LOW COST WATER SUPPLY

3

Hand Drilled Wells

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LOW COST WATER SUPPLY Series

This series of publications highlights sustainable methods of providing water supply to the rural areas of developing countries, notably in Africa.

When complete, the series will consist of four volumes:

Volume 1 - Well Siting
Volume 2 - Dug Wells
Volume 3 - Hand Drilled Wells
Volume 4 - Handpumps

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Your comments and proposals for improvement will be highly appreciated. Please send these to our address mentioned above, so that they can be taken into account for a following edition.

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WHY HAND DRILLED WELLS ?

Open and closed wells

Point sources for water supply, i.e. individual sources of water, without a pipe system attached, can be distinguished according to:

- the type of construction: open and covered wells or boreholes
- the depth to the groundwater: shallow and medium-depth to deep wells or boreholes

Open wells were the earliest types of point sources created by man. With gourds, leather bags or buckets as water containers, and ropes or winches used for pulling them up, these wells have been in use since times immemorial, for drinking water, cattle watering and irrigation water supply

Except under very favourable circumstances, open wells can be constructed only by skilled persons, since they need to be protected against collapse, both during construction and during normal use (see *Volume 2: Dug Wells*). Lining of a dug well, nowadays often with concrete — either prefabricated rings or concrete cast *in situ* — but formerly often with brickwork, stones, wooden planks or even woven branches, is necessary for virtually any open well, except when the walls are exceptionally stable (which would imply a soil with poor water bearing characteristics) Even though they may not normally require very specialized equipment for their construction, open wells are, therefore, relatively expensive to construct. In addition they are vulnerable to damage by buckets scraping against the well walls.

Their major draw-back, however, is their susceptibility to contamination

- bird droppings,
- leaves,
- deliberate human contamination,
- small animals drowning in the well, etc

Another, less obvious disadvantage of open wells is that the underside of the bucket becomes dirty when it is put down on the ground near the well, in between use Especially if the well is used also for cattle watering, cattle droppings may easily become mixed with the soil around the well, thus causing bacteriological (faecal) contamination and rendering the water unsuitable for human consumption. Comparable problems are experienced with large, so-called *step wells,* where users may contract guinea worm by standing in contaminated water.

The use of unprotected open wells by large numbers of people may result in a water quality that is actually worse than that of natural sources such as rivers and lakes

In spite of the various water supply programmes that are going on in Africa, the over-all situation for rural water supply is still far from satisfactory, with a relatively large percentage of the rural population still having to rely on unprotected water sources like pools and rivers. Unprotected open wells, when used by larger numbers of people, do not constitute a major improvement to this situation, and may — in fact — provide a poorer quality water than natural unprotected sources.

To prevent pollution, wells have thus been covered (against bird droppings) and raised above ground level (so that children or small animals could no longer fall into them), while various elaborate constructions were devised for preventing the bucket or bag from becoming contaminated. The safest option nowadays is obviously the use of a well-constructed handpump (see *Volume 4: Handpumps*).

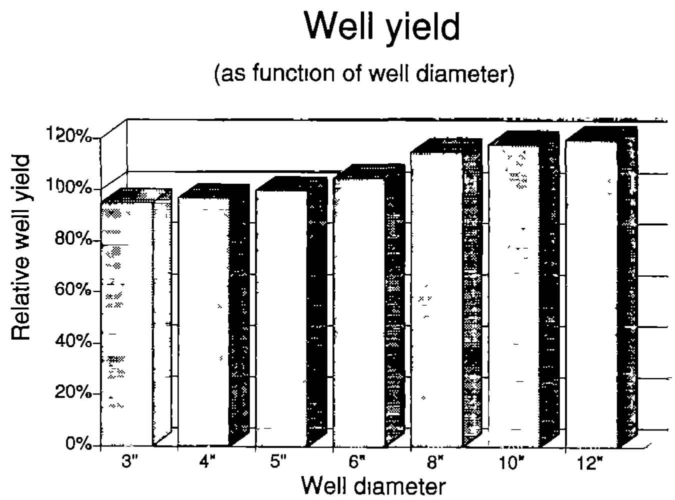
Large and small diameter wells

Boreholes, whether shallow or deep, have the great advantage that they are - by definition - covered, while they, being small-diameter wells, also have a relatively higher yield than wells with large diameters (see diagram at the right). Bored wells with handpumps have thus become the most widespread means of groundwater abstraction.

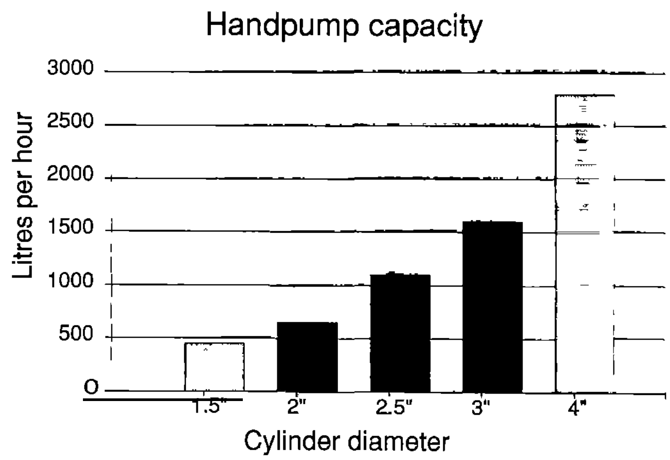
The expected use of a well will to some extent determine its dimensions: a larger output will, for instance, require a larger-size handpump cylinder, and — therefore — a larger well diameter.

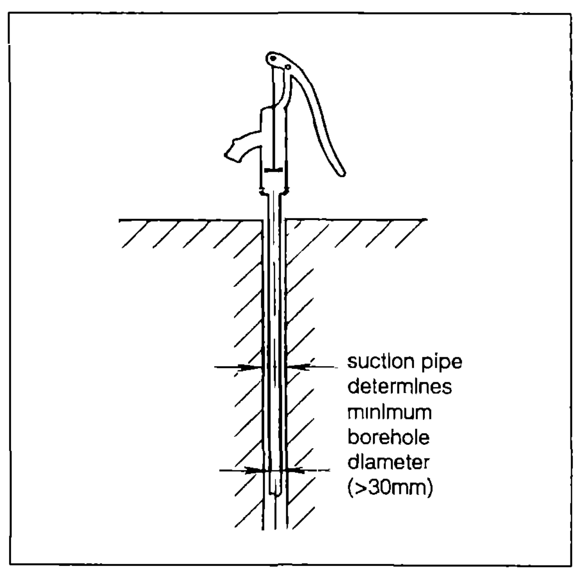
Considerations of water depth and required output are often interlinked: a high output (thus: larger cylinder diameter; see graph at right) may be desirable, but the use of large-diameter cylinders may not be practical in view of the water depth, as it may require too much effort in pumping. A high water table, on the other hand, may allow the use of larger-than-necessary pump cylinders, thereby offering the benefit of additional water which can be used for keeping a small vegetable garden.

In practice, and certainly for projects covering a larger number of wells, it is often recommended to standardize on a single pump cylinder size. This not only facilitates construction, but also maintenance of handpumps with a standard cylinder size is much easier as it limits the numbers of different spare parts that has to be taken along by a maintenance crew or pump mechanic.



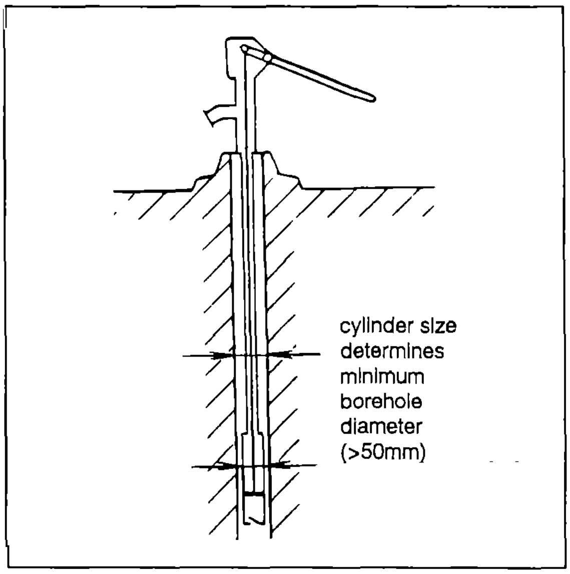
*Limited effect of enlarging well diameter on well yield. yield of 3" well taken as 100%·
Wells with a 4 x larger diameter (and 16 times larger cross section) only yield about 20% more water'*





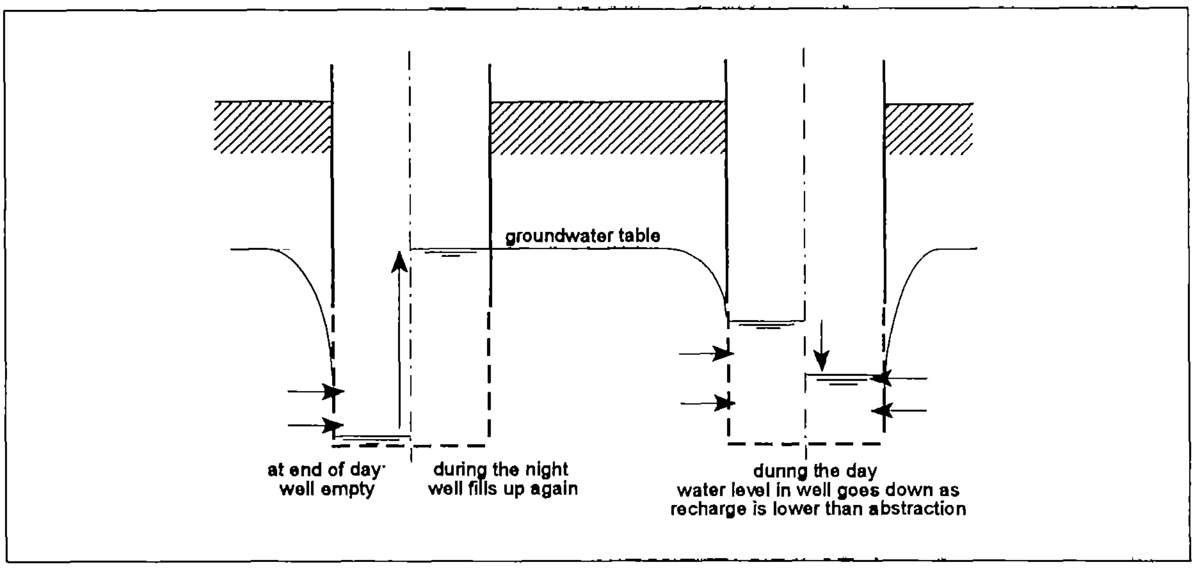
Suction pumps require minimum well diameter

Depending on the type of pump or other abstraction device, the smallest possible well diameter will vary somewhat:



Minimum size for other handpumps and electrical submersible pumps depends on cylinder/pump diameter

- a suction-type handpump allows the smallest possible well diameter, as only the suction pipe needs to be fitted inside the well, while the rest of the pump may be mounted on top of it. Even a net internal well diameter of close to 3.5 cm would thus be possible
  Such a type of pump has several draw-backs, however (see *Volume 4· Handpumps*), including the fact that it can not be used when the water table is deeper than about 7 m. Even then this restriction applies only to areas located at sea level; for areas located at a considerably higher elevation, as is the case for many areas around the great African lakes, the lower atmospheric pressure reduces the practical suction head to around 3 - 5 m only. For reliable and safe water supply suction pumps should, therefore, not be used;
- handpumps that have a cylinder below the water table require a net well diameter that allows the cylinder to be lowered into the well without damaging the casing. Practice in large-scale handpump projects shows that cylinder diameters are generally limited to the range of 50 - 75 mm (2 - 3"). At smaller diameters the pump efficiency drops too much (too many strokes are required for filling a bucket), whereas larger cylinder sizes, while speeding up the process of pumping, require too much effort, so that they are unsuitable for smaller children and elderly persons;
- submersible electrical pumps are normally limited to sizes of 100 mm (4") and larger,
- the use of water bailers and buckets, even when these are of a specially adapted design, requires wells that have an internal diameter of at least 200 mm, and more often close to 500 mm.



Large diameter well in a relatively poor aquifer

RELATIVE ADVANTAGES AND DISADVANTAGES OF SMALL AND LARGE DIAMETER WELLS

	SMALL	LARGE
EQUIPMENT REQUIRED for construction	- Specialized equipment such as augers and bailers required - No dewatering of wells is necessary	- Hardly any specialized equipment is absolutely necessary However, speed of construction improves when using specialized equipment - Special dewatering equipment is normally required
for raising water	Pumps or special small-diameter buckets are necessary	Ropes and buckets are frequently used if top of well is open, otherwise the same equipment is used as for small-diameter wells
COST OF CONSTRUCTION	Lower, because relatively little material is required, and less man-hours	- Higher, because much more material is required Especially lining materials (e g concrete rings or aggregates and moulds) may require costly transportation - Number of man-hours involved is larger
SPEED OF CONSTRUCTION	Higher (approx. One week per well)	Lower (approx One month per well, or more)
HYGIENIC ASPECTS	Potentially good, especially when a hand-pump is used	Potentially good when the well top is covered and a handpump is used, poor when top of well is open Bucket and ropes may be dirty, thus contaminating the well
SAFETY during construction	Negligible danger during construction	Danger of cave-in may be eliminated by proper construction. Danger of something dropping in well is always possible Handling heavy well linings is dangerous for unskilled labourers.
during use	Danger during use negligible	Raising the well lining to well above ground level can minimize danger of people falling in Negligible danger in case of covered wells
MAXIMUM NUMBER OF PEOPLE ABLE TO USE THE WELL CONCURRENTLY	Normally one, two in case of duplex pumps.	In open well three to six, depending on well diameter, in covered well same as with small-diameter wells
RATE OF DISCHARGE POSSIBLE	Theoretically/potentially better - more than one aquifer can be tapped, - well can be made almost any depth below static water level, - good possibility of putting filter in material of high permeability	Theoretically less. - well yield increases less with larger well diameter than with larger depth, - depth to which well may be excavated below static water level is more limited than with small-diameter wells
SKILL REQUIRED well construction	- Little, in case of hand-operated augers (can be taught within one month), - Much, in case of sophisticated drilling equipment (several years)	Much Well sinking is a difficult job, which takes up to 2 years to master.
water raising	Must be able to maintain and repair pump and/or small-diameter buckets	Little skill required in case of open wells, otherwise. same as with small-diameter wells
RELIABILITY well	Excellent	Somewhat less, as depth is more limited. Poorer aquifers may be tapped, however, and water stored in the well overnight
water raising	Somewhat less, as for pumps a certain local maintenance and repair potential is required	Somewhat better in case buckets are used, otherwise. same as for small-diameter wells
ABILITY TO STORE WATER (important when permeability of aquifer is low)	Negligible.	Larger as diameter and depth below static water level are larger.
LIMITATIONS ON WHEN WELL MAY BE CONSTRUCTED	None, except accessibility of site (may be problematic in rainy season)	- Well to be constructed preferably at time of year when water level is at its lowest Otherwise - high-capacity dewatering equipment required, or - well constructed in stages major part at any convenient time, lower part of well when groundwater level is at its lowest

In fact there is only one obvious reason for constructing a large-diameter well, viz. when the transmissivity of the aquifer is not sufficient to allow water entering into the well at the same rate at which it is pumped out In such situations, where the yield of the water bearing layer is marginal only, a larger well has a particular advantage. even at the relatively low velocity at which water enters the well, it will still be possible that the well is completely filled (to the groundwater level) during the night, so that the well contents are available for use the next day, in addition to the — limited — inflow of water into the well during use. Large-diameter wells (which are essentially dug wells) are thus a feasible option when the sustained yield of the aquifer is less than about 500 litres per hour (which is the yield of a Ø50 mm handpump cylinder, as can be seen in the graph on page 2). Obviously, that yield should not be too much lower, or very large wells would be required to store enough water for the people using it (generally in the order of 150 - 300 persons per well). Even then, however, there may be no option but to accept the effort required to construct extremely large wells, if no feasible alternative exists. An example is the situation whereby rainfall, even though it has a reasonably large intensity, can not be absorbed by the soil because the top layer is essentially clay, and most of the rainfall disappears as surface run-off and in small rivulets and streams. In that particular case, however, a potentially more feasible option would be to construct rainwater collectors (which require a relatively large and expensive storage capacity, however).

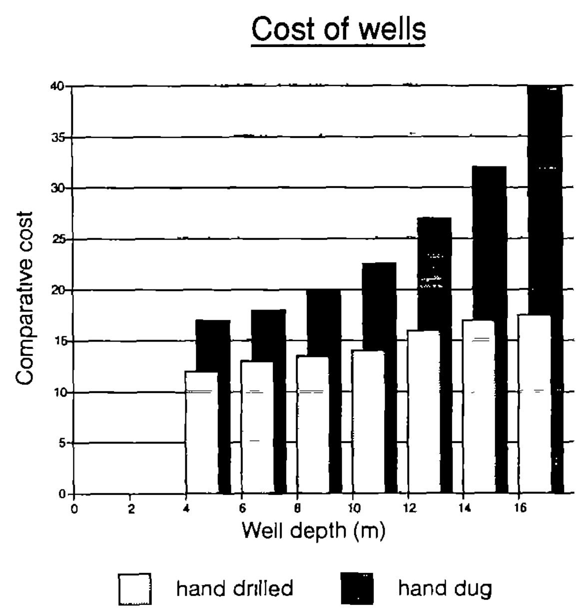
Under normal conditions, however, the yield of the aquifer should be sufficient to keep pace with the abstraction that is possible with a handpump fitted with a Ø 50 - 75 mm (2 - 3") cylinder This is based on practical experience, as about 80% of the handpumps supplied is provided with 2.5" cylinders, with the remaining 20% about equally divided over 2" and 3" cylinder handpumps. When aquifers with a reasonable yield are found, a well which allows a Ø 50 - 75 mm (2 - 3") handpump cylinder to be fitted inside, should thus be fully acceptable.

In order to make certain beforehand that aquifers of sufficient capacity are present, it may be preferable — and for larger-scale programmes this should be even compulsory — to carry out a systematic surveying and well siting programme in preparation of the actual well construction. During such surveying, which is covered in more detail in *Volume 1: Well Siting*, a pump test is carried out which gives an indication of the yield that may be expected. If, during that pump test, the yield of the survey borehole is less than about 400 litres per hour, the site should be considered unsuitable for constructing a small-diameter well.

A comparison of characteristics of small and large diameter wells is presented overleaf.

Cost of wells

Large-diameter wells are more expensive than small-diameter wells of the same depth: for a typical large-scale wells construction project the cost of a hand-dug well of a limited depth would be around twice the cost of an equally deep small-diameter well For wells deeper than 7-8 m the difference in cost goes up considerably, for various reasons:



- *At this depth it is no longer possible to use simple suction pumps for dewatering the well*
  Especially a well in a good aquifer will show a considerable inflow of water into the well, also during construction. Still, it will be essential to continue

digging for some depth below the water table, as the well should be deep enough to hold water also after a prolonged dry period. For the construction of a single well it would — at least in theory — be possible to wait for the end of such extremely dry period before finishing the well, so that it would hardly be necessary to dig much below the groundwater level at that time.

For projects that involve a number of wells, however, such approach is not really possible, and each well should be dug down well below the water level that is encountered at the time of construction, with a sufficient safety margin to allow a subsequent seasonal lowering of the water table without the well falling dry.

The simpler types of pumps that can be used for dewatering a well are suction pumps, and their use is limited to about 7-8 metres of level difference (and often even less), because the atmospheric pressure, being the driving force for these pumps, does not allow a larger suction head under field conditions Dug wells deeper than 7-8 metres thus often require the use of more expensive pumping arrangements.

- *The difficulty of work, e.g. the effort required to bring up excavated soil, is more than directly proportional to the depth.*

Cumbersome handling of pre-cast concrete rings for lining a dug well

The type of materials used for lining dug wells, e.g. concrete cast *in situ*, pre-cast concrete rings or brickwork, is not only more expensive than that used in small-diameter wells (which often have a PVC casing pipe), but also much heavier and therefore more cumbersome to apply. By contrast, all work on drilled wells takes place above ground, which makes the operation less dangerous and troublesome

When deciding which type of well should be constructed, it is necessary to realise that the arguments presented in this chapter are valid especially for larger-scale programmes. An individual well hardly warrants investments if the duration of construction is not a critical issue and labour is readily available. On the other hand, in a programme for constructing several handpumps that is carried out by an NGO, or in a large programme financed by a bilateral or multilateral donor, investments in equipment and tools that lower the construction costs and reduce the construction time of wells are certainly warranted.

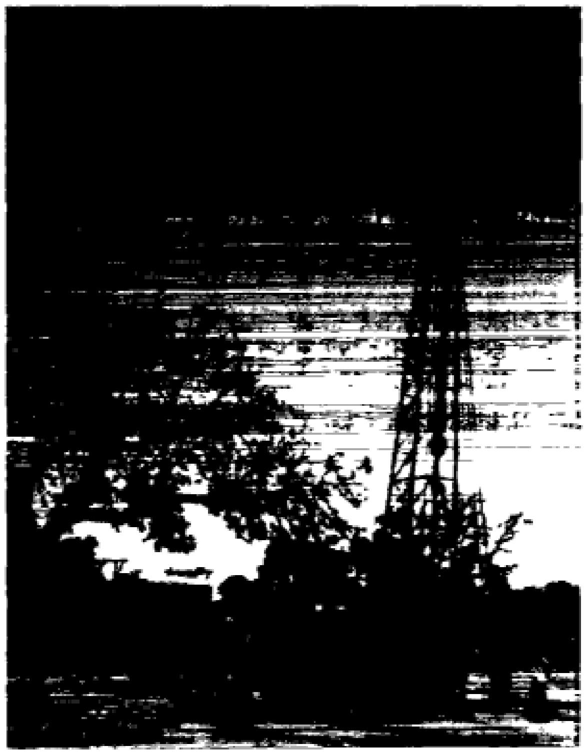
In areas with poor aquifers, even though more wells may be required, the need to go for bored wells may often be less than with good aquifers: whereas in the latter case the inflow of plenty of groundwater into a well being dug requires special measures for pumping out the water, to prevent the walls from collapsing, etc , rendering well drilling — in spite of the additional investment — a preferable alternative, in the case of a poor aquifer the soil conditions may paradoxically be better for digging a well without expensive preventive measures, and thus not warrant investment in well drilling equipment The end result will still be a poorly functioning well, but at minimal cost

Construction time

Small-diameter wells, whether hand drilled or machine-drilled, have the obvious advantage of considerably shorter construction time: where the construction of hand-dug wells of approximately 1 m diameter and 8 - 10 m depth takes around 3-7 weeks, hand drilled wells of the same depth can be constructed in less than one week. Leaving alone the construction of the pump platform and installation of the handpump — which are normally done by different groups — a hand-drilling crew can thus produce some 50 wells per year, whereas the annual production of a hand-dug wells group is about 7 wells as a maximum, taking into account that well digging may not be possible during the rainy season. All together, drilled wells can thus be constructed in less time, at lower cost than dug wells (or at a greater depth for the same cost). The fact that a drilled well can tap a deeper aquifer than would normally be possible for a dug well, also means that the quality of its water is likely to be better: because of the greater depth there is less chance of contaminated water reaching the aquifer from the surface.

Hand drilled versus machine drilled wells

In industrialized countries, deep boreholes are often constructed with heavy machinery: truck-mounted rotary or percussion drills, which allow for speedy construction of boreholes even in difficult soil formations. The high wages in such countries favour a solution whereby the labour input is reduced to the extent possible, even if that requires high investment in advanced machinery. These drilling rigs require a major capital outlay and skilled personnel, which may not be readily available in rural areas of developing countries. Often the provision of — imported — spare parts and materials for the truck(s) involved, for compressor and drilling rig, is a major obstacle for large-scale use of this type of equipment under such conditions.



Typical heavy-duty drilling rig

Although the use of machine-drilled wells may be the only feasible option under certain circumstances, normally its use is not economically feasible for constructing wells with a relatively low output, as is the case with wells equipped with handpumps.

This manual therefore focuses on the use of hand drilling (also called hand boring) equipment.

Restrictions

Hand drilled shallow wells constitute the cheapest and most efficient method of supplying the rural population with good-quality drinking water, provided that the following conditions are met:

- soil conditions are favourable for hand drilling (layers are not too hard to be penetrated by hand drilling equipment). If soil conditions are unfavourable (which would be shown during the survey phase as the survey drill would not be able to penetrate the soil either), the only remaining options would be drilling by percussion rig or rotary drilling rig, or digging the well (provided that its depth should not be too great, and that the soil can be broken with a hand chisel, jackhammer or similar equipment) A cost comparison of these alternative options should indicate which of these is to be preferred, assuming that they are feasible at all;

- the water bearing layer (aquifer) is not deeper than about 25 m (which may be considered the maximum depth that can be attained with hand drilling equipment under favourable conditions). If deeper wells would be required, the weight of the drilling assembly would become too much too handle, even with a tripod;
- transmissivity (say· yield) of the aquifer is not too low for a small-diameter tubewell, otherwise storage capacity in the well would be necessary for overnight recharge, requiring a large-diameter well. If during the survey drilling and subsequent test pumping a yield of around 400 l/h could be achieved, it may be assumed that aquifer transmissivity will not constitute an obstacle for the use of small-diameter wells.

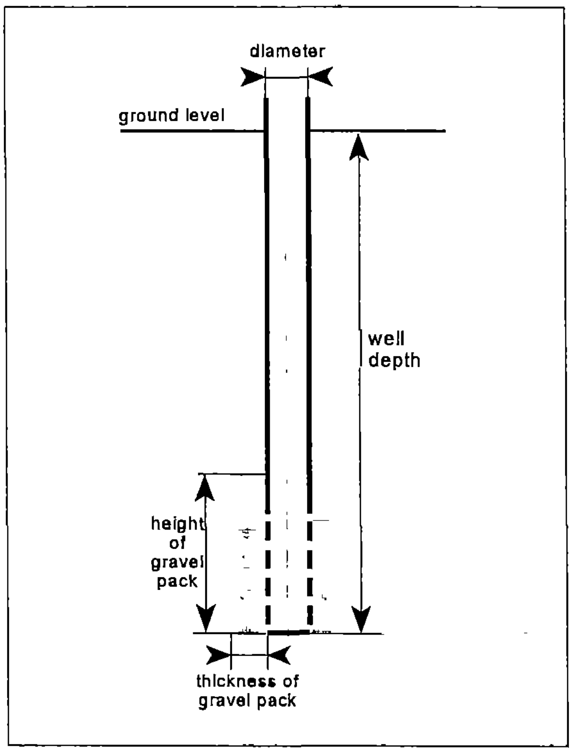
WELL DESIGN

If at all possible, carry out a survey first

Especially — but not only — for larger programmes it is important that a proper well survey is carried out, to check whether hand drilling a well is at all possible at the prospective site. For details on how to conduct a well survey, see *Volume 1· Well Siting*. If the survey is successful, it also provides a proper soil description for the well site. On the basis of that description the well drilling team can prepare the well design.

This should indicate:

- total well depth
- length and diameter of filter pipe/screen
- height of the gravel pack
- estimate of required materials (sand, cement, etc.)
- quality of the groundwater.



Main parameters for well design

Groundwater quality may be a reason to reject a well site, e.g. because the salinity or fluoride content of the water is too high, rendering the water unfit for drinking or even dangerous for human health. Blindly following existing (inter-) national water quality standards is not recommended: often existing standards are — by their very nature — conservative, and might result in the rejection of water sources that could still be acceptable under certain conditions. Several standards, moreover, are based on economic rather than health considerations hard water is not injurious to health, but requires more soap for laundry, leads to scale formation in piping, etc., and may thus be perfectly acceptable for rural water supply. Similarly, high iron contents may constitute a problem for laundry, may discolour rice and impair the taste of tea, but — lacking other alternatives — may be fully acceptable from a health point of view. Certain constituents are indeed harmful, but for a certain group of consumers only: higher nitrate contents are dangerous for babies and infants, but are relatively harmless for adults, and water of such composition might thus be used by adults. Also the reaction of individuals to certain constituents may differ, depending on the local situation: water containing fluoride well in excess of 2 - 5 mg/l hardly caused any visual effect in a certain area in Tanzania, for example, whereas even a lower concentration caused very visible skeletal fluorosis in a certain area in India.

Especially if there are indications that the groundwater quality might be problematic, a water sample must be taken during the survey stage, and analysed in a suitably equipped laboratory It is realised that this may be easier said than done, especially in the interior of the African continent, but it should be attempted anyway. In case of doubt it is always best to refer to specialists, e.g. to the nearest medical doctor or health clinic staff, who might also be in a position to analyse the water chemically and bacteriologically

The survey description will also provide information on the drilling process and difficulties that may be expected during the construction of the well.

- it can be decided beforehand which types of drill bits are likely to be needed, based on the soil types,
- the required casing and screen lengths can be determined, to prevent unnecessary (or insufficient) materials to be brought along. This is especially important for areas that are difficult to access.

Making the design

Making the design of a well comprises:

- analysis of survey and laboratory data — when available — so as to obtain information about the depth and thickness of the aquifer(s), its yield and the quality of its water;
- selection of proper dimensions for the well components;
- choice of materials to be used in constructing the well.

The approach and equipment mentioned in this manual have been developed and tested during several decades of extensive experience, gathered in a number of national and regional shallow well programmes in rural areas

Variables that must be taken into account for designing a well are:

- *diameter of the well*, determined in practice by the size of the handpump cylinder,
- *depth of the well*, determined by the location and thickness of the aquifer(s), and possibly by the soil composition. If at all possible, it should be tried to tap the second aquifer, so as to reduce the possibility of abstracting water that is contaminated by polluted water (e.g with insecticides) that has entered into the well from the surface;
- *location and length of the screen (filter pipe)*, determined by the location and thickness of the aquifer(s). For normal handpumps, a total filter length of 2 pipe sections (6 m in total) should be sufficient;
- *dimensions (height, thickness and grain size) of the gravel pack*, determined by the composition of the aquifer material and the total thickness of the aquifer.

Each of these variables is dealt with in greater detail below

Well diameter

The required diameter of the well depends on the size of the handpump cylinder that will be used. Using SWN handpumps and standard well drilling equipment, the required sizes are as follows:

Nominal cylinder size:	40 mm (1½")	50 mm (2")	63 mm (2½")	75 mm (3")
Outer diameter of pump cylinder [mm]	55	66	81	96
Inner diameter PVC casing [mm]	58	69	103	103
Outer diameter PVC casing [mm]	63	75	110	110
Thickness of gravel pack [mm]	13	25	25	25
Minimum drill diameter [mm]	70	100	140	140
Maximum drill diameter [mm]	100	150	180	180
Nominal size of required drilling set [inch]	4"	6"	8"	8"

As can be deducted from this table, the clearance between the pump cylinder and the PVC casing pipe for a 40 mm cylinder in a 4" borehole is minimal. The 4" drilling set is in fact the *survey* drilling set, and as such not really developed for production boreholes. The output of a 40 mm pump cylinder, moreover, is not considered very effective under normal conditions, so that this combination should be considered only in special cases.

For hand drilling, the 6" set is best suited for drilling boreholes catering for relatively small communities. Allowing a 50 mm pump cylinder, its output is lower than what is considered the standard yield for a village-level handpump (catering to between 150 and 300 people), but its low weight allows it to be transported in the trunk of a normal car, while drilling itself can be carried out without having to use a tripod for lifting the drilling string. It therefore constitutes the most cost-effective means of constructing a small-capacity borehole.

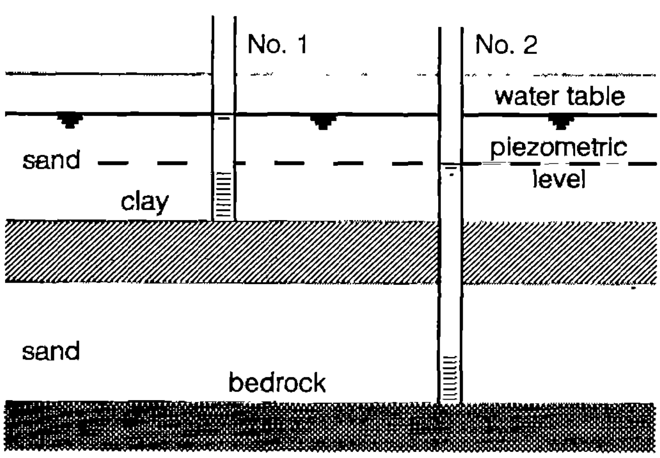
Both the 63 mm and 75 mm handpump cylinders can be accommodated in a borehole constructed with the 8" hand drilling set, and this combination is perfectly suitable for a community handpump catering for at least 250 persons. Due to its greater weight, however, it must be transported in a 4WD or pick-up, and a tripod is required for the drilling operation itself (see page 18).

Except for special circumstances, a well diameter of 150 - 180 mm should thus be sufficient.

Well depth

The depth to which the well must be drilled, depends entirely on the depth and thickness of the water bearing layer, the *aquifer*. Several types of soil may contain water, but not all of them are suitable as an aquifer. Clay, for instance, has a high porosity (45-55%) and may contain much water, but its permeability (i.e. its capacity to conduct and release the water) is extremely low as the pores are very small. For that reason clay is not a good aquifer, whereas sand and gravel, even though their porosity is lower, are good aquifers. In general: the coarser the sand/gravel is, the better its suitability as aquifer material will be. The best aquifers are therefore those consisting of sand, gravel, and sometimes weathered bedrock. For hand drilled wells, sand or very fine gravel will offer the best possibilities.

A distinction must be made between ***unconfined*** and ***confined aquifers***: water bearing layers that have a free water table, at atmospheric pressure, or a water table under a different (higher) pressure, caused by the fact that the aquifer is covered by an impermeable layer (see figure below). Confined aquifers offer the advantage that they are less likely to dry up due to seasonal changes, while the presence of the impermeable layer on top precludes contamination by polluted water from the surface.



The water table in the top layer of sand is under atmospheric pressure: water in the filter pipe rises to the same level;

The water in the lower sand layer is under pressure, so that water in the filter pipe rises to a level higher than the top of that layer.

Whether the water level in filter pipe 2 is higher than that in filter pipe 1 is different from location to location, and can not be predicted.

Unconfined (top) and confined aquifers (bottom)

For these reasons, preference should be given to tapping confined aquifers whenever possible.

As a rule, staff that has no special training in surveying or hydrogeology, will not be able to decide whether an aquifer is confined or not In such a case, the moisture content of the soil that is removed from the drilling bits can be used as an indication:

- once the soil gets moist (or even wet) this is an indication that an aquifer will be near. Continue drilling — when necessary after having installed a temporary casing — until the soil is dry again;
- depending on the depth and thickness of the moist/wet soil layer, decide whether it would be possible to continue drilling for at least 5 m, to try and tap a second water bearing layer If the first water bearing layer is 5 m thick or more, the chances of successfully tapping a second aquifer below will be slim, since the depth to which the survey drill can proceed is limited, whereas also the second aquifer should have a sufficient thickness, and should be overlain by a so-called *aquiclude* (impermeable layer) of sufficient thickness to create a confined aquifer, all adding to the depth of the borehole;
- if a second water bearing layer is indeed found, with a dry layer in between the two, it is likely to be a confined aquifer.

It goes without saying that any aquifer, whether unconfined or confined, is only suitable as a source of water to be tapped by hand drilling when:

- the bacteriological and chemical/physical water quality meet the drinking water standards (see *Volume 1: Well Siting*);
- permeability and thickness of the aquifer are adequate to guarantee a sufficient yield, say: 500 litres per hour or more (see graph on page 2),
- it is not located deeper than about 25 m;
- it is not covered by one or more hard formations that can not be penetrated with hand drilling equipment.

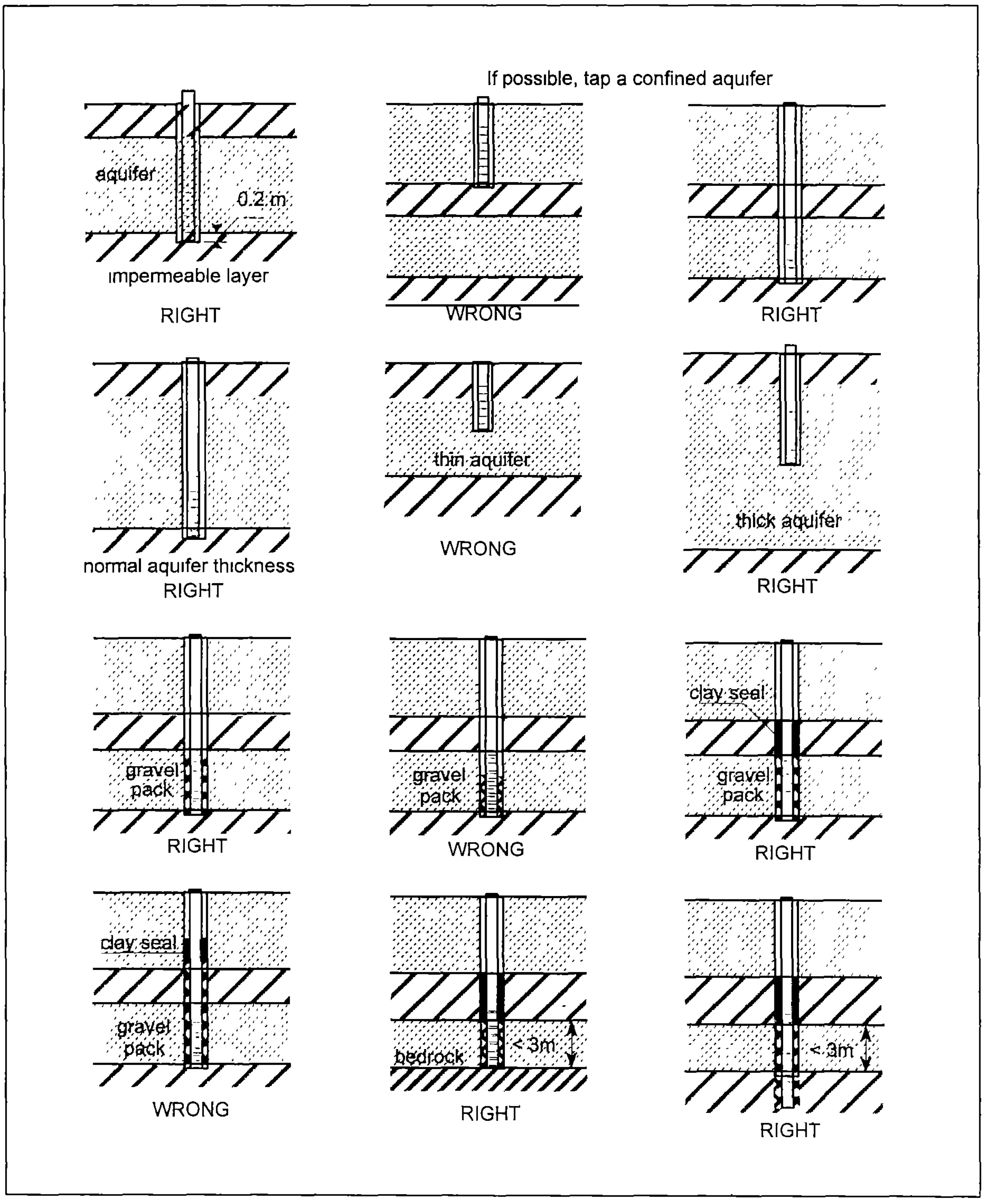
In principle, all these issues can be checked during the well surveying stage: if the survey drill can penetrate the soil and reach the required depth, then the construction drilling set certainly can. Both water quality and yield can be determined during the survey drilling as well.

The basic principles for determining the depth of a well and the location of the well screen are described below. They should be followed as far as the local situation, and especially the degree of training of the well drilling crew, allow. For that reason they must be seen as an indication rather than a strictly prescribed approach:

- whenever possible, the bottom of the well should be about 0.2 m into an underlying impervious layer, as this allows the temporary casing to pass fully through the aquifer material, thus preventing any possibility of the soil caving in;
- as mentioned above, if at all possible, the screen should be located in a confined aquifer;
- if there is more than one confined aquifer within a reasonable depth, tapping the deepest of these provides extra protection against pollution from above;
- with 2 lengths of filter pipe (of 3 m each), even a relatively poor aquifer can yield sufficient water;
- install the filter pipe/well screen as deep as possible in the aquifer, to reduce the risk of the well drying up. Only in case the aquifer is very thick, e.g. more than 10-12 m, is it possible to place the screen halfway;
- always apply the gravel pack over the full length of the screen, to prevent particles from the aquifer or other layers from entering into the well;
- always install a clay seal around the casing/filter pipe at the level where an impervious layer is penetrated, to prevent short-circuiting of — possibly different types of — groundwater from above and below the impervious layer;
- if the thickness of the aquifer is less than 3-6 m, first try to make the borehole deep enough so that 1 or 2 full sections of filter pipe can be installed below the top of the aquifer. Only when this is

impossible, e.g. because of the presence of bedrock, should the lower filter pipe be cut to the required length;

- if there is no other possibility but to put the filter pipe in an unconfined aquifer, the well should only be constructed if that aquifer is reasonably thick. Often, however, there simply is no choice, and the well must tap a rather shallow, unconfined aquifer. The storage capacity of the well can then be maximized by enlarging the well diameter through *reaming*. Nevertheless, it should be realized that the water from such a well is ***not bacteriologically safe***, and should be well boiled before use



Recommendations for placing screen and gravel pack

Screen

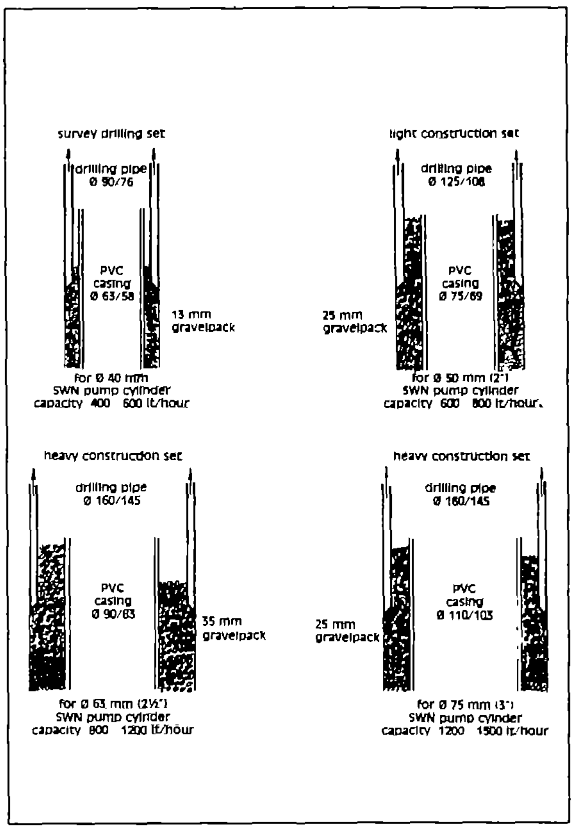
The location of the screen (filter pipe) is in principle determined by depth of the well, as shown in the diagrams at left. The screen should be positioned in the aquifer, and as low in that aquifer as reasonably possible. Only in case the aquifer is much thicker than would be necessary for positioning the screen, is there a large degree of freedom in determining the location of the screen. Otherwise, it should be positioned at the bottom of the aquifer. Basic hydrogeology indicates that the diameter and length of screen and gravel pack should be decided on the basis of the characteristics of the aquifer: the length of the screen (and of the gravel pack) and the outer diameter of the gravel pack (hence: the outer surface of the cylinder formed by the gravel pack) determine the approach velocity of groundwater entering from the undisturbed soil into the well. With finer aquifer material that velocity should be lower, whereas coarser material allows higher velocities.

In a similar manner there is a limit to the velocity with which water may enter into the well screen itself. This is determined by the screen size and percentage of screen openings.

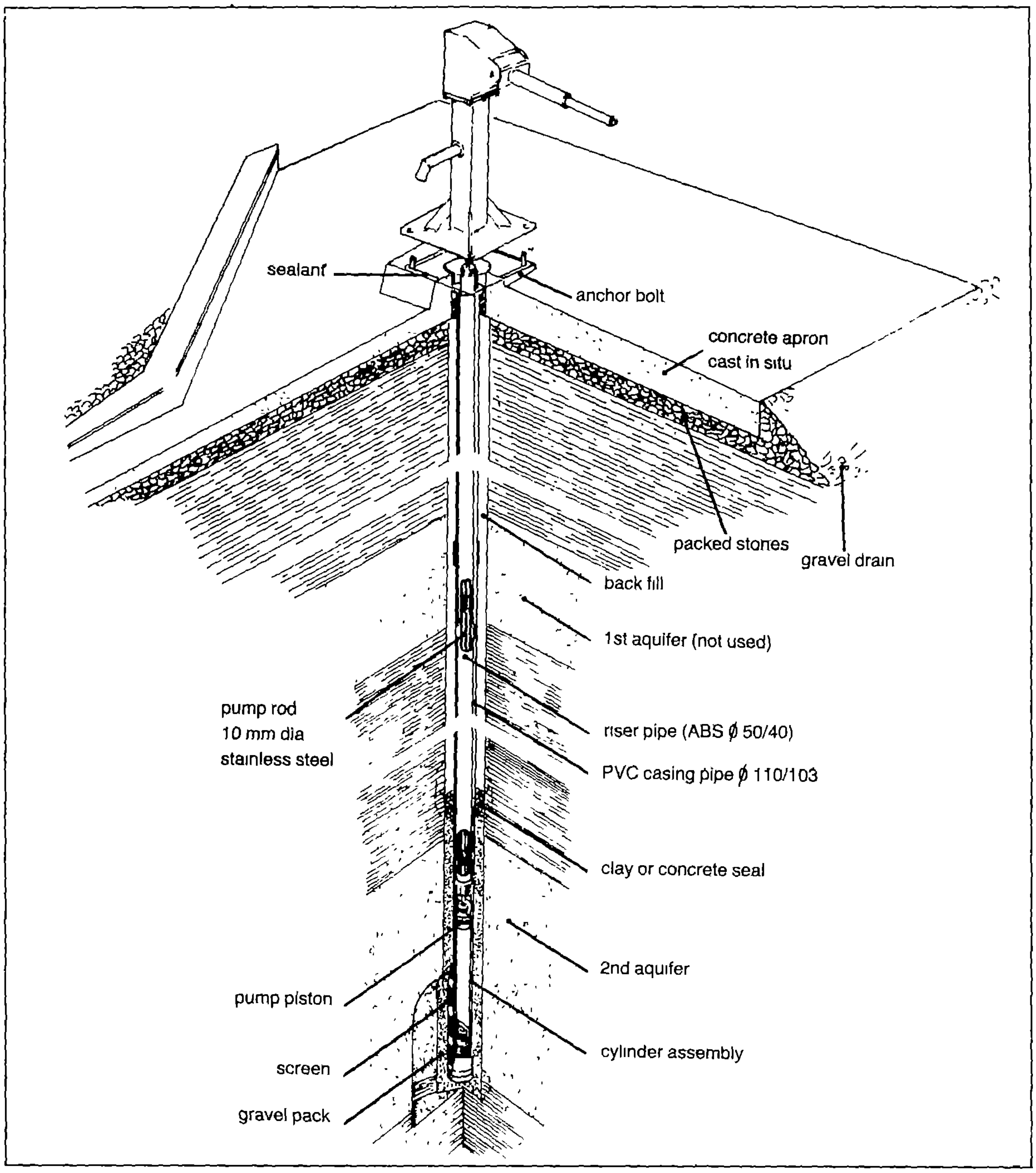
For wells equipped with handpumps, normally the required yield is very low as compared to the maximum yield that would be possible on the basis of these factors, and the variations in aquifer characteristics that are normally encountered are well within the range that can be accommodated by one type of screen. For that reason, standard screen pipe sections can be applied when the boreholes are fitted with handpumps. Only when mechanically driven pumps are to be used in a hand drilled borehole, it is essential that traditional well capacity calculations are carried out to carefully match the characteristics of the well screen and gravel pack against the required output of the well. In special cases, the allowable output can be increased by utilising special screens with a high percentage of slotted area (Johnson well screens and similar).

For hand drilled wells with handpumps, the standard screen size depends on the well diameter: the table on page 9 shows the range of PVC casing sizes and gravel pack thicknesses, as a function of the size of hand drilling set used. In all examples given, the inner and outer diameter of the screen/filter pipe is identical with that of the PVC casing pipe.

Under normal conditions a single length of casing pipe (3 metres length) may be sufficient (as is suggested in the drawings on page 12), but it is recommended to apply two sections (6 m in total) as a rule. Even in rather unfavourable situations such a length of filter pipe would be able to provide sufficient water for the size of handpump cylinder that fits inside the casing (see table on page 9).



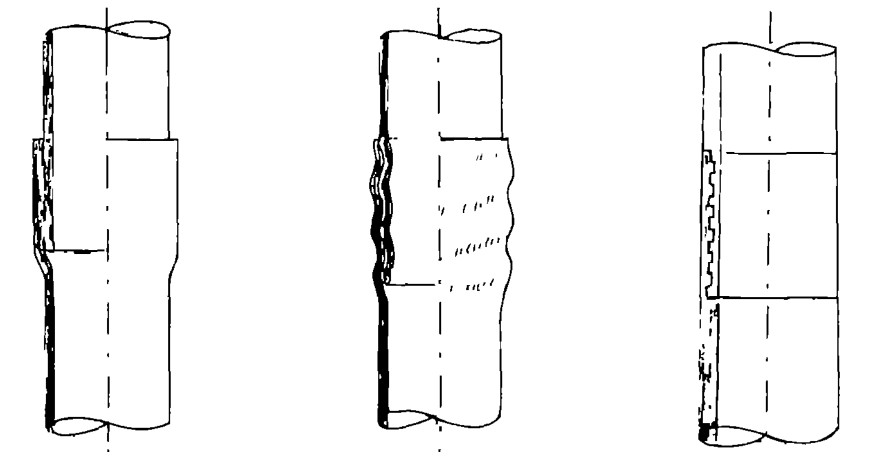
PVC casing and gravel pack



Typical hand drilled shallow well

All screen pipes are provided with 0.7 mm wide slots[1] parallel to the axis of the pipe. The total percentage open area of the screen pipe is 6 - 8%, which is sufficient for handpump use. In principle it is possible to have a larger percentage open area if slots are used perpendicular to the axis of the pipe ('horizontal' slots) since in that case the pipe may be considered to exist of a series of rings that are all under tensile (or compressive) stress in the same way as the full pipe would be, whereas the strips between 'vertical' slots act as thin 'beams' with corresponding deflections To keep these within limits, the structural strength of each strip needs to be large enough, which limits the open

[1] Due to the 'memory' of the PVC material, during application of the pipes in the field the actual slot width will generally have become somewhat smaller, viz 0.4 - 0.5 mm



Connection options for filter and plain PVC pipes

area. By contrast, it would be impossible to retract filter pipe with 'horizontal' slots from unsuccessful wells, since the material would break easily from tensile stress along the pipe axis.

So-called low-cost filter pipes are sometimes constructed by cutting slits in steel pipe with an acetylene torch. The resulting slit width is so large, however, that these 'filter pipes' are suitable only for very coarse gravel layers, and not for more normal soil conditions Another attempt at low-cost screens is sawing slits, perpendicular to the pipe axis, with a hacksaw. Because of the shape of the cut, the pipe thus loses a disproportionate percentage of its structural strength, compared to the percentage screen opening created.

In some cases, PVC equivalents of the Johnson-type well screens have been used, as these offer a much larger percentage open area (around 50%). For wells with handpumps these — considerably more expensive — screens are not required at all, as a rather low percentage open area is still sufficient, as is shown in the following calculation: For 'vertically' slotted pipe, an open area of 6 - 8% means that for a single 3-m length of screen pipe Ø 110/103 mm the total open area is about 0.07 m^2 With optimum screen entrance velocities — depending on the coefficient of permeability of the aquifer — in the order of 1.5 - 5 cm/s, the allowable discharge capacity per length of filter pipe would be: 1 - 4 l/s (3.6 - 14 6 m^3/h). Even for the smallest size filter pipe (63/58 mm) the corresponding discharge capacity is still 1.2 - 4.8 m^3/h. By comparison, the capacity of a handpump with a cylinder diameter of between 50 and 75 mm is in the order of 0 6 - 1 6 m^3/h, so clearly lower than the allowable discharge capacity

Unslotted PVC pipes of the same diameter as the filter pipe serve as housing for cylinder and rising main. This so-called *casing pipe* forms the lining of the well from the screen/filter pipe up to ground level. Lengths are the same as for the slotted screen/filter pipes.

At the bottom of the well the PVC screen pipe may be closed by a PVC cap, or a — considerably cheaper — wooden plug of about 4 cm thickness, which is fixed with screws through the pipe wall. For the connection between individual sections of screen pipe or 'blind' PVC pipe, several options exist, each with specific advantages and disadvantages·

- spigot and socket connection (also called 'tulip' end), optionally glued with solvent cement. This is the cheapest solution, with the least additional material at the location of the joint (which might otherwise hamper placing the gravel pack material). It is, therefore, the most frequently used connection. Its only draw-back is that, in case the well would prove to be unsuccessful, it is possible to salvage the pipe material only when solvent cement has been used to glue the pipe sections together, which prevents re-use of the pipe material with the same kind of connection. The only possibility would then be to cut off the still usable parts of the pipe, and join these later with glued, loose sockets;

- pipe ends provided with 'rolled', rounded thread. This is a relatively low-cost alternative that allows the pipe sections to be dismantled by unscrewing the connections. A disadvantage, however, is the fact that the outer width of the connection increases considerably. This renders pulling the casing out of unsuccessful wells more difficult, but especially placing the gravel pack is hampered by the reduced space that is left between the connection and the temporary casing pipe;
- more conventionally threaded pipe ends (spigot and socket) This is the more expensive solution as it requires relatively thick-walled PVC pipe, e.g. Ø 110/101 rather than Ø 110/103 pipe. Its advantage is that the outer diameter at the joint is only marginally larger than in the case of the glued spigot and socket connection, thus enabling a relatively easy positioning of the gravel pack, while allowing the pipe sections to be retrieved relatively easily. This option is suitable especially for deeper wells.

Gravel pack

The gravel pack prevents the aquifer material from entering into the well, and at the same time makes it possible to have filter/screen pipe with slots that need not be too fine to be technically possible. For most circumstances coarse sand/fine gravel with a grain size of 2 - 3 mm is sufficient to prevent the coarser aquifer material from entering the well, while during the so-called *developing* of the well (see page 52), finer particles can be removed from the aquifer(s) and can enter into the well without clogging the gravel pack or filter pipe slots.

Gravel pack material can be produced by sieving coarse sand. If no industry-type sieves are available, as may be the rule rather than the exception, the sand fraction that passes through coffee tray wire (4.6 mm) but not through mosquito gauze (1.2 mm) should be of the correct size range.

The gravel pack must:
- be granitic, white, washed material, preferably from a river and without clay or similar parts;
- not contain split, as this has too many flaky parts;
- not be calcareous (chalky), or contain calcrete, as this cements the slits in the screen;
- not contain laterite, reddish stoney material, as this deposits an iron-containing crust with the same effect.

HAND DRILLING EQUIPMENT

Hand drilling sets

The standard range of hand drilling sets consists of 3 sets:

- ❑ the 4" set (Eijkelkamp set 15.01), the lightest set, which has been developed primarily for well siting and surveying, but which can - under favourable conditions, and with additional bits - be used for drilling production boreholes for small communities such as mission posts, dispensaries, etc.;
- ❑ the 6" set (Eijkelkamp set 15.02), which combines low weight with a reasonable well diameter, suitable for handpumps with a Ø 50 mm (2") cylinder;
- ❑ the 8" set (Eijkelkamp set 15.05), which produces wells of a sufficient diameter to accommodate handpumps with Ø 63 mm (2½") and even Ø 75 mm (3") cylinders, sufficient for communities of 250 - 500 persons. Due to its weight, this drilling set can be used only with a tripod, which is not required for the lighter sets.

Drilling set	4"	6"	8"
Diameter of first drill, for drilling without casing [mm]	100	150	180
Outer diameter of drilling pipe (temporary casing) [mm]	90	125	160
Inner diameter of drilling pipe [mm]	76	108	146
Diameter of inner drill, for drilling inside temporary casing [mm]	70	100	140
Maximum diameter of PVC casing, measured over socket [mm]	68	81	119
Outer diameter PVC filter pipe/casing [mm]	63	75	110
Inner diameter PVC filter pipe/casing [mm]	58	69	101
Thickness of gravel pack [mm]	13	25	25
Outer diameter of pump cylinder [mm]	55	66	96
Diameter of piston in handpump cylinder [mm]	40	50	75

Composition of drilling sets

Although there are some differences between the various sets, the basic composition of a drilling set is the same for all.

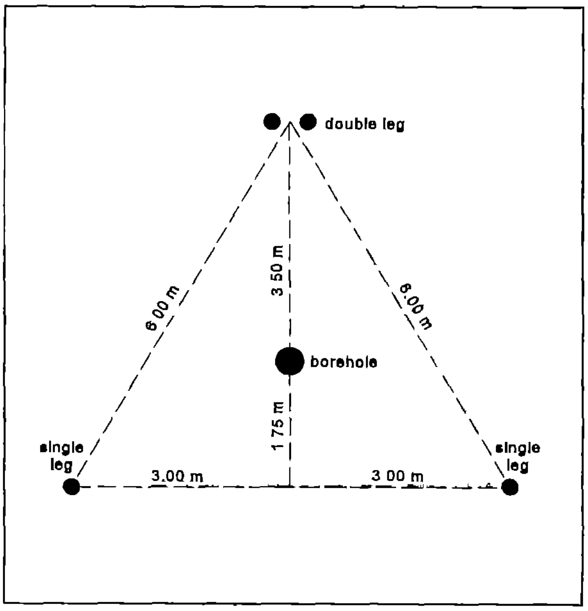
Each hand drilling set consists of two series of drilling bits (for use either without or inside a temporary casing), which are connected to a handle (T-shaped or cross-shaped) by means of extension rods. Casing pipe is provided to prevent the borehole from caving in when it passes through aquifers, and bailers to remove soil material from under water.

Lifting set (tripod)

A tripod is required only for the 8" hand drilling set. It has three legs made of aluminium (light set) or steel pipe (heavy set), each consisting of 3 parts with a maximum combined length of 7 m (1 m at the top, and 2 of 3 m each), and one leg being double over a part of its length and provided with steps (like a ladder). People can thus climb to the top, e.g. to connect a pulley to the ring in the top of the tripod. A winch is mounted on the double leg. It activates a cable that is fed through a pulley hung from the top of the tripod. In this way the force required for operating the drilling equipment can be easily exerted by one or two men.

There are two lifting sets:

- light lifting set (aluminium), bearing capacity 6.5 kN (650 kgf), with a hand-operated winch equipped with a load-brake of 500 kgf maximum. This set is provided with 30 m of Ø 6 mm zinc plated steel cable and a 15 kN (1500 kgf) jack for pulling out temporary casing pipe;
- heavy lifting set (steel), suitable for a maximum lifting height of 30 m; bearing capacity 20 kN (2000 kgf), with a 2-speed (1:1 direct on drum, and 1: 7.5 through reduction) hand-operated winch of 20 kN capacity, which can be operated by two persons. The set is provided with 50 m of Ø 10 mm zinc plated, anti-twist, steel cable. It can be provided with a 50 kN (5000 kgf) jack for pulling out temporary casing pipe.



How to position the legs of the tripod

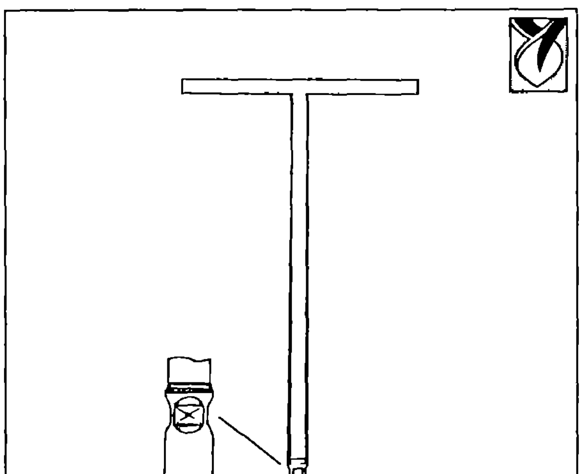
The optimal position for the tripod is such that — once erected — the legs are about 6 m apart, with the borehole in the centre of gravity of the triangle formed by the legs (see figure at right). In this way the stability of the tripod is ensured, while there is enough room around the borehole for handling drilling bits and casing pipe.

The forces that are exerted on the legs of the tripod can be considerable. To prevent the legs from sinking into the soil, they are, therefore, provided with steel foot plates.

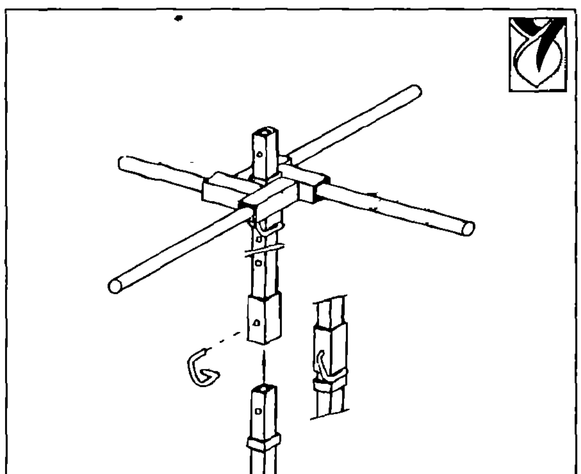
A pulley is connected to a ring at the top of the tripod, and the steel wire from the winch is fed through this pulley. As is mentioned above, the heavy lifting set is provided with a winch that can be set to operate at a reduction (1:7.5) as well.

Handle or cross-piece

The drilling set is operated by turning it around in a clockwise direction. For the lightest drilling set (the 4" survey set) this is done with a T-piece connected to the top of the drilling assembly, for the other drilling sets more power must be exerted, and these sets are provided with a cross-piece to which 4 handles can be attached.



T-piece for 4" (survey) drilling set



Cross-piece for normal drilling set

The *T-piece* is a handle made of Ø 26 mm high quality steel tube, with a length of 60 cm. It is connected to the first drilling bit or extension rod through a coupling with conical thread. The *cross-piece* is a short piece of square tube to which 4 handles (70 cm long) can be attached, and which can be fastened to a section of square pipe with the same outer dimensions as the regular extension pipe, but with a greater wall thickness, and provided with holes at 10 cm distances. This pipe acts as a kelly over which the cross-piece can be slid up or down and connected with a lockpin. In this way the cross-piece can be set at the optimal height above ground (which for handling the heavier sets is obviously more important than for the lighter survey drilling set).

The dimensions of the cross-piece are different for the 6" and 8" drilling sets: for the 6" set the square tube is 30 mm wide; for the 8" set 40 mm wide. The wall thickness for both sizes of pipe is the same: 3 mm. The square pipe used for the coupling is 40 mm and 50 mm wide, for the 6" and 8" set, respectively, and has a wall thickness of 4 mm.

Drilling bits and augers

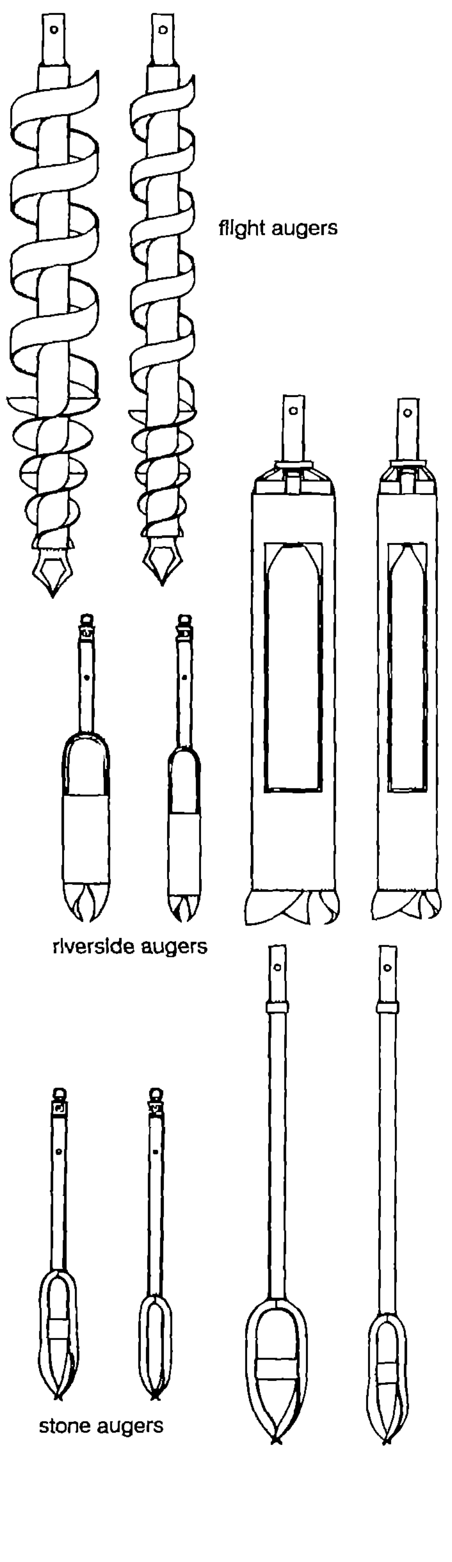
For the different types of soil — hard, soft, dry or wet — different types of drilling bits need to be used, and often best results are obtained by using different bits in succession, in the same borehole.

The following drilling bits are normally included in hand drilling sets (all measures are in mm, except when indicated differently):

Drilling set[2]	4"	6"	8"
For use without temporary casing:			
- flight auger bit	-	Ø 150	Ø 180
- riverside bit	Ø 100	Ø 150	Ø 180
- stone auger bit	Ø 100	Ø 150	-
- stone catcher	Ø 100	Ø 100	Ø 100
- chisel auger	-	Ø 150	Ø 180
- chisel	40x40x500	40x40x500	40x40x500
- reamer	-	-	-
For use inside temporary casing:			
- flight auger bit	-	-	Ø 130
- riverside bit	Ø 70	Ø 100	Ø 130
- stone auger bit	Ø 70	Ø 100	-
- stone catcher	Ø 70	Ø 100	Ø 100
- chisel auger	-	-	Ø 130
- chisel (same as above)	40x40x500	40x40x500	40x40x500
- bailer	Ø 63	Ø 90	Ø 114
Handles, connectors and extension rod specifications:			
- type of handle	T-piece	cross-piece	cross-piece
- size of connections/rods	Ø 26	40/30 mm	50/40 mm
- type of connection between rods/bits	conical	square	square

Although the table suggests that the Ø 100 stone catchers and the chisels are the same for the various sets, in fact this is not the case: the 8" and 6" sets both have square connectors, but of a different size:

2 10" hand-drilling sets have been used in the past, and are still available. However, there is little to be gained by using these larger-diameter sets, whereas their considerable weight renders them cumbersome to transport and more difficult in handling.



50/40 and 40/30 mm, respectively, whereas the 4" set is equipped with conical, threaded connectors.

❑ the *flight auger bit* is the bit with which drilling is normally started, especially for the 8" set. It has a sharp point at its bottom, with which relatively stoney soil can be penetrated, and a screw-like blade that increases in diameter towards its top. The top half of the auger has a constant diameter. For this part the spiral blade is provided with a rim welded to its outer edge, to increase its capacity of lifting sandy materials. The bits are specially suited for use in moist clay, sandy soils and gravelly soils, but because of their conical point they can be used in stoney, layered soils as well.

Like most other drilling bits, the flight auger bits are used in two sizes per set: one for initial drilling (without using temporary casing) and one for use inside a temporary casing pipe. Because of their relatively complicated shape, flight augers are not available in smaller sizes: they are available for the 8" set only The bits have a length of 1 m each

❑ the *riverside bit* is a 1 m long tube, with 2 or 3 blades (depending on the bit size) welded to its bottom. The sharp extremities of the blades point downwards at an angle, and are slightly wider than the tube. The blades are spoon-shaped so that the soil is steadily pushed into the tube. The blades cut at the outside only, so that the soil collected inside the bit is practically undisturbed. The bits are suitable for use in semi-cemented layers such as weathered bedrock (granite, laterite, calcrete), but also in hard, dry clay or gravelly soils.

Of the riverside bit again two sizes are available· a larger one for use without casing, and a smaller one for use inside the temporary casing. The riverside bits of the 8" set are provided with a side flap for easy removal of soil from the bit; for the smaller bits such a flap is not necessary.

❑ the *stone auger bit* is used in case the gravel content of the soil is so high that the riverside bit is not yielding adequate results, e.g. when larger stones block the drilling progress. The bit essentially consists of two blades that can be slightly deflected in use to fit around — and thus catch — stones The bits are useful especially in smaller-diameter boreholes, and are thus included only in the 4" and 6" drilling sets.

- the *stone catcher* is made of a round iron bar, forged in the shape of a spring. It is used for removing larger stones from the borehole, and also as a fishing tool for equipment that has been dropped in the borehole. Except for the connectors, the stone catcher bits are identical for all drilling sets.

- the *chisel auger* is a cross between a riverside bit and a conical flight auger or chisel. It is intended for harder soils: dropping the bit will result in breaking and loosening the soil at the bottom of the borehole, in the same way as the chisel bit, but its body, which combines characteristics of the auger bit and the riverside bit, can collect the loosened soil, whereas the chisel bit always needs to be used in combination with a riverside or flight auger for removing the soil.

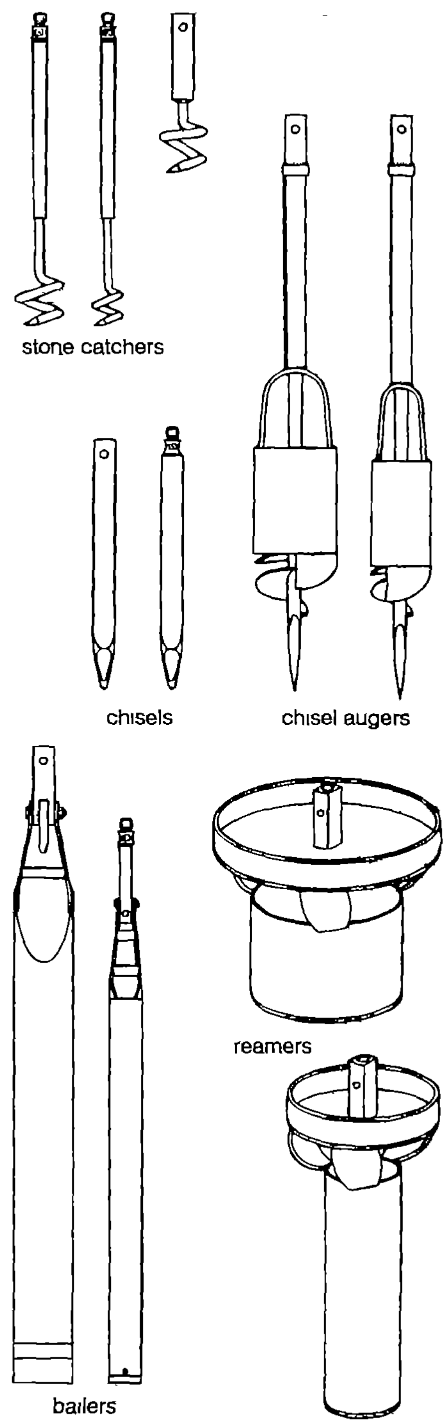
The chisel auger was developed specially for the lighter 6" set (because of its weight the 8" set penetrates hard layers more easily).

- the *chisel* is a simple, pointed steel bar with a 40 mm square cross section and a length of 50 cm. By lifting and dropping it the soil is worked loose, so that it can be removed with a flight auger or riverside bit. Except for the connector, the chisel is identical for all drilling sets.

- the *bailer* is used for the removal of soil from below the water level. It consists of a steel tube of 0.75 - 0.80 m length (depending on its diameter) with a flap door at the bottom. Bailing consists of a vertical movement of the bailer, during which soil is worked into the bailer body. It is prevented from flowing back by the hinged flap door, which acts as a one-way valve.

The bailer of the 4" drilling (survey) set is provided with a conical threaded connector only; the larger bailers are provided both with a square connector (so that they can be operated with the drilling rods/cross-piece assembly) and with a wire eye (so that they can be hung from a steel wire, allowing a more flexible operation). Bailing is carried out only within a temporary casing. For that reason only one size bailer is provided with each drilling set.

- the *reamer* is a non-standard bit, which can be used (under favourable conditions, e.g. in a stable, rather clayey soil) for enlarging the borehole without changing to a different size drilling set.



The reamer consists of a set of knives that are mounted on top of a pipe section that serves to guide the bit. It can be used only in a situation where the entire borehole could be constructed without using temporary casing. The reamer is then used to enlarge the diameter of the existing borehole. A riverside bit, auger bit or bailer must be used for collecting the loose soil that will drop into the borehole during the reaming operation. An example of the use of reamers for constructing a latrine is given on page 60.

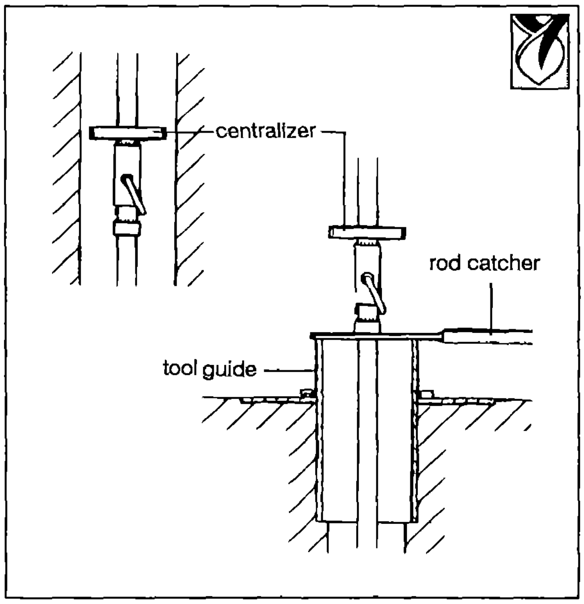
Extension rods and centralizers

When the borehole gets deeper, extension rods must be inserted between the handle/cross-piece and the drilling bit. The connections between the drilling bits and extension rods should be as rigid as possible, to minimize the risk of ending up with a slanting (non-vertical) borehole.

Depending on the size of drilling set used, the extension rods consist of round steel pipe (Ø 26 mm; 2 mm wall thickness) or square pipe (30 mm for 6" set; 40 mm for the larger sets).

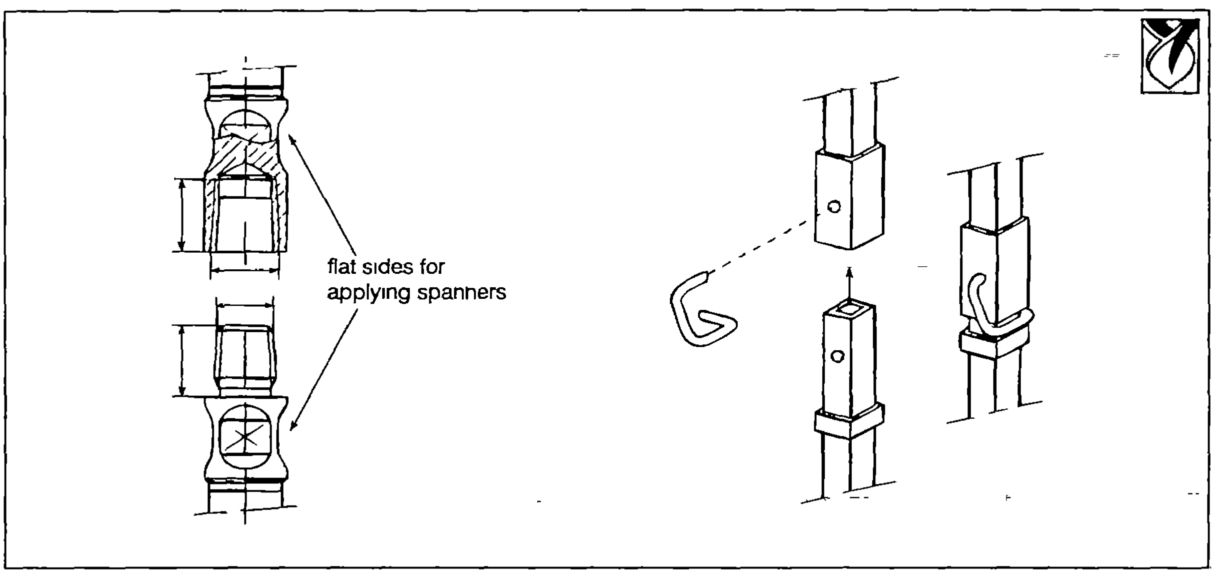
The standard length of the extension rods is 1 m each, which allows them to be transported in normal steel boxes. In addition 0.5 m length extension rods are provided.

To prevent the drilling assembly from moving from the centre of the borehole, a few extension rods with centralizers are provided with each drilling set. These must be used at about 1/3 from the bottom of the string of drilling rods.



Use of centralizers on extension rods

The round steel pipe used in the 4" set is the only one with a threaded (conical) connection, provided with two flat sides to allow the connection to be fixed with spanners. The square steel pipes are connected with special push-twist lock pins that can be applied and removed without spanners or wrenches *(see figure below)*.



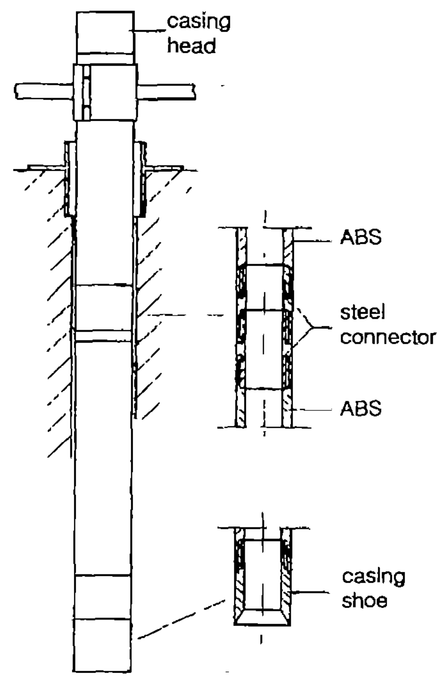
Conical threaded connectors (left) are used for the 4" set only; the other sets have square connectors with lock pins (right)

Casing pipe

Except in soils with fine sandy material, in general the borehole will remain stable for as long as it does not pass a water bearing layer. Loose, sandy soil below the water level has insufficient consistency to support the borehole, however, and measures have to be taken to prevent the borehole from collapsing. For that reason, casing pipe is used to support the borehole during drilling[3].

The temporary casing is built up in sections, of 1 m length, with thread at both ends. Since the hand drilling equipment is operated in a clockwise direction, the casing pipe sections are provided with anti-clockwise thread. This is to prevent sections of temporary casing pipe from becoming unscrewed in the borehole because of the rotation of the drilling assembly, especially when material gets in between the drilling assembly and the casing pipe. The thread is protected against damage by special protector rings.

Standard pipe thread (either Whitworth or metric thread) is too fine for casing pipe, and "square" (in fact trapezoidal) threading has thus become more or less standard. It is, however, susceptible to sand coming between the threads.



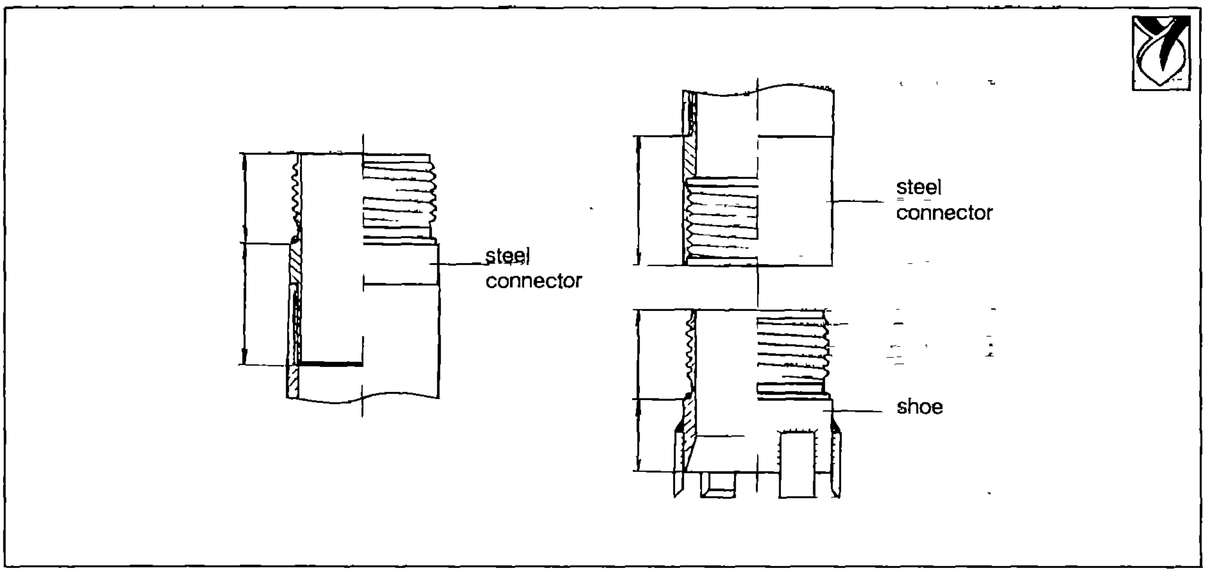
Temporary casing for survey set

With the use of modern lathes "rounded threading" has become available. This is not so sensitive to dirt, and easier to open

Casing specifications / hand drilling set:	4"	6"	8"
Casing pipe:			
- body material	ABS	ABS	ABS
- material of threaded pipe ends	steel	steel	steel
- connection closes in ... turns	2.25	2.25	2.25
- sealing with O-ring	yes	yes	yes
- weight per pipe section [kg]	4.1	6 7	10.2
Material of:			
- threads protectors	ABS	ABS	ABS
- casing head	steel	steel	steel
- casing shoe, with welded teeth	steel	steel	steel
- lifting head	steel	steel	steel

All steel components of temporary casing pipe are made of high quality steel

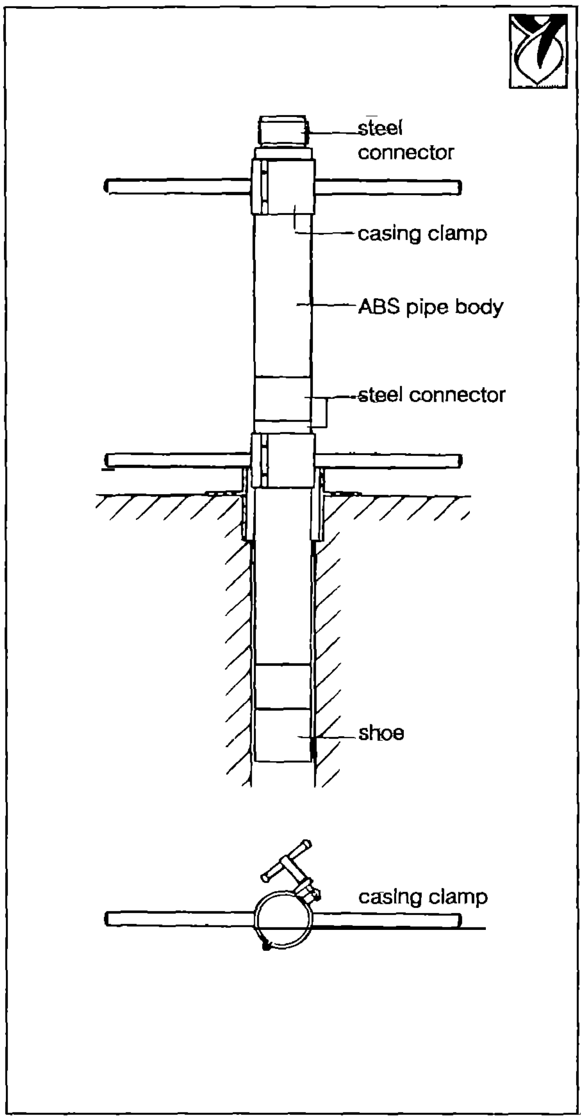
3 To prevent confusion with the filter pipe/casing pipe that is part of the final borehole construction, the pipe that is used during construction only (and removed at the end of it) is often called *temporary casing*.



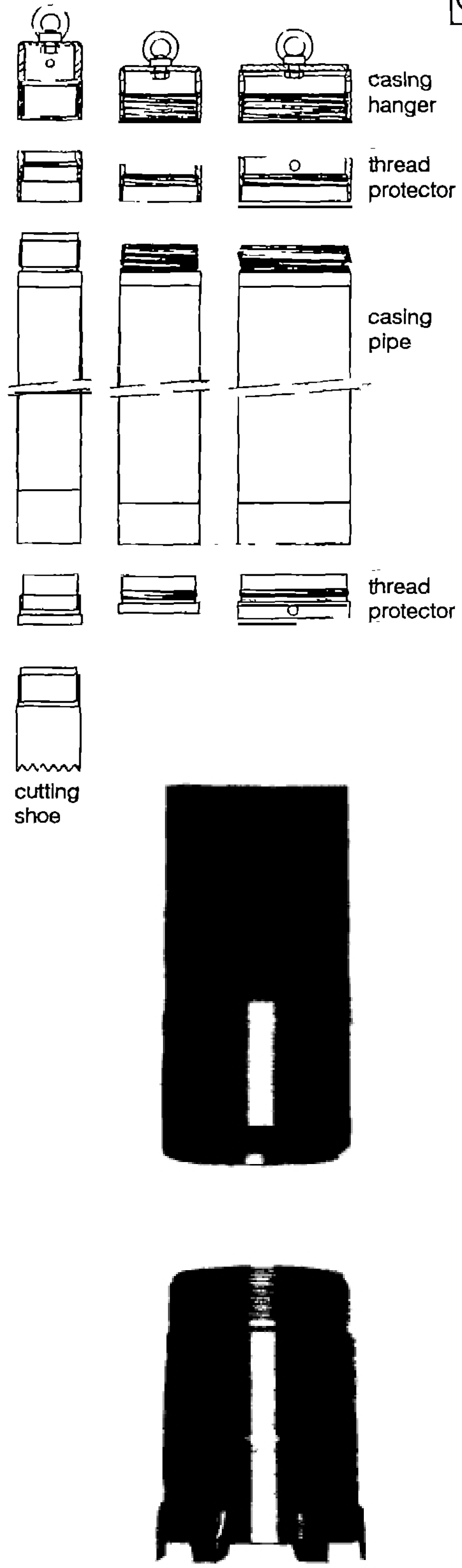
Details of connections for casing pipe

Different materials may in principle be used for temporary casing pipe. The most important are:

- full steel pipe. Steel is a strong material and can well be used for temporary casing pipe Threaded connections need to be thicker than the wall thickness required for the pipe itself. To prevent the string of casing pipes from becoming stuck in the soil, the outside of the pipe connection needs to be smooth, and of constant diameter, and the connection thus protrudes inside the pipe. Its weight renders steel casing pipe less suitable for lighter drilling sets. For that reason it is hardly used any more. On special order, steel casing pipe can be provided for all hand-drilling sets, however;
- full PVC or ABS pipe has the advantage of light weight, but wears too quickly under normal productive use. It is used only in those cases where ease of handling is more important than the expected lifetime of the pipes;
- ABS pipe with steel connectors combines the advantage of low weight (for the casing pipe body), with that of durability (of the steel threaded connectors). They have thus become the standard casing pipes for all hand-drilling sets.
- GRP (glass fibre reinforced polyester) pipe would constitute a very strong pipe material. Its composition, with glass fibres embedded in polyester resin, makes the material unsuitable



Temporary casing for 6" set



for cutting thread, however. For that reason steel connectors would be required as well, negating the advantage of low weight, and rendering this option considerably more expensive than the ABS pipe with steel connectors;

- stainless steel pipe is not strong enough, except with a wall thickness that would render the material prohibitively expensive.

To protect the thread during transportation, each casing pipe section is provided with thread protectors, with inside or outside thread (for bottom and top of the pipe section, respectively), and normally made of synthetic material (ABS). The protectors are removed just before the relevant pipe section is used

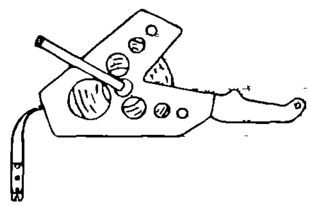
The first section of temporary casing pipe to be inserted is provided with a so-called *casing shoe* with saw-teeth cut in the pipe wall, or with special teeth welded to the outside of the lower rim (see picture at right). The casing shoe is thus a kind of cutting edge which makes penetration of the soil easier. To reduce friction in the soil, the teeth point outwards by up to 10 mm, so that they cut a path that is wider than the casing pipe itself. The casing shoe is provided with external thread at the top, as the casing pipe sections have internal thread at their lower end.

The thread of the connection at the top of the last casing pipe section (the one protruding above the ground) must be protected from damage by drilling tools or bailers. For that reason a steel rather than ABS thread protector (a section of steel pipe without thread) is put over the top of the last casing pipe section in use. This thread protector needs to be kept in place throughout the drilling process, until a new casing pipe section is fitted on top.

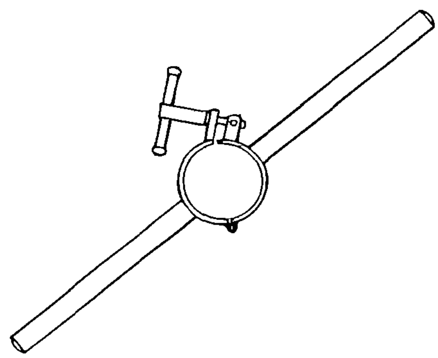
Miscellaneous tools and equipment

The drilling sets include several additional tools and equipment, including:

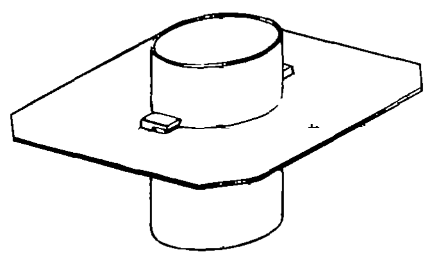
- *sounding device*, for determining water depth. Depending on the client's requirements, simple or more sophisticated devices are available: the simple ones rely on the sounding device giving an audible tone when striking the groundwater surface; the more sophisticated one gives an audible as well as a visual signal (electric buzzer and lamp are operated by an electric contact that is made when the sounding device hits the water);



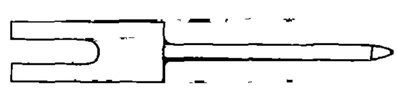
- *casing retriever*, to recover casing pipe that has dropped into the borehole. This cone-shaped device must be lowered in the borehole, inside the dropped casing pipe. Thereafter, some gravel is poured on top of it, securing a tight fit between casing retriever and casing pipe. The combination can then be pulled up together. For each size or temporary casing pipe a separate size casing retriever is required;
- *casing clamps*, for connecting and disconnecting casing pipe sections. For the 4" drilling set each casing clamp is provided with an adjustable quick fastener; for the 6" set one screw-thread spindle, and for the 8" set two heavy-duty screwed connectors are used for fastening each clamp around the casing. Obviously, for each size casing pipe a different size of casing clamp is required;



- *tool guide*. One size tool guide is provided for each drilling set, of a size that allows the largest size drilling bits and temporary casing pipe to pass. It protects the top of the borehole against caving in and other damage that might be caused by the repeated insertion and retrieval of drilling bits and casing pipe, prevents tools from sliding into the borehole, and acts as a support for the rod catcher during (dis)assembly of drilling rods and for the casing clamps during disassembly of casing pipe sections after construction;



- *rod catcher*. This tool is used to support drilling rod sections during assembly and disassembly, to prevent them from dropping into the borehole.



Basic drilling set composition

The composition of the minimum hand-drilling set is as follows.

Hand Drilling Set:	4" (20 m depth)		6" (20 m depth)		8" (15 m depth)	
	size	No.	size	No.	size	No.
Tool guide	Ø 150	1	Ø 200	1	Ø 250	1
Kelly, cross piece, 4 handles	-	-	30x30	1	40x40	1
Handle for drilling rod	Ø 26	2	-	-	-	-
Drilling rod, length = 1 m	Ø 26	20	30x30	20	40x40	15
Rod hanger	-	-	-	-	40x40	1
Spare lockpin	-	-	40/30	20	50/40	10
Rod catcher/cleaner	-	2	-	2	40x40	2
Flight auger, conical	-	-	-	-	Ø 180	1
Flight auger, conical	-	-	-	-	Ø 130	1
Chisel auger	-	-	Ø 150	1	Ø 130	1
Chisel auger	-	-	-	-	Ø 180	1
Riverside auger	Ø 100	1	Ø 150	1	Ø 180	1
Riverside auger	Ø 70	1	Ø 100	1	Ø 130	1
Stone auger	Ø 100	1	Ø 150	1	-	-
Stone auger	Ø 70	1	Ø 100	1	-	-
Stone catcher	Ø 100	1	Ø 100	1	Ø 100	1
Stone catcher	Ø 70	1	-	-		-
Chisel	40x40	1	40x40	1	40x40	1
Bailer, steel	Ø 63	1	Ø 90	1	Ø 114	1
Spare bailer shoe (steel valve)	Ø 63	2	Ø 90	2	Ø 114	2
ABS/steel casing pipe, LHT[4]	Ø 90/76	20	Ø 125/108	20	Ø 160/140	15
Casing shoe, LHT, notched	Ø 90/76	2	Ø 125/108	2	Ø 160/140	2
Casing head	Ø 90/76	1	Ø 125/108	1	Ø 160/140	1
Casing clamp	Ø 90/76	2	Ø 125/108	2	Ø 160/140	2
Hoisting set	-	-	-	-	2 tons	1
Hammer, heavy duty	-	1	-	1	1000 g	1
Steel brush	double row	2	double row	2	double row	2
Screw driver	6 mm	1	6 mm	1	6 mm	1
Adjustable spanner	250 mm	1	250 mm	1	250 mm	1
Acoustical measuring device	25 m	1	30 m	1	30 m	1
Grease	tin	-	tin	1	tin	1
Waste cotton	swab	-	swab	1	swab	1
Steel box with padlock	1.3x0.5x0.5m	2	1.3x0.5x0.5m	3	1 3x0.5x0.5m	4
ADDITIONAL EQUIPMENT, NOT BELONGING TO MINIMUM SET						
Drilling rod, 1m, with centralizer	-	-	30x30	1	40x40	2
Casing retriever	Ø 60	1	Ø 100	1	Ø 130	1
Jack, mechanical	-	-	2 ton	2	5 ton	2
Chain spanner for casing	-	-	Ø 125	1	Ø 160	1
Shovel, fitting in box	-	-	-	-	1 m	1
Pick axe, fitting in box	-	-	-	-	1 m	1
SPARE PARTS, NOT BELONGING TO MINIMUM SET						
Spare set rod connectors	Ø 26	2	40/30	3	50/40	3
Spare riverside auger body	Ø 100	1	Ø 150	1	-	-
Spare riverside knife	-	-	Ø 150	2	Ø 180	3
Spare riverside knife	-	-	Ø 100	2	Ø 130	3
Spare stone auger body	Ø 100	1	Ø 150	1	-	-

[4] LHT=left hand thread

Typical example of inventory sheet for establishing water supply requirements

NAME OF THE PROJECT													
DISTRICT					(make your own inventory according to this index)							SITUATION PER 01-07-1996	
Location (specify as much as possible)	No of people	Type of water supply	Depth of water	Water lifting device	Type or make	Constructed by whom	when	Water supply in use	Distance to alternative source	Quality surface water	Extra supplies required	Villagers willing to contribute	Assistance for the maintenance to be expected from
DIVISION A	70,000												
- Village 1	6,000												
Quarter A	4,000	piped supply	river	subm p.	Grundfos	Govermmt	1975	no	lake 2 km	poor	8 dug wells	yes	Ministry of Water
Quarter B	1,000	2 dug wells	10	bucket		Villagers	1980	yes	lake 3 km	poor	-	no	-
Quarter C	500	1 dug well	12	bucket		Villagers	1975	yes	lake 3 km	poor	-	no	-
Quarter d	500	1 dug well	13	bucket		Villagers	1950	yes	lake 2 km	poor	-	yes	Village Committee
- Village 2	2,000												
Quarter A	350	1 dug well	7	bucket		Villagers	1975	no	river 3 km	-	1 handpump	yes	Village Committee
Quarter B	850	2 tube wells	25	handpump	M&R	Unicef	1980	yes	river 3 km	good	2 handpumps	yes	Village Committee
Quarter C	800	2 springs	0	-		-		yes	river 4 km	poor	improvement	no	-
- Village 3	3,500												
Quarter A	500	1 dug well	8	handpump	India MII	Baptist Ch	1986	yes	river 3 km	fair	1 handpump	no	-
Quarter B	500	1 dug well	10	handpump	Vergnet	Baptist Ch	1986	yes	river 3 km	fair	1 handpump	no	-
Quarter C	2,500	river	0	-					river 7 km	poor	5 dug wells	yes	Baptist Church
- Village 4	1,800												
Quarter A	600	1 tube well	10	handpump	SWN90	Cath Ch.	1992	yes	river 5 km	poor	1 tube well	yes	Village Committee
Quarter B	600	1 tube well	12	handpump	Afya	Inland Ch.	1993	no	river 5 km	poor	1 tube well	yes	Village Committee
Quarter C	600	1 tube well	12	handpump	Juba	Luth Ch.	1994	yes	river 5 km	poor	1 tube well	yes	Village Committee
etc etc													
DIVISION B	65,000												
- Village 1	1,100												
Quarter A	650	2 dug wells	15	bucket		Meth Ch	1975	yes	lake 3 km	fair	2 handpumps	yes	Inland Church
Quarter B	250	1 dug well	18	handpump	Climax	Angl.Ch.	1975	no	lake 4 km	poor	1 handpump	yes	Inland Church
Quarter C	200	1 dug well	10	bucket		Villagers	1985	yes	lake 3 km	fair	1 handpump	yes	Catholic Church
etc. etc													
TOTAL	240,000												
For whom?		***What is available, and does it work?***							***If not, what?***		***What is needed, and who pays?***		

DRILLING

Preparations

Before the drilling process is actually started, it is a sensible practice to carry out a final check on some aspects, a few of which are so obvious that they might be actually overlooked.

- is the borehole really necessary?
- is the location that has been earmarked suitable for a borehole?
- has ownership and maintenance of the well been arranged?

All these questions should in principle have been answered affirmatively by the end of the survey/well siting phase (see also *Volume 1: Well Siting*). Experience shows that it is good practice to start any well construction programme that caters for more than an individual well, with an inventory of the existing situation. Such inventory should indicate both the existing water supply facilities, as well as the numbers of people (per village or even sub-village or hamlet) and other sources of water consumption. A comparison between the existing and the required situation then provides an indication of the number and capacities of water points that still need to be developed. A typical example of an inventory sheet to be used in such circumstances, is shown on the next page.

The well siting phase is intended to result in a sufficient number of well sites that meet the requirements of being suitable both from a technical point of view (yielding water of an adequate quality and quantity, which can be abstracted by means of a hand drilled borehole) and a non-technical point of view (is the borehole located such that it is acceptable to the entire local community: e.g. not on land that is monopolized by a single person, family or community in such a way that others would have no or only restricted access to it; is it located near enough to the village, are there no specific hindrances that would render the location unsuitable for water collection by elderly persons, by women, or by small children?) Once these questions have been answered in a positive sense, the actual well construction activities may be started.

Sequence of well drilling activities

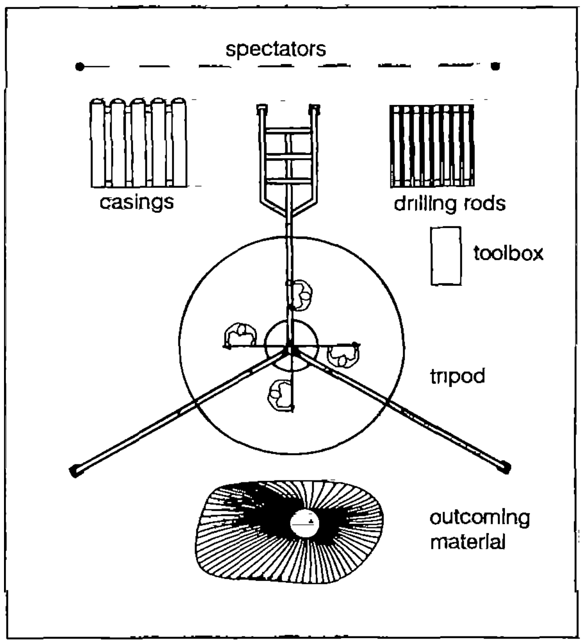
General

The successive steps of constructing a hand drilled well are illustrated in the diagram on page 30. All activities shown there are covered in this manual, except for *handpump installation*, which is covered in detail in *Volume 4: Handpumps.*

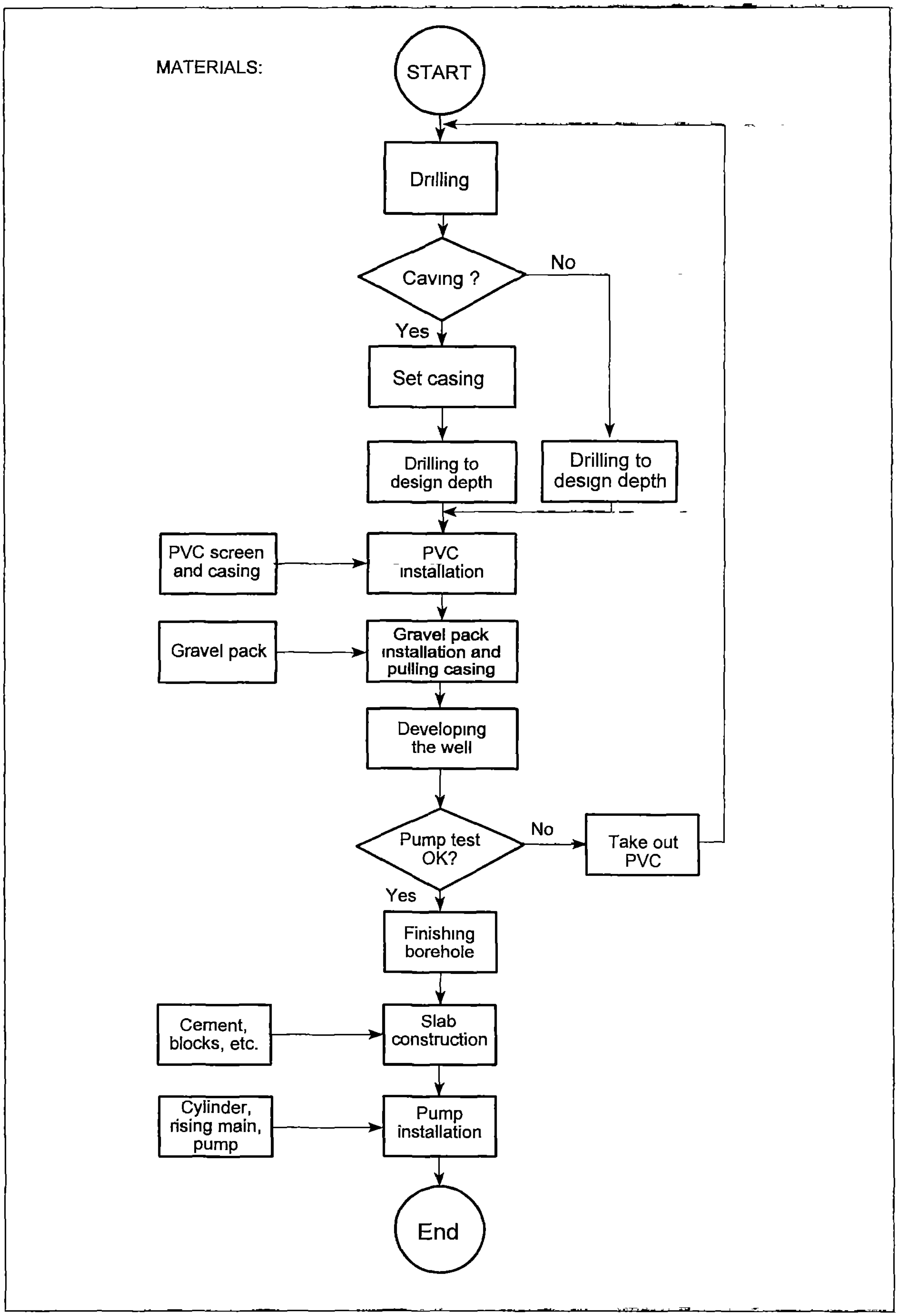
Site preparation

The first step is to prepare the drilling site at the location indicated by the survey/well siting group. The site must be arranged in such a way that the entire sequence of well drilling and handpump installation can be carried out without hindrance, in the space available:

- check that there are no power lines (underground or overhead) in the immediate vicinity of the borehole location, to prevent damage and possible injuries;



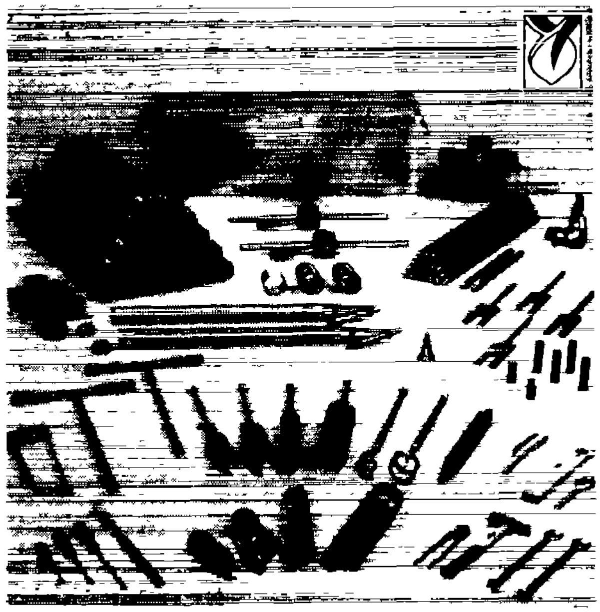
Lay-out of drilling site



Activities for constructing a hand drilled borehole

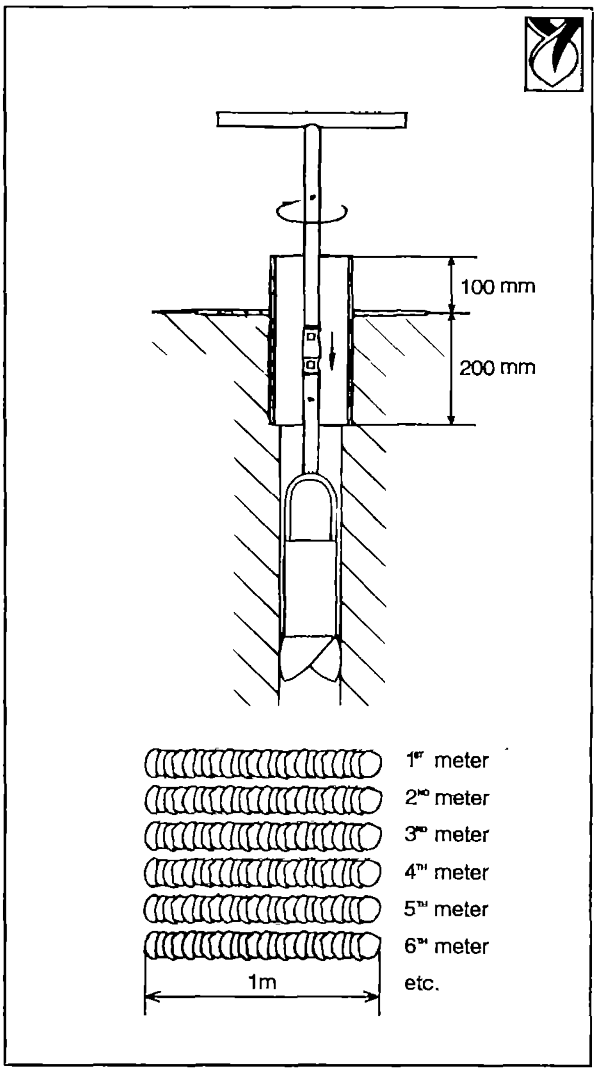
- do not select a site close to trees, as the drill may get stuck between roots, and roots may later penetrate the well screen and (partly) block the well, even if drilling is initially successful.
- check that there is no graveyard on or near the site, as this might make the location unacceptable to the local population and likely cause trouble;
- check that there are no large stones in the area; clear these away where necessary;
- clear and level an area of at least 10 x 10 m around the borehole, allowing a tripod to be set up (for the larger hand drilling sets) while allowing sufficient space to locate drilling bits, casing pipes and soil samples in a neat and compact manner: casings and drilling equipment on wooden beams; smaller equipment in a box

  The site layout indicated on page 29 is of a tentative nature. In practice it will depend on actual site conditions: in stead of the locations shown, drilling bits and casing pipes may, for instance, be positioned at the side nearest to an access road;
- take care that spectators are kept at a distance, by marking the area with a rope and keeping all onlookers behind it.



Survey set (set 15.01), suitable for drilling to a maximum of 20 meter

The borehole must be drilled as close as possible to the original survey borehole, but it is not recommended to use the same spot, as any non-verticality of the survey borehole (which may easily happen with such a light set) is very difficult to overcome as the drill bits will follow the path of the least resistance, viz. the original survey hole. A distance of about 0.5 m between the survey borehole and the final borehole is, therefore, recommended.



Drilling with the survey (4") set

Drilling with this light set has been covered in detail in *Volume 1: Well Siting*. Since the 4" drilling set may be used for drilling production boreholes as well (especially for small communities), the main activities are repeated here. It will be clear that for the use of this type of drilling set no tripod is required, and that also the area to be cleared may be somewhat smaller than indicated above.

When to use the survey set?

A survey set is especially useful in large well construction programmes, or when local conditions dictate the use of the 8" drilling set for making the well:

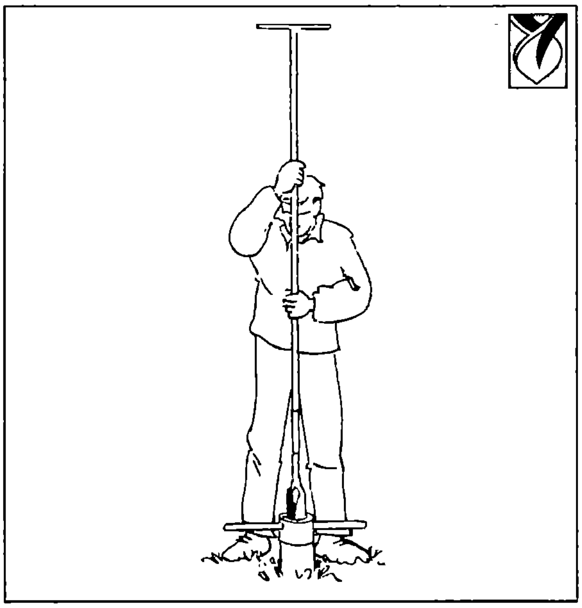
- ❑ in programmes that must produce a larger number of wells, it makes sense to separate survey and construction, so that only specially trained personnel selects potential well sites and carries out test drilling there. In such a case using a relatively light-weight drilling set has advantages, as it is easier to transport and drilling time is shorter than with a heavier set.
  In some programmes successful survey holes are subsequently enlarged with a reamer, to make a production borehole. This is not possible in all cases, however, as it can be done only when the survey hole does not require casing. Moreover, it increases the chance of non-verticality of the borehole;
- ❑ in situations where the number of wells to be constructed is limited, losing some time by doing test drilling with a heavier set is not a problem. For that reason the 6" drilling set constitutes a good compromise between the 4" survey set and the 8" hand-drilling set, and in several programmes the 6" set is used directly, without any prior survey drilling;
- ❑ when 8" sets are required, test drilling with a 4" set is recommended, however, as the heavier 8" set requires a tripod, which makes the drilling process more cumbersome and therefore less suitable for combined test/production drilling.

Prepare the site

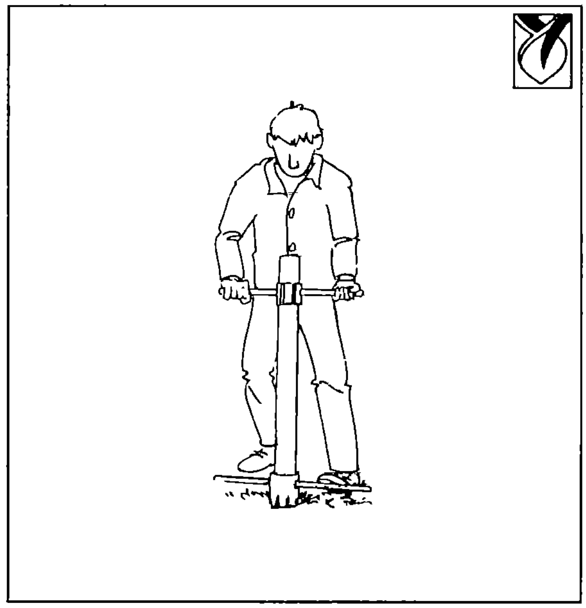
- check the equipment
- check and prepare the site:
  - check that there are no power lines in the immediate vicinity of the location;
  - do not drill close to trees;
  - clear an area of about 3 m x 3 m around the drilling site, removing all stones, rubbish, branches, leaves, etc.

Drilling without casing

- dig a small hole, Ø 120 mm at the intended location of the borehole and insert the tool guide;
- connect the T-shaped handle to the first drilling bit (normally the Ø 100 riverside auger), and start drilling;
- once the auger is filled with soil (normally after some 5- 20 turns), lift the drilling assembly, remove the collected soil from the auger, and continue the drilling process;
- neatly lay out the drilled material in rows of 1 metre depth each, to allow a quick examination of the soil profile
- when the depth of the borehole has become such that the handle is too low for easy drilling, lift the drilling assembly and insert an extension rod between the handle and the drilling bit. Initially a 0.5 m long extension rod can be used. This can later be replaced by a 1 m long extension rod;
- take soil samples every meter and arrange them neatly in a row, next to the borehole;
- depending on the soil composition, better results may be obtained by changing to a different type of drilling bit, e.g. a stone auger or chisel. Often best results are obtained by using different types of bit in succession, e.g. a chisel for breaking up hard soil, and subsequently a riverside auger for removing the (then) broken soil;
- as soon as an aquifer is struck, the soil may start collapsing, until the soil has a solid consistency (generally indicating a poor aquifer). In that case, insert a casing pipe in the borehole, to prevent it from collapsing. Fix the casing hanger/thread protector to the top of this section of casing.



Use of hand drilling equipment inside temporary casing



Using casing clamps to connect or disconnect sections of temporary casing

Drilling with temporary casing

- put the temporary casing in place, slowly turning the casing sections anti-clockwise, so that the wall of the borehole is scraped clean. Do not push on the casing or hammer on it, as it might prove impossible to retrieved it later;
- start drilling inside the temporary casing, now with Ø 70 mm bits,
- continue drilling until an impermeable layer below the aquifer is struck. If there is no impermeable layer on top of the aquifer, the aquifer should be at least 2 - 3 m thick; otherwise this can be less;
- when the auger is full, lift the rod and auger, all the while turning it in a clockwise direction. At the same time, gently lower the casing, while turning it in an anti-clockwise direction;
- connect a second section of casing when the casing clamp at the top of the first section has almost reached the ground;
- keep on adding casing pipe sections during the drilling process, depending on the progress with drilling the survey borehole.

Using a bailer

- when the soil contains so much water that drilling with riverside or stone auger bits is no longer successful, a bailer must be used to continue deepening the borehole;
- bailing is carried out by frequently lifting and dropping the bailer. The vertical movement need not be more than 10 cm;
- by bailing much water is normally removed from the borehole To prevent caving in of the borehole, pour water into the hole before taking out the bailer;
- prevent the bailer from overflowing inside the borehole: sand might be washed into the space between the bailer and the casing pipe, and the bailer might get stuck as a consequence, making it next to impossible to be retrieved.

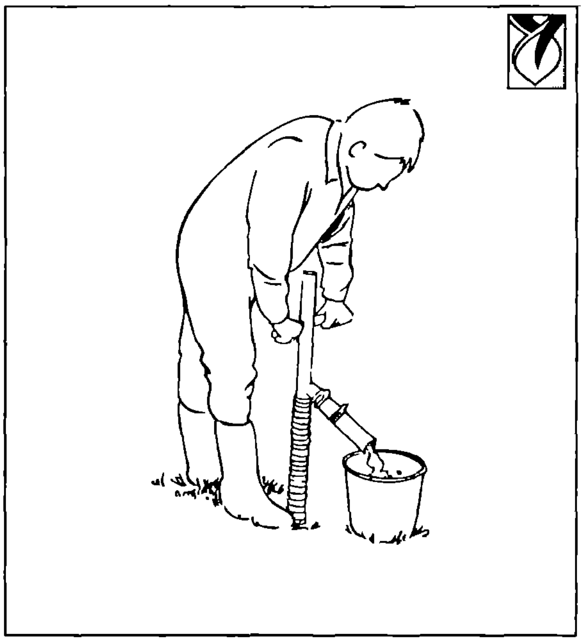
Finishing test drilling

- make a description of the borehole once the drilling has been completed,
- remove the drilling equipment from the borehole. During lifting, disconnect the drilling rods in lengths that do not exceed 3 m each, to prevent bending of the rods or the extensions;
- measure the depth to the water level with a water level indicator (acoustic signal),
- measure the total depth of the borehole with a weighted rope.

Pump test

After completing the test drilling, carry out a pump test:

- lower the test pump until its foot plate rests on the casing clamp. Start pumping by moving the pump body up and down, as if using a bicycle foot pump;
- first pump 5 bucketsful of water from the test hole, to develop it;
- collect a water sample and check the water quality (or have it checked);
- for 2 hours carry out a pump test, pumping with 15-minute intervals. During the test, measure and record the yield and water level just before and after each pumping cycle;
- at the end of the pump test, determine once more the taste, smell and colour of the water, if possible complemented by other physical/ chemical water quality parameters. Note down the results.



Using the test pump

Retrieve temporary casing

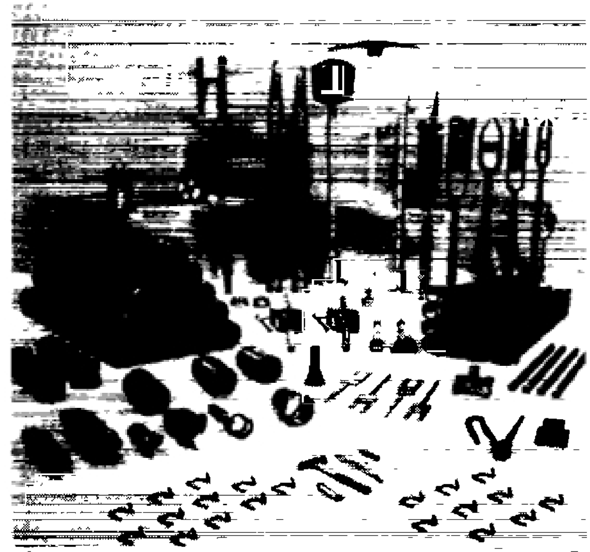
- remove the casing sections one by one, clean and slightly grease the threading, and attach thread protectors to the threaded ends of the casing sections;
- repeat this procedure until all casing sections have been removed from the survey borehole,
- if construction of the well is not started immediately afterwards, place a marker (e.g. a big stone with the code of the site painted on it) at the test hole site if the site has proven to be successful. Arrange with the village elders or headman that the marker is not tampered with, especially by children.

Note: Criteria for approval or rejection of a survey test well include. yield, water quality, location and hydrogeology of the site. Details are given in *Volume 1: Well Siting*.

Drilling with 6" and 8" hand drilling sets

General aspects

The hand drilling sequence described here is based on the use of 6" and 8" hand drilling sets, which are the ones best suited for drilling boreholes that will be equipped with handpumps. Of these, the 6" set is normally used without tripod, whereas the 8" set, due to its larger weight, can be used only with a tripod.



6" hand drilling set (set 15.02), suitable for a maximum depth of 25 m; no tripod is required

Required manpower

Under normal conditions, the staff required for hand drilling a borehole consists of:

- a foreman,
- 2 or 3 skilled labourers, belonging to the project staff, and
- up to 5 strong villagers

The foreman is responsible for the construction of the well and the quality of the finished product. He is also responsible for maintenance of equipment, administration, and safety at the site.

Check transportation and logistics

Before starting the construction of a hand drilled borehole, check that transportation, equipment and materials of the correct size and quality are available. Assuming that either the foreman or one of the skilled labourers doubles as driver, one pick-up is sufficient for transporting the staff, 6" drilling equipment and materials: hand drilling set, moulds for the pump foundation and platform, filter pipe and rising pipe, gravel pack material, sand, cement and handpump components. Depending on the distance between home base and drilling location, camping equipment for the crew may also be required.

Check the equipment

Before departing to the drilling site, check the equipment:

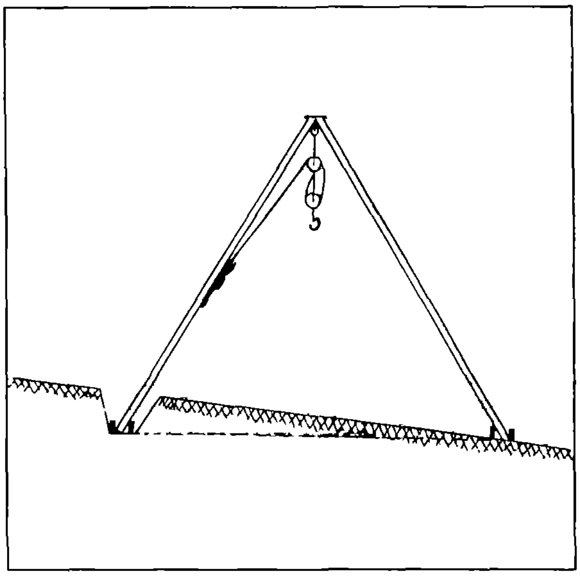
- check that both the hand drilling set and the materials for filter and rising pipe are of the correct size, where applicable based on the results of a well survey;
- check that the knives of the riverside augers are not bent and are pointing slightly outwards;
- check that no items are missing;
- check welds and connections of drilling bits, extension rods and temporary casing pipe. Have (almost) broken connections repaired first;
- check the outside of the drilling bits; replace or repair bits that have worn out;
- check casing pipes for cracks; do not use cracked pipes;
- smoothen damaged thread with a file;
- check connections of the riser pipes for the test pump, repair damaged thread;
- check the action of the foot valves of bailer and test pump, replace foot valves in case they do not close tight.

Setting up the tripod

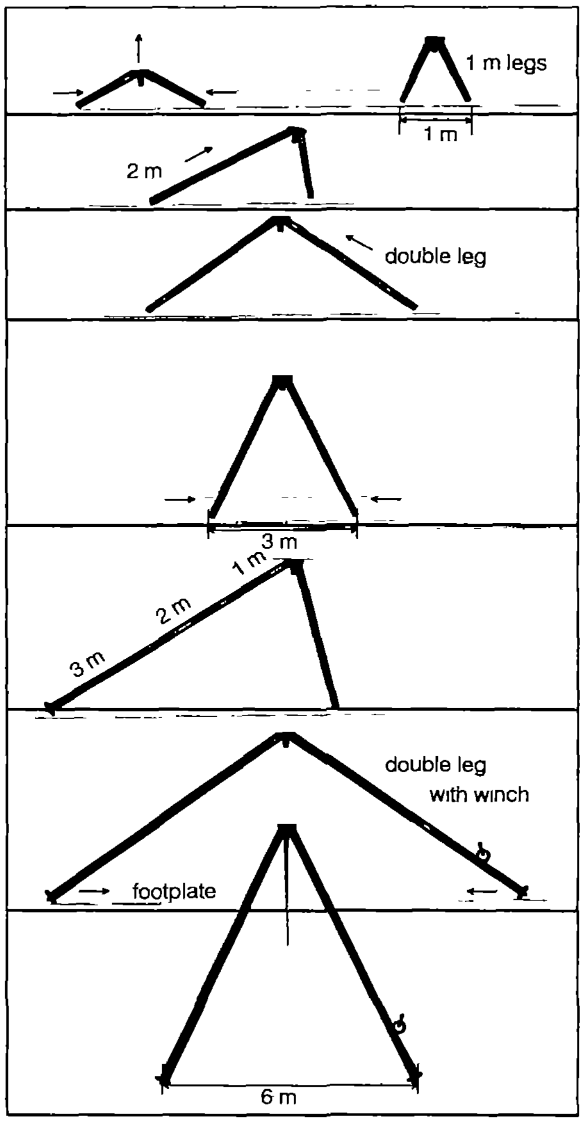
If an 8" hand drilling set is to be used, a tripod is necessary. It must be set up over the borehole location in such a way that the legs are about 6 m apart *(see figure on page 18)*. In doing so, special care must be taken if the site is not level, to ensure stability of the tripod. The foot plates of the legs must be at the same level, so it may be necessary to remove the soil from under one or two foot plates.

Assemble the heavy duty tripod as follows *(see figure below)*:

- lay out the tripod head assembly on the ground, with one of the 1 m long legs pointing towards where the double leg (with winch) is planned to be;
- raise the tripod head on its legs, in such a way that these are about 1 m apart;
- one by one, connect 2-m sections to two of the legs (not the one where the winch will be) and secure the connections with lockpins;
- lift the remaining leg of the head assembly, connect the 2-m double leg unit and secure the connections with lockpins as well;
- by 'walking them towards the borehole', position the legs so that they are about 3 m apart;
- during connection take care that the assembly remains stable;
- lay the footplates down at their respective locations, about 6 m apart, the stubs pointing upward;
- connect two more extension legs, of 3 m each, and fix the connections with lockpins;
- repeat this procedure with the double leg unit with winch. Fix again with lockpins, and take care that the winch and pulley do not get dirty;
- with the assistance of at least two men, walk the legs towards the footplates and fit them on the stubs on these plates;
- attach the pulley and cable to the eye in the top of the tripod and to the winch;
- the tripod is ready for drilling to start.



Unsure that tripod legs are all at the same level



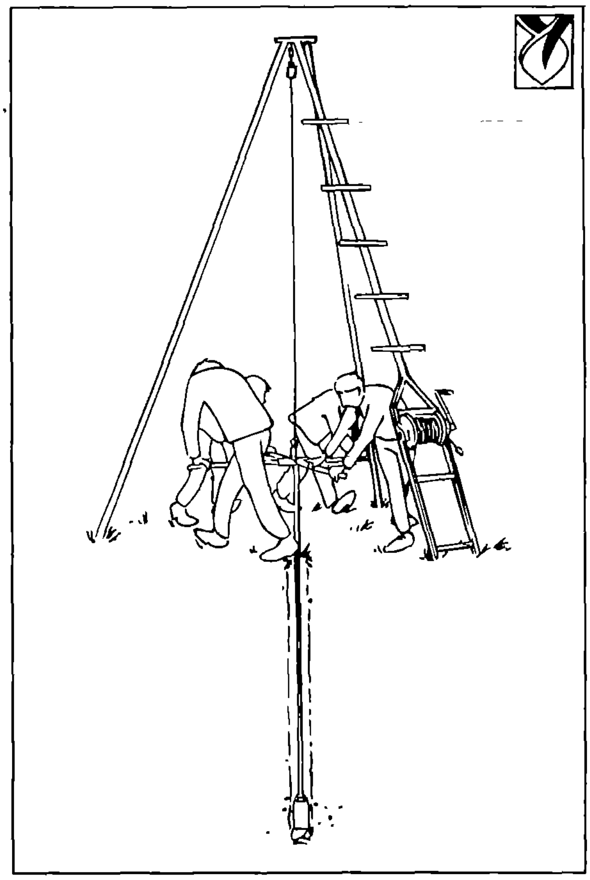
Erection of tripod on site

General drilling procedure

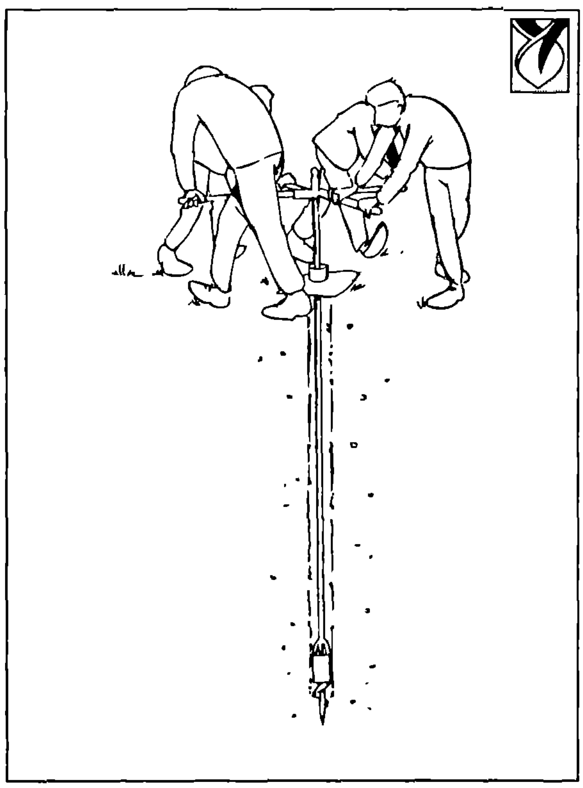
The drill string, consisting of auger, extension rods and cross-piece with handles, is either operated by hand (6" set) or hung from a pulley system that is attached to the top of the tripod (8" set). Four to six people push the handles that are connected to the crosspiece, and thus rotate the drill down, not more than 30 cm at a time. Then the drilling assembly is lifted, soil is removed from the auger, and the procedure is repeated until the required depth is reached, inserting extension rods between the auger and the cross-piece as required. When there is a danger of the borehole collapsing, temporary casing pipes are inserted in the borehole and drilling continued inside the casing, with a smaller diameter auger. This sequence is described in detail below.

Start drilling without casing

- ❑ at the intended location of the borehole, dig a shallow hole, 0.20 - 0 25 m in diameter, and insert the tool guide with its longer end pointing down. In case a tripod is used, take care that the tool guide is inserted at the correct location To ensure this:
    - hang the cross-piece with flight auger *(see below for details)* from the pulley in the top of the tripod, and lower the assembly until it just touches the ground;
    - mark that spot and — after having pushed the drilling assembly out of the way — dig the hole and insert the tool guide there;
    - in place of the tool guide a section of pipe (steel or PVC) may be used, as long as its diameter allows the largest size bit to pass without too much play;
- ❑ connect the first drilling bit to the kelly, and secure the connection with the lockpin. Normally the first drilling bit is the larger flight auger (Ø 150 for the 6" set; Ø 180 for the 8" set; see table on page 17);
- ❑ slide the cross-piece over the kelly, fix it to the kelly with a lockpin, and place the handles in the openings:
    - fix the cross-piece to the kelly in such a way that during drilling the handles are about 1 m to 1.20 m above ground level (depending on the lengths of the persons operating the drill) to make operation of



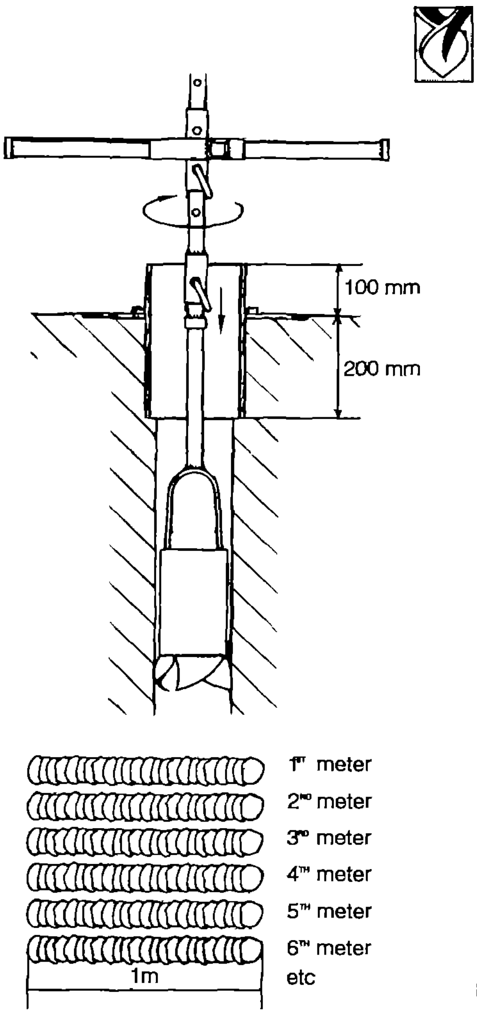
Drilling with use of tripod (8" set)



Drilling without tripod (6" set)

the drilling equipment as comfortable as possible;

- with progressing drilling the whole assembly will slowly sink. The connection between cross-piece and kelly can then be adjusted continually to keep the level of the cross-piece and handles more or less the same. Specially for this purpose the kelly is provided with a number of holes along its length, at 10 cm distances;



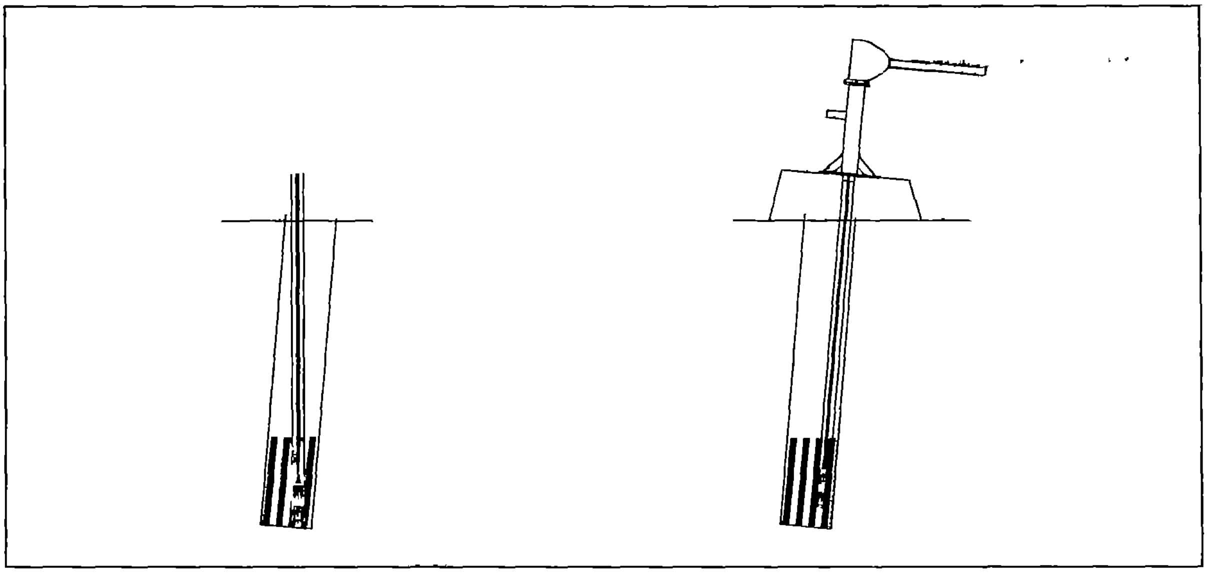
Starting drilling with 6" or 8" set

❑ put the drilling assembly in a vertical position, put the drilling bit on the ground (inside the tool guide) and turn the equipment a few times around while maintaining a downward pressure;

- the hand drilling equipment is operated by turning it *clockwise*, both during drilling and during lifting of the drill string;
- the temporary casing is provided with *lefthand thread* to minimize the danger of the casing sections getting unscrewed when soil material gets stuck between a drilling bit and the casing pipe;
- the number of persons that is required to operate the hand drilling equipment depends on the weight of the drilling set, the type of soil, and the depth to which drilling has progressed. In any case, divide these persons in such a way over the handles of the drill, that equal numbers are employed on two opposite handles, to retain equilibrium during drilling;

❑ take care that the drill remains exactly vertical:

- this is the most critical aspect during this stage, as a slanting borehole will cause problems:
  - if the filter pipe is placed vertically in a non-vertical borehole, the gravel pack cannot surround the pipe completely, and soil may be washed into the borehole, clogging it;
  - if the filter pipe is kept in the centre of a slanting borehole, the pipe itself is not vertical; hence the entire pump assembly, including the rising main, will have to be installed in a non-vertical position, causing premature wear or failure of the pump;



Potential problems with non-vertical borehols

- when using hand drilling equipment without tripod, the foreman should carefully watch the verticality of the drill during the first stage of drilling This can be done visually, or by checking that the drill remains in plumb by holding a spirit level against its side;
- in case a tripod is used, the fact that the drilling string is hung from the pulley in the top of the tripod provides some extra guarantee that the assembly remains vertical. Also here checking with a spirit level is desirable;
- another possibility is to connect an extension rod to the top of the kelly, and hang its top from the pulley. Due to the greater length of the assembly visual checking is easier: the top of the extension rod should be as near as possible to the top of the tripod *(see picture at right)*;
- take care that the drilling string is suspended, and not resting on the drilling bit; otherwise it will not be a straight line but a zig-zag line;
- once the first few metres (2-3 m) have been drilled perfectly vertical, there is a good chance that the rest of the borehole will be vertical as well; however, if the first few metres are not vertical, it is very difficult to correct this later on;
- unfortunately, the first part of the borehole is often not vertical. An approach that has proven its worth in practice is then to repeatedly lower and lift the auger, thus scraping material away from the side of the borehole, until the drill string can be suspended without touching the borehole walls (and vertical drilling is possible once more);

Checking verticality of the drilling string

- once the drilling bit is filled with soil (after going down for not more than about 30 cm), lift the drilling assembly, either by hand, or by means of the winch on the tripod, remove the collected soil from the bit, and continue the drilling process;
  - while lifting the drilling assembly by hand, with 1 or 2 men, keep on turning it in a clockwise direction, to reduce friction between the drilling bit and the soil as much as possible;
  - when turning is no longer possible (cross-piece is too high for handling), remove the handles to make lifting the drilling assembly easier;
  - have two strong men lift the kelly and drilling bit out of the borehole;
  - once the bit has been lifted above the ground, move it to the area where the soil will be deposited, this must be done neatly in rows, each row representing 1 m drilling;
  - the soil can be removed from the bit with a rod catcher, auger cleaner or big screwdriver;


Cleaning flight auger

  - enter a description of the soil characteristics in the drilling logbook or well description form, together with information on the depth of the borehole at this stage (calculate the depth from the lengths of drilling bit, extension rod(s) and kelly);
- the number of turns that are required to completely fill the drilling bit depends on the soil composition and the vertical pressure exerted on the drill:
  - the force with which the cross-piece is pushed down might be enhanced by increasing the weight on the cross-piece, e.g. by having people sit on it, but under normal circumstances such action should not be necessary;
  - if the hand drilling equipment is operated without a tripod, it is difficult to control the rate at which the drilling bit goes down; when a tripod is used, the winch operator can do this by releasing the rope slowly (it is not possible, of course, to *increase* the rate at which the drill goes down by manipulating the winch, only to *reduce* that speed);
- when drilling in clayey soil never completely fill the auger, as it could then act as a piston in the borehole. This might lead to a collapse of the borehole, and it may prove to be impossible to remove the drill string except with the greatest effort.

Use of extension rods

- when the depth of the borehole has become such that the handles are too low for easy drilling, even when the cross-piece is fixed at the highest possible location on the kelly, an extension rod must be inserted between drilling bit and kelly, as follows:
  - lift the drilling string until the connection between the drilling bit and kelly is higher than the top of the tool guide;
  - have one or two men hold the top of the drilling bit section, while another releases the lockpin and removes the kelly;
  - have the kelly either held by a third person or put aside, put the first extension rod on top of the drilling bit section and fix it with a lockpin;
  - then slightly lower the assembly of drilling bit and extension rod, and fix the kelly to the

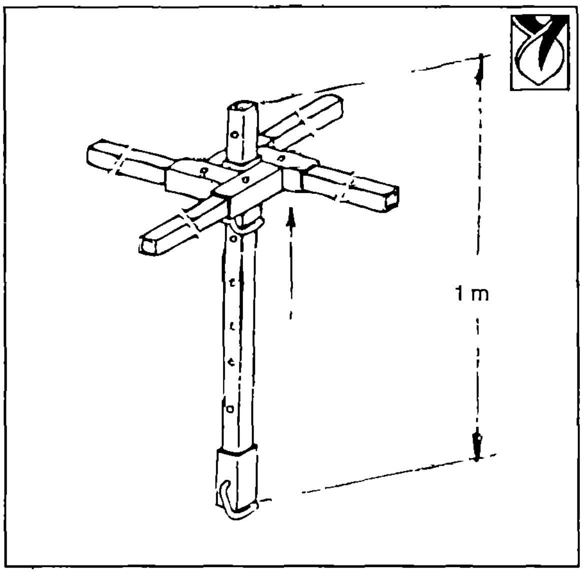
top of the extension rod, with a lockpin. Meanwhile, keep the rod catcher in position on top of the tool guide, to prevent that the drill string is inadvertently dropped in the borehole;
- fully lower the complete assembly; because of the extension rod the cross-piece will now be 1 m higher and will have to be readjusted to the correct level;
- resume drilling in the same way as described above;

❑ when the handles have — again — reached a position that is too low for easy drilling, insert a second extension rod.

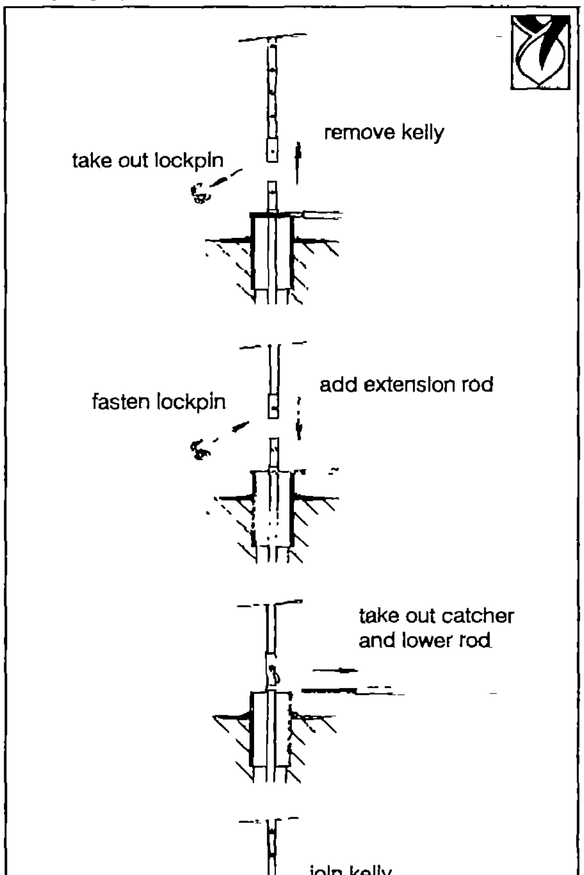
At a certain moment the weight of the drilling string will become too much to follow the procedure as described above. Then proceed as follows:

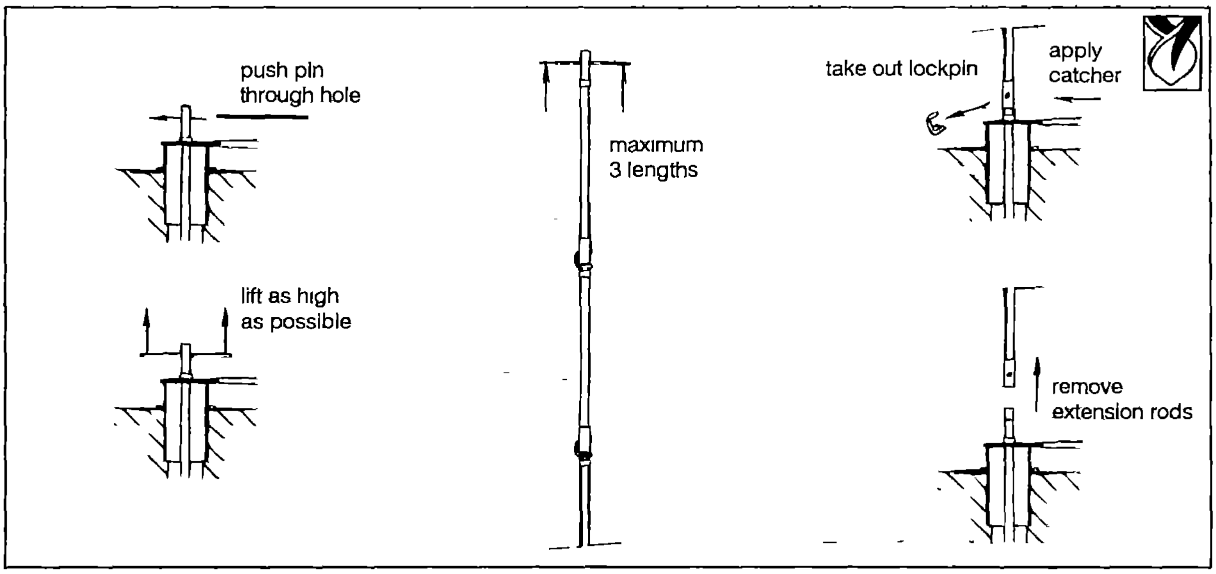
Inserting extension rods:
- while lifting the drilling assembly by hand, with 2 to 4 strong men, keep on turning it in a clockwise direction, to reduce friction between the drilling bit and the soil as much as possible;
- when the coupling between the kelly and the upper extension rod has become visible, slide a rod catcher underneath, so that the drilling assembly is supported by the tool guide;
- open the coupling between kelly and extension rod, and connect a new extension rod to the existing one in stead;
- push the pointed side of a second catcher or a heavy screwdriver through the opening in the lower coupling just above the ground, and have two strong men lift the assembly a few centimetres;
- remove the rod catcher, insert it again above the connection between the extension rods, and carefully lower the assembly until the upper connector rests on the catcher;
- repeat this procedure until the drilling bit has reached the bottom of the borehole and drilling can resume.

Disconnecting extension rods:
- while lifting the drilling assembly by hand, with 2 to 4 strong men, keep on



Adjust the level of the cross-piece with increasing borehole





turning it in a clockwise direction, to reduce friction between the drilling bit and the soil as much as possible;

- when turning is no longer possible (cross-piece is too high for handling), remove the handles to make lifting the drilling assembly easier;
- have the drilling assembly lifted as high as possible;
- have one man slide the catcher under the lower coupling, open the coupling and take off the extension rod(s) above this coupling. Lay down the extension rods, or hand them to people standing by for holding them temporarily;
- push the pointed side of a second catcher or a heavy screwdriver through the opening in the lower coupling just above the ground;
- have two strong men lift the drilling assembly as high as possible;
- slide the rod catcher underneath the lowest coupling, and slightly lower the drilling string so that it rests on the tool guide,
- open the coupling by taking out the lockpin, and remove the upper section(s) of extension rod;
- repeat the above procedure until the drilling bit/auger itself has been brought to the surface;

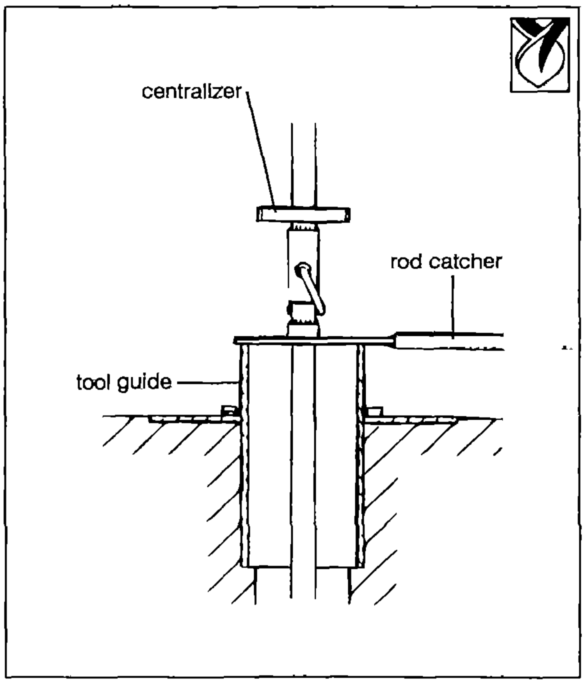
❑ as drilling progresses, the soil stress becomes higher, and it becomes more difficult to operate the drilling equipment;

- you may need to increase the number of people in the drilling crew, but take care not to overload the equipment:
- do not operate the drill with more than 4 people together for the 6" set or 6 for the 8" set;

3-m sections of extension rods used in drilling a 24 m deep borehole in 2 days

- do not drill more than about 0.25 m at a time (about 10 turns);

❑ with increasing depth of the borehole, the effort required to dismantle and subsequently reconnect all drilling rod sections each time the drilling bit has to be raised to be emptied, will also increase. It is possible to keep several sections connected during assembly and disassembly, with the following restrictions:
  - the vertical distance between the pulley block in the tripod and the top of the tool guide determines what is the maximum length of drilling rod that can be handled as one single section;
  - whether or not a tripod is used, do not try to handle the drilling rod in lengths over 3 m;
  - disconnect strings of drilling rods just below the stabilizers *(see at right)*;



Centralizer attached to extension rod, resting on tool guide

❑ when the borehole depth reaches about 5 m, the drilling rod may start shaking, and it will become difficult to keep the hole vertical. To prevent this, install a rod stabilizer (centralizer) on every 3rd extension rod. It will rest against the borehole wall or casing pipe and keep the rod in the middle of the hole.

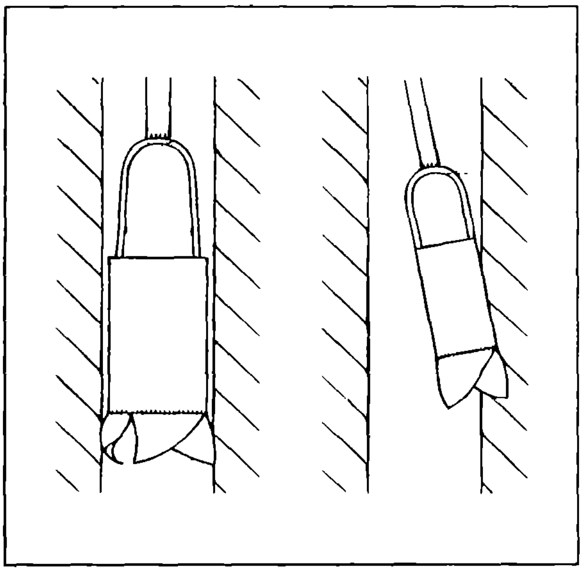
Change drilling bits

❑ arrange the outcoming soil neatly in 1 m long rows, next to the borehole;

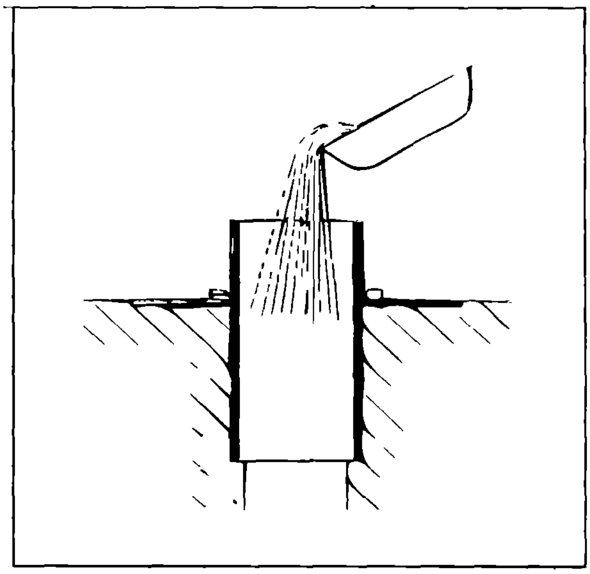
❑ depending on the soil composition, better results may be obtained by changing to a different type of drilling bit, e.g. a stone auger or chisel:
  - often best results are obtained by using different types of bit in succession;
  - if the flight auger or riverside bit no longer penetrates the soil but is just scratching over a hard layer, change to the large-diameter stone auger (for sets up to 6"). This specially takes out larger pieces of soil and stones;
  - if even the stone auger is not successful, use the chisel or the large-diameter chisel auger, and hammer the layer to pieces;
  - to use a chisel or chisel auger, the drilling bit must be operated different from the normal procedure: lift the drill string about 20-30 cm (either by hand or by operating the winch) and then let it fall back;
  - a chisel auger is able to remove the broken soil itself; when a chisel is used, it must be replaced by a regular flight auger or riverside bit to collect the cuttings,
  - turn the chisel about a quarter turn to the right at each stroke, to prevent it from getting stuck;

❑ it may be possible to get better results by using the smaller-size bits (that are actually intended for use inside casing pipe):
  - however, ***be careful***: the borehole may now more easily become non-vertical and thus unsuitable for lowering casing pipes later on;
  - therefore: ***always use the larger-diameter bits immediately after using the smaller-size bits***, to keep the borehole vertical and of uniform diameter;

❑ in case the soil is very dry, it may fall through the drilling bit. In such a case, pour some water in the hole first;



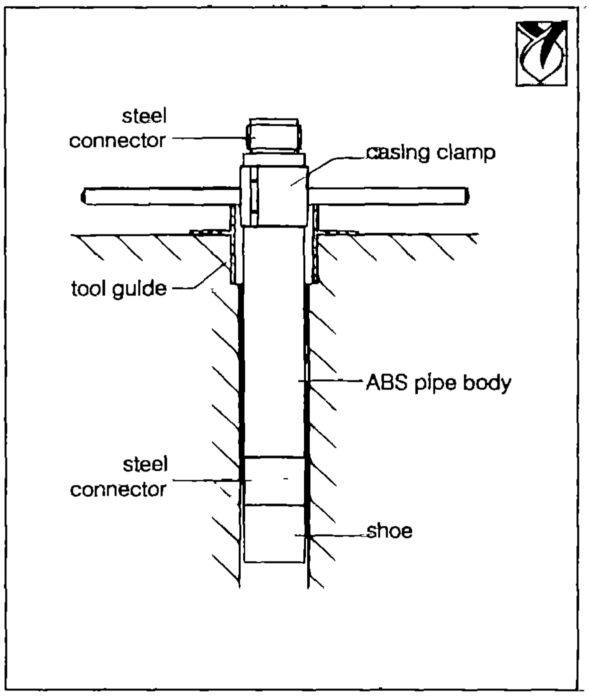
Danger of borehole becoming non-vertical when smaller-size drilling bits are used



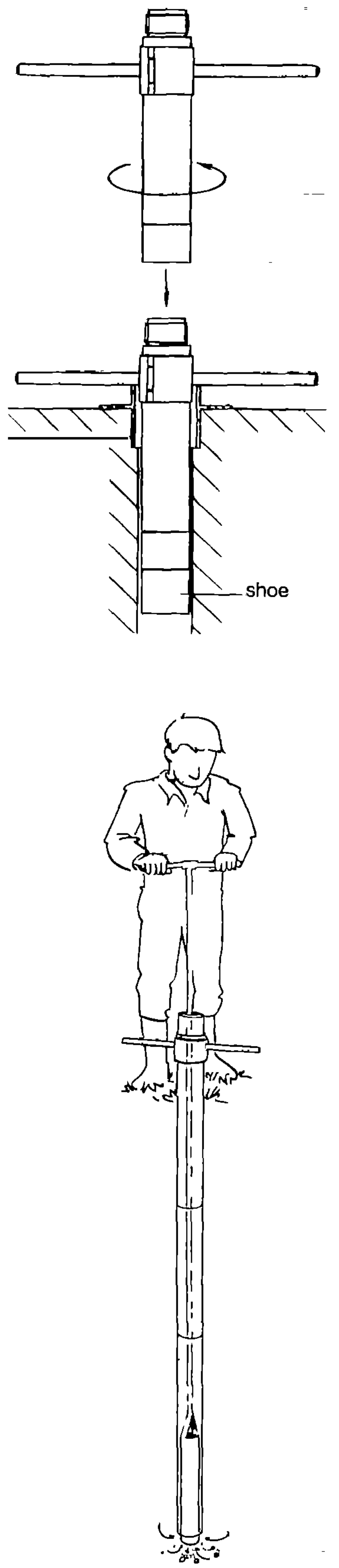
Adding water to the borehole, to increase effect of anger

- ❑ as soon as an aquifer is struck, it may be necessary to insert a casing pipe in the borehole, to prevent it from collapsing. As drilling without casing pipe is easier, it may be advantageous to continue drilling as long as possible, until there are clear signs of the borehole wall caving in, such as:
  - outcoming material is slowly changing from hard, dry, clayey material into lighter, more sandy, stoney material;
  - most of the times the auger is pulled up empty, because the soil is too loose to remain on the auger blades;
  - after pulling up the auger the sounded depth is less than the combined lengths of drilling bit and extension rod(s).

Inserting temporary casing



- ❑ when there is a danger of the borehole caving in, e.g when the water table is passed, (temporary) casing pipes must be lowered in the borehole to protect it:
  - first remove the drill string from the borehole;
  - then take a section of casing pipe, remove the thread protector from the female end and connect the cutting shoe to it;
  - fix a casing clamp around the top of the casing section and lower this in the borehole, on to the tool guide;
  - remove the thread protector (casing hanger in case steel pipes are used) from the top of the casing section (male end) and the thread protector from the bottom of the next casing section (female end) , and connect the two together, first by hand, and then by



using a second casing clamp, fixed to the upper casing section. Remember that the casing pipe has *left thread*!

- remove the lower casing clamp, and lower the entire assembly until the upper casing clamp rests on the tool guide or wooden beams;
- repeat this procedure until the casing shoe has reached the bottom of the borehole;
- for heavier casing (e g. steel casing pipe), lowering the casing pipe sections by hand is not possible In that case the string of casing pipes is hung from the tripod during lowering, rather than be held by hand. To enable this, the thread protector at the top of the casing assembly must be replaced by the casing hanger. This has eyes in it, to allow it to be hung from the tripod.

  A chain spanner may be used only for disconnecting two sections of (steel) casing pipe. This is done in combination with two casing clamps fitted to the other pipe section, and while lightly tapping the casing with a piece of wood

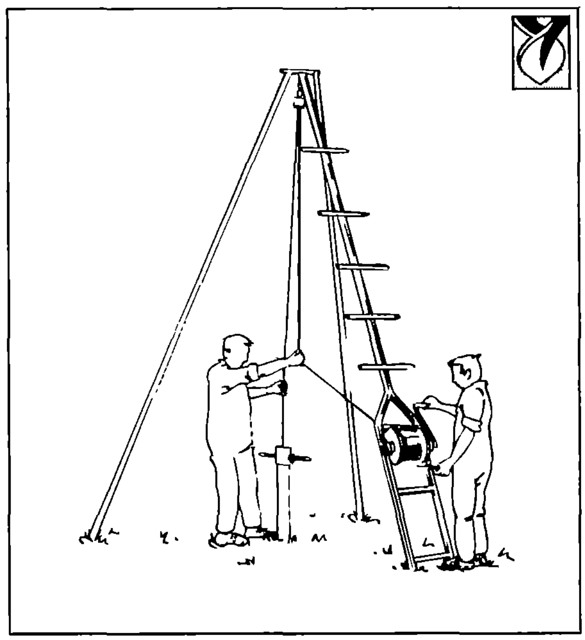
  Otherwise the entire procedure is the same as for the lighter ABS casing pipes with steel connectors;

❑ after the temporary casing has been put in place, drilling could be continued inside it. However, as caving usually occurs in layers of sand — for which the normal drilling bits such as flight augers and riverside bits can not be used — the borehole must normally first be made deeper by using a bailer.

Using a bailer

❑ when the soil contains so much water, or so much sand, that drilling with the standard bits is no longer possible, a bailer must be used for deepening the borehole. Often, the borehole will start caving under the conditions in which a bailer would be used. For that reason the bailing technique is described here, after the description of inserting a temporary casing. Under certain circumstances, however, using a bailer is possible also without a temporary casing,

- ❑ bailing is successful only when the borehole contains some water, say about 50 cm of water. Therefore, pour a few buckets of water into the borehole;
- ❑ first check that the foot valve of the bailer is functioning properly;
- ❑ then install the bailer, as follows:
  - lift the drill string out of the borehole;
  - replace the drilling bit by the bailer (in case no tripod is used; otherwise remove the second pulley from the tripod and connect the cable directly to the eye on top of the bailer, using a D-shackle. Note that the bailer has a swivelling connection at its top, allowing it to be used either with a cable or with the cross-piece and extension rods);
- ❑ start bailing. If no tripod is used, the approach is as follows:
  - lower the assembly in the borehole, until the shoe of the bailer touches the bottom of the hole;
  - lift the cross-piece up, about 20 cm, and drop it;
  - repeat this about 20 times to fill the bailer;
  - *be careful:*
    - the bailer is NOT a chisel;
    - the hole may become oblique, as the diameter of the bailer is much smaller than that of the borehole, especially when bailing is carried out without a casing pipe installed; to keep the borehole vertical, use the correct size flight auger or riverside bit after every 3 times the bailer has been used;
- ❑ using a tripod, it is possible to adapt the use of the bailer to the soil conditions. different techniques are used for fine to medium sand and for coarse sand:
  - in either case:
    - first calculate the length of the casing in the borehole (all ABS sections have a length of 1 m each; steel casing sections are longer: 1.25 m each);
    - measure the same length, plus 20 cm, on the cable, starting from the bottom of the bailer. Mark the point thus found by a piece of rope or ribbon, tied to the cable;
    - by keeping the mark visible above the top of the casing at all times, it is ensured that the bottom of the bailer is never more than 20 cm below the cutting shoe of the casing, preventing a situation where the bottom part of the borehole would collapse and the bailer would get stuck;
    - if the mark would disappear below the rim of the temporary casing pipe, first try to lower the casing by turning it anti-clockwise, without exerting a downward pressure. Under normal circumstances the casing pipe will sink, and bailing can be resumed;
  - *in fine to medium sand:*
    move the bailer quickly up and down in the upper 10 cm of sand in the borehole; this will turn the sand into quicksand, i.e. the sand particles will start floating in the water.
    - one man stands at arm's length from the double leg of the tripod, pulls the cable towards him with both hands and lets it go again;
    - in this way an up-and-down movement of the bailer of about 10 cm is brought about with very little effort;

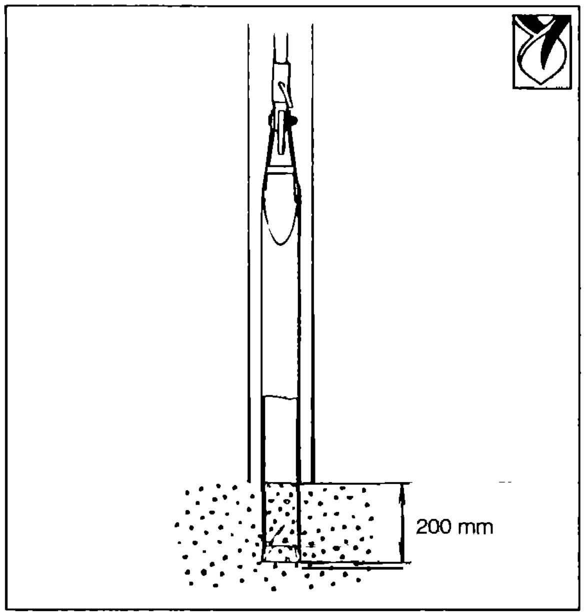


Bailling with a tripod

- after 10 to 20 strokes the bailer is pulled up a bit higher and then dropped by releasing the cable;
- by its own weight it will penetrate the sand — which will be very loose by this time;
- this procedure is repeated until the bailer is about half full of sand, while slightly releasing the cable in the process. Determining when the bailer is about half full is normally based on experience, by judging its weight. If in doubt, it is better to retrieve the bailer early rather than late;

• *in coarse sand or sand mixed with gravel* this method does not work well, as the particles are too heavy for quicksand to be formed To penetrate such coarser layers, the bailer has to be dropped from a greater height:
- one or two men grab the cable at a high point and pull it down rather than towards them;
- in this way the bailer is pulled up about 50 cm, and is then dropped by letting the cable go;
- between successive strokes the cable is released slightly;
- when the bailer is about half full of sand, it must be pulled up and emptied;

❑ if bailing is carried out inside temporary casing, the casing must be lowered as the depth of the hole increases during bailing:
• often the sand is so loose that the casing pipe will sink under its own weight;
• tapping the casing pipe with a piece of wood while turning it in an anti-clockwise direction may help it go down, especially in fine sands;
• if this does not work, the casing is rotated anti-clockwise while being pushed down;
• the best moment to lower the casing is when the sand is in the most loose condition, i.e. when the bailer is lifted; so, every time the cable or drilling assembly goes up, the casing pipe is pushed down. It is important to properly instruct the people who operate the casing pipe about this process;
• sometimes the casing cannot sink because of a stone under the casing shoe. In that case rooting up the sand with the smaller-sized auger may help;



Do not bail more than 20 cm below the casing shoe, to prevent the bailer from getting stuck

❑ take care that bailing is not carried out more than 10-20 cm below the casing shoe, as the hole might collapse and the bailer get stuck;

❑ remember to shift the mark on the cable upwards over the length of a casing section (1 m or 1.25 m) every time a new section is added during bailing;

❑ prevent the bailer from overflowing inside the borehole: sand might be washed into the space between the bailer and the casing pipe, and the bailer might get stuck as a consequence, making it next to impossible to be retrieved;

❑ never leave the bailer at the bottom of the borehole: it might be very difficult to pull it up afterwards, and it would act like a piston, sucking the sand upwards into the casing and spoiling the work done so far;

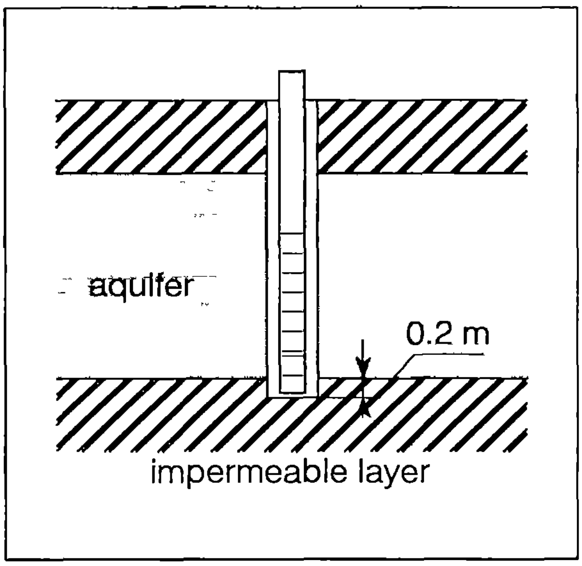
❑ when the bailer has been emptied and inserted in the borehole again, the situation may arise that the cross-piece, or the mark on the rope, is at the same level as the previous time, or even higher. This indicates that the well is collapsing and soil is flowing into the borehole, and that a temporary casing pipe must be installed, as described earlier;

- by bailing much water is normally removed from the borehole. In some cases this will cause caving in through the bottom, because of the difference in water pressure between the borehole and the surrounding soil. To prevent this, lifting of the bailer should be done as follows:
  - quickly pull up the bailer until its top breaks the water level in the borehole and thus becomes visible;
  - pour 2 buckets full of water (about 20 - 30 litres) into the borehole, this will cause the pressure inside the borehole to become higher than outside, resulting in a slightly outwards flow so that the sand grains are pushed back and do not clog the hole;
  - pull the bailer up slowly until it is entirely clear of the water;
  - then pull it up faster until it is above the casing,
  - push the bailer to the soil dump, empty it and take a soil sample;
- the pour water into the hole before taking out the bailer;
- take care not to hold the bailer directly over your feet, as dropping it (or a mistake by the winch operator) would cause painful injuries;
- stop bailing as soon as a more consistent layer has been reached, so that drilling can be resumed with an auger bit or riverside bit

Drilling inside temporary casing

In case there is only one aquifer that can be tapped, the last part of the drilling process is the use of the bailer as described above. Depending on whether the full depth of the aquifer needs to be drilled through, or not, there are slightly different ways of finishing the borehole. This will be described in the next section.

It will often be necessary to continue drilling also when a less permeable layer or clay layer has been reached, either because it is the intention to continue drilling until a second or even third aquifer has been reached, or simply to be able to penetrate the impermeable layer underneath over a sufficient depth to properly finish the borehole, or to position the filter deep enough *(see diagram at right)*. In such cases the approach is as follows:



Drilling into impermeable layer necessary

- after the temporary casing has been put in place, continue drilling inside it, now with the smaller size drilling bits: Ø 100 for the 6" set; Ø 130 for the 8" set. The procedure for drilling and for inserting extension rods remains the same as for drilling without casing pipe, the only difference being the smaller bit diameter;
  - the best way of drilling is to let the drilling bit go some 15 - 20 cm in front of the casing *(never drill deeper than about one bit length below the casing shoe; otherwise, the deeper part of the borehole might collapse on top of the bit, so that this would get stuck)*;
  - then retrieve the drilling bit while pushing down the casing pipe *(turn the drilling assembly in a clockwise direction and the casing in the opposite direction)*;
  - in this way the casing sinks more easily than when casing and drilling bit would be pushed down simultaneously;
  - as mentioned before, the flight auger should not be filled for more than about 50 cm, to prevent the friction between drilling bit and casing piped from becoming too high,
- keep on adding casing pipe sections during the drilling process, depending on the progress with drilling;
- continue drilling until the required depth has been reached *(see below)*

Finishing the borehole

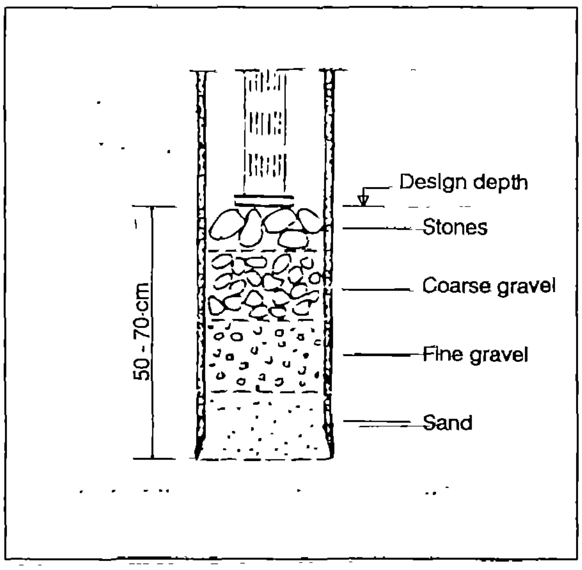
Concluding the drilling process

The way in which the borehole drilling is concluded depends on the type and thickness of the water bearing layer or aquifer. There are two basically different situations:

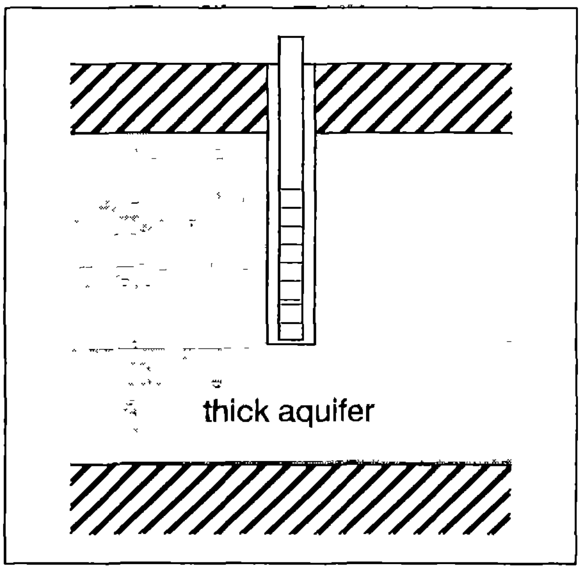
a. the borehole fully penetrates the aquifer, or:
b. it penetrates it over only a part of its height.

The first situation is the more generally encountered one; the second applies only when thickness and yield of the aquifer are such that it is not necessary, or even impossible, to utilize the full thickness of the aquifer *(see diagram on page 12)*. Finishing the borehole under option (a) is also easier than under option (b), as shown below·

- if the aquifer has a limited depth and a layer with low permeability is lying underneath, the simplest method is to let the casing penetrate into that layer for about 20 - 30 cm, so that the danger of caving in has gone. Drilling may be by flight auger, riverside auger, or any other drilling bit required, as described above. (In the case of a poor aquifer, without alternative options, the borehole might be reamed to a larger diameter, so as to provide some, albeit limited, storage volume);
- if the aquifer is very thick, however, it may not be necessary, or even possible, to install a filter over its full height. In such a case, if the borehole would be left as it is, caving would continue and problems might arise when installing the filter pipe, as the loose sand might rise along the pipe when that would be pushed downwards. The result would be that at the lower part of the filter fine sand would enter the well and the pump; *such a well would never produce clear water*! Continuing bailing for about 0.5 - 0.7 m below the design depth and subsequently filling this extra volume with layers of coarse sand and gravel of increasing grain size *(see figure at right)*, with some heavy stones on top, would act as a filter, preventing fine sand from entering the borehole. It should be mentioned, however, that such kind of solution has hardly ever been proven necessary, and that the approach for option (a) can normally be applied here as well.



Filter construction at bottom of borehole in thick aquifer



Borehole is only partially penetrating thick aquifer

Borehole description

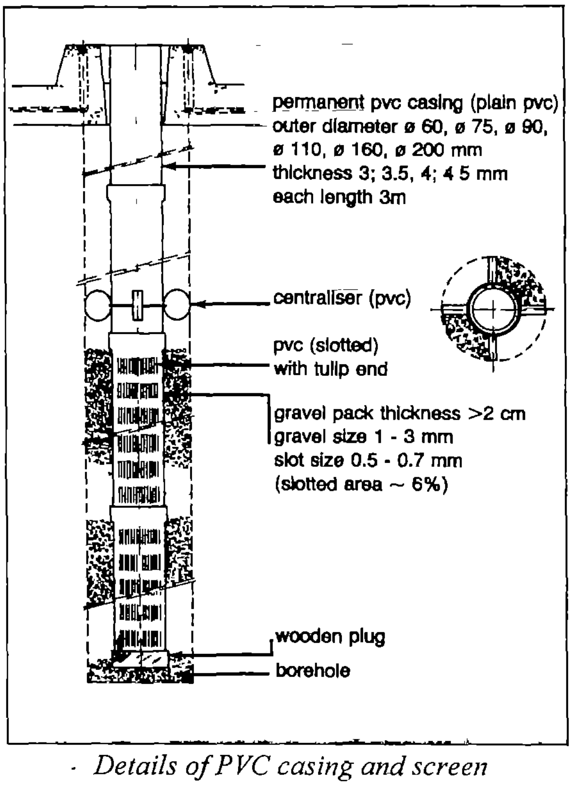
- remove the drilling equipment from the borehole, once the drilling has been completed. During lifting, disconnect the drilling rods in lengths that do not exceed 3 m each, to prevent bending of the rods or damaging the extensions;

- then make a description of the borehole.
  - measure the depth to the water level with a water level indicator (acoustic signal),
  - measure the total depth of the borehole with a weighted rope;
  - note down water level and borehole depth in the borehole description, as well as the so-called *lithological log*: a description of the various types of soil encountered as a function of the depth of the borehole. Also indicate whether the soil was dry or wet at the respective depths.

Installing the filter pipe

The various options for selecting filter pipe/screen materials and connections have been discussed on pages 8 - 16. Unless there are special reasons to do otherwise, the cheapest solution, viz PVC pipe with spigot and socket, is normally fully acceptable. Selection of the correct size of PVC must be done on the basis of the table on page 17. Installation is as follows:

- check the depth of the borehole; the required length of the PVC filter/plain pipe must equal the measured length plus 15 cm (the top of the PVC pipe must protrude above ground after having been lowered into the borehole, to prevent surface run-off from entering into the well);
- fix a wooden plug in the male end of a section of filter pipe;
- connect a second section of filter pipe if applicable;
  - see pages 8 - 16 for background information on how to determine the required length of filter pipe;
  - insert the male end of the second pipe into the female end of the first one, and push it in as far as possible;
  - place the end with the wooden plug against a tree or another heavy object, place a wooden beam against the other end and hammer the second pipe into the first. Glueing is normally not necessary;
- connect further sections of unslotted pipe, up to the required length;
  - repeat the method indicated above, while making certain that the various pipe sections are in a straight line;
  - the maximum length that can be handled in this manner is about 9 m, for longer lengths first lower 9 m of filter and plain pipe in the borehole, hold it firm, with 4 men, while pushing the next length into it and hammering the connection closed by tapping on a piece of wood on the top of the pipe. The connection can be made easier by putting some water and soap on the connection before attempting to join the two sections;
  - repeat this procedure as long as necessary;



Details of PVC casing and screen

- lower the assembly of filter pipe/plain PVC pipe in the borehole;
  - it is important that the pipe is positioned in the centre of the borehole, so that a gravel pack with a uniform thickness can be put around it, and there is no direct contact between the filter pipe and the aquifer material itself;

- therefore, at several places tie small blocks of wood to the pipe, at any rate at the top and bottom of the screen section; the blocks should be small enough not to obstruct the gravel when it is poured in, and may be kept in place with thin steel wire,
- when the borehole is deep, centralizers may be required at a third level; this should not be at the top of the borehole, as there the pipe can be kept centred by hand;
- just before inserting the pipe, check that no fresh material has assembled on the bottom of the borehole; if so, clean it first with the bailer,
- while inserting the PVC pipe, check that the assembly remains straight,
- depending on the depth of the borehole and the water level in it, it may be necessary to overcome the buoyancy of the pipe (which is closed at the bottom and filled with air) by pushing it down, this may be made easier by pouring water inside the filter pipe and thus weighing it down;
- with a hacksaw cut off the last section of plain PVC pipe at about 30 cm above ground level,

❑ immediately after the PVC filter/plain pipe has been inserted, gravel for creating the gravel pack must be poured into the borehole, to secure the stability of the pipe.

Placing the gravel pack

Considerations for selecting a suitable material for the gravel pack are given on page 16. As is mentioned there, coarse sand for the gravel pack can be sieved with standard sieves, but where these are not available, mosquito wire, coffee tray mesh, etc. can be used to construct makeshift sieves that can serve the purpose as well.

The volume of sieved sand that is required for making the gravel pack is determined by

- the total length/height of the screen;
- the size of drilling bit used;
- the diameter of the PVC filter/plain pipe

The volumes required for the standard sizes of drilling bits and filter/plain pipes *(see table on page 17)* are as follows:

Drilling set:	4"	6"	8"
Litres of sand required per m' filter length	1 5 - 5	4 - 13	7 - 16
Ditto, per length of filter pipe (3 m)	4 - 14	14 - 40	22 - 48
Volume of temporary casing pipe (litres/m')	1.8	3.1	3.4
Ditto, percentage of gravel pack volume	38-128%	23-65%	21-46%

The reason why a range of volumes is given for each combination, is that under certain circumstances no temporary casing is required, while if casing pipe is used, when it is pulled up, its original space is occupied partly by the sand/gravel and partly by the soil material. In the table above, the maximum volume was calculated on the basis of the size of the drilling bit only, whereas the minimum volume was based on the assumption that the space of the temporary casing is fully occupied by the soil material.

Placing the gravel pack is something that should be done with care, as a proper functioning of the gravel pack is of paramount importance for the performance of the borehole. For a borehole made with a 6" set, with a temporary casing installed, the procedure is as follows.

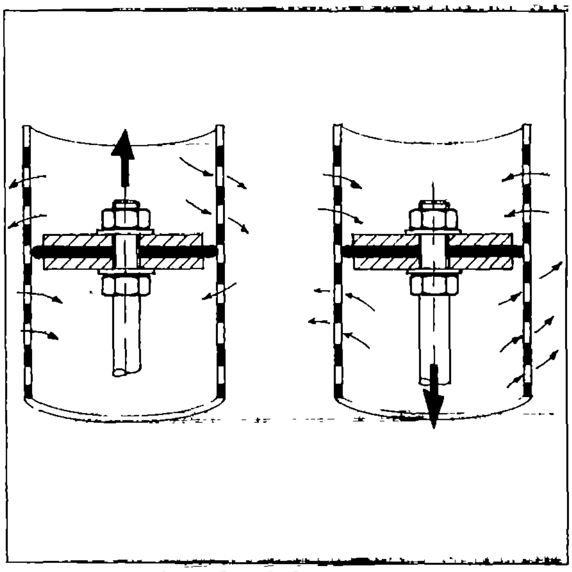
❑ pour in about 5 litres of sand; this will fill the annular space around the PVC pipe for 1 metre;
  - do not pour in the sand too quickly or in large quantities at a time, to prevent the formation of so-called 'bridges' in the sand;
  - spread the sand equally around the PVC pipe; otherwise bending of the pipe might occur;

- ❑ pull up the temporary casing over a height of about 55 cm. This will cause the level of the sand to drop by about 35 cm, so that the new level of sand for the gravel pack is now about 10 cm higher than the cutting shoe of the casing;
  - sometimes it is difficult to remove the casing, especially when it has been in the borehole for several days; therefore always tap the casing with a piece of wood when pulling it up, while continuing to turn it in an anti-clockwise direction;
  - in special cases it may still not be possible to lift the casing by manpower or with the winch of the tripod; in that case use other tools, e.g. hydraulic jacks under the casing clamp, to jack up the casing;
- ❑ measure the depth to the gravel pack with a weighted rope, to make certain that no mistakes are made;
- ❑ pour in another 5 litres of sand, and repeat the procedure, each time the difference between the sand level and the level of the cutting shoe of the casing increases by about 10 cm;
- ❑ stop the process when sufficient sand has been added for the entire gravel pack (see table above); to be certain add enough sand that its top level will be about 0.25 m above the design level;
- ❑ meanwhile, remove casing sections as soon as there is space enough to fix the casing clamp on the next section;
- ❑ when the screen is placed in the second aquifer, pull up the casing just far enough that it is still in the layer between the two aquifers; otherwise the sand from the top aquifer would fill the borehole, and there would be no opportunity to install a clay seal on top of the gravel pack

Developing the well

The objective of developing a well is to remove finer material from the aquifer in the immediate vicinity of the borehole. Thereby the passages in the gravel pack and aquifer are cleaned, opened up or enlarged, so that the water can enter the well more freely. Developing a well brings it to maximum capacity.

- ❑ there are several methods for developing a well, such as:
  - overpumping (pumping the well at a higher rate than it will be pumped under normal circumstances);
  - mechanical surging (reversing the flow direction of the water, into the aquifer);
  - jetting (horizontal jets blowing water at high velocity through the slots of the well screen);
  - as well as various other methods,
- ❑ for developing hand drilled boreholes, a simple and reliable method is required. In practice some higher-rate pumping is often carried out immediately after construction of a borehole, but this does not really qualify as overpumping. It serves, however, to pump the filter clean. Thereafter the well is developed by means of a surge plunger.



Details of plunger body

- ❑ the plunger is a piston-like tool which fits exactly in the filter pipe,
  - it consists of two disks (leather or rubber) between metal plates, with a rubber flap on top, and kept together by a central M16 bolt and nuts;
  - pump rods can be connected to the plunger, allowing it to be operated by hand;

- the rubber flap on top acts as a piston, pushing the water inside the borehole down or sucking it upwards;

❑ the plunger is operated as follows:
  - lower the plunger into the filter pipe until it is a few metres under water, but above the top of the screen;
  - start surging slowly;
  - gradually increase the speed of surging, so that the surging action becomes more pronounced;
  - after a few minutes, pull up the plunger from the filter pipe and remove the sand from the well by means of the test pump (if the water level is too low for the pump to have a good performance, a survey bailer may be used as well to remove the sand. Take care not to damage the filter pipe, and first wait for several minutes until most of the sand has settled on the bottom of the well;
  - then insert the plunger again and repeat the procedure until the amount of sand to be removed has become very small.

Pump test

After the well has been developed and the pumped water has become clean, carry out a pump test, to check once more that the yield of the well is sufficient for the use of a handpump. The equipment required for the pump test is as follows:

- test pump, with handle and hose pipe;
- water level meter;
- measuring strip or tape;
- bucket;
- watch or alarm clock.

Carry out the pump test as follows:

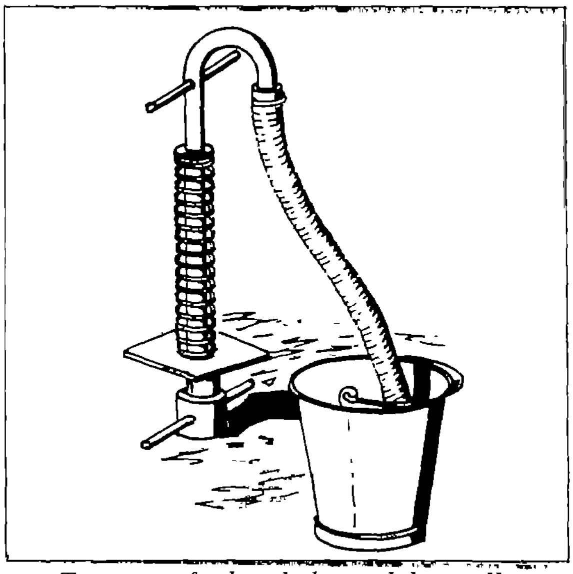
❑ measure the water level in the well, check that it is the same level as before development of the well;

❑ connect a number of riser pipes for the test pump until their combined length equals the total depth of the borehole minus about 0.50 m; do not use wrenches or similar tools for jointing the riser pipes;

❑ check that the lowest section of riser pipe contains the foot valve;

❑ carefully lower the riser pipe assembly into the well and connect it to the test pump;

❑ lower the test pump until its foot plate rests on the top of the PVC pipe, start pumping by moving the pump body up and down, as if using a bicycle foot pump;



Test pump for boreholes and dug wells, suitable up to 20 m depth

❑ start pumping as fast as possible, and continue this for half an hour; do not stop in the meantime (if necessary, have several people pump in turns)

❑ count the number of buckets filled every 5 minutes; continue pumping also during the measurement;

❑ after half an hour, stop pumping, but leave the hose pipe in the well;

❑ measure the water level in the well every minute, for the first 5 minutes after pumping has stopped;

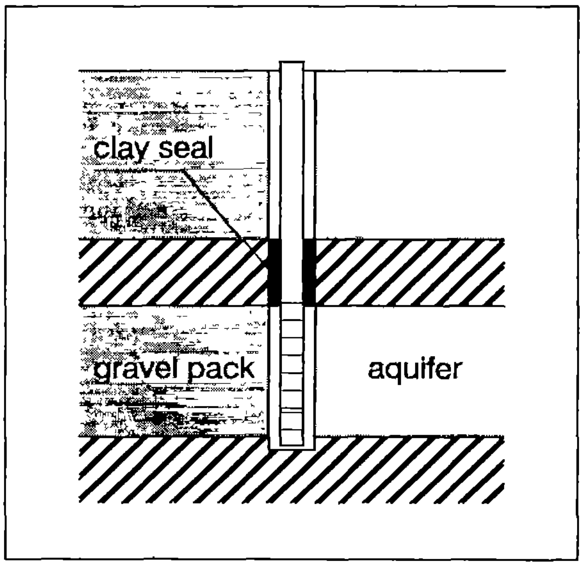
- ❑ write down the results and calculate the yield of the well and the drawdown at every 5 minutes interval.

Should the well prove to have insufficient capacity, the PVC filter can be recovered. A plug (the *retriever*), hanging from a steel cable, is then lowered to the bottom of the filter pipe and gravel is poured on top. Then the entire pipe is pulled up with the winch, while — by vibrating and turning it — the friction is largely removed.

Normally, however, the yield test of the survey test drilling offers a sufficiently reliable indication of the well capacity to prevent the construction of wells of too low capacity.

Clay seal and backfill

Clay seals are installed in the borehole, on top of the gravel pack, to prevent leakage of contaminated water from above into the aquifer and/or well. Especially if the borehole has penetrated an impermeable layer to tap an aquifer underneath, it is important to place a backfill, at the same level and preferably of the same thickness as the impermeable layer.



Use of clay seal to prevent contamination thick aquifer and well

- ❑ to accomplish this, apply small pieces of plastic clay on top of the gravel pack, and compact them in small layers at a time;
  - keep in mind that, even if the original soil material is clay, this has usually been drilled up in big lumps that have subsequently lain in the sun for days and dried out;
  - therefore first break the clay in small pieces, and put them in water the day before use; in that manner they will suitable for use the next day;
  - first check by measuring that the gravel pack has indeed reached the design level; if not, add gravel up to that point;
  - put the pieces in the borehole in layers of about 25 cm thick, and compact them with a clay rammer;
  - measure the level of the clay and check whether the seal has reached its design level;
  - meanwhile slowly retract the casing, while taking care that no fine materials can flow into the well borehole in between the top of the clay seal and the cutting edge of the casing pipe;
  - once the clay seal has reached its design level, remove the casing completely;
  - apply backfill material and compact it well, using plenty of water (in principle the same material that came out of the borehole may be put back as backfill).

Construction of the platform

Functions of the platform

After the well has been backfilled *(see previous page)*, a platform is constructed on top. This has two main functions:

- to provide a foundation for the handpump;
- to protect the well and its surroundings against contamination.

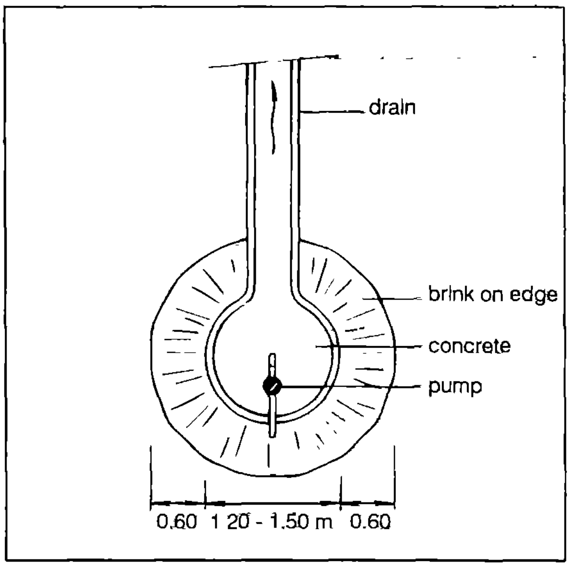
The platform must thus fulfil the following requirements:

- provide a stable and level (horizontal) foundation for the handpump, to prevent damage to the pump (e.g. uneven wear of the bearings, etc.);
- completely cover the borehole opening, so that spill water cannot enter the well from above,
- have a surface that is sufficiently large that all essential operations (e.g cleaning buckets, pumping, putting bucket upon the head, etc.) can be accommodated, while not being large enough to invite washing of laundry, bathing, etc on the platform,
- be provided with a rim or drain around the edge of the platform, to contain or collect the spill water;
- be shaped such that most of the spill water is collected and guided towards a lower drainage area, without creating muddy places or pools that could serve as breeding places for mosquitos and other harmful insects;
- be strong enough to support several people and buckets without cracking or breaking.

Design of the platform

The requirements mentioned above mean that the platform should neither be too small, otherwise the essential actions could no longer be carried out, nor too large, to prevent undesirable types of usage such as laundering, bathing, etc.

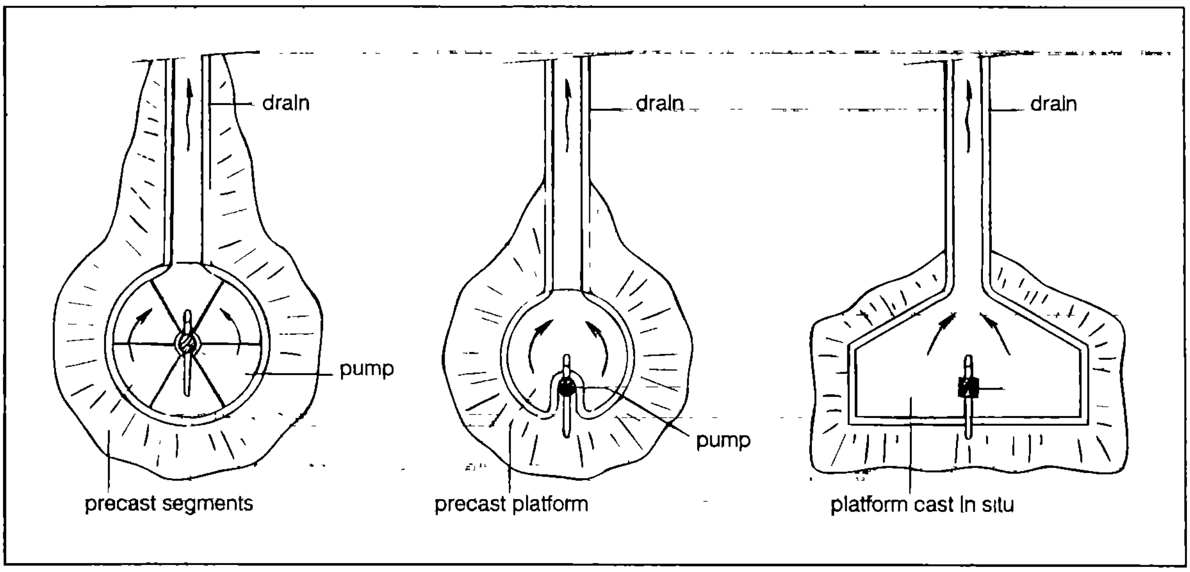
A possibility is then to separate the functions of the platform, and provide a concrete (or plastered) central section that is just large enough to accommodate the buckets to be filled, and to collect most of the direct spill water (e.g. 1.20 m diameter), whereas splash water creating muddy areas around the well is prevented by paving the area immediately outside the concrete slab with bricks on edge (e.g. a strip of about 0.60 m wide). That material meets the purpose of providing a relatively dry (at least not muddy) area, while it is not suitable for washing laundry, and thus does not invite undesired activities.



Central platform of concrete, with brick-on-edge around it; note eccentric location of pump stand

Depending on the type of handpump to be installed, sometimes a part of the pump stand is fixed in concrete *in situ* (e.g. for India Mk. II handpump). This has the obvious disadvantage that the pump body cannot be replaced without destroying the pump platform. For other pumps, including the full SWN range, either a pre-cast pump foundation is installed, or it is constructed locally as the first part of the platform The actual platform (also called apron) may then.

- be assembled from prefabricated concrete elements, e.g platform sections shaped like orange peels that fit snugly around the pump stand;



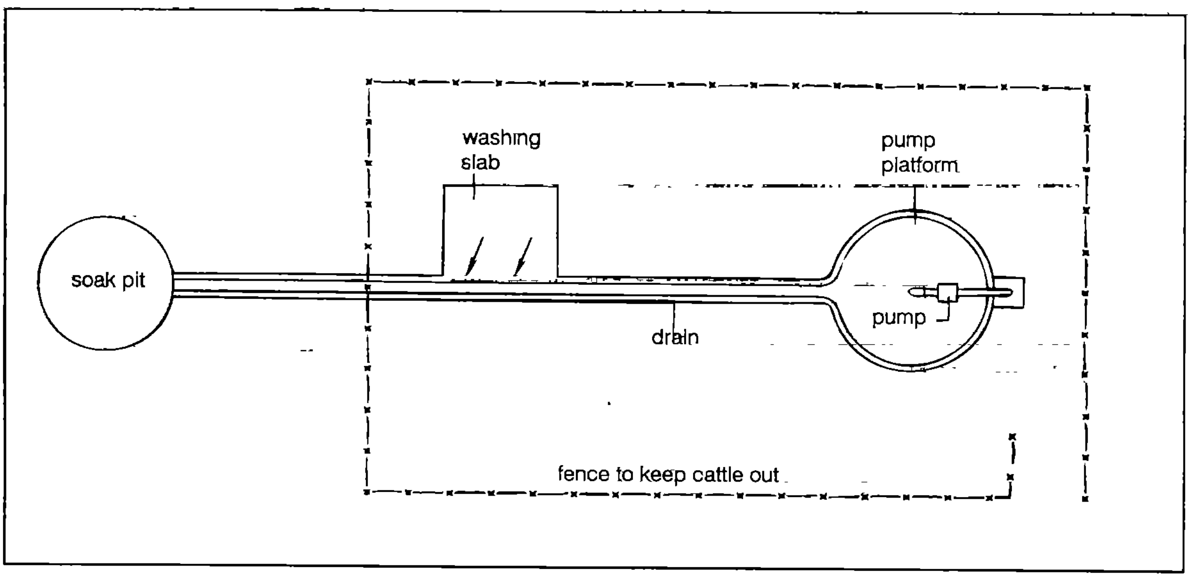
Various types of platforms: precast sections; full-sized precast; fully cast in-situ

- be a full-sized prefabricated concrete platform;
- be constructed *in situ* from concrete (reinforced, plain or hard-core).

Discouraging the use of the handpump platform for washing laundry and bathing (to prevent contamination or undermining of the well) is more successful when an alternative is offered: a separate washing/bathing slab next to the drain, but sufficiently downstream of the well. Similarly, the construction of separate cattle troughs, to be filled with water taken from the handpump by the cattle owner, will prevent cattle from dirtying the surroundings of the well.

Depending on the local situation, excess water (spill or splash water) may be drained away to a lower area (village pond or the like) or to a kitchen garden The alignment and size of the drain or gutter must then be such that the water does not stagnate on the way. It is, therefore, the more important to check the slope of the area before planning the lay-out of the site.

Cattle troughs normally hardly cause spillage of water, so that their location is less critical than that of washing slabs. These must be located downstream of the well, along the drain, so that spill water



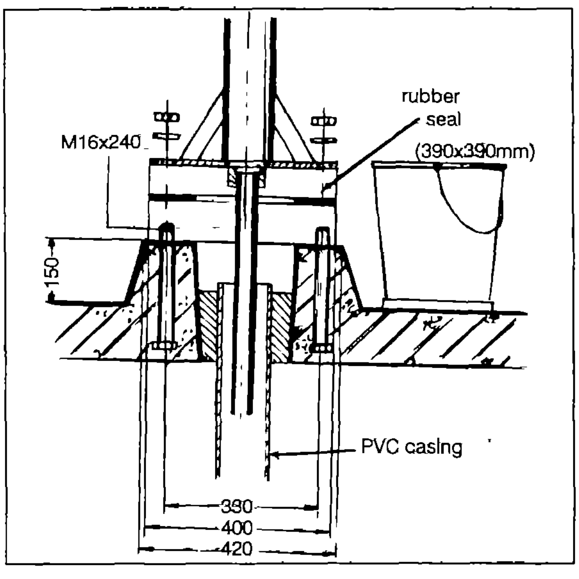
Example of well with drain, washing slab and soak pit is again collected and led to waste. Note that owners of kitchen gardens or other plots where the water is discharged to, may agree to receiving spill water from the well itself, but object to the discharge of water with soap or washing powder from bathing or laundry platforms Depending on the local situation, these may thus have to be provided with separate drains, discharging to another place, and adding to the over-all cost. If no suitable areas for the disposal of excess water can be found, a soak pit might be constructed, to infiltrate spill water into the soil Not all soils are suitable for the construction of soak pits, however, while they add considerably to the costs of the well For that reason they are often not constructed, even under conditions when they are in fact required; as a consequence pools of stagnant water may be created, creating health hazards (mosquito breeding, etc.).

Construction of the platform

General measures
The sequence of activities for constructing a platform for a well depends on whether, or to what extent, pre-cast parts or moulds are used. The following steps apply — with only minor adaptations — in all of these cases:

- determine the direction in which the water can be drained away. If the area is completely flat, select the least harmful direction for the water to drain to,
- stake out the perimeter of the platform on the ground. Always measure distances from the centre of the filter pipe,
- remove the top soil from within the area that has been staked out. Pay extra attention to removing plants and roots, as these will otherwise start rotting after some time, weakening the foundation of the platform;
- around the perimeter of the platform, dig a trench of about 10-15 cm deep and 25-30 cm wide;
- dig a trench sloping down, for the spill water gutter, of a length that is sufficient to fully drain away the spill water;
- compact the soil inside the staked out area. Especially the area just around the filter pipe must be well compacted; this may be done with a casing retriever or a similar heavy item;
- spread a layer of sand (2 -5 cm thick) evenly over the area, the layer immediately around the filter pipe being somewhat thicker, as soil subsidence will be larger there,
- saturate the sand with water and compact subsequently, to obtain a good foundation. Note, if the area is completely flat, raise the platform foundation somewhat, to ensure a proper drainage of the spill water

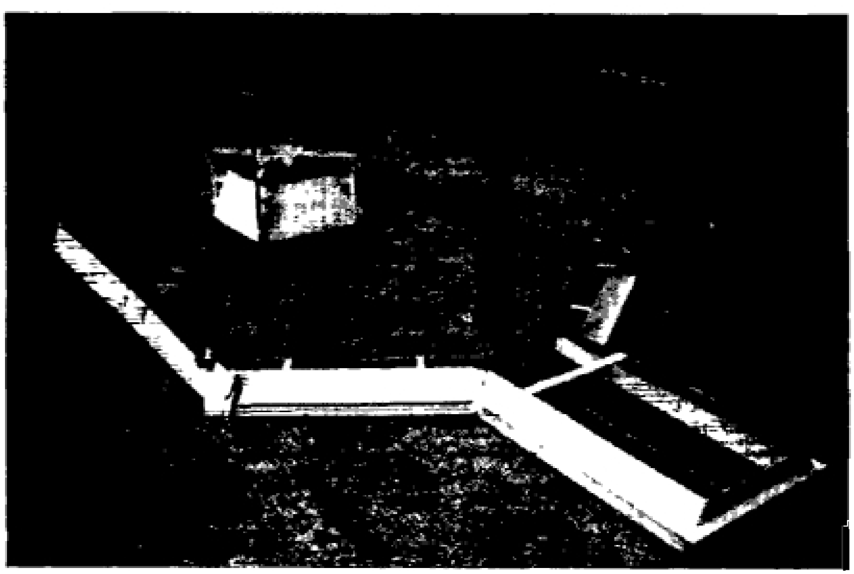
Using a mould for the pump platform
The following description applies to the standard mould for casting pump stands for SWN pumps and other pumps that use the same anchor bolt configuration. The mould consists of sections that can be connected with pins before use, but can be disassembled for easy transportation. It is available either as a mould for the pump foundation only (assuming that the rest of the platform will be cast *in situ*), or as a combination mould, for the pump foundation as well as the rest of the platform. In either case the first part that must be constructed is the pump foundation; this is also made of a slightly drier concrete mix than the platform.



Anchor bolts fixed in mould for pump foundation

The sequence of activities is as follows:

- with a hacksaw cut off the PVC filter pipe at 30 - 40 cm above ground level;
- place a piece of PVC pipe of a slightly larger size around the filter pipe, to prevent concrete from sticking to it later on;
- if no such pipe is available, wrap rags or paper around the PVC filter pipe;
- grease the parts of the mould, assemble them and place the assembly *(see also page 59)* over the well opening in such a way that the top of the PVC filter pipe is exactly in the centre of the opening in the mould. In case the combined mould is used, check that the gutter is pointed in the right direction;
- fix the 4 anchor bolts in the top section of the mould, in such a way that the top of the bolts is 4 cm above the future concrete level *(see drawing on previous page)*,
- set the mould so that its top is exactly horizontal, at 20 cm above the ground level, by adjusting the 4 other bolts (M16 x 200), which are fixed to the mould;
- prepare the concrete mix; use 1 volume cement on 2 volumes of clean sand and 3 volumes of fine gravel (gravel not larger than 2 cm) for the pump foundation, and a slightly wetter mix (1 volume cement on 2 volumes of clean sand and 4 volumes of gravel not larger than 3 cm) for the remainder of the platform;
- apply the concrete mix in layers, continuously compacting;
- after about half an hour, fully retract the 4 adjustment bolts in the pump foundation mould to above the concrete level (about 20 cm up);
- check that the top of the pump foundation is still horizontal, and finish the top with a trowel so that it is perfectly flat;
- carefully remove the nuts from the anchor bolts;
- while softly tapping against the metal, slowly lift the mould from the concrete; repair the fresh concrete with a trowel, where needed;
- finish the top of the platform with a trowel and straight piece of timber so that it is flat and well-finished;
- remove the mould of the apron part after 4 hours;
- at the end of the day, carefully place the pump stand, with some jute rags or paper inside, and without the pump head, on the foundation;
- keep the concrete wet for 5 days, e.g. by placing jute bags on it and keeping these soaked with water. An other way is to cover the concrete with plastic sheets, fixed in place with stones or heaps of sand. Evaporating water will condensate on the sheets and fall back on to the concrete, keeping it moist. Arrange that nobody touches the well or pump stand during that period.



Mould for pump base, apron and gutter

Casting the apron in situ
The approach is the same as indicated above, the only difference being that in place of a mould, wooden formwork is used that is put together locally.

Additional works
Apart from the handpump platform or apron, several other works may need to be carried out, such as:

- *drain;*
  Especially for smaller-size platforms, spill water can fall outside the platform. In such a case, especially if the soil is rather impervious, provisions may have to be taken to collect the spill water and direct it to the main drain. Various possibilities exist, e.g. a concrete drain or gravel drain around the platform, or gravel or coarse sand below the brick-on-edge pavement, connected to the main drain from the pump foundation to the final discharge area. Whereas a concrete drain is easier to clean and thus provides a better guarantee for uninterrupted functioning, a gravel drain is easier to construct and considerably cheaper. Which option will be chosen, will thus depend on the budget and availability of materials.
  The main drain itself may be constructed of concrete or brick masonry, or even be a simple earth channel. In the latter case, however, more extensive and regular maintenance is required to prevent blockage. For the drain a minimum cross section of about 20 x 20 cm is recommended;
- *bricks-on-edge;*
  As mentioned before, brick-on-edge may be used as pavement around the concrete platform, which can therefore be of a smaller size (e.g. concrete platform Ø 1-1.20 m, with 0.60-0.70 m wide strip of brick-on-edge around it. Experience with this solution is positive, but application of brick-on-edge is attractive only when burnt bricks are locally available,
- *steps;*
  Steps, e.g to allow smaller children to use the handpump with ease, can be made from bricks or concrete blocks. These can be constructed as plain masonry, or with a mortar plaster;
- *bucket rest,*
  Bricks or concrete blocks can be used for the construction of a bucket rest, viz. a kind of pedestal on which the full bucket of water can be put before lifting it to the head, thereby making the process of lifting the full bucket from the ground to the head easier,
- *washing slab,*
  The construction of the washing slab (size: about 1.5 m square) follows the same approach as that for the platform. The location of the washing slab must be sufficiently downstream of the well that no contamination of the well site is possible, say at least 3 m. Especially with larger shallow well programmes construction of one or more washing slabs per well may be included as community contribution to the construction of the well, since only relatively unskilled labour is required.
- *soak pit,*
  A soak pit is a dug pit, with a diameter of 1 - 1.5 m, and a depth of about 1.5 - 2 m, filled with coarse stones which are covered with an impervious layer (clay or concrete) at the top, to prevent rain water from collecting in the pit. Spill water from the handpump enters the soak pit through the main drain and infiltrates into the bottom For a soak pit to be successful, the permeability of the soil must be high enough, which must be checked first.

  Due to their extra costs, soak pits are generally only used when other ways to dispose of the spill water are not available Since in the field expertise to check on the technical feasibility of soak pits is often lacking, mixed results are often obtained with the application of soak pits

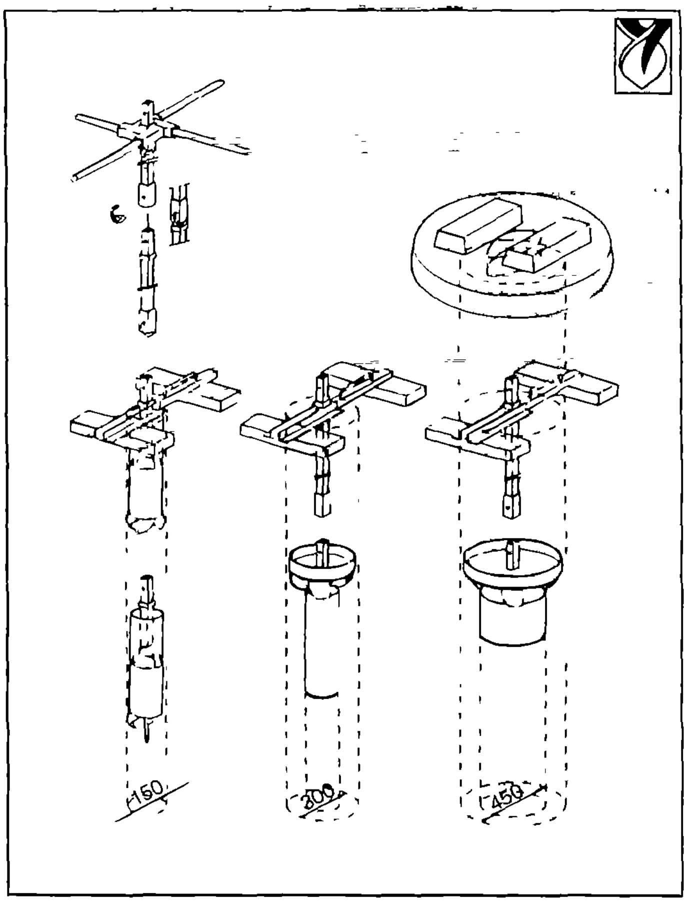
Installation of handpumps

For handpump installation, maintenance and troubleshooting, see *Volume 4. Handpumps.*

Using hand-drilling equipment for latrine construction

The 6" hand-drilling set can be used for drilling pit latrines down to about 10 m, if used in combination with reamers.

- first drill the hole with the standard 6" set, using the riverside auger or chisel auger; because the borehole width must be increased subsequently, a tool guide cannot be used. For that reason a special rod catcher is used, supported on wooden planks *(see at right)*;
- in 2 stages the borehole is then reamed, using Ø 300 and Ø 450 reamers;
- eventually, a 90 cm diameter concrete squatting slab is cast *in situ*, using a special mould. Once the pit latrine is full, the slab can be removed and put on top of a new latrine borehole, and the first one can be covered, to allow the contents to become inert,
- special borehole latrine sets, including all required items, are available, in a lockable steel box.



Similar reamers as shown above can be used for drilling a production well by starting with a survey set (4") and subsequently increasing the borehole diameter through reaming. However, this is possible only if the borehole can be drilled without having to use temporary casing.

MAINTENANCE

The guarantee the sustained use of wells provided with handpumps, maintenance is critical. As maintenance is carried out first and foremost on the most visible part, viz. the handpump, maintenance aspects are mentioned in detail in *Volume 4: Handpumps* (pages 49-57). In this Volume 3, only maintenance aspects that are specifically linked to (equipment for the construction of) drilled wells are mentioned.

Maintenance of drilling equipment

The drilling equipment has been specifically designed in such a way that only limited maintenance is required Also the fact that virtually all equipment can be stored in boxes and can be transported in 4-wheel drive vehicles, makes it easier to store inside in between use, rather than being forced — by the sheer weight and dimensions of the components — to leave it in the open. Nevertheless, the following aspects merit attention:

- keep the equipment clean;
- check augers and bits for cracks and worn parts; replace or repair worn parts. Worn bits may be restored by welding material to the cutting edges and other wearing parts. Use high-quality welding rods for this purpose;
- check that the knives of the riverside bits are still in the correct position, i.e. pointing slightly outwards. If they are not, they must be adjusted. In case the knives are worn too far, they can be replaced by new knives, which are available as spares. The old knives must then first be sawn off, and the new knives welded in place. To ensure that the new knives are set in the right position, as an alternative a ring with pre-welded knives can be supplied. In that case the lower part of the cylindrical riverside body — with the worn knives — is sawn off and the ring with new knives welded in its place. It is also possible to supply the full auger body without the rod part. In that case only the rod needs to be sawn off and welded to the new auger body;
- check the thread of the connections on the extension rods, T-handle and drilling bits of the survey set and keep it greased;
- check the thread of the casing pipe sections; smoothen damaged thread with a file; keep thread protectors on the casing pipe sections in between use;
- check the teeth on the casing shoe; weld on new material or new teeth when necessary;
- check casing pipe for cracks; do not use cracked casing pipe;
- check the foot valve of the test pump(s);
- check the foot valve of the bailer(s),
- check the steel cable on the winch of the tripod; replace sections with kinks

Maintenance of drilled wells

Maintenance of wells, whether dug or drilled, is often mainly preventive maintenance:

- keeping the well surroundings clean;
- keeping the drain open;
- preventing children from using the well area as a playground;
- preventing people from using the well platform as a laundry or bathing place;
- keeping animals out, e.g. by constructing some kind of fence around the well area.

Practice has shown that the best way to realize this kind of maintenance is to form handpump committees: people living near the well site (generally the women) form a group (5-7 people) who take it upon themselves to carry out these activities, while educating the other users in how to use the pump and well. As has been mentioned before, it is easier to get other people to listen to these committee members when provisions for bathing, washing and cattle watering are available near the well site, but at a sufficient distance to prevent contamination of the site. To increase the commitment of the community in realizing the water supply facilities, it is often a good approach to have the community construct the additional facilities (washing slab, cattle trough, etc.) with their own labour and funds.

Maintenance aspects for hand drilled wells are summarized on the next page:

Troubleshooting chart for hand drilled wells

Problem/Symptom	Probable cause	What to do.
a. Insufficient water yield. insufficient flow into the well	a1 Clayey soil, not suitable as aquifer*) a2 Borehole not (well) developed a3 PVC filter slots clogged a4. Iron incrustation in filter slots	a1. Select other well site, and construct new well a2 (Re-)Develop the well a3. Clean slots with hard nylon brush a4. Clean with hard nylon brush and bleaching powder
b. Insufficient water yield: sediment in filter	b. Fines pass filter slots	b (Re-)Develop the well, clean with bailer or pump, if not successful construct new well
c Poor water quality turbidity	c1 Gravel pack of too large size installed c2. Slots in filter pipe too big c3 PVC filter pipe is broken c4 Join(t)s between filter pipe sections is/are open c5 Bottom of filter pipe open	c1 Try to remove filter pipe, backfill and gravel pack, and insert correctly sized gravel pack; if not possible. construct new well c2. Insert smaller-diameter filter pipe with smaller slots inside existing filter pipe c3. Try to replace filter pipe by new one; if unsuccessful construct new well c4. Try to close joint(s) between filter pipe section, if unsuccessful construct new well c5. Install new bottom
d. Poor water quality. bad taste/smell	d1 Rotten smell/ammonia smell, caused by rotting roots, etc : location too close to old rice field or forest*) d2. Iron content too high*) d3. Salinity too high*) d4. Soap from washing clothes d5. Infiltration water from latrine d6. Other cause	d1. Construct new well at different location d2. As d1 d3. As d1 d4. Have washing slab constructed at least 3 m away and downstream from well d5. Relocate latrine, if possible at least 15 m away and down-stream from well d6. Check environment; if cause of poor taste/smell cannot be taken away construct new well elsewhere
e Pump foundation, platform or drain cracked	e. Abnormal wear or low quality of original concrete construction	e Cut out the cracked parts of the pump foundation, platform or drain, and replace by fresh concrete or masonry of good quality.
f. Pump foundation shaky	f Anchor bolt loose	f Cut out the cracked parts of the pump foundation and replace by fresh concrete of good quality Keep anchor bolts well aligned during repair of foundation.

Note. *) these problems are basically survey errors, and should have been foreseen during the survey stage

COSTS

Construction costs

For hand drilled wells construction costs include:

- (depreciation of) equipment
- materials used in well construction
- labour
- transportation
- overhead

At the current price level, the cost of a basic hand-drilling set is around $ 8,000 for a 6" set, and $ 12,000 for an 8" set[5]. Depending on the number of wells that need to be constructed (about 50 wells can be constructed per year, with one drilling set), the depreciation cost per well (discounting interest) may be as low as $ 50 per well, inclusive of small repairs.

Apart from the PVC filter pipe and cement for constructing the platform, the required materials (sand, gravel, clay) can normally be obtained locally, at relatively low cost. As an average, for a 20 m deep well, material costs would be around $ 600.

The cost of labour and transportation depends on the local situation: the distance to the well site and possible free labour contribution by the local population may play an important role here. Overhead costs also will depend entirely on the local situation: in the case of a mission post organizing the construction of wells in its area, these costs may be virtually nil, whereas a large-scale externally financed wells construction project with expatriate management may have a relatively high overhead.

Practical experience has shown that the construction costs of a 20 m deep hand drilled well are in the order of $ 3,000, not including the handpump, which costs another $ 1,000. A machine-drilled well, by comparison, costs around $ 15,000 - 20,000. It may be obvious that providing such a well with a $1,000 handpump is not sufficient to turn it into a low-cost solution.

It may also be clear that hand-drilling is not a low-cost option if only one or two wells must be constructed: the full capital cost must then be depreciated over one or two wells only. Still, such solution is more attractive than having the wells drilled with a drilling rig, as the resulting costs would be substantially higher: when 2 boreholes are to be constructed, the depreciation cost for a hand drilled well, using a 6" drilling set, would be around $ 4,000 each, against about $ 15,000 for a machine-drilled well. If more than one potential donor is active in the area, but none with a larger well construction programme, an option might be to have the hand drilling equipment purchased jointly, so that investment costs can be depreciated over a larger number of wells. Each donor could then, for instance, use the drilling equipment for 2 or 3 months each year.

If no money, or a donor, can be found for investing in a drilled well and handpump, whereas the people are willing to contribute for construction and maintenance of a well, a dug well without lining, and provided with a bucket and rope, might be a solution. It must be stressed, however, that such a well does not give bacteriologically reliable water, and that constructing such a well is not without danger — especially for unskilled people — assuming that it is technically possible (a well that needs no lining is by definition a well in either a very hard soil or in clay, neither of which are very good water bearing, so that only a meagre yield may be expected from such a well.

5 These costs include international shipping and local transport, but are necessarily subject to change. Please check with your supplier for the latest costs.

Maintenance costs

Maintenance costs for hand-drilling equipment are negligible. Only for the wearing parts of augers and other drilling bits need to be restored by welding new material to it or replacing the knives or teeth (riverside augers, casing shoes). These costs are already included in the depreciation cost of the drilling equipment as mentioned above.

Maintenance of the completed well is in fact maintenance of the handpump. This is dealt with in detail in *Volume 4: Handpumps (page 58)*. Assuming that the well or borehole has been properly constructed, and the handpump well installed, with maintenance locally arranged, maintenance costs are as follows:

Period	Activity	Cost involved
Every month:	- clean up well surroundings - clean gutter/drain - repair fence; keep cattle away	local local local
Each year:	- tighten nuts - repair cracks in platform	local $ 15
Total:		$ 15 + PM