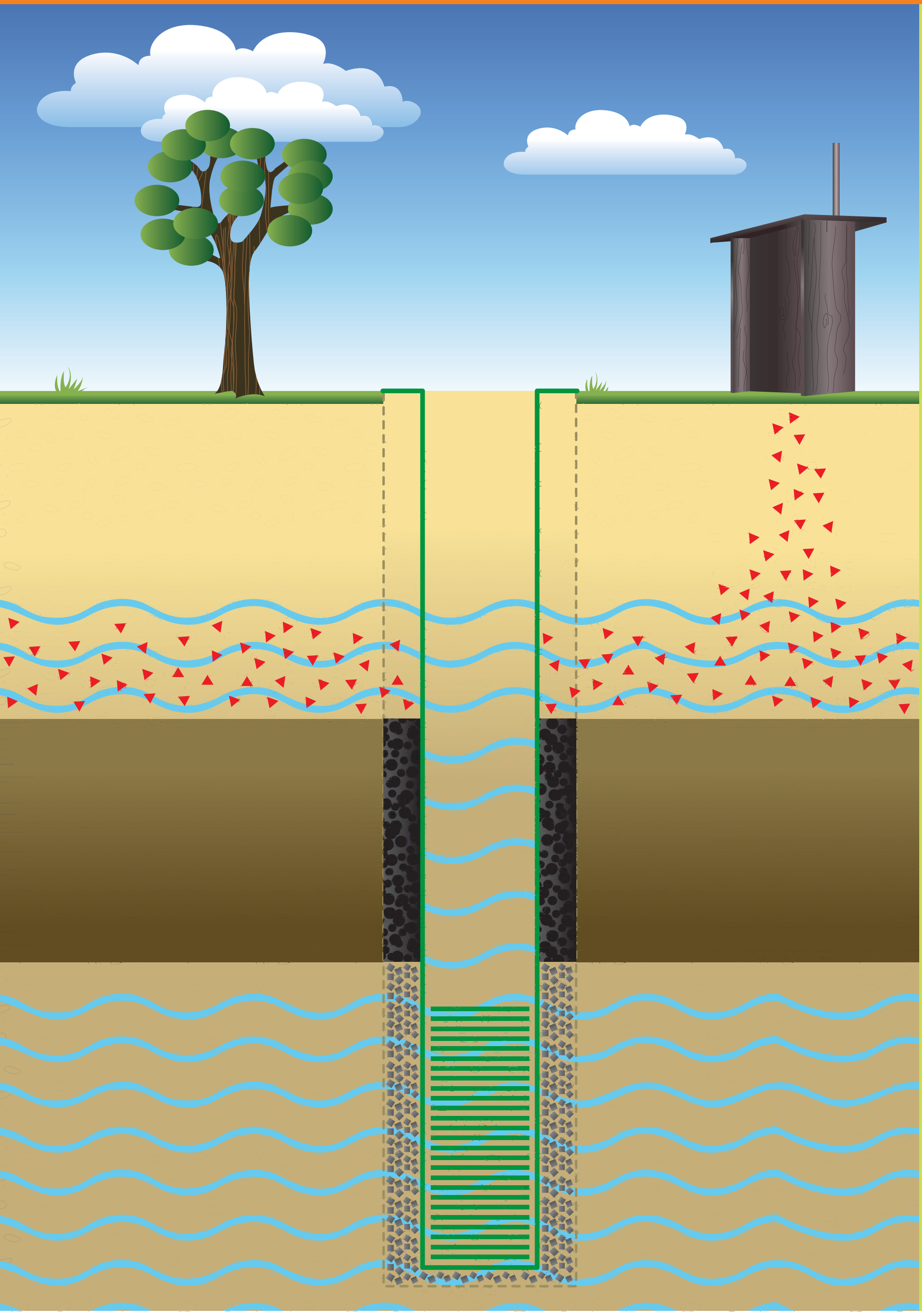
UNDERSTANDING GROUNDWATER & WELLS

in manual drilling



INSTRUCTION HANDBOOK

for manual drilling teams on hydro-geology for well drilling, well installation and well development

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UNDERSTANDING GROUNDWATER & WELLS in manual drilling

Instruction handbook for manual drilling teams on hydro-geology for well drilling, well installation and well development

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PRACTICA Foundation develops and disseminates low-cost appropriate technology in water and renewable energy in developing countries. We focus on technology that responds to local cultural contexts, can be locally produced and maintained, and supports existing markets.

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Disclaimer

This instruction manual is available in English and in French and Swahili and has been developed for use in technical training courses organised for the intended users. In case you want to organize such training, you may contact the PRACTICA Foundation for further information and support.

The first edition of this publication was made possible by a financial contribution from the Technical Training Programme of the ETC Foundation in the Netherlands and the United Nations Children's Fund - UNICEF - office in Chad. An updated version of this publication (the second edition) was made possible by a financial contribution from the United States Agency for International Development (USAID) as part of the West Africa Water Initiative (WAWI).

The United Nations International Children's Fund (UNICEF), PRACTICA Foundation and Enterprise Works/Vita have developed a toolkit for African countries wishing to embark on the professionalization of manual drilling. This toolkit includes Technical Notes, Technical Manuals including this publication, Advocacy Materials, Mapping of suitable areas for manual drilling, Case Studies, and Implementation and Training Manuals. This initiative builds the capacity of the local private sector in order to respond to the ever increasing demand for safe water in rural areas.

The Technical Training Program (TTP) of the ETC Foundation contributed with structural support in the educational aspects of this manual.

Foreword

Context

Over the years much literature on geology, hydrogeology and hygienic aspects has been written and in a lot of countries this information is used by policy makers, project managers, engineers and technicians to construct machine-drilled wells in their countries.

Machine-drilled wells are often very expensive and not affordable by large parts of the population in developing countries. Another option is to drill 'shallow' water wells (up to about 35 meter depth) by hand, so reducing the price of a well by a factor 4 -10 compared to a machine-drilled borehole. This cost reduction not only enables NGOs and Governments to construct more water wells, but also 'opens the door' to villagers, farmers, schools and small communities to have a well constructed independently through the private sector.

Although most of the existing manual drilling enterprises are technically able to drill boreholes, mistakes are easily made during the construction and development of the wells. Furthermore good well construction alone does not ensure good water quality and sustained yield from the well over many years. In order to achieve that, know-how on geology and groundwater is important.

However, many technical workers of manual drilling enterprises may have limited education. Much of the available literature on geology, hydrogeology and hygiene cannot easily be understood without an advanced education.

Technical workers are used to learn through experience and repetition. Of course training could be given to these workers but classroom training alone is known to be insufficient for drilling teams. They need to relate theoretical information to the real practical problems which occur regularly while working on drilling sites.

This book therefore only deals with those essential subjects which are relevant to manual drilling and well installation in practice, in simple and understandable language.*

*Note

Technical terms and the way in which subjects are explained are based on the average expected educational level of the intended users. Sometimes, the use of complicated geological and technical terms has been avoided to create better understanding. Some words (for example 'soil' or 'gravel pack') have been used because they are known by the intended users, although these words are not always the terms that are used by geologists. Please keep in mind that the objective of the handbook is to create better understanding of well drilling in practice, aimed at technical workers of manual drilling teams who may have a limited educational background.

READERSHIP

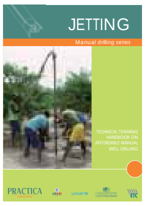
This handbook can be used as a guide during training sessions for well drillers, local trainers and quality controllers. It also serves as a reference for drilling supervisors, NGOs, development agencies, manual drilling teams and enterprises during the entire drilling process. The handbook consists of three sections that can be read together, or used and printed separately for the various target groups.

Colophon

AVAILABLE MANUALS IN THIS SERIES:

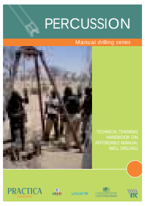
Technical training handbooks on affordable manual well drilling.

These practical handbooks create awareness of manual drilling for affordable water supply and a roadmap for implementation of manual drilling programs. The manuals provide an extensive and detailed guide for trainers and drilling teams in the use of various drilling techniques for making affordable boreholes. The techniques are explained in simple and understandable language, using clear illustrations and drawings.



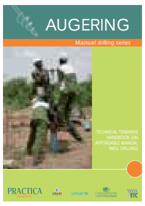
1. Manual drilling series: JETTING

This handbook describes in detail the various jetting techniques that can be used to drill wells in loose and soft soil formations. With this technique, wells are drilled in a number of hours rather than days.



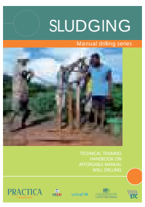
2. Manual drilling series: PERCUSSION

This handbook describes in detail the percussion technique. Although the technique is slower than other drilling techniques, it is the only manual drilling technique that is able to drill through consolidated rock layers.



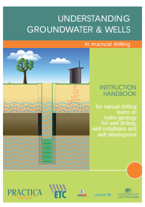
3. Manual drilling series: HAND AUGER

This handbook describes the hand auger technique. This cheap and effective technique is very suitable for sinking shallow wells in soft soils and is excellent for soil surveys. Many drilling teams have this technique in their toolkit to complement other drilling techniques.



4. Manual drilling series: SLUDGING

This handbook describes the sludging technique, and in greater detail the ROTA-sludge technique. It is a combination of sludging and percussion and is particularly useful due to its versatile application for a range of soil formations.



5. Manual: ‘Understanding Groundwater and Wells in manual drilling’

The manual ‘Understanding Groundwater & Wells in manual drilling’ complements the 4 technical training handbooks and highlights those essential subjects which are relevant to manual drilling, geo-hydrology, hygiene, well installation and well development in practice, in simple and understandable language.

Table of contents

INTRODUCTION

MAKING A WELL

The construction of a well, using manual drilling techniques is a complicated process. Before drilling starts a good drilling site has to be selected, where experience suggests that there will be an adequate quantity of good quality groundwater. During the drilling process there are a lot of different aspects which require attention to prevent things from going wrong. Besides the practical drilling skills which are executed at ground level, at the same time attention has to be paid to important processes which are happening below ground level during drilling. Water used in drilling (working water) could flow away or worse; the borehole could collapse, burying part of the drilling equipment. And finally, once the hole has been drilled, the well casing, screen and sanitary seals have to be installed at the right depth, preventing contaminated water from entering, and ensuring a sufficient yield.

In many countries manual drilling teams experience problems with site selection, loss of working water, soil determination, logging, well installation, well development, water quality and well yield (flow rate of the well). These problems may occur when the drilling process is not completely understood and important steps are missed.

This instruction manual describes many of the subjects and problems which you may come across during drilling. The manual will help you to understand the drilling process at ground level and far below ground level in the drilled hole. With the information provided you will be able to understand what is taking place in the hole during drilling, and perform a professional job as you construct high quality water wells.

THE MANUAL

How does this instruction manual work? In the table of contents (see previous page) an overview is given of the subjects and where to find them.

Chapter 1 to chapter 8 contains all the information needed for a good understanding of the drilling process and correct well installation. In the Appendix you will find country specific regulations. These are regulations designed for communal wells and defined by the government or NGO you are working for. In the Appendix you will also find some specific geological conditions, which are unique for the area or country you work in. Furthermore, simple 'blank' drilling logs are included, which can be copied for use in the field.

ADDITIONAL INFORMATION

For more detailed background information for policy makers, project managers, implementing NGOs, trainers and supervisors, some useful titles of existing books and manuals are given at the end of this instruction manual.

1 BASIC GEOLOGY

1.1 GEOLOGY

Geology is *the study of the earth*. It describes the origins and formation of the rock types under the surface of the earth. The original material or "building blocks" of the earth are the *hard rocks* such as granites and *volcanic formations*, formed when molten material cooled beneath or at the surface of the earth. These are known as the *igneous rocks* ("made by fire"). It is from these rocks that *sedimentary layers* have been formed.

Sedimentary layers are formed by the *weathering*, transport (by wind or rivers) and *deposition* (sediment) of particles broken down from rocks. Those particles can range in size from extremely fine (clay particles) through silt-sized to the larger sand and gravel particles. Sedimentary layers may be *unconsolidated* (loose such as clay and sand) or consolidated *(cemented together)* to form harder rocks such as sandstones and lime stones.

Some examples:
The *clay particles* of the clay layer that you have encountered during drilling may have arrived from somewhere else. The clay particles were formed by the weathering of rocks. Then they may have been eroded and transported to your drilling location by a river or the sea. Finally the clay particles were *deposited* (sediment, settled down) in still water, for example a lake.

In the same way a *sand or gravel* layer could have been deposited. The sand and gravel particles may have been transported by a river and were deposited along the river bed. Although now there may not be a river or a lake present, the deposition of particles could have happened thousands or even millions of years ago. Another way to transport particles is by wind. Particles can be blown to another location by the wind.

When a mixture of sand and fine particles has been *compacted* by pressure, created by the weight of layers on top of it and *cemented* by minerals present in the mixture, *sandstone* is created. Sandstone is hard and may look like solid stone, but is in fact *consolidated sediment* and may be possible to drill through.

These are just some basic examples. It goes too far to describe the deposition of all sedimentary layers in detail. The sedimentary surface layers of the earth are most important to manual drillers. Especially hard layers such as sandstone, compacted clay, fragments of un-weathered rock and laterite pose challenges to manual drilling because of their hardness.

1.2 MANUAL DRILLING TECHNIQUES

To drill through all these different types of formation (soil) a whole range of different manual drilling techniques have been developed and used around the world. In each case the drilling technique must (a) break or cut the formation, (b) remove the cut material (the soil) from the hole, and (c) if necessary provide support to the walls of the hole, to prevent collapse during drilling. A short overview of techniques;


Hand auger

THE HAND AUGER consists of extendable steel rods, rotated by a handle. A number of different steel augers (drill bits) can be attached at the end of the drill rods. The augers are rotated into the ground until they are filled, then lifted out of the borehole to be emptied. Specialized augers can be used for different formations (soil types).

Above the water table, the borehole generally stays open without the need for support. Below the water table a temporary casing may be used to prevent borehole collapsing. Drilling continues inside the temporary casing using a bailer until the desired depth is reached. The permanent well casing is then installed and the temporary casing must be removed. Augers can be used up to a depth of about 15-25 meters, depending on the geology.

Advantage: *easy to use above groundwater table. Cheap equipment.*

Disadvantage: *it may be difficult to remove the temporary casing.*

Geological application: Sand, silt & soft clay.


Rota sludge

SLUDGING (or Rota-sludging when the drill bit is rotated) uses water circulation to bring the drilled soil up to the surface. The drill pipes are moved up and down. On the down stroke, the impact of the drill bit loosens the soil and on the up stroke, the top of the pipe is closed by hand (or valve), drawing up the water through the pipe and transporting the cuttings to the surface. On the next down stroke, the hand (valve) opens the top of the pipe and the water squirts into a pit, in front of the well. In this pit, the cuttings separate from the water and settle out, while the water overflows from the pit back into the well. The borehole stays open by water pressure. Thickeners (additives) can be added to the water to prevent hole collapse and reduce loss of working water (drill fluid). Sludging can be used up to depths of about 35 meters.

Advantage: easy to use and temporary casing is not needed.

Disadvantage: working water has to be maintained during the drilling process. The level of the water table is not known during drilling.

Geological application: Sand, silt, clay, stiff clay and softer-consolidated rock formations (weathered laterite).

Jetting

JETTING is based on water circulation and water pressure. As opposed to sludging, water is pumped down the drilling pipes. The large volume of water has an erosive effect at the bottom and the 'slurry' (water and cuttings) are transported up between the drill pipe and the borehole wall. A motor pump is used to achieve an adequate water flow. The drill pipe may simply have an open end, or a drill bit can be added and partial or full rotation of the drill pipe can be used.

Thickeners (additives) can be added to the water in order to prevent hole collapse and reduce loss of working water (drill fluid). Jetting (with rotation) is generally used up to depths of 35-45 meters.

Advantage: very quick in sand.

Disadvantage: a lot of working is needed at once. The level of the water table is not known during drilling.

Geological application: limited to sand and thin layers of soft clay.

Percussion

MANUAL PERCUSSION uses a heavy cutting or hammering bit attached to a rope or cable and is lowered in the open bore hole or inside a temporary casing. Usually a tripod is used to support the tools. By moving the rope or cable up and down, the cutting or hammering bit loosens the soil or consolidated rock in the borehole, which is then extracted by using a bailer. Just as with hand augering, a temporary casing of steel or plastic may be used to prevent the hole from collapsing. When the permanent well screen and casing are installed, this temporary casing has to be removed. Manual percussion drilling is generally used up to depths of 25 meters.

Advantage: drills hard formations.

Disadvantage: the equipment can be heavy and expensive. The method is slow, compared to other methods.

Geological application: Sand, silt, stiff clays, sandstone, laterite, gravel and small stones.

Various other techniques

All existing manual drilling methods can be divided into four main drilling principles: Hand Auger, Manual Percussion, Sludging and Jetting. Within these four main drilling principles, a wide range of variations have been developed in various countries.

1.3 SOIL CLASSIFICATION AND DETERMINATION

An essential quality of a professional driller is his ability to recognize and describe different types of soil (formation material) encountered during drilling. For the classification of the different particles in a soil sample the following table can be used (a more detailed description is given in the glossary of terms in the back of this manual):

Particle name	Particle size
Clay	< 0.004 mm
Silt	0.004 – 0.06 mm
Sand (fine, medium, coarse)	0.06 – 2 mm
Gravel and pebbles	2 – 64 mm
Stones and boulders	> 64 mm

For the construction of a good quality well it is essential to know the *characteristics* of different soils and their influence on the yield (water discharge), water quality and performance of the well. In fact, knowing the *characteristics* of the soil is even more important than to name different soils exactly itself.

First of all it is very important to know whether the types of soil drilled are *permeable* or *impermeable*.

Permeability

Permeability is a measure of the ability of a soil (or formation) type to transmit water through it. In other words;

Figure 1 ; blue is water, white is soil

Sand and Gravel

When coarse sand or gravel is put into a bucket of which the bottom is perforated and a cup of water is added on top of it, the water moves easily through the sand to the bottom of the bucket (fig. 1). The water flows easily through the pores (open space) between the grains. Conclusion; water *easily flows through* sand and gravel. Sand and gravel are thus very *permeable*. When a well-screen is placed in a sand or gravel layer, the water flow through the sand into the well will be high, because the water easily flows through the sand to the well-screen (fig. 2). However, when drilling with water pressure (see paragraph 5.1) 'working water' also easily flows out of the bore hole into the sand layer.

Clay and loam

The opposite is seen with clay and loam. When wet clay is put in a bucket (compressed as in a layer of soil) and a cup of water is added, the water will remain on top (fig. 1). Clay particles are very small (and 'sticky') as are the pore spaces between the particles. Conclusion; Water does *NOT easily flow through clay*. Clay is therefore described as *not permeable or impermeable*. If a well-screen is placed in a clay layer, the water flow into the well will be very low (fig. 2), (in this case, when drilling with water pressure (paragraph 5.1) no additives (par. 5.2) are necessary).

Figure 2: permeability

sand and gravel,
very permeable

clay and loam,
impermeable

mixed soil,
semi permeable

Mixed formations

In most cases the formation consists of a mixture of clay, silt, and sand or gravel particles. For example, clay and sand (sandy clay) can exist as a homogeneous layer (clay and sand are mixed) or in alternating thin layers (layered; small sand and clay layers on top of each other). When those soils are put in a bucket and a cup of water is added, the water slowly flows through the soil (fig. 1).

Conclusion: *Water flows slowly through* mixed soils and they are therefore described as *semi permeable*. When a well-screen is placed in a mixed or layered layer, the discharge of the well will be low (fig. 2).

Field 'tricks'

Sometimes it might be difficult to determine the difference between *permeable or impermeable* layers.

This is a small trick to help you:

Take a representative sample of the soil (paragraph 4.2) and squeeze it into a ball, between your hands. Then drop the ball from a height of one meter above ground level. The ball falls down on the ground.

1. If the ball consists of non cohesive (non-sticky) particles, the ball totally falls apart. In this case the material is *permeable*. The particles of sand or gravel will be easily visible.
2. If the ball falls apart only partially, the soil contains some silt or clay and sand. The formation will have a *low permeability*.
3. If the ball only deforms and/or remains more or less in shape, it is composed of clay, and is described as *impermeable*.

Porosity

Sedimentary layers consist of many particles such as sand, silt and clay. Between these particles there is still a lot of open space called pores. The porosity is a measure for the percentage of free space in the formation. A porosity of 30% means that 30% of the total volume of the sample is open space while the remaining 70% is filled with particles. The pores can be filled with air or water.This does not always mean that the water easily flows through the soil. For example, clay has a high *porosity*, but low *permeability*.

Bottles of water showing low and high turbidity

Turbidity

Turbidity is a difficult word for the *cloudiness* of water, caused by very small particles in the water (called suspended particles), rather like smoke of a fire in the air. Clay and silt-sized particles are very fine. When these particles are found in water they cause it to be turbid or cloudy. If well water is extracted from a clay or silt layer, some of the fine particles in the formation may be transported by the flow and get suspended (mixed) in the water. As a result the water will look cloudy.

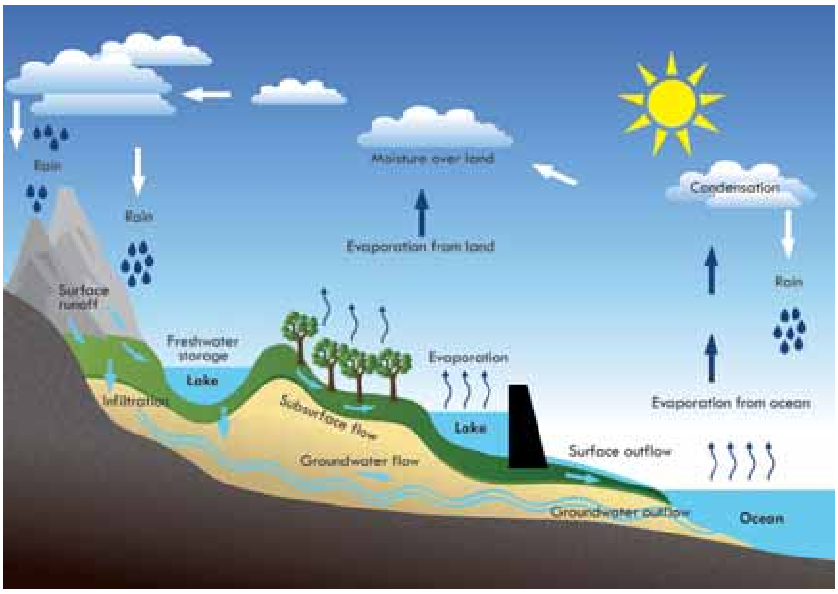
Conclusion

Always continue drilling until a large *permeable* layer (sand or gravel) is reached and install the entire well-screen in this layer. If the layer is permeable, the water flow to the well will be high (the yield of the well will be high). In addition, when the layer consists of sand and does not contain very small particles, the water will be very clear (not turbid).

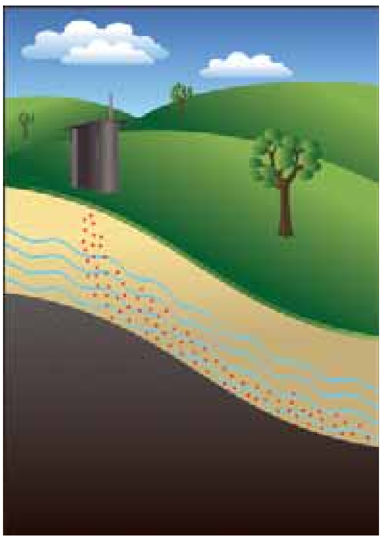
2 HYDROLOGY

2.1 HYDROLOGY

Hydrology describes the *cycle of water* as it rises from the sea and the earth's surface as water vapor. This vapor forms clouds, which fall somewhere else to the earth as rain. Part of the water penetrates in the ground and becomes part of the groundwater while another part flows through streams and rivers, back into the sea. From here the whole cycle can start all over again.



For drillers it is important to know in particular about the location and movement (flow direction) of groundwater in permeable water bearing layers (aquifers), and factors affecting the quality of groundwater.



Latrine and flow of water

2.2 GROUNDWATER FLOW

Just as surface water moves in a river, also *groundwater flows* (although much slower) through the pores and cracks of the formation (groundwater does not stand still). It is not always easy to determine the *flow direction* of groundwater. Still it can be of great importance for the water quality of the well to know in which direction the groundwater is flowing and where the groundwater came from. Imagine a *latrine* close to a well which is to be used for drinking water. The last thing you want is that *bacteria*, *viruses* and *parasites (disease-causing micro-organisms called pathogens)*, originating from the latrine, will flow together with the groundwater to your well (par. 3.1, latrines).

Although it can be difficult to detect the flow direction without detailed surveys, in the case of shallow groundwater, examination of the landscape can help. For instance, when a latrine is located on the slope of a hill or a mountain, the groundwater (contaminated with bacteria) is likely to flow in the same direction as the slope of the hill. In this case it would not be good to place the well *down-slope (downstream)* of the latrine, but rather on the same level or *higher up (up-slope)* of the latrine.

When the area is less hilly, a good indicator can be the presence of a gully, stream or river. Rivers always flow through the lowest-lying parts of the area. And groundwater in turn generally flows to rivers. Be careful: this only counts for a naturally present river, not for man made channels.

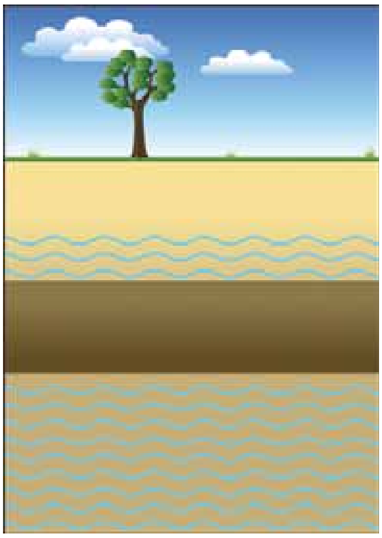
It is NOT preferable to construct the well *down-stream* of the latrine.

Catchment area

Groundwater is fed by the infiltration of rain through the soil and it eventually *flows to lower areas and rivers*. Although this might be difficult to see on the surface (without detailed investigations), always try to imagine where the groundwater would flow to, especially during the dry season. On top of a mountain for instance, the groundwater level can drop dramatically during the dry season, because at that time the groundwater that flows out of the pores of the formation to lower areas is not replaced by infiltrating water from rainfall. Only when the rains start the groundwater level will rise again.

2.3 AQUIFERS

The word '*aquifer*' simply means '*a water bearing layer*'. A good aquifer for the installation of a well-screen is a *permeable layer* below the groundwater table (par. 1.3). During drilling you may come across different aquifers at different depths, separated by *impermeable layers*.



Different aquifers

Phreatic aquifer

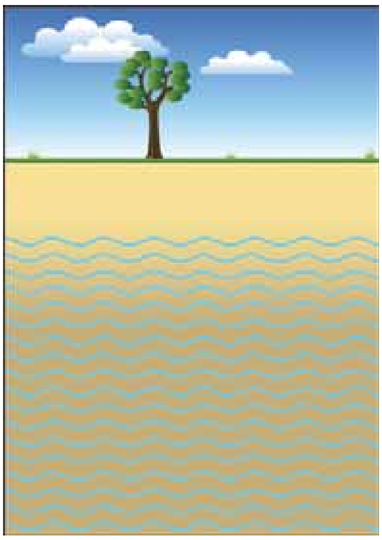
The *upper* aquifer is called the '*phreatic*' aquifer. Rainwater directly infiltrates the soil. The water moves down and when it reaches the water level it is added to this aquifer. The water can take contamination (such as bacteria or pesticides) down into the groundwater. Therefore a phreatic aquifer is prone to pollution from activities taking place on surface (par 3.1). *Phreatic groundwater* exists in a *permeable layer* above an *impermeable layer*. If this phreatic groundwater layer is just a few meters thick, it may run dry during the dry season, leaving your well empty.

Second aquifer

The next aquifer, covered by an impermeable layer on top (for example, a clay layer) is called the '*second*' aquifer. The impermeable layer above this water bearing layer forms a barrier for bacteria and pollution and prevents them from traveling down to the second aquifer (please, see par. 3.2!).

! If there is a second aquifer present, it is generally best to install the well-screen in this *second* aquifer.

Below the second aquifer again an impermeable layer and a third aquifer may be present.

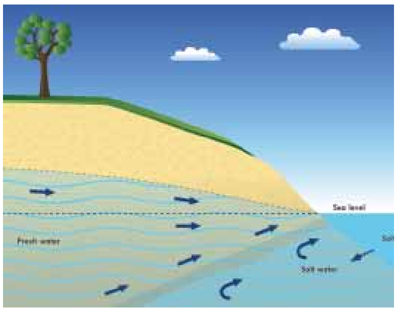


One aquifer

One aquifer

Sometimes only one aquifer is present. In this case it is recommended to drill as deep as possible to prevent bacteria and pollution from entering the well. Drilling deep also reduces problems of wells drying up because of seasonal fluctuations (difference between wet and dry season) of the water table.

! For further explanation and important information on aquifers and hygiene, see chapter 3.



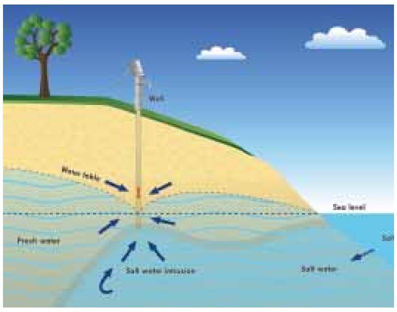
Fresh water on top of salt water

2.4 SEA WATER INTRUSION

In coastal areas, a deeper aquifer could contain salty sea water. Also, during the dry season when the water table is lower, salty sea water could move inland. When this happens it is called *saltwater intrusion*. Salt water is heavier than fresh water. This means fresh water tends to float on top of the salt water layer.

When a well is drilled in a coastal area where *saltwater intrusion* exists, the salty water may move up, due to the suction of the well (see drawing).

Therefore in coastal areas, drilling deeper will NOT always be the best option.



Salt water intrusion

2.5 SALT, IRON AND MINERALS

Besides pollution from the surface (bacteria and chemicals, par 3.1) or salt from the sea (par 2.4), water can taste bad or be damaging to health due to *natural minerals* in the aquifer. These minerals have been present since the formation of the different geological layers and are now dissolved in the groundwater. Some well-known examples of natural minerals (natural chemicals) in groundwater are Calcium, Chloride, Carbonate, Arsenic, Fluoride and Iron, but many more exist. Some minerals, like Arsenic and Fluoride, can damage health badly and therefore a sample of the groundwater has to be analyzed in a laboratory to find out if these chemicals are present. Luckily in most places concentrations of these minerals are low and so the water is safe for drinking.

Some examples:

Salt

When well water <u>in a non-coastal area</u> tastes salty, it is important to determine the origin of the salt. For example, if in the same area two other wells are drilled and completed, at different depths (deeper or shallower), fresh (or less salty) water may be found (just taste the difference between the water from the different wells). Look for different colors or crystals in the soil samples; these may be the origin of the salt.

Iron

The same approach may help when iron is found in the water. Sometimes water has a bad metallic taste and the color of the water turns brown when it is left in a bucket or boiled. The water may create rusty looking spots on clothes and cooking material. This indicates the presence of high iron concentrations. The presence of high levels of iron may cause people to reject the water source. Iron is a very common element of groundwater.

'Peat water'

Peat

When, during drilling, remains of old plants are found, it is recommended not to install a well-screen in this layer. Plant remains, below the water table, are decomposing very slowly and create an acidic environment. A common example is peat. Groundwater extracted from a peat layer smells like decomposed plant material, is very acid and looks brown (see photo).

Acidic groundwater (low pH)

The pH is a measure of the *acidity* of water. If the pH of the water is low the water is considered acid. In areas of acidic groundwater (with a low pH) the acid in the water may cause corrosion to the steel and cast iron components (parts) of a hand pump. In such cases a type of pump made of PVC, plastic or stainless steel components may be considered.

Hard water (hardness of the water)

If water from the well has a high content of the minerals calcium (for example when drilling in limestone and chalk) and magnesium it is called *hard water*. Hard water is generally not harmful (safe for drinking). However, it may give some problems while washing your clothes: Soap lathers (gives foam) easily in soft water but not in hard water. In other words, if the hardness of the water is high it may be difficult to use soap.

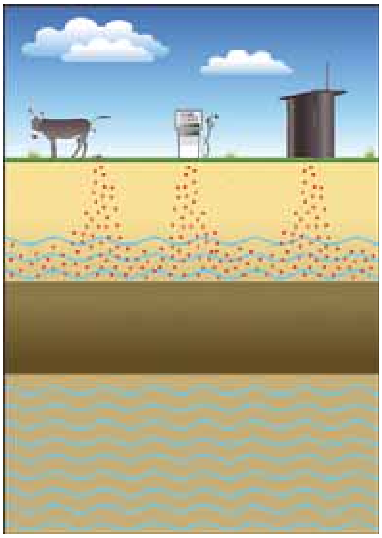
3 HYGIENE IN RELATION TO GEOLOGY

3.1 SITE SELECTION

Before the drilling of a new well starts, a good drilling *site* has to be found. In most cases the villagers or owner of the new well will point out a location which is suitable for them as users. But this may NOT necessarily be the best location to get the best quality of water! As a professional driller you will have the responsibility to inform your clients about *hygiene* and the most hygienic location for the well.

There are two important aspects to keep in mind:

- The presence of sources of pollution such as *latrines, waste (dump) areas, fire places* and *fuel stations*
- *Sun* or *shade* at the location of the well



3 Pollution of the aquifer

Latrines

Some people may find it practical to have their well constructed close to their house or latrine. Unfortunately, in doing so, they may not realize that a well close to a latrine could be contaminated with (micro) organisms such *as bacteria*, *viruses* and *parasites*. Some of these organisms can cause disease (like diarrhea) when the water is used for drinking and are called pathogens. The *pathogens* from the human waste in the latrines move downwards *through permeable* layers, and so locally contaminate the groundwater (see figure 3). Although *pathogens* will not survive long outside the human body, it will take a while before they die off completely. Therefore groundwater close to latrines can contain living and harmful *pathogens*. In selecting a good site for the well, it is recommended to construct the well NOT *down-stream* or *down-hill* (par. 2.2) from a latrine. If it is difficult to determine the groundwater flow direction, construct the well at least <u>30 meter away</u> from the latrine.

Waste (dump) areas, farms, fire places and fuel stations

The same applies to areas where waste is dumped and burned or where *fuel* or other contaminants (for example pesticides or animal waste on farms) may seep into the groundwater, which then will become contaminated. Chemicals in drinking water can cause serious damage to health, (failure of body functions and deformations).

Presence of bacteria indicated by algae

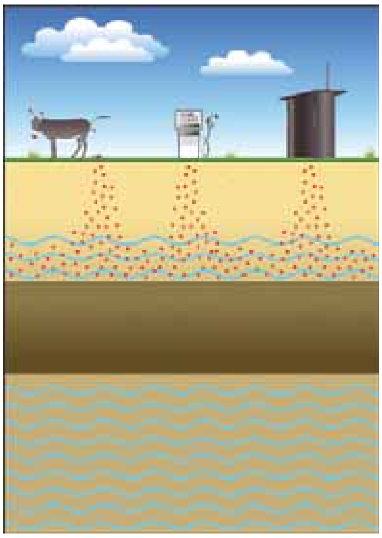
Sun or shade

While drillers may prefer to drill in the shade, it is NOT the best location for a well. A lot of people will visit the well to fetch water, unaware that harmful *pathogens* are traveling on the soles of their feet. For example the bacteria can be picked from street refuse or from a *latrine* if someone has just been to the toilet. These contaminants will be washed off the feet in the well surrounding, which is often wet. These contaminants are a threat to the quality of the drinking water. When a well is placed in the shade, *bacteria* and *algae* will flourish (see photo).

If the well surroundings can dry up daily, the sunlight will disinfect the well surroundings causing all *pathogens* to die.

3.2 MIGRATION OF PATHOGENS (BACTERIA)

As we have seen in the previous paragraph, *pathogens (bacteria, viruses and parasites)* and chemicals *move* downward with the infiltrating (rain)-water through permeable soil layers to the groundwater. Once in the groundwater the *pathogens* and chemicals not only spread *horizontally* (left-right), but also *vertically* (up-down), deeper into the aquifer (see par. 2.3).

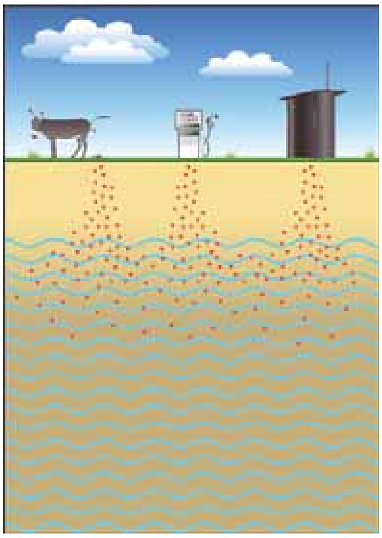


4 Bacteria migration in different aquifers

Different aquifers, figure 4

In par. 1.3 we have seen that groundwater easily flows through permeable layers (aquifers) like sand and gravel. *Pathogens* and *chemicals* which are suspended (mixed with) or dissolved in this groundwater also *easily migrate (move) through permeable layers!*

Water with *pathogens* has to be stopped before reaching the surroundings of the well-screen.Fortunately often *impermeable* layers can be found. Water, and thus the *pathogens* in this water, *does not easily* flow through these impermeable layers. Due to their fine texture (very fine particles), impermeable layers prevent *pathogens* from further vertical migration down into the underlying aquifer. Because the impermeable layer *blocks* the *pathogens* from downward migration, the next lower aquifer contains water without the harmful *pathogens* and chemicals originating from the surface.
(fig. 4).



5 Bacteria migration in one aquifer

One aquifer, figure 5

Sometimes however, only one aquifer exists within reach of manual drilling equipment, for instance a 50 meter thick permeable sand layer.

Although there is no impermeable layer in this case, further down into the sand layer the number of living pathogens will decrease gradually (every meter down, fewer pathogens will be present). It takes time for the pathogens to travel down and while doing so they die off over time.

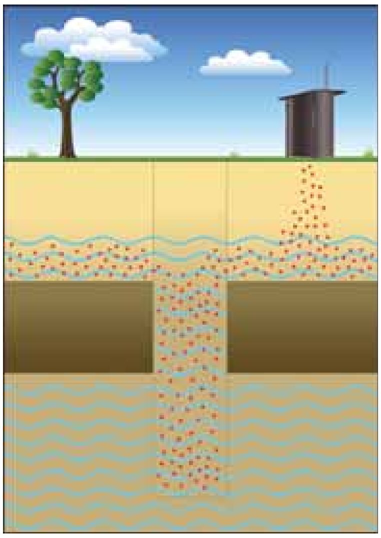
However, there is no impermeable layer to prevent downward movement of pathogens and other contaminants, which marks the exact depth at which contaminants are not further present (fig. 5). Therefore it is recommended to drill as deep as possible at locations where only ONE aquifer exists.

3.3 SANITARY SEAL

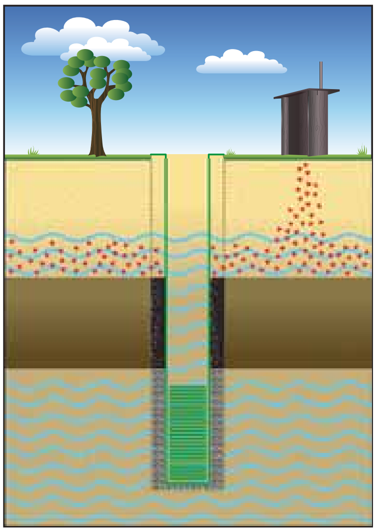
In the previous paragraph we have learned to drill through the impermeable layer to the second aquifer, in order to find clean drinking water. But by doing so, a new problem is being created!

By drilling through the impermeable layer, a connection, *(a short cut)* is created between the first and the second aquifer. Drilling a hole through an impermeable layer is a little like taking the 'plug out of the sink', so enabling contaminants to flow down from the polluted layer to the clean, second aquifer and enter the well-screen (fig. 6).

! To prevent pathogens and chemicals from entering the filter screen and polluting the second aquifer *a sanitary seal* has to be placed *(please see paragraph 6.4).*



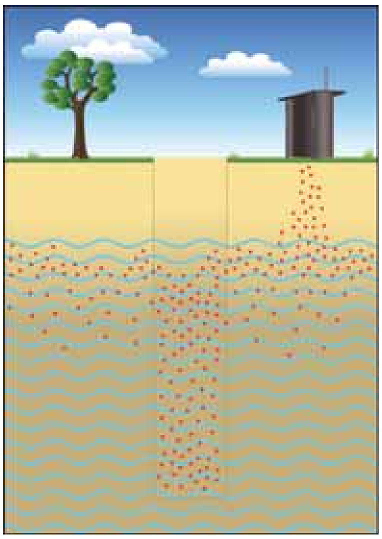
6 Bacteria migration in different aquifers



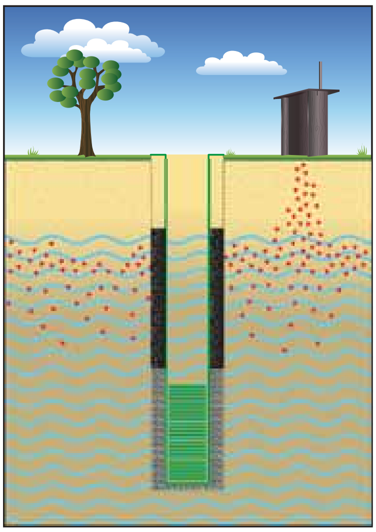
7 Bacteria migration in different aquifers with installed well and sanitary seal

When a borehole is drilled, a well-screen will be installed and a gravel pack placed (par. 6.5). Then the impermeable layer has to be sealed (closed), to prevent contaminants from traveling down into the second aquifer. This is done by a *sanitary seal*. The *sanitary seal* (par. 6.4) is made of cement or bentonite (natural clay which swells to many times its dry volume when wetted) which will seal (close) again the impermeable layer (see fig. 7).

When only ONE *aquifer exists* (fig. 8), a sanitary seal with a thickness of at least 3-5 meter has to be installed above the gravel pack, to prevent the contaminants from entering the well-screen (fig. 9). Water (and pathogens) can travel faster down the loose material in the borehole than though undisturbed soil. An impermeable seal will force the water to flow through the normal undisturbed soil, thus increasing the traveling time (the pathogens die off over time) from the surface to the filter screen.



8 Bacteria migration in one aquifer and the borehole



9 Bacteria migration in one aquifer with installed well and sanitary seal

4 DRILLING LOGS

4.1 WHY DRILLING LOGS

In chapter 1 we learned to install our well-screen in a *permeable layer*. Chapter 2 showed the existence of *different aquifers*. In chapter 3 we have seen the necessity for the installation of a sanitary seal above the gravel pack (which surrounds the well-screen) and/or to seal off the *impermeable layer* above the second aquifer. These are all important aspects of the construction of a well with a good yield of clear and clean water, which is free of contaminants.

! It is therefore very important to determine the exact location (depth) of *permeable layers (aquifers)*, and the location of any *impermeable layers* in our borehole!

To do this, simple but accurate *drilling logs* should be created. A drilling log is a written record of the geological formations (soil layers) drilled, according to depth. Soil samples should be taken at regular depths (e.g. every meter) and described during the drilling process. The soil description is then recorded in the form of a drilling log. The drilling log will help us to determine:

1. The *right aquifer* for installation of the well-screen
2. Depth and length of the well-screen
3. Depth and thickness of the gravel pack
4. Location of the *sanitary seal*

Database

Besides the direct use of drilling logs in the field, drilling logs are also very important to record the hydro geological information of the drill site. For example, if at a later stage other wells have to be drilled in the same village or area, it is very useful for the drilling team to know the geology, depth of the water table and likely total drilling depth. Previous drilling logs are an essential source of information for these purposes, before the new drilling starts. This information could be important for the choice of the drilling equipment. The drilling logs can be kept together in a file, which is called a database. By taking care to record and preserve good drilling logs, the drilling team will present itself as a professional and skilled team to their clients.

Soil samples

Coarse sand sample

4.2 TAKING SOIL SAMPLES

The first step in making a drilling log, is to take *representative samples of the soil (geological formations) encountered in drilling*. This means: the sample should be a pure piece of the layer that is being drilled at the moment of sampling (avoiding mixing the sample with soil from other layers!). Samples should be taken every meter and/or every time the formation (soil) type changes. The samples should be put on a plastic sheet (write down the depth if the sample is not immediately described), away from the drilling activities. Then described and recorded on the drilling log (see appendix C) with the depth at which the soil sample was taken.

4.3 DRILLING DEPTHS

In the previous chapters we have learned to install a well-screen in a permeable layer (chapter 1), which is ideally an aquifer underlying an impermeable layer (chapters 2 & 3).

The final drilling depth is reached when at least 4-6 meter has been drilled into a water bearing permeable sand or gravel layer.

It is then recommended to drill *two extra meters* for installation of the sump (see par. 4.5 and 6.2) and as a *reservoir* for paricles in the borehole, to settle down in, during the well casing installation process (par. 6.5).

4.4 FILLING IN THE DRILLING LOGS

Step 1

Describe samples during every break in the drilling process and write down the depth, name and characteristics on the drilling log (see par. 1.3).

Drilling log

Drawing: PVC pipe	Back-fill	Formation type	Depth (meter)	Description of the formation	hard / soft fine / coarse	Color(s) of the sample
			1	Sand	fine	yellow/brown
			2	Sand	fine	yellow/brown
			3	Sand	fine	yellow/brown
			4	Sand	fine	yellow/brown
			5	Sand	fine	yellow/brown
			6	Sand	fine	yellow/brown
			7	Sandy Clay	………	brown
			8	Sandy Clay	………	brown
			8.5	Sandy Clay	………	brown
			9	Clay	compact	grey
			10	Clay	compact	grey
			11	Clay	compact	grey
			12	Clay	compact	grey
			13	Clay	compact	grey
			14	Clay	compact	grey
			15	Sand	coarse	yellow
			16	Sand	coarse	yellow
			17	Sand	coarse	yellow
			18	Sand	coarse	yellow
			19	Sand	coarse	yellow
			20	Sand	coarse	yellow
			21	Sand	coarse	yellow
			21.5	Sand	coarse	yellow
			22	Sandy Clay	………	grey/brown
			23	Sandy Clay	………	grey/brown
			…….	………………	………	…………

Step 2

Then, especially important for those who can not write, hatch the formation column and show the difference between permeable, semi permeable and impermeable layers by different hatching.

Drilling log

Drawing: PVC pipe	Back-fill	Formation type	Depth (meter)	Description of the formation	hard / soft fine / coarse	Color(s) of the sample
		(permeable)	1	Sand	fine	yellow/brown
		(permeable)	2	Sand	fine	yellow/brown
		(permeable)	3	Sand	fine	yellow/brown
		(permeable)	4	Sand	fine	yellow/brown
		(permeable)	5	Sand	fine	yellow/brown
		(permeable)	6	Sand	fine	yellow/brown
		(low permeable)	7	Sandy Clay	………	brown
		(low permeable)	8	Sandy Clay	………	brown
		(low permeable)	8.5	Sandy Clay	………	brown
		(impermeable)	9	Clay	compact	grey
		(impermeable)	10	Clay	compact	grey
		(impermeable)	11	Clay	compact	grey
		(impermeable)	12	Clay	compact	grey
		(impermeable)	13	Clay	compact	grey
		(impermeable)	14	Clay	compact	grey
		(permeable)	15	Sand	coarse	yellow
		(permeable)	16	Sand	coarse	yellow
		(permeable)	17	Sand	coarse	yellow
		(permeable)	18	Sand	coarse	yellow
		(permeable)	19	Sand	coarse	yellow
		(permeable)	20	Sand	coarse	yellow
		(permeable)	21	Sand	coarse	yellow
		(permeable)	21.5	Sand	coarse	yellow
		(low permeable)	22	Sandy Clay	………	grey/brown
		(low permeable)	23	Sandy Clay	………	grey/brown
			….	………………	………	…………

By hatching, now the *permeable*, *semi permeable* and *impermeable* layers become visible. Following hatching styles are used:

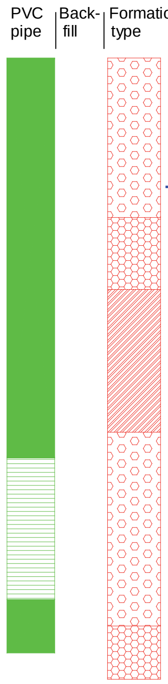
- *Permeable*
- *Low permeable*
- *Impermeable*

Let us assume *the groundwater level* * is at 5 meter below ground level. In this example we can see a second aquifer between 14 and 21.5 meter.

Step 3

Now the *well-screen* length and depth can be determined, which is further explained on the next page, in paragraph 4.5.

Drilling log



Depth (meter)	Description of the formation	hard / soft fine / coarse	Color(s) of the sample
1	Sand	fine	yellow/brown
2	Sand	fine	yellow/brown
3	Sand	fine	yellow/brown
4	Sand	fine	yellow/brown
5	Sand	fine	groundwater
6	Sand	fine	yellow/brown
7	Sandy Clay	....	brown
8	Sandy Clay	....	brown
8.5	Sandy Clay	....	brown
9	Clay	compact	grey
10	Clay	compact	grey
11	Clay	compact	grey
12	Clay	compact	grey
13	Clay	compact	grey
14	Clay	compact	grey
15	Sand	coarse	yellow
16	Sand	coarse	yellow
17	Sand	coarse	yellow
18	Sand	coarse	yellow
19	Sand	coarse	yellow
20	Sand	coarse	yellow
21	Sand	coarse	yellow
21.5	Sand	coarse	yellow
22	Sandy Clay	....	grey/brown
23	Sandy Clay	....	grey/brown
......	....	....	....

In this example a 6 meter *well-screen* was installed between 15 and 21 meter below ground level. And a 1.5 meter *sump* was attached to the bottom end of the well-screen.

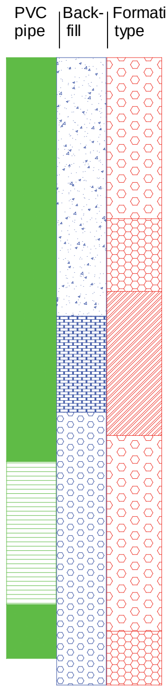
Blind PVC casing pipe and sump

Well-screen

Step 4

Once the well-screen and PVC casing are hatched in the first column, the exact depths for the annular backfill *(i.e. gravel pack, sanitary seal and cuttings)* can be determined by use of the drawings on the drilling log.

Drilling log



Depth (meter)	Description of the formation	hard / soft fine / coarse	Color(s) of the sample
1	Sand	fine	yellow/brown
2	Sand	fine	yellow/brown
3	Sand	fine	yellow/brown
4	Sand	fine	yellow/brown
5	Sand	fine	groundwater
6	Sand	fine	yellow/brown
7	Sandy Clay	....	brown
8	Sandy Clay	....	brown
8.5	Sandy Clay	....	brown
9	Clay	compact	grey
10	Clay	compact	grey
11	Clay	compact	grey
12	Clay	compact	grey
13	Clay	compact	grey
14	Clay	compact	grey
15	Sand	coarse	yellow
16	Sand	coarse	yellow
17	Sand	coarse	yellow
18	Sand	coarse	yellow
19	Sand	coarse	yellow
20	Sand	coarse	yellow
21	Sand	coarse	yellow
21.5	Sand	coarse	yellow
22	Sandy Clay	....	grey/brown
23	Sandy Clay	....	grey/brown
......	....	....	....

Cuttings

Sanitary seal

Gravel pack

Note: This drilling log is designed to be filled in by both people who can write and who cannot write. The drawings are intended to assist in visualizing the geological layers and well completion details.

! Using the drilling log and drawing, the soil types *(i.e. permeable, low permeable and impermeable)* will therefore simplify determination of the exact location for the *well-screen* and annular *backfill.*

To resume: *filling in the drilling logs is a 4 step process:*

1. *Describe the samples and depth*
2. *Indicate permeable and impermeable layers*
3. *Mark the casing, screen and sump in the column "PVC pipe"*
4. *Mark the backfilling and sanitary seal(s) in the column "backfill"*

* Groundwater level

When a borehole is drilled 'dry', meaning without the use of drilling fluid, the depth of the water table can easily be determined during drilling. The soil that comes out during drilling will be wet when the groundwater level is reached.

With a fluid-drilled borehole (see chapter 5), the borehole is kept full of water to maintain water pressure. In such cases, the groundwater level will not always be known from the hole drilled. It then can help to have local people indicate where the water table is likely to be on the basis of a hand dug well, other completed boreholes or river in the neighborhood.

In an area which is new to the drilling team it is advised to drill the first well to the maximum possible depth (in a good aquifer), and measure and record the water level after the well construction.

4.5 DETERMINE THE DEPTH OF THE WELL SCREEN AND BACKFILLING

Once the soil descriptions are hatched on the drilling log, the visible information can be used to determine the exact depth of the well-screen and annular backfill. The drilling log shown above is used in the explanation below.

Well-screen, position and length

The well-screen usually does not exceed a length of 6 meter, for manually drilled boreholes. Fine materials are often present in the extreme upper and lower parts of an aquifer. Also thin clay layers might exist in the aquifer. To prevent the *fines* (which may cause turbidity and pump damage) from entering the well-screen it is important NOT to install the well screen at the same level as these fines in the aquifer. In other words; be sure that the whole screen length is installed in a *permeable layer*, consisting of sand or gravel! To achieve this in some cases the screen length might be less than 6 meters (but should generally never be less than 3 meter, see par 6.2).

! Although carefully taken, the exact *depth* of origin of the soil samples might not always be accurate. To avoid *fines* from entering, it is wise to install the well screen and backfill with a safety margin of at least 1 meter. In the drilling log above, the well-screen was placed in the middle of the aquifer, leaving a 1 meter margin of sand at each end.

Sump

After the installation and during the use of a well, some *soil particles* may still enter the well-screen. The bigger particles (which can cause damage to the pump) *settle down* to the bottom of the well by gravity. To prevent loss of well-screen surface area, a *sump* of 1-2 meter in length, with a closed bottom end is attached to the well-screen (for details on PVC casing and well-screen see par 6.2).

Thickness of the gravel pack

Once the well-screen position is recorded (hatched) on the drilling log, the position and thickness of the *gravel pack* can be determined. The annulus (open space) around the well-screen is filled with coarse sand or fine gravel of specific size (gravel pack), up to about 1-2 meter above the top of the well-screen. The extra meters are necessary because during the development of the well, the gravel pack will *settle* (and shrink). It is therefore good practice to include at least 1-2 meter safety margin above the well-screen during installation of the gravel pack (for details see par 6.3).

Thickness of the sanitary seal

When an impermeable layer is drilled through, it is advised to *seal* (close) again <u>that whole</u> impermeable layer with clay (bentonite) or cement (par 3.3). To be sure the layer is sealed properly, the thickness of this *seal* should be at least 3-5 meter.

If no impermeable layer was found, and the well is thus placed in the first aquifer, the *sanitary seal* should be installed directly on top of the *gravel pack* (1-2 meter above the well-screen) and should have a thickness of at least 5 meter (for details see par 6.4).

Cuttings

On top of the sanitary seal, backfilling of the drilling hole is done by using the *cuttings* (soil which was drilled up during the drilling process).

Sanitary top-seal

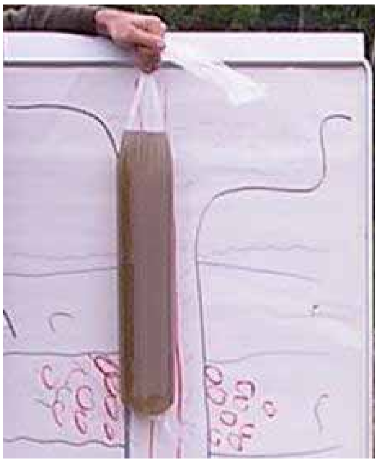
Also a sanitary top-seal of 3-5m thickness should be placed from 3-5m below ground to the surface (for details see par 6.5).

Drilling team filling in the drilling log

5 WATER PRESSURE AND DRILLING FLUIDS

5.1 DRILLING WITH WATER PRESSURE

In paragraph 1.2 we have seen different manual drilling techniques. Some techniques, like the auger and percussion methods, make use of a temporary casing when the groundwater table is reached, to prevent the borehole from collapsing during drilling. Other techniques, like sludging and jetting use water pressure.



A bag of water

Simulation of water pressure in the 'borehole' (bucket)

Collapse of the 'borehole' (bucket)

Temporary casing

It is easy to understand how a temporary casing protects the hole from collapsing. The casing (pipe) is strong and acts like a wall. Soil from the sides of the borehole simply can not pass through the casing. However, the only drawback is that it has to be removed afterwards (when the well-screen is installed). This can be very difficult or it can even become impossible when a drilling was made through a clay layer (the casing can become stuck in the sticky clay).

Water pressure

While a casing pipe is strong and solid, water is just soft and liquid. How is it then possible for water to hold open a borehole while drilling in wet sands?
To find the answer to this question, let's first take a close look at an example we all know; *A bag of water.*

1. Fill a transparent bag (long) with water, for instance one of those drinking water bags which are commonly sold on the street (see photo). Now squeeze the lower part of the bag between your thumb and fingers. It takes very little effort to press the plastic inwards. Then again release the bag. As you see, the plastic returns to its former shape. What happened?

The weight of the water in the upper part of the bag pushed the plastic bag back into its former shape. What you just felt is water pressure.

2. Now put the bag in the middle of a bucket and fill the bucket with very wet sand to one third the height of the plastic bag (so that two-thirds of it emerges above the sand). Pour water into the bucket until the water level is just on top of the sand. The wet sand in the bucket simulates the aquifer. The hole and our plastic bag simulate the borehole. What is happening?

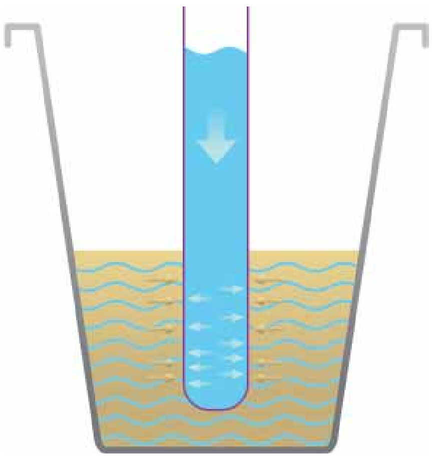
The weight of the water in the upper part of the bag is pushing against the sides of the plastic bag. Due to this pushing (pressure) the bag remains in shape and holds back the sand in the bucket by water pressure.

3. Next cut the plastic bag with a pair of scissors at the same height as the water level in the bucket. You will see that the borehole collapses. What happened?

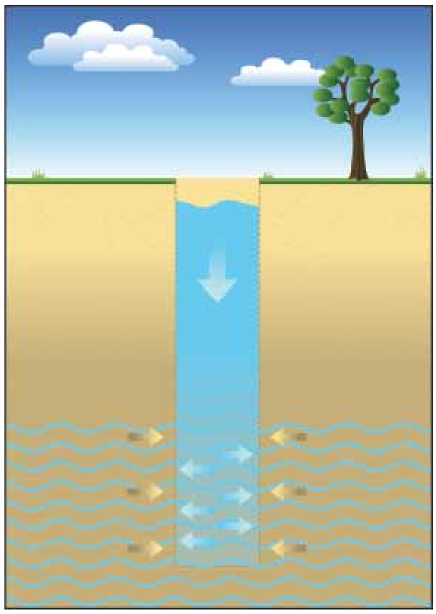
By cutting the bag, the weight of the water from the upper part of the bag is no longer present, and cannot push against the plastic any more. The water level in the bag is now equal to the water level in the bucket. There is no additional water pressure.

Borehole

We have seen how to 'keep open' a hole in wet sand when the sand was in a bucket. But how does it work in a borehole during drilling?



Cross section of the bucket



Cross section of the borehole

The drawing on the left shows a cross section of the bucket with wet sand and a plastic bag. On the right, a cross section of the borehole is shown. Let us compare our 'bucket' borehole with the 'real' borehole;

1. The water level in the bucket represents the water table in our borehole.
2. The upper part of the plastic bag, above the water level in the bucket, is similar to the part of the borehole, filled with water, which lies above the groundwater table.
3. The wet sand in the bucket represents the water bearing sand layer in the aquifer.

However, the plastic bag is absent in the real borehole. In the bucket we have seen that when the plastic bag was cut (the result was that the water level in the simulated borehole and the bucket became the same), the simulated borehole collapsed. In other words,

! If the water level in a real borehole falls towards (and becomes equal to) the water table, the borehole might collapse, especially when the drilling is done in gravel or sand (non-cohesive materials). To avoid collapse, it is necessary to keep the drilled borehole full of water during drilling and construction of the well.

To prevent our 'working water' (the water in the upper part of the borehole) from seeping away into a sand or gravel layer, a substitute for the plastic bag is needed so that we do not loose our *water pressure*! For this reason *drilling fluid additives* are used.

5.2 DRILL FLUID ADDITIVES

When an additive is mixed with our working water *(drilling fluid)* and circulated through the borehole, the walls of the borehole become *plastered*, like paint on a wall. This 'temporary plaster' plays the same role as the plastic bag, in the example of the bucket. Additives also make the drilling fluid more viscous (thicker), so that it is better able to carry cuttings upward from the borehole.

A number of possible drilling fluid additives exist:

- Bentonite
- Other natural clays
- Polymers
- Cow dung
- Fibers (and other solids)

Bentonite

Bentonite is a treated *natural clay*, which, when mixed with water, will *increase the viscosity* of the working water. In most countries bentonite is expensive.

Advantage: Bentonite works extremely well

Disadvantage: Once the bentonite has plastered the borehole wall, it is very difficult to remove it and has to be removed by chemicals or heavy pumping equipment during the well development. If the bentonite is not properly removed, it can *badly affect* the *discharge* of the well! Therefore it is NOT recommended to use bentonite for manual (low cost) drilled boreholes. In some countries its use as a drilling fluid additive is not permitted.

Other natural clays

Natural clay, found during drilling, in termite hills or elsewhere, works like bentonite (only less sticky). Natural clay is cheap, but shares the same *disadvantage* as bentonite: It clogs up the aquifer.

Example of a biodegradable polymer

Polymers

The *best* working water additives are polymers. When mixed with water, they thicken the working water into a *very viscous* fluid. Natural polymers are also used as stabilizers and thickeners in the food industry.

Advantage: Polymers work extremely well and natural polymers are biodegradable. In other words, they disappear naturally in a few days time.

Disadvantage: In most countries they are difficult to obtain and rather expensive. Although expensive, polymers are recommended for manually drilled boreholes. Further research on low cost natural polymers will be done shortly, by the publisher of this manual.

Mixing cow dung with working water

Fresh cow-dung

It might sound dirty, but fresh cow-dung shares many of the advantages of natural polymers. It works extremely well and is biodegradable. Besides, fresh cow-dung is *widely available* in most countries and very cheap to get.

However, there is resistance to the use of cow-dung for water well drilling purposes. Cow-dung also contains the *E-coli bacteria (and other animal pathogens par 7.3)*. The E-coli bacteria is used as an indicator for the presence of fecal contamination (bacteria coming from latrines) that can cause human disease.

Studies so far have shown that cow-dung (indicated by Nitrates) and E-coli both disappear within a few weeks after the construction of the well. However, still more work needs to be done on the health and safety implications of the use of cow dung. It is generally recommended that a newly drilled well in which cow-dung has been used is not used for drinking during the first month of operation

Advantage: Cow-dung works extremely well, is biodegradable, cheap and widely available.

Disadvantage: Carries animal pathogens. Chlorination of the well after development and test pumping is recommended. Further research in the health aspects of use of cow-dung will be done shortly by the publisher of this manual.

Fibers and other solids

To increase the effectiveness of additives in coarse sand and gravel aquifers, fibers and other solids can be mixed in with the drilling fluid. These materials block the pores of coarse layers and help, together with the additives, to prevent working water loss. However, fibers are difficult to remove. Use of fibers is therefore not recommended in the 'well-screen zone' of the borehole. Typical examples of fibers are: sawdust and grain husk.

5.3 REMOVAL OF ADDITIVES FROM THE BOREHOLE

After the drilling and installation of the well-screen and casing the drilling fluid additives have to be removed to maximize the yield of the well. This is done by rinsing, surging and over-pumping of the well in the process known as *well development* (chapter 7).

6 WELL CONSTRUCTION

6.1 WELL DESIGN

The first and most important step in achieving a good well design is to complete a *drilling log* (chapter 4), during the actual drilling process (NB; be sure to describe the drilling samples at least every 'break', as samples can easily get lost or being transformed into nice little clay puppets, by playing children). From the drilling logs the exact depth and length of the well-screen and the depth and thickness of the *gravel pack* and *sanitary seal* can be determined (par. 4.5).

Borehole diameter

The internal diameter of the PVC well casing is selected to fit the outer diameter of the pump that is going to be installed. The drilled diameter of the borehole in turn depends on the outer diameter of the PVC well casing (par 6.2).

For the diameter of the borehole it is important to realize the following;

<u>The drilled diameter of the borehole should be at least 2-inch larger than the outer diameter of the PVC well casing</u> to be able to place the *gravel pack* and *sanitary seal*.

If this rule is not applied and the space between the PVC well casing and the borehole wall is too small, it is almost impossible to place the *gravel pack* and *sanitary seal* at the correct depth. Furthermore the backfill may get 'stuck' on its way down (this is called 'bridging') and end up in the wrong position.

Borehole depth

When the final depth for the bottom of the well-screen in the aquifer is reached (par. 4.3) an additional two meter should be drilled. This is to allow for *fine soil particles*, suspended (mixed with the water) in the borehole, to settle prior to and during the installation of the well-screen and casing (by doing so, the determined well-screen depth can be maintained), and to accommodate a *sump* (par. 4.5).

Completion of the borehole

Finally, before the drilling pipes are lifted, the fluid-drilled borehole should be flushed with clean water to remove all fine particles that are suspended in the hole. If this is not done, the particles will settle at the bottom of the well (influencing the final installation depth) or enter the well-screen during the installation of the well casing, already filling up the sump (par. 4.5 and 6.2).

At exact 1 meter intervals knots are tied in the rope.

Measuring tools

Before the actual well construction starts (par. 6.5) it is important to double-check the final depth of the borehole with a measuring tape. Sometimes the length of drill pipes (which are used during the drilling process for measuring) can vary, or there is confusion among the drilling team members about the number of drill pipes already in the ground. For the latter it is important to count all your drill pipes beforehand. Depth measurements should be done with a measuring tape or specially made measuring tool.

A cheap and accurate measuring tool is easily made. A 1 meter length of reinforcement bar, bent into a loop, is attached to a long piece of a 4mm thick rope. At exact 1 meter intervals knots are tied in the rope. The final depth of the borehole or depth of backfilling can be measured by counting the knots.

6.2 MATERIALS: PVC WELL-SCREEN AND CASING

In many countries several different PVC pipes exist, varying from cheap drain pipes to expensive, high class, slotted well-screens and casing pipes. Which pipes you use out of this range, will depend on different aspects. Three examples:

1. For a *shallow irrigation well*, equipped with a treadle pump, a cheap 2-inch self slotted drain pipe will be sufficient. In this case the diameter can be small (to fit a treadle pump suction hose) and the water quality for irrigation is not critical (shallow well, first aquifer). This well will be *cheap* for the farmer.

2. For a *potable water well* for use by a single household or a few households equipped with a rope pump or other low-cost hand pump, a deeper hole may be needed (to protect water quality, so preferably drilled to a second aquifer). In this case a self slotted 4-inch PVC pipe can be used (no maximum yield required). In doing so, the well stays *affordable* for the users.

3. In large water projects (for Governments or NGOs) for *communal potable water wells*, equipped with a India or Afridev pump, also a deeper hole is needed and 4 to 5-inch standard factory slotted PVC well casing pipes are often required (to maximize yield, to ensure high construction quality, and to accommodate the pump). These wells will be significantly more *expensive*, but of better quality.

As these examples show, the choice of pipes depends on:
- Outer diameter of the pump (pump should fit into the <u>inner</u> diameter of the casing pipe)
- Type of the well (irrigation or potable water)
- Users intensity (household or communal)
- Users budget (cheap or expensive)

Diameter and wall thickness of well casing

There are two main internationally accepted standards for pipe size: *metric* (meters) and *English* (inch). However, in each country the actual size in millimeters differs from the size given in inches by the factory. As an indication you can make use of the table on the right.

! Important: The wall thickness of the pipes should always be more than 3 mm. If a smaller wall thickness is used in deeper wells the pipes might break during use.

	METRIC		ENGLISH	
Nominal inch size	**Outside Diameter**	**Approx Inside Diameter**	**Outside Diameter**	**Approx Inside Diameter**
1.1/2"	40mm	33mm	48.1mm	40mm
2"	63mm	55mm	60.2mm	52mm
2.1/2"	75mm	65mm	75mm	65mm
3"	90mm	80mm	88.7mm	78mm
4"	110mm	98mm	114.1mm	102mm
5"	125mm	116mm	140mm	130mm
6"	160mm	148mm	168mm	154mm
8"	225mm	210mm	219mm	204mm

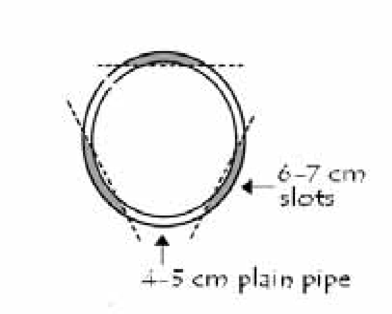
Table 6.1 Comparison between 'Metric' & 'English' uPVC pipe sizes

Factory slotted pipe

Self slotted pipe

Slots

Slots are the openings in the well-screen which allow groundwater to flow into the well. In theory the slot size (width) should be smaller than the mean size of the soil particles. However, in some countries only 1 factory-made slot size (1mm) is available. For low cost wells, one can make the slots by hand using a hacksaw (see below).



For a 4-inch screen, 6 parallel lines are drawn along the full length of the pipe with an in-between distance of about 4-5 and 6-7 cm (see drawing). Within the 6-7 cm lineation the slots are sawn (see picture). The distance between the slots should be about one centimeter. The distance between slots and parallel lines depend on the wall thickness of the pipe (prevent braking).


Bottom end closed by cutting and bending

Sump

To increase the lifetime of the well-screen, it is advised to attach a 1 meter sump at the bottom of the well-screen, into which any particles entering the well screen from the aquifer can settle, without blocking the well-screen and pump (par 4.5). The sump simply consists of a 1 meter plain PVC pipe, which is closed at the bottom end. To close the bottom of the sump a factory-made wooden or PVC cap can be inserted. Alternatively the bottom end of the sump pipe can also easily be closed by some cutting and bending. Make 4 cuts in the bottom part of the sump pipe and heat the pipe end. Fold the four parts inside and allow the parts to cool (see photo). Alternatively cut out 6-8 triangular parts. The remaining parts can be bent together to a point. Making a point will reduce the risk of 'scraping' the borehole wall when the well-screen is lowered into the borehole. To completely seal the bottom of the sump 10 cm of cement mortar should be poured in the sump.


Threaded socket joints

Pipe joints

Casing and well-screen pipes are usually joined by glued sockets. The more expensive purpose-made casings and well-screens with a wall thickness of at least 5 mm are threaded.
When the pipes are glued together, it is very important to clean and roughen both ends, the *inside* of the socket and the *outside* of the pipe to be glued. Then, put sufficient glue ALL around on both ends and put the pipes together in one move.

! Effective length
Be aware that *sockets* and *threads* influence the total length of the pipe. In other words, a 6 meter pipe could become 5.80 meter when glued together. When installing the pipes in a 30 meter deep borehole, over 1 meter of difference might be created, affecting the actual position of the filter screen.


Minimum and maximum sieve

6.3 MATERIALS: GRAVEL PACK

The gravel pack fills the space between the aquifer (sand particles) and the well-screen (preventing the wall of the hole from collapsing on to the well-screen) and may serve to filter some of the fine sand particles from entering the well (par 4.5). The gravel should consist of a grain size (generally 1.5 - 3mm) which is just larger than, and no more than twice to three times, the slot size of the well-screen. Good size gravel looks more like coarse sand, rather than gravel. The grains are best when round in shape. Such material can often be found on river beds or lake shores. The best way to prepare suitable gravel is using *maximum* and *minimum* sized *sieves* (grains which are too small or too big are sieved out).

Bentonite pellets

6.4 MATERIALS: SANITARY SEAL

As we have seen in chapter 3 (par. 3.3) it is essential to install a sanitary seal if the well needs to yield good quality water (par. 4.5). The sanitary seal can consist of cement or bentonite pellets (the volume of the bentonite pellets will increase many times when it gets wet, and so it seals the hole by expanding). Also natural swelling clays can be used, but they are more difficult to handle than processed bentonite. In many countries bentonite pellets are expensive. In these cases it is recommended to use a cement-water mixture (cement grout).

Bag of cement

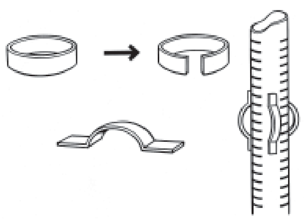
The water and cement are mixed until a thick slurry is created (26 liters of water to one 50 kg bag of cement will make about 33 liters of cement grout). If cement grout is used as a sanitary seal, first a half meter of clay should be backfilled on top of the gravel pack to prevent the grout from penetrating the gravel pack.

6.5 WELL CONSTRUCTION

! Note: Fluid-drilled boreholes must be kept full of water during the entire installation process!

Step 1, Preparations

Prepare all materials needed for the installation and backfilling. Measure out the *effective length* of the PVC pipes and cut the last pipe to a length, allowing 1 meter to be left above ground level, after installation. Number the pipes in order of installation.



Self made spacer rings attached to the filter screen

Centralization of the well screen

To prevent the slots from becoming *blocked* with clay due to *scraping* of the well-screen against the borehole wall during installation, the well-screen should be *centralized*. Centralizing the well-screen in the borehole also allows the gravel pack to settle equally around the screen, leaving at least 1-inch of gravel all around the well-screen. Centralization can be achieved by attaching *spacer rings* or *centralizers* with an interval of every 3 meter around the well-screen. The spacer rings can be made of PVC rings, which can be attached on 4 sides around the well screen (see picture).

Use of rope during installation

Step 2, Installation of the PVC pipes

A practical method of lowering the PVC pipes into the borehole is to use a rope (see picture). One end of the rope is attached to the drill rig and the other end is wrapped three times around the pipe to form a *self closing loop*. The rope is used to *prevent the casing and screen slipping* into the borehole while adding a new length of pipe. Install all the prepared pipes, and leave 1 meter (see *step 1*) of pipe above ground level to so that the well-screen is placed at the *correct depth*.

Flushing the well with water

Step 3, Cleaning and flushing the well-screen

When the well-screen has been installed at the correct depth, the pipes and screen should be *flushed* in the case of *fluid drilled* boreholes. Pour water into the PVC pipes and allow the dirty water to overflow out of the borehole. If the added water only enters the well slowly (or not at all), this could indicate blockage of the well-screen slots by clay or fine material from the borehole wall. Extra water pressure in the casing and well-screen should then be created by adding a *plunger* or *surge block* (or simply a plug of cloth), which is then moved up and down in the casing. Repeat this process until the water directly flows away when added. Continue flushing with clean water until the water which is coming out of the borehole is clean. Only then the gravel pack should be installed.

Pouring gravel in the borehole, water will overflow the pipe

Step 4, Installation of the gravel pack

The gravel pack is now poured in the annular space around the pipe. At the same time the PVC pipe is moved from side to side to guarantee an easy passage for the gravel down to the screen. Pour in the gravel slowly, to prevent *bridging* (gravel getting stuck at the wrong level). Use the measurement tape or tool to measure the depth to the top of the gravel and fill to 1-2 meter above the top of the well-screen (par. 4.5). In fluid drilled holes, water will *overflow* from the PVC casing pipe, as the gravel is dropped around the well-screen. Water will stop overflowing the PVC casing pipe when the entire length of the well-screen has been backfilled.

Backfilling has finished
The top of the pipe is protected

Step 5, Installation of the sanitary seal

When the gravel pack has settled to the right depth (always measure!), the sanitary seal can be installed (par. 6.4). Prepare the cement grout, natural swelling clay or bentonite and pour it into the borehole in the same way (if cement grout is used for the sanitary seal remember to use clay for the first half meter on top of the gravel pack!) Measure to ensure the sanitary seal was installed at *the right depth*.

Step 6, Filling the annular space

Depending on the country regulations (see appendix A), the rest of the annular space is filled up by cuttings and cement grout (see below). Always pour in the material slowly, while moving the casing to prevent bridging of the material.

Step 7, Installation of the top seal

A sanitary top seal of 3-5m thickness should be placed from 3-5m below ground to the surface. The top seal is usually made of cement grout.

Step 8, Well development

See chapter 7.

Step 9, Construction of the head works (apron) and the choice of hand pumps.

See chapter 8. Note: If the well is left alone, before the installation of the hand pump, the top of the PVC casing should be protected (closed, children often drop stones in the well to hear the water splash).

7 WELL DEVELOPMENT AND TESTING

7.1 WELL DEVELOPMENT

'Well development' is necessary to maximize the yield of the well and optimize the filter capacity of the gravel pack. This is achieved by *removing the fines* and *drilling fluid additives*, and *settlement* of the gravel pack.

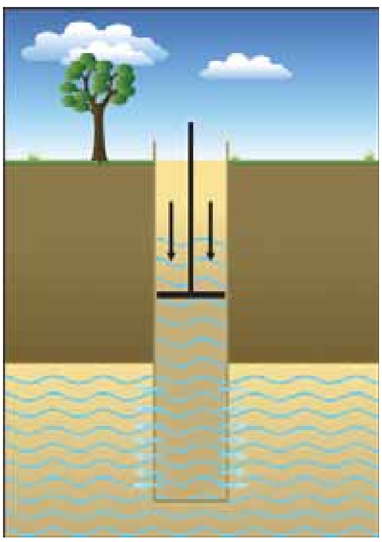
After drilling some of the *fines* and *drilling fluid additives* remain behind in the borehole and are blocking the pores of the surrounding aquifer (par. 5.2) and the new installed gravel pack. After they have been removed by well development the water will be able to move freely from the aquifer to the well screen. During well development also the gravel pack will *settle and become more compacted*, ensuring that there are no large voids (holes) into which aquifer material (sand) could later collapse. The settled gravel pack will filter out some of the fines from the aquifer. Some well development has already started during step 3 of the well installation process: during flushing of the well-screen and the borehole, already some of the fine particles and drilling fluid additives were removed. However, normally this first well development is not enough and more extensive development needs to be carried out after completing the installation process. The remainder of well development takes place after the backfill has been placed and the cement grout of the sanitary seal has hardened (this hardening process takes at least 24 hours).

Several techniques are available for well development and sometimes a combination of these techniques is used to get the best development results. Useful techniques are:

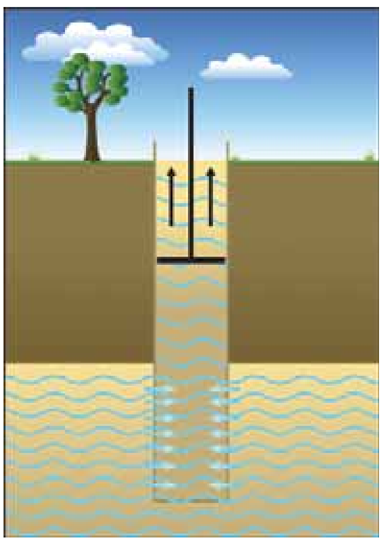
- Surge block or plunger
- Discontinuous pumping (start-stop cycle pumping)
- Continuous pumping with large flows

Surge block or plunger

By the use of a surge block or plunger (creating '*shock waves*' through the gravel pack), the fines and drilling fluid additives are washed loose from the well screen, the gravel pack and the surrounding aquifer and voids in the gravel pack disappear. Then the water containing the fines is pumped out. A surge block consists of a set of wooden discs with rubber valves or alternatively a flexible flat seal (for example, made of a thick rubber sheet). A surge block closely fits in the PVC casing and is operated as a plunger. It is brought *beneath the water level* in the well. Then, by moving the surge block up and down, water is forced into and out of the aquifer (shock waves), washing the aquifer and gravel pack, and mobilizing the fines which they contain (see drawings below).



Down stroke of the surge block



Up stroke of the surge block

The down stroke should be gentle, not forcing the fines and fluid additives further into the aquifer. The upstroke should be rapid, with the result that fines and fluid additives end up in the PVC well casing, which then can be cleaned by pumping (see below).

Motorized centrifugal pump

Discontinuous pumping (start-stop cycle pumping)

After the surge block is used, a pump can be lowered to the bottom of the well to remove the loosened fines and clean the sump. Once the water becomes clear, the surge block is used once again. This process is repeated until the water remains clear. Next, the pump is installed just above the well-screen. Then start discontinuous pumping. Discontinuous (start-stop) pumping is carried out by having the pump run for 5 minutes and then shut off for 2 minutes. Once the water becomes clearer, the pump can be left running until the water is clear. When an electrical or motorized pump is used it is advised to pump at least 2-3 times the design discharge (unless the well runs dry). When a hand pump is used, try to create a maximum flow rate, until the water is clear (please find more country specific well development requirements in appendix A).

Pumps for well development

For well development, different pumping techniques can be used. The best options for well development are electrical deep well pumps and airlifting. However, these pumps are expensive. It is recommended to use these pumps for communal water wells, which require a maximum flow rate. For household wells, which often have to be low cost to stay affordable, hand operated pumps can be used for well development.

Well development by hand

Electrical deep well pump (submersible pump)

A good option is to use an electrical deep well pump. High flow rates can be established. However electricity (probably from a generator) is needed and the pump and generator are expensive.

Airlifting

The same applies to airlifting. Airlifting is a very suitable development tool, by which high flow rates and shock waves can be established. However, this requires a big compressor which is very expensive.

Motorized centrifugal pump

A cheaper option with substantial flow rates for development is a motorized centrifugal or mud-flow pump. However, these pumps are suction pumps and only operate if the *dynamic* groundwater level (water level during pumping) is less than 7 meter below ground level.

Re-development by airlifting

Manual operated pumps

For household wells, also hand pumps (which are cheaper) can be used, although development in this way will be less effective. Nevertheless, when hand pumps are used for well development and are operated to the maximum flow rate for a period of time, until the water is clear, they can be sufficient.

Re-development

After a well has been in use for several years and the yield decreases (becomes less), re-development of the well can be considered. Re-developing a well is easily performed using the same procedure as described above: by *surge* block and *discontinuous pumping*.

7.2 PUMPING TEST – WELL YIELD

Once a well has been developed and is free of any fines, the *well* should be test-pumped. Test pumping gives useful information about both the well and the aquifer. In particular it can indicate whether the well yield will be sufficient for its intended purpose.

Note: Reliable test pumping can only be done when the groundwater level has returned to normal after the well development. The well should rest for at least 24 hours after development before test pumping is started.
There are two ways of testing the well yield: use of electrical deep well or motorized pumps or use of hand operated pumps.


Electrical dip tape

Dip tape

In both cases the water level should be measured. For mechanized pumping tests this can be done by using a (relatively expensive) electrical *dip tape,* which produces an electrical signal when the water level is reached (see photo).
For low cost pumping test with hand operated pumps a simple *measuring tape* or self made *measuring rope* can be used.

Yield test with motorized or deep well pumps

Step 1

Before the yield test starts it is very important to *measure the water level* in the well. This level is called the *rest* level or *static* level. When measuring, use a fixed reference point, for instance the top of the well casing.

Step 2

Insert the pump (or suction hose for the motor pump) at a maximum depth of 1 meter above the well-screen.

Step 3

Start pumping, initially at a *minimal flow rate* (for example 0.2 or 0.5 m^3/h). Measure (with bucket and stopwatch) and write down the flow rate and monitor the water level during pumping. Continue pumping at the same flow rate until the water level stabilizes. Note down the *water level*, *flow rate and time.* The difference between the rest water level before pumping, and the pumping water level at any time during pumping is called the *drawdown*.

Step 4

Increase the flow rate step by step. Each time after the flow rate is increased, you may note some cloudiness in the water, as fines are still being removed from the well. Only increase the flow rate after the water becomes clear and the water level has stabilized. Note down *the water level*, *flow rate and time.*
Note: the water level should not drop below the top of the well-screen. If the water level has stabilized just above the top of the well-screen, then the flow rate should not be increased any further.

Step 5

Increase the flow rate until the desired discharge for the pump to be installed is reached. Typically for the average hand pump, this discharge would be about 1000-1500 liters per hour (1-1.5 m^3/h). Pump at this flow rate for *several hours* until the water level in the well is stable and the water is clear.

Final step: Conclusion

If the water level stabilizes with the water level still above the top of the well-screen, (the water level should not drop below the top of the well-screen), the well's discharge is sufficient for the installation of a hand pump. If the water level has dropped below the top of the well-screen (in step 4 or 5), then the answer is to stop pumping, let the water level recover (wait until the water level becomes equal to the earlier measured rest water level. This will take from several hours up to one day) and re-test at a lower flow rate. When only a small flow rate (less than the estimated flow rate of the pump to be installed) can be maintained the well is not successful. Together with the owner (and sometimes the donor) a decision should be taken on what to do next.

Yield test with hand pumps

Step 1

Before the yield test takes place it is very important to *measure the rest water level* in the well. When measuring, use a fixed reference point, for instance the top of the well casing. To measure the water level a measuring rope can be made.

Water level measuring rope

Water level measuring tape or measuring rope

Take a 6 cm long piece of ¾-inch galvanized pipe. Close one end by welding, and weld an eye on top of it. Attach the eye to a rope, which is knotted every meter (like the measuring rope used for checking backfilling). Move this tool up and downward when it is lowered in the well. When the galvanized pipe touches the water level a 'plopping' sound can be heard. Count the knots to measure the depth.

Step 2

Install the hand pump and pump at a steady rate (maximum flow rate) for as long asZpossible. Ask the villagers / users to assist. Pump at a steady flow rate. Don't start too enthusiastic and don't stop, not even for a few minutes in between. Continue pumping for 4 hours and measure every hour the flow rate with a bucket and stopwatch.

Step 3

Then quickly remove the pump and monitor the rise of the ground water level by measuring the water level every frequently. The shorter time it takes to return to the rest level, the better the aquifer. During the test, write down as much information as possible (water level at start and end, time and discharge monitored from time to time). A basic form for a simple yield test is attached in appendix D.

Final step: Conclusion

If the pump didn't run dry during pumping and the water level returns to its rest level (measured before the test) within 6-12 hours, then the flow rate will be sufficient for the installation of a hand pump.

7.3 WATER QUALITY TESTING

Good quality (potable) drinking water is free from pathogens (disease causing bacteria, etc.) and excessive (above the standard) amounts of harmful chemicals. The taste and smell should be good and the water should be clear and free of color. To ensure the water quality of the well is suitable for drinking water the water should be tested.

Drinking water should be tested on a large number of parameters. To give you a broad idea just a few examples of parameters:

1. **Chemical parameters;** Hardness (calcium, magnesium), pH (acidity), electrical conductivity (to indicate the total salt content), iron, heavy metals (cadmium, lead, etc.) nutrients (nitrogen, phosphorus), artificial threats (pesticides from farms, hydrocarbons from fuel, etc.) and natural chemicals (chloride, sodium, fluoride, arsenic, etc.).

2. **Biological parameters;** pathogens (bacteria (E-coli form), viruses (Hepatitis), parasites (worms, Amoeba), etc.) Often E-coli bacteria are analyzed to indicate a faecal contamination (latrines).

3. **Physical parameters;** Turbidity, color, odor (smell), etc.

Most of the water quality analyses have to be done in a laboratory, but some of these analyses can be done in the field. For more information on water quality testing and for country specific requirements please refer to your National Ministry of Water Resources.

Representative water samples

When taking water samples for testing, wait until the whole development process and pump testing is finished. Preferably then wait another few weeks to allow some parameters (contents) originating from drilling fluid, working water or cement, to disperse (disappear). Do not take a sample immediately after well disinfection because the result will be predictable (no pathogens) but will not be useful.

Well disinfection – chlorination

After the completion of the well, it can be disinfected in order to kill harmful organisms (pathogens) that may have entered the well through the working water, annular backfill or pump, during the installation process. A well can be disinfected by chlorination. For more information on chlorination, see appendix E. For country specific requirements refer the National Ministry of Water Resources.

8 FINALIZATION

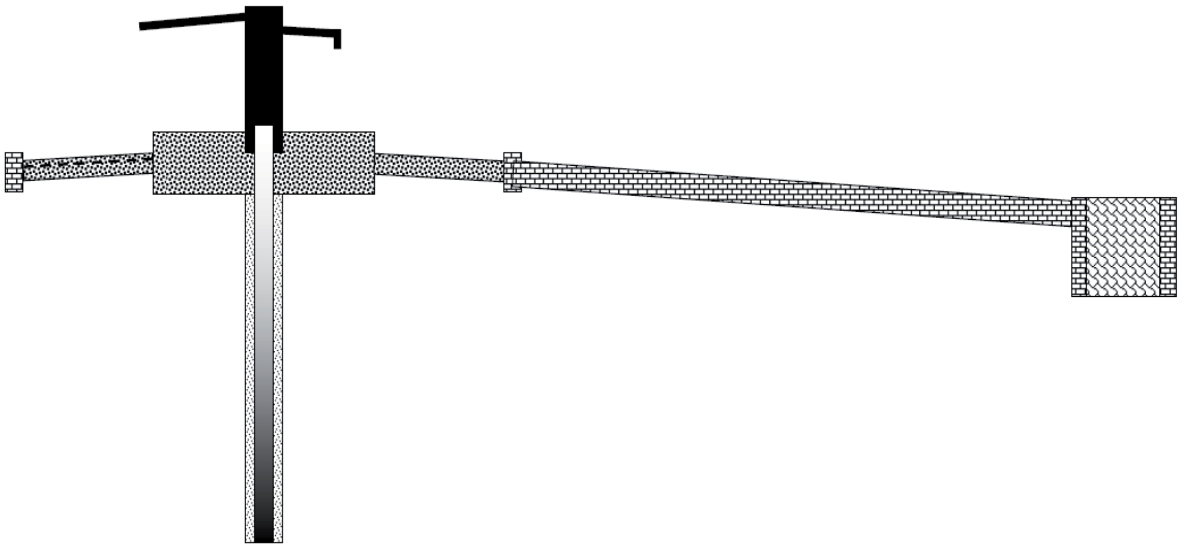
8.1 CONCRETE SLAB/APRON

Finally (after pump testing) the head works or concrete apron should be installed. This apron will prevent surface water and contamination to flow into the borehole directly. The apron also provides a solid and clean base for the hand pump and the collection of water. The apron is usually 2-3 meter in diameter with a (small) wall around the outside.

There are many different designs for the concrete apron and the choice may depend on factors such as: national standards, type of pump to be installed, price and need for protection against floods (in some areas), etc. Finally it is important that the users are comfortable with the design too. A fence can be constructed around the well to keep animals away and, in some places, to control access to the well.

8.2 SOAK PIT

As we have seen in paragraph 3.1, it is for hygienic reasons important that the apron dries up every now and then. Doing so, the sunlight will *disinfect* the well surroundings causing most *pathogens* to die. To make drying of the apron possible it is advised to construct the apron under a small slope. A drain (a small outlet) or channel is constructed at the lowest part of the apron, which will carry the water away from the well. The drained water can then soak away in a so called soak pit. The soak pit is generally constructed 4-6 meter away from the well. The construction of a soak pit is simple. It is a 1 by 1 by 1 meter drain pit filled with pebbles (coarse gravel) and stones.



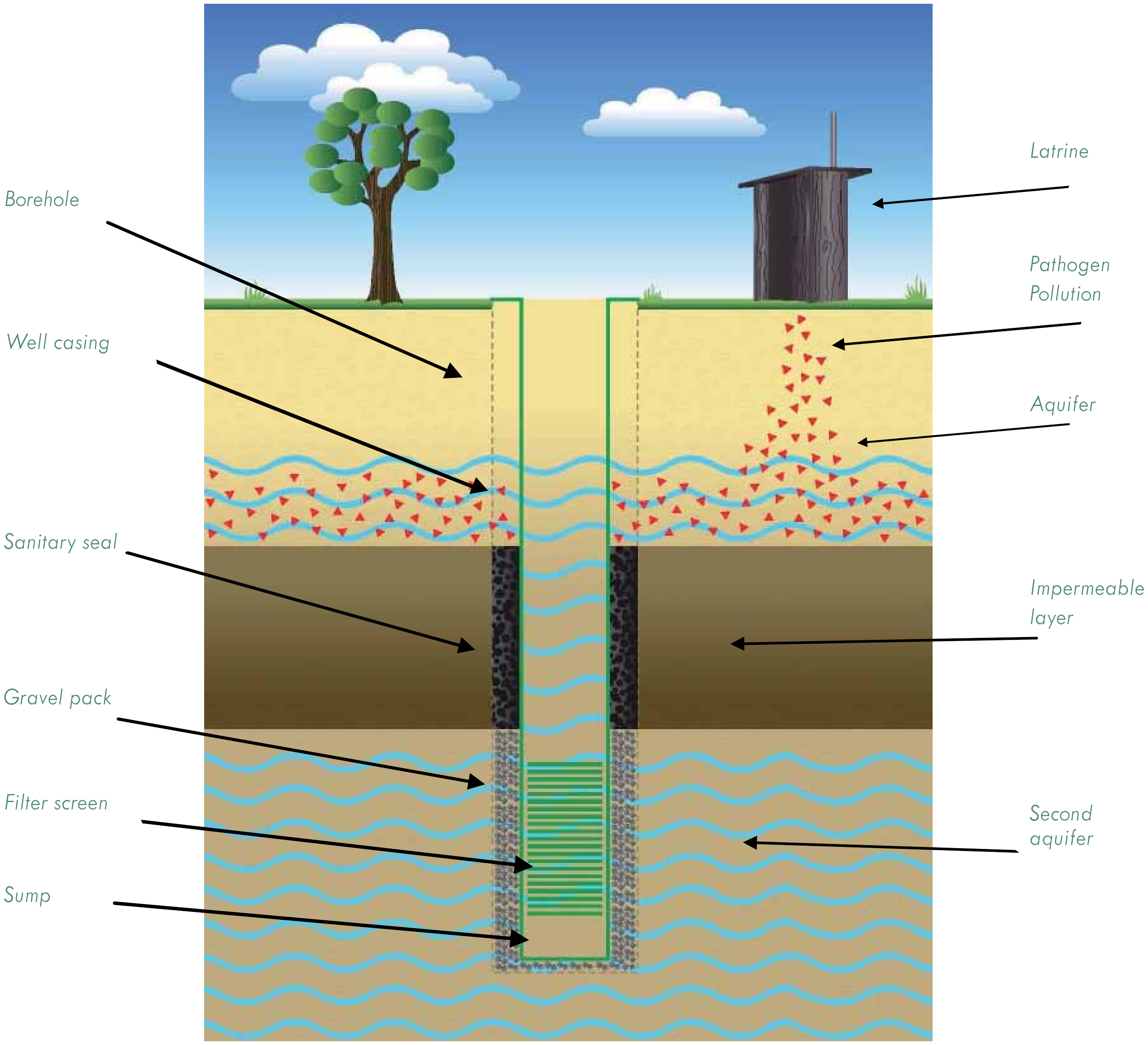
Cross section of a well, concrete apron, soak pit and hand pump

8.3 PUMP CHOICE

There are many types and models of good pumps but the choice of hand pump (the type of pump to install on the well) is very important. The correct choice of a hand pump will depend on a number of factors such as: the national standards, the availability of spare parts, the ease of maintenance, the price, the depth of the water table and the pH of the groundwater (see par. 2.5)

It may be difficult to make the right choice and there are other manuals that deal with this subject. Therefore hand pumps are not discussed in this manual.

GLOSSARY OF TERMS



Aquifer	Permeable water bearing layer (below the groundwater level).
Annular backfill	The material (gravel, sanitary seal and cuttings) which is placed in the space between the well-screen (and casing) and the formation.
Bentonite	Treated natural clay (swelling clay).
Clay	Extremely fine particles, smaller than 0.004 mm in size.
Clay layer	Layer of clay deposits (sediment).
Cohesive	The characteristic of particles that makes particles stick together
Consolidated rock	Particles (such as sand, clay and gravel) 'cemented together' into rock.
Contaminant	Pollution.
Deposition	Sediment.
Drilling log	Written record of the formations (soil layers and characteristics) drilled, according to depth.
Geological formation	Formed rock types / sedimentary layers under the surface of the earth.
Geology	The study of the earth, (formation of rocks and sedimentary layers).
Gravel	Particles ranging from 2 mm up to 64 mm in diameter. Particles from 4 mm up to 64 mm are also called pebble.
Gravel pack	Coarse sand around the well-screen.
Hydrogeology	The study of groundwater.
Igneous rock	Rocks formed when molten material has cooled.
Impermeable	Material that does not transmit water through it.
Laterite	Hard formation with high iron content in tropical area.
Manual drilling	Drilling boreholes with hand powered drilling tools and drilling rigs.
Mechanized drilling	Drilling boreholes with machines or mechanised drilling rigs.
Natural polymers	Biodegradable thickeners. Mixed with water makes an excellent drilling fluid.
Pathogen	Infectious agent that can cause disease (bacteria, viruses, parasites).
Permeability	A measure of the ability of a material to transmit water through it.
Permeable	Material that easily allows water to flow through its pores.

Rest water level	Groundwater level measured in the well before pumping starts.
Sand	Particles in a diameter between 0.063 mm and 2 mm. Very coarse sand: 1 – 2 mm Coarse sand: 0.5 – 1 mm Medium sand: 0.25 – 0.5 mm Fine sand: 0.125 – 0.25 mm Very fine sand: 0.063 – 0.125 mm
Sanitary seal	Seal made of bentonite or cement which is placed in the annular space between the casing and the formation (borehole wall) to stop poor quality water from contaminating the well.
Screen	See ==> Well screen
Sedimentary layers	Layers formed by the weathering, transport (by wind or rivers) and deposition (sediment) of particles.
Silt	Fine particles with a size between 0.004 mm and 0.063 mm. Silt is larger than clay and smaller than sand.
Sump	1-2 meter of plain casing pipe closed at the bottom end, attached to the bottom end of the well-screen.
Unconsolidated layer	Layer consisting of loose particles such as clay, silt, sand and gravel.
Viscosity	Measure of the "thickness" of a fluid.
Water Quality	Term that tells whether water is safe or not safe (polluted or not polluted) for drinking.
Water table	The upper surface of the groundwater (groundwater table).
Weathering	Breakdown of rocks through contact with atmospheric conditions such as heat, water, ice and pressure.
Well	A hand dug or drilled hole to access groundwater.
Well casing	Blind pipe of PVC.
Well construction	The construction (drilling, installation and backfilling) of a well.
Well development	Removing fines and drilling fluid additives from the well and the surrounding aquifer, and settlement of the gravel pack.
Well-screen	Slotted PVC pipe through which water from the aquifer flows into the well.
Well yield	The volume of water produced by the well (generally measured in m^3/day or liter/second).
Working water	Water with or without drilling fluid used during the drilling process.

ACKNOWLEDGEMENTS

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Feedback

This manual is based on the experience with a number of local NGO's and micro drilling enterprises, trained and/or evaluated during projects in Tanzania, Chad, Ghana, Senegal, Ethiopia, Madagascar, India and Nicaragua. The contents of the manual can be used as a guide during training sessions (including training sessions by local trainers) and as a reference book for drilling supervisors, NGOs, manual drilling teams and enterprises during the entire drilling and well installation process. The manual treads essential subjects like geology in relation to hygiene, related to manual drilling, in simple and understandable language.

We are keen to continue improving the manual. Therefore we would appreciate it enormously to receive your feedback and suggestions for improvements so that we can take these up in future editions of the manual. Please send them to the PRACTICA Foundation by e-mail: info@practicafoundation.nl

APPENDIX

A Country specific regulations

B Country specific geological conditions

C Drilling logs

D Test pumping form (yield test)

E Chlorination