The Environmental Protection Agency

EPA DRINKING WATER ADVICE NOTE

Advice Note No. 14:

Borehole Construction and Wellhead Protection

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Office of
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Enforcement

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David Ball, consultant hydrogeologist, prepared the technical report which formed the basis for this Advice Note. Contributions to this Advice Note were made by the Geological Survey of Ireland, the Drinking Water Committee of the Health Service Executive, the EPA Office of Environmental Assessment and the EPA Office of Environmental Enforcement.

The Advice Note has been prepared by the EPA to provide advice to local authorities in relation to the proper construction of water wells and wellhead protection.

1. INTRODUCTION

1.1. Objectives

The objective of this Advice Note is to set out the recommended guidelines on how to construct a water supply borehole to internationally accepted standards and protocols for Irish conditions. The Advice Note sets out the guidelines on how a water supply borehole should be constructed given the nature of Irish aquifers, and the nature of common potential risks to groundwater quality in Ireland.

This Advice Note refers to, and is based upon, a previous document compiled by an experienced working group of the Institute of Geologists of Ireland (IGI). This document is entitled *"Water Well Guidelines"*. The document was endorsed by the Environmental Protection Agency (EPA), and published by the IGI with the support of the EPA and the Geological Survey of Ireland (GSI) in March 2007. The Water Well Guidelines were written with the objective of informing the public about groundwater supplies for domestic purposes. The printed Guidelines contain three booklets entitled *'Summary', 'Explaining Groundwater and Water Wells'*, and *'Guidelines on Water Well Construction'*. The IGI Water Well Guidelines can be obtained on-line at *http://www.igi.ie/publications/codes-guidelines.htm.* The printed document can be obtained from the IGI.

This Advice Note sets out the best practice for the design, construction and protection of a drinking water supply borehole for Water Services Authorities. The Advice Note is in three parts which include details of:

- How groundwater changes with depth and how a borehole works;
- The best practice for design and construction; and
- A check list and methodology for assessing the construction and protection of an existing water supply borehole.

The purpose of this Advice Note is to inform and instruct all Water Service Authorities and private regulated water suppliers to apply the IGI Guidelines when assessing the construction of existing drinking water supply boreholes, and also apply the Guidelines when commissioning the construction of new drinking water supply boreholes.

The final section of this Advice Note provides a combined desk and field based methodology to determine whether an existing water supply borehole is drawing upon shallow groundwater as well as deep groundwater.

1.2 BACKGROUND

The EPA has adopted the World Health Organisation (WHO) water safety plan approach to ensuring drinking water is both safe and secure. This approach uses a comprehensive risk assessment and risk management approach. The first part of the approach is to describe the water supply system from source to consumer. One of the primary risks in a drinking water supply are the features of the source in relation to the characteristics of the natural water resource upon which the source depends. There are further risks in the downstream treatment and supply system between the source and the consumer, but the significance of risks in the treatment and supply system heavily depend upon the initial quality of the raw water. For example, a temporary failure of a chlorination system is highly significant if the raw water is from an easily polluted river, whereas the risks are far less significant if the source draws solely upon unpolluted groundwater that may be years, decades or centuries old from deep in the earth.

The exploitation of Ireland's groundwater resources for drinking water supplies in the past was usually dominated by a fear of not getting enough water. Boreholes were designed and constructed to let in as much water as possible. Quantity was always perceived as the first issue, whereas water quality was a secondary issue. Poor water quality could always be corrected by treatment, just as in a river intake scheme with a water treatment works. Now, the issues are reversed; water quality and the protection of water quality are paramount. The modern objective is to protect and selectively make the best of what nature can provide. This requires a greater understanding, and this Advice Note aims to explain and inform.

The information and guidance provided in this Advice Note are focussed on appropriate design and construction of drinking water supply boreholes that provide good quality water. The design and construction is not focussed on maximising quantity, but instead concentrates on obtaining the best quality water from the natural groundwater resources that are available.

In this Advice Note, a “borehole” refers to a bored well used for drinking water purposes and the term ‘well’ is used as a generic term for a groundwater source. Boreholes are constructed using drilling rigs operated by professional drillers and should be designed/supervised by a hydrogeologist/groundwater engineer.

2. GROUNDWATER FLOW AND HOW A BOREHOLE WORKS

The best way to understand the risks to groundwater, groundwater flow, and appreciate the benefits (or defects) of borehole construction, is to imagine the subsurface in the vertical dimension. In other words, to view things from the side - in cross-section, rather than from above - in plan view.

2.1 GROUNDWATER FLOW AND RECHARGE

Like surface water, groundwater flows ‘downhill’ under the pull of gravity. Groundwater flows through conduits or passageways formed by interconnected pore spaces or fractures in the rock and soils. There is a physical limit to the amount of water that can flow through the underground conduits.

Groundwater generally flows from higher ground down to a stream, river or lake in the valley floor. In other words, surface water features in the valley are drains that receive both groundwater from beneath the surface, and runoff from the surface of the valley sides (see Figure 1). On occasions when there is no rain, almost all the water seen flowing in the rivers and streams is groundwater. Groundwater near the coast may flow directly to the beach or the base of cliffs before flowing out to sea, or it may discharge from the seabed itself.

Groundwater starts as rainfall, or snow melt, that percolates through the soil and root zone, and down through the unsaturated soil or rock to the ‘water table’. This process is termed recharge. The water table is not a fixed or static feature. It is merely the level, underground, below which all the pore spaces and fractures in the rock are full of water, at a moment in time. When it rains the water table (or the top of the saturated zone) rises. When it has not rained for some time (i.e. recharge has ceased) the water table will fall as water drains away downhill. The degree to which the water table rises and falls depends upon the balance between the rate of recharge and the rate of groundwater drainage.

Figure 1, on page 6, is a colour coded diagram that shows how rainfall on a slope incrementally adds water to the groundwater flowing under the slope down to a river or stream in the valley floor or the coast. Rain falling on the valley slopes percolates down to the water table and adds water on top of the deeper groundwater that came in as recharge further up the valley slopes. Rain falling on the lower slopes adds further recharge, as does rain on the flood plain. The diagram is illustrating how the origin and flow path of groundwater in the vertical dimension in an aquifer is not the same.

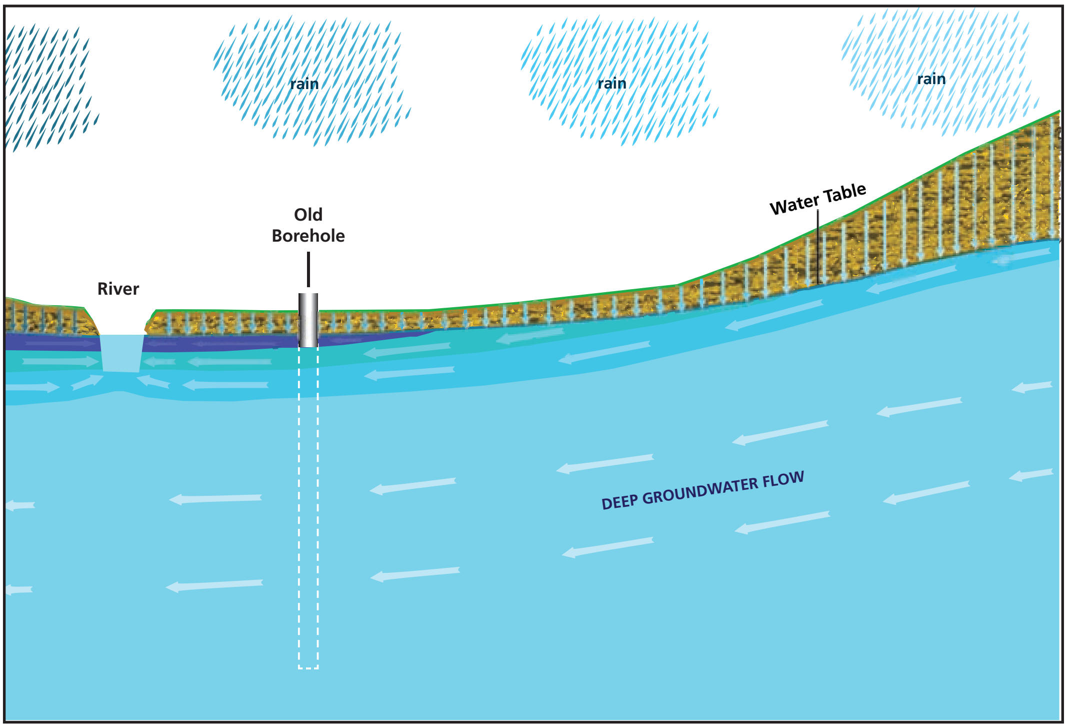


Figure 1: Conceptual representation of the nature of groundwater flow.

A simplistic representation of a borehole is on the left side of the figure. The borehole contains a short length of steel casing in the upper part, preventing the soil and subsoil from falling into the borehole. The lower part of the borehole is uncased and flow into the hole is unrestricted.

The diagram illustrates how recharge higher up the slopes has a longer travel path before it reaches the borehole. There is a greater opportunity for this water to be filtered along this flow path. There is also a greater opportunity for attenuation of contaminants or pollutants or die off in the relatively thick unsaturated zone above the water table, and during the travel path down gradient.

The diagram shows the important point that the water flowing through the borehole is unrestricted. Shallow and deep groundwater can flow into and through the borehole.

There is a common misconception that a deep borehole obtains safer, purer water because it draws only upon deep groundwater. As the diagram shows, the depth of the hole is irrelevant. It is the position or depth of the open section of the borehole (the producing section) that controls whether shallow or deep groundwater enters the borehole.

2.1.1 THE LINK BETWEEN RECHARGE, GROUNDWATER FLOW AND BOREHOLE DESIGN

Water that has recently passed through the surface and near surface layers is likely to contain more pollutants than older deeper water that has travelled a longer distance underground. One of the fundamental principles of good borehole design is therefore to construct a borehole so that it preferentially draws upon deeper water, and excludes shallower water.

Figure 2 (A) is based on Figure 1. It illustrates how shallow groundwater will be drawn into an old borehole when pumping is in progress. Though the pump may be deep in the borehole, the water flowing to the pump comes from both the shallow layers of relatively recent recharge as well as the deeper older groundwater from further away.

A schematic representation of a modern borehole is given in Figure 2(B). It shows the same features as Figure 1 and 2(A), but the borehole has a solid lining that excludes the shallow layers of groundwater. The deep lining is made from water well graded PVC. There are no slots or gaps in this casing. It is called a pump chamber casing.

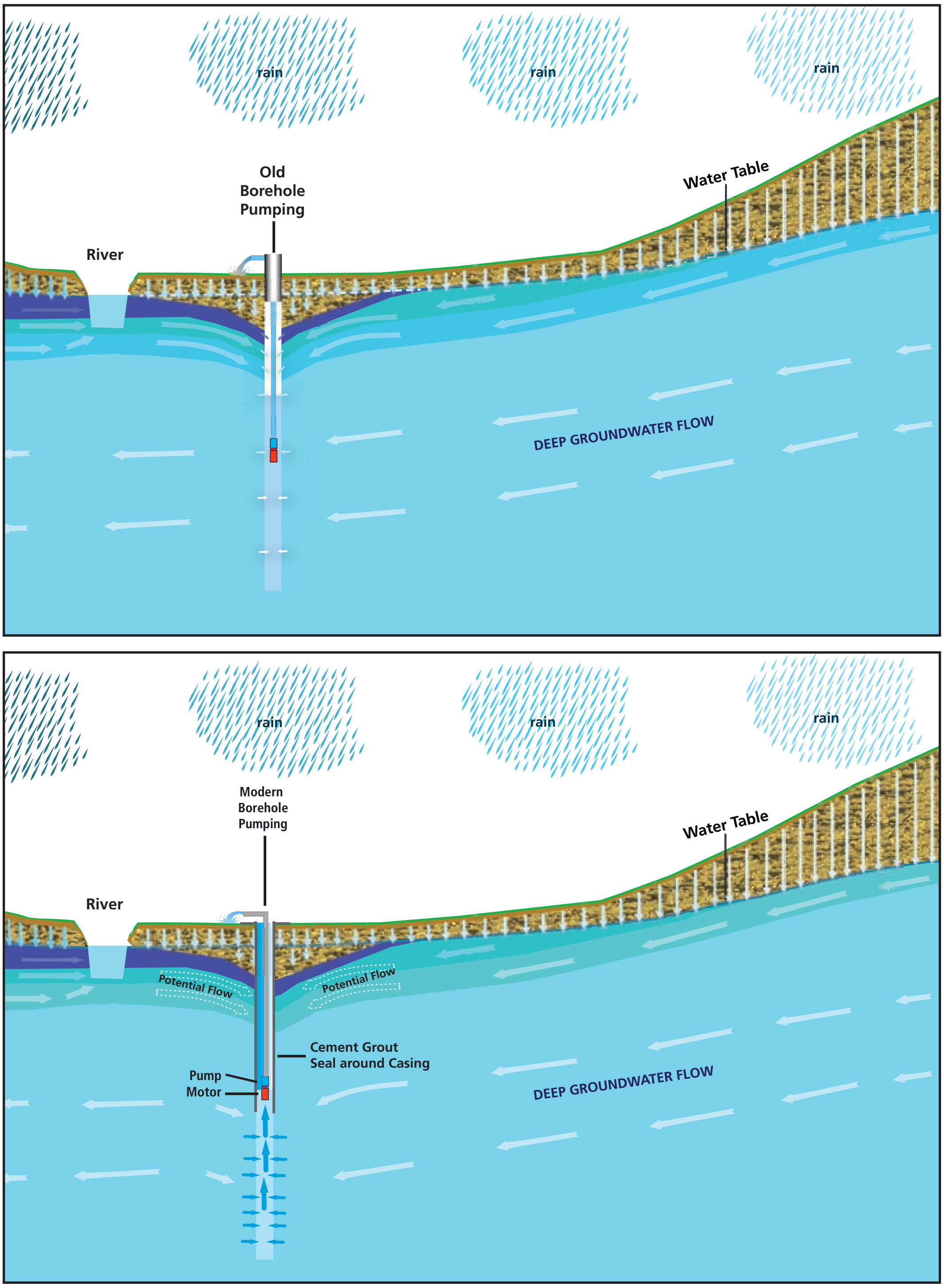


Figure 2(A) and (B). Groundwater flow into an old type borehole and modern constructed as outlined in this advice note.

The intake for the pump is inside the casing. The bottom of an electrical submersible borehole pump is the motor, shown in red. Above the motor is the intake strainer, and above this are the pump impellers (shown in blue) that lift the water up to the surface. The water level in a borehole cannot be pulled down (or drawn down) to below the intake for the pump when the pump is operating. Therefore, if the pump is inside the pump chamber casing, the water level in the borehole, and water level in the aquifer, cannot be drawn down below the bottom of the casing. Shallow water cannot flow down the outside of the pump chamber casing because the gap between the outside the casing and the inside of the bored hole has been completely sealed by an injected cement grout. It is for this reason that Figure 2(B) shows arrows in the shallow groundwater layers with the label 'Potential Flow'. There is the potential for flow to occur, but it is prevented because there is no route open down to the bottom of the pump chamber casing.

Although groundwater flows under the influence of gravity down to the discharge point or zone, the gradients are generally low except near the summits in highland areas. Over much of the country, and in particular the Midlands, the horizontal distance from the point of recharge to the point of discharge is much greater than the vertical distance. The gradients in Figures 1 and 2 are exaggerated for illustrative purposes. Normal groundwater gradients have a fall of a few metres over a distance of several hundred metres or a kilometre.

Below much of the country, in areas where groundwater is used as a source of supply for drinking water, it is generally easier for groundwater to move sideways rather than vertically.

Groundwater flow is therefore stratified or layered because of the way that recharge is incrementally added to the water table along a flow path, but also because near horizontal preferential flow paths are better developed than vertical or steeply inclined flow paths. Groundwater generally takes the easiest, and shortest, available route between the point of recharge to the point of discharge.

The objective of a modern borehole design and construction is to effectively exclude shallow groundwater during pumping, and specifically select to draw upon deep groundwater which will be relatively old and will have travelled further. There is a greater opportunity for pollution to be diluted and broken down with increased time and distance of travel.

2.1.2 GROUNDWATER MOVEMENT AND THE PRINCIPLES OF BOREHOLE DESIGN IN HETEROGENEOUS BEDROCK IN IRELAND

Figures 1 and 2 represent the aquifer as a homogeneous, permeable porous media. There are no preferential flow paths shown in the aquifer. Such an aquifer is found in text books but would be unusual in Ireland.

While the soils and subsoils in Ireland are relatively young and immature, the bedrock in the Republic of Ireland is relatively old. Rocks are about 300 million years old or more, and have been compressed and deformed. There are no open pore spaces in the solid rock, instead groundwater usually moves through fractures or gaps around the edges of the intact pieces of solid impermeable rock. These gaps could be joints or tension cracks, fractures, faults and fissures as illustrated in Figure 3. The bedrock aquifers in Ireland are not homogeneous porous media. They are the opposite; they are heterogeneous, impermeable and non-porous.

Many very thin joints and bedding planes in layers of black shales and limestones provide a low yield

A single open passageway in a wide fault zone and calcite vein in limestoen provides a high yield of water

Figure 3. Joints and conduits controlling groundwater flow and storage.

Limestone rocks are very common in Ireland, and the solid rock can be dissolved by water. Cracks in limestone can be widened by water dissolving the rock on the sides of the crack. In this way, small cracks or gaps in the solid limestone rock can be widened to become large conduits passageways or pipes, or even small and large caves that can be horizontal, vertical, or any angle in between.

Figure 4 consists of a cross section that attempts to provide a more realistic illustration of a bedrock aquifer and the relationship between the heterogeneous rock and overlying the soils and subsoils.

Figure 4 is an extension of figures 1 and 2. It shows the travel paths of water down into and through both the subsoil and limestone bedrock. There are two boreholes shown in Figures 4 (A) and (B). These boreholes have the same design as the boreholes in Figure 2(A) and (B). Figure 4 goes beyond Figures 1 and 2 by showing pollution or contamination on the ground close to the boreholes and also further away on the slope of the valley sides. It shows how pollutants can move down into the bedrock and flow into the subsoil. It shows how pollutants can move both through the subsoil and the bedrock. It illustrates how pollution or contamination from the surface (and the shallow subsurface) will be found in the interconnected permeable layers of sand and gravel in the subsoil, and in the upper bedrock conduits. Pollution does not sink unless it is denser and heavier than water. Certain industrial solvents and creosote are heavier than water, but common agricultural or domestic groundwater contamination in Ireland tends to stay in the upper parts of the groundwater system.

Figure 4 (A) shows an old type of borehole designed and constructed with the intention of maximising the flow of groundwater into the borehole. The figure shows how the water pumped from the borehole will be an undiscriminating blend of shallow contaminated water and deeper good quality water.

Figure 4 (B) shows a modern borehole with a PVC pump chamber casing surrounded by an injected cement grout seal (shown in grey). Figure 8 shows this cement grout seal as it is being installed. No shallow water can go down this space around the outside of the pump chamber casing because it is filled with cement grout that hardens after a few hours. The modern borehole selectively draws upon groundwater only from the deeper conduits in the limestone. The pump is installed inside the PVC pump chamber casing. Groundwater flows from the conduits in the limestone into the open hole below the casing and then up to the pump. The modern borehole has been designed and constructed in accordance with EPA, IGI and international standards to deliberately exclude the shallow, more easily contaminated, groundwater and deliberately draw upon only the deeper less vulnerable groundwater. The modern emphasis is on sustainable quality, rather than quantity. In the past everyone was worried about not being able to get enough water. Now, it is realised that well fields of more than one borehole can be constructed, and it is better to invest in constructing water supply boreholes properly at the outset, rather than paying for high on-going costs trying to treat polluted water.

Unfortunately, most drinking water supply boreholes have been constructed in the past to the standards of the borehole shown in Figure 4 (A). Therefore, water from many off the old water supply boreholes does require treatment to ensure microbiological quality.

The remainder of this Advice Note adds to the description in the IGI ‘Water Well Guidelines’ of locating, designing constructing and pumping a modern borehole.

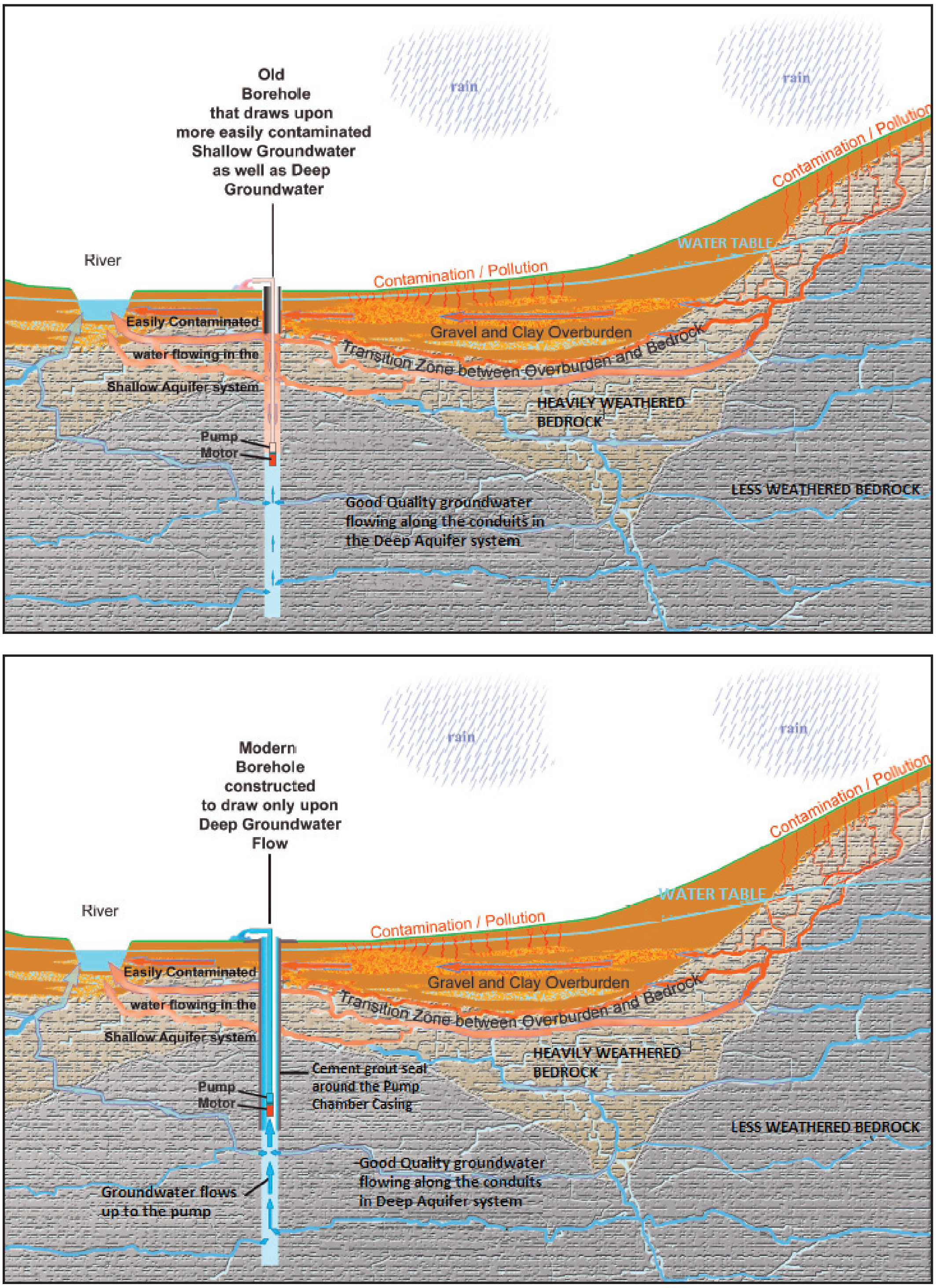


Figure 4 A and B. Sections illustrating the heterogenetity of Irish groundwater flow systems and the difference between an old type of borehole and the modern water supply as described in this advice note.

2.2 HOW A BOREHOLE WORKS

The description of how a borehole works is covered in more detail, with diagrams in the *Water Well Guidelines* 2007 Part 2 entitled *"Explaining Groundwater and Water Wells"*.

In summary; a borehole is a vertical void or hole in the subsoil and bedrock. The hole is bored into the ground into what is commonly called the 'water table' (i.e. into the saturated zone). When the soils and rock are taken out to make the hole, there is an empty space, with the breaks in the surrounding rock filled with water. The water in the rock fractures flow by gravity into the empty space, created by the borehole until the water level in the borehole is the same as the water level in the rock fractures around the borehole. This is illustrated by the simple diagrams in Figure 5.

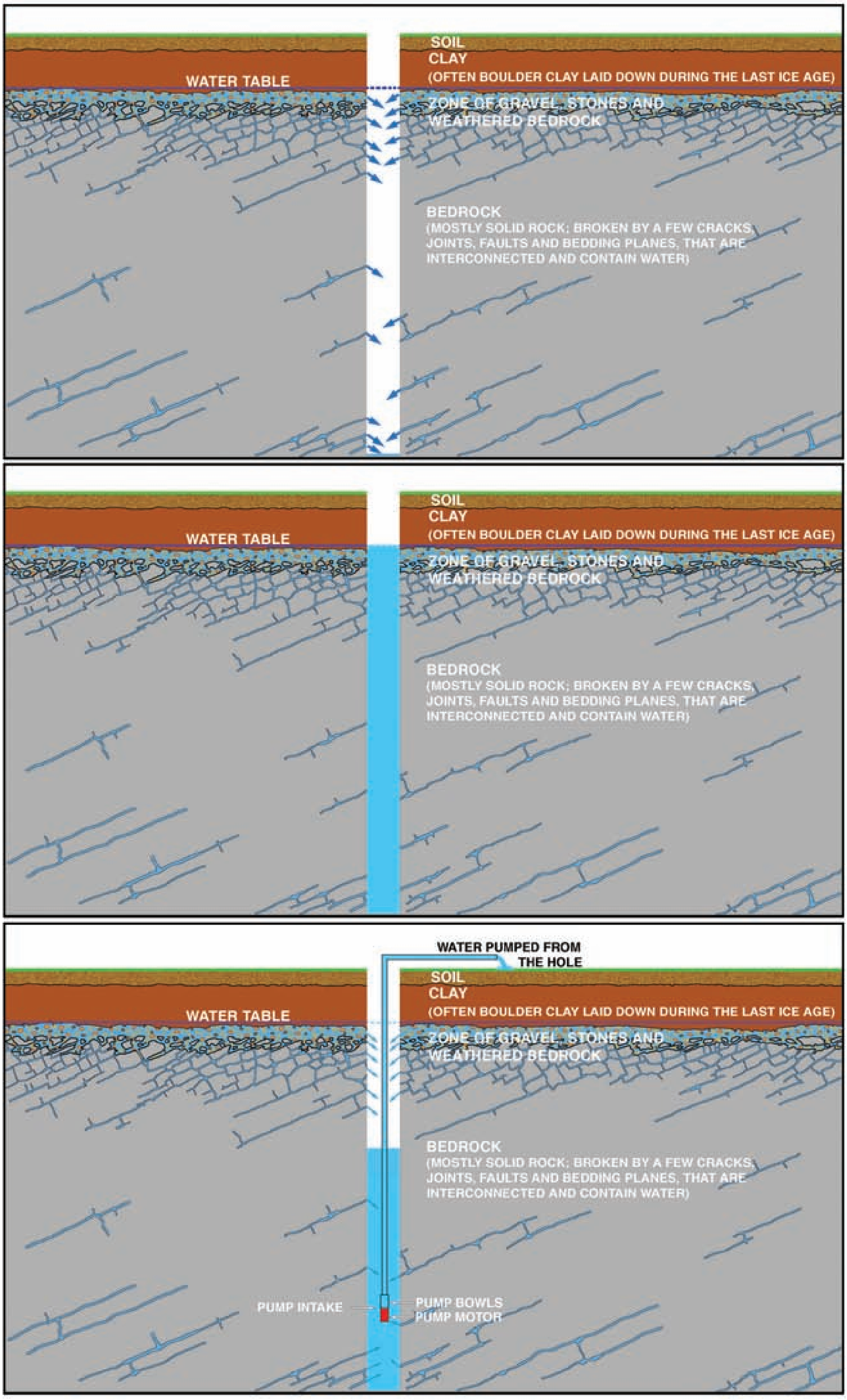


Figure 5. Groundwater flow into a borehole.

In order to obtain a water supply, a pump is placed into the borehole below the rest level. Pumping first removes water stored inside the borehole (the borehole is like a long round vertical storage tank), and the water level in the borehole goes downward. As the water level goes down, groundwater will begin flowing (again by gravity) into the borehole from the water bearing fractures in the surrounding rock and the saturated pores and fractures in the subsoil. If the rate of groundwater inflow from the rock is less than the rate of pumping (also known as the abstraction rate), the pump will start to suck air.

The rate of inflow into the borehole depends on three factors as follows:

1. The relative difference between the water level in the borehole and the level of the water table in the bedrock aquifer (i.e. the rest water level in the borehole). This is called drawdown;
2. The ease with which water can flow into the borehole from the gaps (e.g. fractures, bedding planes etc.) within the surrounding rock or subsoil;
3. The ease with which groundwater can flow towards the borehole from, and through the interconnected fractures or pores in the bedrock or subsoil that surrounds the borehole and the extent of these fracture or pore networks.

The combined effect of these factors on the yield or flow rate from a borehole usually can be estimated from the results obtained during and at the end of the drilling.

In Ireland, the bedrock itself is impermeable, and groundwater only flows through fractures or solution conduits in the rock. Therefore, the characteristics and position of water bearing fractures in the rock is a fundamental consideration in the location, design, construction and operation of a water supply borehole.

The diameter or open area of a borehole in Ireland is less important than the width and aperture of the fractures or conduits encountered by the borehole. A two centimetre diameter cavity in a limestone in Ireland is still the same, whether it is encountered by a six inch borehole or a 24 inch borehole. The flow into the borehole is controlled by the diameter of the conduit in the rock, and not the diameter of the borehole (as described below, however, the diameter of the borehole will determine what size of pump can be deployed, with smaller diameter pumps generally having smaller pumping capacities.)

Interconnected fractures or conduits in the bedrock are often isolated from other systems of interconnected fractures or conduits in the bedrock, and from the permeable sands and gravels in the subsoil, and the transition zone between the bedrock and the subsoil, close to a pumping water supply borehole. In other words, it cannot be assumed at the scale of a borehole that the fractured bedrock aquifer behaves in a manner that matches the general aquifer description, and for example, that groundwater levels in the subsoil will be influenced significantly by the withdrawal of water from a fracture system or conduit system deep in the bedrock. Horizontal layers of clay in the subsoil can isolate flow in gravels in the subsoil from flow in the bedrock. Similarly, 30-40 metres of largely un-fractured rock between an upper and a lower flow system in the bedrock can isolate each from the other.

The degree to which groundwater flow systems are isolated cannot be predicted in advance. This introduces a level of uncertainty into borehole design and construction before drilling takes place. However, experience has shown that effective isolation between shallow and deeper groundwater flow systems is common. This separation can be very useful in the context of water quality. It means that a borehole designed and constructed only to draw upon water from deep in the bedrock, can be unaffected by poor quality shallow groundwater flowing in the subsoil or the upper bedrock in the immediate vicinity of the borehole.

3. HOW TO CONSTRUCT A DRINKING WATER SUPPLY BOREHOLE

The information on where to site and how to construct a water well is provided in detail with numerous illustrations in *"Part 3 Guidelines on Water Well Construction"* **of the document** *"Water Well Guidelines"* **as referred to in Section 2.2 above.**

Part 3 of the Water Well Guidelines on constructing a borehole describes:

- *"Drilling a well into a bedrock aquifer"*. followed by
- *"Alternative methods for converting an exploration borehole into a proper water supply borehole"*. This latter section provides details of three alternatives for converting a successful exploration borehole into a suitable water supply borehole. A recommended way of constructing an appropriate water supply borehole in a sand and gravel aquifer.
- Basic information on how to complete the wellhead on a water supply borehole.

The EPA endorses the methodology, descriptions and diagrams given in the IGI *Water Well Guidelines*, and advises that all Local Authorities, State and Semi-State bodies, contractors and consultants follow these Guidelines, and the supplementary information in this Advice Note, when constructing new drinking water supply boreholes in Ireland.

3.1 DESIGN AND CONSTRUCTION OF DRINKING WATER SUPPLY BOREHOLES IN THE BEDROCK

Figure 6 illustrates a water supply borehole that has been designed to draw upon unpolluted water from deep in the bedrock. Drinking water supply boreholes must be designed and constructed with a water well grade PVC pump chamber casing from the surface down to sufficient depth to seal off shallow groundwater in the subsoil and the upper bedrock. The only exception to sealing off the groundwater in the upper bedrock is when the subsoil is very thick and provides good protection around the borehole, and over the bedrock, in the Zone of Contribution (catchment area) of the borehole. As an example, 10 metres or more of clay, or clayey till uniformly covering the zone of contribution for a borehole would usually provide good protection for the groundwater in the upper bedrock that could be exploited by the borehole. Due to hydrogeological differences in the nature of sites and their ground conditions, the conditions for establishing where upper bedrock should be cased off or left open should be determined on a case by case basis. It is the role of the experienced hydrogeologist/groundwater engineer to decide on the design of this element of the drinking water supply borehole, based on the results obtained during the drilling programme and their assessment of existing information on groundwater vulnerability.

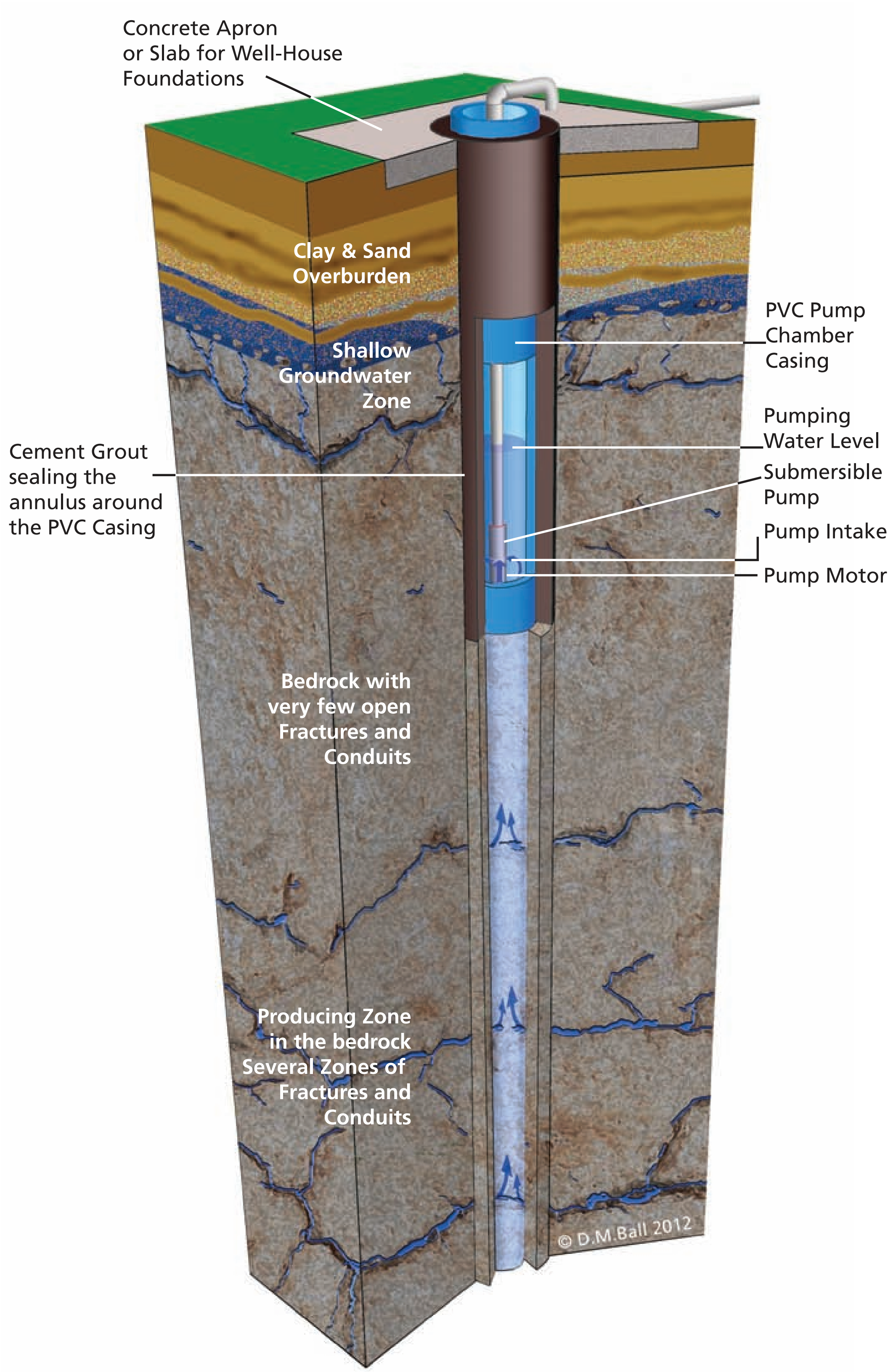


Figure 6. Design for a bedrock water supply borehole in Ireland.

3.1.1 PUMP CHAMBER CASING SELECTION AND SIZE

Water well grade PVC casing is recommended, because it is chemically inert and stable. A list of approved products for use in contact with drinking water has been compiled by the Drinking Water Inspectorate in the UK (*DWI list*). PVC will not corrode in acidic groundwater, and it does not react with strong acids or alkalis that may be used in the development or sterilisation of the borehole. Glass Reinforced Plastic (fibreglass) or stainless steel are alternatives that can be used. The EPA do not recommend that mild steel casing is used for the pump chamber casing. Mild steel casing can corrode or dissolve in low pH and low Eh water, and also provide a source of iron for red biofilms made up of ferrophyllic bacteria. The photograph in Figure 7 was taken during the airlift cleaning and development of a drinking water supply borehole containing 100 m of mild steel casing, and illustrates the highly coloured water that can be associated with the use of mild steel casing.

Airlift surging and pumping to clean iron oxide and ferrophyllic biofilms clogging a Local Authority water supply borehole lined with slotted mild steel casing. The slimey biofilms had clogged the slots in the steel and the small water bearing fractures in the rock. The borehole was pumped until clean and the sustainable pumping rate had increased from 36 to 340 cubic metres per day

Figure 7.

Mild steel casing can only be used where it is known that the groundwater is not corrosive, and it is necessary to 'drive' casing to the design depth through unstable broken rock. PVC casing is brittle and will shatter if it is 'driven' or 'hammered' into the ground. Mild steel casing, with or without a lower 'drive shoe', is stronger.

Boreholes designed to provide drinking water for public supply often require a six inch diameter powerful electric submersible pump. This size and power of pump is required either because the yield and pumping rate of the borehole is large, and / or, because a powerful pump is required to pressurise a delivery main or raise water to a high level reservoir.

The diameter of the pump dictates the diameter of the pump chamber casing. A six inch diameter pump and motor should be installed in an eight inch diameter pump chamber casing. This is to allow groundwater rising up to the pump, from the producing section of the borehole below the casing, to flow easily around, and cool, the pump motor (as shown by arrows in Figure 6). A gap of one inch around the pump also permits the pump to be easily installed, and removed.

The six inch pump described above requires an eight inch casing. To install an eight inch casing and successfully inject an effective cement grout seal into the annulus between the casing and the drilled hole, it is necessary to drill a 12 inch hole in order to install an eight inch casing.

3.1.2 CEMENT GROUTING

The injection of a cement grout into the annulus around the casing is an essential, and very important, component of the construction of a drinking water supply borehole. The grout is injected from the bottom of the casing up to the surface.

The process of cement grouting the annulus around the pump chamber casing is described in Step 5 of Part 3 of the *Water Well Guidelines*. The only difference between the example described in the Guidelines and a Water Services Authority drinking water supply borehole in this Advice Note are the diameters. The example in the Guidelines is for a six inch pump chamber casing for a domestic water supply borehole for a house, or small group scheme. The drilled open hole for the six inch pump chamber casing is 10 inches in diameter, whereas a Water Services Authority drinking water supply borehole would need a 12 inch diameter open hole for the eight inch diameter pump chamber casing. Otherwise the design and methodology are the same.

It is recommended that a grout composed of neat cement and water and a specific gravity of 1.7 to 1.8 is used. Figure 8 shows an example of the consistency of this cement grout. Cement grout is recommended to ensure an effective seal between the casing and the rock and subsoils. The cement grout is easy to emplace, and hardens to form a solid seal that cannot be washed out by groundwater flow in conduits.

It is important to fill the inside of the PVC casing with water before grouting, and to calculate the differential pressure between the column of grout on the outside of the PVC casing and the water column on the inside of the casing. A casing with a wall thickness and collapse resistance that exceeds this pressure by a factor of two is then selected. The water inside the casing reduces the differential pressure, and also dissipates the heat from the hydration of the cement as it sets.

A cement grout of 1.7 to 1.8 specific gravity is much denser than water. It displaces water and air above it when it is injected, via tremie pipes, from the base of the annulus between the borehole wall and the pump chamber casing. The grout will flow into all the irregularities in the hole and will flow into fractures, cavities and conduits in the bedrock and subsoil. The rise of the grout and water levels inside the casing must be monitored continuously by the driller and a hydrogeologist/groundwater engineer experienced in grouting whilst the process is taking place. Changes, such as a sudden fall in the grout level, must be investigated and assessed immediately. Step 5 of Part 3 of the *Water Well Guidelines* describes how clean drill cuttings can be used to bridge across or stop loss of grout into large cavities or conduits. Other proprietary additives can also be used to limit the loss of grout into cavities in the rock.

Grout should never be poured down the annulus from the surface. It must always be injected from the bottom of the annulus to guarantee an effective seal that ensures that shallow more easily contaminated groundwater cannot seep or flow down outside the casing and mix with the better protected deeper groundwater and enter the water supply.

Figure 8. Cement grouting in the annual space around a PVC water well pump chamber casing.

3.2 PUMP POSITION IN THE BOREHOLE

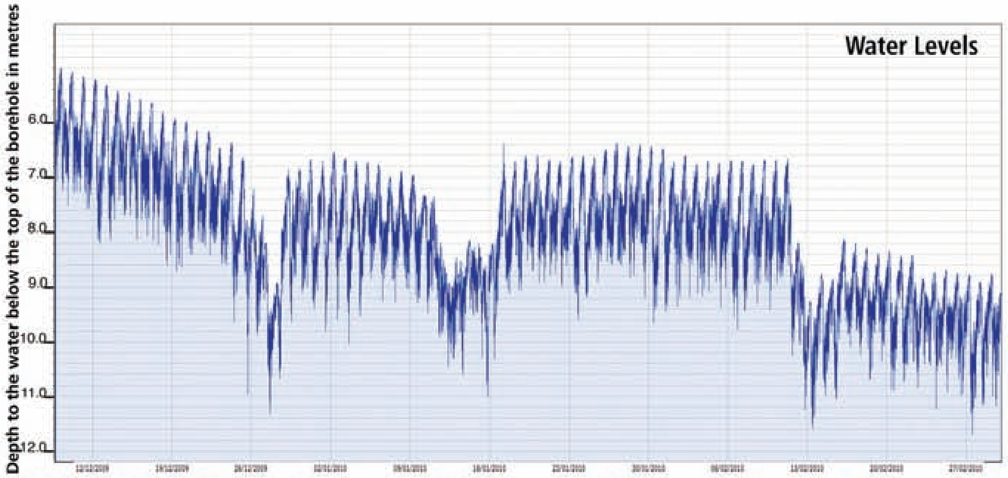
The position of the pump is very important in the design and operation of the drinking water supply borehole. The pump intake should not be below the bottom of the pump chamber casing. The casing is to protect the pump. If the pump is placed below the casing, and often at the bottom of the hole, there is a real danger that an unstable piece of bedrock may fall across, or down the hole, and trap the pump rising main or the pump. When this has happened, attempts to withdraw the pump for servicing or replacement will often fail and the well may be abandoned.

Another reason for not putting the pump deep in the hole is that groundwater can carry sediment from water yielding conduits and fractures in the bedrock. The amount of sediment is not large, perhaps one or two grains of sand per cubic metre of water. However, all the water taken from the borehole has to go through the pump. A small, but persistent, low level of sediment will wear away the pump impellors that are rotating at a high speed inside their separate pump bowls. The efficiency of a pump depends upon an exact fit of the impellor inside the pump bowl. Depending upon the amount, and nature of the sediment, the pump may be worn out in a matter of months. The installation of the pump inside the pump chamber casing above the inflows of water means that all groundwater has to flow up to the pump. Coarse sediment drawn into the hole from a fracture or conduit 20-40 metres below the pump intake will usually settle by gravity down the hole to the bottom and not reach the pump.

A pump motor creates heat when operating. A seven kilowatt pump creates as much heat as a seven bar electric fire. The motor of the pump must be cooled by a continuous flow of water around it. When the pump is installed correctly inside the pump chamber casing, cool water flows past the motor as it rises to the pump intake. By contrast, when a pump is put at the bottom of the borehole, all the flow of water is down the hole to the pump intake. The water in the borehole around the motor, below the intake, is usually static. In addition, sediment can settle at the bottom of the hole around the pump motor. This further limits cooling and temperatures can rise close to 100 degrees, and the pump motor will overheat and cut out.

Putting a pump deep in the borehole below the main water yielding fractures does not increase the sustainable yield from the borehole. Instead, if the water level is pumped down to the pump intake in order to try to get the highest drawdown and highest yield, the opposite will often occur. A drawdown of the water level in the borehole below the water yielding fractures will create a drawdown in the fracture system in the rock adjacent to the borehole. If the fractures in the rock become dewatered, then no water will flow along the dry fracture into the borehole. In other words, the yield from the rock will suddenly decrease. With most of the supply from the bedrock cut off, the water level will rapidly fall in the borehole, until it reaches the 'cut-out' probe, just above the top of the pump. The pump will stop. The water level in the borehole will recover until it reaches the pump 'restart' probe, and then the cycle will be repeated (see Figure 9). This rapid cycling, 'hunting', or turning on and off of the pump, is a very effective way of stressing, and perhaps destroying, the thrust bearing at the bottom of the pump. Ideally, a pump should be operated continuously at a constant rate against a constant head. An example would be pumping water from the borehole to the open inlet in a high level reservoir. The pump operates continuously to meet the total daily demand, and storage in the reservoir meets the surges in demand during the course of the day.

The principle, and sound practice, of putting the pump in the pump chamber casing also applies to shallow drinking water supply boreholes in sand and gravel aquifers, as shown in Part 3 Figure 14 of the *Water Well Guidelines* as referred to in Section 2.2. A pump below a screened section or at the bottom of the borehole will suck in small amounts of sand that passes through the screen, particularly when the



A) Water Supply Borehole pumped at high unsustainable rates for short time periods

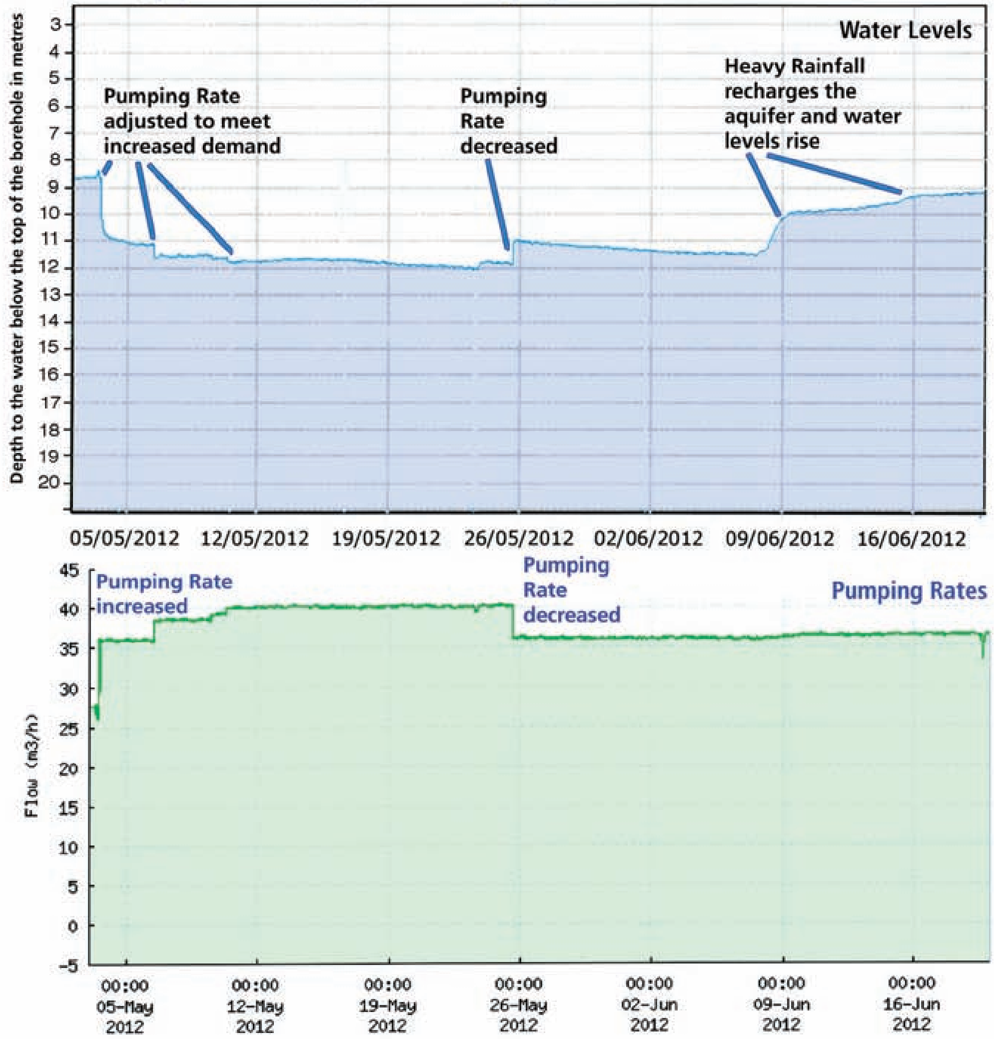

B) Water Supply Borehole pumped at an appropriate sustainable rate

Figure 9. Water supply borehole pumping rates and water levels.

An additional reason is to keep the water level above the open/slotted screen section to avoid air/oxygen ingress and additional rusting/biofouling. The final reason for installing the pump inside the pump chamber casing is to prevent a drawdown in the borehole, and hence a drawdown in the sand and gravel aquifer or the fracture conduit flow system in the bedrock, below the bottom of the casing and the grout seal. The purpose of preventing this is to discourage the ingress of shallow more easily contaminated groundwater into the borehole. If the water level inside the borehole is drawn down below the bottom of the pump chamber casing, then there is the potential to draw down the water level in the aquifer to the same level. Therefore there is the potential for shallow groundwater to flow down through the sand and gravel or rock, and by-pass the barrier created by the pump chamber casing and grout seal. This is more likely to happen in thin, shallow sand and gravel aquifers. It can only happen in bedrock boreholes if there is a good hydraulic connection between the shallow groundwater flow pathways and the deeper flow pathways. An open vertical fault zone or vertical cave close to the borehole can provide such a connection.

3.3 SUMMARY

It can be seen from the foregoing that there are three interlinked design features that are important in the construction and operation of an appropriate drinking water supply borehole as follows:

- The diameter and depth of the pump chamber casing;
- The injection of a cement grout seal in the annulus; and
- The position and operation of the pump.

The EPA recommends that the pump is installed with the pump intake above the bottom of the pump chamber casing in all drinking water supply boreholes.

It is not possible, before drilling commences, to pre-determine the amount of draw-down in the drinking water supply borehole necessary to induce sufficient flow from the aquifer to meet the demands of the water supply scheme. Therefore, the EPA recommends that one or more exploration boreholes are constructed under the full-time site supervision and direction of a hydrogeologist/groundwater engineer. The borehole(s) should be pump tested in order to determine the relationship between water level drawdown in the pumping borehole and the sustainable yield. This information will provide the foundation for designing the production borehole to both exclude shallow groundwater, and yet provide for sufficient draw down in the pump chamber casing to obtain the desired yield from the deeper groundwater system.

The pumping tests may show that it is not possible to obtain a sufficient yield without having a deep pump chamber casing that partially excludes or blocks the flow from important water yielding fractures or conduits in the bedrock due to the large drawdown needed to obtain that particular yield. In this case, the EPA recommends that two or more production boreholes are constructed to create a single source, a ‘wellfield’ that is made up of several boreholes. The water supply demand is met by pumping two or more boreholes gently, with a lower draw down, than trying to obtain all the water to meet the demand from one borehole with a high drawdown.

The IGI *Water Well Guidelines* (Part 3 pages 12 - 13), describes how an exploration borehole can be converted into a production borehole that meets the recommendations of the EPA in this Advice Note.

4. HOW TO COMPLETE THE BOREHOLE AT THE WELLHEAD

The main factors that protect the quality of groundwater obtained by a drinking water supply borehole are:

- The natural characteristics of the ground,
- The design and construction of the borehole,
- The position and operation of the pump, and
- Adequate completion of the wellhead.

The wellhead is the part of the borehole that is visible at the surface. Proper design and completion of the wellhead ensures that the borehole rising main, electric power supply and controls are secure. The proper completion of the wellhead is the final step in the construction of a high quality drinking water supply borehole.

The design principles for wellhead completion are straightforward and as follows:

1. The top of the borehole should be accessible for machinery and people to install or raise the pump, carry out pumping tests, and measure water levels. The borehole should not have a small block-work 'pump house' with a fixed roof built on top of it. Ideally it should be covered by a weather proof and vermin proof, detachable pre-fabricated kiosk that is bolted onto a concrete plinth. The whole kiosk can be unbolted and lifted to provide unrestricted access to the wellhead for servicing the pump. See Figure 10.
2. The top of the borehole should be secure so that unauthorised people or animals cannot get access to openings at the top of the borehole. The top of the pump chamber casing should be sealed by a strong cap or circular plate that is not welded or glued to the top of the casing. The cap should have a hole that will fit the rising main from the pump and the electric cable to the pump. The cap should have a second smaller hole that is at least 25 mm in diameter. This hole may be filled by a 'hydradare' plastic tube that runs all the way down the hole to the top of the pump. The purpose of the tube is to allow instruments to obtain measurements of the static or pumping water levels in the borehole. The internal diameter of the tube must be at least 25 mm in diameter. Note that water level measurements can be made without the 25 mm tube as 25 mm hole in the cap can be used for water level instruments. The 25 mm tube should have an adequate seal or bung when not in use.
3. The top of the rising main above the casing should consist of an elbow or 'T' piece, from which there is a lever valve and short pipe connection for pump testing, scouring or cleaning the borehole. There should be a second valve on the distribution side of the 'T' to prevent back flow from the distribution main.
4. The top of the pump chamber casing should be above flood levels (either natural surface flood levels, or a flood in a wellhead chamber caused by a leaking pipe or valve. Surface water should not be able to flow down the borehole from ground level. The top of the pump chamber casing must be at least 500 mm above the top of the concrete pad around the casing.
5. A concrete pad, apron or slab should be cast around the top of the casing, and the concrete should be 'keyed in' to the cement grout in the annulus around the casing. The concrete pad should be 150 mm thick to a distance at least 500 mm away from the casing in all directions. Ideally, the concrete pad should form the floor slab of the detachable well-head kiosk, and extend beyond the kiosk. If there is no kiosk then the surface of the concrete pad should be sloping at a gradient of 1 in 20 away from the casing.
6. An alternative cover can be provided by a low block work wall on the slab with either a large manhole cover, or large, hinged lockable aluminium plate covers which are sealed to prevent water ingress or animal entry.
7. A secure raw water sample tap of suitable materials (i.e. that can be sterilised prior to sample) to enable sampling of the water prior to any treatment.

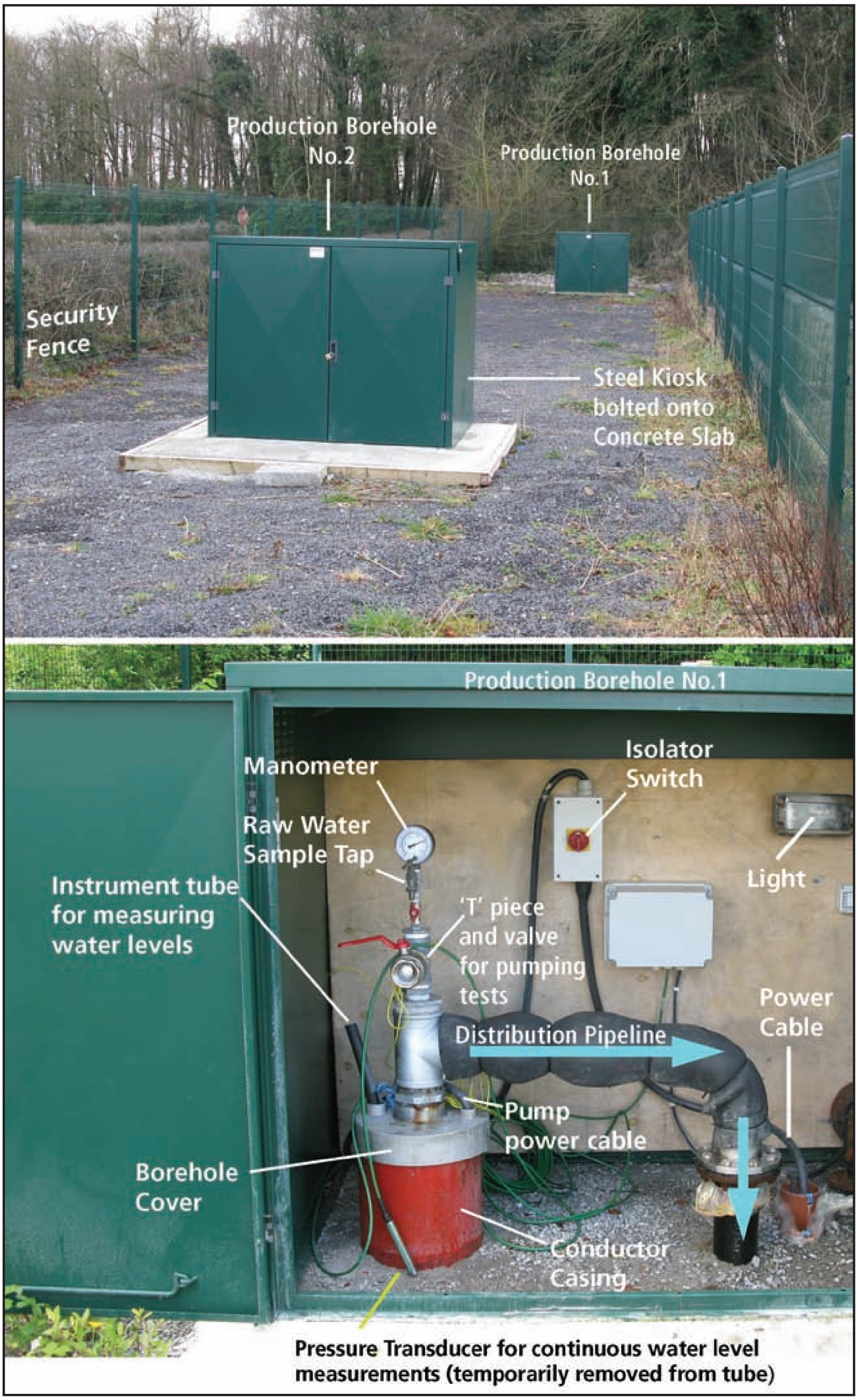


Figure 10. Well head arrangements at a modern wellfield.

It is necessary sometimes in areas of traffic, or for landscape and security reasons to construct a wellhead chamber below ground level. The EPA does not recommend that this is undertaken unless there is convincing evidence that the maximum height of the saturated zone (water table) is never closer than one metre below the base of the proposed wellhead chamber. Every sub-surface wellhead chamber must have a drain hole that is protected with a mesh on the inside of the chamber and perforated pipe to a percolation area outside the chamber. This drainage is important to ensure that leaking or dripping water in the chamber can drain away. A sub-surface wellhead chamber will always have service ducts entering the chamber carrying electric cables or delivery pipes. These often go from the wellhead chamber to a nearby pump house that contains electric controls and also chemicals for water treatment, for example chlorine or fluoride solution. In the past, accidental spillages of these chemicals in the pump house have flowed down the service ducts back to the wellhead chamber, and without drainage out of the chamber, have flooded the chamber and flowed into the borehole. The EPA recommends that all service ducts into the wellhead chamber must be effectively sealed at both ends, and that the subsurface wellhead chamber must have a water tight lid, and a drain at the lowest part of the chamber floor.

Section 2.6 in Part 3 of the *Water Well Guidelines* provides a description of wellhead arrangements and two illustrations.

5. GUIDANCE ON THE ASSESSMENT OF THE CONSTRUCTION OF EXISTING DRINKING WATER SUPPLY BOREHOLES

There is an understandable and natural tendency to pay most attention to the obvious visible condition of the wellhead to the detriment of paying attention to the design flaws and condition of the hidden components of an existing water supply borehole.

It is important to start the assessment with the subsurface. The subsurface provides the context for assessing the more obvious condition of the wellhead. A less than perfect wellhead may be irrelevant within the context of a poorly designed and constructed borehole hidden below the surface.

The assessment process is a series of steps. The first part takes place before visiting the site and consists of obtaining and assessing existing information. The second part occurs at the wellhead and consists of observations and measurements to verify and amend the existing information. The steps are listed and described below:

5.1 PART A - DESK STUDY

Water supply borehole records are seldom found in the ‘pump house’ that is at, or adjacent to, the wellhead. The caretakers or superintendents in charge of the water supply seldom have any written records, or have seen records, of the design or construction details of the water supply borehole. Their information on the position of the pump in the borehole is often based on hearsay, rather than a record based on measurement.

The prime source of this information is contained in the records in the Water Services Section of the relevant Water Services Authority. Some information may be in ‘Capital Projects Section’, or even the Accounts Department, where details of the construction of a borehole have been retained to justify payment of an invoice by the driller. Secondary sources of information are Source Protection Reports, borehole records and consultant’s reports filed in the Groundwater Section of the GSI, and the Water Supply Borehole, or Source Reports compiled by consultants for the EPA. The latter Source Reports should contain all the existing information on a groundwater supply source. However, critical information is often missing because it was not available or found.

An assessment should be made of the existing information and this should include:

1. A plan showing the position of all existing and historical boreholes at a site, and the position of service mains, control valves, scour valves and flow meters;
2. The bedrock and subsoil geology encountered in each borehole;
3. The construction details of each borehole and a description of the drilling compiled either by the driller or a supervising engineer or hydrogeologist;
4. The results of the original and subsequent pumping tests. This should consist of water level and flow rate measurements recorded against time. Ideally, these records should be in the form of graphs and tables;
5. Any digital records of pumping rates, water levels, turbidity and chlorine residual monitoring measurements that have been made in recent years. Ideally, this information should be in the form of graphs with standard scales and tables;
6. All records of water chemistry and microbiology analyses carried out. Ideally, this information should be in a standard format spread sheet so that anomalies or trends in individual parameters can be easily recognised.

This information should be collated and a desk based assessment should be undertaken to ascertain if there are anomalies. It is essential to draw a scaled construction log of each borehole at a site, if it has not already been done by the Water Services Authority or their consultants. The process of drawing the construction log is important because it will probably highlight the basic information that is missing, and the potential weaknesses in the design, construction or operation of each borehole.

Figure 11 highlights the key details that should be included in the borehole construction log, an example of which is shown in Appendix 1.

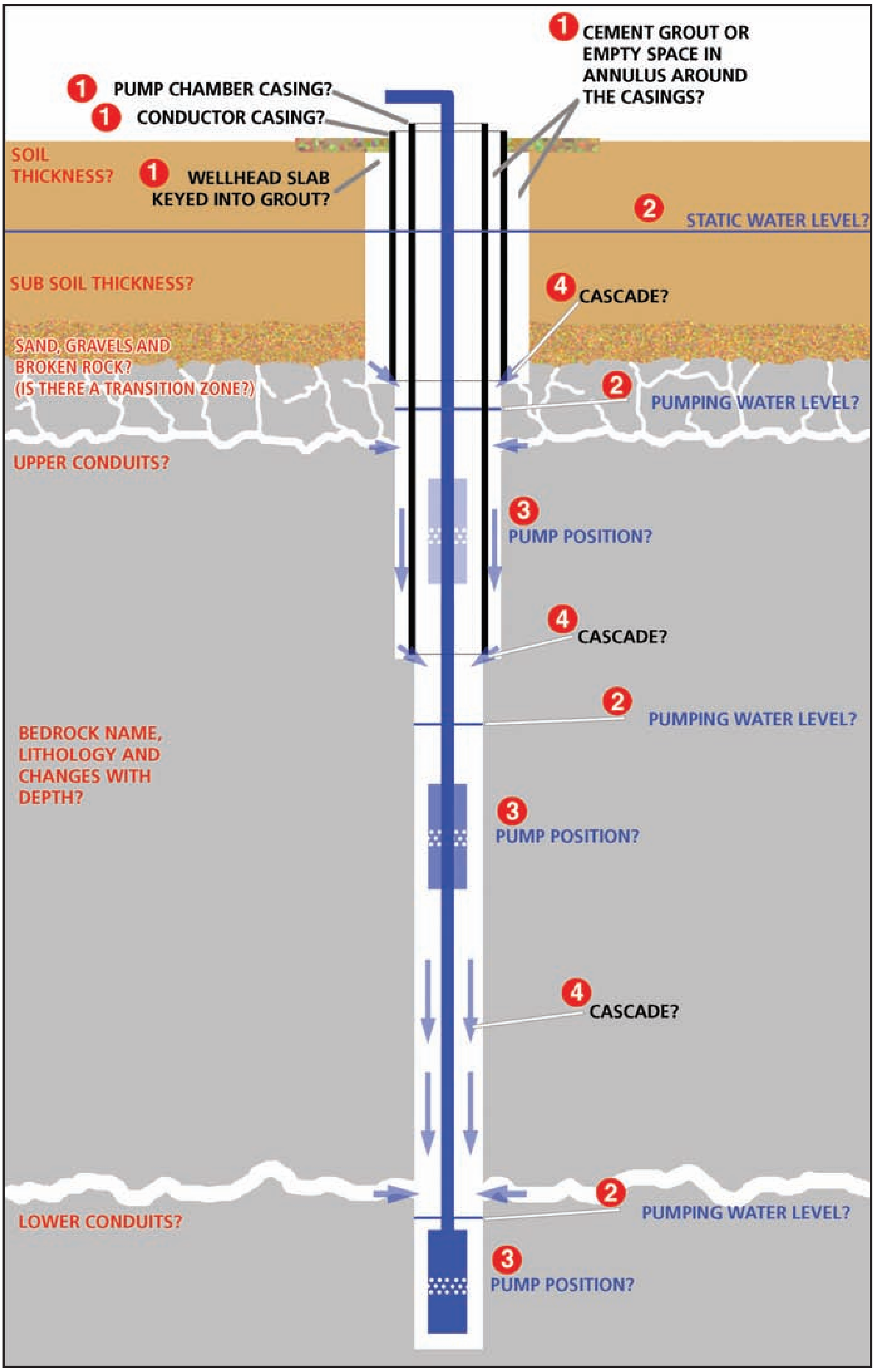


Figure 11. Existing borehole construction log – example of assessment details.

The details shown in the borehole construction log should be correlated and assessed with the information on pumping water levels at various pumping rates and the water chemistry and microbiology information. For example, it might be found that the bacterial quality shows an improvement at the end of a dry summer because the pumping rate is high and the water levels are low. This would suggest that shallow groundwater, containing bacterial pathogens, has been depleted and is no longer making a contribution to the flow from the borehole. This would indicate that the source of bacterial quality issues throughout the rest of the year is shallow contaminated groundwater from the overburden or subsoils leaking into the borehole.

5.2 PART B - SITE ASSESSMENT

The purpose of the site assessment stage is to verify and correct the existing information, and try to obtain missing information. It will be necessary to use basic equipment to carry out the site assessment. See Appendix 1 for checklist.

This equipment would be:

- A 'sounding line' or 'dipper' (otherwise known as an electric water level contact measurement tape) in order to measure groundwater levels in the borehole and also determine the position of the top of the pump;
- A small pear shaped 100 g or 200 gramme fishing weight attached to a 50 metre fine cord or line to act as a plumb bob and line;
- A camera;
- A 5 metre tape measure;
- A bright spotlight/torch and a mirror. The spotlight is to provide illumination when looking down the inside of a borehole. The mirror can sometimes be used for the same purpose. Sunlight reflected from a mirror provides very powerful illumination down a borehole;
- 'Crow Bar' (Nail Bar or Prise Bar) to act as a lever to test whether steel or plastic casing is fixed or loose, and for levering aside pump clamps or lifting man hole covers.

The site assessment should first consist of verifying and correcting the plan showing the location of the borehole(s), pipes, 'pump house', valves, meters, scour pipes and valve.

The wellhead should be photographed and a sketch, labelled with dimensions, should be drawn.

The number, diameters and material composition of all casings observed at the wellhead should be recorded and related back to the borehole construction log (items labelled **(1)** in Figure 11).

The 'sounding line' or 'dipper' should be used to measure the water level in the borehole several times. This should be recorded as either a pumping water level, static water level or recovery water level **(2)**. The water level measurements should be related back to the existing information on water levels.

The 'sounding line' or 'dipper' can then be used, either inside or outside a measurement tube, to feel for the top of the pump **(3)**. If there is an obvious danger that the sounding line might become stuck, then it is advisable to use the plumb bob and line. Sound travels easily through water. The sound of a metal probe or plumb bob striking the top of the pump is usually audible when listening close to the top of the hole.

Usually, it is not possible to get a sounding line or a plumb bob beyond the pump inside the casing in a production borehole unless the pump is over to one side of the hole. Boreholes, and casing, are rarely perfectly straight or absolutely vertical. A borehole is usually a very gentle helix shape and can be off vertical by 1-2 degrees.

It is important to either turn off a pump that is in operation, or turn on a pump that is not in use, and then listen at the top of the borehole. The objective is to listen for the sound of water flowing into the borehole. It might be a noisy cascade or the sound of water squirting or spraying against the rising main, casing or borehole walls **(4)**. It is important to take water level measurements whilst listening. The depth at which the sound of water pouring into the hole suddenly ceases can be measured as water levels rise after the pump has been turned off. Conversely the level at which the noise of water starts to be heard can be measured during drawdown when a pump has been turned on. Listening, whilst measuring water levels, can provide invaluable information on leaks through the casing, leaks or flow around the bottom of the casing or flow into the hole from fractures or conduits in the bedrock. The information obtained should be correlated with the borehole construction log.

The site assessment stage is a forensic investigation. The basic measurements will often indicate the need for further tests, measurements or sampling. It is not possible within the limits of this Advice Note to prescribe every measurement, test or interpretation that can be made. It is important that a hydrogeologist or groundwater engineer with considerable field experience of water supply borehole drilling, testing and operation is engaged to carry out at least Part B of the assessment of an existing water supply borehole.

5.3 REMEDIAL ACTION

The results of the Desk Study and/or the Site Assessment of an existing drinking water supply borehole should be interpreted and assessed in light of the guidance provided for new water supply boreholes. Flaws or weaknesses in the existing water supply borehole and pumping arrangements may need to be adjusted, retro-fitted or repaired.

It is relatively easy to improve the protection at the wellhead or adjust the pump position. However, it is usually either very difficult, or expensive, to pull out old casing from a borehole, re-drill the upper hole and then re-fit a new pump chamber casing with a proper cement grout seal. Consideration should be given to drilling and constructing a new borehole in line with this Advice Note where this is appropriate. The water supply borehole assessment report should include recommendations and detailed proposals for remedial actions.

The assessment of the vulnerability of the existing borehole construction will also influence the type of treatment necessary for the water supply. The cost effectiveness of installing and operating increased treatment as opposed to repairing, or constructing a new borehole should be considered by the Water Service Authority prior to undertaking any action.

Where a new borehole is constructed it is important to deal appropriately with the old borehole. An old borehole is likely to provide a vertical conduit that forms an open link between the shallow and deep groundwater resources. The old borehole could, in effect, 'short-circuit' the improved design and protection in an adjacent new water supply borehole. It is important to obtain appropriate design advice and construction supervision from an experienced hydrogeologist or groundwater engineer in order to back fill and decommission old water supply boreholes after a new borehole has been constructed. It is important to ensure, during the back-filling of the old borehole, that the materials used and their emplacement does not adversely impact the new borehole.

6. CONCLUSIONS

This Advice Notes sets out the recommended guidelines on how to construct a water supply borehole to internationally accepted standards to minimise the risk of contamination of the borehole from surface water and shallow groundwater which may contain pathogens and other contaminants. These guidelines should be followed when constructing new boreholes. Water Services Authorities and other water suppliers should examine existing boreholes to assess the vulnerability of the supply. This should be done in the context of the Water Safety Plan approach as outlined in EPA Advice Note No. 8. Where this assessment identifies an unacceptable risk to the quality of the water supply the Water Services Authority or private water supplier will need to implement remedial measures to reduce this risk. These measure may include remediation of the borehole (e.g. where surface water ingress is the main issue) or replacement of the borehole where it is not feasible to remediate the existing borehole.

7. REFERENCES

1. EPA (2011). *EPA Drinking Water Advice Note No. 8: Developing Drinking Water Safety Plans.*
2. IGI (2007). *Guidelines on Water Well Construction.*
3. IGI (2007). *Summary.*
4. IGI (2007). *Explaining Groundwater and Water Wells*
5. WHO (2011). *Guidelines for Drinking Water Quality (4th Ed).*
6. DWI List *hyperlink for Approved List*
7. SEPA Good Practice for Decommissioning boreholes and wells. *SEPA guidance link*

APPENDIX 1

Local Authority Water Supply Borehole Construction Check List

Prior to auditing the boreholes at each site try to obtain before, or request that they are brought to the site, the following:

- drillers and or consultants borehole geology and construction logs
- details of pump position and pump specification
- details of pumping tests
- records of present pumping regime
- records of water quality analyses
- records of chlorine and flourine dosage
- source protection reports

Request that the borehole(s) have been turned OFF for at least about two hours before your scheduled visit to give groundwater levels time to recover. Request that the Area Engineer and the borehole superintendant are present. The first objective is to confirm or revise existing information on each water supply borehole. The second objective is to confirm compliance with the EPA Advice Note 14.

On Site carry out and assess the following:

1. Walkover the site and draw a preliminary borehole site plan. Photograph the covered wellhead and surrounds. Inspect the interior of the building housing the pump controls and water treatment arrangements. Inspect any ledger or diary record of daily pumped volumes and chemical usage. Make notes as appropriate.
2. Record the flow meter reading.
3. Remove the borehole cover. Measure and draw a preliminary plan and section of the wellhead. Measure casing diameters and pipe diameters. Photograph the exposed wellhead. If the wellhead is in a chamber, check the side walls to see if there are any gaps through which shallow groundwater, or surface water, can enter. Look for 'tide marks' on the side of the chamber.
4. Request the removal of any debris from around the wellhead, or inside a wellhead chamber.
5. Request the use of a steel bar, shovel or pick axe to assess the wellhead grout seal around the casing.
6. Shine a bright light down the borehole between the casing & pump rising main.
7. Measure the static water level below a clear reference point (e.g. top of casing).
8. Ask for clarification of the depth of ON and OFF contact probes pump controls.
9. If feasible lower the 'sounding line' slowly down the hole between the pump rising main and the borehgole casing. Note depths where the probe is constrained. Note sounds of the probe hitting metal, try to reach the reported depth of the top of the pump. Confirm pump depth.
10. Set up to measue pumping water levels.
11. Ask that borehole pump is turned on. Measure and record the depth of the falling water level in the borehole at regular intervals*. Listen carefully to sounds from inside the borehole. In the first seconds and minutes listen for the sound of cascading water. Try to record the depth of the water when these sounds first occured. If the sounds stop, record the time and depth.
12. Plot the drawdown on an arithmetic scale graph during intervals between readings.
13. Towards the end of the test, run water through a clear glass, sample bottle, observe whether bubbles are entrained in the water. Leave the water sample to settle and observe whether there is sand/silt at the bottom of the bottle.
14. Towards the end of the test observe the workings of the dosing equipment.
15. Stop the pumping either when the lower contact probe automatically switches off the pump, or when the drawdown does not appear to be significantly increasing.
16. Record the time and the volume pumped.
17. Measure the recovery of water levels. Listen and record the time and depth when noises from inside the borehole (such as cascades or drips) stop.
18. Ask the borehole superintendant about problems, accidents, uncertainties, leaks, history of pump replacements, pollution events. Record relevant information.
19. Complete the observations and measurements necessary to fill in the Water Supply Borehole Field Audit Sheet.
20. Correlate and assess all existing information within the context of the above field observations, follow up uncertainties, and determine the compliance of the water supply borehole construction with the EPA Advice Note 14.

*mins - 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 16, 18, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100 as required.

WATER SUPPLY BOREHOLE FIELD AUDIT SHEET

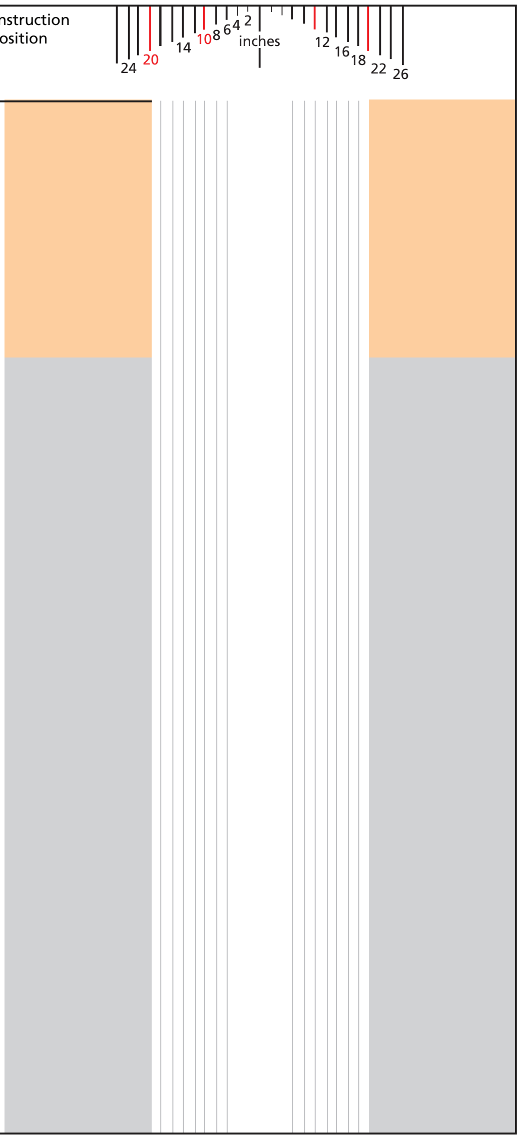
borehole name and number

date

plan of well head

Section of well head

borehole construction and pump position



depths

borehole site plan

descriptions