

# Chapter 5 - Locating And Accessing Groundwater

## Introduction

Groundwater is abstracted from beneath the earth's surface using methods similar to the oil industry. Wells are drilled into aquifers and pumps are used to bring groundwater to the surface. In some cases groundwater may naturally flow out of a well, which is known as artesian flow and is relatively common in the Lower Wairau Plain area. Well 0403 near the north-eastern end of Morgans Road, is an example of a naturally flowing well (Fig. 5.1).

The existence of artesian flow is not necessarily an indication of high well or aquifer yield. It is a physical phenomenon reflecting aquifer conditions whereby groundwater is trapped below an impermeable layer, in conjunction with recharge at a higher level. Alternatively it can be caused when groundwater intercepts very impermeable material or a boundary, forcing flow to the surface.

The first challenge for someone looking to use groundwater is to locate a viable source, particularly if large quantities are required such as for crop irrigation. Domestic supplies are more widely available because only smaller volumes are needed, which can often be pumped at low rates to storage tanks.

A prospective well owner will usually go through a preliminary assessment process to reduce the risk of a dry hole and maximise the chances of ending up with sufficient water. However there is no guarantee when dealing with nature, nor is there any substitute for drilling a well to confirm what is down there.

The possibility always exists that a well may be lower yielding than expected or even dry. In areas where many wells exist such as the Wairau Plain, there is a greater understanding of likely well yields and drillers have more experience to call on, which brings with it a higher chance of success.



Figure 5.1: Naturally free flowing well 0403

Historically most enquiries to the MDC regarding groundwater supply would more often than not involve the Wairau Plain. Today however, with the Wairau Plain nearly covered in vineyards, most questions centre on new areas away from the traditional centres of agriculture where groundwater availability is marginal. As groundwater resources approach full allocation across the region, there is an increasing call for information on regulatory matters, reflecting competing demand between water users.

## Resource information

### Geology and geomorphology

The subsurface mapping of geological formations and the location of old stream channels can help build a picture of how an area has been formed and where groundwater may be found. This is a systematic and scientific way of learning about the potential groundwater resources of an area, that is a relatively cost effective first step.

Despite the fact that today there are various methods available for predicting the nature of sub-surface formations, there is still only one sure way of finding out and that is drilling. The present understanding of the sub-surface deposits beneath the Wairau Plain is almost exclusively based on drilling. The most frequently used and reliable descriptor of underground strata and groundwater are drilling contractor's records commonly referred to as well logs (Fig. 5.2 and Fig. 5.3).

Well logs describe the material that was encountered during drilling and general details such as yield information and physical dimensions. The well logs also show the results of the test pump. The value of these well logs can't be underestimated in defining Marlborough's regional scale aquifer hydrology.

In some areas it is obvious that the local geology will not support a significant groundwater resource. However, even in these areas there may be sufficient water to meet stock or domestic needs. If the indicators point to a favourable aquifer, then a decision is made by the investigator, be it private or otherwise, to go to the next level of investigation.

### Water divining

Drilling a hole in the ground can be an expensive business, particularly if water is not found the first time. A traditional means of groundwater exploration is called water divining or dowsing. The mystique of water divining or dowsing still has a hold on the popular mind today and is regularly used by some drilling contractors and many well owners. Water divining is not universally accepted as a proven method of locating groundwater.



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WATER WELL ENGINEERS TO MARLBOROUGH

Well # 10170

Log No 1313  
 Well Owner Marlborough District Council  
 P.O.Box 443  
 Blenheim  
 Contact Name Stewart Donaldson  
 Driller John Butt  
 Drilling Date 08/10/2009  
 Locality Spring Creek Sewer pond Grid ref 2591453-5971327  
 Map Sheet No  
 Altitude (m): South  
 Grid Ref East: Wairau Aquifer confined structure.



Depth To Strata Top (m)	Strata Bottom (m)	Strata Thickness (m)	Static Level (m)	Strata Description	Strata Picture
0.00	1.50	1.50		Flanged above ground level	
1.50	2.40	0.90		Yellow clay	
2.40	11.40	9.00		Brown sand	
11.40	12.90	1.50		Grey fine gravel to coarse sand, and shellfish shells	
12.90	13.10	0.20		Brown sand	
13.10	16.10	3.00		Brown and grey coarse gravel, coarse sand, good water bearing (very sandy)	
16.10	18.50	2.40		Brown coarse gravels, some yellow clay, water bearing (very sandy)	
18.50	20.50	2.00		Brown and grey cobble to medium sand, yellow clay bound	
20.50	23.40	2.90		Grey marine sand	
23.40	25.80	2.40		Brown and grey cobble to medium sand, yellow clay bound	
25.80	29.60	3.80		Brown and grey cobble to medium sand, some yellow clay, water bearing	
29.60	34.40	4.80		Brown and grey cobble to medium sand, yellow clay bound	

Figure 5.2: Example of the first page of a typical well log

While there have been some notable successes locally, there have also been some costly failures. Water divining is either something you believe in or not, and it's effectiveness is very much in the eye of the beholder.

Diviners have on several occasions been tested scientifically and some researchers have gone as far as to conclude that diviners have at best about a 10 to 12% chance of success. Some diviners claim very high success rates, but in Marlborough these claims must be weighed against the fact that over a much of the northern Wairau Plain any individual with a relevant background knowledge would have a similar success rate whether they were a diviner or not.

It seems more than likely that diviners have a value in areas they know. They can compute in their mind the many factors they have assimilated such as topography, history and geology; and make a good prediction at the best location for a well. Divining gives people confidence to proceed which they may not otherwise have had, particularly if all other approaches have been exhausted. Whether this is false or otherwise will be argued far into the future.

## Geophysical exploration

Well drilling is the only direct way of exploring for subsurface groundwater systems, but it is very expensive. Enough bores have to be drilled to sufficient depth to describe the depth, extent and constituency of the various geological formations. Indirect methods such as geophysical prospecting are still expensive, but provide the benefit of covering large areas.

Geophysical techniques identify anomalies or differences in the earth's properties such as changes in rock type, the degree of saturation or its chemical composition. Through experience these results have been interpreted to tell us about subsurface conditions. Of particular interest is the existence or absence of groundwater, its quality and depth.

Geophysical methods only give an indication of what is below the ground because they are indirect methods. Less reliance is placed on the results, but they are useful for defining parameters such as the depth to basement or the likely location of aquifers for example, where less precision is acceptable.

During the initial stages of Marlborough groundwater investigations in the early 1970s, test drilling was the only option. Geophysical surveys were first applied locally in the early 1980s to prospect over larger areas of local sediments than a single well could represent. Geophysical surveys were widely used by both private landowners and the Marlborough Catchment and Regional Water Board to understand the nature of the Southern Valleys Aquifers, and guide the location of exploratory drilling at selected target sites.



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WATER WELL ENGINEERS TO MARLBOROUGH

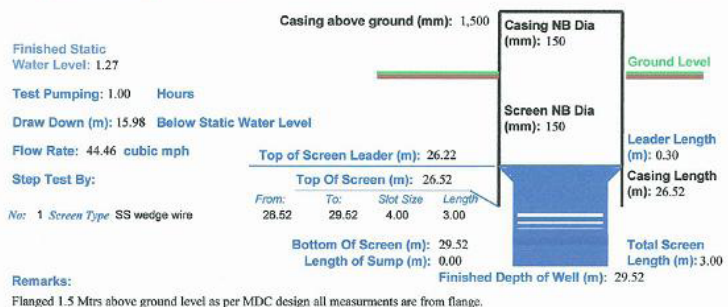


Figure 5.3: Example of the second page of a typical well log

Geophysical methods were originally developed for oil and mineral exploration, but as water has become scarcer and more valuable, they have been adapted and applied to groundwater exploration. However, it is an inexact science, and the results are often difficult to interpret. While it hasn't always been successful, overall it has improved understanding of groundwater resources and particularly subsurface sedimentary structures.

## Electric resistivity

To date the most commonly used prospecting method in Marlborough has been the electric resistivity technique. It is especially useful in targeting the most likely drilling sites in marginal areas, and in some but not all cases, this has paid off locally. This method is a reasonably cost effective way of obtaining a broad coverage of sub-surface formations. It involves inducing a known electrical current into the ground via two electrodes, and evaluating the resistivity of the ground material based on the measured potential difference in two other electrodes (Fig. 5.4).

Electric resistivity is a relatively cheap method and suited to the gravel type aquifers which predominate in Marlborough, although the results it provides are a simplification of nature. Earth resistivity is the resistance of rock or soil to the passage of electric current (GroundSearch - 1984). The method relies on different rock types having different resistivity values depending on their density, porosity, water content and the quality of the water (Todd - 1980). Thus the resistivity values are directly related to the physical properties of the medium. Therefore this method is good for assessing the bulk properties of different layers below the surface.

For porous material like the gravels forming most of Marlborough's aquifers, changes in resistivity are primarily controlled by the nature of the fluids or material filling the pore spaces. Clay minerals and water are good conductors of current and exhibit low resistivity values, whereas air is a poor conductor.

If the pores are filled with water the formation will be least resistive, particularly if it contains saline groundwater. If the gravels are dry or empty they will be very resistive, but will be slightly less resistive if there is a silt or clay matrix (Bouwer - 1978).

An interpretation of resistivity soundings provide an indication of the sub-surface sediments and the associated groundwater characteristics. However, it isn't a direct measure, and relies on a high degree of interpretation. A consultant with significant experience in applying the technique locally concluded that it was best at measuring relative changes of silt content (GroundSearch - 1984). It provides a more objective assessment of the subsurface geology than the observations of different drillers who may interpret and describe their drilling cuttings differently.

Because of the alluvial nature of local aquifers, the targets for geophysical prospecting are usually more permeable ancient river channels. Those having a lower silt content make better natural reservoirs and represent where ancient or recent rivers have reworked silty gravels to form cleaner, silt free high yielding aquifers (GroundSearch - 1984).

As many factors affect resistivity measurements, there is no universal value indicating good prospects for locating groundwater. However as a rule of thumb in the southern valleys catchments where the technique has been most widely applied, measured resistivity

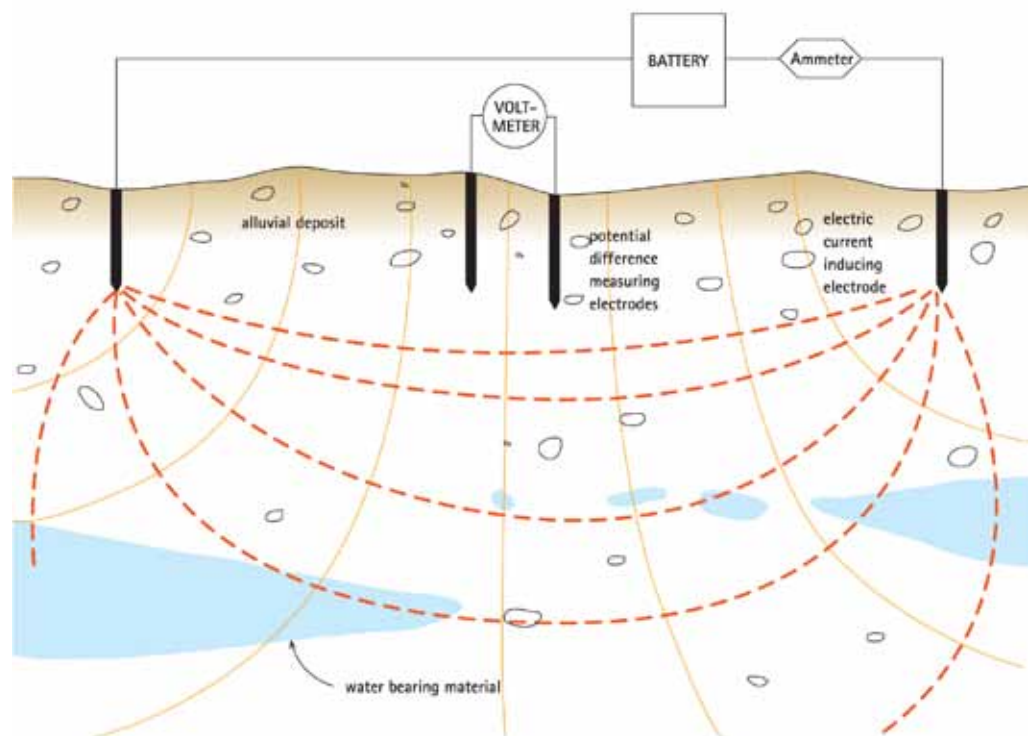


Figure 5.4: Electric resistivity survey method

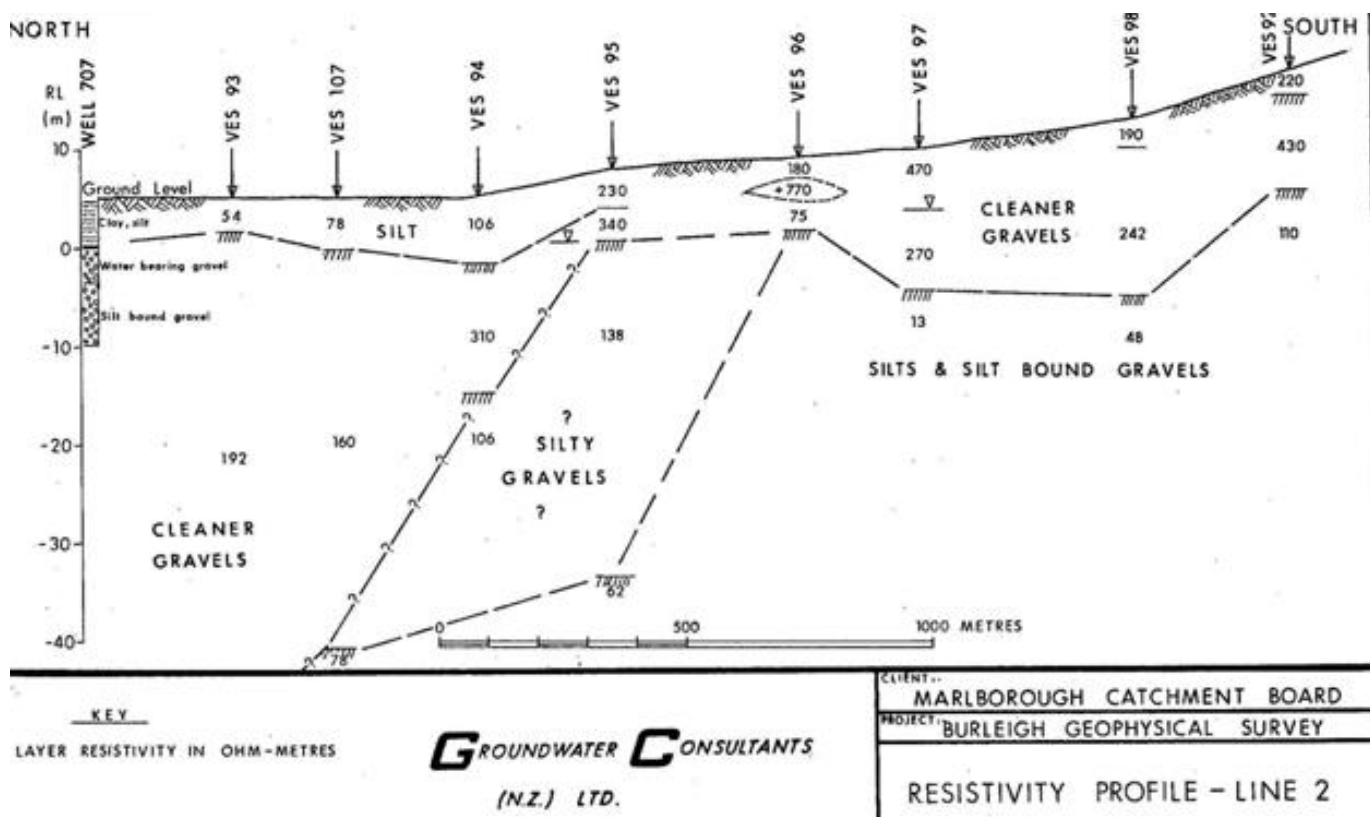


Figure 5.5: 1983 Battys Road resistivity section. VES refers to vertical electric sounding.

values of between 160 and 500 ohm-metres were most likely to correspond with sub-surface water bearing strata. Ohm-metres are the units of measurement for electrical resistivity.

A particular resistivity value is also not unique but a product of a combination of the rock type, grain size and pore water characteristics. Furthermore, a strong signature at shallow depths can mean that resolution is lost at depth. Also, deeper units will only show up if they are thick and have a strong signature. This is why field records require calibration against known well information before any serious predictions are made about the extent of the formations over the full survey area.

The limitations of the method are best summed up by Paul White, a GNS Science geophysicist: "...equivalence of sounding interpretation means that water table depth and the resistivity below water table can't be uniquely defined from soundings alone." (White - 1986).

### Marlborough applications

Electric resistivity surveys have been carried out by both private landowners looking for a water supply and local authorities as part of resource assessments on behalf of the community. So far their use has been restricted to the lower yielding areas of Marlborough. They have not been applied to the Wairau Aquifer where medium to high yields are generally available and there is no advantage in a preliminary assessment of the best sites to drill. Their worth was best described

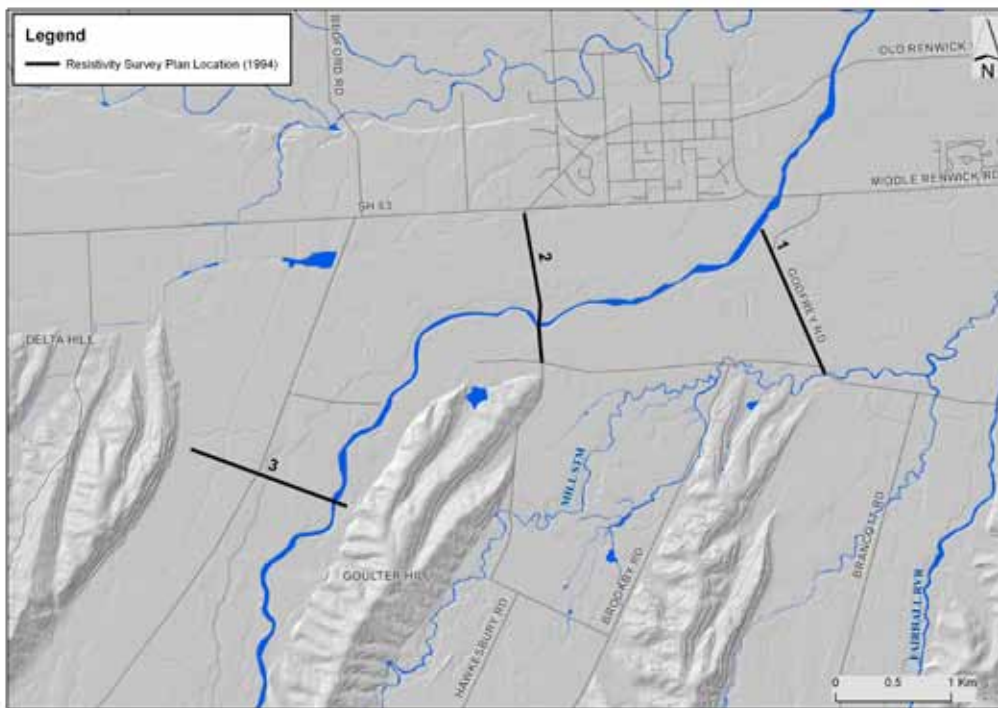
in the 1984 report by groundwater consultants documenting a series of surveys in the Southern Valleys area as: "...delineating areas in each valley where there are better prospects for finding groundwater. However, even in these areas, well yields will be low compared with the Wairau Plain proper and there will be a high risk attached to drilling."

In 1984 an electric resistivity survey of the Omaka/Hawkesbury and Fairhall/Brancott Valleys, commissioned by the MCRWB was carried out. The aim of the survey was to assess potential groundwater resources in an emerging grape growing area where water demand was likely to increase. Field measurements involved six traverses over a relatively large area.

The results categorised local sediments into a sequence of four broad types based on their resistivity signatures.

Resistivity (ohm-metres)	Interpreted Materials
200-1600	Partially saturated, less silty surface gravels
110-160	Saturated silty gravels with probable presence of thin, cleaner water yielding gravel layers; good prospects for wells in 130-160 ohm-metre materials
70-100	Saturated silty gravels, occasional thin, cleaner gravel; poor prospects for wells
30-70	Saturated, clay-bound silty gravels; very poor prospects for wells

Table 5.1: Omaka Valley resistivity model (Groundwater Consultants 1984)



**Figure 5.6: Omaka River Aquifer resistivity survey location map**

Resistivity values generally decreased with depth as Table 5.1 shows. The highest resistivity material occurred closest to the surface and represented relatively clean, unsaturated gravels located above the water table. The pore spaces are dry making them poor conductors which explains the high resistivity values. The next layer down is interpreted as relatively permeable gravels, and represented the best water bearing prospects for wells. The two lower layers are dominated by high clay content in the pore spaces which makes them good electrical conductors, but poor aquifers.

The survey results are far from definitive and illustrate the difficulties of interpreting resistivity measurements. Even when drill-hole information is available, the variable nature of the Southern Valleys geology makes it difficult to extrapolate the results too widely.

In 1988 PPCS Ltd who owned the meat processing works to the south of Blenheim at Riverlands, used seismic and resistivity surveys to guide drilling for groundwater with improved quality. The electric resistivity survey provided the least ambiguous results and concluded that the prospects of sufficient groundwater occurring south of SH1 were poor, but the likelihood increased in a northerly direction (DSIR - 1989).

A very successful application of the electric resistivity method was represented by the 1983 survey carried out by Groundwater Consultants NZ Ltd at Burleigh west of Blenheim. This was a joint venture between the MCRWB and Marlborough County Council (MCC). The purpose of the survey was to investigate the feasibility of locating a new public water supply well.

The interpreted results of this survey clearly demonstrate the resistivity contrast between the two dominant gravel formations (Fig. 5.5).

The survey line along Battys Road north of New Renwick Road identified a thickening layer of cleaner gravels representing the Rapaura Formation. These gravels are underlain by less permeable silt-bound gravels emanating from the Southern Valleys catchments. This pattern is consistent with the increasing influence of the Wairau River to the

north, creating more permeable material by reworking the underlying silt-bound fan deposits of glacial outwash gravels. The results of this survey confirmed what had shown up in water level surveys. At some point between Battys Road and Waters Avenue, a clear physical boundary delineates Wairau River derived sediments from those deposited by the Taylor River, Omaka River or Fairhall River.

Two surveys of the Omaka River gravels were commissioned by the MDC in 1994 as part of a baseline hydrology assessment of that catchment, and complimented an earlier private investigation. The aims of the MDC survey were to confirm the extent of the Omaka River Aquifer, the extent of vertical stratification and the prospects for locating new sources of groundwater.

Soundings were made along two lines, the first up Hawkesbury Road, from SH63 to Dog Point Road. The second straddled the Omaka River channel from opposite Delta Hill east to near Goulter Hill and bisects the present day Spy Valley Wines vineyard (Fig. 5.6). An older survey carried out in 1983 along Godfrey Road was included for completeness.

Three broad sedimentary layers were recognised in all three surveys, although there were local differences as expected in an alluvial deposited system. Beneath survey line three, a layer of higher resistivity material with values of greater than 380 ohm-metres represents the upper three to six metre thick band of highly permeable recent river gravels (Fig. 5.7).

The river gravels are underlain by a 20 metre thick middle layer with lower resistivity values of 200–270 ohm-metres. These sediments are interpreted to be saturated gravels with a higher clay content. Along the sides of the valley this middle layer had lower resistivities of 200-170 ohm-metres, suggesting more fine grained material or less throughflow of water. A deeper layer exhibiting resistivity values of 200-170 ohm-metres was interpreted as lower permeability material, with poor prospects of supplying reasonable volumes of groundwater.

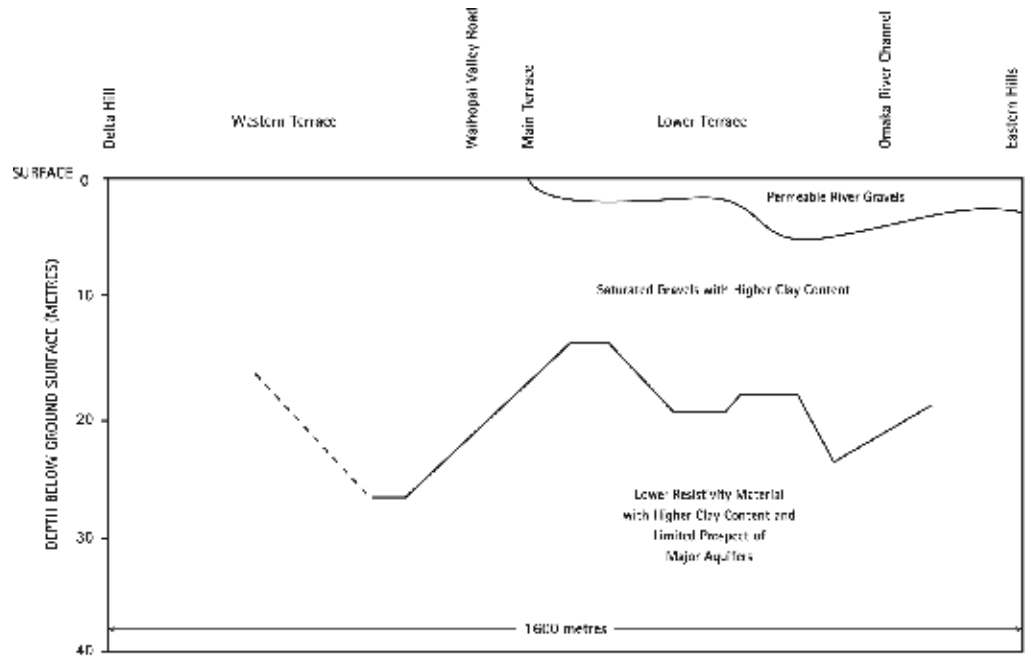


Figure 5.7: Upper survey section 3

Beneath the Hawkesbury Road survey, permeable recent river gravels were also found to a depth of about five metres around the Omaka River channel. Two other high resistivity zones appear rather anomalously, separated by lower permeability material. This pattern is consistent with the laterally discontinuous nature of Southern Valley Aquifer sediments found elsewhere.

Below this is a 10 to 20 metre thick band of lower permeability material interpreted as clay-bound gravels. The prospects of finding reasonable water supplies probably decrease below a depth of about 25 metres. At this depth resistivity values fall below 120 ohm-metres, indicating sediments with a high clay content (Fig. 5.8).

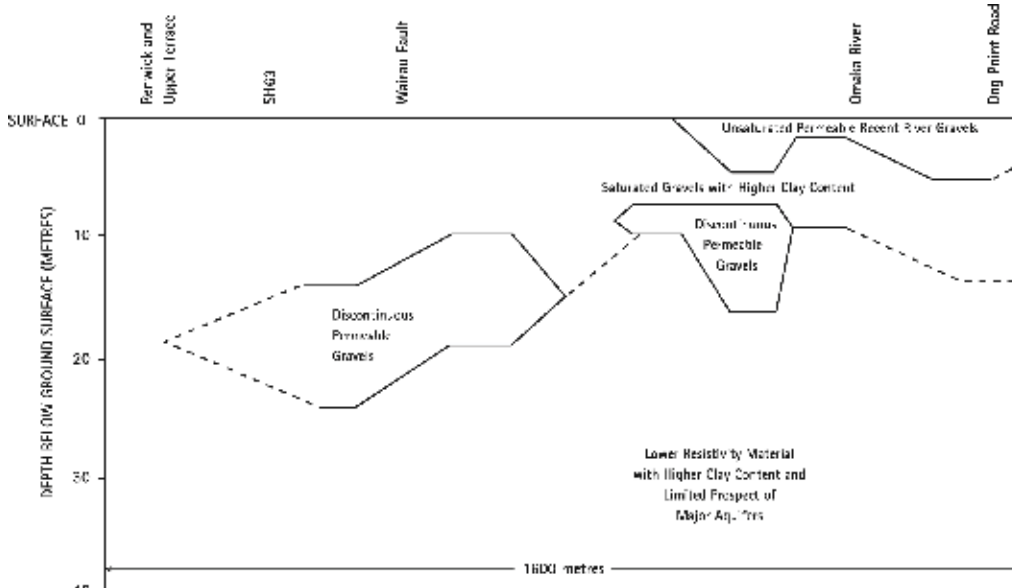


Figure 5.8: Middle survey section 2

The final survey traversed Godfrey Road from the Omaka River south to the intersection with Dog Point Road. A similar sequence to the other survey lines was inferred, consisting of unsaturated sandy gravels overlying ancient channels of saturated cleaner gravels. These rest on a base of low permeability silt bound gravels (Fig. 5.9).

The geophysical interpretations match drillers descriptions of actual water bearing layers in the Southern Valleys which tend to be thin, discontinuous and irregularly distributed in the alluvium. Plots based on the resistivity surveys represent a simplification of what actually exists in nature (Fig. 5.7, Fig. 5.8 and Fig. 5.9).

Of all the geophysical techniques, the electric resistivity method is limited to shallow prospecting of generally less than 100 metres depth below the surface. Under Marlborough conditions experience has shown that the depth of accurate penetration is generally less than 30 metres. The reason for this is that resolution is lost at depth because of strong contrasts in the resistivity of the upper layers.

Electric resistivity has also been used for locating the boundary between water of differing quality.

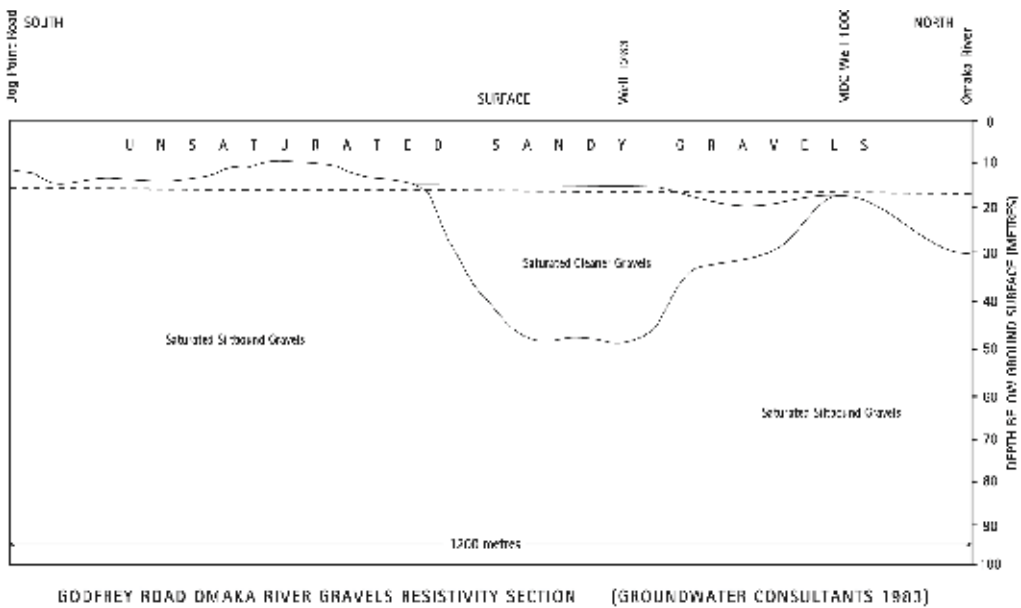


Figure 5.9: Godfrey Road section 1

Examples include the sea-water interface separating Cloudy Bay ocean water from the Rarangi Shallow Aquifer, and the saltwater at Wairau Valley.

## Groundwater tracers

In 1986 resistivity measurements were used to measure the rate of sub-surface groundwater flow at a site on the north-bank of the Wairau River at Kaituna, just upstream of the SH6 Bridge to Nelson. The survey was conducted by science staff from the MWD to assess the leachate pollution potential on surrounding groundwater of a proposed landfill by the MCC (White - 1986) (Fig. 5.10).

The travel time of a salt solution through the local gravels was used to measure the groundwater flow direction and velocity. Surface resistivity electrodes induced an electric current which detected progress of the introduced slug of saline tracer with time.

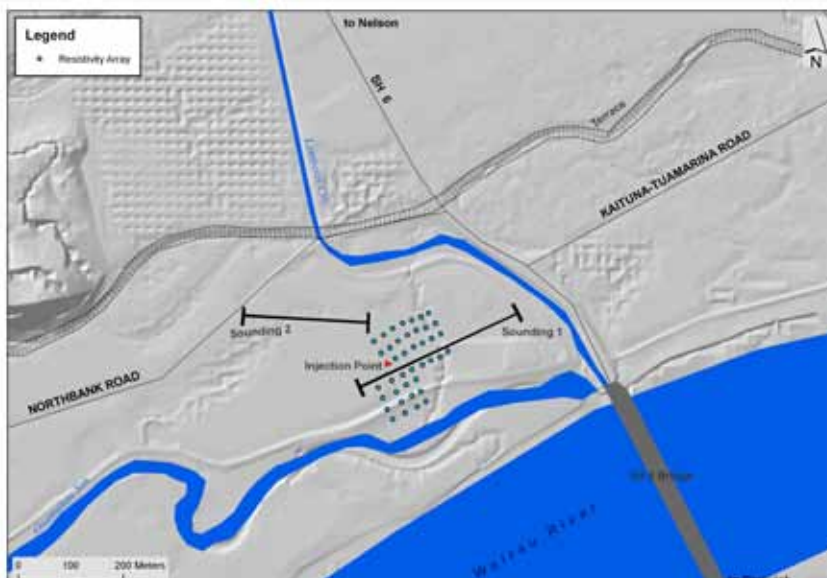


Figure 5.10: Survey location map

The site is underlain by highly permeable alluvial gravels, which have been reworked by the Wairau River in recent times. Knowledge of the rate and direction of groundwater flow was needed to determine the risk of landfill leachate affecting downstream wells or surface waters.

The calculated travel times averaged 430 m/day in the trial. Based on the groundwater gradient of 0.0033 the report calculated the

hydraulic conductivity of the local gravels to be 33,000 m/day, which is extremely high. Interestingly the resistivity of the saturated gravel material below the water table was 820 ohm/metres which is also very high and reflects the low silt or clay content in the pore spaces of this material (White - 1986). This is consistent with their very transmissive nature.

## Seismic

Seismic surveys are another geophysical method used locally, which can penetrate to greater depths below the earth's surface than the electric resistivity technique. This method has been used to identify regional scale geological differences such as the depth to basement and boundaries between sedimentary materials.

The seismic method works on the principle that sound waves travel at different speeds depending on the density of a rock and its water content. Hard, crystalline

rocks transmit sound waves at speeds of up to 5,000 metres per second compared to only several hundreds of metres per second for an unconsolidated sand or alluvial gravel.

The method works by measuring the two way travel time for sound or seismic waves generated at the surface to travel through the earth's crust at very high speed. Because these waves travel at different velocities through rocks or sediments of different types, differences in subsurface material can be interpreted. It does however only work well if there are contrasts in the densities of the material encountered.

The method for example, may not differentiate between granite and schist or between two sedimentary gravel formations because they are too similar in composition. It may also be unsuccessful if the basement rock is highly weathered, and a sharp boundary doesn't exist with the overlying alluvium.

The seismic reflection method measures the two way travel time of sound waves generated at the surface. Returning waves can travel a number of different routes (Fig. 5.10). They can take a direct line, or be reflected or refracted; depending on the earth's composition locally. Receivers called geophones are laid out in a specific pattern at the surface. These record the time that sound waves arrive at varying distances from the source. The depth of penetration is limited to the layer with the highest sound velocity as this layer will tend to deflect all waves from travelling deeper.

The depth to a boundary between two rock types is determined by the difference in arrival times of the first shock waves at each geophone. The first arrivals will represent waves travelling the short distance through the shallow sand formation. Deeper waves that are reflected back after travelling faster through the denser, deeper material will start to arrive first in the more distant geophones (Fig. 5.11).

As with all geophysical techniques the seismic method is an approximation of the real world, and there is normally no unique answer for any set of results. Computers are used to analyse the large amount of information collected during a typical survey and create a model of what may exist in reality.

Seismic surveys are commonly used overseas for identifying regional scale structures such as salt domes or anticlines that naturally trap gas or oil, and lie up to several kilometres underground. In Marlborough the depth of penetration is limited to a maximum of

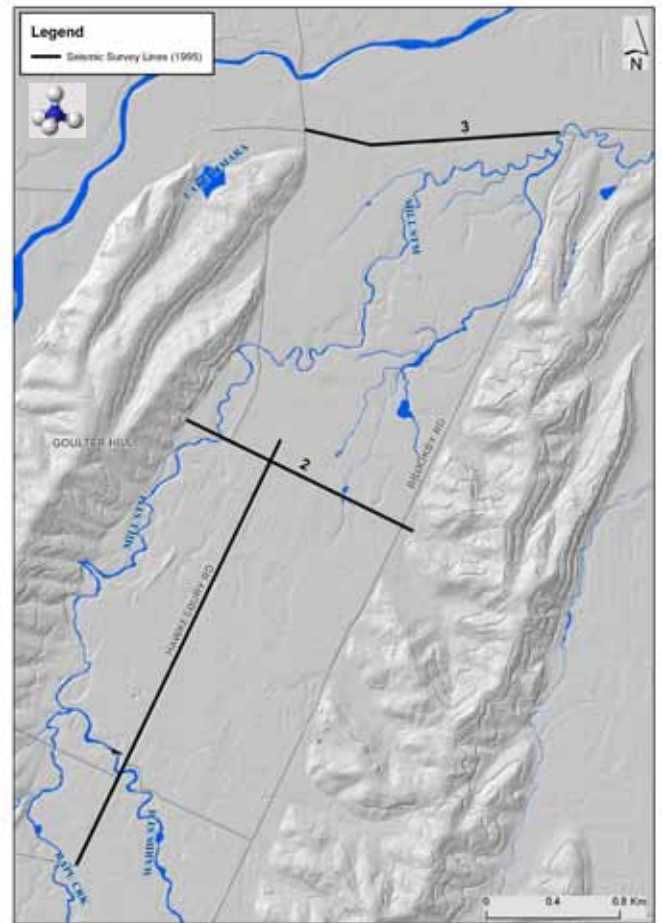


Figure 5.12: Exploratory bore seismic surveys around 500 metres, which represents the estimated depth to basement rock.

Two seismic surveys have been conducted by or on behalf of the MDC in recent times. The first was carried out in 1995 to define the site for Marlborough's deepest test bore at Hawkesbury Road. This survey identified the location with the best prospects of providing a representative section through the Southern Valleys aquifer terrain, and identifying the existence of any undiscovered aquifers. Road compactors were used to produce the sound wave which intrigued local landowners!

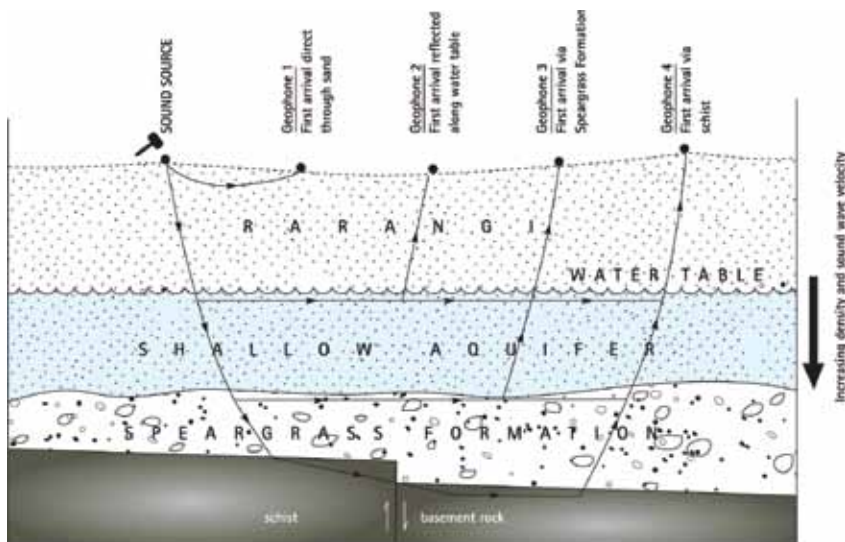


Figure 5.11: Seismic method (After Driscoll 1987)

The seismic refraction method was not expected to recognise the typically thin water bearing layers which typify the Southern Valleys Aquifer systems. At best it was hoped to identify the basement and regional scale features which may contain groundwater.

Seismic surveys were carried out along Dog Point Road, Hawkesbury Road and Kennedys Roads in the Omaka-Hawkesbury Valley, south of Renwick (Fig. 5.12).



The seismic results over-estimated the depth of sediments at 700 metres where in fact drilling showed a depth of 400 metres (Fig. 5.13). This commonly happens in New Zealand because of the lack of contrast between weathered greywacke basement and compacted claybound gravels in terms of how they transmit sound waves. This highlights the reconnaissance role of geophysical methods in general.

The black linear features represent layers of differing properties within the sediments. The whole sequence slopes gently to the north-east. The highly stratified structure of the sediments act as good reflective surfaces to the sound waves. A prominent reflector occurs at a depth of approximately 300 metres throughout most profiles, but didn't appear to correspond with any particular strata in the subsequent drilling.

The continuity of the alluvial beds implied by the seismic results wasn't borne out by drilling. Most water bearing layers intercepted by wells appear as small, discontinuous lense shaped gravel beds corresponding with old stream channels, rather than extensive layers. Correlatable hydrogeologic units rely on large rivers for their formation which weren't known to exist in this area.

A site for the exploratory bore 2917 was selected to target the intersection of the reflector layer and the Graben structure, which due to their geometry had the potential to intercept and store groundwater. As it turned out no new sources of groundwater were found by the exploratory bore.

The poor correlation between seismic survey results and the subsequent drilling illustrates the limitations of the method for precision assessments of water bearing layers in alluvial conditions. It is best suited to regional scale structural or basin surveys.

A second seismic survey was conducted by Scott Wilkinson at Rarangi as part of a student field project supported by the MDC in 2005. The main aim was to map any faults in the area and the sequence of alternating terrestrial and marine geological formations. The method successfully detected the series of interglacial and glacial units and the results are described in the regional geology chapter.

Seismic profiling was also used by PPCS Ltd and Clemence Drilling in 1988 to decide whether to drill deeper at a new water supply well near the Opawa River for the freezing works at Riverlands on the southern outskirts of Blenheim. The results were ambiguous at this well, but were clearer at the more inland site where a greater contrast in seismic velocity existed between alluvium and cemented conglomerate rocks.

### Downhole logging

Downhole logging of boreholes is a common geophysical technique worldwide but one that has rarely been used locally. It was used by the MDC in relation to the assessment of the Deep Wairau Aquifer wells drilled in the late 1990s. It is understood that the MWD also carried out some downhole logging at various sites on the Wairau Plain in the 1970s or 1980s, but no details are available.

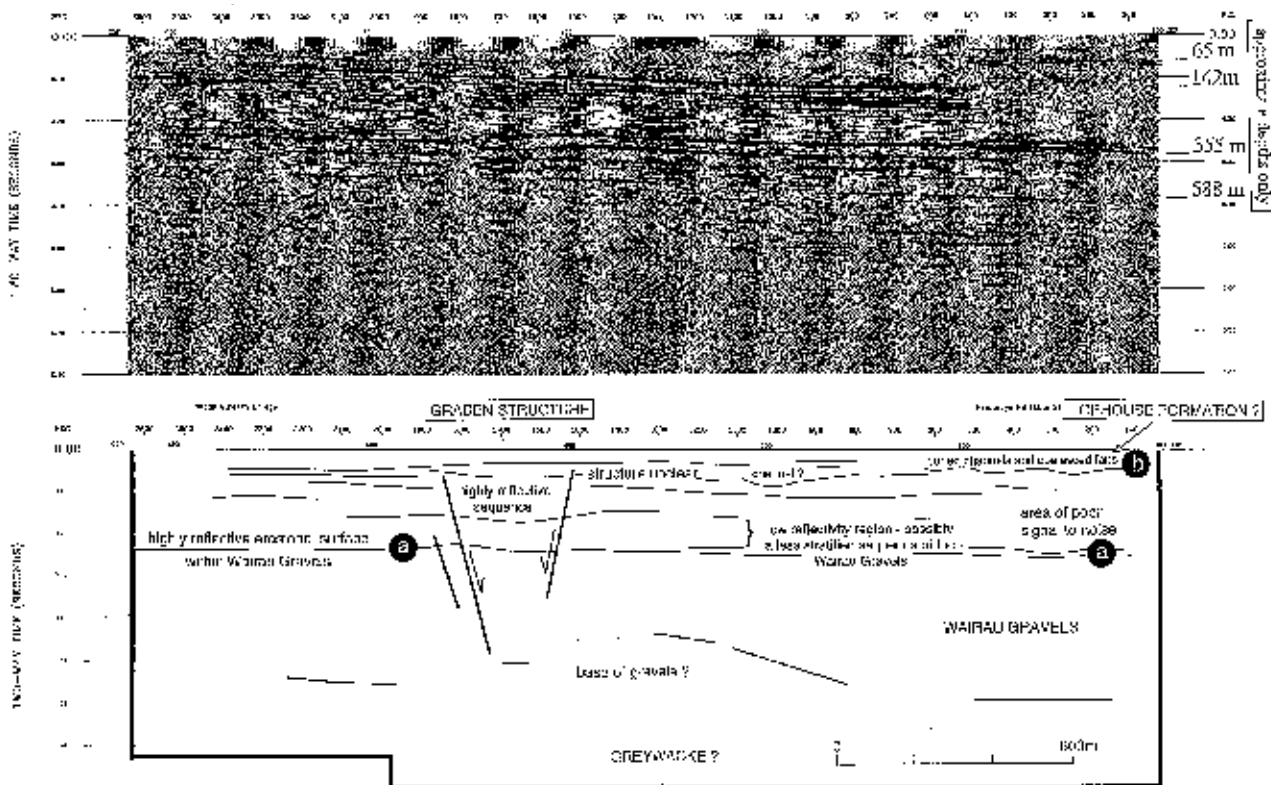


Figure 5.13: Seismic survey results and interpretation for Hawkesbury Road transect 1 (IGNS 1995)

As the name implies, a probe containing a range of instruments is lowered down the well and the location of water bearing formations, structures or geological discontinuities are pinpointed from the readings. The method is used in conjunction with the drillers log, and works best in uncased wells as soon as drilling is completed. This avoids the build-up of fine sediments, ensures the hole is in good condition with no collapses, and the rock formation is well preserved without weathering.

Geophysical logging is especially useful for verifying drillers strata descriptions for very deep wells because the rotary drill method tends to crush or mix the natural strata, making it difficult to recognise it at the surface. The travel time for drill cuttings to go from the base of the well to the surface where they are identified by the driller also introduces uncertainty into their actual depth of origin. The interpretation of downhole logging results is a specialist job, and the results are enhanced by knowledge of the local geology and drilling.

Downhole logging was used by the MDC to identify the source and distribution of groundwater within six wells tapping the newly discovered Deep Wairau Aquifer in 1998 and to confirm the accuracy of the geological logs for these exceptionally deep wells.

## Downhole logging techniques

### Natural gamma

This is a measure of the naturally occurring radiation coming from formations and is measured as counts per second of scintillation or CPS. It relies on the fact that clays contain more of these naturally occurring gamma ray emitting elements than sands or rocks.

Clays give higher counts compared to sand or gravel formations (GroundSearch EES Ltd - 1998). This method has the advantage of being able to be used in cased wells as rays pass through steel or PVC. Low values can mean a wash-out or collapsed section of the well.

Because gamma ray logging is primarily used to distinguish between clay and non-clay materials, it is useful for identifying the degree to which strata are claybound, as higher clay content generally means a lower yielding aquifer.

### Geological formation density

An active radioactive source is mounted on the logging tool sending gamma radiation into the side wall of the bore hole. Two shielded detectors measure the back scattered gamma radiation. The amount of back-scattered radiation is dependant on the density of the formation. The long-spaced detector measures density further into the sidewall, while the short-spaced

(SS) detector measures shallow side-wall density (GroundSearch EES Ltd - 1998). Measurements are given in grams per cubic centimetre.

The density measurements show subtle changes in the material related to grain size and packing. In general the higher the density the lower the porosity. Clay material has low density compared to a gravel layer. As with gamma radiation, density measurements can be affected by washouts.

### Electrical resistivity

The electrical resistivity of a particular formation depends on many factors and these have been discussed in detail earlier. Generally fine grained material such as clays or silts have low resistivity, whereas sands or gravels have high resistivity. Dry formations have high resistivity compared to material lying beneath the water table. Water quality also affects resistivity with saline water or water with higher concentrations of dissolved minerals having relatively low resistivity. Water contained within clay units is generally highly mineralised, which contributes to its low resistivity (GroundSearch EES Ltd - 1998)

### Caliper tool

An extendable arm on the logging tool measures the diameter of the drill-hole as it moves down the well. Obviously it only works for uncased wells. It is useful for identifying washouts which may confuse other methods. When the caliper tool is fully extended it may mean the bore hole has been washed out and conversely small diameters may indicate the hole is squeezed by a boulder or has collapsed.

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