Chapter 6 - Well Construction Methods

Introduction

Most of what we know about Marlborough's groundwater resources comes from drilling records, observations and related testing and without it the groundwater resources would be a complete mystery.

The technology of drilling a well has been around for thousands of years with many cultures independently developing similar drilling techniques in different parts of the world. By the mid 11th century the ancient Chinese were drilling wells to depths of several hundreds of feet to find salt. They used the same percussion principle as modern cable tool rigs operating in Marlborough today (Kurlansky - 2003).

The types of wells used around the world vary depending on local conditions and the end use of the water. Most local wells apart from monitoring piezometers or infiltration galleries consist of a sealed upper section near the surface with an opening at the lower end (Fig. 6.1).

The closed section is called the casing and is normally made of mild steel welded together in sections, or PVC. This lining acts as a conduit for groundwater to be pumped to the surface, to house the pump and to prevent the well from collapsing. The intake at the base is to let groundwater enter the well and is called the screen.

Drilling a well is a very skilled business. One of the most important aspects involves keeping the casing true or vertical so that once a pump is fitted, it won't get stuck. This is not as simple as it might appear, especially if there are boulders or gravels pushing the drill-bit off-course.

In Marlborough we have had the benefit of some extremely skilled and ingenious craftsmen over the years (Fig. 6.2).

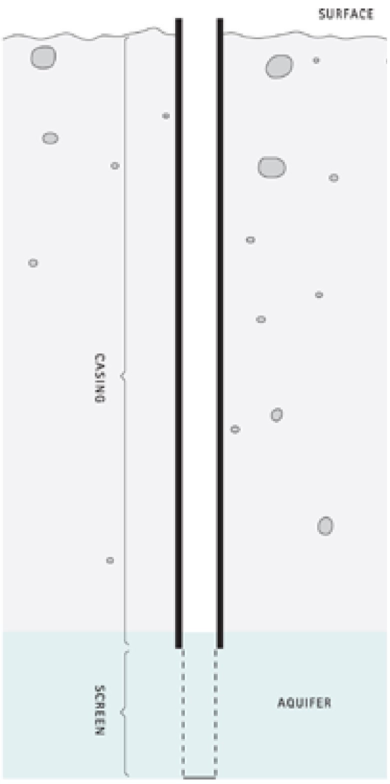

Figure 6.1: Conventional water well

Locating a site and making a well

The first step in making a well is to choose a site. Locating an aquifer is straightforward in an area like Rapaura where groundwater is generally available everywhere. Elsewhere water availability is much more uncertain and to improve the chances a well owner will do some research first. There are also many practical considerations such as power supply, location of crops or irrigation systems and maintaining a reasonable separation distance from other wells.

The next decision to be made involves selecting the diameter of the well casing. Well diameter has little to do with yield as fluid dynamics tells us that doubling the casing diameter will only result in about a 10 percent increase in flow.

Figure 6.2: Cable tool resting on the ground to the right of the driller, Colin Simpson during construction of Renwick municipal wellfield 2008

Generally the casing diameter is chosen to accommodate the size of pump required and allow it to operate efficiently. This means minimising friction losses within the annulus, which is the space between the casing and pump, or delivery pipe to the surface. The larger the casing diameter the more expensive the well becomes. This reflects the higher price of wider steel pipe and the fact that the drilling process is slower. Once the site is selected there are a number of considerations including how deep to drill and what construction method to use. In more explored areas of the Wairau Plain the depth to the aquifer is known but in other areas the location of water bearing layers is unpredictable.

Many shallow or exploratory wells are drilled using the percussion method to provide the best samples for describing the sub-surface geology, or because it is relatively cheap. This approach is commonly used by the MDC where detailed information is needed for making a decision on where to place the screen and the most efficient slot size in public water supply or test wells.

However the percussion method is too slow for deeper wells of more than about 15 metres. In this case and for private well owners where it is more important to discover if a viable water bearing layer exists, a faster method such as rotary drilling is used.

In some areas of Marlborough wells can be drilled without the need to case as the ground material is self supporting and won't collapse. This is true of the clay-bound gravels found in the Southern Valleys, but most wells drilled in permeable gravels close to rivers or the northern Wairau Plain require casing. Drilling without the need for casing speeds up the drilling time and is ideal for test wells.

Cable tool/percussion drilling

The two main methods for drilling water wells locally are the rotary and cable tool/percussion systems. The cable tool method is the oldest, and is an adaptation of the method used since ancient times to drill holes.

The percussion method involves rising and dropping a large chisel shaped tool weighing several tonnes repeatedly in the same hole. The tool is twisted each time to create a circular hole. The crushed material is then bailed to the surface. Water is added to the hole to form slurry which enables the cuttings to be bought to the surface. Made of toughened steel, the cutting tool is usually about one metre in length and screwed to what is known as the drill stem or tool. This adds weight to ensure the vertical alignment of the hole. This in turn is connected to the drill rig by a steel cable that passes over the top of the mast or derrick.

During the drilling process cuttings accumulate at the bottom of the hole as a watery mixture and are removed by a simple bailer made of hollow pipe fitted with a non-return valve at the base. This is also known as a sand pump. The bailer is lowered down the well on the end of another cable, filled and then hoisted back to the surface where it is emptied (Fig. 6.3).

Figure 6.3: Sand pump in operation. Sand bought up from the well is falling from the hole in the bailer and gathering in a pile.

Figure 6.4: New section of casing being added.

The casing is then driven downwards to prevent the formation from caving in and blocking the well. A hardened steel shoe is fitted to the leading edge of the casing at the bottom of the well to prevent it from fraying. A new piece of casing is welded to the top of the existing length in the ground (Fig. 6.4). Triple welds are used to make sure the joint won't break under the stresses of the drilling process as it would be disastrous to have a weld shear off below groundlevel. The drill bit is removed from the stem and replaced with a collar for driving the casing. The casing is then driven downwards to line the hole by repeatedly striking the rim with the drill stem. The process will then be repeated as many times as is needed until an adequate water bearing formation is found.

Todd (1980) describes the advantages of the cable tool method as being: more accurate sampling and logging of formations, lower water requirement compared to the rotary method.

The cable tool method is an advantage in dry or isolated areas. Also simplicity of design and ease of maintenance. However the disadvantages of the cable tool method are its slow rate of progress. For this reason it is limited to depths of about 50 metres. It is a slow method because of the need to case the hole in unconsolidated material to prevent collapses.

Rotary drilling

This method was developed for drilling oil wells and relies on revolving the drill bit in a circular motion to cut a round hole through the sediments. Unlike the cable tool method which combines an intermittent up and down action with twisting, the rotary system is a continuous process. Drilling is only stopped to add casing or attach extra rods as the hole deepens.

Figure 6.5: Rotary drill bit

The rotary drill bit is more complicated than its cable tool counterpart, with hardened metal teeth which rotate on bearings (Fig. 6.5). This particular type is commonly used under Marlborough conditions and is known as a tricone roller bit.

The rotary method uses a series of hollow pipes called rods which connect the drill bit at the face of the hole, with the rig at the surface. The earliest rigs used a drive located at the base of the drill platform to rotate the rods, which can be in a string hundreds of metres long which turn the drill bit to create a hole. This is called the table rotary method to distinguish it from rigs which provide the motive power at the top of the mast. Its major advantage over the cable tool method is its speed with a 30 metre deep well being drilled and developed within a day. A downside of the fast drill rate and the crushing action of the rotary bit is a less detailed description of the geology, and the possibility that small water bearing layers go unnoticed.

Another difference between the two methods is the way in which drill cuttings are bought to the surface. The rotary method uses a circulating fluid that moves downwards inside the drill rods, out through the bit, and then back up the annulus between the outside of the drill rods and the hole (Fig. 6.6).

The fluid, most commonly water but also air, performs a number of functions. The weight of the fluid maintains pressure on the inside wall of the hole to prevent it from collapsing. It also cools the drill bit, and brings the cuttings to the surface. If compressed air is used, foam or other additives can increase the bulk of the fluid so drill cuttings are lifted to the surface more easily. If water is being used the cuttings are emptied into a tank at the surface where the solids settle out, and the water continues its journey back down the hole. With air rotary machines the cuttings are literally blasted out of the back of the rig.

Special additives are sometimes used depending on the circumstances, most of which break down with time to avoid clogging the gravels. They are used to change the viscosity of the drill fluid either to seal the well wall and stop the loss of drill water into the surrounding gravels, or to improve the process of bringing cuttings to the surface. Sometimes drilling fluid is lost from the hole out into the surrounding gravels and indicates the existence of a water bearing layer nearby. Extra water then has to be added to the mud tank to compensate. However the drill fluid has a tendency to become too thick and block the pores of the formation. This complicates the next stage in the process which is developing the well. These additives have been used in Marlborough to suppress high artesian pressures that interfere with welding and fitting new rods.

There are many variants on the rotary drill method. A major advance was the development of the top drive which allows the casing to be driven at the same time as the hole is drilled, providing a more seamless drilling process. As the name suggests the major difference between it and the conventional table rotary method is the motive power to turn the drill bit which is applied at the top of the drill stem.

The most modern rigs operated by Butt Drilling Ltd are of the top drive type and drill most of the wells in Marlborough (Fig. 6.7). The air rotary method is the fastest and most cost effective for commercial well owners. However cable tool or percussion rigs are still commonly used for shallow domestic supply wells, or large diameter municipal supply wells. They are also

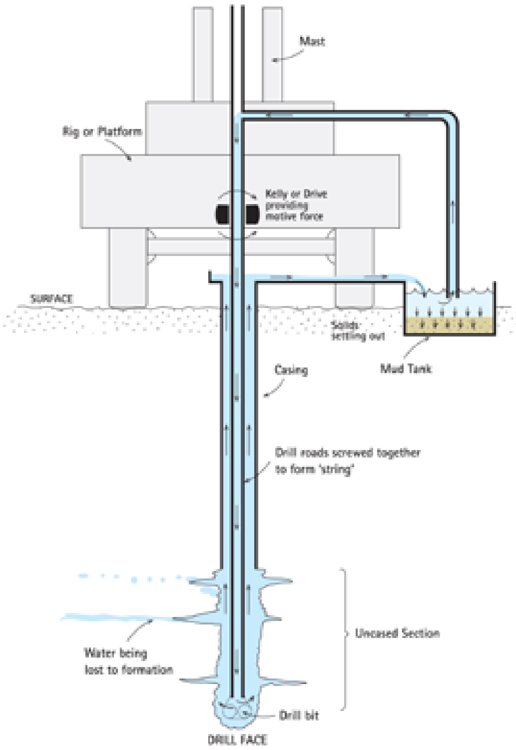

Figure 6.6: Rotary drill method water circulation

particularly suited to shallow exploration drilling where the emphasis is on identifying the subsurface material rather than speed.

In some cases the well may be drilled using a rotary rig, and then developed or tested using a cable tool rig. Or a telescopic well is drilled consisting of a large diameter hole closest to the surface using a percussion rig, with successively smaller diameter holes inside this using a rotary rig.

Another innovation over the past few decades has been the pneumatic hammer which was developed to cope with harder drilling conditions, and increase the rate of penetration. The concentrics drilling system is a tool with a similar purpose and used by Butt Drilling Ltd to penetrate boulders and other localised obstacles. It relies on a disposable hardened shoe with sintered carbide buttons that is fitted to the bottom of the casing and creates a hole the same diameter as the casing.

Well screens & development

Once the well is drilled to its target depth and has located sufficient water for the purpose required, the next stage is to optimise its hydraulic performance. The aim is to minimise the friction losses associated with groundwater flowing into the well.

Friction losses reduce the performance of a well as extra drawdown is needed to overcome it and the well produces less water. Friction losses are made up of two components. The first is caused by the friction as the water passes through the geological formation just outside the well. The second type of loss is associated with turbulence caused by water travelling through the screen into the well.

Figure 6.7: Top rotary drive rig. The top head drive is the square shaped object opposite the driller. Drill cuttings emerge from the round hole below this and have formed the wet patch on the ground. Two portable air compressors are required to drive the drilling process and provide air through the large hoses connected to the rig.

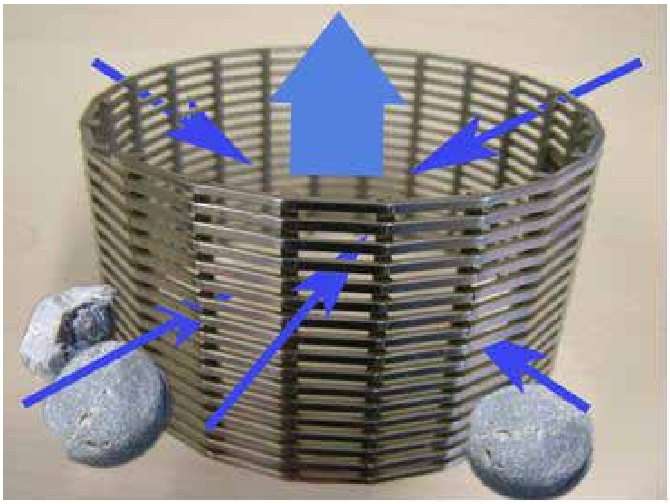

Figure 6.8: Stainless steel wedge wire wound screen

Well screens

Well screens act as the interface with the aquifer and perform the important function of letting groundwater into a well, while retaining the gravels which form the aquifer. The screen is normally set opposite the most permeable strata. Screens used in Marlborough wells come in a variety of materials and configurations. Some are machined locally by slotting or drilling steel casing or PVC to meet specific site requirements. Wells which need a higher level of hydraulic efficiency for irrigation or municipal supply, normally have a higher specification factory manufactured screen.

Factory screens are generally made of a corrosion free metal such as stainless or galvanised steel and are made by winding wire around a vertical frame. They come in different slot sizes to match the local geology. Because the wire wound types generally have a wedge shape, they are also referred to as wedge wire screens (Fig. 6.8). Steel screens are stronger than those made of plastic meaning they are better able to withstand the natural compressive stresses on the inside wall, particularly in deeper wells. Plastic screens have the advantages of being corrosion resistant and cheaper, but they are more susceptible to collapsing. They are also prone to snaking, a term used to describe when the PVC screen or casing concertina (Fig. 6.9). Another potential issue with this type of construction is the column load of several hundreds of metres of PVC, which in itself can cause the screen to compress.

The installation of wells with long screens was common place in the Southern Valleys Aquifers during the 1980s and 1990s, but is not ideal as it links aquifer layers together. Also the well can't be redeveloped so its performance declines over time. Generally there is limited benefit in developing these types of wells as the open area is small, the space between the well and the rock wall is large, and local gravels are claybound.

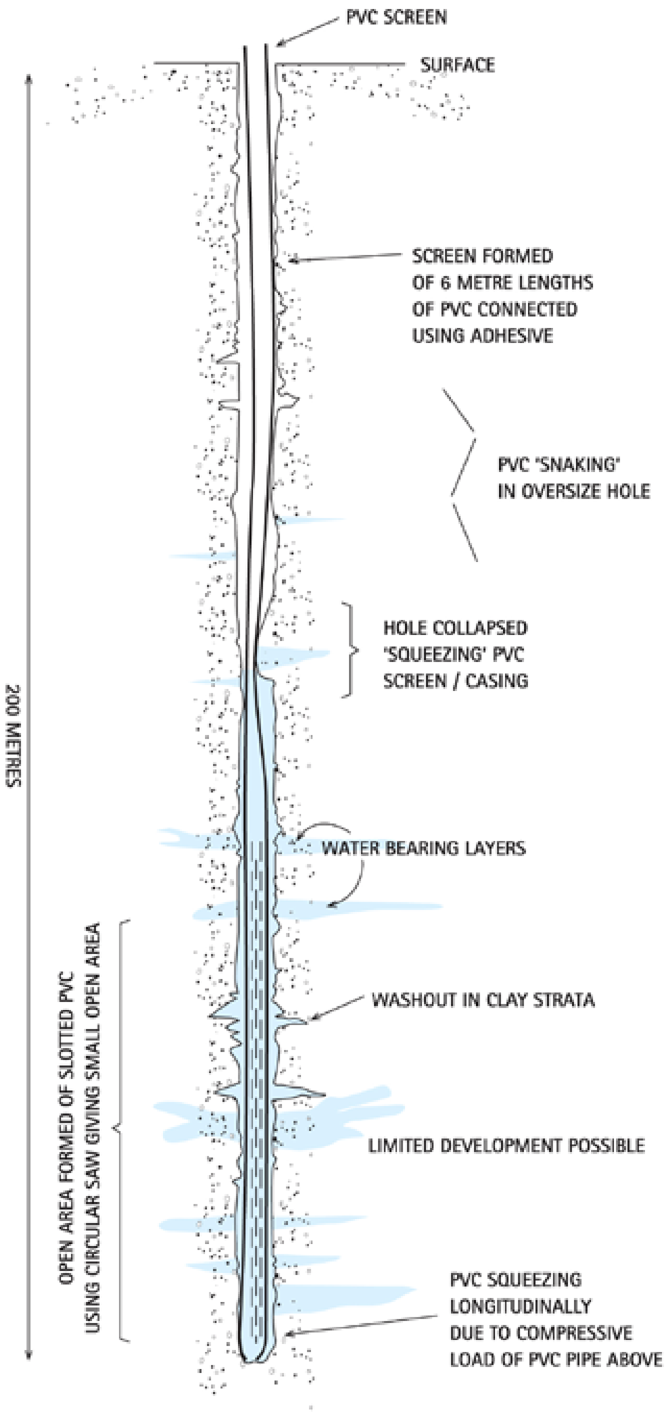

Figure 6.9: PVC screen behaviour

The open area of a screen has a big effect on well productivity. The prime objective when selecting the slot size is to optimise the performance of the well by maintaining groundwater flow through the screen at acceptably low velocities. Entrance velocity is calculated by dividing the rate at which groundwater flows into the well by the open area of the screen. If flow rates are too high, the easiest means of reducing them is to increase the diameter or slot size of the screen, if the natural material allows. The bigger the entrance area the lower groundwater velocity becomes, the more efficient the well.

Slot size has to reflect the geology surrounding the well, its grain size distribution and sorting. The aim is to keep the velocity of groundwater entering the well to less than that which will cause the smallest particles to mobilise. However a lot depends on the uniformity of the aquifer material.

Most Marlborough aquifers are a mix of grain sizes with gravel, sand or clay present. A screen slot size which retains 30% to 50% of the material is a commonly used rule of thumb. Furthermore it would be expected that a percentage of the finer grained clays or sands would be removed during development.

Homogeneous formations such as the sandy Rarangi Shallow Aquifer have very fine and uniform material, and the slot size needs to be small to retain most of the sand. One of the limitations of using a screen with small openings are relatively low pumping rates due to friction losses and the potential for turbidity problems. This is unavoidable unless a gravel pack or other artificial filter is fitted outside the screen. Under these circumstances there is also limited potential for development. While it is common overseas for the grain size distribution of the aquifer material to be measured using sieves before selecting a screen, in Marlborough they are generally not engineered to this degree.

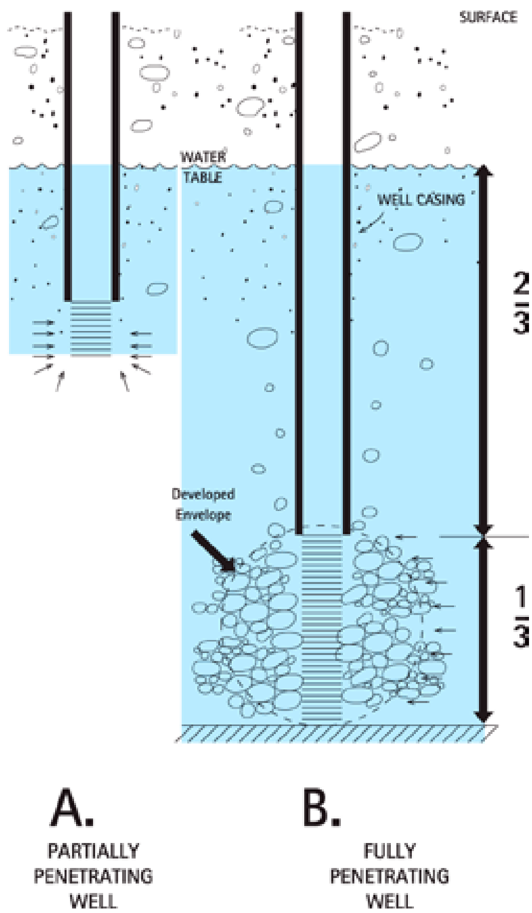

Figure 6.10: Aquifer versus well depth

Where the screen is located within the well is also important from a well performance point of view. As a rule of thumb a screen is placed opposite the lower third of the aquifer in an unconfined system (Fig. 6.10). This is a compromise between screening as much of the aquifer as possible to avoid inefficiencies due to flow convergence, while maximising the available drawdown.

It is useful to explain the hydraulic principles behind this. Well yield in an unconfined aquifer varies depending on how much water it contains. This is reflected in higher well yields and aquifer transmissivity during winter or spring when it is full.

As water levels fall during drier seasons, the well produces proportionately less water for each metre the aquifer is drawn down, and it has been shown that it is uneconomic to pump a well when drawdown exceeds 70% as it will only produce a negligible increase in flow. This doesn't apply to a confined aquifer which doesn't become dewatered, and doubling the drawdown will double well yield.

It is not always economic or even necessary to screen the entire aquifer thickness, especially in high yielding aquifers areas such as Rapaura where a short length of screen often provides enough water for most purposes. In many cases a single well is so high yielding in this area it can provide sufficient water to irrigate 100 hectares or more of grape plants. Generally the longer the screen, the lower yielding the aquifer is.

Conversely in lower yielding aquifers such as in the Southern Valleys, an eight hectare vineyard may require several wells to provide enough water for the irrigation of the same crop type. Not only are multiple wells often required, but the screen length is generally far longer to collect the contributions from many small water bearing layers rather than the single, discrete layer that is characteristic of the Wairau Aquifer.

This is illustrated by well 3287 located opposite the Fairhall cemetery which is screened over a depth from 43 to 250 metres, but can produce only a fraction of the water of a typical 15 metre deep well at Rapaura with a screen length of one to three metres. These deep wells are relatively expensive to construct, have a limited life and often provide turbid water that can shorten the life of submersible type pumps.

A disadvantage of having a partially penetrating well is that hydraulic properties derived from testing such wells will show a lower transmissivity than is in fact the case. While this isn't relevant to the well owner, it does affect the interpretation of aquifer hydraulic information by the MDC. The MDC is responsible for predicting the cumulative effects of hundreds of wells relative to the overall throughflow of an aquifer and the more information it has available the better the predictions will be.

As a standard practice pumps are normally placed just above the screen to maximise the amount of drawdown. In some cases such as for thin aquifers this isn't practical and the pump is set at the base of the screen, but this arrangement isn't ideal from an efficiency point of view.

The last factor to take into account when selecting a screen is groundwater quality. Many of the groundwaters underlying the western and northern Wairau Plain are corrosive due to their naturally low pH, and high levels of dissolved oxygen. Conversely when the pH of groundwater is high and reducing conditions exist within local aquifers, the screen can become encrusted with iron and manganese. This is a common phenomena in the coastal Cloudy Bay area. Iron bacteria are a less common problem, but MDC are aware of several wells in recent times which are known to have been smothered at Rarangi, and reputedly at Riverlands. Iron bacteria are not harmful to human health. To account for corrosive water, the open area of susceptible screens is sometimes decreased. For wells tapping incrusting groundwaters a larger screen area is often chosen.

Figure 6.11: Long screen at Parkes well Linkwater

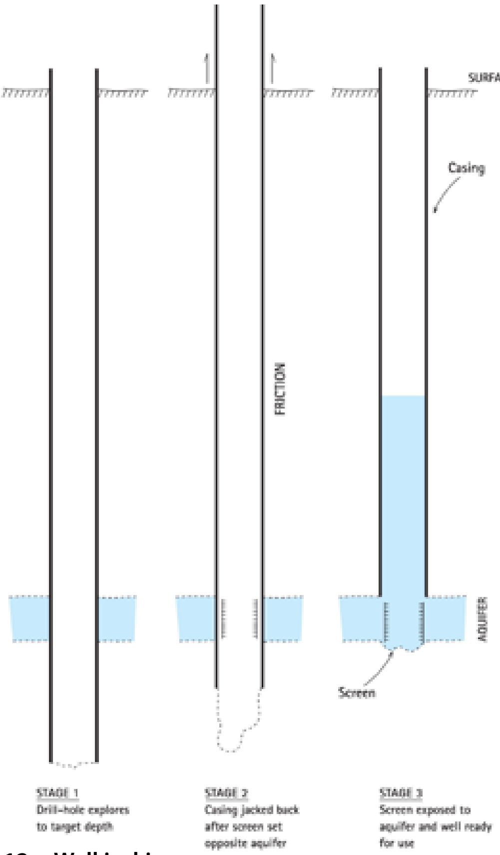

Figure 6.12: Well jacking process

Once these local geological and pumping factors are considered and a screen is selected, the next step is to insert it into the well. The screen is fitted by lowering it gently to the bottom of the well (Fig. 6.11). Once the screen is set at the base of the well the next step is to jack back the casing to expose it to the aquifer (Fig. 6.12).

Development

Once the screen is installed, the next step is to minimise the work needed to induce groundwater out of the aquifer when the well is pumped. This process is known as well development.

A larger hydraulic gradient is required to move water from the aquifer to the well if the surrounding geology is finer and less permeable. This is because a particle of water has a more difficult route to take, which in turn creates more friction and requires more energy to overcome it. If the amount of fine material such as sands or silts within the gravels is reduced outside the screen, the hydraulic gradient is reduced and the well will produce more water for the same drawdown in well level.

Well development involves maximising the effective radius of the well by reducing the proportion of fine grained material. The biggest benefit is gained from development close to the screen because this is where a large percentage of the well drawdown occurs as groundwater flow approaching the screen converges and velocities increase.

As a rule of thumb these friction or head losses should not exceed 30% of the total drawdown in a well, otherwise it is unacceptably inefficient. Another way of looking at it is to say that if a well level is lowered by ten metres, no more than three metres of this should be attributed to friction losses.

The amount of development required depends on the natural composition of the material opposite the screen and whether any damage has been done to the formation during drilling. Development will vary from well to well. For example, a common problem with the mud rotary method of construction is when the well wall becomes clogged with a clay skin which acts like a seal, isolating the well from the aquifer. This requires considerably more development than other wells.

Cable tool rigs generate lots of vibration which can also lead to compaction and reduce the natural porosity. Both effects reduce well performance. The material most commonly removed from wells are sands, however the amount of sand is far less than for Canterbury wells where development may take many days to complete. This was evident by the copious amounts that rose to the surface during the 2010/11 Canterbury earthquakes.

The most common development methods involve jetting with compressed air and mechanical surging. The approach used will depend on local circumstances, and often a combination of methods is used to get the best results. Mechanical surging is similar to using a plumbers plunger to unblock a drain. The reciprocating action sucks groundwater into the well on the upstroke, and forces water out into the aquifer around the well during the downstroke.

This process sluices fine grained clays and sand from the surrounding formation into the well where it is bought the surface and disposed of (Fig. 6.13). Care is needed to not too strenuously develop a well early in the process as this can cause the screen to collapse if there is too much resistance to water flow.

Figure 6.13: Very fine grained sand removed from a Rarangi well in the late 1980s.

Another well development method is the so called airlift method of development which is cheap and effective in alluvial materials. It involves piping and releasing pulses of compressed air at the bottom of a well filled with water. The weight of the overlying water forces the air out into the geological formation, and a slurry spectacularly erupts out of the well at the surface.

A technique commonly applied in the Southern Valleys Aquifers during the 1980s was the use of detergents to mobilise clay or silts from the claybound gravel formations that predominate in this area. The clay naturally blocks the pores, reducing the rate at which groundwater moves through the rocks and lowers well yield. The detergent was used in combination with jets of water to dissolve and sluice out the clay material, thus enhancing well productivity.

Another approach which is not commonly used in Marlborough except for piezometers, is to insert artificially graded material immediately surrounding the well to improve permeability. They are called gravel packs.

Figure 6.14: Mr Bob Thoms grouting a well at Riverlands in the late 1980s.

Well life and maintenance

Most wells are subject to corrosion or deterioration. Some wells are still going strong after 100 years whereas others in more corrosive natural conditions have deteriorated over a life span of 12 years. Each year several very old wells are reported as leaking around the outside of the casing and a professional well driller is needed to seal them up as they are no longer usable.

This process which is called grouting normally involves pumping cement into the well from the base upwards to seal it from the inside (Fig. 6.14).

References

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