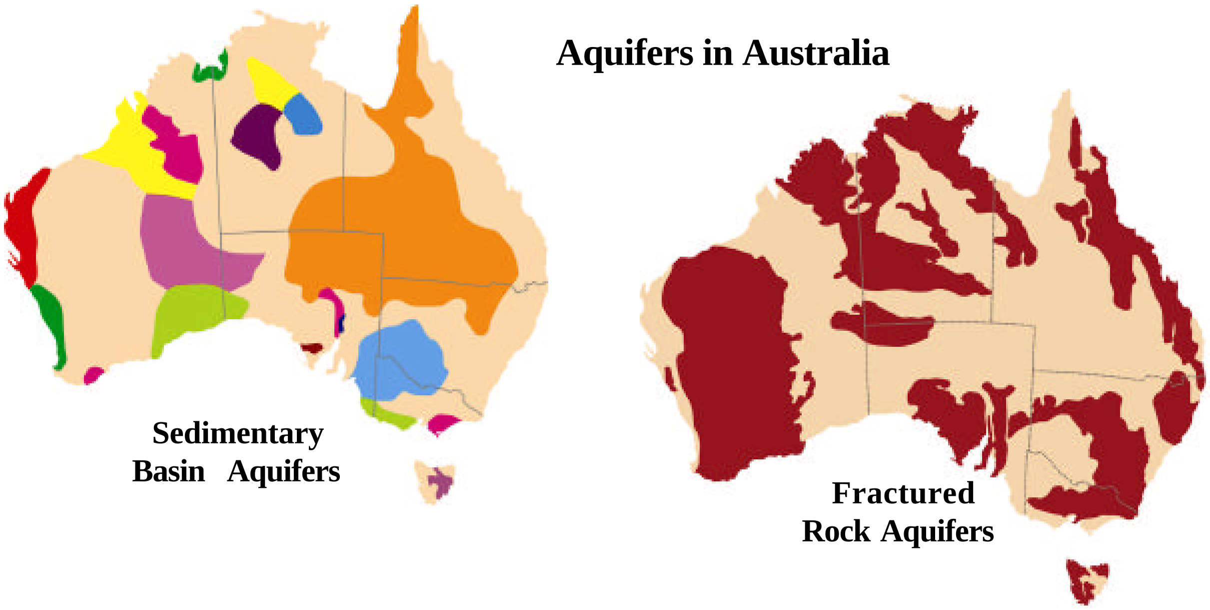
Groundwater is often perceived as flowing in underground streams, similar to surface streams.

In reality, it is only in limestone caves that groundwater will occur in this way.

Groundwater is almost everywhere underground, with groundwater systems ranging from a few square kilometres to millions of square kilometres, such as the Great Artesian Basin.

Water from the atmosphere is the basic source from which groundwater is derived.

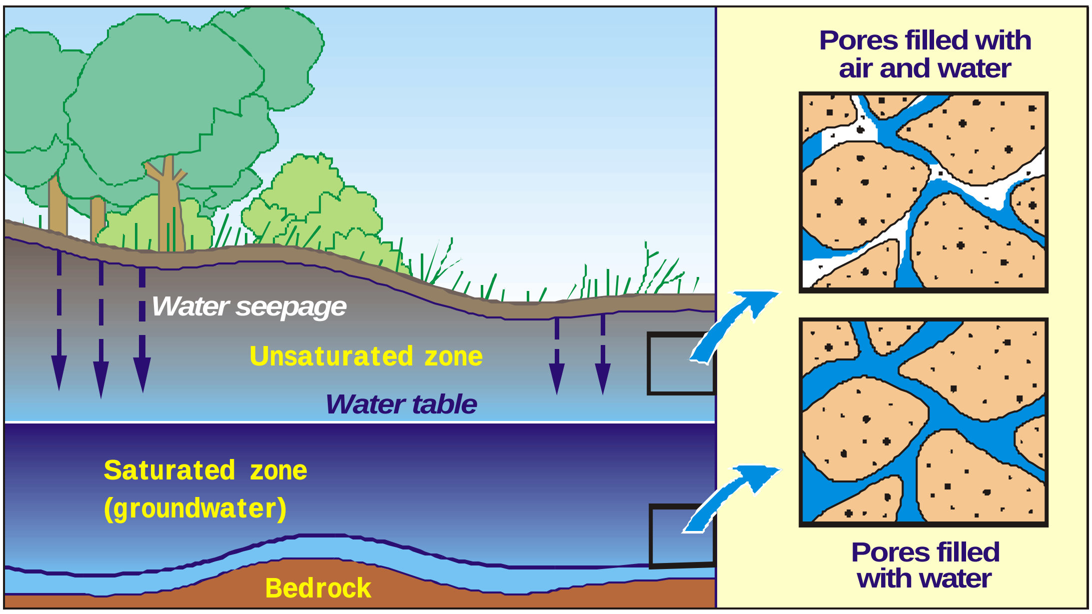
Aquifers in Australia



When it rains water can soak into the soil and then under the force of gravity move through the ground towards the water table.

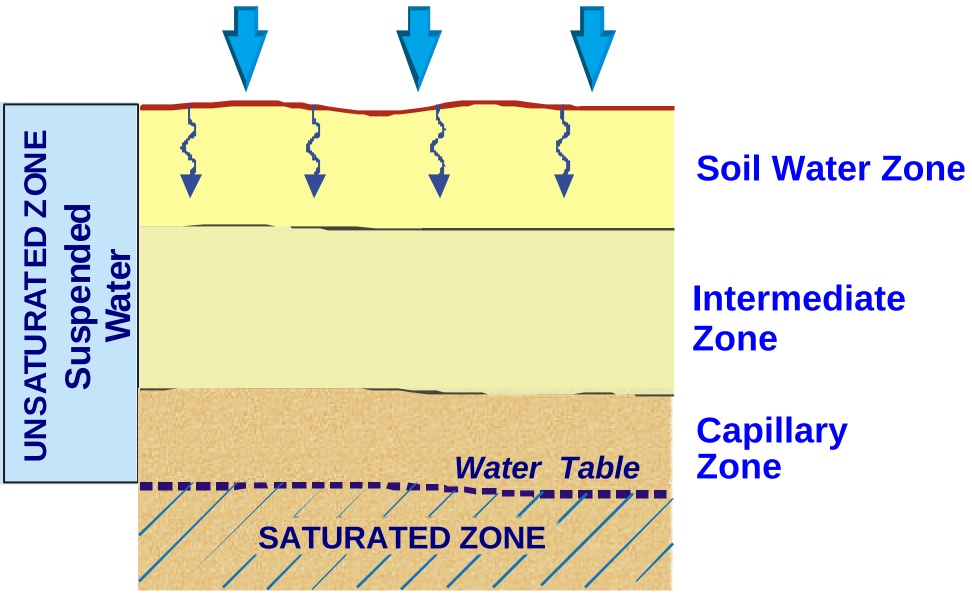
If this water reaches groundwater, then it is known as recharge. Once at the water table it is stored in rocks within pores or fractures, in much the same way as a sponge holds water. The material that holds and transmits the water is known as an aquifer.

There are two zones beneath the surface in which water occurs, the unsaturated zone (zone of aeration) and the saturated zone. In the unsaturated zone, the spaces and fractures within the soil, sediment and rock are filled with both air and water. In the saturated zone all spaces and fractures are completely filled with water.



The unsaturated zone

The unsaturated zone is the area between the surface and the watertable (top of an unconfined aquifer). It is divided into three sections, the soil zone (or root zone), the intermediate zone and the capillary zone (or capillary fringe).



The soil zone is important as it provides the water required for new plant growth. Once water enters the soil zone it moves downward under gravitational drainage. However, in this zone surface tension acts against the force of gravity to store water on the grains and in the spaces and fractures between them. Water is removed from the soil zone by two processes: evapotranspiration, which is the evaporation from soil and transpiration by plants; and percolation which occurs when there is enough rainfall (recharge) that the soil becomes saturated causing water to move downwards under gravitational drainage.

The intermediate zone is located beneath the soil zone. Most water percolates down through this zone, although any residual water will hold onto grains within the rock in a thin layer and little or no movement occurs, except during recharge.

The capillary zone is located just above the saturated zone. The spaces in the rock, sediment or soil in this zone contain air and water. The water is drawn upwards from the water table by the action of capilliarity. Capillary action is important for moving water and all that is dissolved in the water. Capillary action in the sub surface works in much the same way as if we were to dip a paper towel into a container of water, the water will creep up the paper towel until it is overcome by the force of gravity.

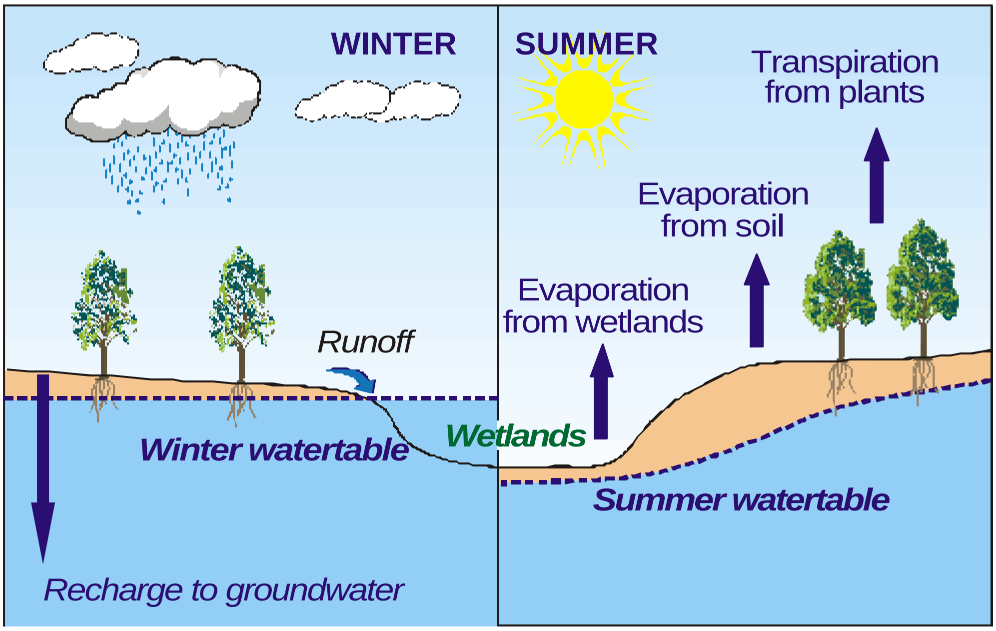
The saturated zone

The top of the saturated zone is known as the watertable. All water below the watertable is known as groundwater (see picture on page 6).

Once water reaches the watertable it can continue moving downwards vertically and outwards horizontally until it reaches a discharge point such as a river or the ocean (discussed later). The water table is not an unvarying surface, it can be shallow under valleys or it can be deeper below the surface hills.

Changes in the watertable

The watertable can rise and fall due to a number of factors. When there are extended heavy rains, recharge to the groundwater can raise the level of the watertable. Alternatively a drought may result in the lowering of the watertable.

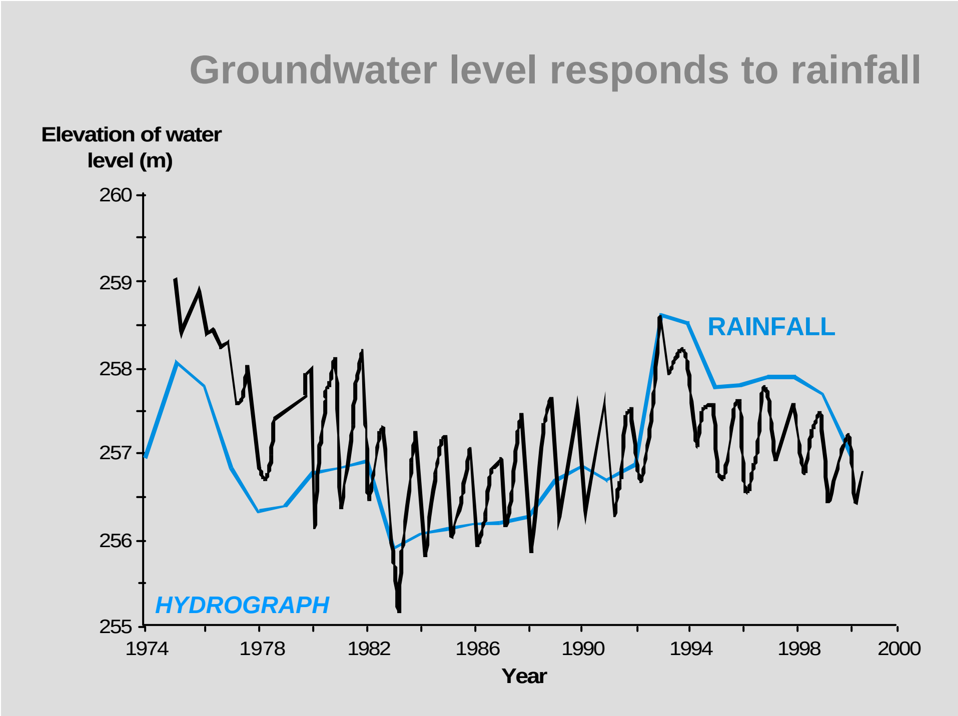


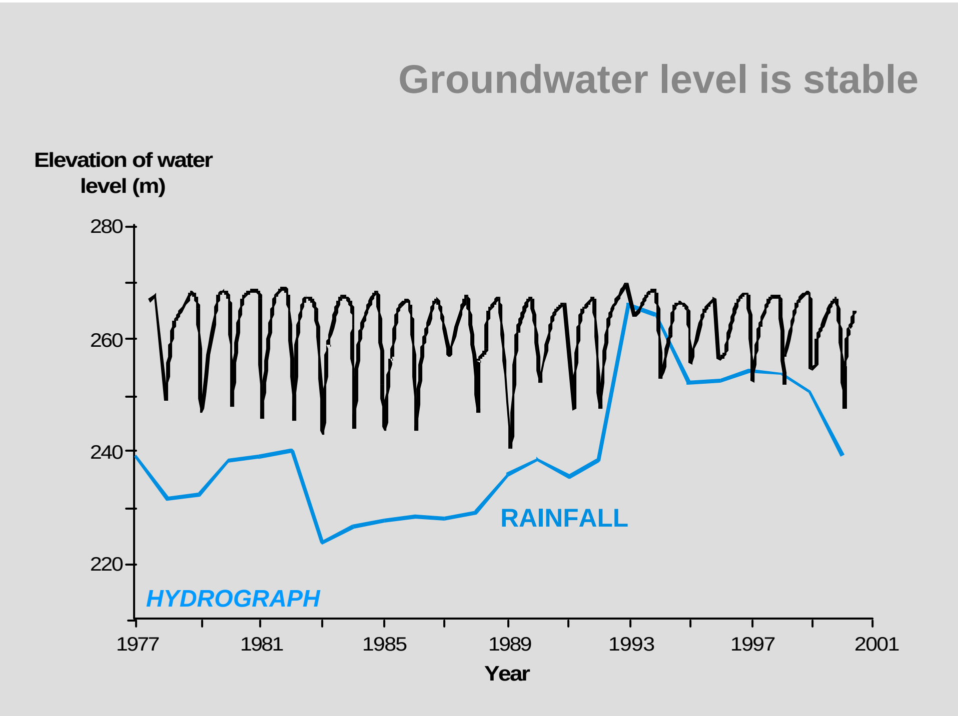
In areas where there is intensive pumping of groundwater during summer for irrigation, the watertable can be lowered as there is generally little or no water reaching the watertable during this time. This is similar to squeezing water from a sponge, if the water is not replaced then the sponge will obviously have less water in it. In winter there is generally an increase (or recovery) in the level of the watertable.

In periods of drought there is usually more groundwater pumped during both summer and winter from the saturated zone and there is often a dramatic lowering of the watertable. This is also observed to a lesser extent when there are consecutive “dry” winters.

Hydrographs can provide a “picture” of how the watertable in a certain well can vary with time. A hydrograph is as the name suggests, a graph. If the depth from the surface to the watertable is measured in metres each month for several years, then the depth can be plotted against time.

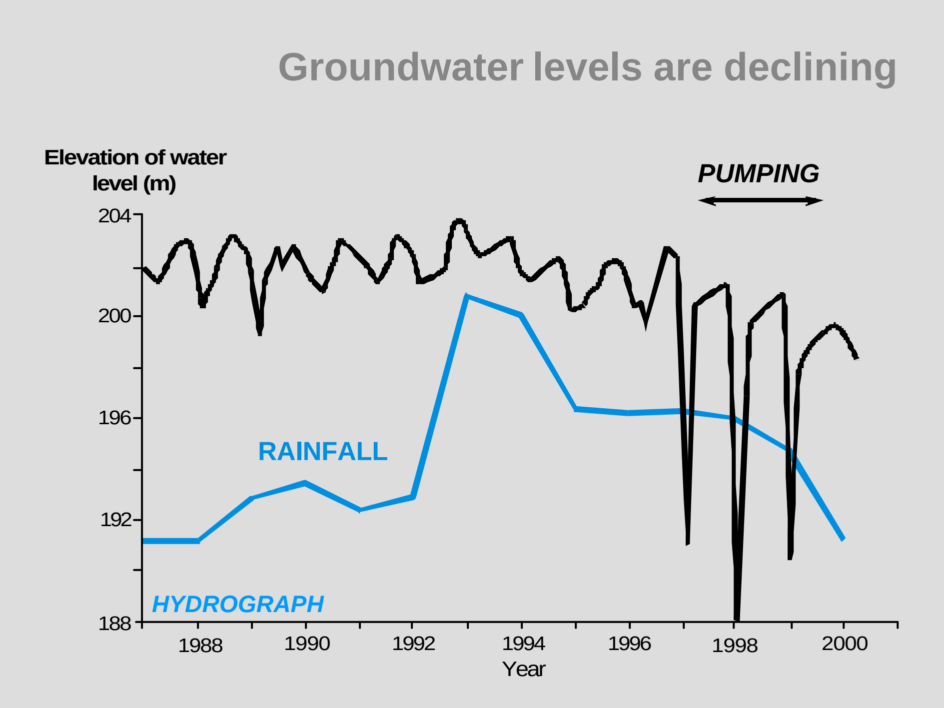
Graph 1shows that the groundwater level varies with rainfall and is not affected by pumping close by.





Graph 2 is at an even level and is not affected by rainfall or pumping.

Graph 3 is not affected by rainfall, but may be affected by pumping.



The hydrographs can provide valuable information such as whether the watertable is declining too steeply from over pumping, which may cause stress on the aquifer, or how fast an aquifer recovers after a drought from a major rainfall event. This allows groundwater to be used in a way that sustains the natural resource.

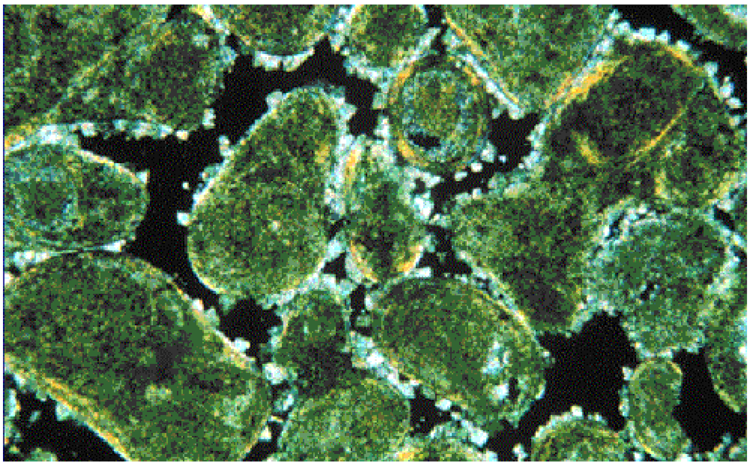
Aquifer

Groundwater is found in an aquifer. An aquifer is defined as a saturated geological material, that when a well is drilled, can yield a useable quantity of groundwater. A geological material may be sandstone, limestone, basalt, granite or any number of rock types. Although the saturated zone is completely saturated below the watertable, it is only geological materials with certain properties that are classed as aquifers.

Porosity

As discussed earlier, water fills the spaces between the individual grains in sediments or rock (geological materials), these spaces are known as pores or porosity.

The measure of geological materials to hold water is known as its porosity. A geological material with high porosity (more pores), is able to hold more water than a geological material with low porosity (less pores). For example, an aquifer that was 100 metres thick that has a porosity of 30%, would have a water depth of 30 metres.



Microscopic thin slide section of sedementary rock

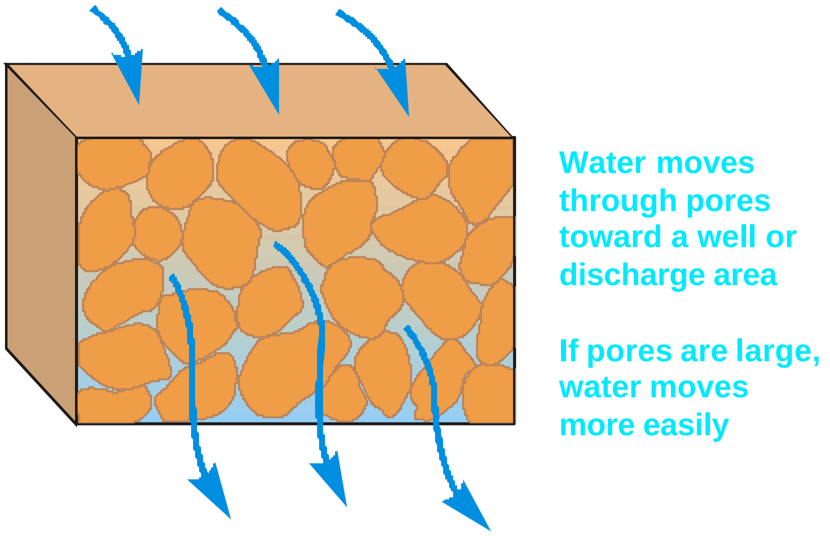
POROSITY (%)	STRATA
40 to 60	Clay
35 to 50	Silt
10 to 35	Sand and gravel (mixed)
25 to 30	Well sorted sand and gravel
5 to 30	Sandstone
<1 to 20	Carbonates
5 to 50	Karst limestone
0 to 10	Shale
0 to 10	Fractured crystalline rock
5 to 50	Fractured basalt
< 1	Solid rock, dense

Table 1

Table 1 shows the porosity of different geological materials. A geological material may have a high porosity, but unless it has adequate permeability, it is unlikely that a well would yield any groundwater.

Permeability

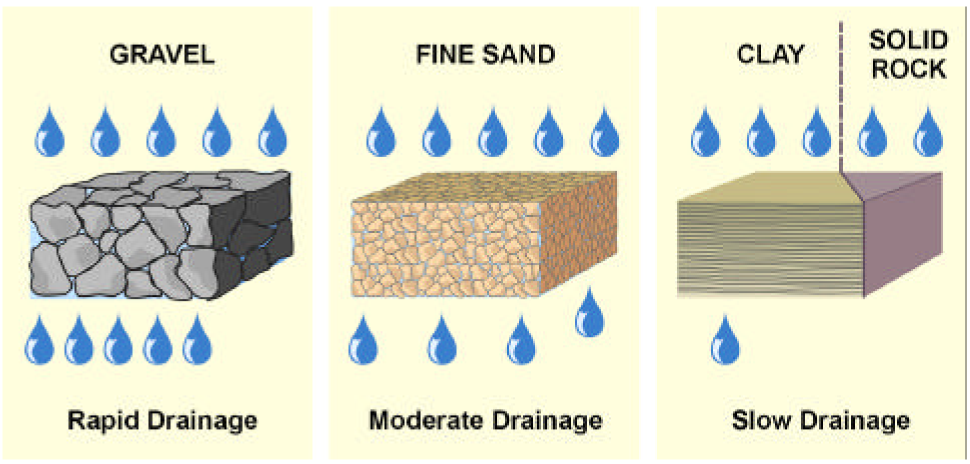
Permeability is a measure of the interconnecting spaces or cracks between pores that allow water to move from one pore to the next. In order to gain an adequate yield the spaces and cracks must be abundant.



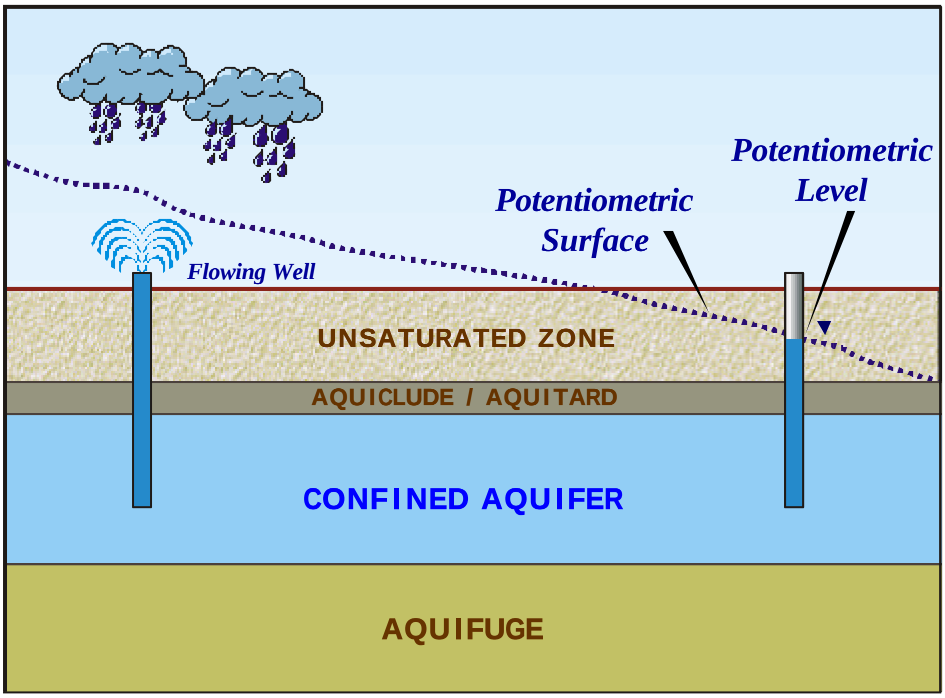
Confining bed

Since geological material usually occurs in beds or layers, an aquifer may be overlain or underlain by a layer of geological material which is saturated but has poor porosity and/or permeability and can not provide a useable yield. This type of geological material is known as a confining bed.

To gain a better understanding of a confining bed, picture two sponges one on top of the other. When water is poured into the top sponge you would expect it to drain down under the force of gravity into the second sponge. If a confining layer in the form of a piece of plastic was to be placed between the two sponges,then you can see that water poured continuously and slowly into the top sponge would saturate the sponge and the water would leak sideways from the sponge onto the plastic. The bottom sponge remaining dry. There are three different types of confining beds.



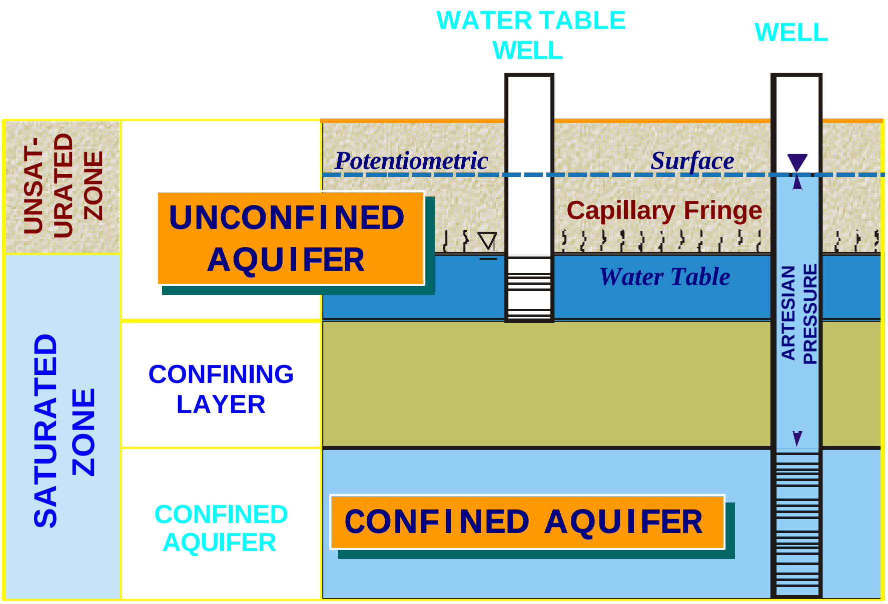
Confining beds that are saturated and allow water to move vertically through them are known as **aquitards**, for example a silty clay or silt which have high porosity and some permeability. These layers are important sources of recharge to underlying aquifers. Confining beds that are saturated but do not allow water to pass vertically through them are known as **aquicludes**, for example clay that has high porosity and low permeability. Confining beds that neither contain nor allow water to pass through them are known as **aquifuges**, for example solid granite that has no porosity and no permeability.



Groundwater generally occurs in three sorts of aquifers, unconfined, confined and perched.

Unconfined aquifers

Unconfined aquifers have the water table as their upper boundary and are usually recharged by infiltration from the surface. The watertable in an unconfined aquifer is able to rise and fall. If a well is drilled within a unconfined aquifer, then the water level in the well will rise to the same level as the watertable.



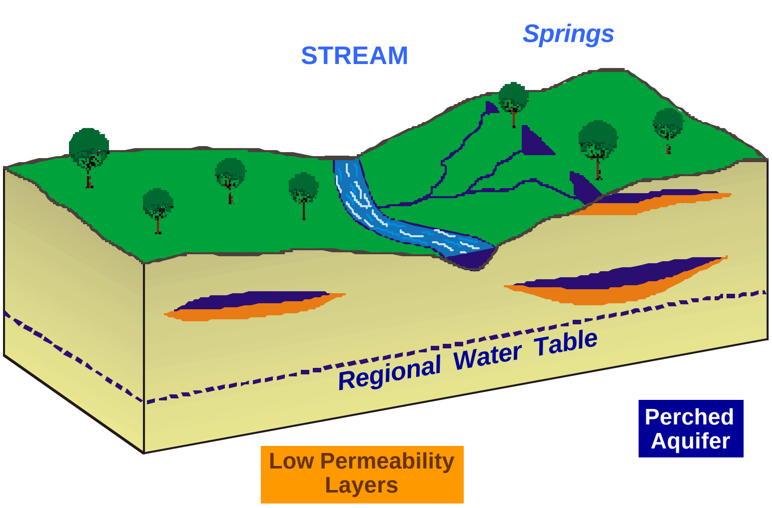
Confined aquifers

Confined aquifers usually have a confining bed as their upper boundary. Unlike an unconfined aquifer, a confined aquifer is fully saturated. Confined aquifers are recharged where they are exposed at the surface and from leaky confining beds (aquitards). The water level in a well drilled in a confined aquifer will usually rise above the level of the confining bed due to the high pressure that the confining bed places on the aquifer.

The level to which the water rises is known as the potentiometric surface. The potentiometric surface is also known as the pressure surface and is a hypothetical surface above the actual water surface in a confined aquifer (see picture on page 13).

Confined aquifers are also known as artesian aquifers where the water level in a well that has been drilled into the confined aquifer rises above the surface of the ground.

Perched aquifer



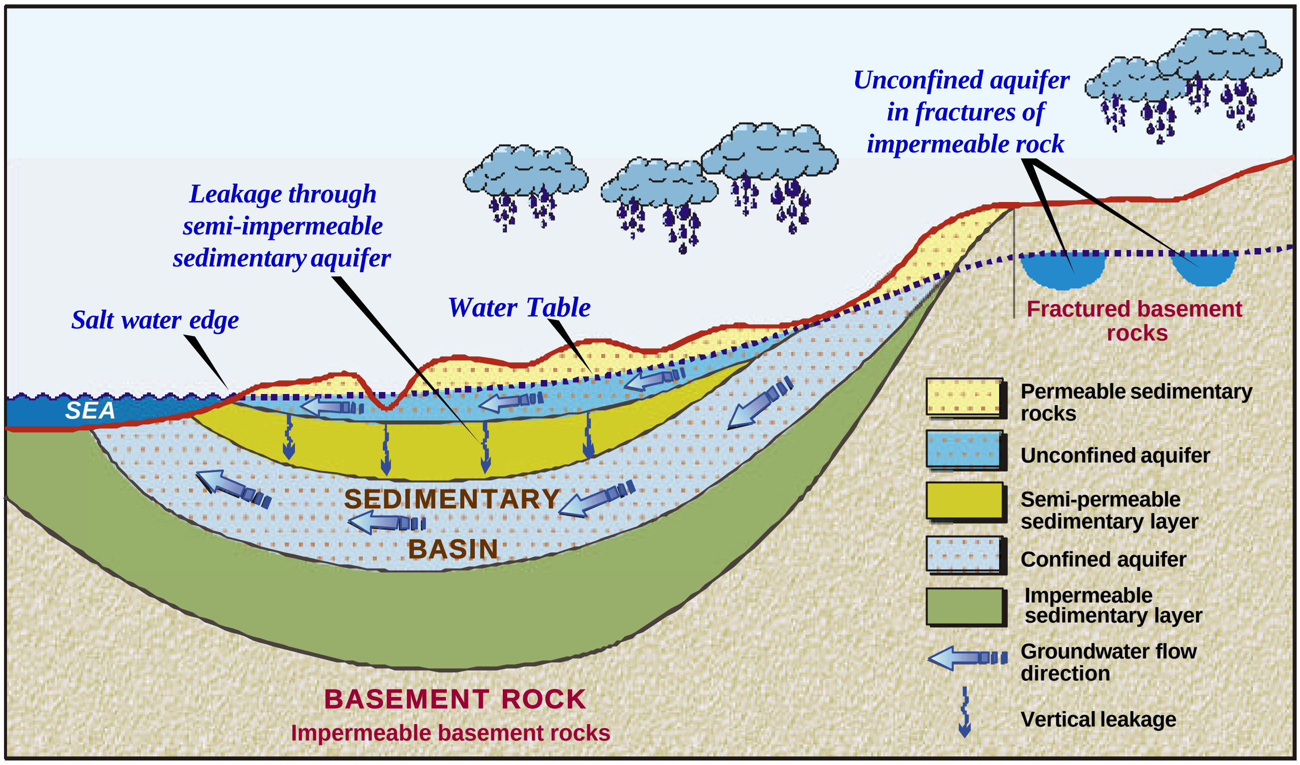
A perched aquifer occurs where there is a confining layer with low permeability and is a limited size. It is located above the watertable within the unsaturated zone.

This layer will trap water as it percolates downwards and form a lense/limited layer of water. It may only be ten centimetres thick or it may hold a significant amount of water.

There are two types of aquifer systems in Australia, sedimentary aquifers and fractured rock aquifers (see picture on page 6).

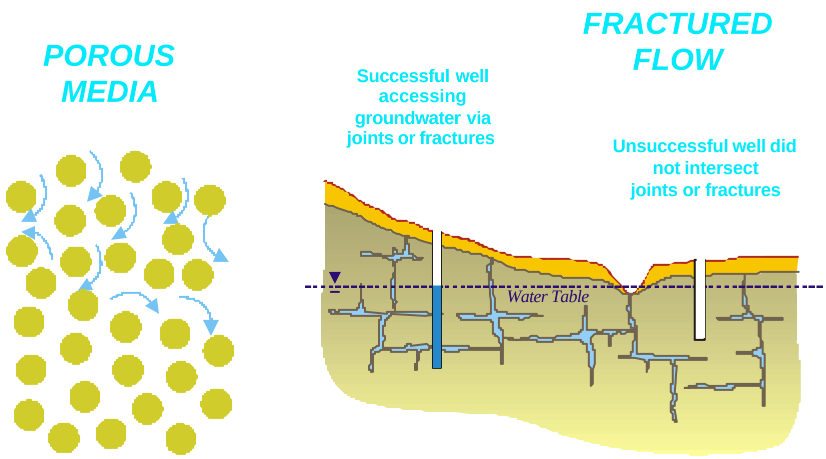
Sedimentary and Fractured rock aquifers

Sedimentary aquifers are made up of sediments such as sand and gravel. They have high porosity and permeability, allowing water to move more easily. Sedimentary aquifers are often in layers, and consist of unconfined aquifers often with numerous aquifers beneath it, separated by confining beds. In Australia the majority of sedimentary aquifers occur in sedimentary basins, which are basins underlain by igneous or metamorphic rock and contain layers of sediment. They can also occur in sediment associated with river networks.



Fractured rock aquifers are made up of metamorphic rock such as slate and shale, and igneous rocks such as granite and basalt. These rock types have only minor porosity. They are very similar in structure to aquifuges, but are able to transmit water due to a property known as secondary porosity.

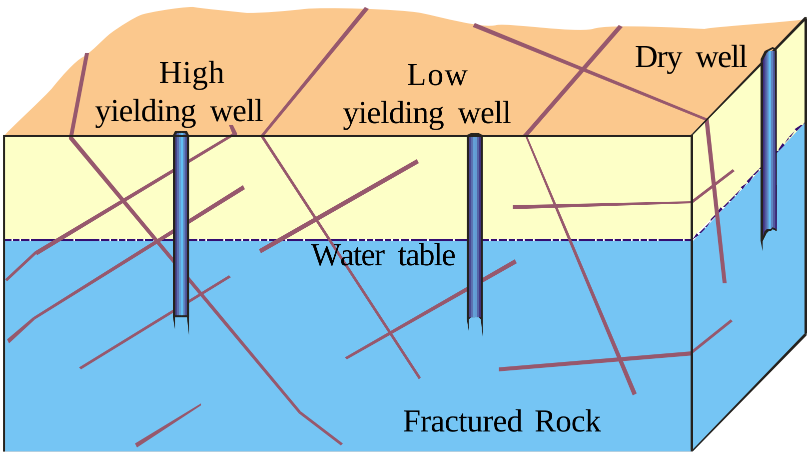
Secondary porosity can be fractures, joints or solution features, which are formed in the rock by tectonic movement and dissolution processes after it has been deposited.



The pores and permeability of sedimentary aquifers are a part of the sediment when it is formed. Groundwater moves through the fractures in the rock.

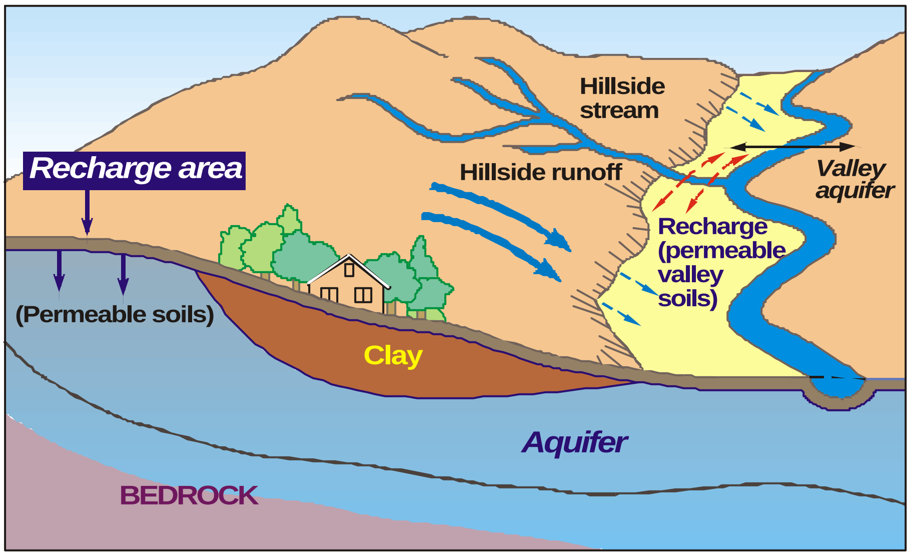
In a sedimentary aquifer a well drilled below the watertable will intercept water where ever it is drilled. In order to get a useable yield from a fractured rock aquifer, an inter-connected fracture system must be intercepted below the water table.

If a well is drilled that does not intercept a fracture system, then the well will be dry. Within a sedimentary aquifer the quality (salinity) and quantity (yield) of the groundwater pumped from the aquifer is usually constant. In a fractured rock aquifer the quality and quantity between wells in the same aquifer and sometimes only a hundred metres apart can differ dramatically. At this stage it is not known exactly why fractured rock aquifers have such variable salinities and yields within the same aquifer system.



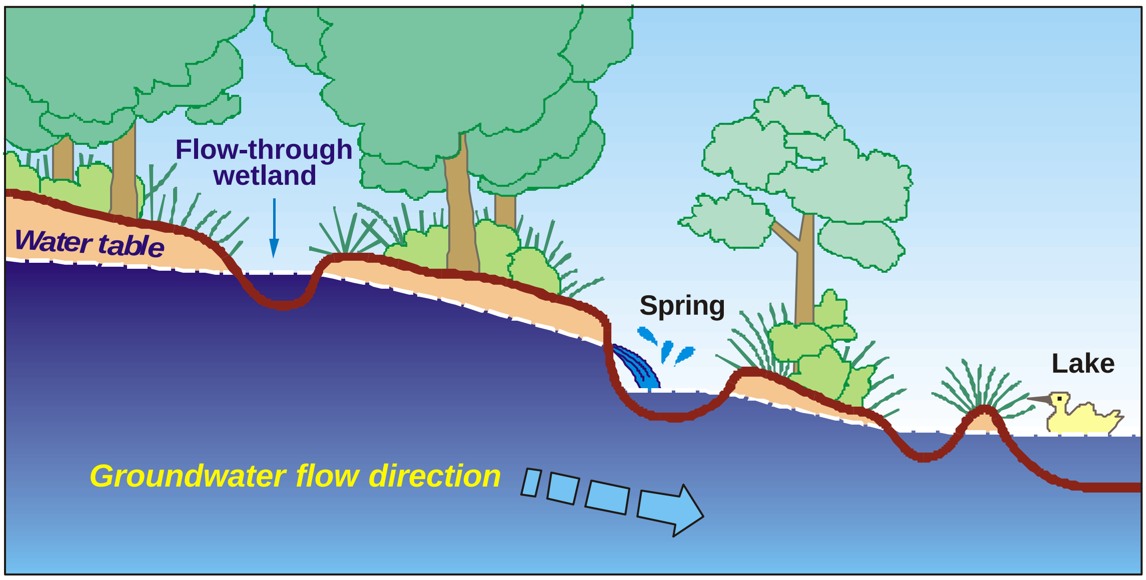
Groundwater Flow

Groundwater generally flows from areas of recharge to areas of discharge, usually areas of high elevation to areas of low elevation . As has already been mentioned recharge to an aquifer occurs via rainfall.



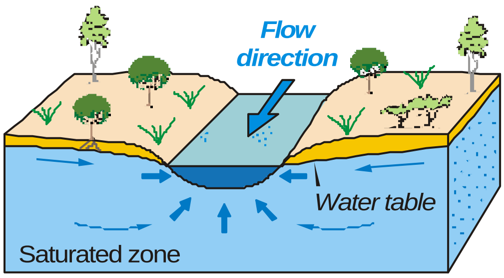
Recharge to a confined aquifer can also occur through a leaky confining bed. Creeks, rivers, lakes and wetlands can also recharge groundwater if the conditions are right.

The water then flows through the groundwater system toward an area of discharge, that can be a spring, wetland, along rivers, lake, plants, the ocean or a pumping well.

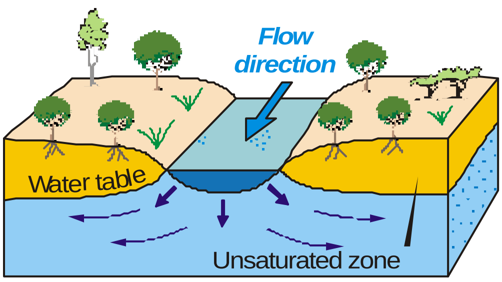


Surface and groundwater are not separate, but interact with each other. If the watertable is below the stream then stream water will flow to the groundwater, and if the watertable is above the stream bed then groundwater will flow into the stream.

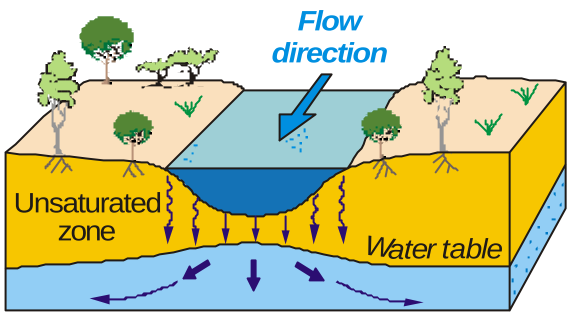
GAINING STREAM



LOSING STREAM

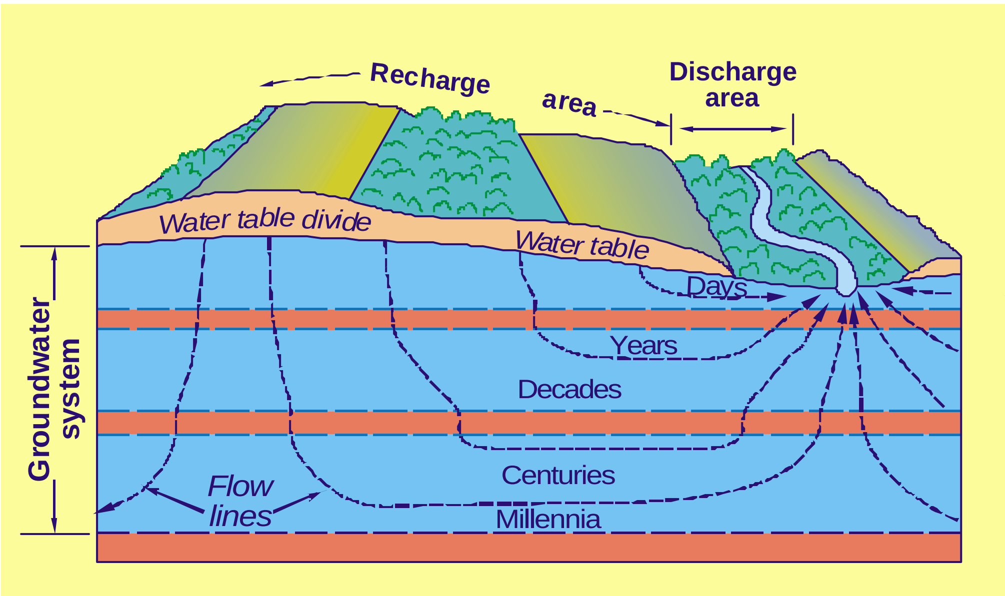


LOSING STREAM THAT IS DISCONNECTED FROM THE WATER TABLE

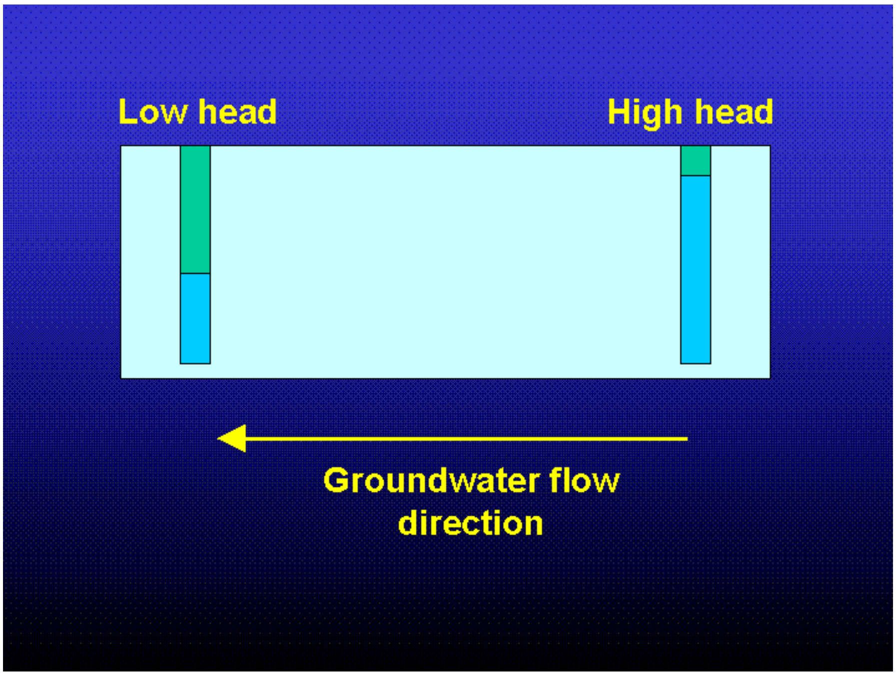


Direction of groundwater flow

The direction of flow of groundwater does not often reflect the direction of flow of surface water. Like surface water such as run-off, groundwater flows towards rivers, lakes and the ocean, but unlike surface water it generally moves very slowly.

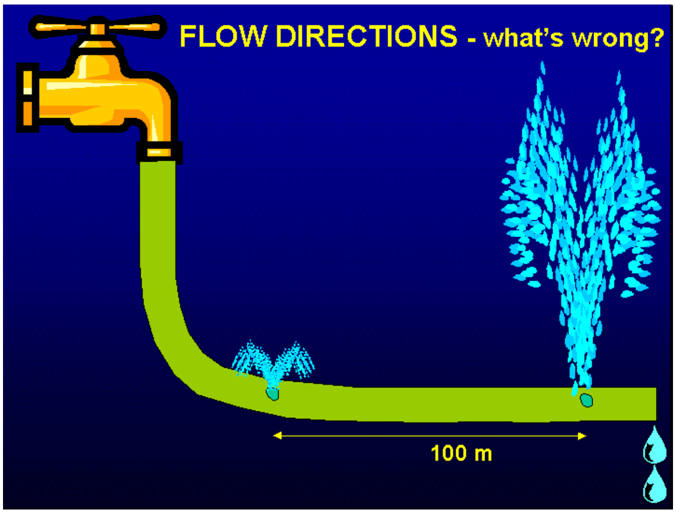


Groundwater can flow anywhere from one metre a day, which is considered to be quite fast, to a metre a year or a metre every ten years. In sedimentary aquifers groundwater moves as a slow seepage through the pores via the cracks and spaces connecting the pores. The larger the pores, cracks and spaces are, the faster the groundwater will move. In fractured rock aquifers groundwater is thought to move at a much faster rate.



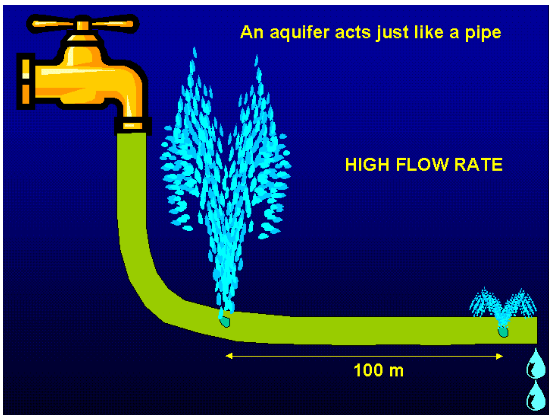
When groundwater moves from an area of recharge to an area of discharge it has moved along a groundwater flow path. There are three types of groundwater flow system within an aquifer system, the local, intermediate and the regional flow system. As groundwater moves through these flow systems it increases in age.

The direction of groundwater flow is usually downwards in the aquifer from a high water elevation (high pressure or head) to a low water elevation (low pressure or head).

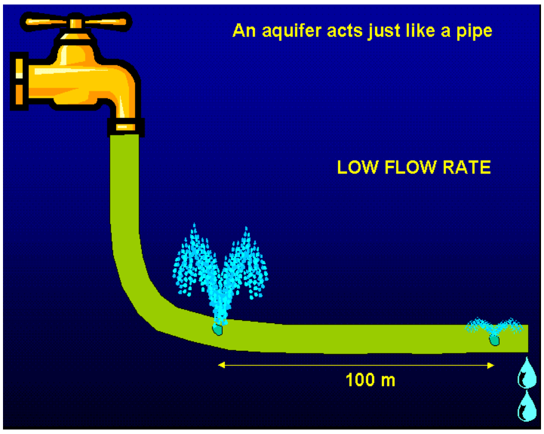


The slope of this flow is known as the **hydraulic gradient**. The discharge of groundwater into rivers or river water recharging groundwater depends on the hydraulic gradient, this is true for lakes and wetlands as well. The hydraulic gradient is determined in unconfined aquifers by measuring the level of the water in a well. By measuring a series of wells the slope of the watertable can be determined, and hence the direction of flow.

The process is similar in confined aquifers except the slope is not the watertable but the potentiometric surface. In a confined aquifer the direction of flow is very much like the direction of flow in a garden hose.



The pressure (or pressure head in a confined aquifer) will be greatest where the water enters the hose via the tap (recharge) than where it leaves at the end of the hose (discharge)



Local groundwater flow systems

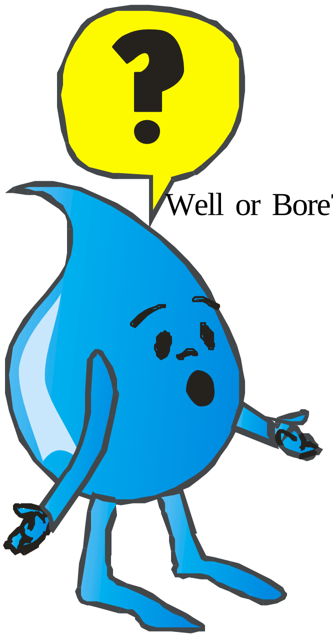
Local groundwater flow systems are generally shallow and move from a recharge point to the nearest discharge point. They are often only a few square kilometres in area and extend from a few metres to hundreds of metres. The groundwater that discharges from this system is usually quite young in age, ranging from one year to ten years to hundreds of years. Local flow systems are often close to each other, the area that separates them is known as a groundwater divide.

Intermediate groundwater flow systems

Intermediate groundwater flow systems are deeper than local flow systems and can be tens to hundreds of square kilometres in area. They extend from hundreds to thousands of metres and are often separated from each other by a groundwater divide.. The age of the groundwater discharging from this system can be from hundreds of years to tens of thousands of years.

Regional groundwater flow systems

Regional groundwater flow systems are generally deeper and often cover hundreds to thousands of square kilometres. The length of these flow systems range from thousands to hundreds of thousands of metres. The age of groundwater discharged from these systems can be tens of thousands of years old to millions of years old. An example of a regional flow system is the Great Artesian Basin, where groundwater that is being discharged today in South Australia actually entered the aquifer two million years ago in Queensland.



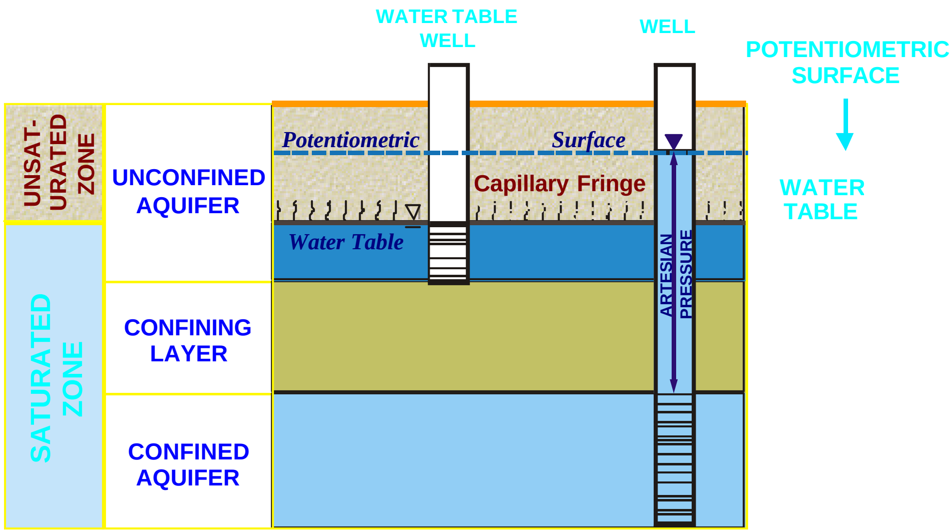
Accessing Groundwater

Since we can't see or handle groundwater, the most reliable way information can be collected is by drilling a well (also known as a bore) into an aquifer.

We rely on information from a series of individual wells to provide us with an overall picture of the aquifer.

• The porosity and permeability of an aquifer can be estimated by collecting samples of the geological material during the drilling of a well.

• The depth to the watertable or the potentiometric surface can determine the direction of groundwater flow and can also help to determine whether an aquifer is under stress from over pumping or low rainfall.



• Properties of the aquifer such as transmission and storage can be calculated by performing an aquifer test. This involves pumping the well for preferably twenty-four hours or more. During this time the decline in the water level is recorded, and then after pumping has ceased the time it takes the waterlevel to recover to it's original level is recorded.

• Water samples can be taken from the well to measure such properties as salinity and chemical components.

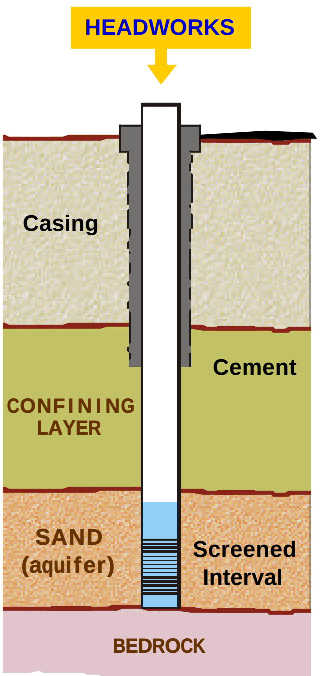
• Wells provide access for groundwater to be studied using electronic equipment. Geophysical loggers measure the electric, gravitational and magnetic properties of the aquifer . A sonde can measure the salinity, the temperature and the pH of the groundwater relative to the depth of the well.

Drilling a Well

Position of well

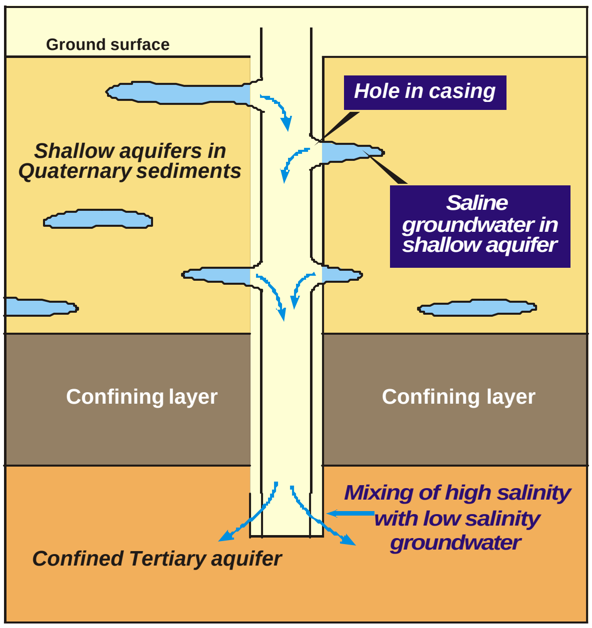
The position of a well must be considered carefully before drilling begins. Drilling rigs are often mounted on large vehicles so it is important to take into consideration whether the drilling rig can actually reach the site. Due to the height that the drilling rig extends, it is important that the site is at least five metres away from power lines. To avoid any possibility of contamination the well must be sited at least five metres away from septic tanks and wastewater treatment units, and at least fifty metres from septic tank outfall or surface irrigation disposal of effluent. The position of telecom and electricity cables and water pipes should be checked.The new well should be positioned so that surface water drains away from it. It is also important that the proximity of existing wells be considered when siting a well. When a well is pumped, water levels surrounding the well are lowered. If the well is too close to an existing well, then the existing well may have it's water level dramatically reduced. This process is known as interference.

Water Resources acts in several states require that all water wells deeper than 2.5 metres be drilled by a licensed driller, except for the owner of the land who can drill up to 15 metres on his own property.



Well casing

Casing is required when drilling a well, to prevent the well collapsing in on itself and to prevent surface water entering the well. Casing is generally made of steel, due to it's strength, but in areas where corrosion is a problem an inert material such as PVC or Fibreglass (FRP) is used.

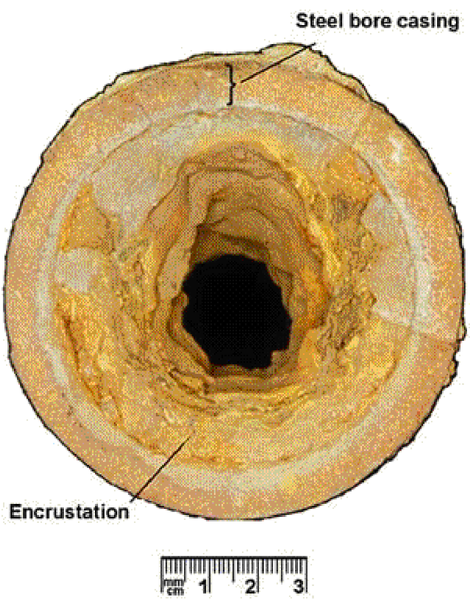


The casing finishes short of the bottom of the well to allow an opening for groundwater to enter. In a sand aquifer a screen and sometimes gravel packing are required at this opening to prevent the sand being pulled into the well during pumping. The space between the casing and the edge of the hole is often cemented. This is done to prevent contaminated surface water from entering the aquifer.

It protects the casing from corrosive water and soils. Where the well passes through multiple aquifers with differing salinities cementing prevents mixing of the different quality groundwaters. It may protect the fresh water aquifer the well is sourcing from above saline aquifers by sealing them off. Headworks are often placed over the top of the aquifer to prevent material and small animals from getting into the well. In artesian wells headworks are used to prevent groundwater from flowing out of the well and being lost to waste when the well is not in use.

Perparing the well for use

Once a well is completed two processes need to be carried out before the bore can be used.



Disinfection of the well is recommended to prevent the growth of iron bacteria.

Iron bacteria occur naturally not only in wells, but also in wetlands, rivers, lakes and dams. The bacteria consume iron and other minerals in the water, which are excreted by the bacteria onto solid surfaces. In wells this occurs on the well casing, screen and the pump. If the well is not treated with a mild chloride solution then the encrustation may build up and affect both the yield and the quality of the groundwater. Signs that a well contains iron bacteria usually include a change in the colour, odour and taste of the water, a decrease in yield, or motor burn out in the pump.

Development is essential to the proper completion of wells, without development a well will perform poorly. Development is where water within the well is agitated and pumped out to clean out the well after drilling. The process also increases the permeability of the adjacent aquifer material, particularly if the well is drilled using the Rotary mud method so that groundwater can move freely into the well. In sand aquifers this process stabilises the sand adjacent to gravel packing and the screen so that water in the well is sand free.

Salinity Conversion Table

Groundwater quality is usually expressed as salinity in units of milligrams per litre (mg/L). This value is obtained by measuring the electrical conductivity of a sample in EC units and then converting to mg/L, using the following table :

TOTAL DISSOLVED SALTS CONVERSION TABLE

mg/L	EC Units at 25° C	Grains/gallon
250	455	17
500	910	35
750	1360	52
1000	1810	70
1500	2710	105
2000	3600	140
2500	4480	175
3000	5300	210
4000	7100	280
5000	8800	350
10 000	17 000	700
15 000	25 000	1050

NOTE : *For quick conversion use*
EC units x 0.6 = mg/L   mg/L x 1.8 = EC unit
mg/L x 0.07 = grains/gallon

Of course the well may only be of use if the salinity is in the range for the intended use of the bore. Groundwater quality is usually expressed as salinity in units of milligrams per litre (mg/L), which is known as the total dissolved solids (TDS).

This value is obtained by measuring the electrical conductivity of a sample in EC units and then converting to mg/L, using the provided table. The dominant ions (or salts) found in groundwater are sodium and chloride, it is the combination of these two ions that causes water to taste salty. When present in large quantities, sodium and chloride cause groundwater to become corrosive. Corrosive groundwater may damage infrastructure. Other important ions are calcium, magnesium, iron, fluoride and manganese. A high level of calcium and magnesium carbonates results in hardness that makes soap difficult to lather and leaves scaly deposits to form in water heaters and pipes.

Livestock

- **Stock vary considerably in their ability to tolerate salt in drinking water.**

Enterprise	Max. For healthy growth (mg/L)	Max to maintain condition (mg/L)	Maximum tolerated (mg/L)
Poultry	2000	3000	3500
Pigs	2000	3000	4000
Horses	4000	6000	7000
Dairy cattle	3000	4000	6000
Beef cattle	4000	5000	10 000
Sheep	6000	13 000	*

* *Depends on type of feed available (e.g. Green feed, dry feed or saltbush)*

Crop and Pasture - Salinity Limits

SALINITY LIMIT (mg/L)	CROP TYPE		
850	Field peas and beans		
1000	Broad beans		
1200	Clover *	Groundnut	Rice (paddy)
2000	Berseem clover * Millet Sudax	Corn (forage)* Soy bean	Lucerne Safflower
2800	Phaalaria *	Sorghum	Sunflower *
3200	Fescue * Sudan grass *	Perennial rye grass *	
3700	Barley	Cotton	Sugar beet

* *Relative yields for salinity figures is approximately 75%*

A high level of iron and manganese in groundwater can cause discolouration of the water and staining of anything that the water comes into contact with. Sulphates cause groundwater to have a bitter taste and may have a laxative effect if drunk. It is important when using groundwater to test for the full chemical composition, especially if the water is for human consumption.

Humans can tolerate a salinity of up to 1000 mg/L, depending on individual tastes, in areas where better quality water is not available up to 1500 mg/L is acceptable. Plants and stock vary considerably in their ability to tolerate salt in drinking water.

Lawn Grass - Salinity Limits

SALINITY LIMIT (mg/L)	CROP TYPE		
800	Bent grass		
1200	Bluegrass	Fescue	Rye Grass
3000	Tall fescue		
5000	Santa Anna couch		
25 000	Sun Turf *(Papsalum vaginatum)*	Kikuyu	

Flowers and Shrubs - Salinity Limits

SALINITY LIMIT (mg/L)	CROP TYPE		
300	Violets		
700	Aster Begonia Fuschia Rose	Azelea Camellia Gladiolus Zinnia	Bauhinia Dahlia Poinsettia
1000	Bougainvillea Hibiscus	Carnation Vinca	Coprosma
1350	Chrysanthemum	Oleander	Stock

Vegetable - Salinity Limits

SALINITY LIMIT (mg/L)	CROP TYPE		
700	French Beans	Peas (< 500 mg/L)	
1000	Beans (broad and field) Celery Potato (sweet)	 Radish	Capsicum Lettuce
1350	Broccoli Onions Cauliflower	Gherkins Carrot * Sweetcorn	Cantaloupe Potato † Cucumber
1750	Artichoke	Tomato (furrow irrigated)	
2100	Asparagus Spinach	Cabbage	Beetroot

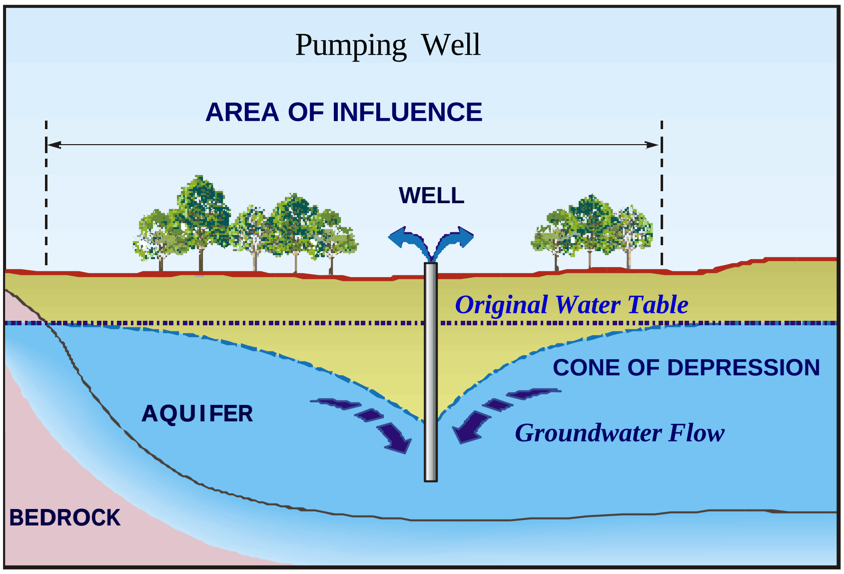
* *after 3-4 fern leaves* † *need good drainage*

Fruit - Salinity Limits

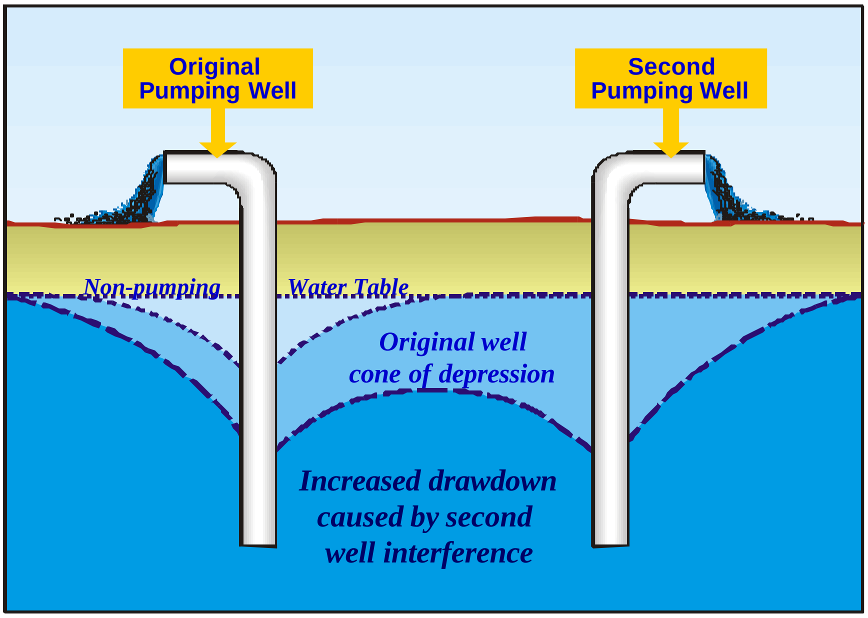
SALINITY LIMIT (mg/L)	CROP TYPE		
300	Loquat		
700	Avocado Walnut	Blackberry	Strawberry
1000	Apple Grapefruit Peach Raspberry	Almond Lemon Pear	Apricot Orange Plum
1350	Fig Pomegranate	Grape	Olive

Cone of depression

When a well is completed and pumping begins the watertable around the well is altered. Groundwater is removed from near the well, lowering the level of the watertable in this area. As pumping continues the watertable is lowered further away from the well to a point where the watertable is at the original level. At some point the pumping water level stabilises near the well, leaving the watertable level in a cone shape around the well in what is known as a cone of depression.

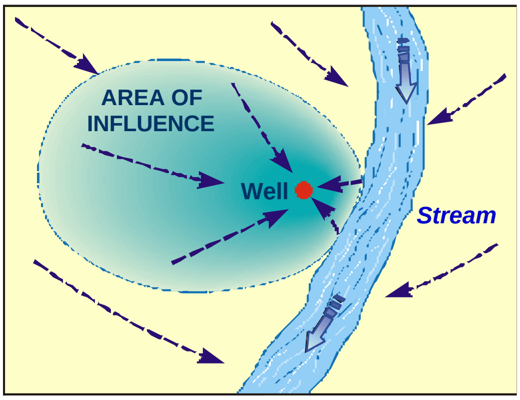


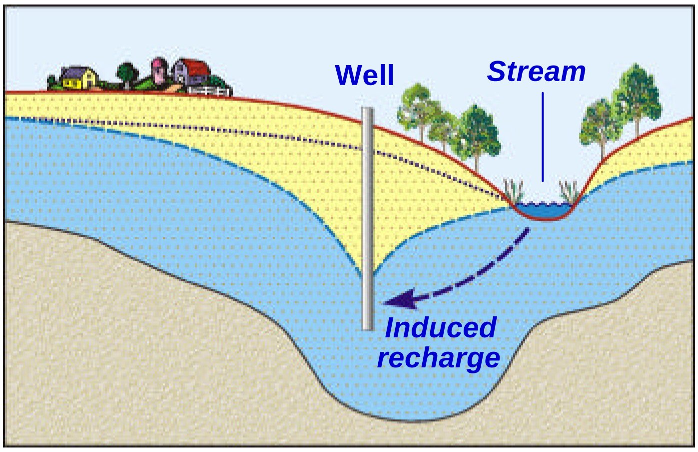
The cone of depression can extend over a hundred metres from the well. This can be a problem if an adjacent well is, say, within two hundred metres of a pumping well as it may be affected by interference.



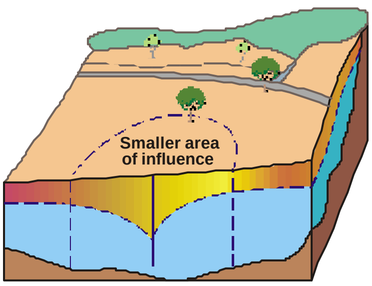
When the adjacent well is caught in the pumping wells cone of depression the water level in the adjacent well can be dramatically reduced. In the case where numerous wells are pumping water within proximity to each other, the cones of depression can overlap, increasing the size of each of the wells cone of depression.

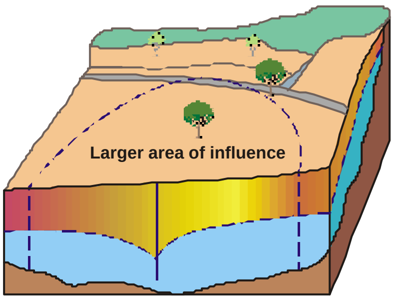
There may also be interference with streams, where the watertable is lowered and stream water is pumped towards the well.





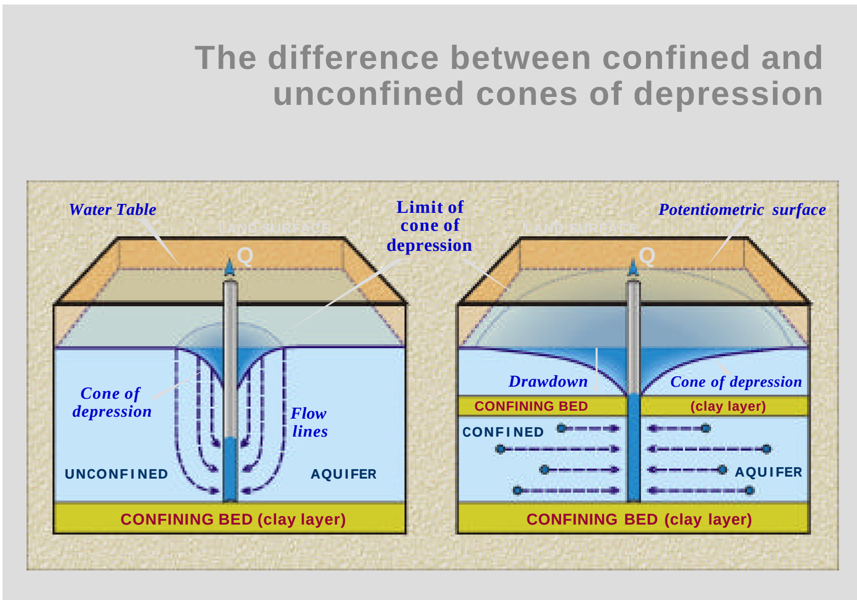
The shape and the size of the cone of depression is controlled by the amount of time that the well is pumped, the aquifer material and the amount of groundwater that is removed from the aquifer.



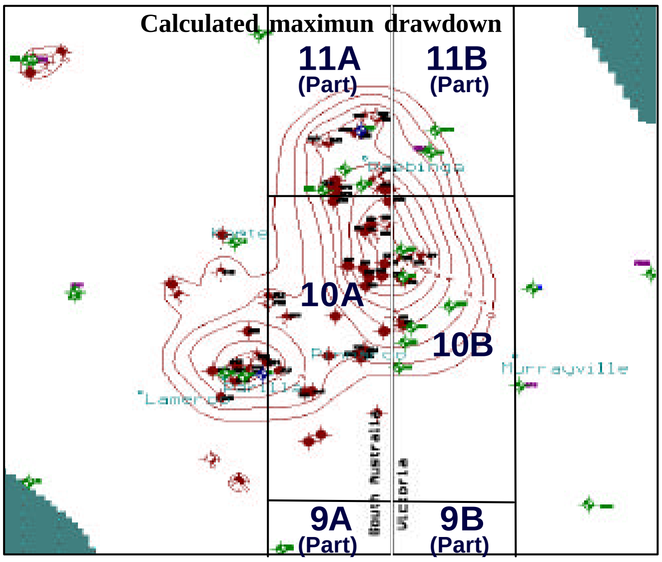


Drawdown and the cone of depression is different in confined and unconfined aquifers. It is generally much larger in confined aquifers than in unconfined aquifers.

This is the result of the two different ways in which the aquifers respond to pumping. Unconfined aquifers undergo de-watering from between the sand grains but confined aquifers remain saturated during pumping. In the latter case, there is a decrease in head and pressure in the aquifer permitting the water to expand slightly resulting in a minor compression of the material within the aquifer.

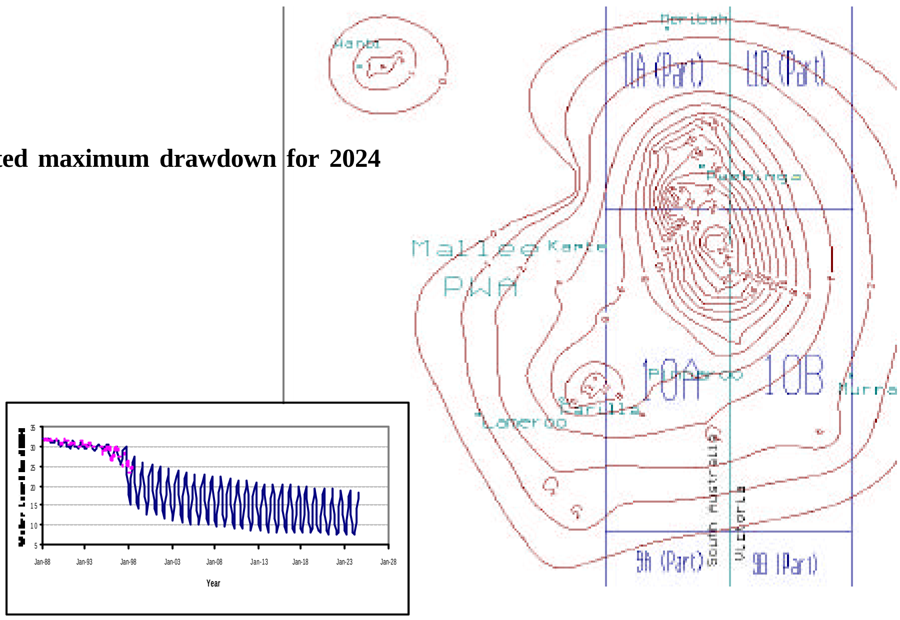


Groundwater Modeling



Hydrogeologist's often need to predict the behavior of groundwater systems to be able to make management decisions for future use in an area or catchment. For instance, if pumping continues at it's present rate in an irrigation area, will there be a detrimental effect on the groundwater system in 30 years time? The tool that is often used to make these predictions is computer modeling. Computer modeling is frequently used to predict the consequences of a proposed action, but can also be used to understand how a groundwater system works, for example examining how lake groundwater interaction occurs. Basically a computer model is a mathematical equation into which field data is input to create simplification of any groundwater system. Conditions are then entered into the model to represent future conditions. There are many models available commercially to analyse such issues as pollutant transport and groundwater flow. When used correctly by an experienced modeller, computer models are a useful tool in groundwater management. It is important to remember though that computer modeling is only a component in a hydrological assessment and not a solution in itself.

Predicted maximum drawdown for 2024



MANAGING GROUNDWATER:

Groundwater is a natural resource

It is important to remember that groundwater is a natural resource. In most cases the problems that arise with groundwater systems are due to human activity. As with any natural resource that is utilised, the system as a whole needs to be managed appropriately to preserve the resource for future generations. Management of groundwater has two basic elements that are closely related,

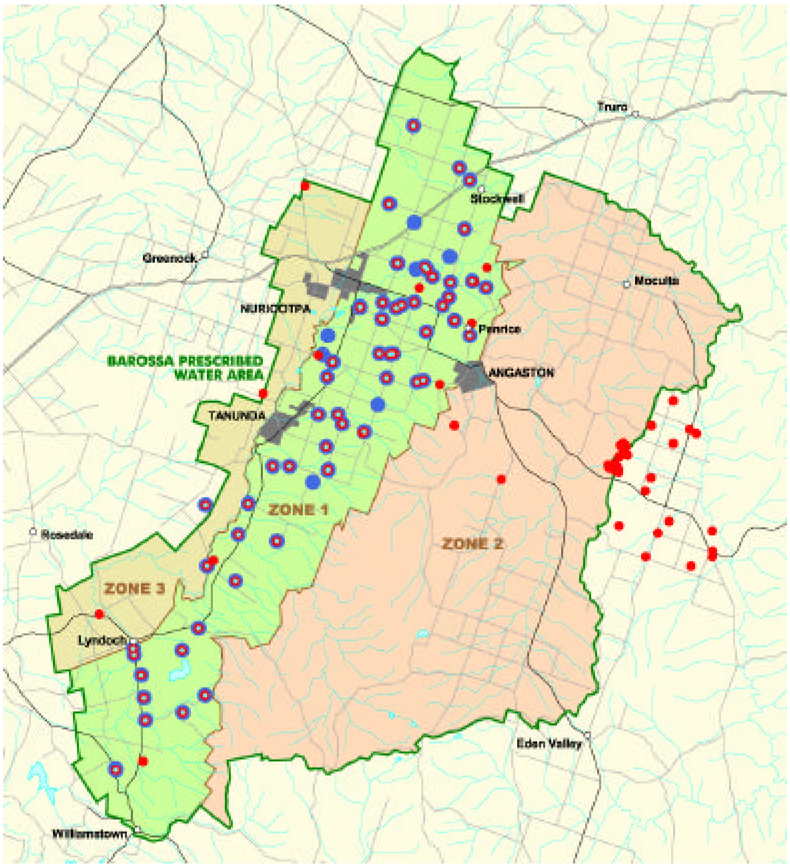
- protecting the quality, and

- maintaining the volume of groundwater.

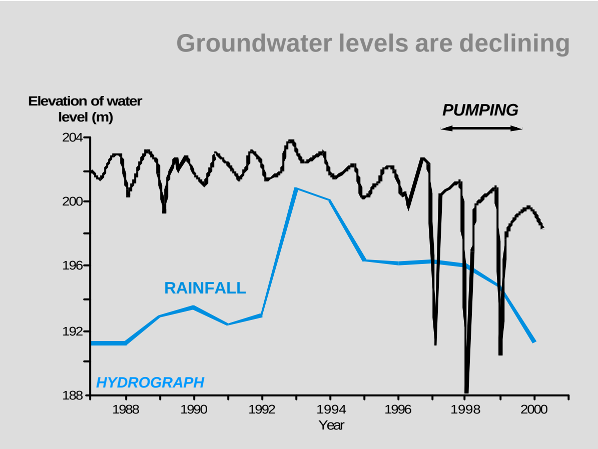
There are several management techniques employed to manage the quantity and quality of a resource.

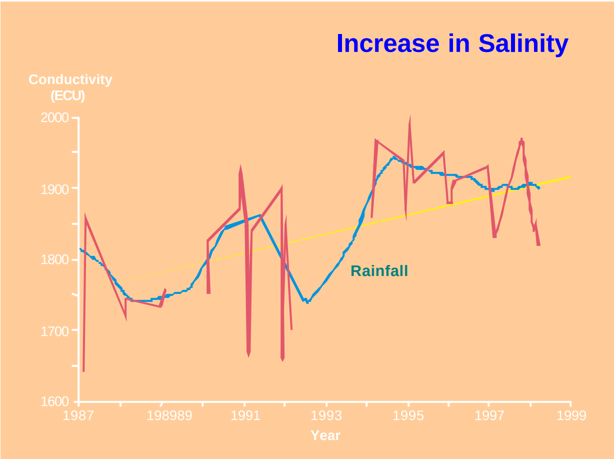
Monitoring groundwater

The proper management of groundwater depends on good quality monitoring data. Without adequate monitoring there is no means by which to assess how much of an impact human activity is having on a groundwater system. An aquifer system is monitored by selecting an even spread of wells that extends across the aquifer and regularly measuring the groundwater depth (quantity) and the salinity or quality of the water. Any continuous decline or rise in water level and increase in salinity may indicate that the groundwater system is under stress from human activity and without adequate



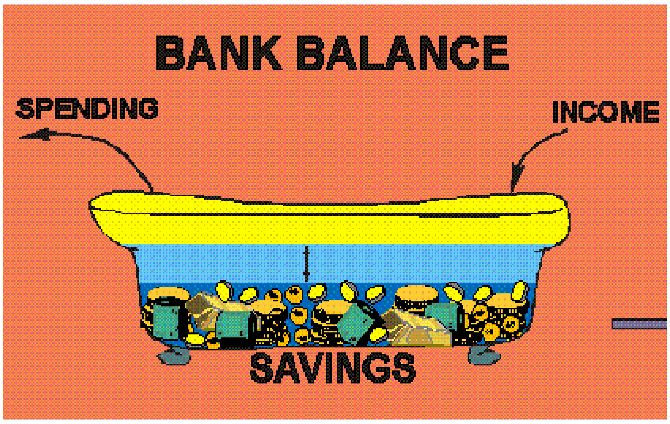
action may be severely degraded. Groundwater systems can take thousands of years to reach a natural balance, where the volume of water entering the system is similar to the volume of water leaving the system. Not only does depleting groundwater reserves affect a groundwater system, it can also have a detrimental affect on surface water and the environment. Groundwater is often hydraulically connected to creeks, rivers, wetlands and lakes such that any degradation in the quantity and quality of the groundwater will almost certainly damage the surrounding groundwater and surface water dependent environments.





Water Balance

While monitoring is important to detect problems within a groundwater system, a water balance is useful as a preventative tool in determining the amount of groundwater that can be 'safely' used before the system is likely to become stressed and unsustainable. To be sustainable a groundwater system must have a balance between the volume entering it via recharge and the volume leaving it via pumping and discharge. Under natural conditions a groundwater system will reach a balance where the inflow volume equals the outflow volume. A water balance calculation is able to detect if there is more water leaving the system than is entering it.



A water balance is similar in principle to a bank balance. If more money is withdrawn from a bank account than is deposited in it, then over time the balance dwindles until there is no money left to use and problems start to occur. Due to the slow movement of groundwater, a groundwater system may take some time to recover from uncontrolled pumping. A limit on groundwater pumping is preferred to no available groundwater.

Control of Human Activity

If it can be shown that there is a rapid increase in the number of new wells being drilled in and/or there is stress within the aquifers, then a moritorium can be placed on the basin or fractured rock aquifer. A moritorium is a period of time in which no additional water can be pumped in order for hydrogeologists and hydrologists to determine whether the area needs to be prescribed or not. In a prescribed area all new irrigation wells are licensed and a license is only issued if certain conditions are met. Such as;

• that a well can not be drilled within a certain distance of an existing well, unless an aquifer test proves that pumping from the well will not interfere with the existing well.

• Or that no new licenses are to be issued in a certain area and only the transfer of a license can occur. Monitoring still plays an important role in a prescribed area as it may highlight areas of stress where useage needs to be reduced for the aquifer to survive.

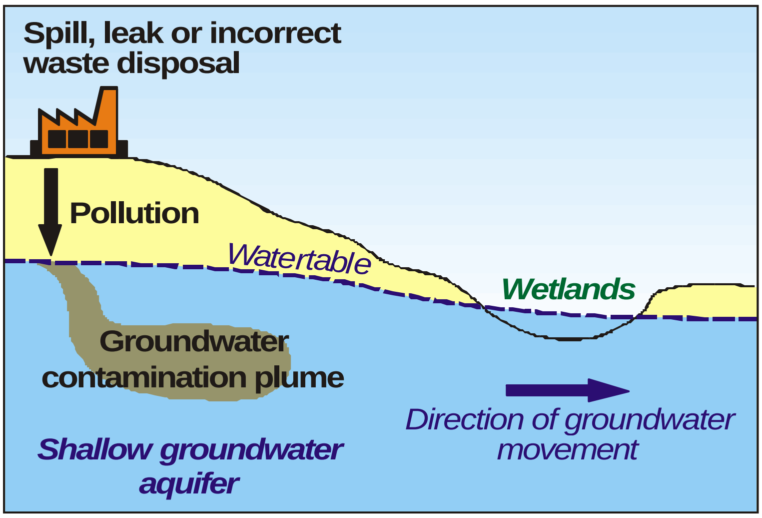
Issues with Groundwater Quality and Quantity

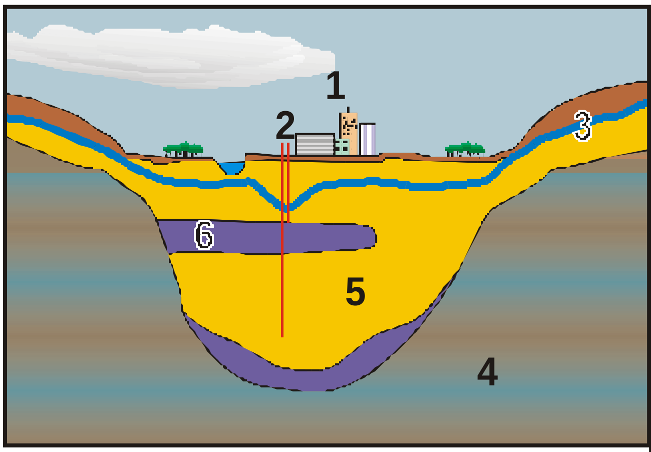
A sedimentary basin or fractured rock aquifer are not only susceptible to poor salinity and low groundwater levels, aquifers are also at risk from such processes as pollution, dryland salinity and salt water intrusion. Any impacts in the groundwater section of the hydrological cycle will have an impact on other parts of the cycle.

Human development and activity has increased the number of contaminants that can enter an aquifer during recharge. A contaminant is considered to be any substance that degrades the water quality so that it can no longer be used by plants animals and humans (Waters and Rivers Commission).

Pollution

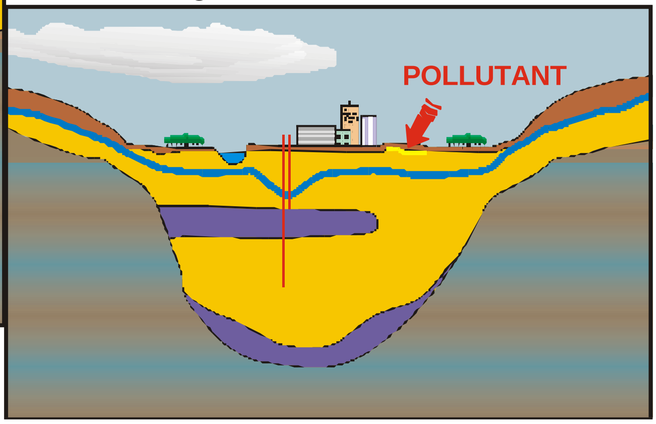
Unconfined aquifers are especially susceptible to pollution as their area of recharge is much lager than confined aquifers. Continuous confining beds which are not leaky often protect confined aquifers from pollution as they are not connected to the surface. There are two types of pollution, point source pollution and dispersed pollution.

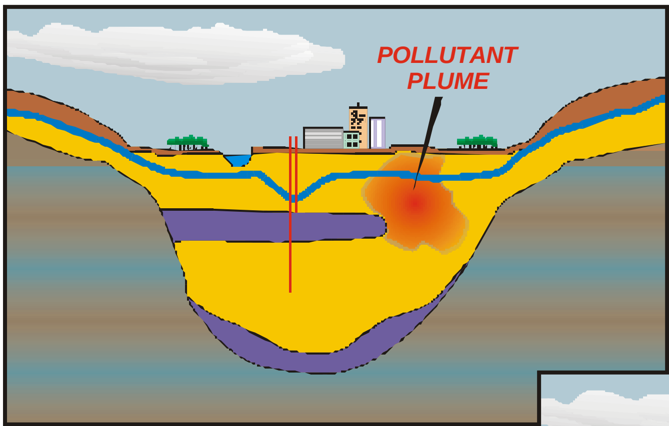




1. City 2. Production wells 3. Watertable
4. Bedrock 5. Sand & gravel aquifer
6. Impermeable layer

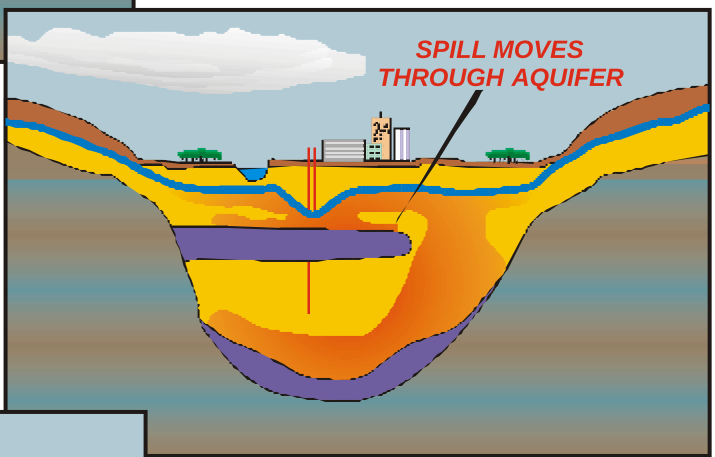
Step 1: A hazardous substance is released at or near ground surface

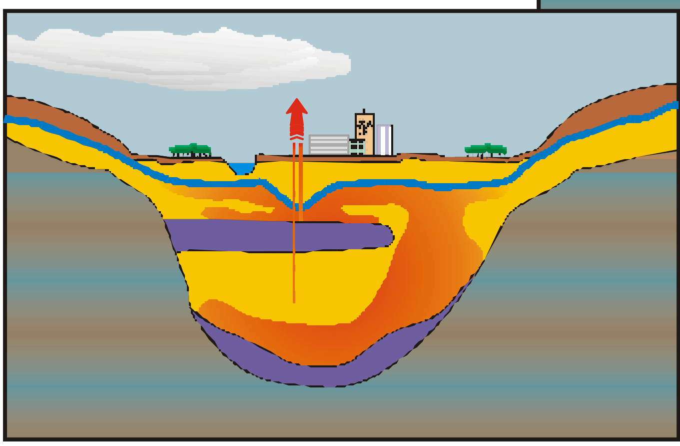




Step 2: Spill percolates through soils

Step 3: Spill moves through aquifer towards wells

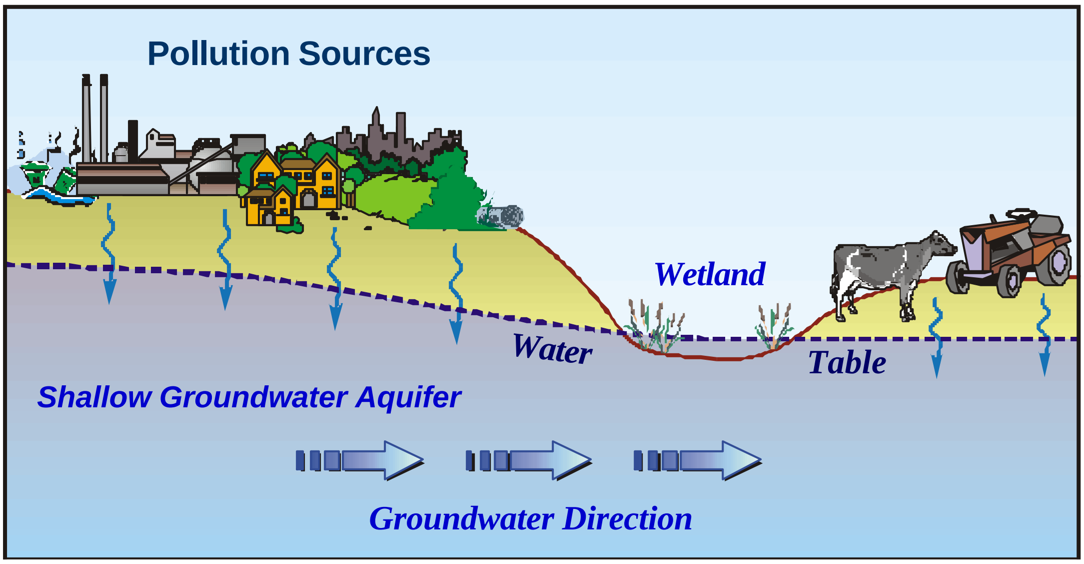




Step 4: Chemicals drawn into public water supply

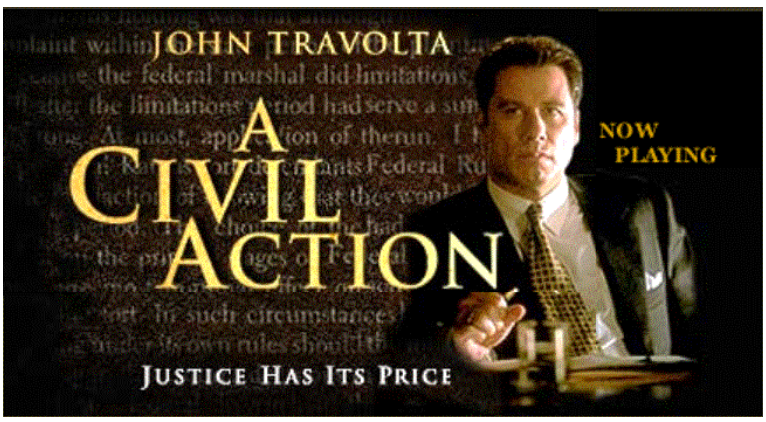
Point sources discharge pollutants at specific locations through pipes, septic tanks, ditches, or sewer outlets into bodies of water. As their name suggests, these are sources from which pollutants are released at one readily identifiable spot. Because point sources occur at specific places, they are relatively easy to identify, monitor and regulate. Provided there is the appropriate support, progress can be made in cleaning up waterways affected by point source pollution.

Dispersed pollution, or non-point sources, are (1) big land areas that discharge pollutants into surface and groundwater over a large area plus (2) parts of the atmosphere under which pollutants

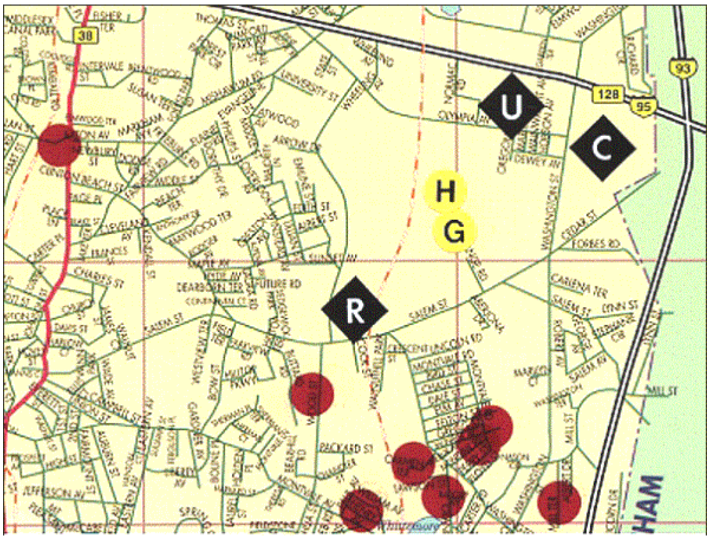


are deposited on surface waters. Examples include fertilizer runoff from farmland and acid drainage from an abandoned strip mine. Dispersed pollution in Australia largely emanate from agriculture and are very difficult to control.

Examples



Pollution of groundwater by human activity can often put human life at risk. A famous example of groundwater pollution comes from North America where groundwater is extensively used for drinking water supplies and pollution is often a problem. A book and a movie have been released on this example, both named “A Civil Action”. In the early 1980’s a leukemia cluster was identified in the town of Woburn, Massachusetts, USA. Woburn is a working-class Boston suburb with a population of 35,000 people. The town obtains it's drinking water supply from six groundwater wells (known as wells A through to F). Due to urban growth in the late 1960's two extra water wells, wells G and H, were drilled in East Woburn. Wells G and H were drilled in a different aquifer from the towns existing water supply wells. Initially these two wells were used during times of water shortage or emergency. Soon up to 28% of the communities water supply was being provided by wells H and G. Almost as soon as the residents in East Woburn began using the new groundwater supply there were complaints about the taste and the smell of the groundwater. The groundwater from two wells was repeatedly tested by local and state health officials that declared the water to be unpleasant but safe.



Woburn polution locations

During the 1970's one resident, Anne Anderson went as far as to question whether her sons childhood leukemia, diagnosed in 1972 when her son was aged 4, was the result of the groundwater. Initially people dismissed Anne Anderson's claims as those of a distraught mother, but at the time of her sons death in 1981 many people believed she may have been right.

In 1979 it was discovered that illegal dumping of chemicals had occurred only kilometres from wells H and G. While it was found that these chemicals had not contaminated the wells, it was found that the groundwater had already been contaminated with several chlorinated organic compounds, one of which was trichloroethylene (TCE). TCE is a nonflammable, colourless liquid with a somewhat sweet odour and a sweet, burning taste. It is used mainly as a solvent to remove grease from metal parts, but is also an ingredient in adhesives, paint removers, typewriter correction fluids, and spot removers. Drinking large amounts of TCE may cause nausea, liver and kidney damage, convulsions, impaired heart function, coma, or death. Drinking small amounts of TCE for long periods may cause liver and kidney damage, nervous system effects, impaired immune system function, and impaired fetal development in pregnant women, although the extent of some of these effects is not yet clear. The wells have not been used as a water supply since this discovery.

The discovery lead to the investigation of Woburns leukemia rate, which was four times higher than would be expected for a community of its size. Also most of the illnesses were amoung families that had received their water supply from wells G and H.

Eight families, including Anne Anderson, hired lawyer Jan Richard Schilichtmann to file a law suit.

Three companies were suspected of contaminating the groundwater,

• W.R. Grace and company, that owned a manufacturing plant located 732 metres northeast of the wells. The company manufactured equipment for the food packing industry and used solvents to clean and cool tools, cut grease, and dilute paint.

• Beatrice Foods Company which had owned a tannery 213 metres from the wells. It was alleged that the company had dumped chemicals on adjacent land which it had owned.

• UniFirst Corporation, that operated an industrial dry-cleaning business 610 metres north of the wells. The company used solvents as part of it's business and these solvents were found on the property in large quantities in the soil and the groundwater.

W.R. Grace and company settled out of court in the late 1980's for $US 8 million dollars without admitting responsibility. Beatrice Foods Company won their court battle. UniFirst settled prior to trial in 1985 for $US 1.05 million without admitting responsibility. The US Environmental Protection Agency clean up is still continuing.

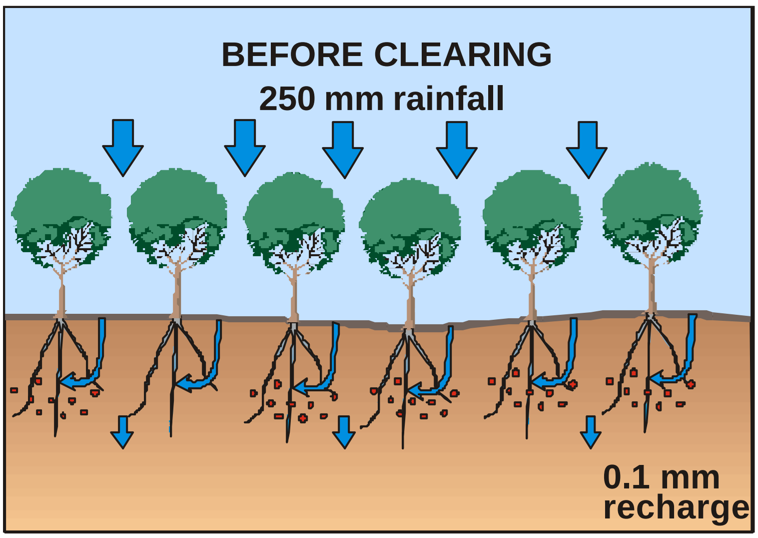
A place in Australia where groundwater is used extensively for drinking water in an Urban environment, is Perth. Approximately 70% of Perth's water comes from the unconfined aquifers in the Perth Basin. The watertable here is shallow (close to the surface) and the soils have a high permeability, which would allow a potential contaminants to move very quickly over the short distance to the watertable (Nelson et al, 1999). According to researchers (Hirschberg, 1991) there are potentially 1200 sources of groundwater point source and dispersed contamination in the Perth Basin with approximately 700 of these sources in the Perth metropolitan area. The Western Australian Waters and Rivers Commission has recently, with National Heritage funding, set up a series of procedures and a database which is designed to provide further strategic assessment of contamination issues in the Perth Basin (Nelson et al, 1999). This is a good example of how groundwater in a high risk area can be appropriately managed.

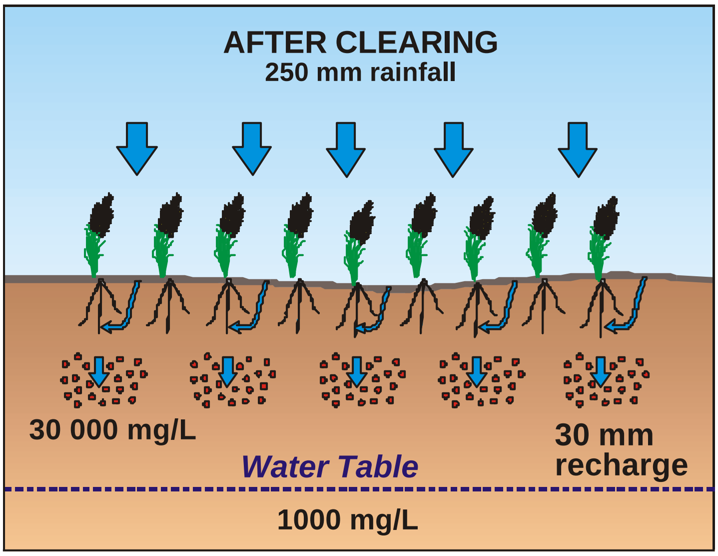
Groundwater is the gallery of 18 million graffiti artists, most of whom are unaware that their idle doodling, will be judged by future critics. The soil above aquifers is for their own protection, but soil has a limited capacity to attenuate contaminants. It is very important to remember that it is not only industry, mining and agricultural activity that can unintentionally pollute groundwater, but also the way we dispose of products in our own yards. For example, emptying car oil on our lawns has the potential to contaminate the underlying groundwater. We can all contribute to keeping groundwater clean by assessing our own waste disposal practises.

Salinisation

Changes in land use occurred after European settlement in Australia. This change in land use involved the clearing of native trees to make way for farmland and crops. It has been estimated that 20 billion trees have been removed since European settlement. These deep-rooted trees and other native perennial plants act like pumps, keeping the water table away from the surface by the process of evapotranspiration. The removal of trees has essentially resulted in changes to the hydrological cycle. There is now greater evaporation from the soil, and a greater amount of recharge entering the groundwater system as root systems are not there to intercept and use it. The increase in these two processes are directly linked with salinisation. Salinisation destroys farm land by increasing the salinity. There are two forms, dryland and irrigation salinisation.

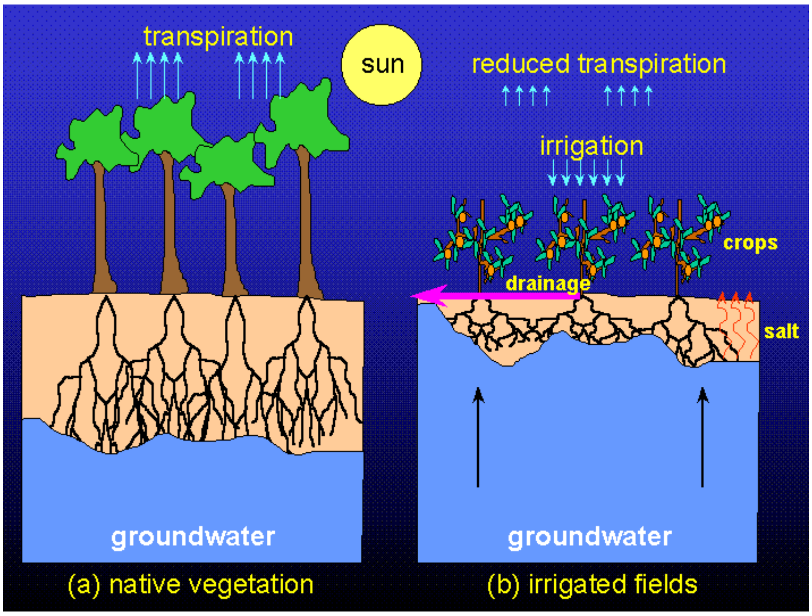
Dryland salinity areas are where water is not pumped to water crops or plants. What makes dryland areas susceptible to salinisation is the removal of deep rooted native pants in favour of shallow rooted introduced plants. The introduced plants may not be required to take up water during the winter months when the majority of precipitation occurs. Instead they may take up most of their water during spring to summer.





This results in more water passing through the root zone to recharge the aquifer, raising the watertable. Salts which are stored in the unsaturated zone are mobilised by the rising watertable towards the surface. Near the surface (within two metres) this groundwater is evaporated leaving the salt behind, resulting in dryland salinity.

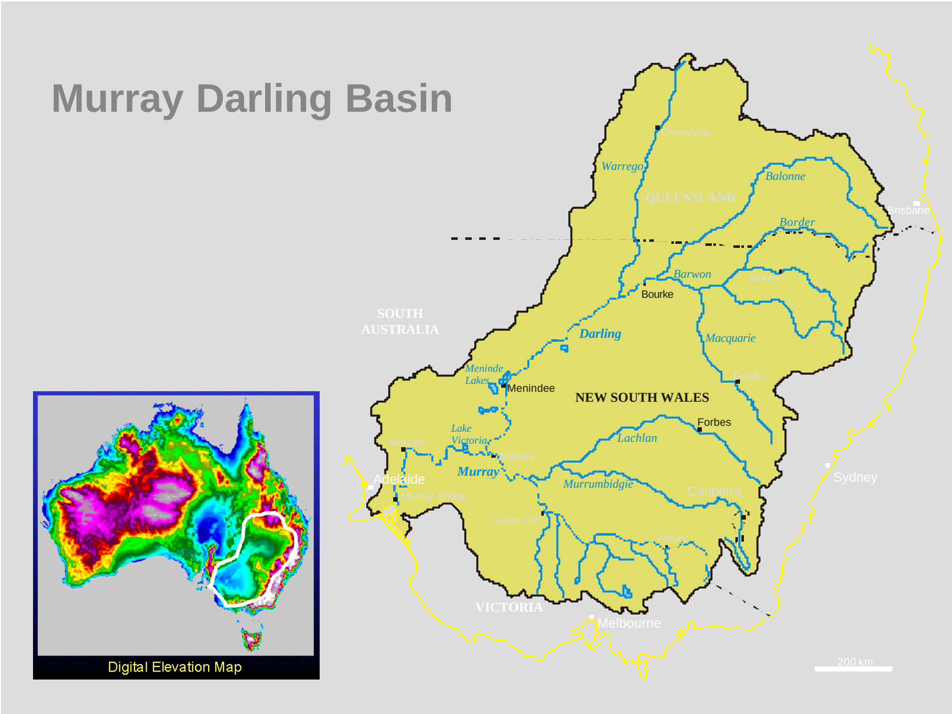
Irrigation salinisation occurs in areas where surface water is used to irrigate plants. This process occurs more quickly than dryland salinity, because there is irrigation water reaching the watertable as well as the increased recharge from rainfall. The water is used to meet plant growth and flush salt from the root zone. If this water is added too fast for the aquifer to transport it away in groundwater flow, then the water table below the irrigated area will rise forming an irrigation mound. This transports salt closer to the surface. Unless the groundwater is saline, the problem first appears to be one of water logging (when soil becomes saturated), but as time passes the yield of the crops will decrease due to the salt. This usually occurs as a result of inefficient irrigation practices.



Examples

Salinity is an increasing problem in the Murray-Darling Basin. The Murray-Darling Basin covers one seventh of the Australian land mass and is within four states.

Dryland salinity is affecting many sectors in the Basin,



• In the agricultural sector, salinity results in an estimated $130 million loss of production annually. It is thought that the value of land that has been salinity affected is around $700 million. Salt affected land is usually defined as land where productivity is reduced by 50%

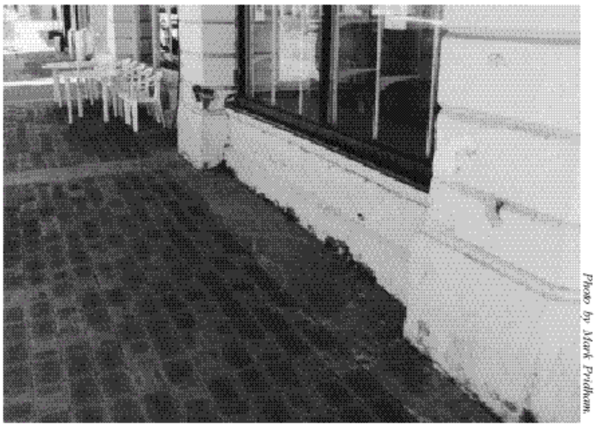
(The Salinity Audit, 1999). The impacts are being felt mainly in the grains, wool and grazing industries.

• Regional infrastructure is badly affected by dryland salinity. Roads, buildings, pipes and bridges are all damaged by rising saline water tables which have a corrosive affect on the infrastructure. The very first recorded evidence of dryland salinity was the loss of local water supples for steam trains (The Salinity Audit, 1999). Roads which have not come into contact with rising saline groundwater have an average life of four times one which has. In NSW it has been estimated that high water tables have affected 21% of national highways and 34% of State roads, resulting in $9 million per year in damage costs. In Western Australia (which is outside of this basin), 230 kilometres of road

Photo by Mark Pridham

has been affected and this is expected to double in ten to fifteen years with a damage bill of $50 to $100 million during this period. The town of Wagga Wagga in NSW has been one of the worst affected by dryland salinity, with the local government spending $500,000 per year on damage to roads, footpaths, parks, sewage pipes and industry.

• Where dryland salinity affects urban areas, house foundations are decayed and gardens and trees are unable to grow, lowering property values. There is also an increased cost to householders through damage to hot water systems and household appliances, to increased use of soap, detergent and water conditioners. It is estimated that the increase in salinity in the Murray-Darling Basin costs Adelaide $55-65 million per year mainly in treating hard water.

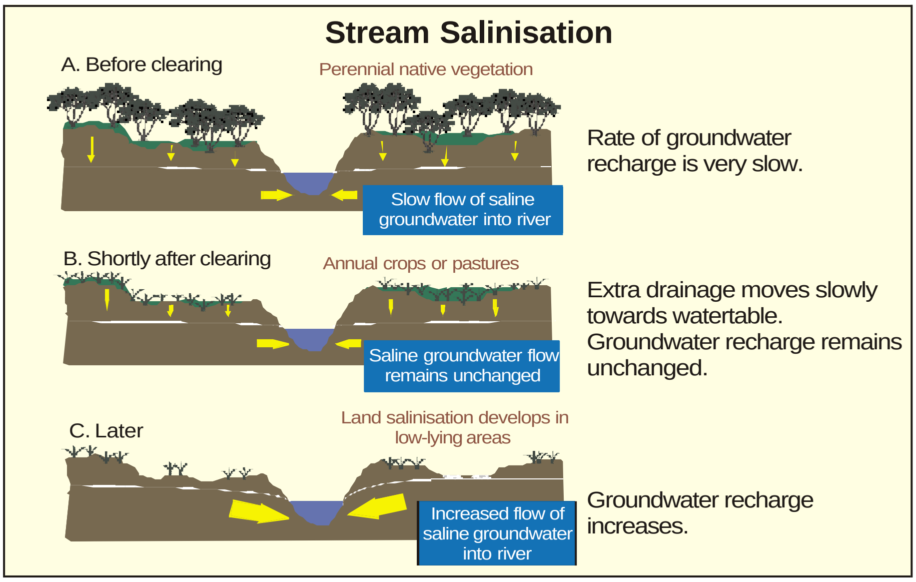


Damage to shops in the main street of Pingelly (November 1998) due to rising damp and fretting of brick walls.

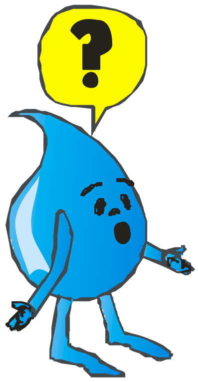
• The environment also suffers, remaining native vegetation is threatened also placing animal species that rely on the vegetation as a habitat under threat. Wetlands areas are being damaged as too is riparian vegetation, which holds stream banks together.

Irrigation salinity is also affecting many sectors of the Murray-Darling Basin,

• Irrigation near the River Murray using the river water results in an irrigation mound forming beneath the area of irrigation. This mobilises salts transporting them towards the surface. The highly saline groundwater from the irrigation mound may then seep into the Murray River, adding to the salt load of the river. Irrigation salinity is mainly the result of poor irrigation practices and effectively the irrigation brings about the demise of not only the soil, but of the crops it is meant to nurture. Within South Australia 52,000 hectares of irrigation occurs in a ribbon development along the Murray River (The Salinity Audit, 1999). Approximately 12,500 hectares are waterlogged and have been drained to remove the salt and water, but without further intervention this area is likely to increase to 20,000 hectares (The Salinity Audit, 1999).



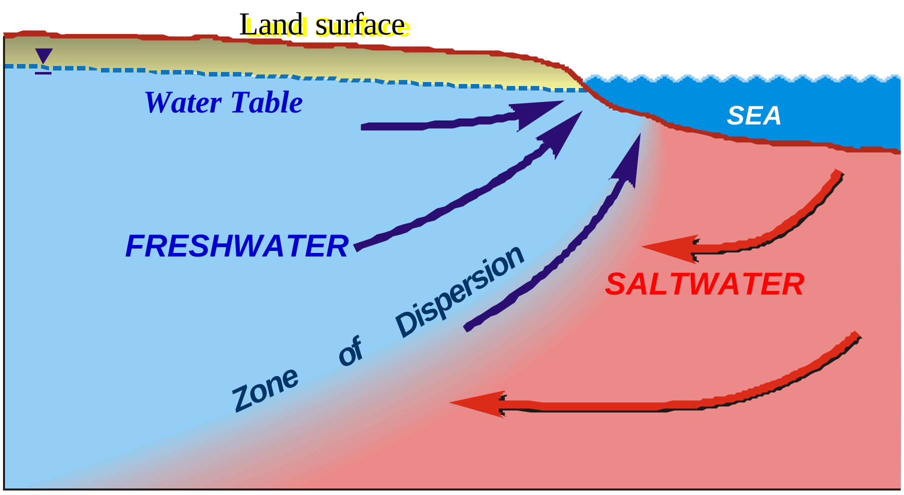
What can we do?



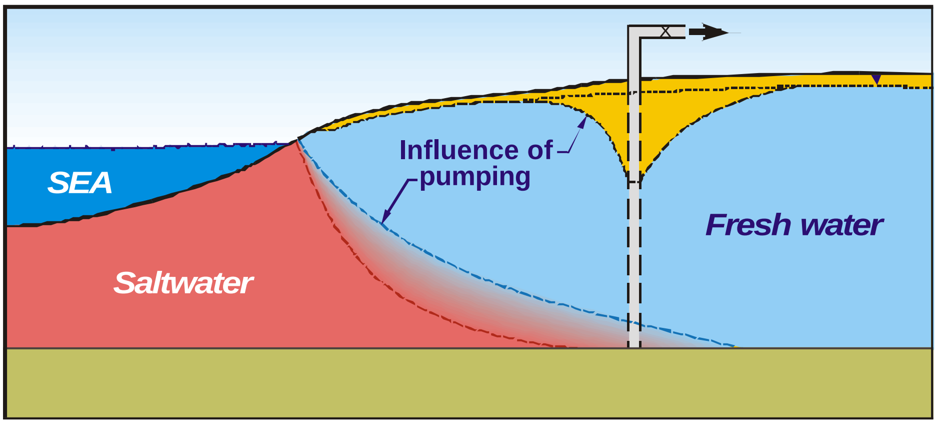
In terms of dryland salinity the key is to focus on the cause, which is the hydrologic imbalance and not the symptoms. This is proving to be difficult even in developed countries with short-term socioeconomic and political considerations providing a constraint. Some farmers are helping to repair the hydrologic imbalance by setting aside some of their land for tree farming. An example is of a farmer in Victoria who has leased his land for 20 years at $170 hectare per year to a company which is growing Tasmanian blue gums. The company provided, planted and maintains the trees and will harvest the trees twice in the next two decades, using the short sturdy fibres for it's high grade paper (The Bulletin). Companies in the Northern Hemisphere gain carbon credits for growing plantations in Australia. A recent example is the Tokyo Electric power company, who made a $120 million deal with NSW State Forests to plant thousands of hectares to be grown for carbon credits (The Bulletin). In some areas though there is no other alternative than to live with the salt. In terms of irrigation salinity, efficient irrigation practices need to be adopted.

Saltwater Intrusion

Along coastal areas fresh groundwater is separated from the saline water of the ocean by a zone of water ranging from fresh to saline, known as the **transition zone or zone of dispersion**. This zone is the result of density differences between fresh groundwater and saline ocean water. When a well in the aquifer



that contains or is near the zone of transition is pumped, the zone will move slightly towards the area of pumping. If the transition zone moves far enough inland, wells that are close to the coast become saline, which contaminates the wells supply. This a classic example of how closely quality and quantity are related. Once seawater moves into coastal aquifers it ruins the quality of the groundwater and is extremely hard to reverse. In effect the aquifer is damaged permanently. Coastal aquifers exist in a delicate balance with the sea and require careful management. Monitoring is needed regularly to detect any increase in the salinity of the water or if the water level in the bore is dropping then it could indicate that the salt/freshwater interface is moving inland.



Influence of pumping in an unconfined coastal aquifer

Techniques for managing groundwater in a coastal environment include;

• Limiting groundwater extraction from wells so that there is enough groundwater outflow towards the sea, that the salt/freshwater interface is kept at bay.

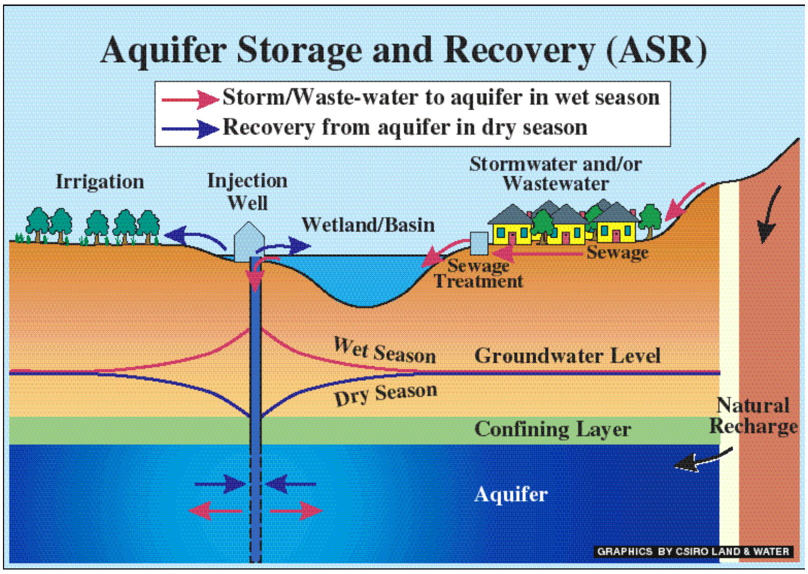
• By placing wells at strategic locations and depths so as to minimise the impacts of saline intrusion on the wells.

It is clear that we now live in an environment where the natural balance has been disturbed by human activity. And with continuing development there is very little chance for the environment to establish a new balance. Watertables have risen due to increased recharge resulting in salinised and water logged land. Watertables have fallen due to increased discharge resulting in lower yields and more saline water. Water quality in streams changes in response to deteriorating groundwater quality and dependent ecosystems change. Groundwater cannot be considered in isolation, effective groundwater and environmental management is required and failure to do so will affect the environment and the community.

Many management options have been discussed along with the issues. A possible management solution for an increase in discharge due to groundwater extraction is ASR.

Aquifer Storage and Recovery (ASR)

ASR involves harvesting surplus water from a number of sources, its temporary storage underground in a suitable aquifer, and subsequent retrieval for re-use in potable, irrigation and industrial uses. Aquifers are a more efficient storage area than surface ponds as there is no evaporation of the water and the water is less susceptible to pollution. ASR is becoming increasingly important in Australia with the expansion of urbanisation and irrigation areas placing an increasing amount of stress on the surface water and groundwater resources of this state. For example, reservoirs in the Adelaide Hills catchment cannot sustain metropolitan Adelaide demand, and water needs to be pumped at a higher cost from the Murray River. A number of aquifers beneath irrigation areas have been fully allocated and restrictions have been placed on groundwater extraction, which restricts further economic development in these areas.



ASR is achieved by the injection of surface water by either gravity or a pump through a purpose built well. Surface water used may be, stormwater, streamflow and pipeline supplies. Surface water may contain contaminants such as sediments, heavy metals, nutrients and bacteria. Any water that is injected into an aquifer must first be tested and then if required it must be filtered or treated. It is a general rule of thumb that surface water is not to be injected into an aquifer if it is more saline than the native groundwater. A common practise among irrigators is to shandy irrigation water by injecting fresher surface water into saline groundwater. Once the surface water has undergone the necessary treatment the water is injected directly into the aquifer. Since the surface water is usually of a lower salinity than the native groundwater a freshwater “lens” or “bubble” usually forms around the injection well. There is generally mixing of the two waters at the margins of the lens. Over a period of time this lens may dissipate, but groundwater flow rates are generally very slow (discussed previously) and the injected water is generally able to be recovered.

An example of ASR in South Australia is the supplementing of the town water supply of Strathalbyn.

Groundwater Ecosystems

It is believed that the one important element yet to be factored into the way we manage the environment is groundwater (Cribb, J 1998). Without the role of groundwater many native vegetation, animal and bird species would be unable to survive. This is particularly true in central Australia where surface water soon dries up and groundwater is essential in supporting ecosystems. Even though we cannot see the water at the surface, if the watertable is lowered, or the groundwater becomes polluted or saline then vegetation will die adversely affecting plant, animal and bird species. Yet how much or to what extent the role groundwater plays in supporting these ecosystems is still poorly understood.

Many native trees in the Australian landscape depend on shallow groundwater systems to keep them alive during the dry season. An example of groundwater dependent vegetation are river red gums, which are usually found along river beds throughout Australia. In South Australia the Marne River Catchment has been under investigation after recording record low groundwater levels. The area has experienced three below average rainfall seasons in a row. Hydrogeologist Steve Barnett and his team were investigating where the groundwater in the catchment was going as irrigation did not appear to represent the amount of groundwater extraction. After a detailed investigation including computer modelling it was discovered that the river red gums along the Marne River were extracting approximately twice the amount of groundwater through their root systems than the groundwater users in the region were extracting. This finding is a first of it's kind in terms of determining how much groundwater contributes to ecosystems.

Another example is the Great Artesian Basin. In the Great Artesian Basin mound springs support diverse ecosystems which are under threat from human activity. Mound springs are formed by artesian wells, as the groundwater flows onto the surface the water is evaporated and salts are left behind. Wind bourn sediments are deposited onto these moist soils and gradually a mound builds up around the spring. In South Australia the mound springs form an arc of about 400 km along the south-western edge of the basin The mound springs are home to a combination of plants and animals that are found nowhere else in the world. The environment supports many types of rare and even unique plant life, animals, fish and freshwater snails. Many species only exist in a certain spring. These ecosystems are under threat from human activity, bores used for stock can lower the pressure in the aquifer to the extent that natural springs can dry up. In the last 100 years many springs have dried up, destroying various species even before they could be discovered. Stock are also a hazard, trampling the environment.

As has been previously discussed, groundwater and surface water are interconnected, making groundwater an important factor in supporting ecosystems in rivers and streams. Also, aquifers themselves contain forms of life and biological processes, some of which are new to scientists (Cribb, J, 1998).

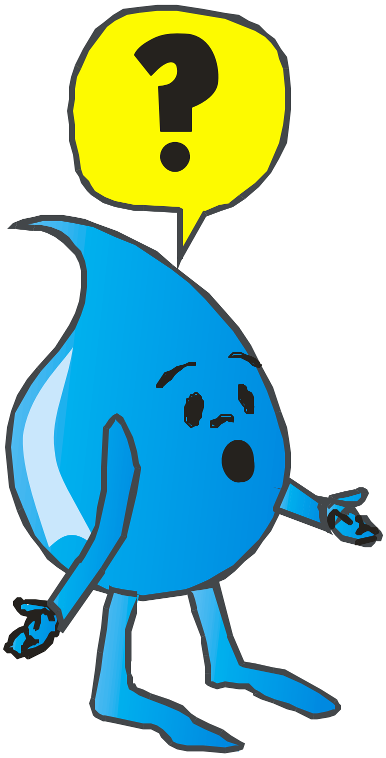
Clearly groundwater is a very important component in the environment and any plans to extract groundwater should take into account any detrimental effects on dependent ecosystems.

Groundwater Resources exist within social constructs

In most parts of Australia the management of groundwater is the province of the various state governments. In South Australia groundwater is managed predominantly by the Groundwater Section of the Department for Water Resources. The formation of the new Department for Water Resources has seen the bringing together the management of surface water and groundwater into the same department. Where a basin covers several states, the relevant government agencies will work together.

Groundwater in Australia is legislated under state Water Resources Act. These require that certain conditions are met when using the states groundwater. Licensing can be required in prescribed areas. Licenses are the property of the holder and are not linked with the land. A licensed driller must be used where a well is deeper than 2.5 metres although a landholder can drill a well up to 15 metres deep on his/her own property. A permit is required to drill or deepen any well or the casing within a well deeper than 2.5m. Drillers are required to provide information on depth, casing, water cuts and lithology to the relevant government agency. Where a person has lawful access to a well, that person has a right to take water from it provided that it does not interfere with another persons right to take water from their well. A well owner is also responsible for maintaining a well on his/ her property and may be required to undertake remedial work.

Often, groundwater is considered available for consumptive use only after environmental needs have been assessed. The impact of the well on other water resources must also be considered. Only then an allocation is issued. Where water has been over allocated the appropriate state Minister has the power to reduce the size of allocations.



What can you do?

There are many examples of how a community or individual may become involved.

So what can you do?

- Join a local action group in your area
- Education – go to workshops and seminars to learn about the issues and understand how you may help
- Look up the WWW for information and resources – see following page for places to start
- See following list of issues/problems 'What Activities can I do?' and examples of community activities to address them
- **TAKE ACTION!**

There are many groups doing much to help already.

Much is happening overseas where groundwater is a main source of drinking water – example - The Groundwater Foundation, U.S. is an example of how communities can be effective.

The Internet (WWW)–
A place where you can find a broad range of information

If you do not have access to the internet at your home or office you can access it at any library.

The following is a list of web site addresses you can try.

These sites will provide information, activities, definitions and much more, leading you to even more sites to explore.

Centre for Groundwater Studies	http://www.groundwater.com.au
Flinders University SA	http://www.es.flinders.edu.au/
Primary Industries and Resources SA	http://www.pir.sa.gov.au/index.html
CSIRO Land and Water, Australia	http://www.clw.csiro.au/
Water & Rivers Commission	http://www.wrc.wa.gov.au/home.html
Department for Environment and Heritage (SA)	http://www.dehaa.sa.gov.au
University of Western Australia	http://www.uwa.edu.au/
United Water International	http://www.unitedwater.com/
Ministry for Planning WA	http://www.wa.gov.au/planning/
Water Corporation (WA)	http://www.watercorporation.com.au/index.html
Natural Heritage Trust	http://www.nht.gov.au/index.html
Agriculture WA	http://www.agricwa.gov.au
Ribbons of Blue/Waterwatch WA	http://www.wrc.wa.gov.au/ribbons/index.html
Cockburn Wetlands Education Centre	http://carmen.murdoch.edu.au/community/cwec/home.html
Catchment Water Management Board - Torrens and Patawalonga	http://www.cwmb.sa.gov.au/
Catchment Water Management Board - Onkaparinga	http://www.onkaparinga.net/plans/summary-01.htm
Catchment Water Management Board - Northern Adelaide and Barossa	http://www.cwmb.sa.gov.au/nab/index.htm

Waterwatch Australia	http://www.waterwatch.org.au/welcome.htm
Urrbrae Wetlands - Activities	http://www.denr.sa.gov.au/wrg/watercare/ database/activity/urbanact.htm
Environment Protection Agency (SA)	http://www.dehaa.sa.gov.au/epa/water.html
South Australian Murray Darling Basin web site	http://www.lm.net.au/~sacare/
Belair Primary School Eco Schools Page	http://ee.environment.gov.au/ecoschools/belair.htm
Watercare III	http://www.watercare.sa.gov.au/sitemap.htm
WSAA - Water Services Association of Australia	http://www.wsaa.asn.au/
Welcome to Environment Australia	http://www.environment.gov.au/
Land & Water Resources Research & Development Corporation	http://www.lwrrdc.gov.au/
National Dryland Salinity Program	http://www.senet.com.au./~bcmunday/1home.htm
South Australian Water Industry	http://www.sa.waterindustry.net.au/mainmenu.htm
Australian Water & Wastewater Association	http://www.awwa.asn.au/
ARMCANZ Home Page	http://www.dpie.gov.au/dpie/armcanz
Masters Program in Hydrology and Water Resources	http://www.scieng.flinders.edu.au/teaching/ Hydrology/Hydrology.htm
CSIRO Land and Water - Scientific Publications	http://www.clw.csiro.au/publications/scientific.htm
Environment Australia	http://www.erin.gov.au
Groundwater Centre - Faculty Centres - Faculty of Engineering Handbook – UNSW	http://www.publications.unsw.edu.au/ handbooks/engineer/18201312.htm
Urban Water Resources Centre	http://www.unisa.edu.au/uwrc/project.htm
National Centre for Groundwater management	http://www.uts.edu.au/oth/ncgm/
Cooperative Research Centre for Catchment Hydrology	http://www.catchment.crc.org.au/
Indonesian Governmental Links Page	http://www.dfa-deplu.go.id/english/govern1.htm

Lifewater Canada: Safe drinking water for rual poor.	http://lifewater.ca/
UWIN: Universities Water Information Network	http://www.uwin.siu.edu/
Water Supply and Sanitation for Developing Countries: Directories of UK-based research	http://www.lboro.ac.uk/departments/cv/wedc/wssdc/contents.htm
Water Environment Research Foundation	http://www.werf.org/
Water Online	http://www.wateronline.com/
SOAS: Geography: Water Issues Group	http://www.soas.ac.uk/geography/waterissues/
Cooperative Research Centre for Freshwater Ecology CRCFE - Homepage	http://enterprise.canberra.edu.au/WWW/www-crcfe.nsf
Hydrological Societies - World Meteorological Organization	http://www.nwl.ac.uk/ih/devel/wmo/hhcsoc.html
New Zealand Hydrological Society	http://www.landcare.cri.nz/hydrosoc/
IMWA International Mine Water Association	http://www.inggeo.tu-clausthal.de/~gpcw/IMWA.htm
AGU Home Page - American Geophysical Union	http://www.agu.org/
Canadian Hydrogeology Mailing List Thread Index	http://gwrp.cciw.ca/internet/gwcan-archive/1997/threads.html#00058
The home page of the Groundwater Protection and Restoration Group (GPRG) at Sheffield University	http://www.shef.ac.uk/~gprg/
USGS Water Resources Education Initiative Program	http://water.usgs.gov/public/outreach/wrei.html
NC-Groundwater Section	http://gw.ehnr.state.nc.us/
USGS Water Science for Schools -Where is Earth's water located?	http://wwwga.usgs.gov/edu/earthwherewater.html
US EPA-Safe Drinking Water - Environmental Education for Kids: Build Your Own Aquifer	http://www.epa.gov/OGWDW/kids/aquifer.html
Aquafest 1997 Handbook	http://sunsite.anu.edu.au/canberra/lakewatch/aquafest/

EARTHWORKS worldwide career and employment opportunities in the geosciences
http://ourworld.compuserve.com/homepages/eworks/HOMEPAGE.HTM

What Activities Can I Do?

The following are examples of issues that may occur in your area and a selection of activities that a community may undertake to address them.

Of course you are not restricted to these activities and in many cases different types of activities may be more appropriate for your group.

This list will get you thinking about what you and your community may do!

Some of the activities may also require skills and cooperation from government agencies, local council and other expertise to achieve your goal.

ISSUES ⇨ **ACTIVITIES** ⇩	**Over extraction of ground-water**	**Contamination of portable supplies of Groundwater**	**Surface water / groundwater interaction**	**Aquifer Storage and Recovery (ASR) – storm water recycling**	**Aquifer Storage and Recovery (ASR)- recycled water (effluent)**	**Dryland salinity**	**Irrigation salinity/ water logging**	**Diffuse source pollution**	**Waste disposal– domestic/ industry**	**Fe bacteria, bore maintenance, use of water (drink or not?)**
Place signs throughout the community (variety of messages)		✹						✹		
Create a community brochure on local issues and distribute	✹	✹	✹	✹	✹	✹	✹	✹	✹	✹
Identify and map abandoned and leaking bores	✹									✹
Manage and organise tours of local water facilities / demonstration sites to the public and students				✹	✹	✹				
Create marketing strategies to encourage local newspapers to feature groundwater articles	✹	✹				✹	✹	✹	✹	
Community clean-up days for local problem areas		✹						✹	✹	

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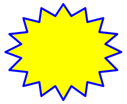
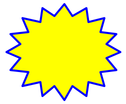
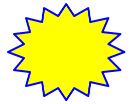
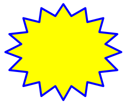
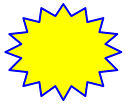
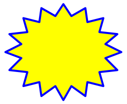
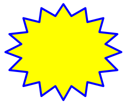
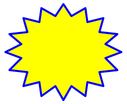
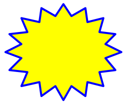
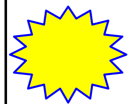
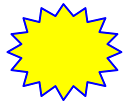
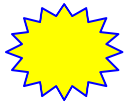
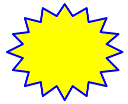
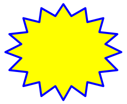
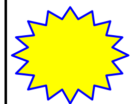
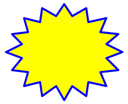
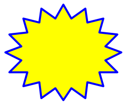
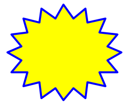
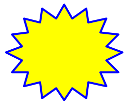
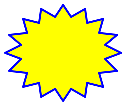
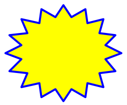
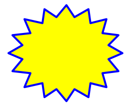
Conduct community information sessions on water-efficient landscaping										
Exhibit water awareness displays at local functions / libraries etc.										
Initiate an ongoing household hazardous waste collection program										
Implement a toxic material disposal pubic information campaign										
Initiate study of local issues ie. Monitoring water table levels (may involve University students project work, local schools)										

ISSUES ⇨ **ACTIVITIES** ⇩	**Over extraction of ground-water**	**Contamination of portable supplies of Groundwater**	**Surface water / groundwater interaction**	**Aquifer Storage and Recovery (ASR) – storm water recycling**	**Aquifer Storage and Recovery (ASR)- recycled water (effluent)**	**Dryland salinity**	**Irrigation salinity/ water logging**	**Diffuse source pollution**	**Waste disposal– domestic/ industry**	**Fe bacteria, bore maintenance, use of water (drink or not?)**
Fundraising by producing a calendar that is water focused – hints and tips on each page- how to wash your car and not pollute, how to dispose of paint etc.		★						★	★	
Regular water quality sampling program		★		★				★	★	
Paint warning signs on storm drains		★		★						
Conduct a colouring-in competition of water issues through local paper / schools	★	★	★					★		
Develop and distribute homeowner bore and septic tank education packages	★									★
Organise a community water testing day		★						★		★

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Produce information sheets to be sent out with council notices	★	★	★	★	★	★	★	★	★	★
Initiate a sewerage system surveillance program								★		
Storm drain / creek clean up days		★	★	★						

Student Activity Sheet

OBJECTIVES

This activity is designed to give you a simple appreciation for groundwater systems and should be undertaken as a team project. Your team of 5 students should meet to discuss your plan of action before you start the activity. It is meant to be easy and is meant to be fun! We will learn about what groundwater is, where it comes from, how it becomes contaminated and what we can do to protect it. In order to understand how groundwater systems work, we are going to build a simple groundwater model and then look at the factors that affect groundwater storage and movement.

This activity is divided into two parts. In Part A, we will build a groundwater model and in Part B, we will examine the concepts of permeability and porosity, two hydrogeologic properties which affect how water is stored below the ground and how easily it is transmitted to a well

PART A: MAKING A GROUNDWATER MODEL

Since it is impossible to travel underground to learn about groundwater, scientists create models to help us understand what we can't see or experience first-hand. Models can be computer programs that attempt to simulate the real world or they can be physical experiments. In this activity, we are going to make a simple physical model of a groundwater system. Below are the directions for making a very simple groundwater model. Be creative with your models!

MATERIALS:

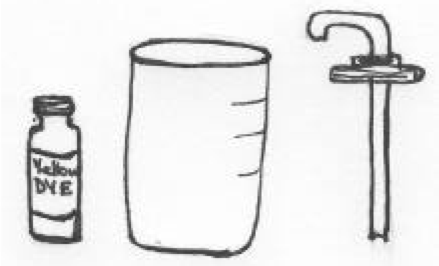
- 2 or 3 clear plastic cups or jars
- sprinkling can, spray bottle or cup
- pea-sized aquarium gravel or sand
- blue and yellow food coloring
- pump from liquid hand washing soap

SETTING UP THE MODEL:

Container filled with water dyed dark blue.

Place gravel or sand in cup.

Keep pump, yellow dye and a spare cup close by.



LEARNING ABOUT GROUNDWATER USING YOUR MODEL:

1. Imagine you are outside, you've removed some grass and are digging a deep hole.

   What would you expect to find in the top metre or so below the grass you have just removed?

   What would you expect to find as you went deeper and deeper?

   Look at and feel the gravel in your cup. Pretend the cup contains gravel from an aquifer (a geologic formation that both stores and transmits water in significant quantities). The bottom of the cup is solid bedrock.

2. The word "groundwater" tells us what it is .... water found in the ground.

   Do you know the source of this water?

   Pour blue dyed water over the gravel until the cup is half full. Watch as the water moves down through the gravel, travelling through the spaces between each particle of gravel. Notice how the bottom of the cup acts just like solid rock or clay and stops the water from going down any further.

3. Look at the gravel in the upper part of the cup. The spaces are not filled with water, but the gravel is wet. **Touch the gravel to prove to yourself that water is there even though it may be hard to see**. There is water clinging to the gravel particles but the spaces are filled with air as well as water. This is what we call the *unsaturated zone*.

4. Now look at the bottom half of the cup and observe how the water fills every space between the gravel particles. The air that used to occupy those spaces has been pushed out by water. This, in a stricter sense, is groundwater. The gravel (sand, or other soil combination) that holds or stores the groundwater is called an *aquifer*.

5. The water table marks the top of the groundwater. (Find the water table "line" on your model.) In a few minutes we will change where the water table is located by pumping.

   Can you predict what we are about to find?

6. To really be an aquifer, it is necessary for the soil particles to store water and allow the water to move back up to the surface of the earth so it can be used. To get water out of the ground we often dig a hole, called a well, and use a pump to draw the water out of the aquifer.

Using your finger "drill a well", by making a hole into the gravel. Place a soap pump into the hole. Be sure the tube reaches down into the cup's groundwater.

7. **Begin pumping groundwater out of your aquifer. Pump it into another cup.**

   What happens to the water table as you pump?
   What would happen if you kept pumping?

   Keep the system going by adding a little more water to the aquifer by "raining" on it with your sprinkling can.

8. So far we have used our model to help us understand the concepts of groundwater, aquifer, water table and well. You will now see how groundwater is sometimes made unfit to use when it is contaminated. **Squirt several drops of yellow food coloring onto the gravel. "Rain" on it again to make it seep down into the groundwater.** The dye represents a chemical that can be dissolved in water and carried down to the aquifer with rain or snow. Some of the contaminants that have been found in groundwater include;
   - wastewater from a kitchen, bathroom, or laundry that went into a septic system,
   - petrol leaking from an underground storage tank,
   - spilled and buried waste (e.g. used car oil or poorly constructed landfill),
   - fertiliser that was put on farm crops or animal waste from a poorly maintained animal feedlot,
   - lawn and garden projects especially if applied at the wrong time, wrong way, or in the wrong amount;
   - and oil-based paints, strong cleaning supplies, insect or weed killers that were not disposed of properly.

9. **Begin pumping again**. Pretend the water is from your home well or the city well that supplies drinking water to your house.

   What is happening to the yellow contamination as you pump?
   Is it in your drinking water yet?

   The water being pumped out will turn green as the "contaminant" comes through. In "real life" it isn't so easy to spot a contamination problem. Contaminated water might not look, smell or taste bad. In addition, it may be hard to find the source of the contamination. Groundwater moves much slower than it did in our model. (Sometimes only centimeters a year). It may be years before the contamination becomes known. By then it may be too late to make the responsible people clean it up.

APPLICATION TO REAL LIFE

Groundwater clean-up is expensive (sometimes millions of dollars). It can also take many, many years. What we must do is to try and prevent contamination from occurring in the first place! Conserve water, properly use, store and dispose of fertilizers and pesticides, clean and maintain septic systems, check underground storage tanks for leaks, properly dispose of used car oil and other household hazardous products, reduce, reuse and recycle. (The making, transporting, and disposing of products cause many water pollution problems as well as other environmental problems.)

PART B: GROUNDWATER MOVEMENT - POROSITY & PERMEABILITY

OBJECTIVE: To discover the rates at which water moves through different types of soils and to demonstrate that water percolates through soils with different grain sizes at different rates.

DEFINITIONS:

Permeability: The ability of a fluid to move through a rock or soil
Porosity: The percentage of a rock or soil that is void of material

MATERIALS:

- Three two litre (or one litre) soft drink bottles
- Stockings or cloth and rubber bands
- Three cups or containers to catch the water that percolates through each bottle
- Samples of clay, course sand, fine sand, gravel, and top soil
- Or gradulated sizes of plastic beads, about 2 cups of each
- A stopwatch or timer

PROCEDURE:

- Cut the bottom of each soft drink bottle (see Figure 1).

- Secure stocking to the bottom of each bottle with a rubber band.

- Place different soil sample or size of bead in each bottle until the bottle is about 1/2 full. Make sure all bottles are filled to the same level.

- Pour 100 mL or more of water through the bottles, one by one. You shouldn't use too little water or else none will break through at the end of the bottle. You can put in more than 100mL, say a couple cups of water, just as long as the amount you put in each bottle is the same.

- Time the passage of the water through each bottle.

- Measure the amount of water that passes through each bottle after 2 minutes (you could weigh the cups and the water in them using a kitchen balance or just do this visually).

- If using soil samples, note the color of the water in the collection beaker.

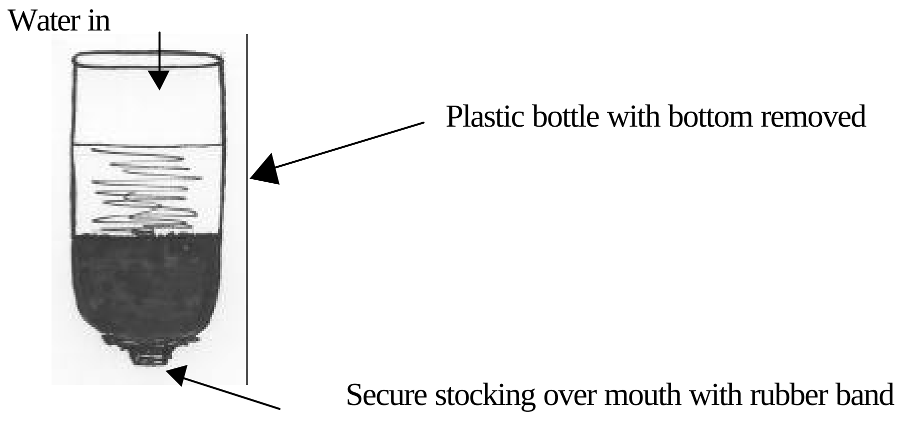


Figure 1. Set up for examining porosity and permeability

RESULTS:

SOIL TYPE	Time water is poured	Time of first drop	Appearance	Amt. Of water at 2 minutes
SAND				
GRAVEL				
CLAY				

A table similar to this one, indicating the soil type of the samples you tested, should be used to record your results.

Questions to answer:

- Did the water go through all of the columns at the same rate?
- If not, why not?
- Describe the relationship between the rate at which water passes through the soil and the size of its grains.
- Which soil sample is the most permeable (allows water to flow through the fastest)?
- Which soil sample is the least permeable?
- If you mixed the gravel and clay together, would the rate of water moving through the soil be faster or slower than the clay alone?
- Which soil retained the most water after 2 minutes (the most porous)?
- Comment on any differences in the colour of outflow water collected below the column?

If an accidental chemical spill occurred in an area of sandy soils, would there be a potential for groundwater contamination? If the same spill occurred in an area of clay soils, would you expect to see any difference?

GLOSSARY

Aquifer, is a saturated geological material, that when drilled, can yield a useable quantity of groundwater.

Aquiclude, this is a confining bed where all the pores in the geological material are full of water (saturated), and water may move vertically through the geological material.

Aquifuge, this is a confining bed where none of the pores in the geological material contain water and the confining bed does not allow any groundwater to flow vertically through it.

Aquitard, this is a confining bed where all the pores in the geological material are full of water (saturated), but no groundwater can pass vertically through the confining bed. Also known as a leaky confining bed.

Capillary Zone, where water is drawn up above the watertable by capillarity.

Capillarity, the affects of surface tension drawing water up into narrow pores against the force of gravity.

Cone of Depression, is a depression in the water table or potentiometric surface in the shape of an inverted cone, forming in response to pumping from a single well.

Confined Aquifer, is an aquifer that is bound above and below by a confining bed. The pressure in confined aquifers is usually greater than atmosheric pressure resulting in water levels in wells being above the elevation of the top of the aquifer.

Confining Bed, geological material usually occurs in beds or layers, a bed that cannot produce a useable yield is known as a confining bed. There are three types of confining beds, aquitards, aquicludes and aquifuges.

Contamination, a contaminant is considered to be any substance that degrades the groundwater quality so that it can no longer be used by plants, animals and humans (Water and Rivers Commission, Western Australia)

Discharge, when water enters groundwater it will flow through the aquifer to a point of exit known as a discharge point such as a river, a spring, or the ocean.

Evaporation, the conversion of liquid into vapour driven by the energy from the sun.

Evapotranspiration, the process that returns water to the atmosphere via evaporation and transpiration.

Fractured Rock Aquifer, is an aquifer where the groundwater moves through secondary porosity.

Geological material, is rock or sediments in a group of formations or layers.

Glaciers, are a large mass of ice formed on land by the recrystallization of snow, and moves down slopes due to its own mass.

Groundwater, is considered to be water in the saturated zone.

Fractures, see secondary porosity.

Hydraulic Gradient, in an unconfined aquifer is the watertable gradient (slope) in the direction of flow and in a confined aquifer is the pressure gradient (slope) in the direction of flow.

Hydrogeologist, is a scientist who works with groundwater.

Hydrographs, are graphs of groundwater levels or salinity values measured from one well at regular intervals (such as once a month) over a period of many years (decades). The graph shows a property of groundwater as a function of time.

Hydrological Cycle, is the endless movement of water from the atmosphere to the earth and back to the atmosphere via precipitation, evaporation, transpiration, runoff, and infiltration.

Hydrologist, is a scientist who works with surface water.

Infiltration, the process of surface water soaking into the unsaturated zone.

Interference, is where the cones of depression of two wells that are located too close to each other and they interact resulting in the lowering of the groundwater levels within the wells.

Intermediate Zone, is located between the soil zone and the capillary zone.

Perched Aquifer, is located in the unsaturated zone, where there are discontinuous confining material and infiltrating water becomes “stranded” on these layers forming a “lense” of water.

Percolation, see infiltration.

Permeability, is the interconnectedness of pores such that water can move through the pores toward a well or a discharge area. The larger the pores the more easily the water will flow through the aquifer.

Potentiometric Surface, is also known as the pressure surface, it is an imaginary surface representing the height to which the groundwater level will rise when a well is drilled into a confined aquifer. It is the hypothetical surface that the groundwater would equilibrate to if not confined.

Pores, are the voids between the grains in a sedimentary geological material in which water is stored.

Porosity, refers to the number of pores present in a geological material and the amount of water that can be stored in the material.

Precipitation, the conversion of vapour into liquid driven by the energy from the sun.

Primary Porosity, the porosity that was present within the sediment at the time of deposition.

Recharge, is the process of replenishment to an aquifer due to the infiltration/percolation from rainfall. Recharge to groundwater may also occur from surface water bodies such as lakes and streams.

Runoff, is the water that reaches streams after a rainfall event.

Saturated Zone, is the zone in the subsurface where all pores are saturated with water at a pressure that is greater than atmospheric pressure. The watertable borders the upper boundary of the saturated zone.

Secondary Porosity, the porosity that occurred after the geological material was formed due to such geological processes as weathering and fracturing.

Sedimentary Aquifer, is an aquifer where groundwater is stored and moves through primary porosity.

Sedimentary Basin, is a topographic low that contains layers of sediment.

Soil Zone, is the first section in the unsaturated zone directly below the surface. Water moves through this zone under gravitational drainage, but water retained by surface tension is used by plants.

Storage, the amount of groundwater held in an aquifer.

Subsurface, is the area under the ground surface.

Surface Tension, is the property of a liquid surface to behave like a stretched elastic film due to the molecular attraction between air and water.

Surface Water, is any body of water on the surface, such as streams and lakes.

Transmission, is the rate at which groundwater moves through an aquifer.

Transpiration, is the process where water is absorbed through the roots of plants and moves through the plant to its leaves where it is evaporated.

Unconfined Aquifer, is an aquifer has the watertable as its upper boundary and a confining bed as its lower boundary.

Unsaturated Zone, is where the pores in the geological material is filled with both air and water. There are three zones within this zone, the soil zone, the intermediate zone and the capillary zone.

Watertable, is the surface in an unconfined aquifer where the pore water is at atmospheric pressure, is also known as the free atmospheric pressure surface. It is the height to which the water level will rise in a well drilled in an unconfined aquifer

Yield, is the amount of water pumped from a well, measured in litres per second.

Acknowledgments

Some of the pictures contained in this document have been adapted for use from the following;
Environment Canada- web site
Raymond, L S Jrn, Cornell University- web site
Waters and Rivers Commission, WA – web site
Published by Community Groundwater Protection Project Massachusetts Audubon
Society- web site
USGS- web site
DENR Victoria- web site
Focus- Australian Salinity Newsletter- web site
TECHSALT – web site