WATER WELL CONSTRUCTION

1. Siting of new water wells in relation to contamination sources

Locations of new wells should take account of the proximity of potential sources of contamination.

Many wells are polluted because they are located too close to a source of pollution, or are not properly constructed. The most common sources of pollution are septic tanks, silage pits, oil tanks, manure, and dirty water draining from farmyards.

As a general rule, a well should be located upslope from, and as far away as possible from, potential sources of pollution. The safe distance depends on the nature of the subsoil, the depth to the water table, the slope of the land, the rate of pumping, and the size of the pollution source. Suggested safe distances are shown in the table below.

Leaking tanks of diesel and central heating fuel have contaminated a number of wells in Ireland. Other wells have been contaminated by nitrate from fertiliser bags stored beside the well. Oil, fertilisers, pesticides or other chemicals should never be stored or left in the pump-house or anywhere near the well.

Table 1. Recommended distance of a private well from likely pollution sources¹

Type of subsoil	Depth of subsoil above bedrock*	groundwa	nimum distand nter flow direct estim nt from well	tion is kno nated) where own or can be dient from well	(meti ground	um distance res) where dwater flow n is unknown
	(metres)	farmyard	septic tank percolation area/polishing filter/ oil tank	farmyard	septic tank percolation area/polishing filter/ oil tank	farmyard	septic tank percolation area/polishing filter/ oil tank
Clay or Silt/Clay	1 - 3	100	40			100	40
(low permeability,	>3	75	30	50	15	75	30
poor drainage)	> 8	60				60	
Sandy clay, silt	1 - 2	120	45			120	45
(moderate	2 - 8	90	30	50	15	90	30
permeability)	> 8	90	30			90	30
Sand and gravel	1 - 2	150	60			150	60
(high permeability,	2 - 8	150	40	50	15	150	40
free draining)	> 8	120	30			120	30

^{*}Note: Depths are from the base of the farmyard structure or from the level of the percolation pipe, and not from ground level

Departures from the above guidelines should be made only on the advice of a competent person, following a careful examination of the site.

^{*} Examples of likely pollution sources include: farmyard, silage pit, septic tank system, public sewerage pipe, railway track, oil tank.

2. Water Well Construction

2.1 Introduction

Most water wells in Ireland are drilled using an air-hammer ('down-the-hole' or DTH) rotary rig. A few wells are sometimes drilled using a cable-tool (percussion) rig.

- Air-hammer Rotary Drilling: This uses compressed air both to drive the drill, with a rotating hammer
 action, and to carry the cuttings to the surface. Temporary steel casing can be driven, i.e. hammered
 through the soft soils overlying the bedrock, but hammering casing into place may mean that the casing
 cannot easily be withdrawn after it has served the purpose of supporting the unstable hole sides whilst
 drilling in the bedrock takes place. Air hammer drilling is very fast in hard rocks with moderate yields but
 sometimes finds difficulties with high flow rates combined with loose materials.
- Cable Tool Drilling: The cable tool rig is operated by repeatedly raising and dropping a heavy tool or bit at the end of a cable. Every metre or two, another tool (a bailer) is used to remove the cuttings, providing good samples of the rock encountered. Casing is usually driven as the well is drilled. Though relatively slow, one of the method's advantages is that the bore is kept relatively clean and any fissures containing water are unlikely to be blocked by the action of the drill.

2.2 Basic Requirements

- The drilling equipment must be in good condition and appropriate for the terrain, expected site ground conditions, and soils and rock anticipated. The equipment must include ancillary equipment suitable for cement grout mixing and injection.
- The drilling equipment must be clean and free from contaminants which would otherwise be introduced into the aquifer. All equipment should be cleaned by means of high-pressure hoses and/or steam, as appropriate. Where equipment has been used in circumstances where it may have been contaminated, e.g. by lying on ground recently occupied by livestock, it should be disinfected using appropriate disinfectants approved by the Department of Agriculture & Food.
- Drilling fluids must be free of harmful chemicals. As far as practicable, drilling fluids should be limited to clean water, air, and approved foaming agents.
- Water used for mixing drilling fluid must be clean (of potable quality).
- Returned drilling fluid which is not re-circulated must be disposed of in a satisfactory manner, i.e. using
 (a) a sediment trap, and (b) a soakpit.
- A water well should be (a) straight, and (b) vertical: permanent well casing should not deviate more than 2° from the vertical. Straightness should be demonstrated by lowering down the hole a 6-metre (20-feet) length of casing with a diameter about 10 mm less than the inside diameter of the permanent well casing.
- Fuel should not be stored on the site nor within 60 metres of the well. If repairs or re-fuelling on site are
 necessary, every care must be taken to ensure that no leakages or spillages occur. A drip tray should be
 used, and absorbent material should be available for mopping up any spillages quickly. If a large leakage
 of fuel or hydraulic fluid from the drilling equipment occurs, the contaminated ground must be rapidly
 excavated and removed off site for appropriate treatment and disposal.

2.3 Sanitary protection for wells

A properly designed and constructed well should prevent contaminants entering the well from the ground surface or from shallow soil or subsoil, and should prevent pollutants entering the aquifer from the well. This requires:

- The use of good quality materials for casing and well screen, of suitable size, carefully installed in the well to appropriate depths.
- Grouting of the well around the casing to prevent ingress of contaminated water from the ground surface or from shallow depths.

Functions of Casing

Well casing performs several functions:

- Supporting the walls of the well and preventing them caving into the well.
- Preventing surface water, or shallow groundwater (which is liable to pollution) from entering the well.
- Protecting the pump and the rising main from damage.

Casing Material

Water well casing may be constructed of steel or plastic (of various types). Permanent steel casing is not advised as it may corrode in certain groundwaters and also encourage the development of biofilm slimes.

The driller should certify that the casing is suitable for the specific borehole. Factors that affect casing selection include: cost, diameter, drilling method, water quality, strength requirements, and corrosion resistance. The joints between lengths of casing must be watertight.

- Steel casing used in water wells should conform to the standards of the American Society for Testing and Materials (ASTM), British Standards Institute (BSI) or American Petroleum Institute (API).
- Plastic casing may be of several types: Polyvinyl chloride (PVC), Acrylonitrile butadiene styrene (ABS), rubber-modified polystyrene (SR), High Density PolyEthylene (HDPE), polyolefin, polypropylene, and Glass-reinforced plastic (GRP or 'glass fibre').
- Plastic casing must have sufficient strength to withstand the pressure and setting temperature of the
 cement grout that will be placed in the annulus outside the casing. Well casing should be specifically
 designed for that purpose. Cheaper but weaker types of pipe, such as sewer pipe, should not be used.

Casing Depth

Casing should be installed to sufficient depth to fulfil the three functions listed above.

Where the aquifer is unstable, e.g. sands or gravels, the casing and well screen (see below) should normally be installed to the full depth of the well.

- In rock, casing should be installed and grouted to a minimum depth of 20 metres below ground, or to 10 metres into bedrock, whichever is the greater.
- Casing should also be installed to at least 2 metres below the depth at which the pump will be set. This will ensure that (a) the pump and rising main are protected from any collapse in the well, and (b) the pump is set a good distance above any muddy sediment in the bottom of the well.

Table 2. Water Supply Wells: Minimum Casing and Grout Depths

Depth to Bedrock (metres)	Minimum depth of Casing and Grout
< 10	20 metres
> 10	10 metres into bedrock
Bedrock not met - well constructed in a Sand/Gravel Aquifer	At least 6 metres, and as deep as possible up to 20 metres

Casing Diameter

Permanent water casing must be large enough to accommodate the pump with enough clearance to allow easy installation and easy access for maintenance work.

Well Screen

Well screen is a type of casing with openings (usually slots) which allow water to enter the well in a controlled manner. It is normally used in sand/gravel aquifers but rarely may be used in bedrock aquifers which are unstable. The slots may run vertically or horizontally, and the open area (i.e. the total area of the slots) should represent a few percent of the total area of the screen wall.

Where the aquifer is unstable, e.g. sands or gravels, casing and wellscreen (see below) should normally be installed to the full depth of the well.

Filter Pack

A hydrogeologist may advise that an artificial filter pack (gravel pack) is placed around a well screen drawing water from an aquifer comprising sand to fine gravel grain sizes. The pack is placed around the screen to help support the well walls and keep out fine sediment. Filter packs should be made of clean, well-rounded grains of uniform size, preferably siliceous rather than calcareous (especially if the water is slightly acidic). The filter pack should be at least 50 mm thick and should extend at least one metre above the screen to allow for settlement after development. There is seldom any need for a well screen and filter pack in a borehole drawing water from a bedrock aquifer. A filter pack and well screen set against flow from isolated narrow water-bearing fissures or fractures in bedrock merely impedes the flow of water into the borehole, reduces well efficiency and increases pumping costs.

Filter Pack Seal

Where a filter pack is used in a sand and gravel aquifer, a seal should be placed above it, consisting of 30% solids bentonite if using bentonite pellets. The seal should be placed by tremie pipe, to minimise the risk of pellets bridging in the borehole and ensure the correct placement of pellets. Pouring of pellets may be acceptable in shallow boreholes (less than 15 metres) where the annular space is large enough to prevent bridging and to allow measurement with a tape to ensure correct placement. The pellets should be tamped into place to prevent bridging.

The bentonite seal above the gravel pack should be at least 0.5 m thick. The hydration time for the bentonite pellets should be at least 8 hours or the manufacturer's recommended hydration time, whichever is greater. The seal depth should be measured and not estimated. Other forms of bentonite (e.g. granular bentonite and bentonite chips) are not recommended for the bentonite seal unless special conditions warrant their use. If the water table is below the pellet seal interval, water of at least potable quality should be used to hydrate the pellets.

2.4 Drilling a well into a bedrock aquifer

Figure 1 gives an overview of the recommended well design and pumping arrangements. The following are the main points:

- It is recommended that the water well casing is installed deep into the bedrock and a considerable depth below the natural (non-pumping) water table level. PVC casing is recommended because it does not corrode. Many groundwaters throughout Ireland are slightly or seriously acidic and will corrode steel casing and may give rise to unacceptable levels of dissolved iron in the water. Where the groundwater is known to be non-corrosive, steel casing can be used.
- It is recommended that the annulus or void around the casing is completely backfilled by injecting pure cement grout from the bottom. This will prevent surface contaminants or poor quality shallow groundwater entering the borehole via the annulus. Sealing the annulus around the casing can also have a negative impact no water can enter the borehole from either the permeable transition zone at the top of the bedrock or from fractures in the upper bedrock. Hence this design may reduce the yield (sustainable pumping rate) from the borehole. In past times the yield of a borehole was the main yardstick for judging its success. However, while the yield is still important, family and public health is even more important. The success of a borehole should be judged by 'quality rather than quantity'. A borehole producing abundant water which is unfit to drink is no longer acceptable either for families or by national water quality standards.
- It is recommended that the pump intake is deliberately positioned *inside* the casing, above the bottom of the casing and the grout-sealed annulus. This position ensures that the water level in the borehole and the surrounding rock never falls below the bottom of the casing. This has four main benefits:
 - The flow of water is up the hole and around the pump motor, which is therefore adequately cooled.
 - Groundwater is drawn from deep in the bedrock and not from the shallow, more easily contaminated, bedrock and transition zone. Although shallow groundwater may be drawn down in the rock around the casing it does not displace the water flowing into the hole from deeper in the rock. It may pool in the cone of drawdown around the outside of the casing when the pump is operating, but when the pump is turned off and water levels recover to their non-pumping state, the regional groundwater flow gradient is restored and contaminated water can flow down-gradient away from the borehole.

- Because the water level never falls below the casing, the producing section of the borehole is never exposed to the air. Exposure to air during pumping, followed by submergence when the pump is switched off, encourages the growth of biofilms on the inside of the borehole. Biofilms are sticky bacterial mats or slimes that flourish where groundwater contains small quantities of dissolved iron. These bacteria are not normally harmful to human health, but the slimes can clog small fractures or cracks that allow water to flow from the rock into the hole, reducing the yield. Biofilms periodically slough off into the water, particularly when a pump is turned on and there is sudden turbulence in the hole. Sometimes the biofilms are blood-red in colour, and the broken-up clumps of bacteria in the water are visually unattractive and stain laundry.
- The pump, rising main and cable are protected and can easily be installed or withdrawn from
 inside the casing. Problems can occur when a pump is placed at the bottom of an open hole in
 rock power cables can be snagged or abraded by sharp edges, and objects dropped or dislodged
 can trap a pump at the bottom of the hole.

Figure 1 is an overview of the recommended borehole design and pump position. Subsequent figures introduce the main steps in the drilling process necessary to construct the borehole:

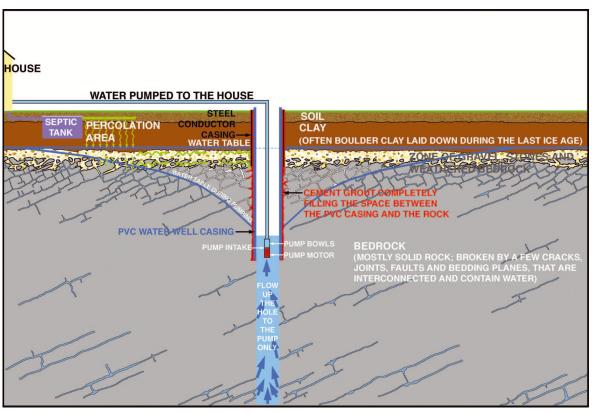


Figure 1. Section showing the recommended design of a domestic borehole where PVC casing (pump chamber casing) is sunk deep into the bedrock and fully cement grouted into place. The pump is positioned inside the casing so that the drawdown of the water table in the rock can never be deeper than the bottom of the casing and cement grout. With this design, pollutants from the surface do not seep into the borehole. The water principally comes from deep in the rock.

Step 1: Drilling into Bedrock

Figure 2 shows a hole drilled through the subsoil into the upper bedrock. It is recommended that the hole diameter is at least 250 mm (10 inches) and preferably 300 mm (12 inches) in order to fit a temporary 250 mm internal diameter (I.D.) steel conductor casing to support the loose subsoil and broken rock.

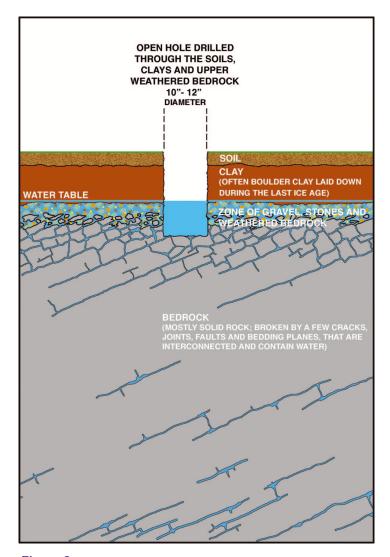


Figure 2.

Step 2: Installing Temporary (Conductor) Casing

Figure 3 shows the 250 mm ID steel conductor casing in position. This casing should not be driven hard into the bedrock because ideally this casing should be removed when drilling and grouting are completed. However, it may be necessary to drive the casing if the upper bedrock is very unstable and large flows of water and loose rock are entering the hole from the upper bedrock or transition zone.

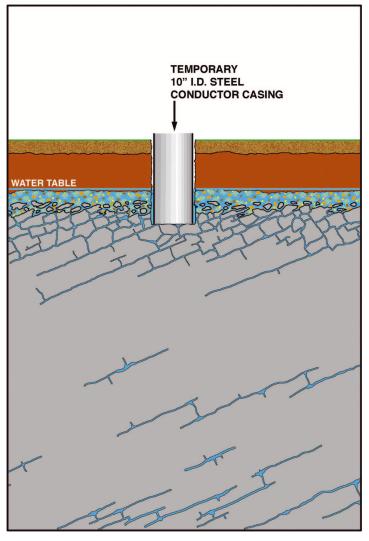


Figure 3.

Step 3: Deepening the Hole

Figure 4 shows the open hole deepened at 250 mm diameter through the bedrock to a depth of 20-40 metres below ground. The depth of this section determines the length of permanent casing and grout that, together, will seal off the water flow from the upper rock and transition zone. The risk is that the fractures or cracks in the lower bedrock below the casing will not yield enough water for the client's requirements. Intuitively it is difficult to deliberately seal off water that appears to be 'in-hand' in the hope that a sufficient flow will be encountered at greater depth. However, as explained above (Figure 1) the aim of a modern borehole is not just to obtain water - it is to obtain good quality water, which must normally be drawn from the deeper groundwater system. This requires a responsible and deliberate choice to exclude shallow groundwater, which common sense indicates, and experience has shown, is more vulnerable to contamination and may require long term and expensive treatment. Fortunately, experience shows that most boreholes in Ireland will yield enough for at least a domestic water supply from fractures below 30 m depth.

The depth of the 250 mm hole and the casing is partly determined by the drawdown anticipated to obtain the yield required. Experience has shown that a drawdown of up to 25 metres below the static water level is usually adequate to obtain the maximum sustainable yield from a rock containing several small water bearing fractures. A drawdown greater than 25 metres seldom leads to any significant increase in sustainable yield. If, on the other hand, the rock contains a large number of wide waterbearing fractures the yield will be high, and can be obtained with a small drawdown in the borehole.

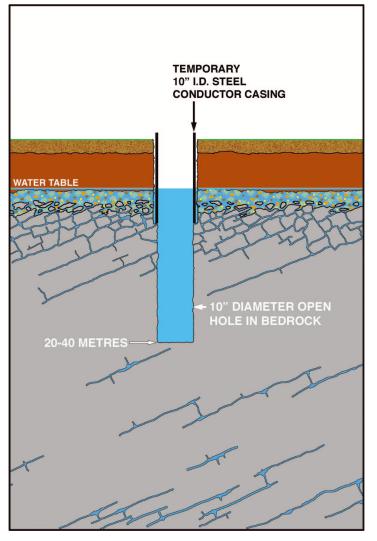


Figure 4.

Step 4: Installing Permanent Casing

Figure 5 shows the 150 mm ID water well casing in position in the 250 mm hole. Note that the casing has an end cap on the bottom in order to prevent the cement grout (to be injected in Step 5) flowing up inside the casing. Note that the (PVC) casing has been filled with water. Empty PVC casing with an end cap is very buoyant in a hole filled with water, and this buoyancy increases when cement grout is pumped into the annulus around the casing. In other words, when the cement is injected, empty casing would rise out of the hole and could not be forced back into the hole without shattering the plastic at the joints. To prevent this, the casing is filled with water as ballast.

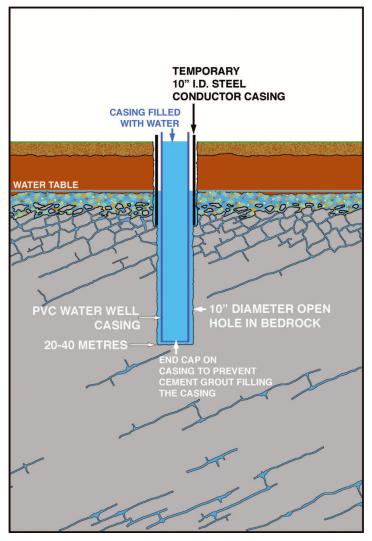


Figure 5.

Step 5: Injecting Grout

Figure 6 shows the injection of cement grout via a tremie pipe (a narrow diameter pipe that fits between the outside of the casing and the inside of the borehole). The aim is to fill the annulus from the bottom. Being heavier than water, the grout will displace the water in the annulus upwards.

It is important to continually watch the water level in the annulus during grouting. The level will rise as the cement is pumped in, but if it remains static for more than five minutes, or suddenly starts to fall, it usually means that the grout is flowing sideways into a cavity or large fissure in the upper rock. This requires a quick assessment of the situation, the probable position of the cavity, and a decision. There are several possible scenarios and mitigating measures. The decision on whether to continue grouting will depend on the driller's experience and the observations made during drilling. For example, if the grout appears to be flowing into a cavity close to the base of the casing, there is a danger that the cement will flow on down into a system of inter-connected fractures, fissures and cavities in the deeper rock and consequently reduce the final yield of the borehole. A remedy that has been successful under these rare circumstances is to stop grouting, pull out and clean the tremie pipes, and pour 100-200 litres of clean rock drill cuttings down the annulus. These will settle out on top of the cement grout and usually block the cavity. Grouting with the bottom of the tremie pipes above the cavity can usually recommence after about half an hour.

Another possibility is that the cement grout is flowing into the weathered rock at the top of the bedrock. This would usually mean that 20-30 metres of the annulus has been successfully sealed by grout, creating an effective seal between the upper shallow water in the transition zone and the lower aquifer. In this case it is possible to accept that an effective seal has been made and to stop grouting. Another alternative is to pour 100 litres of clean cuttings down the annulus, raise the tremie pipes above the cement loss zone in the weathered bedrock, and complete

the grouting to the surface.

As Figure 6 shows, the cement grout will usually flow beneath the steel conductor casing and fill the annulus around it.

Leaving quality steel casing in the ground is unnecessarily wasteful. If possible, the steel casing should be lifted from the hole in the final stages of grouting, before the cement sets. The level of grout will fall slightly when this happens, as the grout fills the void left by removing the casing. Grouting should stop when neat grout (and not just grey water) flows out of the top of the annulus around the casing.

Step 6: Waiting Time

A waiting time is necessary to allow the cement grout to cure ('go off') and reach sufficient strength to continue drilling.

Ideally a cement grout of specific gravity 1.7-1.8 should be allowed 48 hours to reach sufficient strength. However, this may not be practical unless there is a weekend between the end of grouting and the start of Step 7. The waiting time can be reduced by using 4 kg of Calcium Chloride flake additive mixed into the final 200 kg of cement. This accelerates the setting and hardening of the cement (although the final strength is reduced). With the tremie pipes just above the bottom of the annulus, these last batches of grout displace the earlier grout

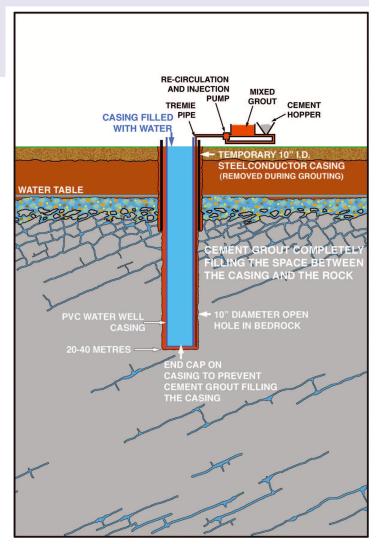


Figure 6.

upwards, so that the grout containing Calcium Chloride is placed at the bottom of the annulus, around the end of the casing.

The drilling, casing and grouting in Steps 1 to 5 can usually be completed in one day. Adding 2% Calcium Chloride should allow the cement to harden to sufficient strength in 12-14 hours. The waiting time can therefore occur overnight, and Step 7 can begin the next morning. Using Calcium Chloride in this way can thus reduce drilling costs and increase efficiency.

Step 7: Drilling the Producing Section

Figure 7 shows the completed drilling of the open (producing) section of the borehole. This hole will be slightly less than 150 mm in diameter, because the internal diameter of the casing, through which the drill tools must pass freely, is 150 mm. The depth of this section of the hole will depend upon the number, openness and water yield of fractures or cracks encountered in the deep bedrock, and the total length of drill rods carried with the drilling rig. It is recommended that drillers should bring 120 metres (400 feet) of drill rods to the site, because experience has shown that open water-yielding fractures can occur down to that depth. It is usually neither rewarding nor necessary to drill boreholes deeper than 120 metres, particularly for small domestic supplies.

The producing section of the borehole is the most important part of the hole in terms of yield. The aim is to ensure that all water-bearing cracks, fractures, fissures and cavities are opened up and cleaned fully. It is therefore advisable to drill this section paying particular care and attention to any slight change in penetration rate or colour of the drill cuttings and slurry discharged from the hole.

Sometimes a change of hammer rhythm or rotation speed can signify a change down the hole. For example;

a sudden change in the slurry colour to orange brown may indicate that a clayfilled fracture has been drilled: if so, it is advisable to stop drilling, lift the drill bit above the level of the fracture, and vigorously pump the hole using the air from the hammer. A steady stream of yellow-orange-brown water indicates that water from behind the clay in the fracture or cavity is beginning to wash the clay into the hole. Removing this clay will clean the cavity and allow water to move more easily into the borehole. This airlift pumping should be continued until the yield is steady and the intensity of the clay colouring in the water has noticeably diminished. The hammer bit is lifted slightly above the cavity in order to avoid stones or gravel from the cavity falling in above the hammer and jamming the drill tools into the hole.

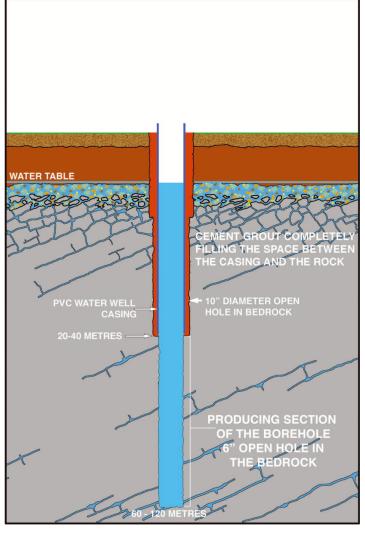


Figure 7.

Step 8: Airlift Pumping

The drilling of the producing section in the bedrock usually ends with a short phase of airlift pumping by the rig, with the drill tools set just above the bottom of the hole to obtain a nearly clean flow of water from the hole. A final short period of airlift pumping can be carried out with the end of the drill tools set inside the casing. If the water flow is completely clear of sediment after 30 minutes of airlift pumping, it is reasonable to assume that further airlift surging and development is not necessary.

The borehole construction work carried out in the above steps is likely to take one and a half to two days.

Alternative Grout Designs

Many people will have grave misgivings about constructing a pump chamber casing with cement grout sealed annulus, before having proved that the final borehole will provide a sufficient yield:

"Why go to the extra trouble and expense of constructing the well properly if we don't know whether we will strike enough water deeper down."

For drillers, there is the risk of not being paid if they don't find water.

A water supply which periodically contains manure or septic tank effluent is not worth having. If a customer wants quantity and poor quality, then they do

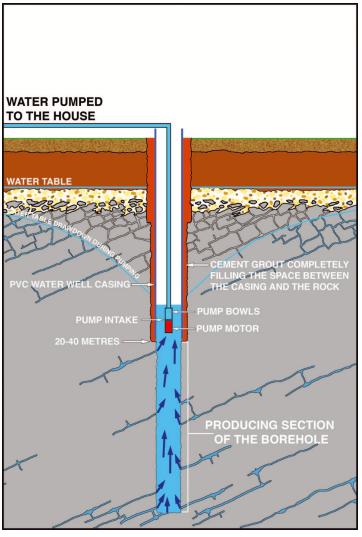


Figure 8. Final well construction

not need a modern driller. The main purpose of these guidelines is to provide modern designs that will maximise the chances of getting consistent high quality water.

However, as all drillers know, there are different ways of doing the same thing. The basic design described so far is the simplest and most straightforward, but a deep-set pump chamber casing *can* be installed and fully grouted *after* a yield has been proved - it is just a bit more difficult.

Below is an alternative, based on a simple exploration borehole, that overcomes the misgivings described above, and offers three ways of converting an exploration borehole into a production well.

Changing a successful exploration borehole into a proper borehole takes a little bit longer and requires greater care, but at least both the customer and the driller will know that the effort is worthwhile.

A basic exploration borehole:

- 1) Drill an 8 inch exploration hole to 2 metres into the bedrock. Use a 6 inch steel casing to seal off the overburden, and push the casing gently into the bedrock to hold back or seal off most of the overburden water. Don't hammer the casing too hard at any stage because the casing may need to be withdrawn if the deeper part of the hole has a sufficient yield.
- 2) Drill on at 6 inch through the bedrock, noting all the depths where an increase in water flow occurs. Note also whether there are cavities or unstable zones in the upper 30-40 metres.
- 3) If there *are* open fractures, cavities, or zones of weathered bedrock below, say, 30 metres, and these seem to yield a sufficient flow of water then both the customer and the driller can have confidence to re-drill and construct the hole as a proper borehole.

Alternative methods for converting the exploration borehole into a proper water supply borehole:

Method A

- Withdraw the 6 inch steel casing
- II. Drill at 12 inch diameter through the overburden and through the bedrock to 30 metres depth. (Note: 12 inch diameter is recommended because most of the bit face will be cutting into rock, whereas a 10 inch or 8 inch bit will wear on the outer buttons and may also go off centre.)
- III. Remove the 12 inch bit and plumb the hole. Cuttings from the 12 inch drilling may have backfilled the original 6inch hole, but it may be necessary to shovel fine cuttings back into the hole to completely fill the 6inch hole. The cuttings in the 6 inch hole will prevent the cement grout filling the 6 inch hole. Plumb the hole again to check that the 6 inch hole is filled.
- IV. Install the 6 inch PVC pump chamber casing as described in the standard method above, and grout in the standard method.
- V. Drill carefully through the end plug on the 6 inch casing, and find the original 6 inch exploration hole. Drill or clean out the 6 inch hole as the producing section of the borehole and establish the productive yield of the hole.

Method B

- I. Withdraw the 6 inch steel casing
- II. Drill at 12 inch diameter through the overburden and through the bedrock to 30 metres depth. (Note 12 inch diameter is recommended because most of the bit face will be cutting into rock, whereas a 10 inch or 8 inch bit will wear on the outer buttons and may also go off centre.)
- III. Change hammer and bits to 6 inch. Go back down the hole to clean out, if necessary, the previous 6 inch exploration hole to 3.5 metres below the bottom of the 12 inch hole.
- IV. Install 5 inch ID (<6 inch OD) strong PVC casing with an 8 inch diameter prefabricated steel ring secured by coach bolts or rivets at 3 metres above the bottom of the PVC. Install the casing so that the lower 3 metres enters the old 6 inch hole and the plate rests gently on the lip or bench at the change from 12 to 6 inch diameter. Take the weight just off the PVC and the steel ring and clamp the PVC at the top of the hole.
- V. Pour fine gravel or 1/4 inch stone chippings down the annulus to bring the level to 2-3 metres above the steel ring. Pour fine sand down the annulus to further bring the level up to 3-4 metres above the ring. Install the tremie pipes to about 5-6 metres above the ring in order to ensure that the injected grout does not scour away the sand and gravel above the ring. Grout the annulus in the standard manner.
- VI. Clean out the casing and the lower producing section of the borehole using either a 4-inch hammer and bit or the open-ended drill rods.

Method C

- I. This design is for a single house domestic well that will be pumped with a narrow diameter (<4") pump, and is based on the assumption that the 6 inch exploration borehole open section in the bedrock is 163 mm in diameter. It is a simple design in theory, but can easily go wrong because of the small diameters and the need to make and prove an effective seal at the bottom of the casing. The only advantage of the design is that it omits the need to re-drill the upper 30 metres of the borehole.
- II. Install 110-112 mm OD strong PVC casing with a 150-152 mm outer diameter prefabricated steel ring secured by coach bolts or rivets above the bottom of the PVC casing or at a casing joint 3 metres from the bottom.
- III. In addition clamp a centraliser both below and above the steel ring.
- V. In addition clamp $\frac{1}{2}$ " pipe to the PVC casing for future use in grouting. The bottom of the $\frac{1}{2}$ " pipe should be 3 metres above the steel plate.
- V. It requires great care and patience getting the casing with the steel ring and ½" pipe through the 6 inch steel casing and welds and into the 6 inch open hole below.
- VI. Install the casing to 30-33 metres below ground level and suspend the casing with clamps from the surface.
- VII. Back fill the annulus around the PVC as described above, bearing in mind that the casing may be slightly lying to one side, and/or the gravel may bridge on the upper centraliser or in the annulus above the lower end of the ½" pipe. If there is no effective seal below the end of the ½" pipe, then the grout will go to the bottom of the hole and seal the producing section of the borehole. In other words the borehole will be destroyed. The effectiveness of the seal can be checked by removing a small quantity of water from inside the casing to create a drawdown of about a metre and observing whether the level in the annulus immediately goes to the same level. If it does then there is no effective seal.
- VIII. Other alternatives to make the seal would be the use of proprietary 'cement baskets', robust inflatable packers, or the use of ½" and ¾" high density plastic balls above the steel ring.
- IX. Inject cement grout down the narrow $\frac{1}{2}$ " 'tremie' pipe clamped to the side of the casing as in the standard method. A slightly lower viscosity grout may be necessary to reduce the pressure in the $\frac{1}{2}$ " pipe.

2.5 Drilling a well into a sand/gravel aquifer

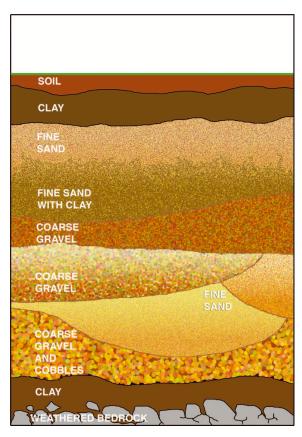


Figure 9. Illustrates a typical sequence of subsoil – clay, sand and gravel – above bedrock in Ireland.

During the drilling, it is important to obtain good samples of the geological deposits as they are encountered, and to record the depths at which these are met. The samples of the coarser layers then need to be analysed by a laboratory to determine the relative proportions of sand and gravel in those layers. **Figures 9 to 14** illustrate a typical well design and construction in a sand/gravel aquifer. The following are the main points:

• While the well is being drilled, the borehole walls need to be supported to prevent them collapsing into the hole. This is normally achieved by installing casing. Down-the-hole hammer rigs, as used for most well drilling in Ireland, can best do this using a double-tube system, whereby the casing is advanced at the same rate as the drill bit.

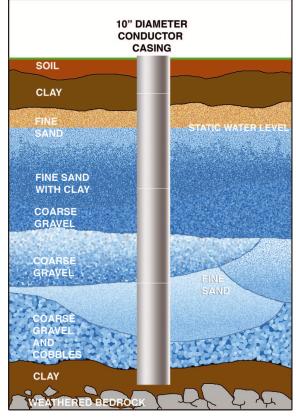


Figure 10. Drilling borehole and installing outer conductor casing

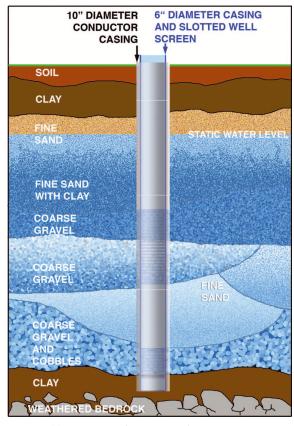


Figure 11. Installing final casing/well screen assembly

- The final well construction i.e. where to install well screen and where to install blank casing depends on knowing the correct depths of the best water-bearing layers in the borehole.
- The size of the openings (slots) in the well screen depends on the laboratory analysis the coarser the sand/gravel, the wider the slots can be.
- The final casing/well screen assembly is then installed in the borehole (Figure 11), and the outer conductor casing is partially withdrawn (Figure 12) to expose the producing section of the well to the aquifer. The sand/gravel around the well collapses to fill the annulus.

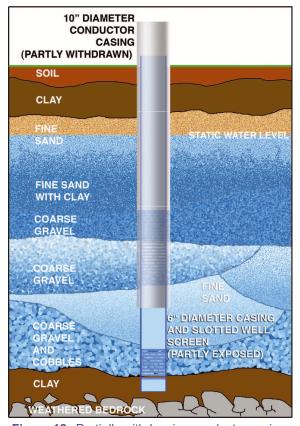


Figure 12. Partially withdrawing conductor casing

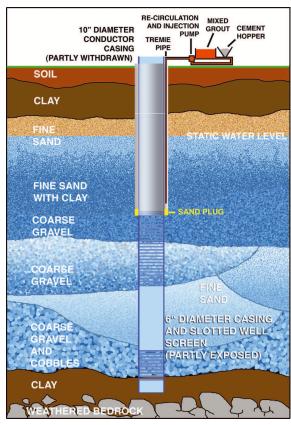


Figure 13. Placing grout and withdrawing conductor casing

- A sand bridge is installed (to prevent grout penetrating further down and blocking the well) and then the remaining annulus between the permanent and temporary casing assemblies is filled with grout through a Tremie pipe (Figure 13).
- When the grout is in place, but before it sets, the temporary casing is finally withdrawn, the grout being topped up as necessary.

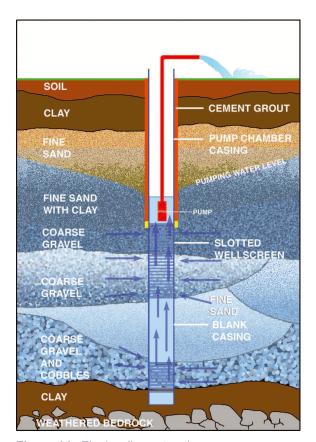


Figure 14. Final well construction

2.6 Well head completion (Figure 15)

Above Ground Riser Pipe and Outer Protective Casing

Borehole headworks should be completed above ground level where possible. The diameter of the borehole should be large enough to allow for the installation of the rising main and power cable, and a 25 mm (one inch) diameter dip tube (to allow the water level to be measured by a 'dipper' (electric tape)).

The permanent well casing, after installation and grouting, should extend at least 500 mm above ground level. There should be sufficient clearance around the inner well casings so that a short outer well head protective casing will not come into contact with the inner casing after installation.

Concrete Surface Pad

A concrete surface pad should be installed around the well casing to a distance of 500 m and a depth of 500 mm. Concrete should be poured into the formed pad and keyed into the borehole annulus (on top of the grout) in one operation to make a contiguous unit. The finished pad should be sloped (1:10) so that surface water will drain off the pad and away from the protective casing. The concrete pad should be extended with a thickness of at least 150 mm to at least 2 m from the well.

Alternatively 25 mm drainage pipes with vermin screens leading to a surface outlet or appropriate soakaway should be installed in the wellhead housing to prevent water from lodging around the borehole.

Wells installed in high traffic areas may need to be finished at ground level with watertight flush mounted manhole covers extending from the ground surface down into the concrete plug around the well casing. The concrete plug should have the same dimensions as above and should be established below ground level with a gradient away from the casing. The casing should protrude above the concrete and be fitted with a lockable cap. Flush mounted covers should have seals that make the unit watertight when closed and secured. The flush mounted covers should be installed as far above grade as practical to minimise standing water and promote runoff.

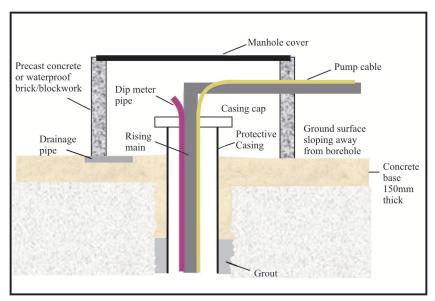


Figure 15. Well head completion

Pump House

It is best not to have the pump house directly over the well: an off-set distance of 2m is sufficient, to allow ease of access for maintenance. Ideally the pump house should be constructed of concrete block with a concrete floor (at least 150 mm), fitted with a floor drain. It should be at least 2 m x 2 m in area and 2 m high. The roof should be insulated, the room ventilated and it should contain a heat lamp to prevent pipes freezing in cold weather.

A vandal proof fence with a lockable gate should surround the wellhead and pump house, ideally to about 5 m from the well and pump house. The gate in the fence should be large enough to allow access for heavy lifting gear. The well head should be adjacent to the gate.

The wellhead (top of casing) should be covered with a manhole (Figure 15) fitted with either a metal or a concrete cover. The manhole floor should consist of at least 100 mm of concrete, with a watertight seal to seal the joint of casing and concrete. The manhole floor should slope away from the casing and have a drainage outlet. The top of the casing should be at least 150mm above the floor of the manhole.

The top of the casing should be protected with a cap. There should be a small hole (~25mm) in the cap with a plug to allow access for dipping the well. The rising pipe joint with the casing cap should be protected with a seal (rubber, etc.). The water pipe(s) should be supported by a timber or metal clamp on the top of the casing.

The pipes to the pump house should be laid in a 100 mm plastic pipe (Figure 16). The top of the 100 mm pipe should be at least 150 mm below ground (frost level).

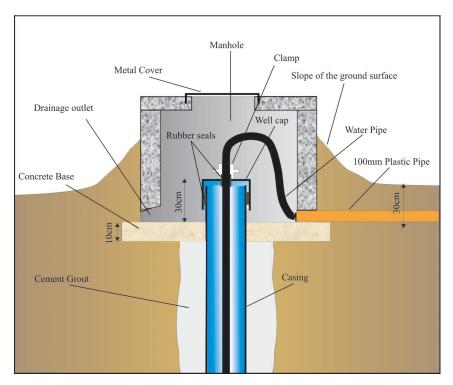


Figure 16. Well head completion

Additional Reading:

Geological Survey of Ireland Information Circular 79/1 (Water Wells)

Geological Survey of Ireland Information Circular 85/1 (Groundwater Quality and Pollution)

Finding Water, A Guide to the Construction and Maintenance of Private Water Supplies (1983), by Rick Brassington, published by Pelham Books Ltd, London. ISBN 0-7207-14451.

2.7 Developing the Water Well

When the well has been drilled to its full depth and the final casing/screen assembly has been installed, the well should be cleaned and 'developed'.

'Well Development' encompasses a range of techniques designed to remove drilling fluids and loose sediment from the well and from that part of the aquifer (within fissures or pores) closest to the well, to increase the yield

and efficiency of the well. It includes the use of surging, backwashing, jetting and chemical dispersants (e.g. Calgon) to remove fine sediment, and the use of acid (in limestones) or explosives to enlarge fissures.

Surging, jetting, and the use of acid or explosives require specialist expertise and experience.

Normally, adequate development of wells should be achievable through the judicious use of compressed air and an airlift assembly consisting of an air line and eductor pipe.

2.8 Disinfecting the Water Well

Every water well should be cleaned and disinfected before being brought into use, to ensure that any harmful bacteria or viruses introduced into the well during construction are removed, and that subsequent sampling of the water quality in the well is truly representative of the aquifer conditions.

First the borehole should be pumped until the water is visibly clean.

The recommended procedure for disinfection is as follows:

Materials:

- (1) 2 lb (900 gm) of chloride of lime (containing about 35% available chlorine) OR
- (2) 1 lb (450 gm) of "High test Hypochlorite" (50 70% available chlorine) OR
- (3) 2 gallons (9 litres) of 3% strength, or 1 gallon (4.5 litres) of 5% strength Laundry Bleach (Sodium Hypochlorite, 3-5% available chlorine).

For (1) or (2) dissolve in 5 gallons (23 litres) of water. For (3) make up the solution to 5 gallons (23 litres). Mix thoroughly.

Pour half the solution into the well, start the pump and open all taps until water from each tap has a distinct smell of chlorine. Then stop the pump and add the rest of the solution. Allow to stand for 12-24 hours, then pump to waste until the smell of chlorine disappears.

3. Testing the Sustainable Yield of the Well

Objectives

A pumping test on a domestic or farm well should:

- confirm that the well can satisfy the user's needs as to the quantity and quality of the water supply, allowing a safety margin for times of the year when the water table is at its lowest level, OR
- determine the maximum sustainable yield of the well, AND
- provide baseline data on the well performance, against which future tests can be compared.

The test should be carried out after cleaning, development and disinfection. The recommended procedure for a private domestic well is as follows:

- A short preliminary test usually by air lift to indicate a likely sustainable pumping rate.
- A longer test at least 4 hours at a constant pumping rate.

Measuring the Pumping Rate

The pumping rate should be measured by one or more of the following:

- Measuring the time taken to fill a container of known volume e.g. a 45 gallon (200 litre) drum (this method makes it difficult to monitor fluctuations in the pumping rate).
- A water meter which is calibrated for the range of flow expected. The meter *must* be positioned so that
 it is always full of water, either behind a partially closed gate valve or at the bottom of a U-bend. If
 possible, check the metered rate by another method. (Note: Water meters are unsuitable where water
 contains significant amounts of sediment, because they will clog up.)

• sharp-edged V-notch weir or weir-tank, which must be properly set up (levelled). These are useful where the pump discharge comes in pulses or surges, e.g. with reciprocating pumps or air lift systems.

The pumping rate should be maintained as constant as possible throughout the test. Where possible the pumping rate should be regulated by a gate valve on the discharge pipe. A pressure gauge located behind this valve is very helpful in maintaining a constant discharge rate.

Measuring the Water Level

During the test the water level in the well should be measured from a fixed reference point such as the top of the borehole casing or a particular point on the rising main. Mark the reference point with tape or paint, and note its elevation in relation to ground level.

The water level in the well should be measured by a 'dipper' (electric tape). Take care that the tape does not snag on cables or pipes. To avoid this, especially where the rising main has flanges, a 25mm (1") plastic pipe (dip tube) should be inserted alongside the rising main, to allow access for the dipper. This pipe should be perforated at its lower end, to ensure good access for water.

The **drawdown** in a well is the difference between the initial static water level (SWL) before pumping started, and the pumping water level (PWL) during pumping. Water levels should be measured at intervals of 15 or 30 minutes throughout the constant discharge test.

Discharge of Water from the Pumping Test

It is ESSENTIAL that the pumped water is carried a good distance away from the well to avoid any chance of it returning quickly into the aquifer. In general about 20 metres is adequate if the water is discharged to a watercourse. Where the risk of recycling is greater (e.g. a shallow gravel aquifer or a highly-fissured limestone with thin subsoil) a longer discharge pipe should be used. Polythene sheeting can be used to line a shallow channel to carry the water away safely. Discharged water should never be allowed to pond up.

Water Quality Sampling

A sample for laboratory testing can be taken near the end of the test (see Section 4).

Production pump setting depth and operation

The pump intake should be set above the base of the permanent casing. Similarly, for boreholes fitted with a slotted well screen in sand and gravel aquifers, the pump intake should be in the un-slotted casing above the well screen section. The over-riding objective is to obtain high quality water.

Two types of pump are commonly used in Ireland to pump boreholes:

- **Jet pumps** are usually used for low yielding boreholes for single domestic water supplies. The pump and motor for a jet pump are mounted at the surface next to the borehole.
- Submersible pumps can provide higher yields and can be used for single domestic supplies or farms
 and group schemes. The pump and motor for a submersible pump are housed in a single cylindrical unit
 installed below the water level in the borehole.

Frequent stopping and starting of a pump stresses the pump and motor and reduces the life of the pump. A good quality pump that is either run continuously or for long periods of several hours at a time, will last for 20-25 years. Most small domestic, farm or group schemes do not pump from the borehole into a large high level reservoir which would balance out the peaks and troughs in the demand for water and provide a gravity-fed supply to the users. Instead, small supplies use a small pressure tank at the well head as a reservoir. These small tanks provide very little storage and when a tap is turned on in the house the pressure falls in the tank and a pressure switch turns on the borehole pump. In some instances the pump turns on every time someone in the house fills a kettle for a cup of tea!

Boreholes should also be pumped gently and for long periods. Frequent stopping and starting of a pump and, in particular, pumping at high rates above the long term sustainable pumping rate, causes rapid oscillations in the water level in the borehole and turbulent flow into the hole from the aquifer. This stress on the borehole, and turbulence in the aquifer supplying the borehole, can lead to suspended sediment in the water.

It is therefore recommended for small water supplies that larger pressure tanks at the well head and larger attic tanks are installed to provide storage to meet varying levels of water demand in the house or farm. It is also strongly recommended that the pump capacity should be limited to the long term sustainable pumping rate determined during the pumping test. In order to obtain the volume of water required it is better to pump gently for longer, rather than rapidly for a series of short periods.

4. Testing Water Quality - Chemical & Microbiological Sampling/Analysis

When a water well is completed, its water quality should be tested. This section makes recommendations for chemical and microbiological sampling, including sampling frequency, laboratory selection, field sampling procedures, and reporting.

Sampling Frequency

Water underground is continually moving. It is replenished by rainfall, particularly from October to April. Groundwater levels and flow rates vary with the seasons. Bacteria levels in the upper part of an aquifer can fluctuate between harmless and harmful values over the course of a year. The water chemistry and bacteria levels can also change with depth below ground. In general, deep groundwater is older, more sterile and has a chemical composition that reflects the chemistry of the aquifer. On the other hand, shallow groundwater can be as recent as yesterday's rainfall. A water well should be designed to draw from deeper groundwater rather than shallower water that may have been recently contaminated.

It is recommended that domestic drinking water supplies should be sampled at 1east once a year. It is suggested that sampling takes place in late September or early October, shortly after the start of the autumn rains. It is also suggested that a sample should be taken immediately if there is any sudden change in taste, colour or turbidity of the water.

Selection of Laboratory and Analytes

A suitable laboratory, e.g. Health Board or private laboratory, should be selected before sampling. The laboratory should recommend how samples should be taken, provide sample bottles and instructions on sample delivery.

The appropriate suite of analytes (i.e. the substances and parameters measured) depends on a number of factors, primarily the intended water use and the proximity of potential pollution sources. It is recommended that water intended for human consumption includes the following analyses as a minimum:

Bacteriological:	E. coli	Total coliforms	Total plate count		
Chemical:	Nitrate	Nitrite	Ammonia	Chloride	рН
	Colour	Conductivity	Total Hardness	Bicarbonate	Sulphate
	Sodium	Potassium	Calcium	Magnesium	Fluoride
	Iron	Manganese	Copper	Lead	Zinc

Bicarbonate, nitrate, sulphate, chloride, calcium, sodium, potassium, and magnesium are known as the 'major ions' since they normally comprise the great majority of the minerals in the water.

If industrial or commercial activities using potentially toxic materials occur close to the well, it may be appropriate to analyse for additional parameters relating to these materials, e.g. petroleum-related compounds if the well lies close to a petrol station or an oil storage tank, and pesticides where the site lies close to a railway line. Private well owners can obtain advice from their local Health Board, Local Authority, or the EPA.

Certain analytes require particular containers, sampling conditions, preservation, and/or submission to the laboratory within a certain time period. Guidance on these requirements can be sought from the laboratory.

The above list of analytes does not encompass all possible contaminants nor ensure that the water meets drinking water standards. A comprehensive list is contained in SI No. 439 of 2000.

Field Sampling Procedures

General observations

Note any features near the well which might influence water quality, such as swallow holes, rivers, lakes, fuel storage tanks, effluent pipes, farmyards, roads, septic tank percolation areas and soakaways. For each feature, note the distance from the well and whether it is up-slope, down-slope or across-slope from the well. Concentrate on the area extending 60m (~200ft) up-slope of the well and approximately 15m (~50ft) down-slope of the well. These observations will assist interpretation of laboratory results by a hydrogeologist or environmental health officer — especially where these results suggest contamination. Don't ask the laboratory staff to provide an interpretation.

Pre-sampling measurements

- Measure the height above ground of all casings exposed at the surface, and of any protective structures
 which could prevent surface water entry to the top of the well (e.g. the raised concrete floor of a pump
 house).
- Measure the diameter of the inner casing.
- Measure the depth to water inside the inner casing. Measurements are best made using an electric 'dipper', and read from a marked point on the rim of the inner casing.
- Measure the total depth of the borehole inside the inner well casing. If this is not possible (e.g. if a pump has been installed), the drilled depth may be obtainable from the driller or from the pump installer. Ask the pump installer for his record or recollection of the depth of the pump intake.
- All measurements taken should be recorded on the form to accompany the sample. Keep a copy.

Obtaining a representative sample

The aim is to obtain a sample which represents the chemistry and bacteria levels in the groundwater system feeding the borehole.

Unless a sample is taken near the end of a pumping test, purging is required in order to remove stagnant water from the well. Purging should be carried out with (and through) the pumping system and the rising main:

- Where a well is plumbed into a water system, at least one tap in the system draws directly from the pump (in a private house, normally in the kitchen). Use this tap to purge water through the system, and sample from it.
- Where a well is plumbed into the water system with no sampling tap and no tap connected directly to the pump (i.e. all taps draw from a storage tank), sample from the main supply tap. Purge water through this tap, and as many other discharge points as possible, to ensure vigorous flushing of the storage tank.

Avoid leaking taps which allow water to flow over the outside of the tap.

In new wells, or wells which have not been in recent daily use, purging should involve flushing through the sampling system three times the volume of water in the inner casing, calculated as follows:

[Purge volume in m³] = 3 ´ 3.14 ´ [(radius of inner casing in m)²] ´ [(depth of hole in m) – (depth to water in m)]

Example: if well diameter is 6" (150mm); depth is 45 m; depth to water is 3 m:

Purged volume = $3^3.14^3(0.075)^2(45-3) = 2.25 \text{ m}^3$.

If the pump is not yet plumbed in, and if it is able to pump 10 gallons/minute (~2.8 m³/hour), purging and sampling could take place by discharge through the rising main to ground. In this example, purging would take 45 minutes. Clearly, significant amounts of water can be involved, so considerable time is saved if sampling takes place during yield testing. If a well has been in regular daily use for some time, the purging of 3 well volumes is unnecessary and it is sufficient to purge through the selected sampling tap (fully open) for at least 10 minutes.

Take note of any changes in water colour or odour during purging.

Sampling

Sample as soon as possible after purging. Samples are best taken in bottles supplied by the laboratory, using procedures specified by the laboratory. Bacteriological sampling requires special care.

Sample bottles should be clearly labelled in accordance with the laboratory's requirements.

Once taken, the sample may require particular preservation. Bacteriological samples, for example, often require storage in a cool box or fridge. Again, appropriate procedures are best obtained from the laboratory.

Sample transport & delivery to the laboratory

These requirements are determined by the laboratory. Bacteriological analyses require delivery within a particular time-frame. Some Health Boards run a sample delivery service from certain population centres.

Reporting

The sampling results represent the chemistry and bacteria levels in the sample bottle at the time of analysis. They do not always represent the characteristics of the water in the ground, though usually they are a fair approximation. Results from one sample should be viewed as a 'snapshot' of the water's characteristics at a moment in time. Results from several samples provide an important record of the variation (or lack of it) over a period of time.

Sampling results provide important information on the property. They will prove vital in the event of disputes over changes in water quality as a result of new developments on nearby properties, or as a result of leaks and spills from existing developments. Furthermore, sampling results could become important documents during property transfers. As such, copies of the laboratory results and the sampling field sheets should be retained with other key information on the property.

Table 3. Water Well Purging/Sampling Field Sheet

Owner	Owner		ss (include t	Address (include townland and county)	unty)			Grid ref.	Sampling date	te		Sampled by:		
Descri	Description of purging/sampling system (e.g. pump - rising main -	mpling syste	em (e.g. pun	np - rising main	kitchen tap)]		Treatment system	Well yield/ number of people supplied 2.	number of pe	dns əldo:	plied ² .		
Gener downs	al Observations.	Note water for	eatures or po	otential pollution weather conditi	n features closions on day of	e to the well ³ .	Note dista	General Observations. Note water features or potential pollution features close to the well ³ . Note distance from the well to each feature and whether each feature is upslope, downslope, or across-slope, of the well. Note also weather conditions on day of purging/sampling.	feature and w	hether each	feature i	dolsdu s	e,	
Well No.	Depths (m)	Height (r casing(s)	Height (m) of casing(s)	Diameter of inner casing	Purge volume (note units)	ne (note	Describe a	Describe appearance of the purged water. Colour? Smell? Surface Sl	ged water. Surface Sheen?	Time of sampling	On-site	On-site measurements ⁴	ements	4_
	Water Base level hole	Inner	Outer ⁵	(mm)	Required	Actual					EC	DO	J _o	hф

¹ NB: It is <u>very important</u> to note in this section if the sampled water is treated or untreated.

² Specify units

³ Examples: stream, septic tank, swallow hole, roadway, petrol station, heating oil tank, silage pit, etc.

⁴ May not be possible in a domestic well situation. EC: electrical conductivity (specify units). DO: dissolved oxygen (mg/l). °C: water temperature. pH: acidity (no units).

⁵ Note height of highest structure surrounding the inner casing which will prevent entry of surface water into the well. This would not include buildings with doorways, but might include the raised concrete floor of a well house.