Chapter 15: Groundwater And Surfacewater Interaction

Introduction

Aquifers, springs, rivers and wetlands are naturally connected. Some of these links have long been recognised in Marlborough, while others have come to light recently through targeted investigations or monitoring. The loss of Wairau River water to the adjacent Wairau Aquifer for example, was discovered in the early 1970s based on flow gaugings. It has also long been apparent that Spring Creek and other Wairau Plain freshwater springs represent up-welling groundwater and are directly connected to the Wairau Aquifer.

Hydrological studies conducted by the MDC between 2004 and 2007 confirmed that the Rarangi Wetlands represent the surface expression of the Rarangi Shallow Aquifer where it breaks the surface in low lying areas between dunes (Fig. 15.1).

Flow in the Tuamarina River catchment moves backwards and forwards between the channel and groundwater in the gravels forming the valley floor depending on the hydraulic conditions in a particular reach.

Mill Creek at Wairau Valley and Are Are Creek both gain channel flow, sourced from the underlying aquifer, along their length. Other connections remain to be discovered or quantified such as the Cloudy Bay coastal springs. These springs are likely to exist due to upward leakage of pressurised Wairau Aquifer water appearing at the surface.

Not all of these interactions occur naturally. Pumping from wells, for example, can affect flow in nearby rivers or springs. Urbanisation also has the potential to reduce spring flow through less infiltration of rainfall.

Historic distinctions between the water in aquifers, rivers, springs or wetlands is often an arbitrary classification, with water moving backwards and forwards between them.

Figure 15.1: Rarangi Shallow Aquifer dependant wetlands. The water ponds located on the Nobilo Wine Group vineyard in the centre of the photo represent Rarangi Shallow Aquifer groundwater exposed at the surface.

Groundwater dependant ecosystems

A groundwater dependant ecosystem is a relatively recent term used to describe surface systems such as wetlands or springs which exist because of the presence of underlying groundwater. The best known example for Blenheim residents are the freshwater springs which rise in a belt through the central Wairau Plain.

Groundwater dependant wetlands

Groundwater dependant wetlands are unique in that baseflow is maintained by groundwater. As a result, even in the worst drought, the lower reaches of the wetland still have water in them. This is not to say that parts of the wetland don't naturally dry-up seasonally, however the primary controlling factor of the ecosystem fauna and flora is its hydrology. This dependence means that maintaining aquifer levels above a certain minimum is essential to maintaining wetland health.

If groundwater is the predominant source of water to a wetland, such as the Rarangi wetlands north of the Diversion channel, then they are classified as a Fen (Preece - 2007)(Fig. 15.2).

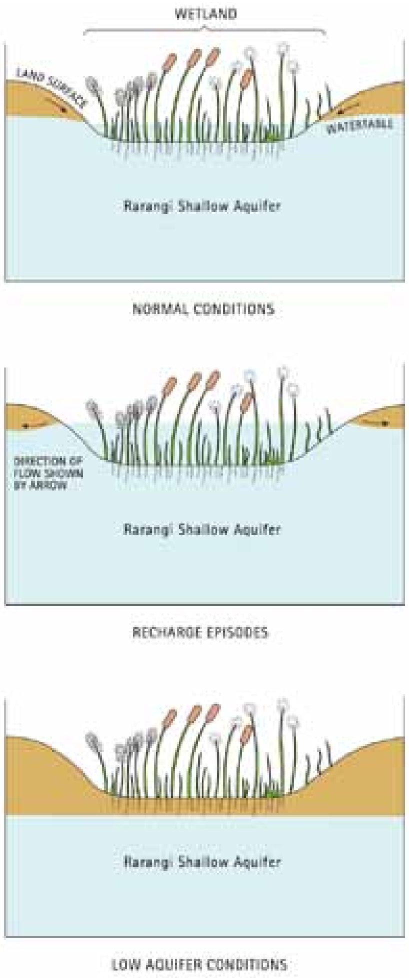


Figure 15.2: Rarangi Shallow Aquifer interaction with fen wetlands

Groundwater springs

There are many freshwater springs in Marlborough, mostly on the Wairau Plain, but also at Kaituna, Wairau Valley and localised areas such as the Tuamarina River Valley.

Offshore submarine springs also occur when pressurised groundwater comes to the surface of the sea bed. Examples have been reported at Whatamonga Bay and Ward Beach, but may also occur off the Cloudy Bay coast, although none have yet been recorded. In these cases groundwater is forced upwards because it is trapped beneath pressurised confining layers. This geological structure commonly occurs around the New Zealand coastline where low permeability marine sediments provide the capping layer.

Not all springs in Marlborough are caused by pressurised groundwater. Some are geologically or topographically controlled, meaning groundwater appears at the surface because it is the path of least resistance. Minor springs occur everywhere groundwater flow meets an obstacle and breaks out at the surface. This can be seen in the Awatere River area where many localised seeps occur where the mudstone papa meets the gravel alluvium.

High profile springs include Fultons Creek, which flows through Pollard Park (Fig. 15.3), or Spring Creek where it crosses Rapaura Road, but many more are located on private property and aren't visible to the public (Fig. 15.4).

The Blenheim suburb of Springlands is aptly named for the number of springs which pop to the surface in back yards. Most have been channelised over the last century by farmers, developers or public bodies as land was subdivided for residential settlement. They are also commonly used to convey stormwater running off urban areas after rain.

Figure 15.3: Fultons Creek at Pollard Park

Figure 15.4: Spring Creek at Stump Creek Lane.

Springs represent one of the few occasions when the Wairau Aquifer is naturally visible. What's more they can be seen by the public and any deterioration in their aesthetic properties is noticeable, particularly in the headwaters which are the most sensitive to change in aquifer level. However in their lower reaches it is more difficult to detect changes in flow because of the deep, narrow channel shape of Wairau Plain springs.

Wairau Plain springs

By far the most extensive and largest spring flows rise in a belt through the mid Wairau Plain area and to a lesser extent in the Lower Wairau area through to the Cloudy Bay coast (Fig. 15.5). These springs exist by virtue of groundwater losses from the underlying Wairau Aquifer. This gives them some very unusual characteristics compared to other rivers or streams in the district.

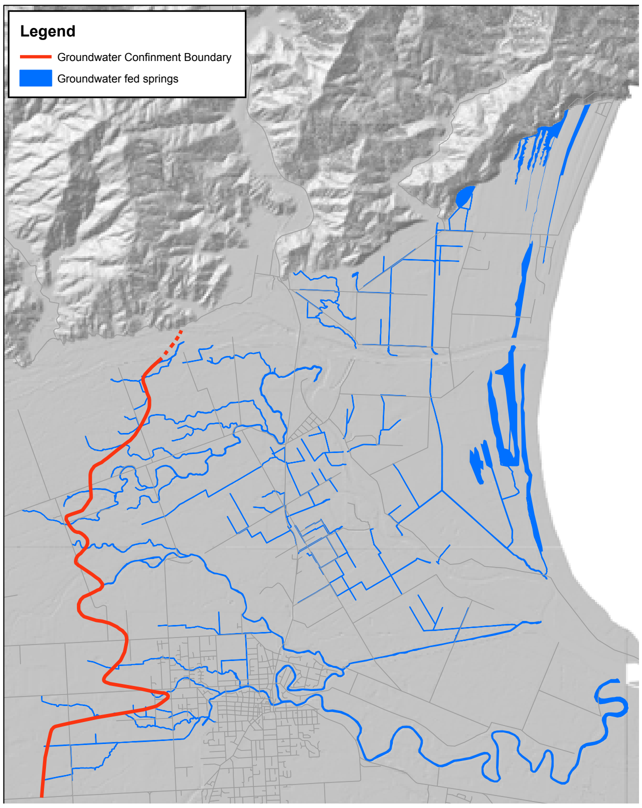


Figure 15.5: Wairau Plain spring belt

The Wairau Plain springs are essentially groundwater overflows, spilling water which the Wairau Aquifer can't transmit through the gravels below ground. In other words it is easier for water to exit the aquifer at the surface and flow downhill rather than remaining as underground flow.

What makes the springs special is their steady and continuous flow of cold water generated by up-welling groundwater (Fig. 15.6). Flow is maintained at a far more constant rate than occurs in a river due to the massive volume of groundwater stored within the Wairau Aquifer that regulates a steady input regardless of whether it rains or not. Small floods in spring fed streams are however occasionally associated with intense rainfall and runoff.

River catchments are far more susceptible to extremes of climate and this is reflected in the difference in their flow characteristics.

The mean flow and the median flow of groundwater fed springs are typically very similar as springs don't experience the large floods which skew the flow record of rivers.

The shape of flow duration curves is quite different for spring fed streams and catchment fed rivers. Spring fed streams have a stable flow regime whereas rivers experience large variations due to floods (Fig. 15.7).

The steady flow and even temperatures of springs provide a unique habitat for fish, plants and animals. These same attributes mean they also have a special appeal for people. Another distinguishing feature of spring fed streams is that channel flow characteristically increases in a downstream direction due to gains from groundwater in the absence of rain.

Springs discharge the upper most groundwater in the aquifer. Because of this they are most vulnerable to drying up in their upper reaches as groundwater levels fall. Their headwaters are very dynamic and responsive to aquifer level or localised pumping, especially when water table and topographic slopes are flat.

Figure 15.6: Upwelling groundwater in Spring Creek headwaters.

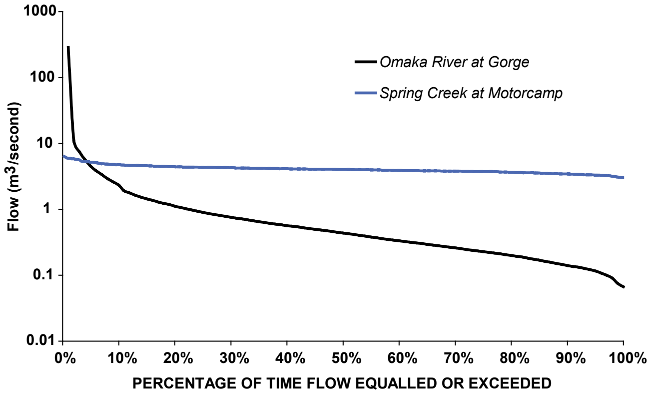


Figure 15.7: Flow duration curves

Modelling studies by the MDC during the early 1990s first identified the sensitivity of the springs to groundwater abstraction, and the susceptibility of the southern most springs in particular. This reflects their relative distance from the Wairau River recharge source on the south-western outskirts of Blenheim. By contrast, Spring Creek is relatively close to the Wairau River and the recharge , which helps to maintain flows at a relatively steady level.

The findings of the Wairau Aquifer model show that if spring flows are maintained, other regional scale issues such as seawater intrusion will be prevented from developing (MDC - 1994). For this reason trends in spring flow act as good barometers of aquifer health. In other words if there are acceptable spring flows then the rate of groundwater abstraction is likely to be in balance with seasonal or Wairau River recharge.

The MDC has been gauging Wairau Plain spring flows regularly since 1996 and now has sufficient record to identify trends in spring behaviour and correlate changes with rainfall, Wairau River flow and aquifer levels.

While the Wairau Aquifer is the local driver of spring flow, this relationship forms part of a larger regional scale hydrological circulation which ultimately relies on a continuation of the flow regime of the nearby Wairau River. Without river leakage to the gravels, there would be no aquifer and in turn no freshwater springs would exist.

Analysis of the water chemistry of spring water and river water confirms their hydraulic interconnectedness. Values of pH, electrical conductivity, temperature and 18-Oxygen are very similar for both spring and groundwaters (Table 15.1) This demonstrates that they are the same waters and originate from the same aquifer source.

Aquifer	Site	Date	pH	Electrical Conductivity (mS/m)	Temperature (°C)	$\delta^{18}O$ ($^o/_{oo}$)
Confined Wairau Aquifer - Lower Wairau area	MDC Mills and Ford Road well 4404	19-2-2009	6.6	9.6	14.3	-8.60
	Drain N near outlet beside Mills & Ford Road	9-2-2009	6.8	9.2	14.0	-8.54
Semi-confined Wairau Aquifer pair in mid plains area	Dick Drain	9-2-2009	7.3	12.1	14.7	-8.31
	Dick irrigation well 188	19-2-2009	7.1	7.8	13.7	-8.33

Table 15.1: Comparison of groundwater versus spring water chemistry

Historically the focus of spring investigations has been on spring hydrology. More recently there has been a trend towards viewing the springs as living ecosystems with biochemical and ecological functions. In part this reflects the full allocation of many water resources in New Zealand, and recognition of their connection to other parts of the hydrological cycle. The natural character of springs on the Wairau Plain has always been highly rated by the local community.

Aquifer invertebrates

Aquifer systems in New Zealand are primarily used as sources of water for stock supply, drinking, and industrial processing or to irrigate crops. What isn't commonly realised is they also provide a habitat for many varieties of invertebrates.

These tiny animals are restricted to porous type aquifers with sufficiently large gaps between grains to allow them to move and live below ground. The alluvial gravel aquifers which are common in Marlborough are ideally suited to these animals, but little is known about their extent or distribution locally or nationally.

Knowledge of groundwater fauna is poor worldwide, but New Zealand is further behind the rest of the world in terms of community appreciation of their existence, and describing local species or their ecology, according to Dr M. Scarsbrook of NIWA. Over 100 species have been identified in New Zealand, however research has been sporadic and explains their anonymity, even amongst groundwater professionals.

Figure 15.8: Groundwater invertebrate Paraleptamphopus sp.

Aquifer invertebrates were first discovered in Britain in 1813. Their existence was completely unknown in New Zealand until 1882 when Charles Chilton, the Rector of Canterbury College, surprised the scientific world by describing four species collected from his eight metre deep well at Eyreton, just north of Christchurch (Scarsbrook and Fenwick - 2003).

Life cycles

Representatives of a range of different invertebrate groups including insects, molluscs, crustacea and worms exist underground in New Zealand aquifers. To adapt to the perpetual darkness and cramped living conditions, they have developed a very distinctive physiology including a lack of eyes or body pigment. Their bodies are elongated to allow them to move through the tiny spaces between gravels, and they are very small at one to ten millimetres in length. Not only do invertebrates inhabit porous aquifers, but also the area between the groundwater and the surface water, called the hyporheic zone. They are also known to live in caves where they are much easier to study. They are also occasionally found in spring fed streams.

In Marlborough a continuous bed of alluvium makes up our lowland flood plains. This allows groundwater fauna to potentially exist and move over large areas of the Wairau Plain in a variety of habitats.

Because there is no light underground, no photosynthesis takes place and any organic matter must be flushed into the aquifer from the surface. A food chain exists within the aquifers with micro-organisms such as bacteria or fungi/algae providing food for various levels of invertebrates including predatory types. Most of the invertebrates are scavengers which appear to graze on the organic matter, but more is to be learnt.

Marlborough invertebrates

Little is known about the invertebrates inhabiting our local aquifers. Given the variety of potential habitat on the Wairau Plain and other floodplains, it is likely that a wide range of species are present.

In 2001 Dr G. Fenwick of NIWA in conjunction with MDC staff, sampled a series of shallow wells tapping the porous gravels of the Wairau Aquifer and found several specimens. A further study was carried out by Dr D. Olsen of Cawthron and MDC staff in late 2010. A variety of species were collected at six sites across the Wairau Plain and North Bank. A number of crustaceans and mites were discovered, with eleven amphipods (Paraleptamphopus species) being found in one northbank well (Fig. 15.8). An invertebrate found by MDC staff in a shallow well on the North Bank of the Wairau River in 2006 was identified by the Cawthron Institute as Paracrangonyx Winterbourni.

Functions and threats

Invertebrates are potentially important bio-indicators of aquifer water quality and indirectly the impacts of overlying land-uses. Free flowing alluvial aquifers are relatively clean environments and interestingly these creatures may only inhabit an aquifer area if it has sufficient organic matter to feed on.

According to NIWA, areas of aquifer recharge and discharge appear to have different fauna, so it is possible to use community structure to describe water bodies in terms of their hydrological connections with groundwater and surfacewater.

Changes over time in populations may also reflect the impacts of intensifying landuse on aquifers or their habitat. The seasonal effects of drought are likely to induce them to migrate away from the receding headwaters of freshwater springs. They may also move out of a stream which was drying up in a summer drought and find refuge in the adjoining aquifer with cooler water, or move throughout an aquifer to areas with more food.

Large seasonal fluctuations in the water table probably mean they move deeper into the aquifer. If invertebrates are close to a well, rapid changes due to pumping could leave them stranded. Because they are known to be slow reproducers, the rate of recolonisation may be slow (Harding et al - 2004). The effects of heavy metals, pesticides and other surface contaminants are uncertain.

Groundwater invertebrates act as bio-remediators, feeding on waste that could potentially harm human health and clog aquifer pores, which would in turn slow groundwater flow.

There is much to discover about these mysterious animals of the subterranean world of complete darkness and in the future it is certain that they will become a vital component of understanding the human impact on groundwater quality.

Figure 15.9: Monitoring well 4577 beside Ganes Creek

Stream depletion

In Marlborough, surface and groundwaters are usually connected to some extent, and changes in one are likely to affect the other. Stream depletion occurs when pumping from a well changes the flow of a stream or groundwater fed spring. Pumping either increases flow away from the channel, or intercepts seepage that would otherwise contribute flow (Lough & Hunt - 2006).

The most common stream depletion scenario is that of a well situated beside a waterway (Fig. 15.9). Stream depletion happens on a variety of scales. It can be generated by a single well in isolation, or the cumulative effect of many hundreds of wells being pumped. A well tapping the unconfined Wairau Aquifer can be hydraulically linked to a nearby river. Pumping from a well can potentially create a gradient that induces water away from the river or intercepts water that would otherwise contribute to surface flow. (Fig. 15.10).

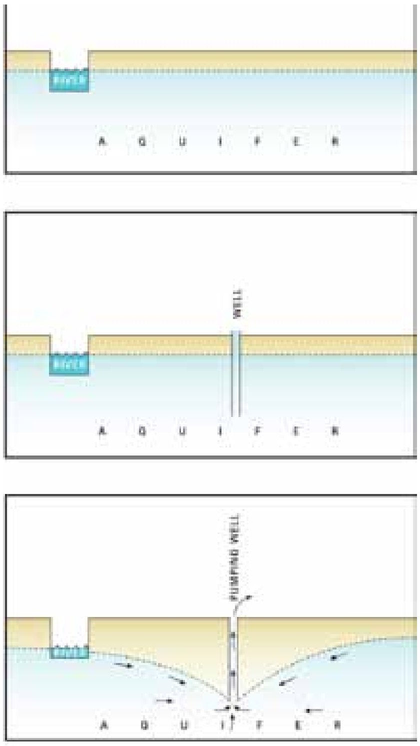


Figure 15.10: Stream depletion concept

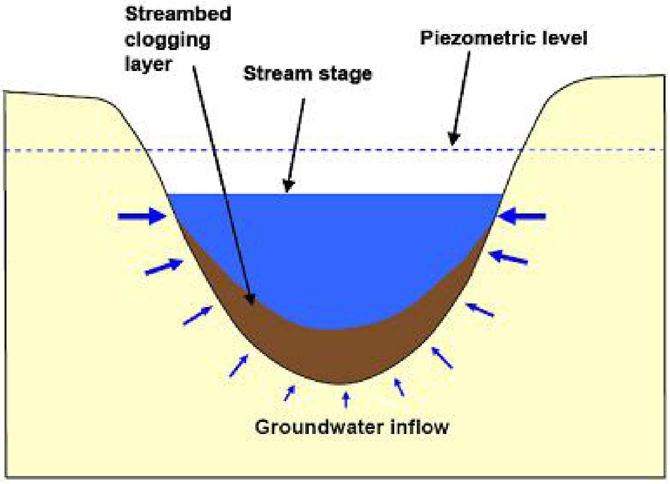


Figure 15.11: Streambed clogging layer.

Stream depletion effects are influenced by a range of factors. For instance, the closer a well is to the channel, the higher the rate at which the well is pumped or the longer the duration, the greater the stream depletion effect will be.

The nature of the aquifer also influences the rate of stream depletion. Systems with lower storage or that are more transmissive will generate larger effects. If the aquifer has a confined structure or if the streambed is lined with impermeable silts, these will tend to separate the two water bodies (Fig. 15.11).

Streams with relatively coarse gravels forming the bed, such as Murphys Creek (Fig. 15.12), have a higher stream bed conductance than streams with beds consisting of finer grain muds, such as Fultons Creek (Fig. 15.13).

Confinement may increase or reduce the stream depletion effect of pumping, depending on how thick the layer is and the impact it has on aquifer storage.

The pressures within a confined aquifer cause upwards diffuse flow of groundwater through the confining layer. Natural discontinuities through the confining layer, such as old logs or fissures, create pathways where the water can move through the layer at a higher rate. Where these discontinuities naturally reach the surface they become artesian springs (Fig. 15.14).

Figure 15.12: Coarse sediments in Murphys Creek.

Until recently the nature of the interaction between streams and aquifers was poorly understood, and the effects of consented pumping were largely unquantified. The main reason for this was the tools didn't exist to define it, or its influence on streamflow in Marlborough was minor.

In many cases and for much of the time, the effect of groundwater pumping on surface flows will be negligible. But for some highly valued or high profile waterways, or those more sensitive to seasonal pumping such as the headwaters of springs, the effects need to be known.

Care is needed to distinguish between the natural seasonal variation in springs or rivers, and changes induced by pumping, and in many cases this is an inexact science.

The clear water and stable flows of groundwater fed springs make them very attractive. This desirability enhances residential land values in many areas, such as Springlands and rural lifestyle blocks near Spring Creek.

Marlborough parameters

Over the past decade there have been a number of major advances in stream depletion hydrology, including its prediction and measurement. For instance, in 2000 Environment Canterbury in collaboration with specialists at Pattle Delamore Partners, produced the first national guideline for assessing stream depletion effects (ECAN - 2000).

There were parallel advances in mathematically describing the response of streams or groundwater fed springs to pumping from aquifers. Much of this work was pioneered by Dr B. Hunt, a lecturer in the Civil

Figure 15.13: Fine sediments in Fultons Creek.

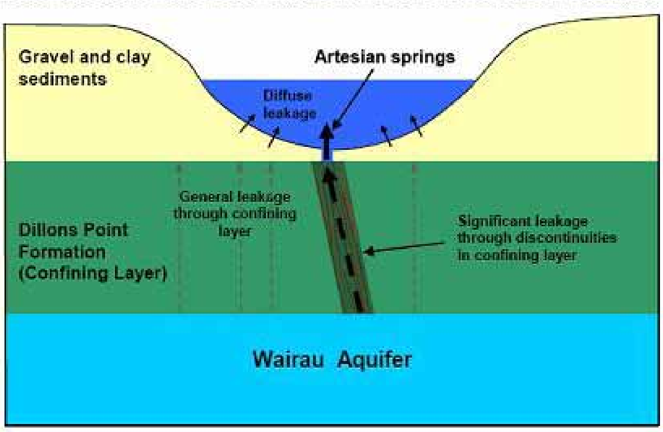


Figure 15.14: **Groundwater interaction with springs.**

Engineering Department at the University of Canterbury. A major limitation in applying these new methods was uncertainty over local values of the hydraulic properties controlling the interaction between ground and surfacewaters. MDC commissioned Sinclair Knight Merz (SKM) in 2006 to measure the value of streambed conductance for local streams, as this was the parameter with the greatest uncertainty and fewest measurements.

Stream bed conductance is the measure of the permeability of the streambed sediments, in the base of the channel, that separate the groundwater and surface water. Stream bed conductance is also known as the stream bed clogging factor or Lambda and is expressed in units of m/day.

To measure the stream bed conductance a seepage meter was made out of a cut-off plastic drum forced into the spring bed with a balloon attached to the top. Groundwater flowing upwards through the stream bed fills the balloon in a given time. Using Darcys Law the permeability of the stream bed sediments can be calculated in conjunction with the difference in water level between the aquifer and stream (Fig. 15.15). However, measurements of streambed conductance were too low during the SKM investigations, and there was also significant variability between nearby sites. This probably reflects the actual variability in streambed sediments and the disturbance of these sediments by the meter itself.

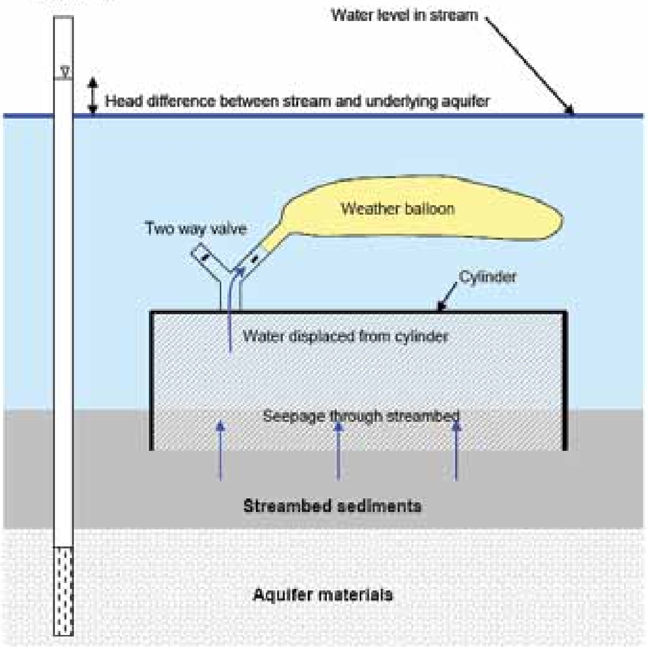


Figure 15.15: **Seepage meter.**

To improve the representativeness of measurements, the concurrent stream gauging method was used instead. It averages the natural variability in stream bed conductance for a set length of the channel. The hydraulic properties of the stream bed are calculated by measuring the change in channel flow over a given reach, in relation to the difference in level between the spring and aquifer.

It is of fundamental importance to know the force driving water upwards through the confining layer or channel bed sediments into the spring channel. This is measured by taking the difference between the level in the spring and a pipe driven into the underlying aquifer (Fig. 15.16). The stream-bed conductance measurements made by SKM during the two field surveys show that all values are relatively high with the exception of Ganes Creek (Table 15.2). This shows that the bed sediments of Wairau Plain springs generally do not form a barrier to flow and that ground and spring water are the effectively one and the same. Potentially this means that pumping groundwater near a spring is likely to affect surface flow to some extent.

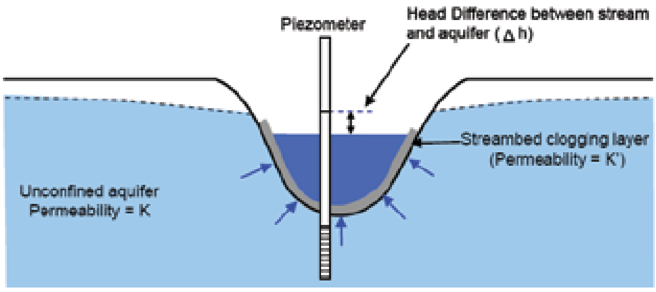


Figure 15.16: **Groundwater seepage driving force.**

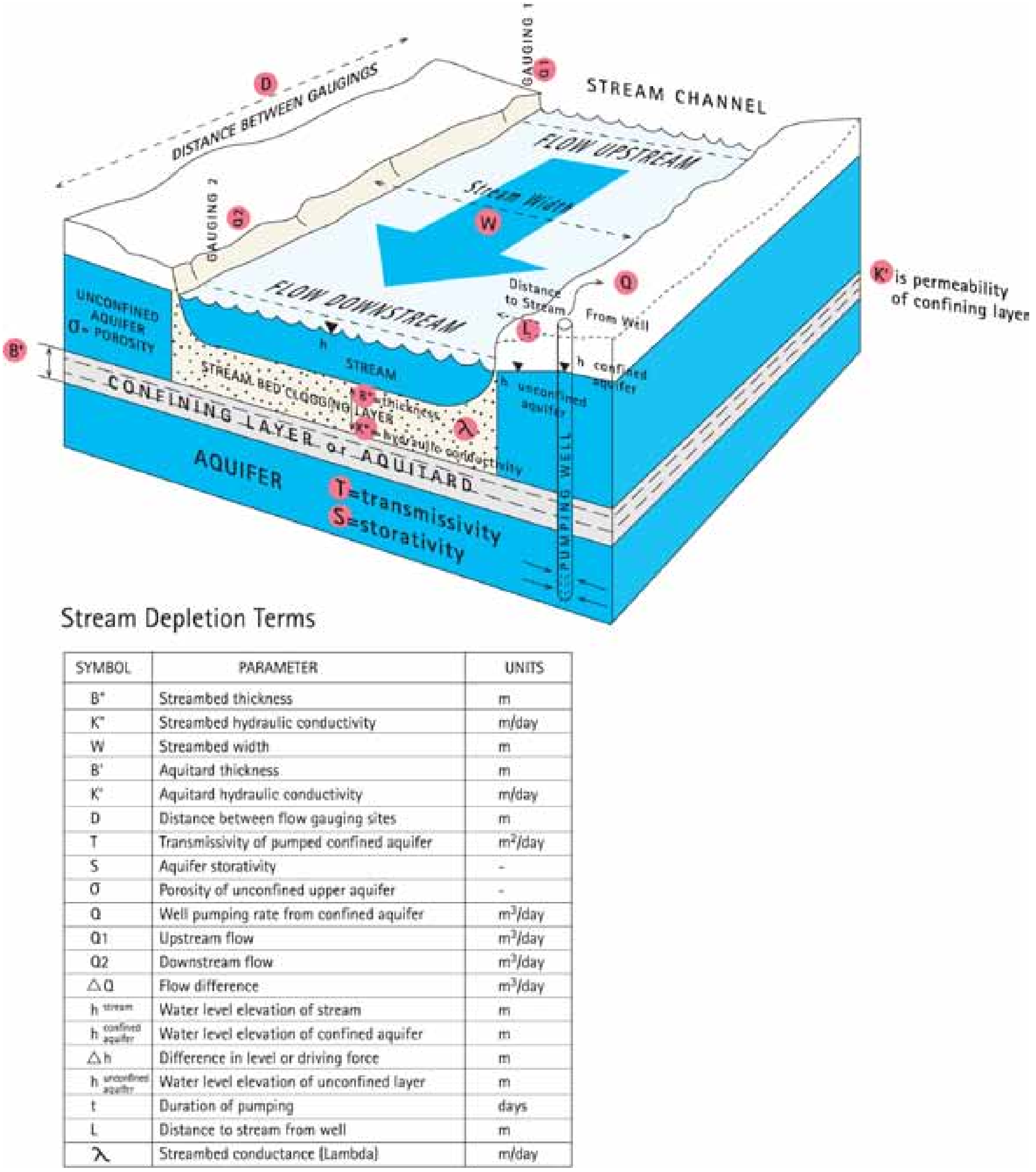
Calculating stream depletion is a complicated process and requires a knowledge of a large numbers of parameters. Errors can easily occur when calculating stream depletion effects if some of the parameters are not accurately known.

Figure 15.17 has been provided to help understand the physical process of stream depletion and the terms or units used for each of the main parameters. It conceptually shows two aquifer layers separated by a confining layer known as an aquitard, and a stream which relies on groundwater leakage to maintain channel flow. In some cases the porosity refers to the property of the aquitard and not the unconfined water table aquifer. In other words during the driest part of the year the upper aquifer effectively doesn't exist, otherwise pumping

River, Stream Or Groundwater Fed Spring	Reach	Number Of Gaugings	Streambed Conductance (m/day) 2006 Field Survey	Streambed Conductance (m/day) 2007 Field Survey
Dentons Creek	Main stem	2	134	106
	Northern tributary	1	194	-
	Southern tributary	1	90	-
Roses Creek	1 kilometre west of Cravens Road	1	99	-
Ganes Creek*	Upstream of Selmes Road	1	7	-
Yelverton Stream	Upstream of David Street	1	130	-
Fultons Creek	Pollard Park	2	64	-
Fairhall Co-op Drain	Downstream of Bells Road	5	-	22
Dowlings Creek*	Upstream of O'Dwyers Road	6	-	77
Doctors Creek	Taylor River confluence	3	-	>100
Taylor River	Beaver Road footbridge	6	-	170
Murphys Creek	Springlands	6	-	1400

**Assuming head difference of 0.1 metres*

Table 15.2: **Measured streambed conductance values.**



Stream Depletion Terms

SYMBOL	PARAMETER	UNITS
B''	Streambed thickness	m
K''	Streambed hydraulic conductivity	m/day
W	Streambed width	m
B'	Aquitard thickness	m
K'	Aquitard hydraulic conductivity	m/day
D	Distance between flow gauging sites	m
T	Transmissivity of pumped confined aquifer	m^2/day
S	Aquifer storativity	-
σ	Porosity of unconfined upper aquifer	-
Q	Well pumping rate from confined aquifer	m^3/day
$Q1$	Upstream flow	m^3/day
$Q2$	Downstream flow	m^3/day
ΔQ	Flow difference	m^3/day
h^{stream}	Water level elevation of stream	m
$h^{confined}_{aquifer}$	Water level elevation of confined aquifer	m
Δh	Difference in level or driving force	m
$h^{unconfined}_{aquifer}$	Water level elevation of unconfined layer	m
t	Duration of pumping	days
L	Distance to stream from well	m
λ	Streambed conductance (Lambda)	m/day

Figure 15.17: **Stream depletion parameters.**

would have a limited effect on the springs

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