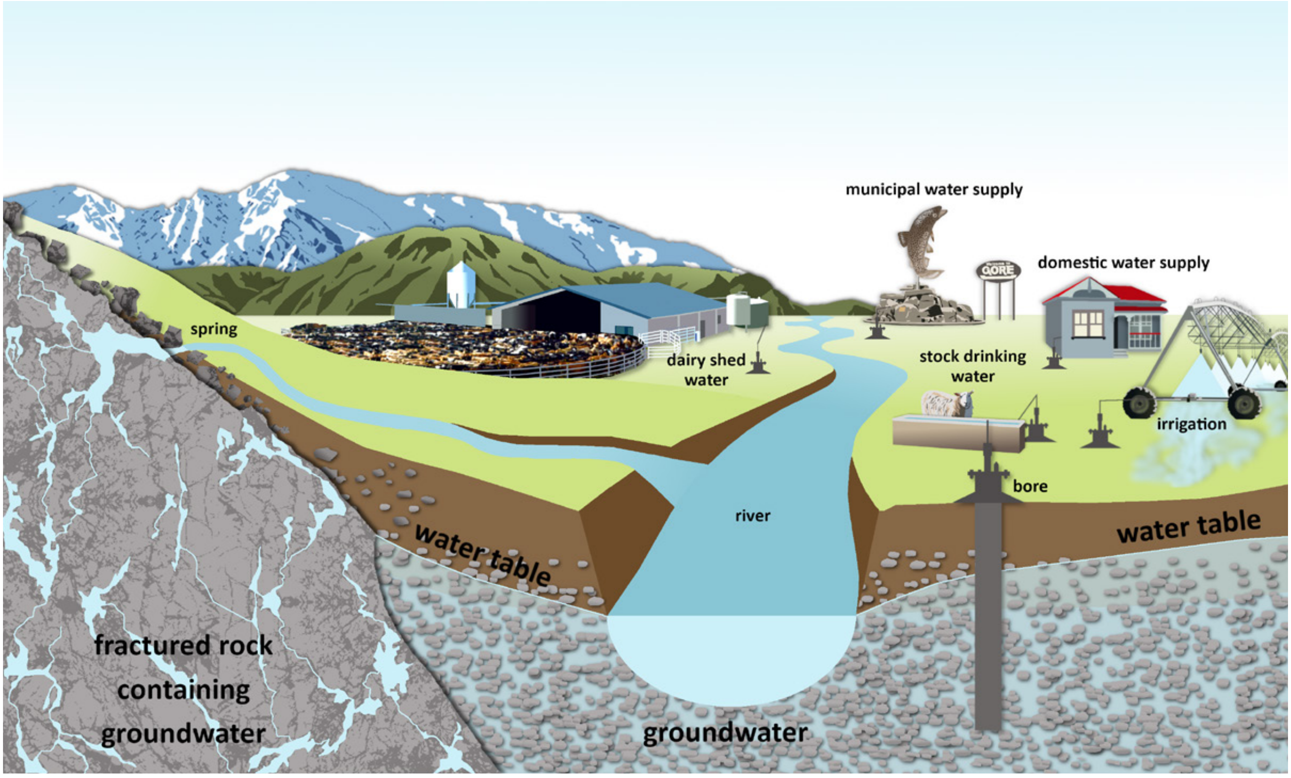
SOUTHLAND'S MONITORED GROUNDWATER

A guide to groundwater ecosystem health monitoring

environment SOUTHLAND
REGIONAL COUNCIL
Te Taiao Tonga



▲ **Groundwater can be found within a variety of geological formations, for example rock cracks and fissures (left) and within the pore spaces of gravel deposits (right). Bores extract groundwater, which is then used for commercial and domestic supply.**

What is groundwater?

Groundwater is subsurface water that occurs beneath the water table in soils and geological formations that are fully saturated.

When rain falls to the ground, water does not stop moving. Some of it flows along the land surface to streams or lakes, some is used by plants, some evaporates and returns to the atmosphere, and some seeps into the ground. As water seeps into the ground, some clings to particles of soil or to plant roots providing them with moisture they need to grow. Water not used by plants moves downwards filling any empty spaces and cracks. The water that fills the spaces and cracks is called groundwater. The top of where the spaces and cracks are saturated is called the water table.

What are aquifers?

An aquifer is saturated rock or soil material capable of transmitting and yielding water in sufficient quantities for abstraction.

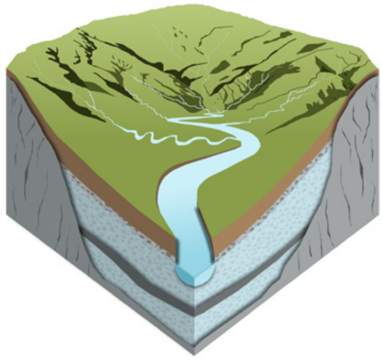
Aquifer is the name given to underground soil or rock through which groundwater can move easily enough to be abstracted for human use. The amount of groundwater that can flow through soil or rock depends on the size and number of spaces in the soil or rock and how well the spaces are connected.

Why is groundwater important?

Groundwater is an extremely valuable resource. It is an integral part of the hydrological cycle and has an important role in our environment and our economies.

Water storage

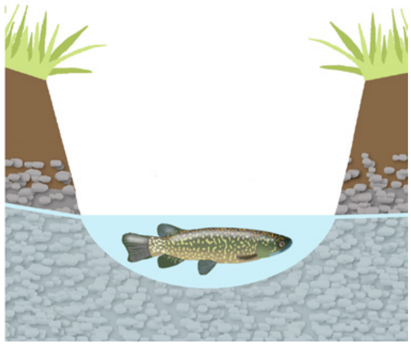
Aquifers play an important role in the water cycle by storing large amounts beneath the ground. Aquifers retain water during periods of high rainfall or river flows and release it slowly to surface waterways over subsequent months or years. Together, Southland's aquifers represent a large percentage of our region's total freshwater.



Did you know? Nearly one third of the earth's freshwater is found below the ground surface as groundwater. About two thirds of the earth's freshwater is frozen in glaciers and in the polar ice caps. Only about 1 percent is sitting on the earth's surface in lakes, streams and rivers. This means that groundwater accounts for approximately 98% of Earth's freshwater that's available for human use.

Baseflow to streams and rivers

The flow of groundwater into streams and rivers as seepage through the river bed, known as baseflow, can be essential to the health of wildlife and plants that live in the water. Baseflow discharge also exerts a significant influence on both physical and chemical water quality in rivers and streams, particularly during periods of extended low flow. In Southland, many of our streams and rivers rely on groundwater as the main source of water flow during dry months.



Groundwater ecosystems

Groundwater provides important habitats for a range of species that have evolved to live their entire lives beneath the ground surface. Highly specialised species of invertebrates (called stygofauna) have evolved to live in the cold, light-less waters found deep underground. They are colourless and blind, and include water mites, aquatic snails, many different types of worm, and several types of 'well shrimp'.

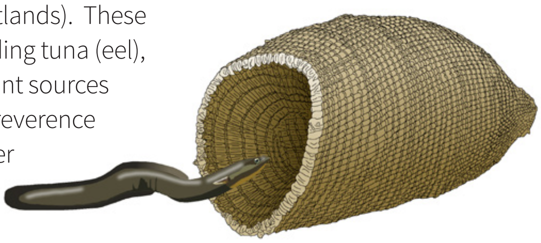
Springs

Springs come in many types and sizes, forming unique ecosystems that rely on the continual source of groundwater. Springs have stable flow and temperature conditions all year round, resulting in a stable habitat. Many Southland springs contain relatively high numbers of invertebrate species, particularly snails and crustaceans.

Why is groundwater important?

Cultural use

Groundwater emerges as waipuna (springs) and repo (seepages and wetlands). These sites provide habitat and food for a number of freshwater species, including tuna (eel), and kōura (freshwater crayfish) and are valued by Māori for their abundant sources of mahinga kai (food and natural resources). Waipuna are often held in reverence according to tribal custom and tradition. Pure, fresh running spring water may be valued for customary and spiritual purposes such as waiora (sources of healing water) and waitohi (sources of ceremonial water).

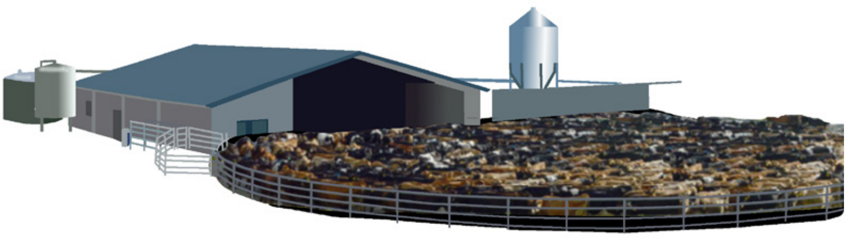


Treating pollutants

The soils and rocks through which groundwater flows can help to remove pollutants. In addition, the groundwater itself hosts organisms that form a complex ecosystem that can protect water quality through the cycling of nutrients. For example, groundwater contains a very specialised group of bacteria that, under the right conditions, use the oxygen present in nitrate as an energy source, with the nitrate ultimately changing or 'reducing' to nitrogen gas.

Water supply

Groundwater is used for a water supply, especially where there are limited surface water sources or the quality of groundwater is very good and does not require treatment prior to use. Southland relies on its groundwater as a water supply for a range of uses including human and stock drinking water, dairy shed water, irrigation, domestic supply and commercial and industrial use. Agricultural production and processing are both major users of groundwater in the region.



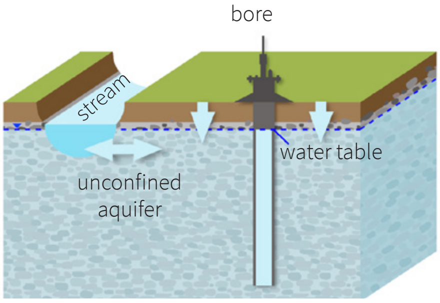
Aquifer types

There are many types of aquifers. The most common types sit on a spectrum ranging from unconfined to confined.

Unconfined aquifers

Unconfined aquifers are those into which water seeps directly from the land surface. In Southland, these aquifers tend to have a shallow water table and are well connected to streams and rivers. They are recharged by infiltrating rainwater and some also get recharge from surface water such as streams or rivers. These aquifers usually provide the most accessible source of groundwater.

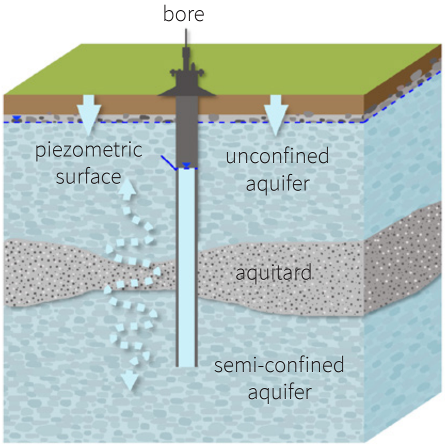
How easy the water is to extract from the aquifer depends on factors such as the age and composition of the aquifer substrate. For example, substrates with a high gravel component tend to have a higher water yield than substrates with a high clay or fine silt component, because gravel has greater porosity and permeability.



Semi-confined aquifers

Semi-confined (or 'leaky') aquifers are partly confined by a top layer of lower permeability substrate through which water can move through very slowly. Water may flow upwards or downwards depending on the situation. For example, pumping in these aquifers can induce downward flow of water from overlying aquifers while under natural conditions, pressure may cause groundwater to leak upwards into the unconfined aquifer.

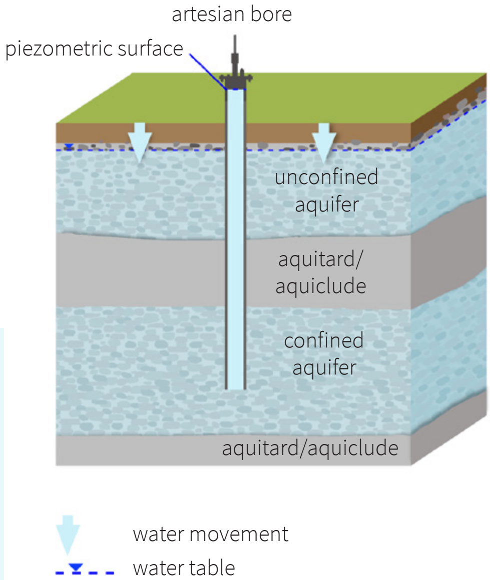
These aquifers have a piezometric surface rather than a water table. The piezometric surface is the level groundwater under hydrostatic pressure rises to in a bore. In sedimentary basins, such as those that occur in some parts of Southland, systems of interbedded permeable and less permeable layers are common resulting in a sequence of interconnected semi-confined aquifers.



Confined aquifers

Confined aquifers are bounded above and below by rock or other low permeability barrier material (called an aquitard) or by impermeable material (called an aquiclude).

The pressure of water in a confined aquifer is usually higher than atmospheric pressure, which is why when a bore is drilled into a confined aquifer the water rises to a level higher than the aquifer. If this level is above the land surface, it is called a free-flowing or artesian bore.



Groundwater Management Zones

In Southland, unconfined aquifers have been subdivided into 30 groundwater management zones based on areas of similar hydrogeological characteristics. Information sheets have been produced for each groundwater management zone to provide an overview of their characteristics.

Confined aquifers are managed separately because they respond differently to abstraction and are much more difficult to map.

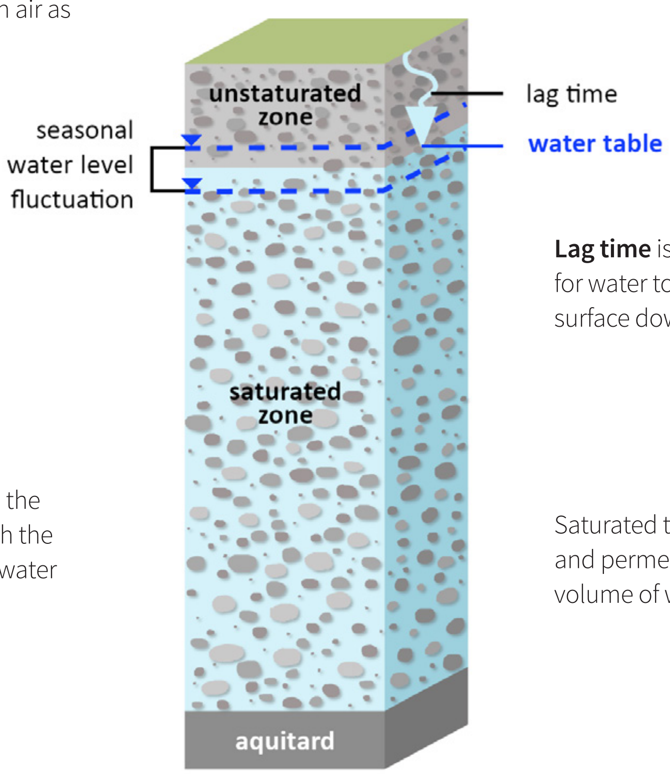
Information on Southland's aquifers, including the groundwater zone information sheets, can be found on our website.

Aquifer characteristics

In Southland, aquifers typically consist of gravel, sand, and sandstone sediments, or fractured rock such as mudstone and limestone. Groundwater can move through these materials because they have a sufficient number of pores (the ratio of pores to rock is called porosity) and the pores are well connected (or permeable).

The amount of groundwater stored in an aquifer is also dependant on aquifer size and depth. The part of the aquifer that is completely filled with water is called the 'saturated zone'. At the top of this zone is the 'water table'. The water table may be very near the ground surface or it may be many tens of metres deep. The area above the water table contains water, but it is not totally saturated so it is called the 'unsaturated zone' (or vadose zone).

The **unsaturated zone** sits above the water table. Pore spaces contain air as well as some water



Lag time is the amount of time it takes for water to move from the ground surface down to the underlying aquifer

Saturated thickness describes the thickness of the aquifer in which the pore spaces are saturated with water

Saturated thickness, area, porosity and permeability will affect the volume of water in an aquifer

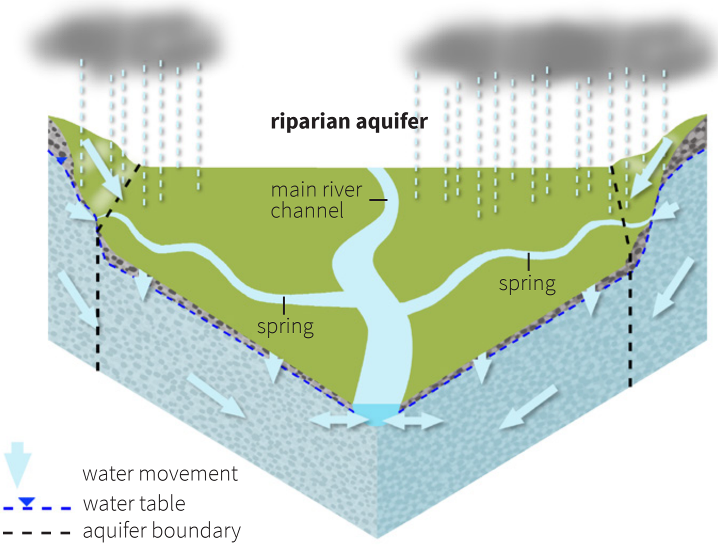
Generic unconfined alluvial aquifer cross-section showing the unsaturated zone, saturated zone and water table.

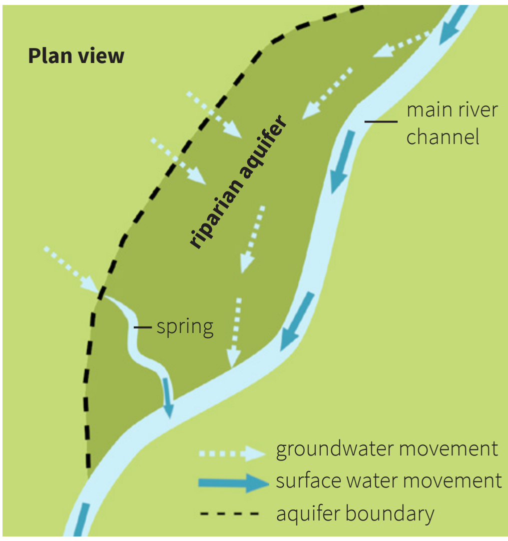
Unconfined aquifer types

Southland's unconfined aquifers can be grouped into three main types depending on their position in the landscape. Cut-away and plan view diagrams are depicted for each aquifer type, showing position in the landscape, groundwater and surface water movement, and aquifer boundaries.

Riparian aquifers

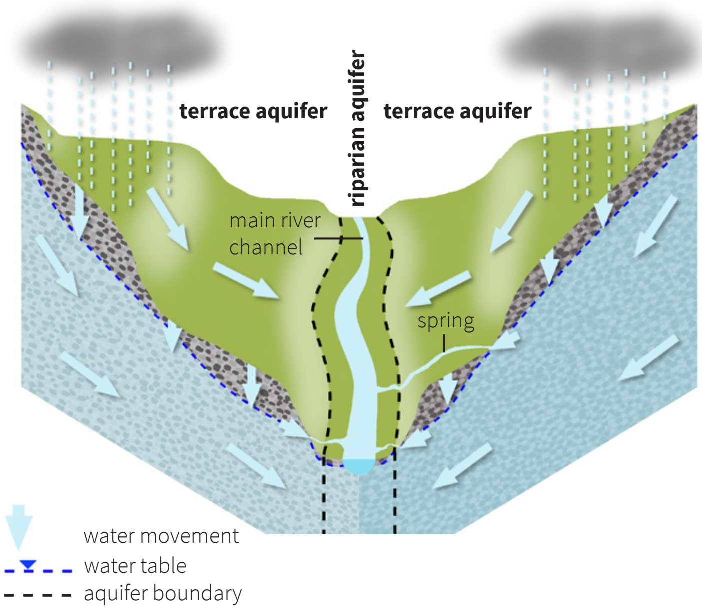
Riparian aquifers are highly permeable and found underlying the recent floodplains of major river systems. Commonly in these aquifers systems, flow is lost from the river to the aquifer near the upstream aquifer margins and returns to the river in the downstream section via seepage through the river bed or as spring-fed stream discharge. These aquifers also receive recharge from rainfall infiltration as well as throughflow from adjacent terrace aquifers located along the valley margins. These aquifer systems exhibit a high degree of interaction with surface water (recharge and discharge), which can influence the quality and quantity of both ground- and surface water. Riparian aquifers can be found along the margins of all Southland's major rivers.

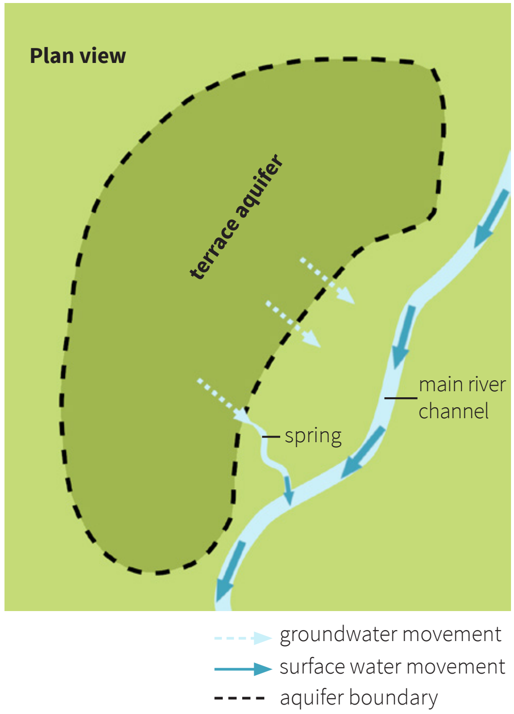




Terrace aquifers

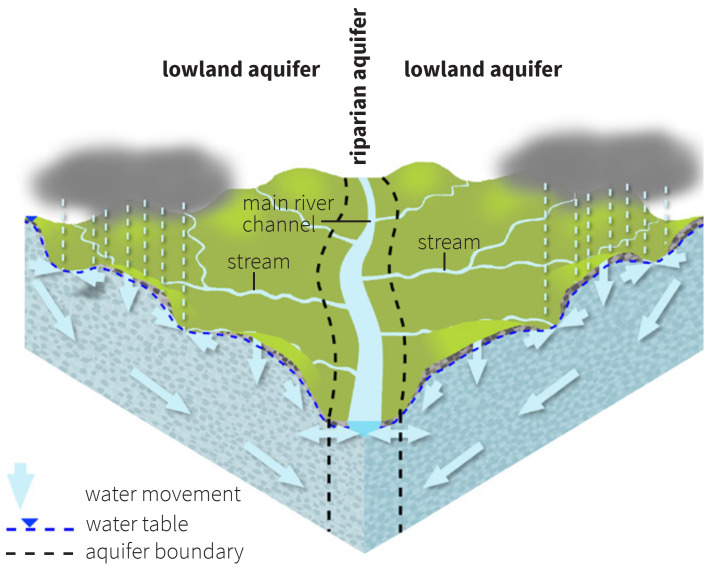
Terrace aquifers underlie elevated gravel terraces along the margins of the major river valleys. Due to their age and origin, the aquifer gravel deposits often have a high proportion of clay and silt limiting permeability. These aquifer systems are recharged by rainfall and runoff from the surrounding hills and usually have little interaction with surface water. Springs commonly form along the terrace margins where the water table intersects the land surface. These aquifers may also discharge into lower-lying riparian aquifers. As a result, they do contribute significant discharge to surface water but generally not directly.

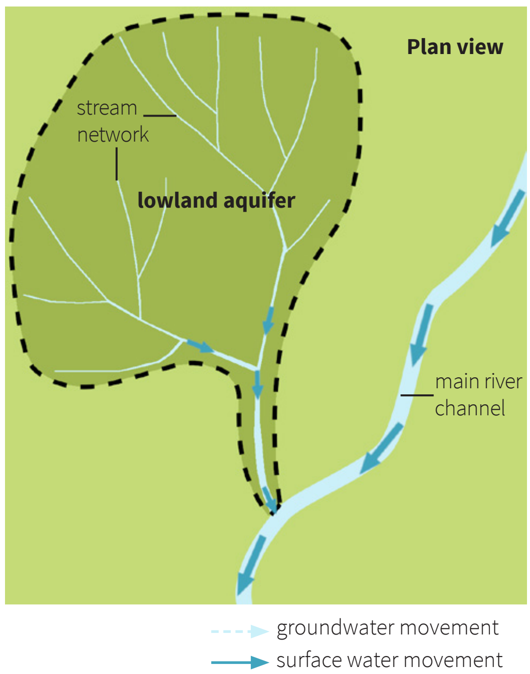




Lowland aquifers

Lowland aquifers generally exist in the remnants of older, highly weathered glacial outwash or alluvial gravel surfaces which are crisscrossed by numerous small streams to form a gently undulating landscape. These aquifer systems are typically thin (less than 30 metres deep) and made up of poorly sorted, weathered gravels limiting permeability. Their low-lying topography and often poor soil drainage has resulted in significant modification of the natural hydrology of these areas. Their groundwater flow is mostly local drainage of rainfall recharge to nearby streams and creeks, with some slow circulation of deeper groundwater following the overall catchment drainage.





What's the problem?

Quantity

Demand for groundwater has grown in Southland, and is expected to rise further with population growth and land use intensification.

Abstraction

Under natural conditions, the amount of water in an aquifer varies depending on recharge, mostly from rainfall, and discharge, mostly to other water bodies including rivers, streams, lakes and wetlands. While rainfall recharge processes are highly variable, the outflow from an aquifer is relatively constant. This means an aquifer acts as a storage buffer where groundwater levels vary about some average condition in response to climatic variation. If not well managed, human activities, like abstraction, can alter the equilibrium between aquifer recharge and discharge resulting in undesirable outcomes. Some of these are outlined below.

Streams that are hydraulically connected to groundwater may have their flow reduced to a point they can no longer support aquatic life if groundwater levels drop too much from excess abstraction. In extreme cases, springs and streams may lose flow altogether and dry up until groundwater levels recover.

A cone of depression forms around a pumped bore. This cone can lower groundwater level enough it limits or impedes the ability of a neighbouring bore to extract water. If there is too much drawdown or bores are too close together, or not drilled deep enough, there will not be enough water for both bores to operate.

Pumping of groundwater near a surface water body can result in the surface water to flow into the aquifer to replenish depleted groundwater levels. If surface water is contaminated, pollutants such as excess nutrients and bacteria, can be drawn into the groundwater.

Land subsidence occurs when there is a loss of structural support below ground. This is most often caused by overuse of groundwater leading to collapses, sinks, and drops. When too much water is withdrawn, the rocks below ground can fall in on itself causing changes to the land surface.

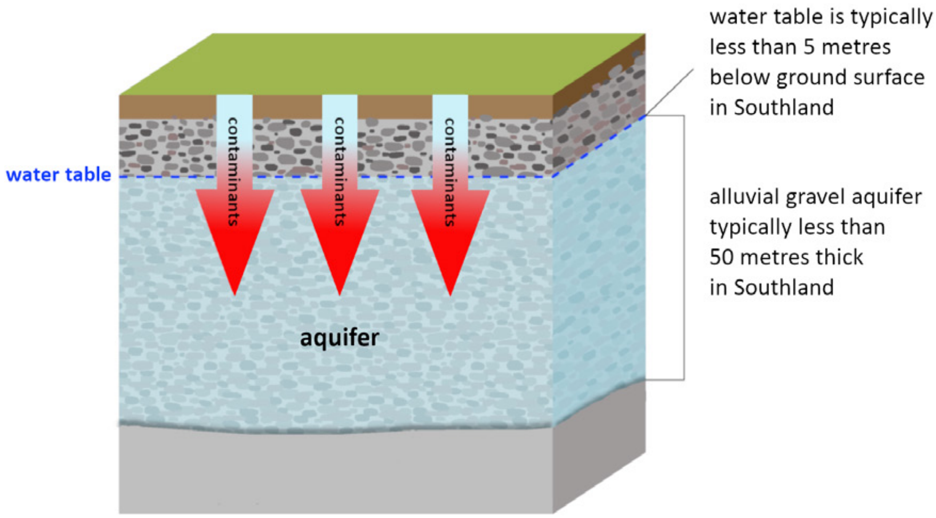
Pumping in coastal areas can cause saltwater from the ocean to move inland and upward, resulting in saltwater contamination of aquifers and water supplies. Coastal aquifers are also at risk of seawater intrusion with rising sea level.

The terms 'recharge' and 'discharge' refer to the movement of water into an out of an aquifer.

Quality

Land use activities can contaminant groundwater. Southland's unconfined aquifers, which are typically shallow, are at greatest risk from activities occurring on the land surface.

Southland's unconfined aquifers are typically thin and have a high water table, often less than 5 metres below the ground surface. A high proportion of their water volume is closely connected to the land surface above, putting them at risk of contamination from the land use activities occurring on the land. The figure below illustrates how easily contaminants can move from the ground surface to underlying aquifers, particularly when the water table is high.



'Typical' Southland alluvial aquifer, showing high water table and high level of connectivity with the ground above.

Contaminants

Nitrogen and phosphorus are important plant nutrients and are used extensively used in agriculture to promote grass and crop growth. Nitrogen enters the soil via animal waste or fertiliser. However the amount of nitrogen in the soil often exceeds the amount that be used by plants and this excess nitrogen changes form to nitrate in the soil. Nitrate is water soluble, so easily leaches down through the soil to the groundwater below. Phosphorous can also enter groundwater via the soil; particularly in areas where the soil organic matter content is very high (such as peat).

Excess nitrogen and phosphorous in groundwater becomes a problem when it seeps into streams, rivers and lakes. Upon entering waterways, excess nitrogen and phosphorus can encourage the growth of nuisance aquatic plants and algae. These plants can choke up waterways and out-compete native species.

Excess nitrogen in groundwater can also be toxic to stygofauna (species that have adapted to live in areas of groundwater), in the same way elevated levels can be harmful to fish in surface waters, such as rivers and streams.

Nitrate, and other contaminants such as disease causing microbes, pesticides, hydrocarbons, heavy metals and cyanotoxins can be harmful to humans in excessive quantities.

Redox

Redox (short for reduction-oxidation reaction) is a type of chemical reaction that changes the oxidised state of atoms.

If dissolved oxygen is present, the water is 'oxic'. If no dissolved oxygen is present, then the water is 'anoxic' (see figure below).

The redox conditions of groundwater strongly affect the mobility and persistence of many contaminants in groundwater. Redox conditions determine whether some chemicals, like arsenic and manganese, are released from aquifer rock and sediment into the groundwater. In Southland, some aquifers are naturally unsafe for human drinking water due to elevated levels of manganese that are released from organic-rich rocks, like lignite, into the groundwater.

Redox conditions also determine whether some contaminants from human activities travel with the groundwater, react with the aquifer material, or degrade into other chemicals. Under the right conditions, nitrate leached from land use activities can undergo a process of 'reduction' that ultimately changes nitrate into nitrogen gas. This process occurs via a group of specialised bacteria that are able to survive in groundwater that has both low levels of oxygen and a ready supply of carbon (fuel for the bacteria). Groundwater that is well oxygenated and has a low carbon content will have much lower rates of nitrate reduction and therefore are at risk of nitrate contamination.

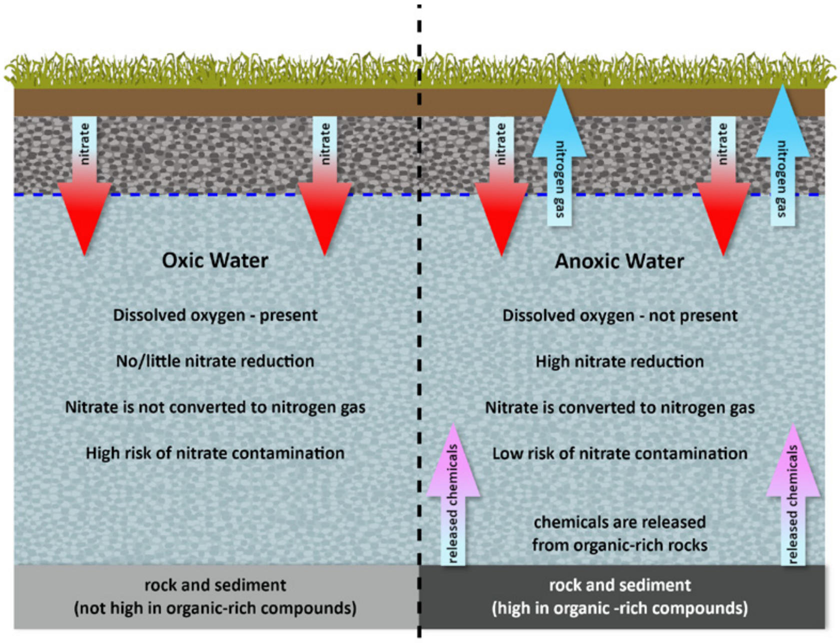


Figure showing the differences in water chemistry between aquifer with oxic water (left) and one with anoxic water (right).

Lag times

'Lag time' is the amount of time it takes for water, or contaminants in water, to move from the ground surface to the underlying aquifer. The composition of the unsaturated zone affects the lag time between the land surface and underlying unconfined aquifer. In general, areas with sand and gravel will drain more quickly than those with silt and clays. The proportion of water running over the land surface as overland flow, or laterally through the soil via mole-pipe drains, also increases with silt and clay, with a small proportion of rainfall reaching the underlying aquifer.

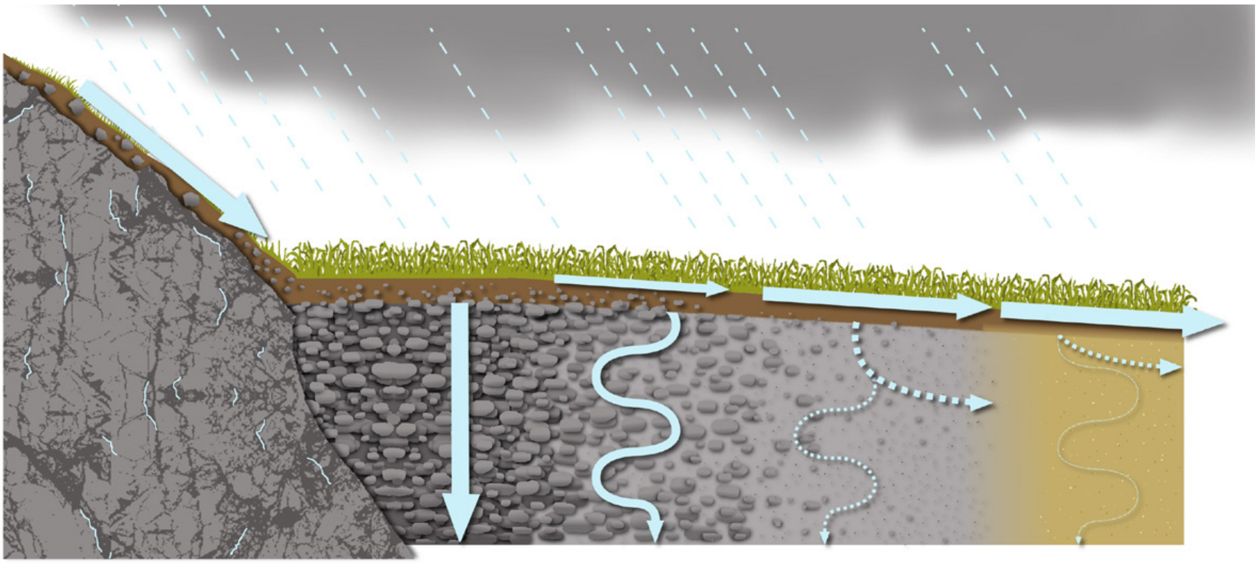


Figure showing the proportion of water flowing over the land surface vs the proportion draining down through the unsaturated zone, for each sediment type. The thicker the arrow, the greater the rate of flow.

The lag time means that current groundwater quality in Southland can reflect land use from as little as only one or two years ago, or as much as decades ago, depending on the location. This also means that we may not see the effects of current land use activities until some time in the future.

Scientists estimate that for about 80% of Southland it takes less than one year for nitrate to travel from the soil down to the groundwater. For 90% of Southland, it takes less than two years. The quickest draining areas tend to be found on 'young' substrates located in lowland areas. The slowest draining areas are found on 'old' substrates at higher elevations.

Given the large storage capacity of most aquifer systems, groundwater response to land use impacts will usually be gradual and often delayed. Moreover, groundwater quality degradation, once it has occurred, is likely to be long-lived and costly to remediate.

Groundwater monitoring programme

Environment Southland has a monitoring programme that assesses groundwater quantity and quality. Using a range of indicators, we combine results from bores to make an assessment. Some key indicators are discussed below.

Groundwater levels

Over time, groundwater levels can be used to tell us whether the amount of water in aquifer storage is changing. A reduction in aquifer storage can reduce the amount of water in rivers, streams, lakes and wetlands and can reduce bore yields.

Human health – drinking water

Nitrate
Nitrate is water soluble and leaches down through the soil to the groundwater below if water is oxic. Too much nitrate can affect the health of people, particularly bottle-fed infants who have increased risk of methaemoglobinaemia (sometimes referred to as 'blue-baby' syndrome).

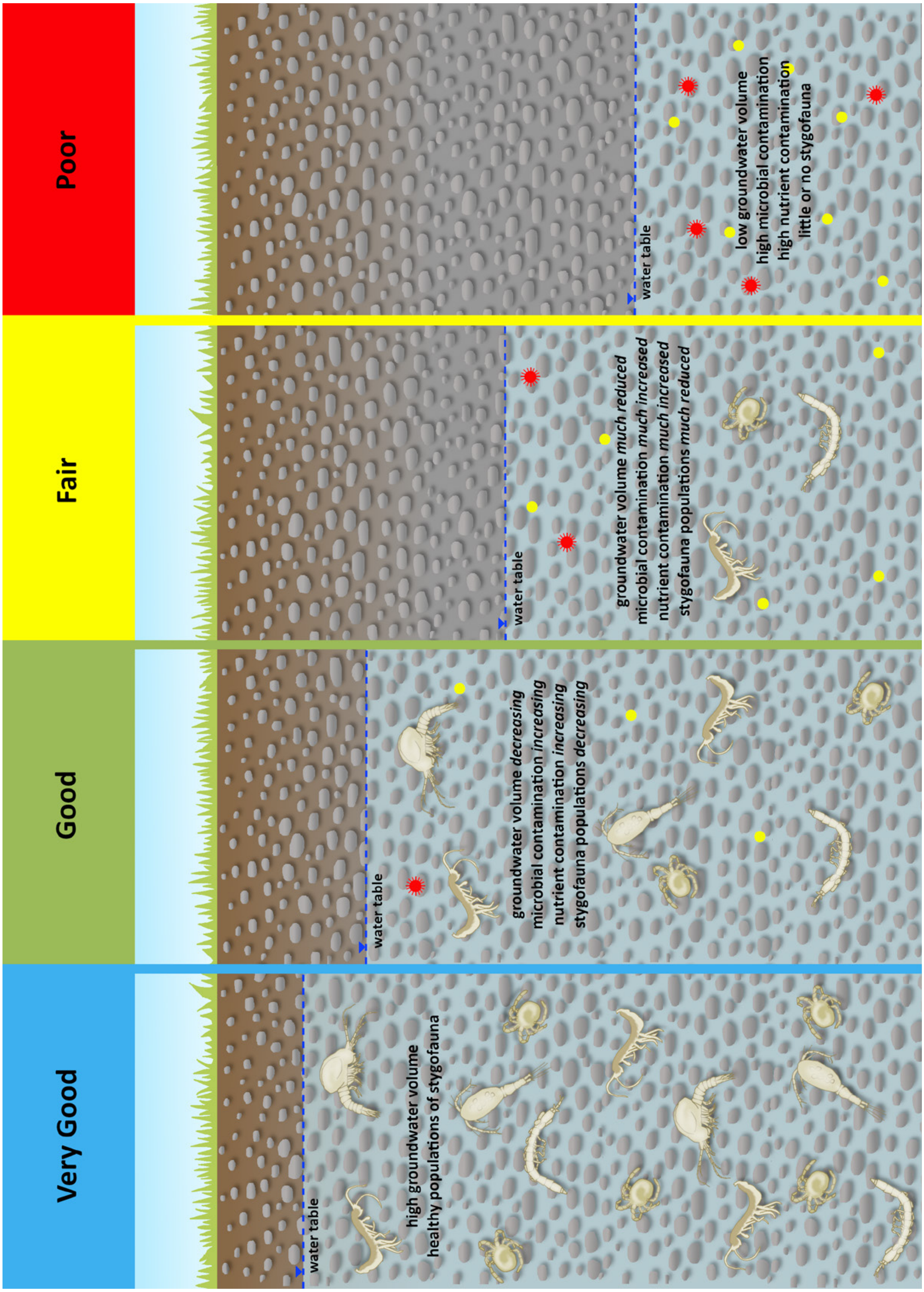
Microbes
Escherichia coli (E. coli) is a type of bacteria commonly found in the intestines of warm-blooded animals, such as birds and mammals (including people, cows and sheep). The presence of these bacteria indicates faecal contamination and potentially the presence of other disease causing micro-organisms, which can be harmful to people and stock.

Ecosystem health

Nitrate
Short-term (acute) and long-term (chronic) exposure to excessive levels of nitrate can impact groundwater ecosystem health. Stygofauna are small, unpigmented invertebrates that have adapted to aquatic life underground. They include a variety of life forms such as, worms, shrimps, mites and snails. Stygofauna and bacteria play a key ecological role by feeding on and 'cycling' organic material in groundwater. However, stygofauna cannot tolerate high levels of nutrients and are particularly sensitive to contaminants. Where nitrate levels are low, stygofauna communities are diverse and ecosystem health is classified as 'very good'. However, where nitrate levels are high, stygofauna communities are likely to be severely compromised, and ecosystem health is 'poor'.

Groundwater health ratings

Groundwater health ratings, including causes and effects



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