EXPLAINING GROUNDWATER AND WATER WELLS

This document aims to provide a non-technical description of groundwater: how it occurs, how it moves underground, and the basic principles behind constructing and operating a borehole as a sustainable source of high quality water. The aim is to demystify groundwater and boreholes and enable a private householder, in particular, to understand the principles behind siting, constructing and pumping a borehole.

The occurrence and movement of groundwater, and the design and operation of a borehole water source, depend on a simple principle - ***water below ground, like water on the surface, always tries to flow downhill.*** If water cannot flow one way because its route is blocked or constricted, then it flows another way - an easier way - always trying to move to a lower elevation under the pull of gravity. The ultimate destination (or base level) to which water moves is sea level. All water, on or under the ground, is moving back towards the sea. Some groundwater, near the coast, flows directly through the soil and rock to the sea. Further inland, groundwater flows through the soil and rock to the bottom of the nearest valley, into the stream or river on the valley floor, and thence to the sea. Much of the flow in rivers and streams is groundwater, except during, and shortly after, heavy rain. Most of the time, rivers and streams act as 'groundwater drains'.

With this principle in mind, and the information in this document, any householder can use their common sense to understand what a driller is doing in constructing and equipping a borehole for domestic use.

Some technical terms

Well: in this document, a general term used for a man-made excavation, constructed for the purpose of drawing water from, or monitoring, the groundwater system. Old wells were often dug by hand and relatively shallow, the depth being limited by the ability of the diggers to pump or lift water out of the hole as they deepened it - it was not possible to dig by hand under water.

Spring: sometimes used as a synonym for 'well' – most 'holy wells' are, in fact, springs. A spring is normally a natural feature where groundwater emerges at the surface. Sometimes it is just a small seepage, surrounded by soft wet ground and rushes. Other springs can be large flows, like a stream issuing from a cave at the base of a cliff. Springs usually occur where the rate of flow of groundwater is too great to remain underground. The position of a spring often reflects a change in soil or rock type, or a change in slope.

Some natural springs, including some 'holy wells', have been modified by man, i.e. have been deepened to improve the supply. Occasionally, a flowing spring has actually been created by excavation.

Borehole: a particular type of well - a narrow hole in the ground constructed by a drilling machine in order to gain access to the groundwater system. Boreholes are usually narrow (typically 150 mm (6 inches) in diameter) and can be constructed quickly. Modern drilling machines use compressed air to drive a rotating hammer that smashes up the rock. The air exhaust from the hammer tool blows the broken rock chips, and any water in the hole, up to the ground surface.

Groundwater: is simply water that is below the ground. It is the same as, and behaves like, water that is seen on the surface - in pools, streams, rivers, and lakes. Like surface water, groundwater moves downhill under the influence of gravity, and must overcome obstacles and barriers to do so. Just as rain falling on a sloping field of grass has to weave its way through the grass stems in order to reach a drain at the bottom of the field, likewise groundwater has to fight its way through the soils and rock. It cannot flow through solid matter - such as a grain of sand or a piece of rock - it can only flow through gaps between the grains, or through cracks in the solid rock.

Because groundwater is hidden from view, it carries a sense of mystery and uncertainty about where it comes from, how it is moving, and where it is going. This allows myths and misconceptions to arise and persist in the public consciousness. This document aims to provide a clear understanding of groundwater for everyone using it, so that the reasons for the technical 'do's and don'ts' become clear.

Groundwater is found in the soils and rocks below the entire surface of Ireland.

Soil: includes the topsoil, subsoil, peat, sand, gravel, clay and boulder clay lying on top of the rock.

Rock: includes all the different types of ancient hard rock (sometimes called 'bedrock') found throughout Ireland, including limestone, sandstone, shale, granite, volcanic lava and metamorphic rock (rock that has been altered by heat and pressure).

The main difference between rocks and soils are that the 'rocks' in Ireland are old - usually over 300 million years old – and are hard and solid, whereas the 'soils' are 'young' - usually less than 10-12,000 years old - and relatively soft. This difference has implications for the construction of a well. It is usual to line or support the sides of a hole drilled into soils because unsupported soils may slump or collapse into the hole. It is usually unnecessary to support the sides of a hole drilled into hard rock, which is usually stable and self-supporting and unlikely to fall in after it has been drilled. The drilling methods used in Ireland are usually forceful enough to dislodge all loose pieces of rock from the sides of the hole. However, some rocks are so broken or weathered that they do need permanent support.

It is important to realise that groundwater is not actually inside the solid rock, nor inside the solid grains that make up the soils. Groundwater is found only in the cracks or spaces that break up the solid rock, or in the pore spaces inbetween the grains of the soils. So, if a driller, hydrogeologist or engineer says, for example, that limestone rocks have better groundwater potential than granite rocks, they actually mean that the water-bearing fractures, joints and cracks in limestone rock are usually wider and better interconnected than those in granite rock. Thus, apart from their cracks and fissures, limestone and granite are equally impermeable.

Aquifer: simply a geological deposit (which may be soil or rock) which is permeable enough to allow development for water supply.

Several diagrams are included below to illustrate the above principles and show how a borehole works. All of the following figures are cross-sections down into the earth. As groundwater is always trying to move downwards, it is important to continually view groundwater flow and wells in the vertical dimension.

Figure 1 illustrates how groundwater is always moving. The figure shows a river on the floor of a valley. Groundwater begins its journey as rainfall, some of which percolates vertically down through the soil and rock until it can go no deeper. This level is the position in the rock below which all the pore spaces or cracks in the rock are already filled with water. The newly-arrived water adds to the water in the cracks in the rock and starts filling up those cracks that do not already contain water. The level at which the new water's journey is arrested is called the 'water table', which is defined more precisely as the level below which all available and interconnected spaces in the soil or rock are saturated.

Notice that the water table is not flat, but slopes from the hills, down the valley sides, towards the river. Figure 1 is schematic, so the slope of the water table is exaggerated for illustrative purposes. In Nature, the slope of the water table is much gentler than is shown. It is important to recognise that the water table is always sloping, and groundwater flows in the direction of the slope. If a well is about to be drilled, and the owner is concerned about potential pollution, the owner should look uphill. This will be the direction from which groundwater will flow. For example, if slurry is often spread on grassland uphill from the proposed borehole site, and the soils below the grass are thin, rainfall will probably flush some of the slurry down through the soil and rock to the water table. The dilute and partially broken-down slurry will then enter the groundwater flow system and move in the upper part of the saturated rock, in the direction of groundwater flow, towards the proposed borehole site.

The water table slopes towards the river because groundwater is continually being drained by the river. Water further from the river has to make its way sideways, through the small cracks in the rock, down to the river. There must be a pressure difference, or higher water table elevation, to drive the flow through the rock and overcome the resistance to flow posed by the narrow cracks in the rock.

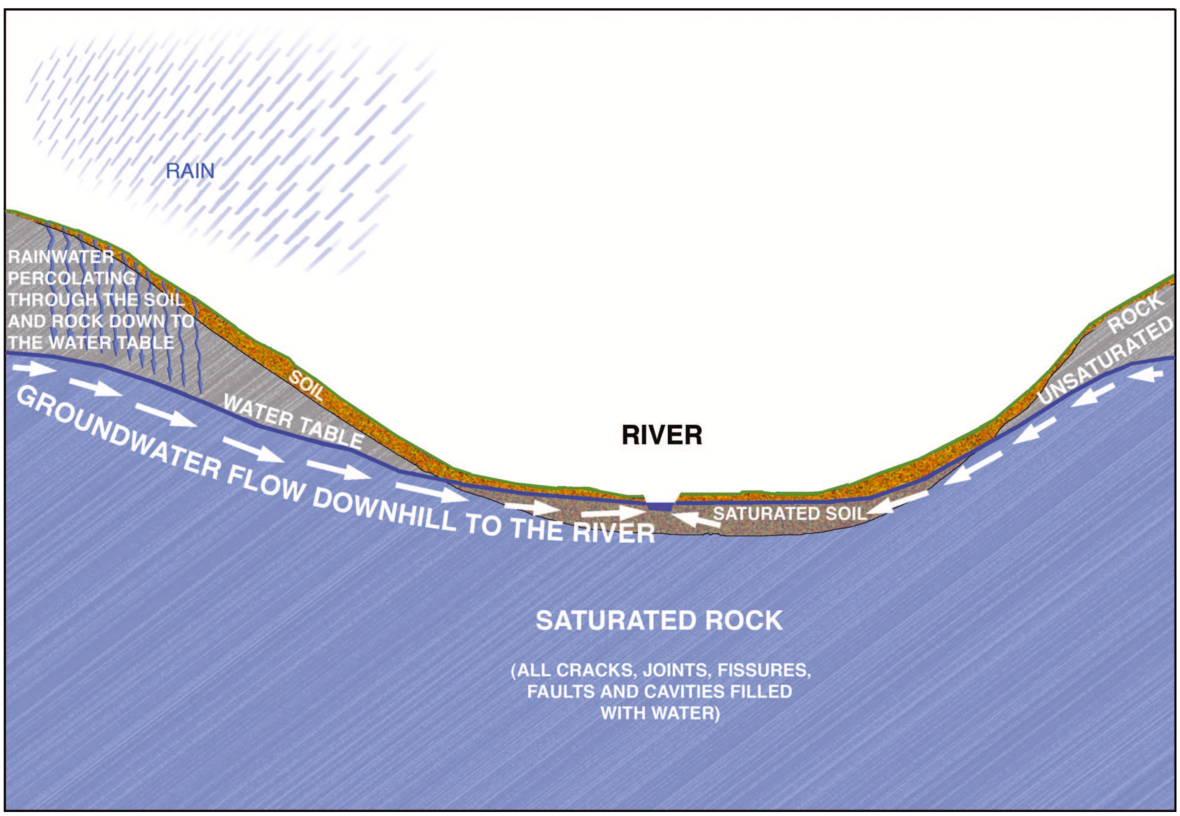

Figure 1.

Figure 2 shows a sequence of soil and rock typically encountered when drilling a borehole in Ireland. Below the topsoil there is often a layer of clay – usually a tough, but cracked, clay containing a mixture of grains of sand and gravel, with pebbles, cobbles and boulders, known as 'boulder clay'. It is a material laid down by the glaciers and ice sheets that covered most of Ireland during the last Ice Age, which ended about 12,000 years ago. Thick boulder clay is very useful, because it can form a low permeability barrier that inhibits the downward movement of contaminants from the surface or the topsoil. However, these clays are not homogeneous. They were cracked by freezing and thawing action after the Ice Age and have been penetrated by the deep roots of forest trees. The roots have long since decayed because many of the forests were felled long ago, but the root paths remain as long, dim, nearly vertical, tubular channels down through the clay. The cracks and root channels form vertical conduits down which water and surface pollutants can by-pass the less permeable mass of the clays.

The downward change from soil to hard rock is usually not abrupt. There is often a thin 'transition zone' of sandy gravel, broken rock and softer, weathered rock between the clay and the hard rock. This zone may be less than 300 mm (1 foot) thick, but in some places, particularly in the south of the country, it can be 6-12 metres (20-40 feet) thick. The transition zone is important because it is often more permeable than either the clays above or the solid rock below. It therefore often acts like a drainage blanket at the bottom of the soil zone. As a result, it can be the zone which collects the pollutants that can percolate down from the surface.

Water Well Construction Guidelines gives a table showing how the thickness and nature of the layer above the rock can influence the distance that a borehole should be sited from different potential pollution sources.

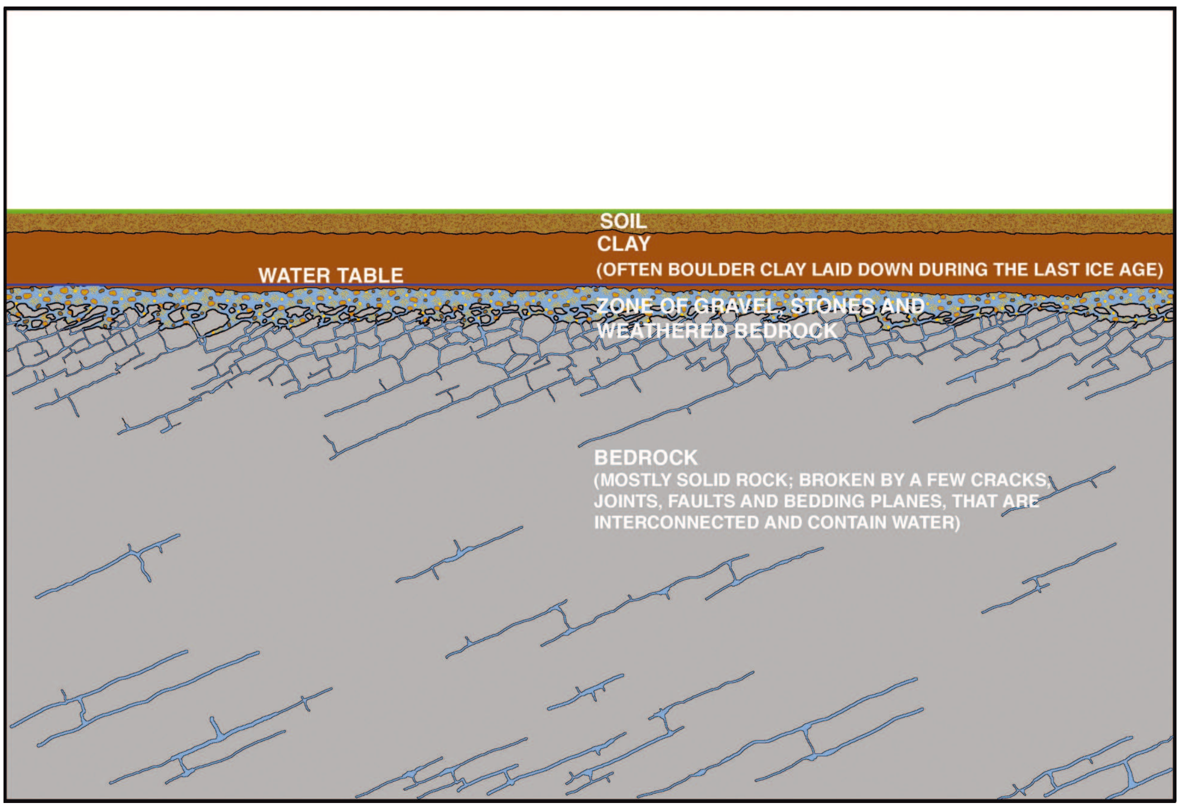

Figure 2. A section down into the earth showing a sequence of soils and rock often encountered when drilling a well in Ireland

Figures 3, 4, and 5 illustrate a hole drilled through the sequence of soil and rock shown in Figure 2.

Figure 3 shows a simple borehole drilled into the rock; the water table is just at the base of the boulder clay and above the transition zone. There is water in cracks and joints in the bedrock – but notice that the majority of the rock mass contains no water. The figure also shows that cracks or joints are more common in the upper part of the bedrock, just below the transition zone. Deeper in the bedrock, the cracks and joints containing water are usually less open because of the weight of rock pressing down from above.

Figure 3 is unrealistic in representing the borehole as being empty, to emphasise the fact that a borehole is essentially an empty structure - a void. When this void penetrates saturated pore spaces or cracks in the rock below the water table, water from these cracks and pores will flow under gravity into the void, until the hole fills up to the same level as the water table, as shown in Figures 4 and 5.

The water flows from the rock and soil into the void, until the borehole water level is the same as the level of water in the rocks and soil. This process is illustrated in Figures 4 and 5 in order to confound a widely-held myth that a borehole only yields water because it intersects an underground spring, or river, or lake. In practice, a borehole drilled below the water table almost anywhere in Ireland will eventually fill up with water flowing in from the saturated cracks in the rock, and the pore spaces in the soils, adjacent to the hole. The speed at which the hole fills with water depends upon how easily the water can flow from the rock and soils into the hole.

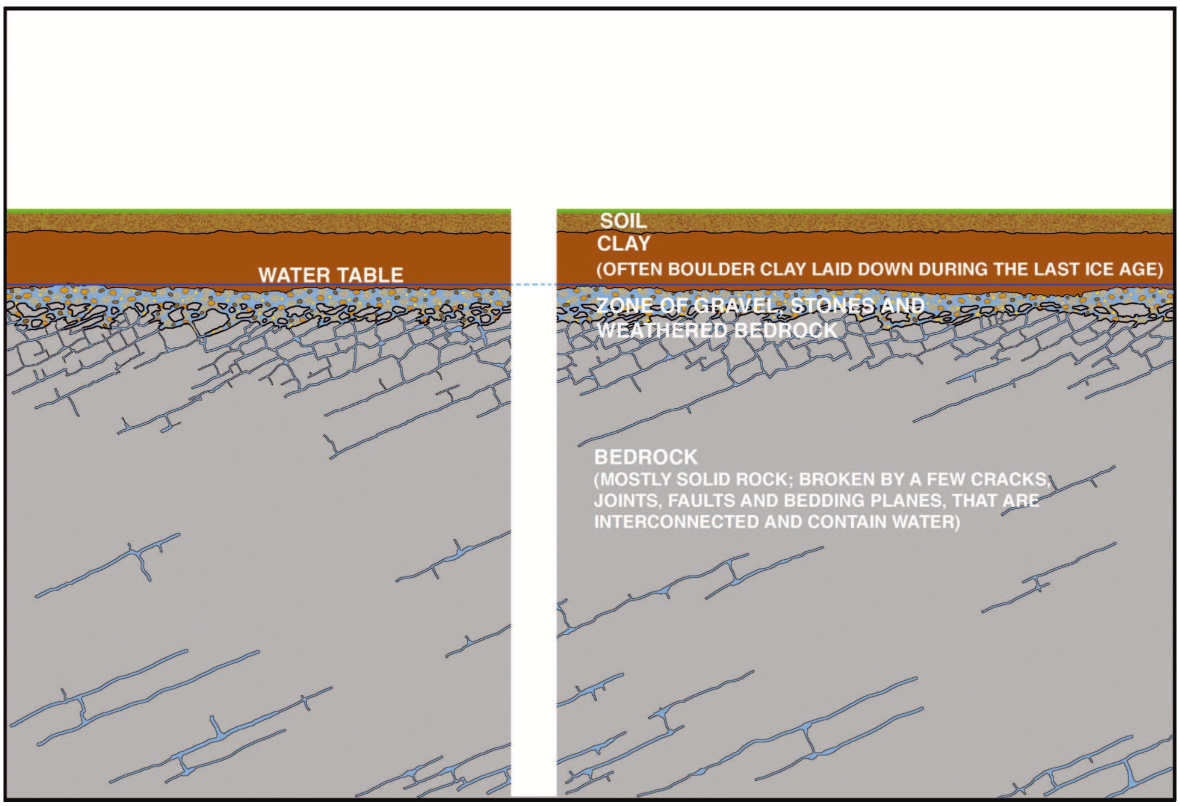

Figure 3. Section showing a simple hole drilled into the rock

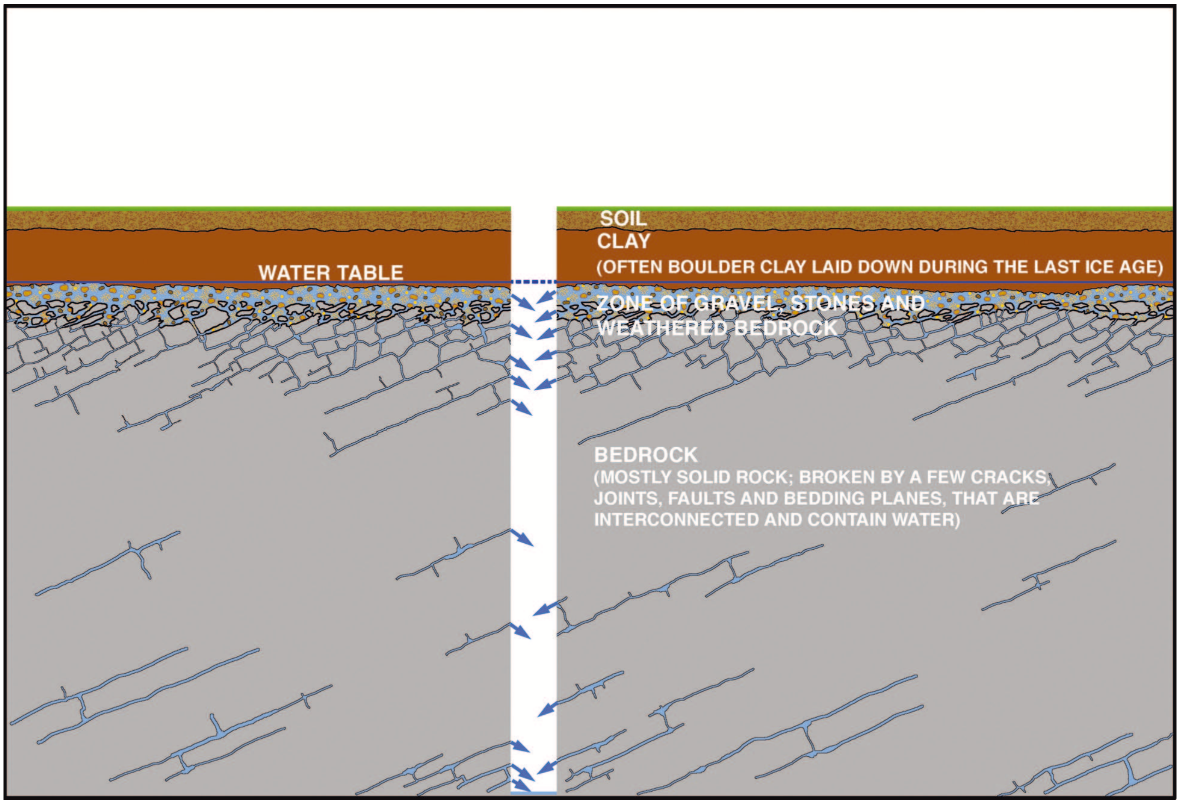

Figure 4.

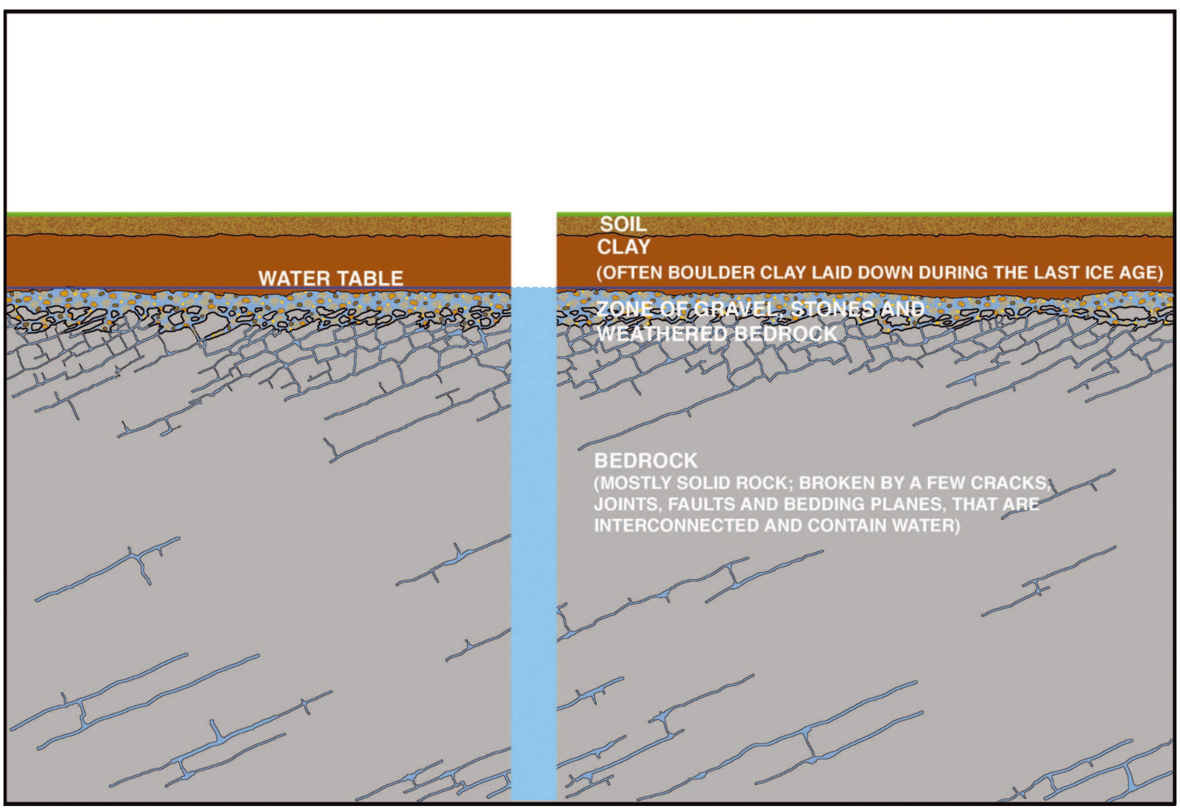

Figure 5. Section showing a simple hole filled with water up to the level of the water table in the rocks

Figure 6 illustrates what happens when we begin to pump water out of the hole. The pump shown is an electrically-powered submersible borehole pump. It has an electric motor at the bottom of the pump, above which is the water intake. The motor drives a shaft, which turns a series of propellers (technically termed 'impellers') which rotate inside pump bowls and push the water up the pipe to the surface. *(Figure 6 omits the electric cable from the surface down to the pump motor. This is usually strapped to the outside of the pipe.)*

When the pump is turned on, it removes water from the hole, causing the water level in the hole to fall below the water level in the rock and soil. As a result, water starts to flow into the void from the transition zone at the top of the rock and the cracks in the upper rock, and from cracks in the rock below the water level in the hole. Water from cracks above the pump intake will flow down to the pump, and water from cracks below the pump intake will flow up the hole to the pump. All these flows are driven by gravity, i.e. by the difference in water level between the hole and the surrounding rock and soil.

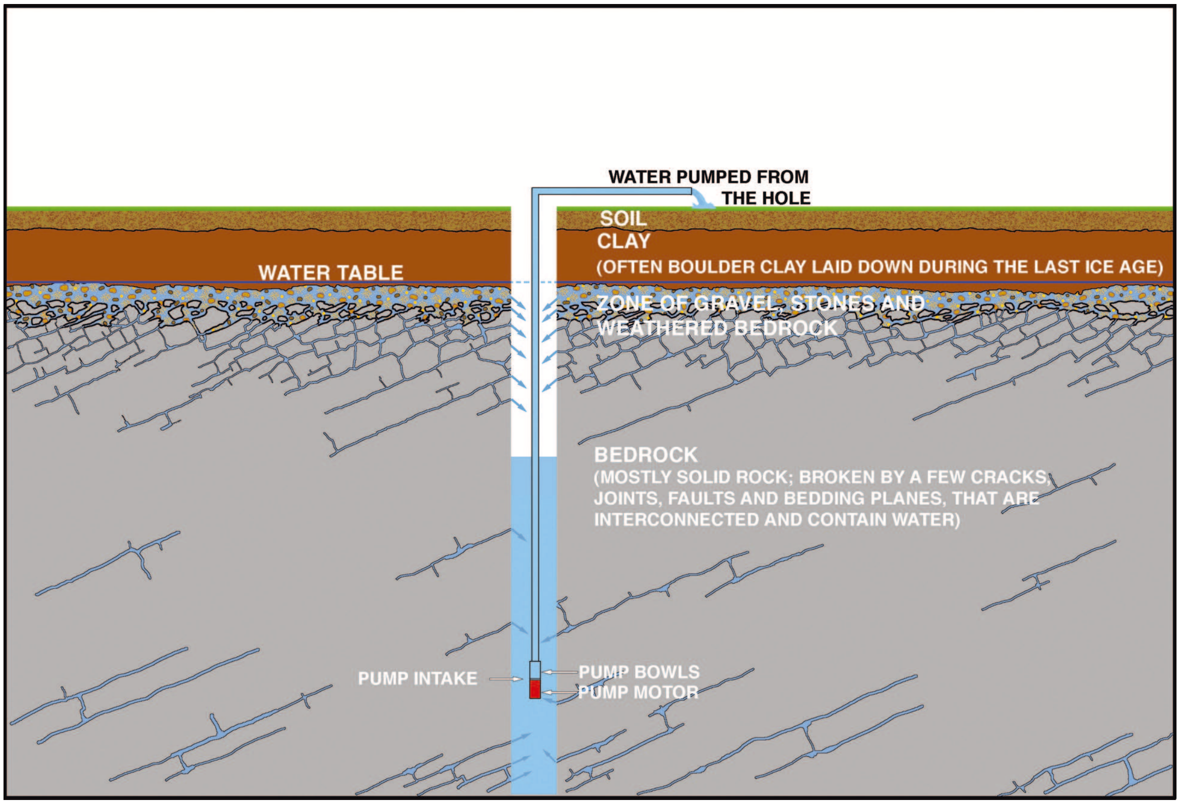

Figure 6. Section showing a simple hole during the early stages of pumping. The water level is lowered in the borehole and groundwater flows into the hole from below the water table

Figure 7 illustrates the situation some time after pumping has started. All the water in the transition zone and in the cracks in the upper rock around the borehole has drained into the hole. These previously water-filled spaces are now effectively dry. The water table around the borehole has been drawn down, as water from the upper zones has drained into the hole. Water still flows into the hole from the saturated, and inter-linked, cracks in the rock below the water table. Thus pumping a borehole affects water levels at some distance from the hole. The drawdown of the water table is greatest close to the hole, and creates a slope or gradient in the water table extending for some distance from the hole.

In three dimensions, the shape of the drawdown of the water table around the hole is a cone. The extent and shape of the 'cone of drawdown' defines the area of land from beneath which water is drawn towards the borehole. As pumping continues, the cone of drawdown continues to extend outwards from the borehole until eventually the volume of water percolating down through the soil balances the amount of water being pumped from the hole. In practice, pumping from a domestic well usually stops before this state of equilibrium is reached. However Figure 7 shows how water pumped from a borehole is replenished by water drawn towards the borehole from some distance away. Any source of pollution within the cone of drawdown can therefore contribute polluted water to the borehole.

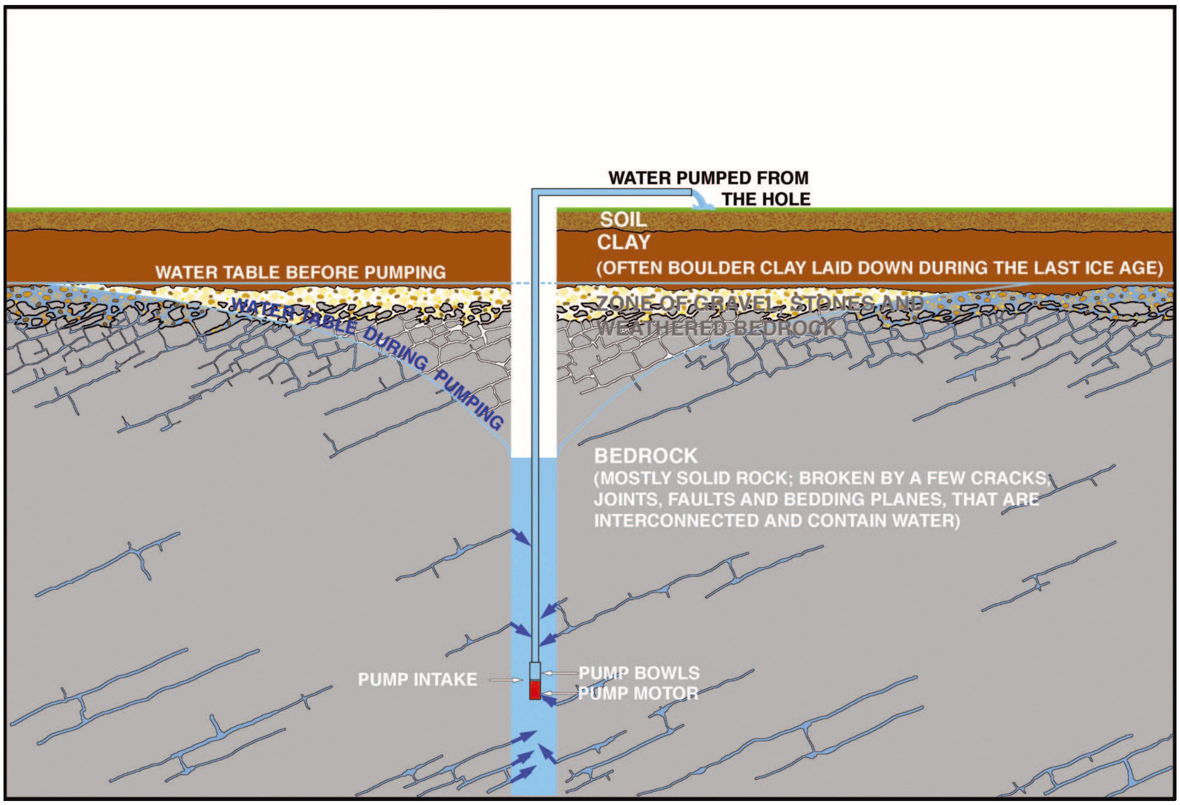

Figure 7. Section showing a simple hole and the effect of pumping (drawdown) on the water table and the depletion of water in the layers within the cone of drawdown

Figure 8 shows a real example of a very common domestic borehole construction. Many boreholes drilled for single houses, small private supplies and group schemes have been constructed in the manner shown.

The borehole in **Figure 8** has initially been drilled at 200-250 mm (8-10 inch) diameter down to the top of the bedrock. This hole has then been lined by inserting a short length of 150 mm (6 inch) diameter steel pipe (casing). The casing supports the sides of the hole and stops the soft soil, clay, loose gravel, and rock in the transition zone from collapsing into the hole. Notice that outside the casing there is a space (annulus) containing air or water, or loose material that has fallen against the casing. After the casing has been installed, drilling continues, at a diameter of 150 mm (6 inch) or less, until the water being blown out of the hole by the compressed air appears to meet the householder's requirements. Figure 8 illustrates the common practice of setting the pump at the bottom of the hole.

Figure 8 highlights an unfortunate but common situation, where the water level in the borehole is drawn down to near the bottom of the borehole, and the cone of drawdown extends out below the percolation area for the household's septic tank. Thus effluent from the septic tank can migrate, either through the soils and rock, or via the permeable transition zone at the top of the rock, into the borehole and end up being returned in the water supply to the house. The absence of a seal around the casing often permits water containing partially-treated septic tank effluent to move down and around the bottom of the casing and then inside the borehole, directly to the pump intake.

It is obvious from Figure 8 that if the cone of drawdown extends under the septic tank percolation area of a neighbour's house, then the neighbour's effluent can also be drawn into the borehole. The quality of the water supply from such a borehole depends upon the position and effectiveness of the septic tanks and percolation areas, and the speed with which water can migrate down from the percolation area to the water table. If the downward seepage from the percolation area is slow, then there may be enough time for bacteria in the soil to break down the effluent. But if the flow is rapid or, worse, if the septic tank is in fact an open-bottomed soakaway without a percolation area, then the household and neighbouring households can pollute their own water supplies.

Figure 8 illustrates the urgent need for national guidelines or standards for improved borehole construction and operation (see "***Guidelines on Water Well Construction***").

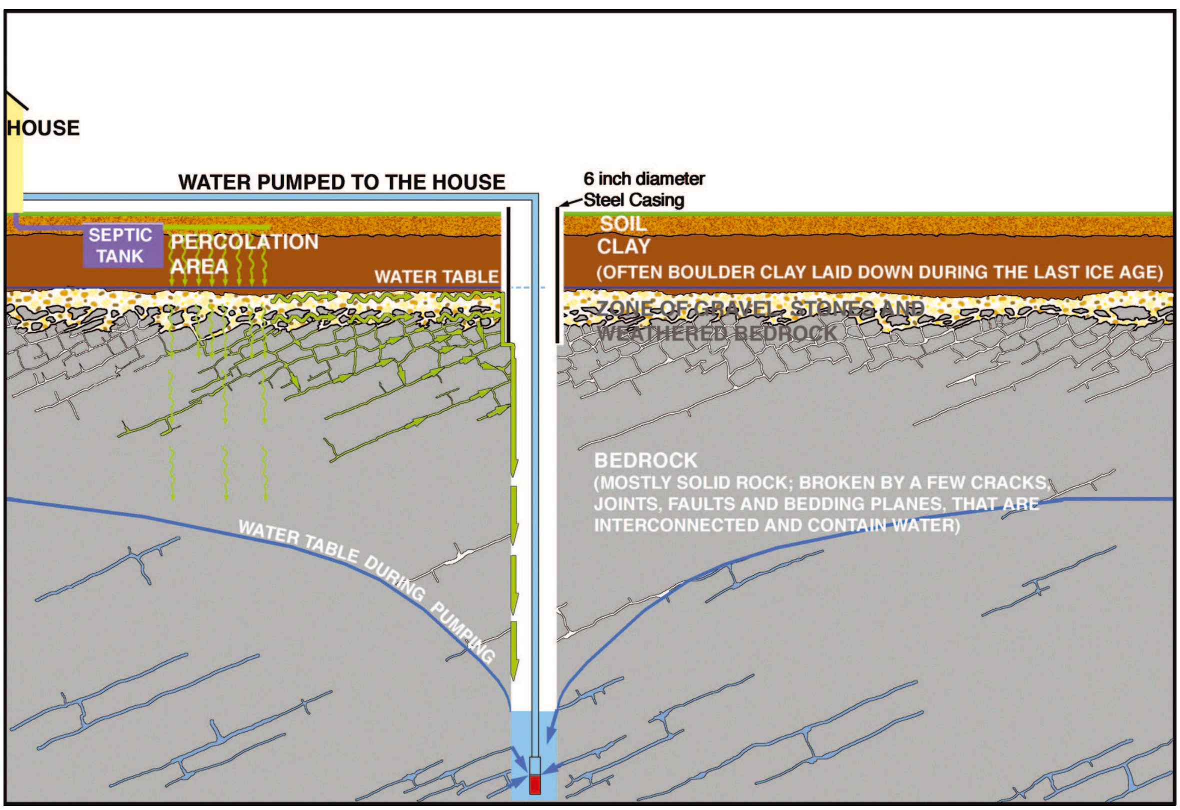

Figure 8. Section showing a very common construction of a domestic borehole, and position of a pump in Ireland and the routes by which domestic effluent can seep down into the water supply borehole