Groundwater abstraction

What this unit is about

This unit introduces ways in which groundwater can be extracted, particularly for small- and medium-scale water supply schemes.

What you will learn

On completion of this unit, you should be able to:

• explain the basics of boreholes, hand-dug wells and springs;
• show a basic understanding of groundwater dams and sand-storage dams;
• briefly describe the range of groundwater lifting devices and explain what affects the choice of appropriate options;
• describe adaptions to water collection facilities to make water collection easier for people with disabilities.

Video resources

• What is groundwater? ONLINE USB
• Affordable water well drilling in Sierra Leone ONLINE USB
• Hand augering boreholes ONLINE USB
• Drilling techniques ONLINE USB

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7.1 **Introduction**

Earlier in your programme you have been introduced to groundwater, one of a variety of potential water sources. This unit introduces ways to access it, particularly from springs, hand-dug wells and boreholes. It also describes methods of raising groundwater to the surface.

Loughborough-based participants of the Management of Village Water Services module take part in a half-day practical session at the WEDC handpump demonstration site. All participants will find relevant information on these topics in chapters 8, 9 and 10 of Small Community Water Supplies: Technology, People and Partnership by Smet and van Wijk (2002).

Distance learners can follow the links below to watch short films of handpump demonstrations at the WEDC site.

As you have learned elsewhere, groundwater has several advantages over surface water sources: it is generally easily accessible if aquifers are present; generally free of bacteriological pathogens or suspended matter; not immediately affected by droughts; and is normally a constant cool temperature (although hot springs can occur from geothermal heating).

You have also learned that rain falling on soil percolates through the unsaturated zone to the saturated zone (i.e. below the water table) and this is what we call groundwater. There it is stored in connected pores or fractures, in the stratum that forms the aquifer. Once water reaches the aquifer it usually continues to move horizontally, albeit slowly. The depth to groundwater will often vary depending on the season, becoming higher during the rainy season due to increased amounts of infiltrated rainwater. If insufficient rainwater percolates into the aquifer to replace groundwater extracted for human use, then the groundwater level will fall and it may no longer be a viable water source.

In some cases, man-made groundwater recharge facilities can be constructed to prevent this situation occurring. Although methods of groundwater recharge are beyond the scope of this module, you can find out more about them in chapter 6 of Smet and van Wijk (2002 pp.101–128).

Figure 7.1 illustrates the different aquifer types that you have already been introduced to. It shows the potential positions of wells, boreholes and springs.
7.1.1 A revision of terms

Normally the elevation of water in a borehole or well is below ground, at the elevation of the groundwater level (i.e. the static level). The water level in the well/borehole will fall to the dynamic level during pumping because of drawdown around the borehole.

An artesian well is a well in a confined aquifer where the piezometric surface is above the top level of the aquifer. If the piezometric surface is above ground level at a borehole, then the water will flow naturally up out of the borehole to form a flowing artesian well [Figure 7.1].

Springs occur where the water table meets ground level. Section 7.5.1 explains the different ways in which this can occur.

A perched water table is an isolated body of water held above the regional water table by a bowl-shaped aquitard, formed, for example, by a localized layer of very poor permeability [see the example in the upper part of Figure 7.1]. Yields from perched water tables are often limited and very seasonal, but may be important for small domestic use. Perched water tables occur locally in the otherwise unsaturated zone of an unconfined stratum.

As you have learned elsewhere, groundwater is often pure because many physical and pathogenic contaminants are filtered out as it flows through the ground, particularly if it passes through sufficient depth of fine granular soils.

Figure 7.1 Confined and unconfined aquifers and springs

Source: Based on Brassington (1998, p.4)
In types of rock where groundwater flows through cracks, it is not filtered as it flows, so it could be polluted. However, if the time of underground travel is extensive (e.g. greater than 50 days [BGS, 2001]) the risk is very low because of natural removal processes or the expiry of harmful organisms.

Chemical contaminants (such as nitrates) that arise from human activities are persistent and may not be naturally removed. Concentrations of natural chemicals (such as arsenic and fluoride) which are harmful to humans can be found in groundwater where it has passed through certain types of rock. The presence of non-harmful chemicals (such as iron) can sometimes cause people to reject a water supply on the grounds of bad taste and colour.

### 7.2 Borehole drilling, assessment and development

For sustainable groundwater development, boreholes (sometimes called tubewells) must be drilled, assessed to determine the rate at which water can be abstracted, constructed and equipped, and developed [see Section 7.3.4].

What follows is a brief introduction. More detailed information can be found in Smet and van Wijk (2002, pp. 226–250) and in TIP 2 of UNICEF (2010).

#### 7.2.1 Drilling

There are many methods of drilling boreholes and it is beyond the remit of this unit to cover them in any detail. If you would like to find out more, read Smet and van Wijk (2002, pp. 226–248) or the section on ‘Boreholes and Drilling Equipment for Rural Water Supply’ [TIP 2.2–2.4] in UNICEF (2010). The Sustainable Sanitation and Water Management (SSWM) website (SSWM, n.d. a) is also an excellent source of resources.

In low- and middle-income countries there is an increasing interest in the lower cost methods of drilling, including hand methods. Danert (2009) has produced an excellent review of hand-drilling methods. She has also produced a good compendium on manual drilling (Danert, 2015). The Rural Water Supply Network (RWSN) website [RWSN, n.d. a] has a useful sub-section on cost-effective boreholes.

Drilling is relatively easy in any unconsolidated stratum. It is also possible in any rock but can be expensive in hard, consolidated rock. Drilling is a complex process and there are many problems that can occur. Drilling rigs come in many shapes and sizes and there are various techniques to suit different rock types. Two essentials of all drilling methods are: firstly, a method to break up or loosen the stratum and then secondly a method to lift out or flush out the loosened particles.
Drilling methods include:

- rotary drilling with flush (mud, water or air);
- rotary-percussion drilling (‘down-the-hole hammer’ (DTH) often with air-flushing);
- percussion drilling (cable-tool percussion drilling) with material removed in a ‘bailer’;
- hand-augured drilling;
- jetting; and
- sludging (reverse jetting).

### 7.2.2 Borehole assessment

Once a borehole is drilled, an estimate of its yield can be obtained by means of a pumping test. The yield of a borehole can be loosely defined as the maximum rate at which a borehole can be pumped without lowering the water level in the borehole below the pump intake. It is important to note that this is not the same as the safe or sustainable yield of an aquifer for which there is a huge range of definitions, and which remains an essentially subjective concept. Ways of estimating the yield from a borehole are covered in the unit *Water Safety and drinking water quality*.

![Figure 7.2  Cone of depression and radius of influence](Source: WEDC)
When water is pumped from a borehole, the groundwater level around it is lowered to form a cone of depression (or cone of depletion). The lower the permeability, the deeper the cone. The maximum distance away from the borehole at which the groundwater level is affected by pumping is known as the radius of influence. If boreholes are to be equipped with high flow-rate pumps, water levels in nearby boreholes should also be monitored during pumping tests, to determine if the drawdown in these adjacent boreholes is affected, and if it is, then to what extent.

When choosing borehole pumps, the lowest elevation below ground to which the water in the borehole will fall, due to the drawdown from the lowest seasonal groundwater level needs to be known. This elevation at the time of pumping and after everything has stabilised is termed the lowest dynamic water level in the borehole. The lowest dynamic water level and the height to which the water must be raised above ground have a major impact on the hydraulic performance of the pump.

### 7.2.3 Borehole construction

A borehole should normally be equipped with the following, as illustrated in Figure 7.3:

- casing;
- a sanitary seal [i.e. impermeable material around the upper part of the casing and a hygienic cover at the top end of the casing];
- an end plug at the bottom of the casing;
- screened interval(s);
- filter (gravel) pack; and
- seals.

The casing [e.g. a steel or plastic pipe] is needed to:

- support the excavated hole to prevent collapse;
- stop pollution; and
- protect the pump.
Often a larger diameter heavy-duty temporary casing pipe is used when the borehole is being drilled. After drilling is completed to the required depth then a weaker, permanent casing pipe that includes one or more sections of screen (i.e. perforated or slotted pipe) is installed within the temporary casing, and the temporary casing is then removed. The gap between the two pipes is filled as the temporary casing is removed. Where the screen is the backfill is a granular material (a gravel pack, as explained below). If there is no danger of pieces of rock falling into the borehole then, often, in hard rock that is not heavily fractured, no casing is needed except in the soil (overburden) zone.
Where the borehole passes through water-bearing strata, screened intervals (i.e. perforated sections of pipe) are provided in the permanent casing. These screens are used to:

- support the borehole;
- allow water in; and
- stop the aquifer material and gravel pack (if used) entering the borehole, filling it up and/or damaging the pump.

The screen is often surrounded by a filter or gravel pack placed between the screen and the inside of the excavated hole. The purpose of the filter pack is to:

- filter water;
- stop the larger particles of the aquifer moving into the borehole (but during development [see below] it allows the smaller particles to be washed out of the aquifer into the borehole); and
- improve water flow.

Data are needed for design of the filter medium and to determine the correct size of sand or gravel to be used. In some cases, the actual aquifer material can be used, and be developed to form a natural pack, but in other situations special aggregate must be procured and used. It is generally recommended that the width between the casing [or screen] and the inside of the excavated hole is at least 50mm to allow adequate space for inserting the gravel pack material.

Cement mortar grout (made with a ratio of 2 parts sand and 1 part cement) is usually used to form a seal around the permanent casing at the top of the borehole. This seal (sometimes called a sanitary seal – although this term can also be used for the cap over the top of the borehole as in Figure 7.3) should be for a depth of at least 3m preferably for at least 6m. It prevents easy ingress of pollutants from the ground surface down any gap that would otherwise exist between the excavation and the permanent casing. Instead of cement, bentonite clay pellets which swell when they become wet, can be added to fill the gap left around the permanent casing as the temporary casing is withdrawn.

### 7.2.4 Borehole development

Once a borehole is constructed, it is essential that it is developed properly, or the efficiency and lifespan of the borehole will be reduced. The objectives of development are to:

- clean the borehole system, including removing and drilling mud;
- improve the grading of the filter pack and aquifer immediately surrounding it by rearranging the particles to form a graded sequence (large near the screen to small near the undisturbed aquifer material) partly through washing out of the finer materials near to the screen; and
- optimize the inflow rates.
More recently, hydrofracturing has increasingly been used in low-yielding, fractured rock aquifers to improve the yield of boreholes. With this method, very high-pressure water is introduced between two packers in an appropriate part of the screened portion of a borehole so that the pressurised water opens up and cleans out any cracks. This often results in a wider zone of cracks being able to carry water toward the borehole more easily, increasing the yield.

### 7.2.5 Completion of boreholes

In addition to the grout seal around the top 3m depth of the borehole, and the sanitary cap (or handpump) on the borehole, the surrounding ground surface needs to be protected in a similar way to what is described for hand-dug wells in Section 7.3.5.

The borehole itself should be disinfected before it is put into use. This can be achieved by adding a source of chlorine to achieve a concentration of 200mg/l of active chlorine throughout the borehole water and let this stand for at least four hours. See the last bullet point in Box 7.2 for some suitable sources of chlorine and recommended doses to achieve this concentration.

### 7.3 Hand-dug wells

#### 7.3.1 Introducing hand-dug wells

What follows is a brief introduction to hand-dug wells. More information can be found in Smet and van Wijk (2002, pp 217–226) and SWMM [no date b].

Hand-dug wells have a larger diameter than boreholes and are relatively cheap and simple to construct as they use local materials, little equipment, and require mainly unskilled labour.

Hand-dug wells are widely used in many parts of the world, and comprise:

- the shaft - the part of the well that is above the intake but below the wellhead. It provides access to the water bearing stratum and provides some storage capacity which is useful in slow-yielding aquifers;
- the intake - the perforated section below the shaft which allows water to enter the well. Water can also enter through the base of the well;
- the wellhead - the above-ground structure that provides a means of extracting the water in a hygienic manner. It includes the upper part of the shaft (say 3m depth), which should be sealed against the soil to protect the well from pollution that might otherwise seep down any gap between outside of the shaft and the excavation.

Comparisons between boreholes and hand-dug wells are shown in Table 7.1.
7.3.2 Water quality and pollution in wells

By far the most common cause of pollution in shallow wells is contamination that has come in from above, rather than the groundwater around the well being polluted. However, groundwater pollution may occur if pit latrines or other source of contamination are located too close to the well and/or the groundwater level is high and the well is drawing water from an unconfined aquifer.

The most common problems include:

- muddy conditions around the well. This is unpleasant for users and can provide a breeding place for pathogens such as hookworms or disease vectors such as mosquitoes) and make it more likely that dirt will enter the well on buckets and ropes;
- dirt and disease-carrying organisms being present on the bottom of buckets lowered into the well or on the rope used. This is particularly the case if everyone uses their own bucket and rope;
- dirt/soil/dust or surface water entering the well because the wellhead does not protrude sufficiently far above ground level to form a parapet wall;
• animals able to approach close to the well and contaminate the surroundings because no fence is used to exclude them;
• dirty water from the surface, or surrounding ground, rapidly seeping down any gap behind the shaft wall; and
• growth of algae and plants in the water or on the inside surfaces of shallow uncovered wells that are exposed to sunlight.

Most of these problems can be overcome by the simple measures illustrated in Figure 7.4 and described in Section 7.3.2.

### Box 7.1 Site selection — some social considerations

A well in the compound of an influential person may be considered by them to be personal property.

A well site may be a place where women value an opportunity to discuss confidential matters without fear of men overhearing. Siting a well in a very public place may mitigate against this.

A well outside a mosque may be only used by men, for washing before prayer.

A well inside a chief’s compound may not be widely used. Men may fear being persuaded to do unpaid work, unmarried women may fear becoming another wife!

*Source: Bah, Hollis and Richards. (1991)*

### 7.3.3 Site selection for wells

Aspects of site selection of hand-dug wells are similar to those for boreholes. As with boreholes, there are important technical and socio-cultural [Box 7.1] factors that must be considered when determining the most suitable location for construction of the well. Wells should not be dug near latrines, cattle corrals and burial areas, or in areas that are unpopular for cultural reasons. It should be sited where it will be possible for spilled water to drain away from the well-site.

Provision of a new and fully-functioning well is only of benefit if the community is able and willing to use it. It obviously must be conveniently located in a geographical sense, but there are also some less obvious factors that may restrict access for some groups of people.

Technical questions to consider when siting a well include:

• Is the site and local soil type suitable for digging a well?

• Is the water table sufficiently close to the surface to be reached without excessive work and at a depth that is suitable for the planned method for raising the water? and

• Will a hand-dug well yield sufficient water?
The answers to these questions are not always readily available, but many clues may be gained from local knowledge, and from the presence (or otherwise) of existing wells.

7.3.4 Construction details for wells

Increasing the diameter of a well has little effect on the water yield (except sometimes in fractured rocks) but it will increase the volume of excavation and quantity of materials required, thereby increasing the construction cost. With very large diameter wells (e.g. 3m diameter), there may also be water loss through evaporation. However, there is an important benefit arising from a large diameter well – this is the increased storage capacity in the portion of the well that is below the water table. Another advantage is that more people are able to use it at one time if they each use their own a bucket and rope (although, as mentioned in Section 7.6.3, this also has major disadvantages). Hence, the agreement of the community will be important if a well is to be covered with a concrete slab to support a handpump.

The minimum diameter of the shaft of the well is governed by the ease with which the shaft can be excavated. This will depend on the local ground conditions and local construction practices; the minimum internal diameter (when lined) is typically 1 metre; 1.3m diameter will allow two people to work in the well. Skinner, Reed and Shaw (2011) is a good guide to the design of apron slabs that are constructed around the well (Figure 7.6).

Lining the shaft will prevent soil erosion and wall collapse, thereby prolonging the life of the well and providing safer working conditions during construction and maintenance. In loose ground the sides of an excavation always require support. There are various techniques for providing this in different strata (Figure 7.5).
One useful method is to use caissoning with pre-cast concrete well-lining rings. In this method, the shaft hole is dug to a depth of about 1 metre, and the first well ring, with a cutting ring at its base, is lowered into the hole. A second ring is placed on top of the first and earth is dug out from within the first ring, which
will then sink further down so that another ring can be put on top of it. Care is needed to keep a good vertical alignment. The advantage of this method is that the workers are always protected from collapse by the rings in which they are working.

Other lining methods (such as brickwork, stonework or in-situ [cast in place] concrete) are constructed within the open excavation. For these methods the soil must be self-supporting until the lining has been constructed and has gained enough strength to provide long-term support to the excavation.

Lining from the bottom up is easiest, but leaving long sections of excavation that are unsupported by lining is dangerous. Therefore some contractors use temporary supports to make unlined excavations safe until they are lined. This is good practice.

Lining sections of the well in short sections [e.g. 1m] as work proceeds, may be necessary to prevent soil slip during excavation. Lining like this is much easier using concrete than using bricks because each section of concrete lining bonds tightly to the walls and can be linked to the previous section with reinforcing bars.

When using bricks, lining in sections as excavation proceeds is much more difficult since at the bottom of each section a ‘corbel’ foundation is needed to support the freshly-laid brickwork, or it will fall into the hole when the excavation continues! This foundation must be constructed partly into the wall of the excavation to provide the necessary support. Alternatively strong metal bars can driven into the excavation and be cast into the lining.

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**Figure 7.5** Suggested digging techniques for hand-dug wells in different strata

*Source: WEDC*
Suitable safety measures should be taken during excavation. Sometimes it will be necessary to provide ventilation to workers in the excavation. Someone should remain at the top of the well to observe the people in the well. Ideally each worker should wear a body harness attached to a rope that goes up the well and around a pulley at the surface. Then in an emergency s/he can be removed from the well quickly. The evacuation procedure to raise an unconscious worker from the bottom of the well needs to be practiced; even with a pulley it needs three or four strong workers to pull someone up. A geared winch is a better alternative.

7.3.5 Protection measures

Attention to several simple details at the well can reduce the risks of pollution, as identified in Figure 7.4. These include:

- A headwall (or parapet wall) to prevent soil, spilled water and to some extent blown dust from entering the well, and to reduce the danger of animals and people falling down the shaft. Walls should not be so tall that most users have difficulty in drawing water. A height of about 0.9 – 1m is usually about right.

- A narrow or curved top to the headwall discourages people from standing on the wall and introducing contamination into the well via dirt that falls off their feet.

- A simple roof, or cover, to keep out sunlight and bird droppings when the well is not in use. If a cover slab is used across the well and people are going to use a bucket and rope it will need a smaller access cover(s) in it that is easy to open (see Figure 7.11 and Figure 7.14). See also the comments at Section 7.6.4.1. Note that the type of roof shown in Section Figure 7.4 can make matters worse if birds come to roost under it!

- The top 3 metres of the well should have impermeable lining. When fresh concrete lining is cast directly against the soil to produce an ‘in-situ’ lining this usually creates a good seal between the soil and the concrete. Where, instead, pre-cast concrete rings or bricks are used to build a lining against the soil it is most important that the gap between the lining and the soil is sealed with clay, concrete or cement grout as the lining is built, for at least the 3m depth below ground, preferably for a greater distance. As with a borehole, this sanitary seal prevents surface water and spilled water from easily entering the well by quickly passing down behind the lining to reach the perforated section of lining and pollute the groundwater.

- A smooth, impermeable, apron slab around the well and drainage of spilled water away from the well is crucial – otherwise the ground becomes damp or muddy, providing an environment for parasites such as hookworm to thrive. If puddles form then malaria-carrying mosquitoes may breed in them. The slab should have a raised edge to direct spilled water into a drain that should lead to a soakaway or other place for safe disposal of the water. Ideally the slab should be about 1.5m wide, measured from the parapet wall. Skinner et al. [2011] offer advice on the design of apron slabs and drainage at water points.

- Provide a hygienic method to help raise water. See Section 7.6 for options.
### Table 7.1 Comparison of wells and boreholes

<table>
<thead>
<tr>
<th></th>
<th>Hand-dug wells</th>
<th>Hand-augered boreholes</th>
<th>Machine-drilled boreholes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Adv:</strong></td>
<td>A flexible procedure which can be adapted to a variety of soil conditions as long as lining materials are available.</td>
<td>Dis: Not usually suitable where there are large stones or hard layers.</td>
<td>Ad: Equipment is available for all types of ground to great depths.</td>
</tr>
<tr>
<td><strong>Adv:</strong></td>
<td>Often only cement, some reinforcement, and locally available materials such as sand and aggregate (or bricks) are needed for the lining.</td>
<td>Dis: Needs borehole casing pipes.</td>
<td>Dis: Needs borehole casing pipes.</td>
</tr>
<tr>
<td><strong>Adv:</strong></td>
<td>The resulting wide-mouthed well is easily adaptable to simple water lifting devices, some of which allow more than one person to draw water at the same time.</td>
<td>Dis: Needs a sustainable handpump/footpump or Blair bucket pump. Only one person at a time can collect water.</td>
<td>Dis: Needs a sustainable handpump, foot-pump or Blair bucket pump. Only one person at a time can collect water.</td>
</tr>
<tr>
<td><strong>Adv:</strong></td>
<td>The well provides a reservoir, which is useful for collecting and storing water from ground formations which yield water slowly.</td>
<td>Dis: Low storage volume in the borehole means it is unlikely to be suitable for a low-yielding aquifer.</td>
<td>Dis: The low storage volume in the borehole means it may not be very suitable for a low-yielding aquifer.</td>
</tr>
<tr>
<td><strong>Adv:</strong></td>
<td>In some situations, the large number of members of the community who can be involved is seen as an advantage since it can lead to an increased sense of ‘ownership’ of the well. The method can use unskilled labour working with a few trained workers.</td>
<td>Possible disadvantage: Requires few people so there is less opportunity for full community involvement and the associated sense of ownership.</td>
<td>Possible disadvantage: Requires only a few people to operate the rig, and generally, there is little opportunity for community involvement.</td>
</tr>
<tr>
<td><strong>Dis:</strong></td>
<td>Takes a long time to construct.</td>
<td>Ad: It is relatively fast.</td>
<td>Ad: It is very fast.</td>
</tr>
<tr>
<td><strong>Dis:</strong></td>
<td>Uses many bulky, heavy materials for the lining that may need to be transported in a lorry.</td>
<td>Ad: Far less equipment needs transporting to the site.</td>
<td>Dis: Heavy rigs require the construction of special access roads to the borehole site. Rigs may not be able to travel in the rainy season.</td>
</tr>
<tr>
<td><strong>Dis:</strong></td>
<td>It needs a dedicated team of people willing to work hard.</td>
<td>Ad: Needs fewer people and the work is not as hard.</td>
<td>Ad: Needs very few people. The machine does most of the hard work.</td>
</tr>
<tr>
<td><strong>Dis:</strong></td>
<td>Construction is usually more expensive than a hand-dug borehole of the same depth.</td>
<td>Ad: Often cheaper than well.</td>
<td>Ad: Usually much more expensive than well.</td>
</tr>
<tr>
<td><strong>Dis:</strong></td>
<td>Hand-digging cannot easily penetrate hard ground and rock. [It may be possible if air compressors and jack hammers (with explosives if necessary) are used].</td>
<td>Dis: Difficult to penetrate hard ground.</td>
<td>Ad: Equipment is available for all types of ground to great depths.</td>
</tr>
<tr>
<td><strong>Dis:</strong></td>
<td>In some soils hand-digging below the water table is not easy. This problem can be minimised by digging the last part of the well at the end of the dry season, but even then, because of the entry of water, it may be hard to dig far enough below the water table to guard against the well running dry during years of drought.</td>
<td>Ad: Can penetrate relatively deep below the water table even in loose sandy soils so the borehole can be constructed deep below the water table.</td>
<td>Ad: Can penetrate relatively deep below the water table in loose sandy soils so the borehole can be constructed deep below the water table.</td>
</tr>
<tr>
<td><strong>Dis:</strong></td>
<td>Open-topped wells and the use of simple water lifting devices have associated pollution risks. These can be avoided if the well has a cover slab and handpump but then only one person can draw water at a time unless more than one handpump is fitted. The handpump needs to be sustainable to ensure continued water supply (a locked access hatch can be provided for a bucket and rope to be used in an emergency).</td>
<td>Ad: Less risk of pollution of groundwater by users during collection.</td>
<td>Ad: Less risk of pollution of groundwater by users during collection.</td>
</tr>
<tr>
<td><strong>Dis:</strong></td>
<td>Difficult to make very deep (often not &gt; 20m, very rarely &gt; 30m).</td>
<td>Dis: Difficult to make deep using hand-augering [rarely &gt;30m except by jetting with drilling mud in fine sands, when depths of over 60m can be achieved]. Cannot usually be deepened.</td>
<td>Ad: Can be constructed to great depth. Cannot usually be deepened.</td>
</tr>
<tr>
<td><strong>Dis:</strong></td>
<td>Safety hazards to diggers (and to users if left open).</td>
<td>Ad: Negligible safety hazards.</td>
<td>Ad: Limited safety hazards.</td>
</tr>
</tbody>
</table>

**Key:** Dis: Disadvantage  Ad: Advantage (usually relative to the hand-dug well statement)

**Source:** Skinner (2003, pp. 24–25)
7.3.6 Completion
As previously mentioned in Section 7.2.5 for the boreholes, after construction the well should be chlorinated before use.

7.3.7 Maintenance
Once the well has been constructed, it is important to look after it. Poor maintenance can lead to contamination of the supply. A checklist of suggested maintenance tasks is presented in Box 7.2.

Box 7.2 Well maintenance – some suggestions

Daily
- Clean and sweep the immediate surrounds and drain.

Weekly
- Make temporary repairs to any damaged/cracked items.
- Inspect lifting mechanism: repair or replace if necessary.

Monthly
- Check that no latrines have been constructed where they risk polluting the well.
- Check that any fence and gate to keep animals away is in good condition.

Annual (when the water table is lowest)
- Clean out well base and walls [lower someone on a bosun’s chair, which is a wooden seat on the end of a rope]
- Repair damage and seal cracks.
- Clean out soakaway [if used].
- Check that the apron is not being undermined by erosion.

Repair if necessary

Other, as necessary
- Disinfect the well whenever contamination is suspected by adding 100 grams of fresh bleaching powder [or 6 litres of domestic bleach] per cubic metre of water in the well. Leave for at least 12 hours, then draw water from the well until the smell of chlorine has gone.
7.4 **Special methods of capturing groundwater**

See SSWM [n.d. c] for more information on groundwater dams (subsurface dams) and sand dams that are briefly described in the following two sections.

7.4.1 **Groundwater dams**

Where streams are only ephemeral (seasonal), although in the dry season there may be no water flowing in the stream, water may still be flowing below the surface of the granular deposits that lie on the hidden bed of the stream. This groundwater can be exploited, particularly if the bed deposits are deep. Where the banks and true bed of the stream are fairly impermeable it may be possible to build an impermeable sub-surface dam within the granular deposits to hold back groundwater so that more is available during the dry season. This water may be extracted using flood-proofed wells in the bed of the stream [Figure 7.6](#) although using an infiltration gallery [Skinner and Shaw, 1999a](#) serving a bankside well is a better arrangement.

![Figure 7.6](#) Clay groundwater dam with an upstream well designed to cope with flooding in the wet season

*Source: after Nissen-Petersen (2006)*

7.4.2 **Sand-storage dams**

In some situations, particularly with ephemeral streams in arid areas, the solids carried in the fast flowing water that results when it does rain are mostly coarse sands and gravels. In such cases, if there is insufficient depth of sand in a stream bed to hold much water then it may be possible to artificially increase the depth of deposits. Where the valley floor and sides are impermeable building a dam across the valley will trap the coarse deposits. The dam is often raised in successive stages over a number of years so that the valley behind the dam
begins to fill up with the sand and gravel which is deposited there by the seasonal flows of water. Finer material that takes longer to settle is expected to mostly be carried over the dam by the floodwater. This dam arrangement forms a sand-dam or more correctly a sand-storage dam [see Figure 7.7].

With a sand-storage dam, surface water that flows in the river during the rainy season will infiltrate into the coarse deposits behind the dam and be stored as groundwater. This water will be partially purified by filtration as it passes through the sand. In the dry season the sand also protects the water from evaporation. Water can be extracted by a well or infiltration gallery in both the wet and dry seasons.

![Sand storage dam](Source: Skinner (2003, p. 59)
7.5 Springs

7.5.1 What are springs?

Springs occur where groundwater seeps from the ground surface, often at the interface between water-bearing strata and impervious strata [Figure 7.1 and Figure 7.8]. At this point the downward flow of the groundwater is effectively blocked by the impermeable layers below and the water emerges from the ground as a spring. Some of the ways in which this can happen are illustrated in Figure 7.8. Figure 7.8 (a) and (b) are overflow gravity springs. Figure 7.8 (c) shows an artesian spring at a fault. Figure 7.8 (d) and (e) show springs from fractures in rock. Meuli and Wehrle [2001] show some other diagrams and information about the occurrence of springs and how to protect them.

Figure 7.8 Spring types

Source: WEDC
7.5.2 How can we locate springs?

Indications of springs are:

- water visibly flowing from a hillside;
- strong growth of vegetation at a particular point on a hillside, particularly when this is apparent in the dry season;
- insects swarming at certain points during evenings;
- aerial infra-red photography (which shows water and vegetation as white);
- temperature variations (damp ground is cooler than dry ground);
- geophysical resistivity measurements;
- maps (topographical and geological); and
- local knowledge.

7.5.3 Water quality and quantity of springs

Since it is groundwater, spring water is usually of good quality, as long as the spring is from a fine-grained aquifer and the area around the spring is properly protected [see Section 7.5.4]. This protection is needed because the groundwater has reached the surface at that point so there is potential around that point for the water to be contaminated by surface water seepage which can carry surface pollutants into the groundwater. That from a confined aquifer should be of very good quality since it is protected by the confining stratum (e.g. clay) above it.

Springs can be a very valuable source of water for local communities. The flow from the spring need not be great; 0.47 litres/sec yields 40,608 litres/day, which provides 1000 people with 40 litres each per day. However, a spring requires protection from pollution, and for a slow-flowing spring storage will be needed to accommodate daily variations in demand.

Flow measurements at a spring may only provide an indication of the quantity of water available at the time when the test is carried out. The flow is likely to show some seasonal variations. Talking to local people can provide information about such variation but it is best to measure the flow at different times of the year. See Technical Brief 27, Smout and Shaw (1991b) in Pickford (1991, p. 27) for guidance on discharge measurement.

Note that if the water differs in temperature during the day and night, or just after rainstorms then the quality is suspect; it may indicate that the spring is containing a lot of surface water that had only been below ground for a short time.
7.5.4 Improvement and protection

The yield of a spring can be enhanced in the following ways:

- if the spring has several small outlets, bring the flows of water together; and
- remove any obvious obstructions to the flow which might be increasing the resistance to the outflow of water.

Storage is usually required to make best use of the spring water that flows day and night. The storage can be in a spring box just below the eye of the spring. However, positioning the storage further downhill is better, so that construction of the storage tank does not adversely affect the impermeably of the stratum below the aquifer near to the point where the spring occurs.

![Diagram of a typical spring box](image)

**Figure 7.9** A typical spring box

*Source: WEDC*

The water quality of the spring can be protected from pollution near the source by observing a few simple guidelines. The key points are:

- avoid contact between the groundwater and the topsoil;
- divert surface water runoff away from the area above the spring using a ditch;
• keep animals and people off the land just uphill the spring by fencing off the area (the ditch just mentioned can be just outside the fence);

• allow a period for settlement of any suspended solids - this can be combined with storage in the spring box;

• filter the water (using coarse sand and gravel where the water is leaving the aquifer. This is sometimes called a gravel pack) to hold back the fine particle in the aquifer; and

• keep the area uphill of the spring free of latrines.

The basic principles of spring protection are illustrated in Figure 7.9 and Figure 7.10.

Protecting an overflow gravity spring usually involves digging back into the hillside along the water bearing layer and constructing a method of collecting the flowing water. This point should be at a point where it is sufficiently deep to be protected from surface contamination.

One method of collecting the water is to construct a spring box as shown in Figure 7.9. The key features of this method of collecting the water are:

• A gravel pack filter behind the open-jointed wall at the back of the spring box (although it is usually better to collect the water through a gravel pack filter and direct it into a pipe which then carries it to a storage tank further downhill).

• Puddled clay [clay which has been wetted and trodden underfoot to mould and re-mould it until it is uniformly soft] on top of the gravel pack to divert infiltrated surface water run-off away.

• The base of the box should not penetrate down through the underlying impermeable layer, or the spring may drain away.

• An overflow pipe for the storage tank. The pipe should be located at an elevation that is below the elevation of the ‘eye’ of the spring; if it is above the eye, the water level in the tank can rise to above the highest previous groundwater level in the aquifer. This will create additional pressure in the aquifer that may cause the spring to breakout somewhere else, and the spring may be lost from the site where it is being protected! Screen the overflow pipe with corrosion-resistant mesh to exclude frogs and rodents etc.

• A drainage pipe at the base of the tank to allow it to be drained down for cleaning.

• The outlet pipe can have a screen to prevent anything entering the pipe and blocking it. A hinge or piece of flexible pipe will allow the outlet to be raised to make cleaning easier.

• An access hole with cover to allow inspection and entry for cleaning. The hole should have raised edges and an overlapping, or watertight, cover to prevent entry of surface water.
- A fence around the area upstream of the spring to keep animals and people away. (Note that Figure 7.9 is a schematic diagram rather than a to-scale drawing. The fence is shown much closer to the spring than it should be and the depth from ground level to the aquifer is shown too little for it to be well-protected from surface pollution.).

- A drainage channel uphill of the fence to divert surface water run-off away.

![Diagram of a Typical Headwall Details for a Protected Spring without a Spring Box](image)

**Figure 7.10** Typical headwall details for a protected spring without a spring box

*Source: WEDC*

**Now read:**

Technical Brief No.3 (Pickford 1991, pp. 9–12) to find out more about the construction of a spring box; and

Technical Brief 34 (Skinner and Shaw 1999b) about protecting springs without using a spring box.
7.6 Raising water at the source

7.6.1 Methods of raising water

This section introduces methods of raising water. Some of the devices mentioned in this section are illustrated in Figure 5.11 to Figure 5.15.

Whatever lifting devices are used at the source they need to be:

- hygienic – if pure water is being lifted its quality needs to be preserved;
- suitable for the nature of the water (e.g. suit its acidity or the type of suspended solids in it);
- able to lift water at an acceptable delivery rate to the required height and to overcome any pumping resistance in the pipework;
- sustainable (e.g. affordable to run and feasible to maintain); and
- acceptable to the users/maintainers.

Common water lifting devices can be categorized in several ways:

- human powered
  - bucket and rope [raised: direct by hand [Figure 7.12]; using a windlass [Figure 7.11]; using a shaduf [Figure 7.13] or using a 'Blair bucket pump' [Figure 7.15 and Figure 7.16]
  - hand/foot pumps [e.g. rope-and-washer pump, reciprocating piston pumps [suction, direct action and deepwell types]; cylindrical diaphragm pumps; progressive cavity pumps].

- wind powered

- water powered - such as hydraulic ram pumps and pressure intensifier pumps.

- engine and motor powered
  - rotodynamic pumps (such as centrifugal pumps);
  - reciprocating piston pumps;
  - progressive cavity pumps; and
  - diaphragm pumps.

One general point to note about pumps is that if the working part of the pump (i.e. the cylinder or pump casing) is above water level that there will be a limit to the depth below the pump from which the water can be lifted. At sea level, this suction limit may be only 3.5m for a centrifugal pump and not much more than 7m for a piston pump. These values reduce with altitude since they depend partly on the atmospheric pressure.

Find out more about types of pumps, then read Chapter 9 of Smet and van Wijk [2002, p169–214]. You may also like to look at TIP 4.3 in UNICEF [2010] that gives good advice on motorized pumps. In the same source TIP 3 deals with solar pumps and TIP 1 deals with handpumps.
The methods of raising groundwater from wells that are mentioned below can be used for raising surface water if a cylindrical reservoir is constructed in the ground (like a sealed well) alongside the source to collect the water either directly or after it has been collected from an infiltration system. Skinner and Shaw (1999a) has examples.

7.6.2 Making provision for people with disabilities

With all types of water supply points the designer should bear in mind the challenges that people with disabilities can face when drawing water. Whilst it is not feasible to make special provision to suit use by people with all types of disabilities often it is not very expensive to make some simple changes that will improve the situation for many disabled users. For example:

- avoiding steps wherever possible;
- providing a wheelchair ramp over the raised edge of an apron slab; and
- providing sufficient space at the water collection point for a wheelchair user to approach it and conveniently reach the handle of the handpump or tap and to place and pick up the water collection container they are using.

When a community is to be served with a new water point the designer should investigate the needs of specific disabled users in that community, to see if other basic adaptions can be made to enable that user to use the water point. For example, the handle of a handpump can be adapted to suit operation by someone seated in a wheelchair or an operating lever can be added to a tap.

Where adaptions are not possible, or are too expensive members of the community may need to volunteer to assist the person with disabilities to carry out certain tasks.

There are a number of useful websites that show examples of suitable adaptions for people with various disabilities; one good one is WaterAid [n.d.].

7.6.3 Bucket and rope

The simplest way of raising water from a well is to use a bucket and rope. Using a windlass [Figure 7.11] or pulley or rolling bar [Figure 7.12], can make raising the water easier. Where the water in the well is not very deep it may be possible to use a ‘Shaduf’ [Figure 7.13] to raise the water.

Having just one dedicated bucket and rope, with provision for storing the bucket off the ground, is likely to reduce the risk of the well becoming polluted, compared with every user bringing their own bucket.
You can drink clean water from your upgraded well by keeping the well and the bucket clean.

1. Keep the bucket clean
2. Hang the bucket on the windlass
3. Keep the well cover in place
4. Keep the apron and drain clean
5. Always use the same bucket in the well
6. Keep chain wrapped around windlass

**Figure 7.11** Windlass with user’s instructions

*Source: Skinner (2003, p.75)*

Note: Wooden rollers can be added to bars to improve the performance.

**Figure 7.12** Roller bars on a well to protect ropes from abrasion

*Source: Skinner (2003, p.72)*
Wherever a rope comes into contact with the ground there is the risk of it picking up pollution which is then later carried into the well so the windlass and shaduf are usually more hygienic since they keep the rope off the ground.

### 7.6.4 Handpumps

#### 7.6.4.1 Using a handpump on a large-diameter well

Fitting a cover slab over the well and installing a handpump (Figure 7.14) provides a hygienic way of raising water from the well, but often maintaining the handpump will be a challenge.

If a pump is used on an open well, it is wise to also provide a locked access cover in the slab, which can be opened in an emergency to allow the use of a rope and bucket (Figure 7.14). The bucket and rope method could then be used if the pump breaks down and it is not possible to repair it quickly.

---

**Figure 7.13** A shaduf

Source: Skinner (2003, p.74)
If normally many people draw water from the well at the same time, using their own buckets and ropes, note that the users may not consider a single handpump on the well to be acceptable because it would lead to the formation of a queue. Handpumps should not normally be used for more than about 150 users because of the number of hours of pumping required for larger numbers of people.

![Figure 7.14: Upgraded well with handpump](image)

*Source: WEDC. Note that in this diagram the clay is filling the top of the original, unlined wide excavation in which the new lined well has been constructed.*
7.6.4.2 Using a handpumps on a tubewell or borehole

Where the number of users is less than 300 (ideally less than 150) then a handpump is likely to be suitable for raising water from narrow boreholes or tubewells.

If there are a low number of users (ideally less than 50) then a narrow, valved bucket (e.g. ‘Blair bucket’, Figure 7.15 and Figure 7.16) can be used in boreholes (or even wells) for shallow depths.

Where large numbers of people need water from a borehole then a motorised pump (Section 7.6.5) will be needed.

![Blair bucket and its valve](image_url)

**Figure 7.15** A Blair bucket and its valve

*Source: after Morgan (1990, pp.101–103)*
7.6.5 Types of handpump

If the depth to the water table is always less than about 7m then a suction handpump (i.e. one in which the pumping cylinder is above ground) can be used. Beyond this depth, a pump with the operating cylinder below the water level is needed (such as a direct action handpump or a deepwell handpump). A handpumps with and open-topped cylinder (OTC), that is a cylinder that has equal, or smaller diameter, than the rising main that connects it to the surface, is the best choice for deepwell handpump. When well-designed, OTCs facilitate easy access to the components in the cylinder when maintenance is required.

Now read:

Skinner and Shaw (1999b) Technical Brief 41: VLOM pumps that deals with handpumps, particularly those that are more suitable for village-level maintenance.
7.6.5.1 Motorized pumps

Motorized pumps of various types can be used for raising water from large-diameter wells and from boreholes. The pumping device is usually positioned below the water table to avoid the suction limit that applies if the pumping device is located above the water level (see Section 7.6.1).

For urban water supplies sometimes a single, large-diameter borehole may be suitable to supply all the town’s needs if sufficient storage is provided for the water distribution system. However, it is more likely that a ‘wellfield’ which is made up of several suitably spaced boreholes is used to meet the demand.

If you want to find out more about motorized (including solar pumps) then see Baumann et al. (2010) or chapter 9 of Smet and van Wijk (2002, pp.169–198).

7.6.6 Sustainability

The handpump or motorized pump needs to be one that can be maintained, otherwise when it breaks down the source becomes useless. For proper maintenance, appropriate skills, tools (sometimes including a strong lifting frame) and a supply of affordable spares will be required. The need for a pump is one of the disadvantages of a borehole compared with a large diameter well. For large diameter wells a bucket and rope can be used and these are easier for the users to maintain than a pump.

*A handpump and apron*
In recent years there has been a growing interest in encouraging families, or small groups of families to improve (or develop) their own water supply points with simple water-collection devices. This approach is called ‘self-supply’ and can often lead to improved levels of sustainability over community water supply points. You can find out more about this approach from links on the RWSN [n.d. b] website.

A case study that proposes an interesting scoring system to help identify the best self-supply sources is described in Carter (2006).

### 7.7 Summary

Figure 7.17 and Figure 7.18 are a decision chart from Skinner (2003, pp.10–11) that shows the main technical questions that need to be answered to assist in the selection of water sources, particularly for small-scale water supply.

### 7.8 Other factors

**Box 7.3  What to aim for when choosing a water source**

Plan which is the cheapest, technically feasible system, that produces the desired health benefits whilst not harming the environment, that the users show their preference for by their willingness to pay and that the appropriate institution/users is/are capable of operating and maintaining.

These notes have mainly focused on the technical aspects of water sources. It is of course important to consider non-technical factors as well. There is a need to consider also the socio-political and cultural factors, economic / financial considerations, legal and management requirements, and the likely impact of the development. These aspects more fully explored elsewhere in your programme.
Q1: Is it feasible to protect/improve existing water sources? Can existing/improved sources provide enough water?

A: Consider protecting and improving existing sources

If unsuitable consider Q2

B: Consider constructing rainwater catchment and storage system

If unsuitable consider Q3

C: Consider protecting springs (providing storage and piped distribution system where appropriate)

If unsuitable consider Q4

D: Consider constructing a tubewell by installing a wellpoint

If unsuitable consider E, F, Q5, Q6

E: Consider constructing a hand-augered borehole

If unsuitable consider F, Q5, Q6

F: Consider constructing a tubewell by jetting

If unsuitable consider Q5, Q6

Q2: Is rainfall amount and pattern likely to be suitable for rainwater catchment? Is present roof and/or gutter design suitable for rainwater catchment?

Is it feasible to change roof and/or gutter system to make them suitable for rainwater catchment?

Are perennial springs available?

Is the yield from the developed spring(s) likely to provide enough water?

Is protecting the spring(s) and using the water feasible?

C: Consider protecting springs (providing storage and piped distribution system where appropriate)

If unsuitable consider Q4

Q3: Is sufficient potable groundwater likely to be available? Is it feasible to change roof and/or gutter system to make them suitable for rainwater catchment?

Are equipment and expertise available for constructing tubewell/borehole?

Is a handpump (or Blair bucket pump) feasible and sustainable?

Are perennial springs available?

Is the yield from the developed spring(s) likely to provide enough water?

Is protecting the spring(s) and using the water feasible?

C: Consider protecting springs (providing storage and piped distribution system where appropriate)

If unsuitable consider Q4

Q4: Is groundwater yield likely to be fast enough from a tubewell/borehole?

Is groundwater within 15 m of the surface?

Is groundwater within 25 m of the surface?

Is groundwater within 60 m of the surface?

Q5, Q6, Q7

Continued on next page

Figure 7.17 Decision chart for choosing a source for a small water supply (Part 1)

Source: WEDC
Figure 7.18 Decision chart for choosing a source for a small water supply (Part 2)

Source: WEDC
7.9 References and further reading

7.9.1 References


BACK TO UNIT CONTENTS


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7.9.2 Additional useful publications


DRISCOLL, F.G., 1986. *Groundwater and Wells.* St. Paul, Minnesota, USA: Johnson Screens. [Chapters 6, 8 - 10, 13, 15 –18].


### 7.9.3 Examples of video resources on groundwater and drilling

Please contact the Module Tutor know if you have comments on any of these links or if you have any other links to suggest:

**What is groundwater:** [https://www.youtube.com/watch?v=PTdHyglCVaw](https://www.youtube.com/watch?v=PTdHyglCVaw)

**Check the latest list of RWSN videos available from:** [https://vimeo.com/ruralwater](https://vimeo.com/ruralwater)

**Affordable water well drilling in Sierra Leone:** [https://www.youtube.com/watch?v=UYay9-2UMwM](https://www.youtube.com/watch?v=UYay9-2UMwM)