

2 HOW GROUNDWATER FORMS AND FLOWS

THE UNSATURATED ZONE, SATURATED ZONE AND THE WATER TABLE

KEY TERMS

Unsaturated zone:

The zone where the pore spaces and fractures in soil and rock contain both air and water.

Soil moisture zone:

The shallowest layer of the unsaturated zone, it contains the moisture utilized by plants.

Intermediate zone:

The zone beneath the root zone of vegetation and the top of the capillary fringe.

Capillary zone/fringe:

The zone immediately above the saturated zone where combination of the size of the pores between soil and rock grains and the attraction of the soil to water causes water to move upward from the saturated zone.

Saturated zone:

The zone where all the pore spaces and fractures between soil and rock particles are saturated with water.

Water table:

The top surface of the saturated zone.

Some of the water holds on to the particles that make up the soil and rock - this water is called soil moisture. Soil moisture is found in the soil zone and is the water available to plant roots.

The **unsaturated zone** (Figure 2.1) can be thick or thin - ranging from a few metres to tens of metres thick. It consists of three zones:

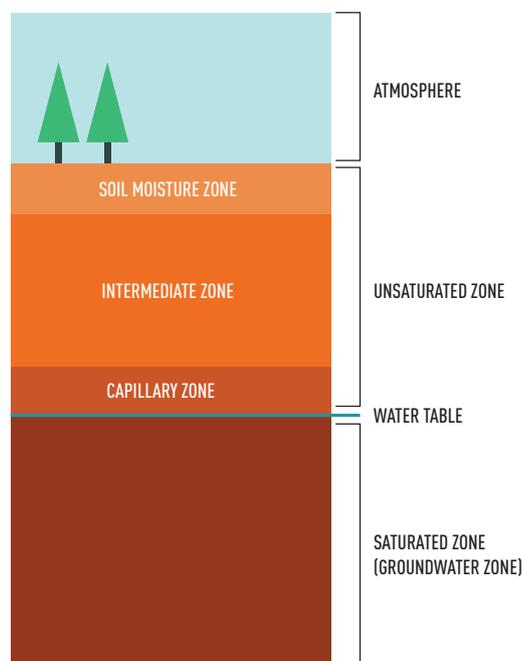
1. The soil moisture zone
2. The intermediate zone
3. The capillary zone (the capillary fringe).

In the unsaturated zone the spaces between the soil, sand, gravel, clay and/or rock particles are filled with both air and water. At the base of the unsaturated zone is the capillary zone. The attraction of the water to soil, and the size of the pores between the soil and rock (capillaries) mean that water is actually drawn upward from the saturated zone below. This creates a zone where there is more water in the pores and fractures than in the unsaturated zone, but it is still not fully saturated.

Water continues to move down through the unsaturated zone to the saturated zone (Figure. 2.1). This is also called the groundwater zone. The tiny spaces between sediment and rock particles are filled with water. The saturated zone can extend from near the ground surface to many thousands of metres below the ground is often many thousands of metres below the surface!

The boundary between the unsaturated and saturated zone is called the **water table**.

FIGURE 2.1 WATER ZONES



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THE POROSITY AND PERMEABILITY OF ROCKS UNDERGROUND

KEY TERMS

Pores:
The voids or "spaces" between grains and particles of soil and rock.

Porosity:
The volume of "space" between solid grains or particles of soil or rock as a percentage of the total volume of the soil or rock.

Permeability:
A measure of how well connected the pores are within a soil or rock so that water can move through it.

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

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

The amount of water moving underground and how fast it moves depends on a number of factors. Two very important factors are the **porosity** and **permeability** of the rocks.

Soil, sediments and rocks are made up of grains. Where there are no gaps between the soil and rock grains and particles, scientists say that the rock has no porosity. At the other end of the scale, some rocks have lots of pore space between grains and so there is room for air or water or other liquids and gases.

The brown spheres represent grains and the grey spaces represent pores. The more space between the grains, the greater the porosity.

The porosity of a rock varies because the size and shape of the grains vary.

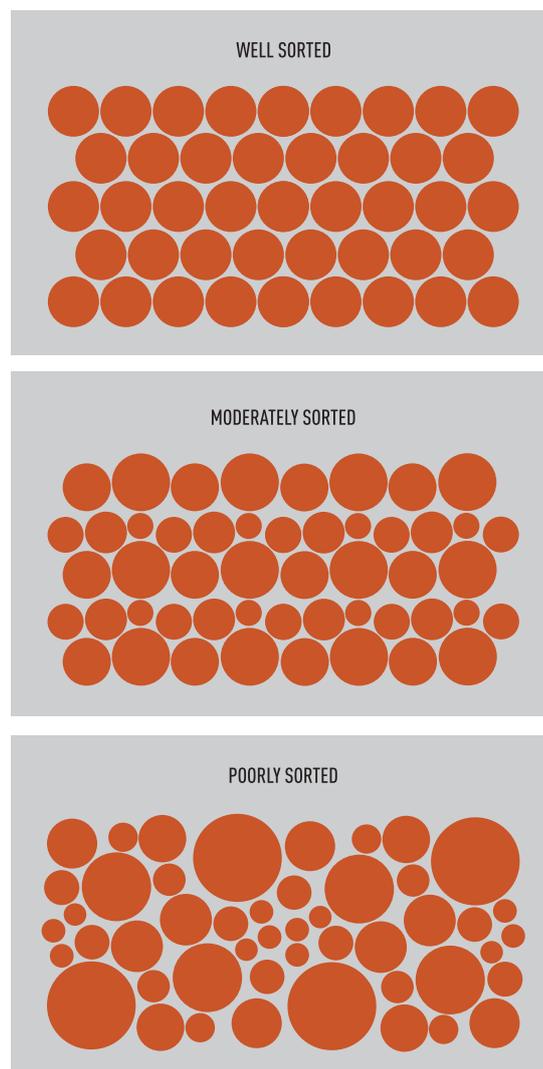
Another factor is the sorting of the grains in the rock. If grains are well sorted this means that they are close to the same size. If the grains in a rock are poorly sorted, this means that there is a mixture of grainsizes.

In Figure 2.2, the top illustration shows the grains that are well sorted as they are close to the same size whereas the grains on the below are poorly sorted because they are a mixture of sizes.

If a rock has a lot of gaps between grains it is said to have good porosity and a lot of water can fit between the grains. A rock with good porosity can hold a lot of groundwater.

Porosity can store groundwater, but for it to flow, the soil or rock must also be permeable. This means that the pores that store the water are connected, allowing groundwater to move from one pore to another. A good groundwater resource requires both porosity and permeability.

FIGURE 2.2 SORTING GRAINS



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AQUIFERS AND AQUITARDS

KEY TERMS

Groundwater:

Is considered to be water in the saturated zone.

Aquifer:

A layer of soil or rock that has relatively higher porosity and permeability than the surrounding layers, enabling usable quantities of water to be extracted.

Aquitard:

A layer of soil or rock that has relatively lower porosity and/or permeability than the surrounding layers, limiting the movement of groundwater through it and the capacity to extract useable quantities of water.

Recharge:

The volume of water that reaches an aquifer to form groundwater.

Subsurface:

Is the area under the ground surface.

The **groundwater** zone might be continuous over a large area or it may be limited to the location of certain sediment or rock layers. This all depends on the porosity and permeability of the layers. Where there are useful quantities of water that can be pumped or extracted from a layer of rock or sediment, that layer is called an **aquifer**. Aquifers can carry water huge distances but very slowly. Water may only move a few centimetres a day or a few metres a day.

Aquifers are underground storage reservoirs of water. To bring groundwater to the surface, a borehole (a slim deep hole in the ground made by a drill rig), or a well (a shallow, hand or machine dug hole into the water table) is required.

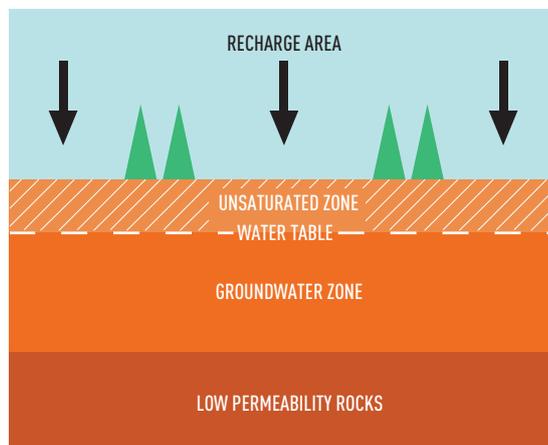
If a rock or sediment layer is not porous or permeable (i.e. cannot hold a lot of water and does not let water through easily), then it is called an aquitard.

Aquifer recharge

Water enters aquifers where they reach the surface (outcrop). These areas are called **recharge** areas. A recharge area for an aquifer will depend on how much of the aquifer “outcrops” at the surface. That means how much of the sediment or rock layer can be seen at the surface.

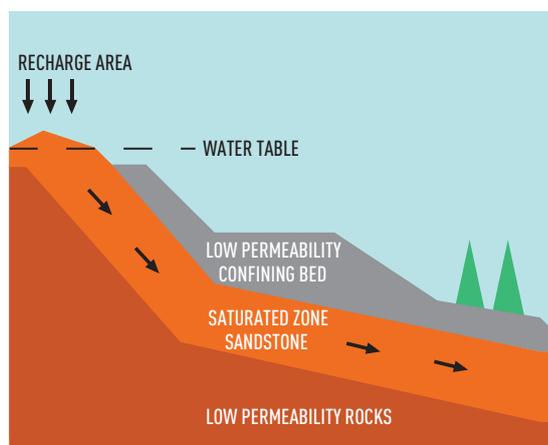
Scientists who study groundwater can calculate how long it takes surface water to reach the **subsurface** in an aquifer. This is known as the recharge rate. Once a scientist has worked out the recharge rate they can then calculate groundwater how long the water naturally stays in an aquifer. For an aquifer that covers a large area or is known to be deep, residence times are usually very long, whereas the opposite is true for shallow aquifers and those that cover smaller areas.

FIGURE 2.3 UNCONFINED AQUIFER



An unconfined aquifer – there is nothing to stop surface water entering the aquifer at all points across the surface.

FIGURE 2.4 CONFINED AQUIFER



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AQUIFERS AND AQUITARDS

KEY TERMS

Unconfined Aquifer:

Is an aquifer which has the watertable as its upper boundary and a confining layer as its lower boundary.

Confined Aquifer:

Is an aquifer that is bounded above and below by a confining layer. The pressure in confined aquifers result in water levels in wells being above the elevation of the aquifer.

Discharge:

Where groundwater becomes surface water again, such as a spring or where it flows back into a river or the ocean.

Confined and unconfined aquifers

When you drill a bore or dig a well, the first layer you hit that has groundwater is called an **unconfined aquifer** (Figure 2.3). Water can move from the ground surface straight into the aquifer. The water at the level of the water table in an unconfined aquifer is at the same pressure as the atmosphere above it. A supply of water could be extracted from an unconfined aquifer by means of a well or a borehole with a pump.

In the case of a **confined aquifer**, an aquitard covers the aquifer. The aquitard prevents groundwater from moving upwards.

Groundwater in a confined aquifer is under pressure (Figure 2.4). The pressure is caused by the weight of water in the aquifer between the recharge area and bore drilled into the aquifer. When a borehole is drilled through the confining layer and into the aquifer, water will rise up the bore above the top of the aquifer until the water column is high enough to balance the pressure in the aquifer.

Aquifer discharge

If groundwater enters the ground at recharge areas then it must come out of the ground somewhere too. Groundwater can come to the surface via boreholes and wells drilled by people. It can also flow out to the ground naturally – these are called **discharge** features (Figure 2.6.3).

Some discharge features that will be very familiar are rivers, creeks, small streams and lakes. Water can drain into these from both the surface and from underground aquifers.

Another type of discharge feature is a spring. Sometimes the confining layer over the top of an aquifer may have cracks in it. These may be small faults or fissures through which water can escape upwards to the surface. Water seeps through the cracks and a spring is seen at the surface. Springs can also occur where there is a change in slope of the land or an abrupt change in the rock type.

Water can also discharge into lakes that dry up leaving only dissolved salts – these are called salt pans or salinas. Salts from salt pans can be harvested for industrial and consumer use.

FIGURE 2.5 EXAMPLES OF SOME DISCHARGE FEATURES

CROSS SECTION VIEW

STREAM



Nearby bores will have a higher water level than the stream

SALINA

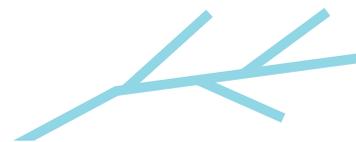


High evaporation in a salt water lake

MOUND SPRING



BIRDS EYE VIEW



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GROUNDWATER FLOW

KEY TERMS

Hydraulic Gradient:

In an unconfined aquifer this is the watertable gradient (slope of the watertable surface) and in a confined aquifer it is the pressure surface or potentiometric gradient (slope of the pressure surface). The direction of the slope of the hydraulic gradient determines the direction of groundwater flow.

Hydraulic Conductivity:

The measure used by hydrogeologists to describe how well water will move through rock and soil. It is dependent on the porosity and permeability. The units of measurement of hydraulic conductivity are length over time (L/T) – usually expressed as m/day or m/sec.

Groundwater flows not so much “down hill” as “down **hydraulic gradient**”. Flow is driven from where the surface of groundwater is at a higher elevation to areas of lower elevation. In many cases the surface of groundwater is a reflection of the surface of the ground – only smoothed out. However, there are also many cases where the surface of the groundwater has a different gradient and direction to the ground surface. It is also possible to change the hydraulic gradient, by pumping groundwater out.

The head elevation of groundwater is measured by drilling bores into the groundwater and measuring the level of the water in the bore relative to some uniform measurement point (sea level or equivalent is often used). By contouring these points of measurement, the overall surface of groundwater can be interpreted.

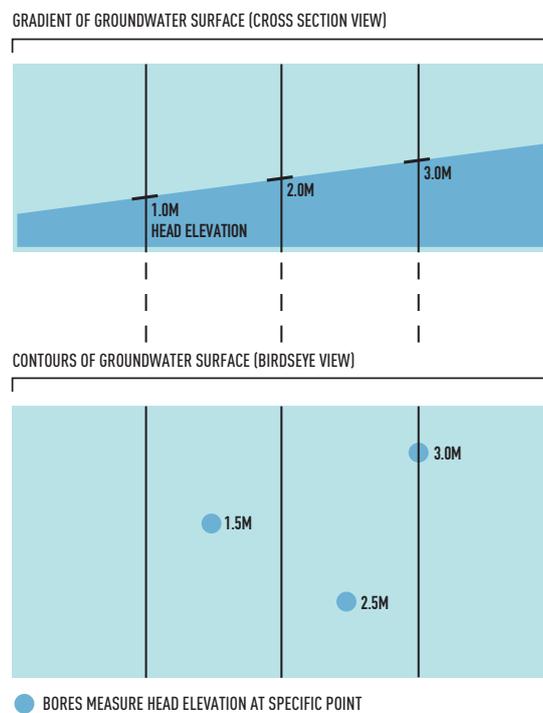
If Figure 2.6 was just an empty tray with no sand in it, and you poured water in from one end, the water level in the trays would (more or less) fill uniformly. Water would rapidly move from one end of the tray to the other and the water surface would be approximately level. Why doesn't this happen in groundwater?

In a groundwater system, the **porosity** and **permeability** of the soil or rock limits the speed of transfer between the top and bottom of the tray. The “hydraulic conductivity” is a measure of the capacity of a soil or rock to pass water through it under a constant gradient. It has units of length over time, usually m/day or m/sec.

As you pour water into one end of the tray, it will form a hydraulic gradient from one end to the other as the speed of transfer of water is limited by the hydraulic conductivity. Over time the surface will level out.

We have already learnt that groundwater moves very slowly through aquifers from an area of recharge to discharge. In some cases, aquifers extend over very large areas, whereas in other cases the areas are much smaller. Scientists who study groundwater divide these areas according to their size. These areas are known as groundwater flow systems. The three types of groundwater flow systems are known as local, intermediate and regional (Figure 2.7).

FIGURE 2.6 GROUND WATER FLOW



How groundwater flows through an aquifer.



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GROUNDWATER FLOW SYSTEMS

Local groundwater flow systems

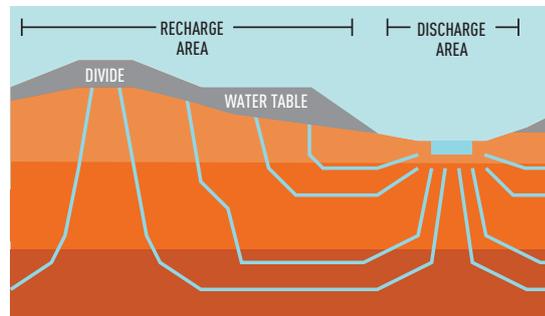
Local groundwater flow systems are generally shallow and groundwater moves from a recharge point to the nearest discharge point. Local flow systems are often only a few square kilometres in area and extend from a few metres up to five thousand metres. The groundwater that discharges from this system is usually quite young in age, ranging from years to decades. Local flow systems are often close to each other.

Intermediate groundwater flow systems

Are deeper than local flow systems and can be tens to hundreds of square kilometres in area. The age of the groundwater in this system can be from hundreds to tens of thousands of years. Intermediate flow systems extend from 5km up to 50km.

FIGURE 2.7 LOCAL, INTERMEDIATE AND REGIONAL FLOW SYSTEMS AND THEIR RELATIVE 'RESPONSIVENESS'

FLOW



● LOCAL ● INTERMEDIATE ● REGIONAL

Regional groundwater flow systems

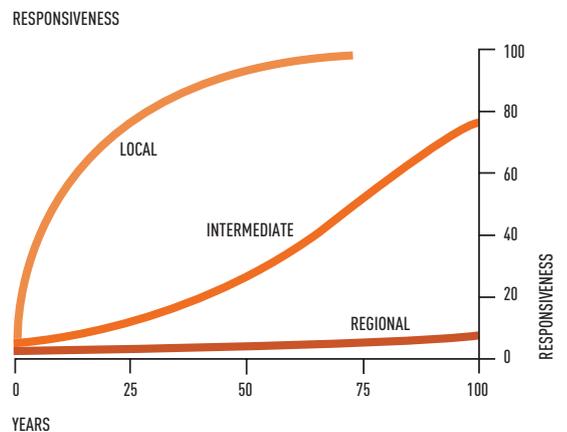
Regional groundwater flow are generally deeper and often cover hundreds to thousands of square kilometres and extend systems over distances from 50 kilometres to many thousands of kilometres. The age of groundwater discharged from these systems can be tens of thousands of years old to millions of years 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.

Responsiveness

The different scales of groundwater systems have different "responsiveness" to change. Local systems have relatively lower volumes of stored groundwater (Figure 2.8). Activities which change the amount of recharge to or discharge from a local system will have a proportionally more significant response than for larger systems. In this way, a management action in a local system may create an observable change in a relatively short timeframe (years). In intermediate and regional systems, the relative change has to be much bigger to generate an impact, and it may take decades to centuries to observe the change. The responsiveness of a groundwater system is a key consideration in groundwater management.

<http://www.anra.gov.au/topics/salinity/management/index.html>

FIGURE 2.8 RESPONSIVENESS OF DIFFERENT SYSTEMS



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