Chapter 14 - Influences On Groundwater

Introduction

Aquifer levels are never stable but are constantly responding to either natural or human influences. Regardless of whether a well is being pumped, there will be natural forces at work. Summer well levels are normally falling as gravity drainage exceeds recharge, while in winter and spring, the opposite trend occurs.

This chapter describes the shorter term and more localised effects on well levels. Some are very subtle such as the gravitational force of the moon, ocean tides and earthquakes. The reason for describing these effects is because they are interesting phenomena, as well as telling us about the properties of the aquifer. The effects of the 2010 Canterbury Earthquake were felt in Marlborough wells and led to major changes in water levels.

Human influences

There is no doubt that the most dramatic effect on aquifer levels is caused by the pumping of wells. This is especially true of low yielding aquifers where pumping rates can be much greater than the natural rate of inflow. Sometimes pumping not only affects the well involved, but also other wells and streams, springs or wetlands that are hydraulically connected.

When a well is pumped, groundwater is drawn out of the aquifer and levels decline. The way in which groundwater in the surrounding aquifer and the well itself behaves depends on a number of factors. These include the pumping rate, hydraulic properties of the aquifer, aquifer size and the efficiency of the well.

Higher pumping rates cause groundwater levels to fall further than smaller pumping rates. An aquifer made up of permeable gravels that can store and transmit large volumes of groundwater will generate smaller drawdowns in a well. Other aquifer characteristics such as its size and the volume of water it stores also dictates the response of a well.

Regardless of the properties of a well or aquifer, a characteristic change in level occurs over time when a well pump is switched on. At first there is a sharp fall in the well and groundwater level, but over time the rate of decline slows. This is commonly referred to as the drawdown phase.

When the pump is switched off the reverse occurs, with a rapid recovery initially, followed by a levelling out over time, before returning to the original pre-pumping level. This is called the recovery phase.

This pattern of changing water level over time has a distinctive symmetric shape when graphed. This is depicted in the water level of the passive MDC monitoring well (0949) located on the western edge of Blenheim (Fig. 14.1). This well experiences daily falls in groundwater levels of about 150 millimetres due to pumping at a distant well somewhere to the west . The well pump turns on at about 6 am in the morning and causes water levels to fall. It then turns off at 7:30 am, resulting in a rise in water levels. The pumping well is likely to be a source of irrigation supply for vineyards on the western bank of the Taylor River; although it's exact identity is uncertain as there are several wells in the area. The estimated distance to the unidentified well based on the known storage characteristics of the local Southern Springs sector is less than 500 metres.
Pumping a well draws down aquifer levels not only in the well itself but further away by generating what is known as a cone of depression. The rate at which this cone expands depends primarily on the wider storage characteristics of the aquifer, and to a lesser extent the pumping rate or duration of pumping.

The way in which aquifer storage controls the distant effects of pumping was demonstrated during a 2006 aquifer test near the Cloudy Bay coast and north of the Diversion channel. Well 4639 was being tested to see how much Wairau Aquifer levels at the nearby coast fell in response to its pumping for a vineyard supply. Groundwater levels in the MDC coastal sentinel well 3667, located 500 metres to the north-east, fell instantly by 0.5 metres (Fig. 14.2). The cone of depression expanded and covered the distance separating the two wells within a few minutes. When the pump was switched off, recovery of the well levels was just as abrupt.

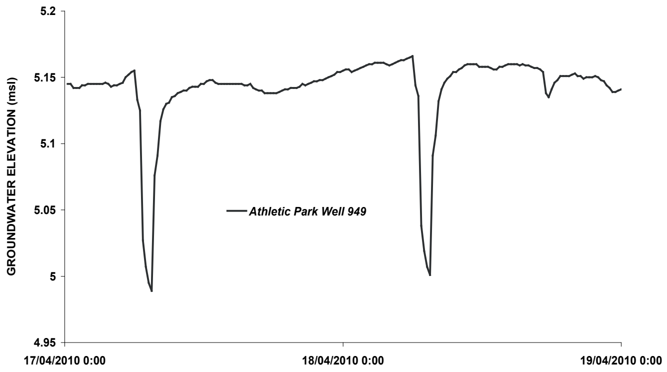

Figure 14.1: Inland semi-confined well pumping effect

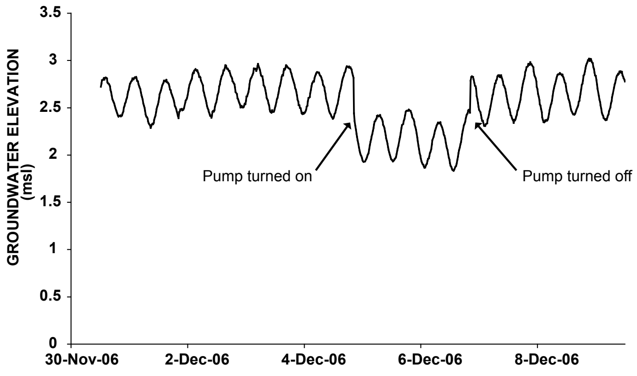

Figure 14.2: Coastal confined aquifer well pumping effect

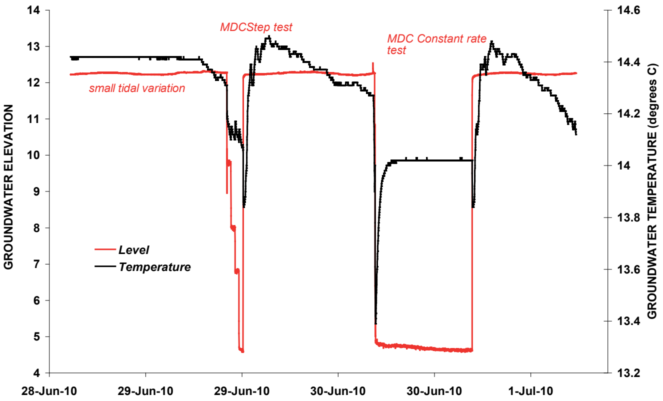

Figure 14.3: Inland Wairau Aquifer well pumping effect

The regular oscillations in water level of around 0.5 metres are caused by ocean tides. These create a changing load over the low permeability strata that confines the aquifer and causes varying levels of compression of the aquifer structure. Ideally these should be removed when analysing aquifer test results as the fluctuations are of the same size as the drawdown effects being measured.

The largest consented rates of groundwater pumping in Marlborough are for public water supply at the MDC Grove Road and Middle Renwick Road well-fields which can pump at a rate of up to 500 l/s. While this is a very large pumping rate, the effects aren't obvious in terms of visibly affecting spring flow or the level in other wells, primarily because of the naturally high aquifer yields. In order to spread the drawdown effect, a number of wells are used to source this water.

The pumping of such high volumes also changes the water temperature in the well (Fig. 14.3). As the pumping starts the groundwater temperature falls and when the pumping stops, the temperatures rise again. A possible explanation for this is that pumping induces cooler Taylor River water into the aquifer as in mid winter groundwater is generally warmer than surface waters.

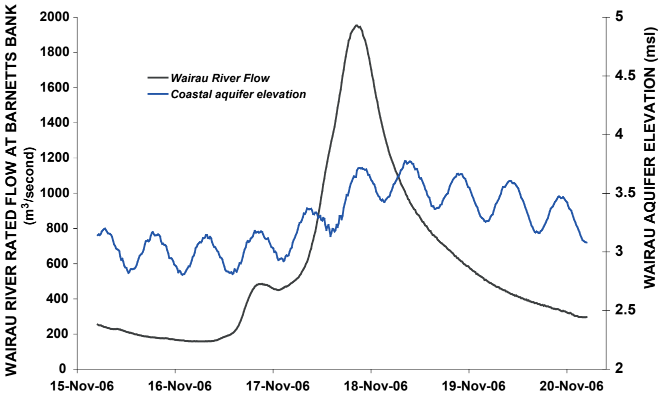

Figure 14.4: Coastal Wairau Aquifer response to Wairau River flood

Natural influences

Rivers

Direct inputs of recharge water from rainfall or rivers cause obvious rises in aquifer levels soon afterwards. River floods create a similar effect as they pass over confined aquifers, although this doesn't involve an actual transfer of water. Like the tidal effect, this is due to the extra weight of the flood waters compressing the aquifer structure. This results in a temporary rise in aquifer level.

Levels at the MDC Bar well 1733 rose by about 0.75 metres in response to an average annual flood flow in the Wairau River of 1,900 m^3/s in 2006. This well taps the highly confined Coastal Wairau Aquifer. The smaller blue oscillations represent the six hourly tidal cycle (Fig. 14.4).

Knowledge of how these mechanisms work is useful for interpreting fluctuations in well levels, and isolating human induced changes from climate variations. They can also tell us a lot about the structure and hydraulic properties of an aquifer. Ultimately this helps manage the effects of pumping or changes in climate.

More subtle influences on well or aquifer levels can include earthquakes, moon and earth tides. What is less obvious is the important role that natural drainage plays in dictating aquifer status and driving seasonal changes.

Drainage

Gravity drainage affects all of Marlborough's aquifer systems to some extent, although in the case of less permeable systems such as the Deep Wairau Aquifer, rates of groundwater movement are imperceptibly slow. Rates of aquifer drainage of five to ten millimetres per day are not uncommon in Marlborough. The riparian gravel aquifers of the Southern Valleys have higher rates of drainage than the Wairau Aquifer because they are on a steeper slope than the main Wairau Plain.

The largest falls of 100 to 200 millimetres per day have been observed in the Omaka River Aquifer deep layer well 1000 in Godfrey Road. These are very high rates by any standards and are caused by the Omaka River becoming disconnected from the deeper aquifer. Deprived of recharge, the aquifer levels fall rapidly (Fig. 14.5). Aquifer levels however, rise just as rapidly when higher river flows return in winter.

Ocean tides

Coastal aquifers are affected to varying degrees by the rise and fall in sea-level as the tide changes every six hours. During the incoming or flood tide, the increased weight of water overlying the confining layer compresses it, causing water levels in wells to rise.

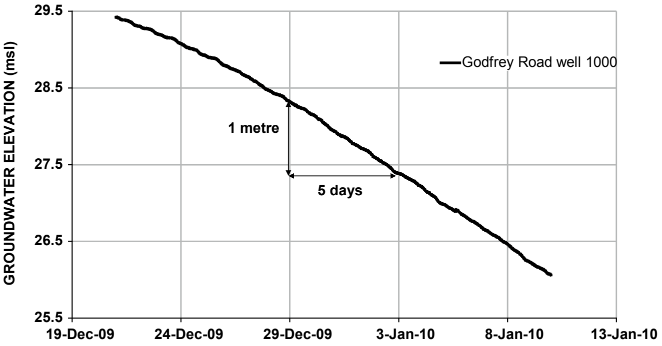

Figure 14.5: **Rapid aquifer drainage in the Omaka River Aquifer**

Conversely when the tide ebbs the load is reduced and well levels fall. This phenomenon doesn't mean the aquifer has taken up the volume of water equivalent to the change in well level, it simply represents a temporary pressure change.

Confined aquifers are most affected because of their compressible nature with wells in Blenheim still showing a measurable tidal variation. This reflects the elastic properties of the aquifer structure, allowing them to expand or contract as the tidal loading varies. Except right on the margin, unconfined aquifers are largely unresponsive to tides due the absence of a low permeability capping layer that compresses the groundwater.

The continual fluctuations in tides generate sinusoidal waves which propagate and diminish with distance inland through the compressible clay material forming the aquifer confining layers (Fig. 14.6).

The tidal range is defined as the difference between high and low points on any tidal cycle. The tidal amplitude is one half of the tidal range. The wave period is the time taken for a tidal cycle to occur which is half a day, reflecting the tide cycle. Unlike barometric pressure induced changes, tidal effects are direct. High tides cause water levels in wells to rise, and low tides cause levels to fall.

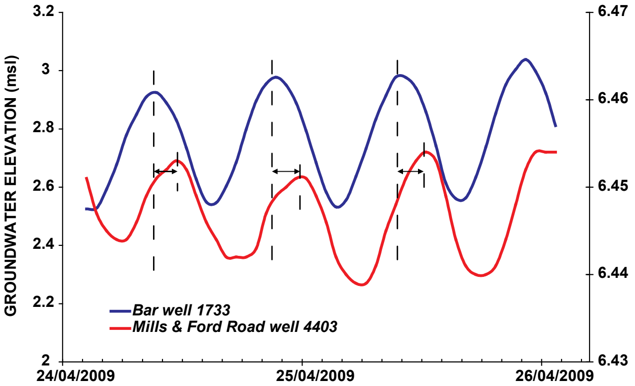

Figure 14.7: **Tidal wave time lag**

The distance inland from the sea that wells respond to ocean tides depends on the nature of the materials forming the aquifer confining layer. Tidally induced waves propagate further through elastic sediments such as clays and diminish less with distance. It is no coincidence that this also corresponds with the inland extent of the marine transgression which was responsible for creating the confining layer that transmits the waves.

There is a time lag between the state of the tide at the coast and the same phase occurring at an inland well. The time difference between the peak level at the Bar well 1733 near the coast, and its arrival at well 4403 at Mills and Ford Road 7.5 kilometres inland, is about three hours (Fig. 14.7).

The one known exception where an unconfined aquifer responds to ocean tides is well 4349 located near the shoreline at North Rarangi. Depending on sea conditions, it is between 50 and 80 metres from the shore (Fig. 14.8).

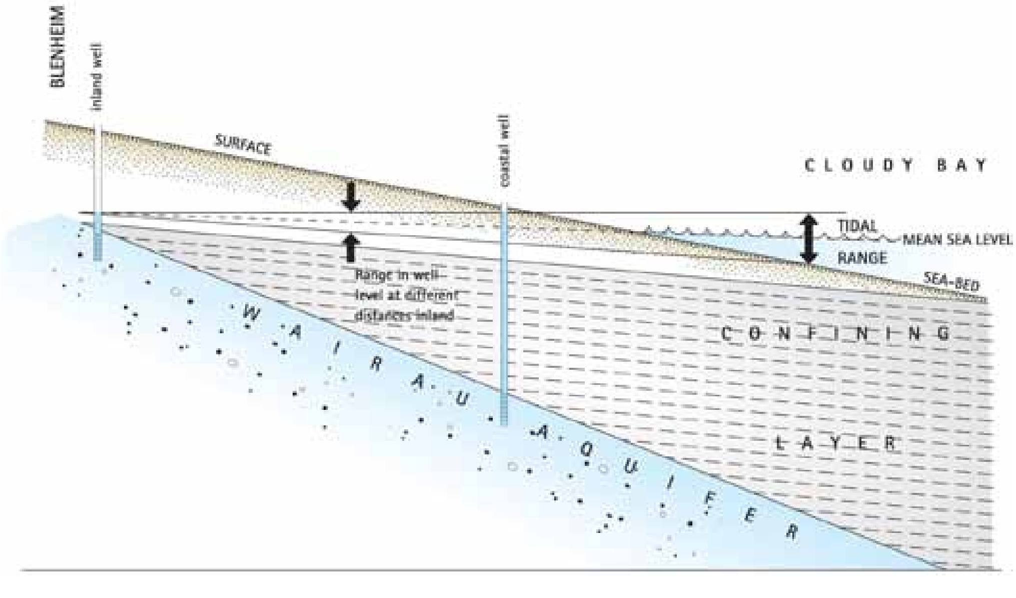

Figure 14.6: **Tidal loading mechanism**

The mechanism causing well levels to rise is different to that acting on confining aquifers. Elevated sea-levels at high tide temporarily dams freshwater flow offshore, releasing it when the tide goes out. This results in six hourly fluctuations in the water level of well 4349 (Fig. 14.9). There are however, no signs of tidal effects on groundwater levels at monitoring well 1901 in the same aquifer only 400 metres inland.

The tidal effect on well 4349 also creates a

Figure 14.8: MDC North Rarangi well 4349

variation in the conductivity of the groundwater. When ocean storm surges, low barometric pressure or particularly high tides result in higher sea-levels, the conductivity in the well increases. These elevated conductivity levels fluctuate in unison with the tide phases (Fig. 14.9).

In addition to daily tides there are also longer cycles which coincide with the movement of the sun and moon relative to each other. Twice each month during the new and full moon, the tide producing effects of the sun and moon are aligned, causing larger than average tides called spring tides. Alternately, during first or last quarter phases, the tide generating mechanisms of the sun and moon oppose each other, resulting in smaller than average or so called neap tides. This cycle doesn't appear to influence Cloudy Bay well levels and currents generated by the converging effect of Cook Strait may explain the absence of these seven day patterns locally (Fig. 14.10).

If the range in level at the Bar Wharf is assumed to represent the variation in the ocean tide opposite Cloudy Bay and the driving force causing changes in well levels, then we can calculate the tidal efficiency of the aquifer which is about 75%.

The extent of the tidal influence on Wairau Plain well levels has been mapped using derived information from observation wells. The shape of the contours shows the response to tidal influence is not uniform, with larger fluctuations beneath the centre of the Wairau Plain, and smaller changes on the margins at Riverlands or Rarangi (Fig. 14.11).

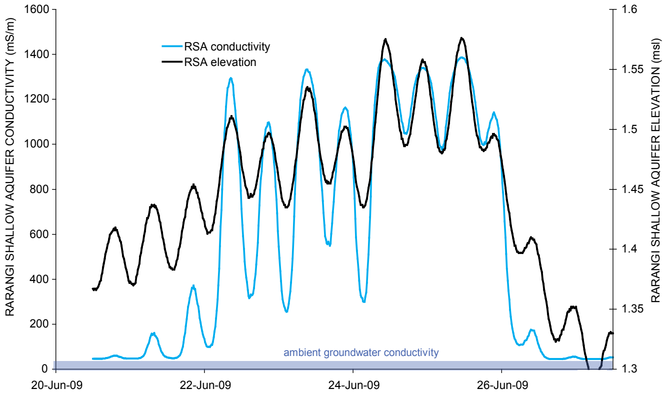

Figure 14.9: Conductivity versus water level

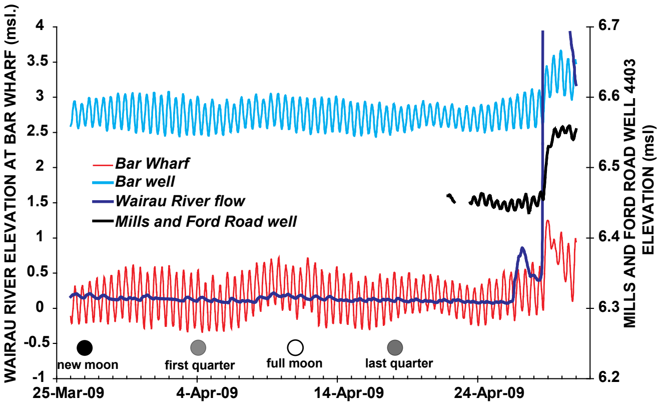

Figure 14.10: Tidal induced groundwater variation

The explanation for the curved shape of the contours reflects a number of natural factors. These include the curve of the Cloudy Bay shoreline which determines the distribution of tide generating forces, and natural variation in the aquifer hydraulic properties of transmissivity and storativity. The pattern demonstrates that the most transmissive part of the aquifer with the most permeable gravels, underlies the central plain. This is consistent with Len Brown's conclusion (Brown - 1981a) that down cutting of glacial outwash deposits

Figure 14.11: Wairau Plain tidal contours

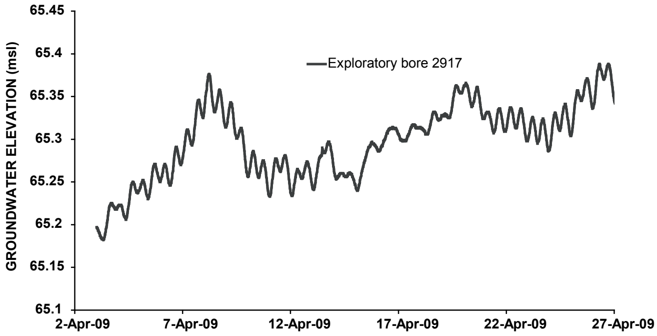

Figure 14.12: Earth tides at inland well 2917

during postglacial times was more pronounced in the central areas of the Wairau Plain than on the northern and southern margins. The presence of younger and chemically less evolved groundwater also supports this concept.

Earth tides

Earth tides are generated by the same gravitational forces of the sun and moon that cause ocean tides, but occur far from the coast. Whereas ocean tides create a direct loading effect on coastal confined aquifers, earth tides are a result of a dilation or expansion of the earths crust due to the varying gravitational pull of the moon. They affect aquifers formed of compressible materials.

The MDC exploratory bore 2917 in Hawkesbury Road, approximately 20 kilometres inland from the Cloudy Bay coast has a distinctive 6 hourly tide cycle (Fig. 14.12). This well penetrates a 400 metre thick sequence of alternating claybound gravels and clay beds.

The MDC Mill Road test well O28w/0219 also shows the earth tide induced variation. The tidal variation of earth tides is however much smaller than the ocean induced tidal variation (Fig. 14.13). Earth tide peaks and troughs at the inland and coastal sites match. This means the state of the tide at Cloudy Bay, 50 kilometres away, can be predicted at any time from the stage of the groundwater cycle at Wairau Valley.

Shock waves

Any loading or stress on a confined aquifer will change its storage volume and as a consequence affect the level of groundwater in nearby wells.

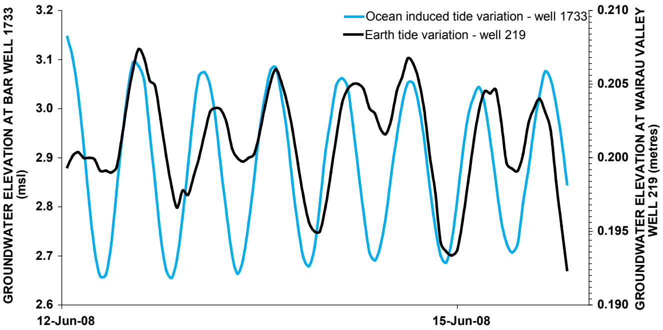

Figure 14.13: Earth and ocean tide comparison

A common phenomena that alters water levels is seismic waves generated by earthquakes. These travel long distances through bedrock very rapidly and can affect well levels. The MDC monitoring well 4404 in Mills and Ford Road shows an instant response to the 15th of July 2009 magnitude 7.8 Southland earthquake (Fig. 14.14). This very large earthquake was detected by water level recorders as far afield as the Manawatu and Northland. Groundwater levels responded instantaneously to the earthquake which shows how fast seismic waves travel.

The 2010 Canterbury earthquake was detected at many Marlborough wells and caused large changes in groundwater levels. The largest changes were associated with deep wells penetrating claybound gravels in the Southern Valleys catchments. Most groundwater levels fell with the exception of well 3333 representing the Deep Wairau Aquifer in the Lower Fairhall-Brancott Valley. At this well levels rose by almost one metre (Fig. 14.15).

Some earthquakes aren't recorded by the Marlborough groundwater monitoring network because the 15 minute recording intervals are too coarse for such a short term phenomena.

Barometric pressure

The weight of air in the atmosphere may seem trivial but it exerts a continuous pressure on the earth's surface which is in turn transferred to underground formations and groundwater stored in its pore spaces. For example, a change in atmospheric pressure from 1030 to 920 millibars reduces the weight by the equivalent of one metre of water.

Well levels in confined aquifers rise in response to low atmospheric pressure, cyclonic weather systems; and fall during higher pressure, when an anticyclone system prevails. This induces the opposite effect to ocean tides.

The different effect occurs because the water level in a well casing experiences the full effect of the change

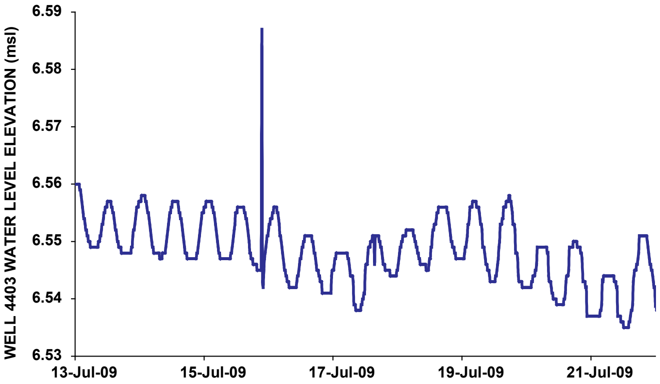

Figure 14.14: Water level spike as a result of July 2009 Southland earthquake

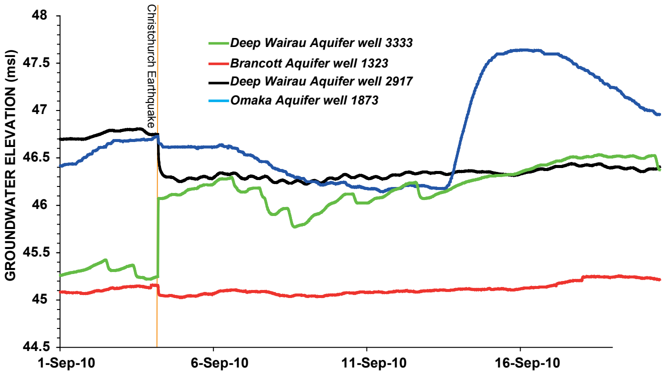

Figure 14.15: Marlborough aquifer response to September 2010 Christchurch earthquake

in barometric pressure, whereas the water within the aquifer only experiences part of the pressure change, because the other component of the pressure change is transmitted through the aquifer strata.

The effect of barometric pressure can be clearly seen by the response of the 50 metre deep MDC test well at Wairau Valley in mid 2008 (Fig. 14.16).

Diurnal patterns

MDC monitoring wells in aquifers with water tables close to the surface exhibit a small diurnal variation in groundwater level. These once daily fluctuations are caused by differences in evaporation and transpiration losses. In the heat of the day groundwater levels fall as the rate at which plants transpire water through their roots, or groundwater fed springs evaporate water, exceeds the rate of recharge. For example water levels during February 2011 vary by 10 to 15 millimetres over a day at well 4331 in the Rarangi Shallow Aquifer, and by a similar amount at well 3954 tapping the Wairau Aquifer in Murphys Road (Fig. 14.17).

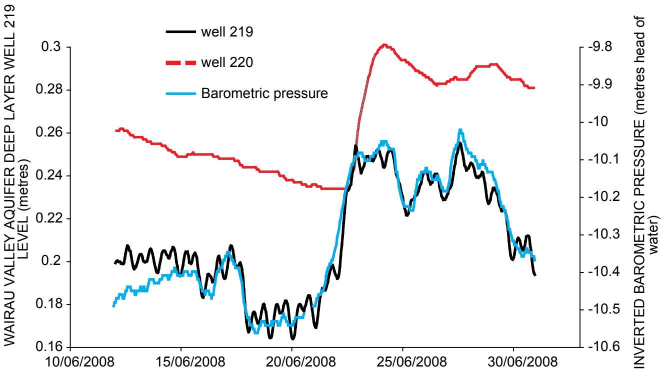

Figure 14.16: Barometric variation at Wairau Valley well O28w/0219

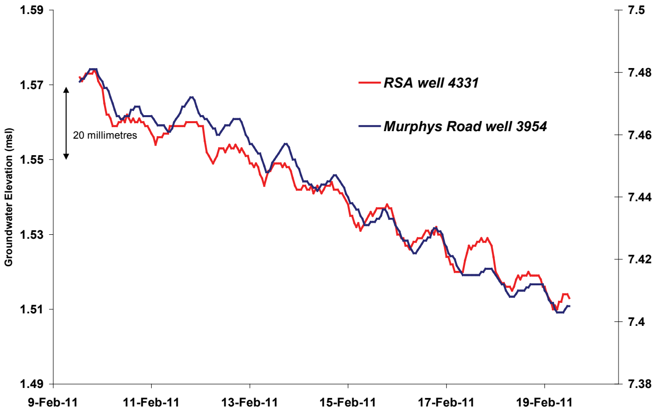

Figure 14.17: Diurnal fluctuation in shallow groundwater

References

Brown, L.J. 1981. Late Quaternary Geology of The Wairau Plain, Marlborough, New Zealand; NZ Journal of Geology and Geophysics 24: 477-490