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# Small Water Supplies

Sandy Cairncross
Richard Feachem

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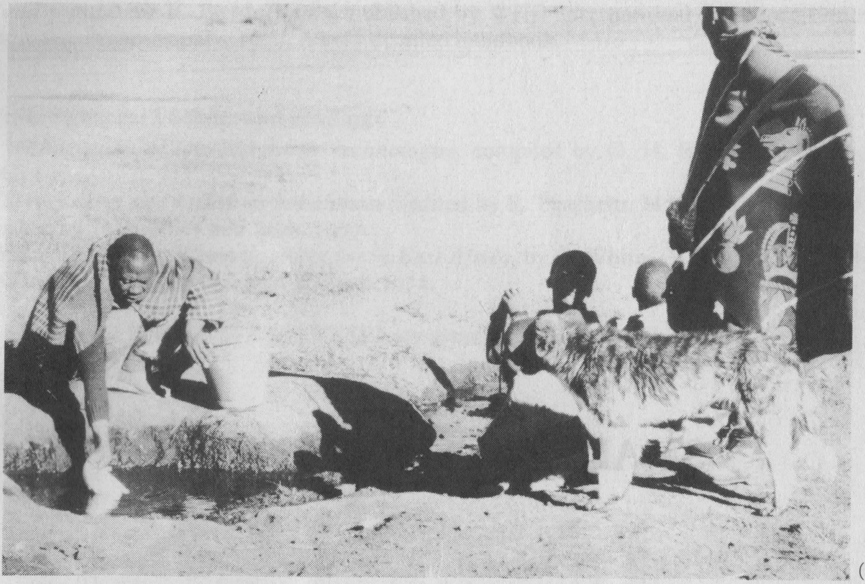
# SMALL WATER SUPPLIES



(a)

(b)

Traditional sources of water. (a) An unprotected spring, exposed to pollution by surface water, animal faeces, and soiled utensils for water collection. This spring could be protected from pollution as described in Section 2.3.
(b) An open well. The ground around this unlined well has collapsed, creating a hollow so that all spilt water drains back into the well. This well requires some form of protection from pollution, such as cover and handpump or a headwall, particularly as it is an area of endemic guinea worm (Section 2.7). (Photos: R. G. Feachem).

# THE ROSS INSTITUTE

## Information and Advisory Service

Bulletin No. 10 January, 1978

# SMALL WATER SUPPLIES

by

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and

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## FOREWORD

Everyone has a water supply, otherwise he or she cannot live. But for the majority of people in tropical and other developing countries that supply is neither as wholesome nor as conveniently available as it could be. So people have to make do with inadequate quantities of poor quality water. But even when funds are limited, some improvements are possible.

Since its foundation over fifty years ago, the Ross Institute has been concerned to help with improving water supplies, initially in plantation industries of south-east Asia. A Bulletin giving advice to estate managers was produced and the results can be seen in many tea plantations. In the last few years a much wider range of readers has grown up. Therefore Dr. Cairncross and Dr. Feachem have extensively re-written the Bulletin. With the recent resurgence of interest in water supplies and in 'intermediate' technologies, this account of small water supplies should be of practical interest to all those who have responsibility for them, from plantation managers to health inspectors and many others.

*David Bradley*
Professor of Tropical Hygiene
Director of the Ross Institute

# PREFACE

In writing a booklet of this size it is inevitable that some material must be omitted, and so it cannot suit every reader. We have pictured our reader as a person having at least secondary school education but not necessarily having any technical training. This booklet is not aimed principally at those engaged on large scale rural water supply programmes, but rather at someone who wishes to build only a few supplies using simple equipment easily available to him; typically a rural health worker. We also include a section on water treatment in the home, for private individuals or institutions who wish to improve their own domestic water supply.

We have tried to describe each technique as fully as possible, but it will often be impractical for someone without some technical experience to construct a water supply using only this booklet. We recommend that, prior to any construction, you should look carefully at any water supplies already built nearby, and preferably consult the agency who built them. The local agency for village water supplies can usually help with technical advice, and may even be able to lend necessary equipment.

We have also tried to emphasize techniques which have been tested in the field. If, however, you come across unforeseen difficulties, we would be glad to hear from you. We may then be able to suggest a solution to your problems, and also to make corrections to future editions of this Bulletin.

Appendix D includes a selection of other publications on small water supplies, which we recommend to anyone engaged on water supply construction in the field.

## ACKNOWLEDGEMENTS

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| Cover | We are grateful to Ms. J. Allen for designing the cover for this Bulletin. |
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# CHAPTER 1 INTRODUCTION

## 1.1 PRELIMINARY DECISIONS

This booklet describes methods for building water supplies to serve small communities ranging in size from an individual household to a village or construction camp of a thousand people. For larger communities you should ask for the advice of an engineer. In any case, it is worthwhile to consult any national or local village water supply agency, if it exists, before you build a supply. Their technical experts can advise you and possibly help you with equipment.

Before building any supply, you must decide who will use it and who will maintain it, and how its construction and maintenance will be paid for. Detailed arrangements should be made, and agreed by everyone concerned, before the building work begins. It is also a good idea to examine any existing supplies, and see if they could be improved more easily than replaced.

You must also decide whether the water will be collected by the users from a public place – well, standpipe, etc. – or piped into the buildings. Compared to the first kind of supply, a tap inside each house is much more likely to improve health in a village, and will lead people to use much more water, but it is likely to cost much more.

## 1.2 DESIGN CAPACITY

When designing a water supply, it is necessary to know how much water it should provide. The amount of water used will vary between countries and it is helpful to measure how much is used from existing supplies nearby. Something like this pattern will emerge:

| | |
|---|---|
| Water carried from a standpipe – | 20 litres[1] per person per day |
| Water from a single tap in the home – | 80 litres per person per day |
| Larger house with bath, W.C., etc. – | 200 litres per person per day |

For example, consider a village of 1,000 people, 200 of whom are to have house connections. If you know that roughly 300 more are likely to have house connections in the next few years, it is worthwhile to allow for this. You should also allow for future growth of the community. A typical allowance for this is to build the supply with 50% extra capacity. A design calculation might then run as follows:

| | *litres/day* |
|---|---|
| Total of 500 people at 80 litres per person | *40,000* |
| Remainder, 500 people at 20 litres per person | *10,000* |
| Total | *50,000* |
| Plus 50% allowance for future growth | *25,000* |
| Design capacity in litres per day | *75,000* |

A figure in litres per day such as this is useful for estimating the storage capacity you will require. In this example, a storage tank holding 75,000 litres would be required to hold one day's supply of water. For calculations involving the rate of flow, a figure in litres per second is more convenient. If water is flowing throughout the day and night, a figure in litres per day can be converted to litres per second by dividing by 86,400. For instance, 75,000 litres per day is about 0·87 litres/second, averaged over a 24 hour day. If water only flows for part of the day, a higher flow rate is necessary to supply the same daily total. For instance, if a pump only runs for 8 hours a day, water will only flow for one third of the time. The capacity of the pump and the pipeline must then be three times the 24 hour average.

Extra allowance should be made if livestock are to drink from the supply (e.g. cattle need about 30 and small stock about 5 litres per day each), or if gardens are to be watered from it. For a hospital or school at least 50 litres are required per day for each person staying there, counting all staff and their families, boarding pupils, inpatients, and an equal number again of inpatients' relatives or dependents. Fifteen litres per day should be allowed for each day pupil, outpatient or outpatient's relative.

These water-use figures are averages, and can be used because the storage reservoir will even out variations in the rate of flow of

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[1] All measurements in this Bulletin use the metric system. Methods for converting these measurements to Imperial units are given in Appendix C.

water. But when estimating the capacity of distribution pipes from the storage tanks to the water points, you must make some allowance for the fact that water is collected mainly at certain times of day. A suitable working rule is to multiply the average daily flow by 4.

So for example, the design capacity for a branch pipeline supplying 200 people at standpipes could be calculated as follows:

200 people at 20 litres per person per day will use a total of

$$20 \times 200 = 4000 \text{ litres/day}$$

Add 50% allowance for growth, giving 6000 litres/ day

Divide by 86,400 to convert to litres/second:

$$\frac{6400}{86400} = 0.07 \text{ litres/second: (average flow)}$$

Multiply by 4 to find peak flow:

$$0.07 \times 4 = 0.28 \text{ litres/second}$$

The design capacity of the pipeline is then *0·28 litres/second.*

A simpler working rule, although less accurate, is to count how many taps are served by the section of pipeline you are considering, and to allow 0·1 litres/second for each public tap.

So, if a branch pipeline serves 4 standpipes, the design capacity would be:

$$4 \times 0{\cdot}1 = 0{\cdot}4 \textit{ litres/second}$$

When the design capacity of a section of pipeline has been calculated, this can be used to derive the diameter of pipe required, as described in Section 6.3.

# CHAPTER 2 SOURCES OF WATER

## 2.1 CHOOSING A SOURCE OF WATER

The first step in designing a water supply is to choose a suitable source of water. In this Section we outline the main types of source, and in the rest of the Chapter we describe in detail how to obtain clean water from them.

The source must be able to supply enough water for the community. If not, another source, or perhaps several sources will be required. The purification of unsafe water under rural conditions can be expensive and requires some trained supervision if it is to be reliable. Sufficient supervision is not usually available, so that *it is much better to use a source that provides naturally pure water,* and then to protect it from pollution. If the existing source used by the community is polluted, it may still be possible to improve it so as to make it suitable for the new supply.

When water falls as rain, it runs either in streams or through the ground, to rivers which take it to the sea. Water in streams and rivers is called surface water, and water flowing underground or emerging at springs is called ground water.

Reasonably pure rain water can be collected from the roofs of buildings if they are clean and made of tiles or sheeting, and not of thatch or lead. However, rain water collection as the only source of water is only suitable for countries with reliable rainfall all the year round or where other sources of water are not available, because individual storage facilities for every household in a community may be expensive.

Ground water is also usually quite pure because it is filtered as it flows through the ground. When ground water is less than 20 metres deep, it usually flows downhill in the same direction as water runs on the ground surface above, and can carry pollution with it some distance. The source of ground water (the well or spring) should therefore be as far away as possible (at least 30 metres) from concentrations of harmful bacteria such as pit latrines and septic tanks, especially on the uphill side of the source. In some kinds of rock, particularly limestone, water flows through cracks and fissures and so is not filtered as it flows. Ground water in these rocks may carry pollution further than 30 metres, and should be tested bacteriologically if it is to be used for a village water supply (Appendix A). Similar precautions are necessary in coarse gravel soils.

In most areas, there is a level underground, below which water saturates the soil, and above which there is only a little moisture. This level is called the 'water table', and ground water can only be extracted from below it. To see what this means, fill a glass with sand and pour a little water into it. You will see the water table through the sides of the glass, which remains level when the glass is tilted. However, in certain types of ground, such as clay or cracked sandstone, the water table may appear to vary from place to place because in some places the ground is relatively impervious and so will not let the water seep through it.

The ideal source of ground water is a spring, where ground water flows out at surface level. The water then needs protection from pollution by harmful bacteria. Some springs dry up at certain times, and it is important to choose springs which have sufficient flow throughout the year. The local inhabitants will know a lot about the springs in their area, and will usually be able to guide you to the best ones. You should check that any spring you wish to use really is a spring, and is not polluted by any water disappearing into the ground or into cracks in rock, further uphill from it.

If no convenient springs are available, the next best alternative is usually to raise water from underground, using a tube well, a dug well, or a borehole. Before you decide to construct any of these, try to find out about ground water in the area. The best places to look are where the water table is near the surface. This is almost always true near to a river, and ground water will also tend to be near the surface in low places generally. In dry areas or seasons, the presence of water near the surface may be indicated by a richer growth of vegetation. You can also discover a lot by looking at the level of water in open wells, or by talking to people who have built them. Finally, it is useful to find out about the local soil conditions. A layer of rock, for instance, may make well-digging impossible. The best soils from which to extract water are gravel and sand.

If you have decided that a ground water supply is appropriate, there are five main methods which you can employ to extract it. In rough order of preference these are:

driven tube well,
bored tube well,
jetted tube well,
hand-dug well,
borehole.

These methods are schematically illustrated in Figure 1. Each technique has various advantages and disadvantages and these are briefly discussed below.

The easiest type of well to install, if the ground conditions make it possible, is a *driven tube well,* which is made by hammering a special pipe into the ground. However, it is small, and it cannot normally be sunk more than 10-15 metres, or into heavy clay soil or rock. It also needs a special filter at the tip called a 'well point', which would usually have to be imported. Its advantage is that it can be pulled out and re-used if only a temporary water supply is required.

Another simple type of tube well, which can be constructed cheaply with local materials is a *bored well,* which uses a hole bored by hand. These can be put down to a depth of about 25 metres in a couple of days. If you cannot find enough water within this depth, then you should consider 'jetting' a tube well, or digging a well by hand.

*Jetting* can be used to sink wells up to 80 metres deep. It involves pumping water down a hole. The water overflows from the hole carrying soil from the bottom and loosening the ground, so that a pipe can be pushed down into the hole. Jetting requires plenty of water, some steel pipe, and usually a pump and various special fittings. A bored well, on the other hand, might only require an auger.

It may be possible to dig a well by hand if a tube well is not satisfactory. This may be the case where water is present in the ground but only seeps into tube wells very slowly. A *hand-dug well* is bigger than a tube well, so that water can seep in more quickly. Also, a dug well has a large storage capacity, so that a lot of water can be taken out in the day without it running dry, and it will then have time to fill up again at night. However, digging a well by hand can take a great deal of effort – about five man-days per metre of depth. It can also be dangerous for inexperienced workers. You should only sink a dug well if you cannot use one of the other methods, and where you have good reason to expect water within 60 metres. Of course, you may know that hand-dug wells are suitable, either from seeing others nearby, or from specialist advice. Or you may wish to improve an old well to make it suitable for a safe water supply.

The most expensive type of well is usually a *borehole.* Boreholes can only be drilled by large drilling rigs, which are very expensive. In some countries it is possible to hire one from a private contractor or from the government. Boreholes can be drilled to over 100 metres deep, but even then they do not necessarily find water. If the water in a borehole is over 60 metres deep, it is difficult or impossible to pump it by hand. If you hire a private contractor to drill a borehole for you remember you may have to pay him even if he finds no water. As with a dug well, it is important to choose carefully beforehand exactly where a borehole is to be drilled.

Detailed technical information on driven, bored, jetted, dug and drilled wells is available in other manuals (VITA, 1970; Watt and Wood, 1977; USAID, 1969).[1] In this Bulletin we describe only the simplest techniques which do not require much special equipment.

In some places the ground water may be too deep, or may contain salts which make it undrinkable, although iron and manganese salts can be removed (Section 4.5). In other cases, the ground may be too hard to sink wells, or too impermeable for enough water to collect in them. Alternatively, you may not be able to afford the cost of sinking the kind of well you need. It may then be necessary to use

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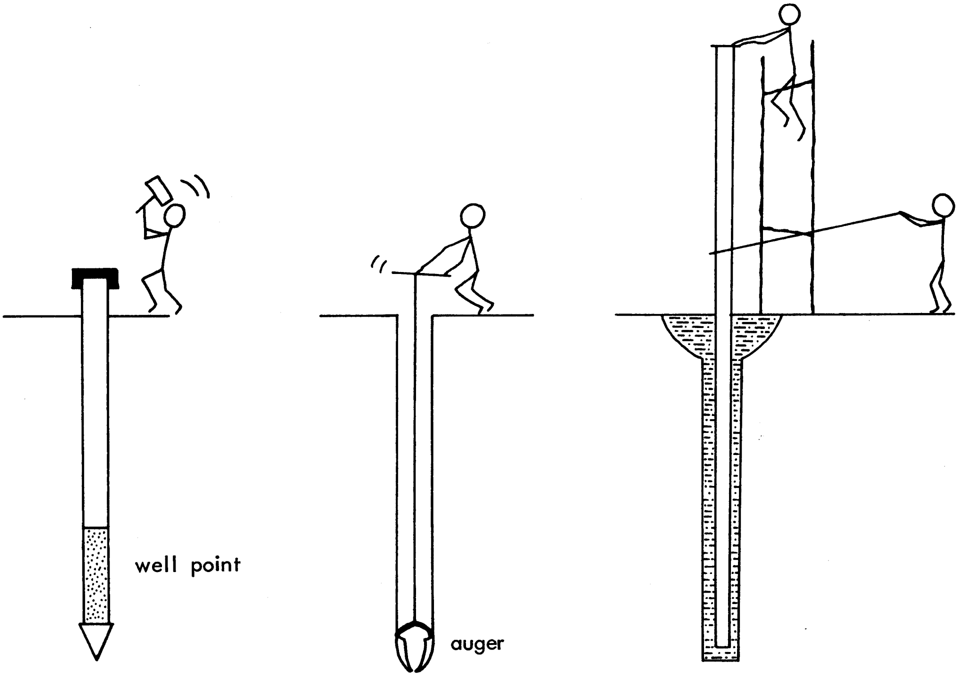
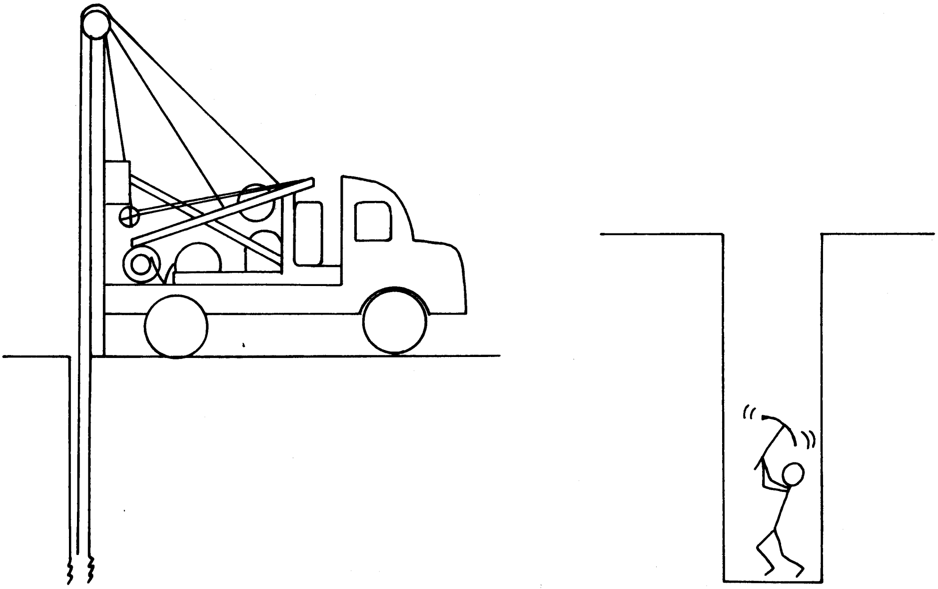
[1] References are listed in Appendix D.



Driven tube well

Bored tube well

Jetted tube well



Borehole

Hand dug well

*Fig. 1.* Schematic illustration of five basic methods of groundwater extraction.

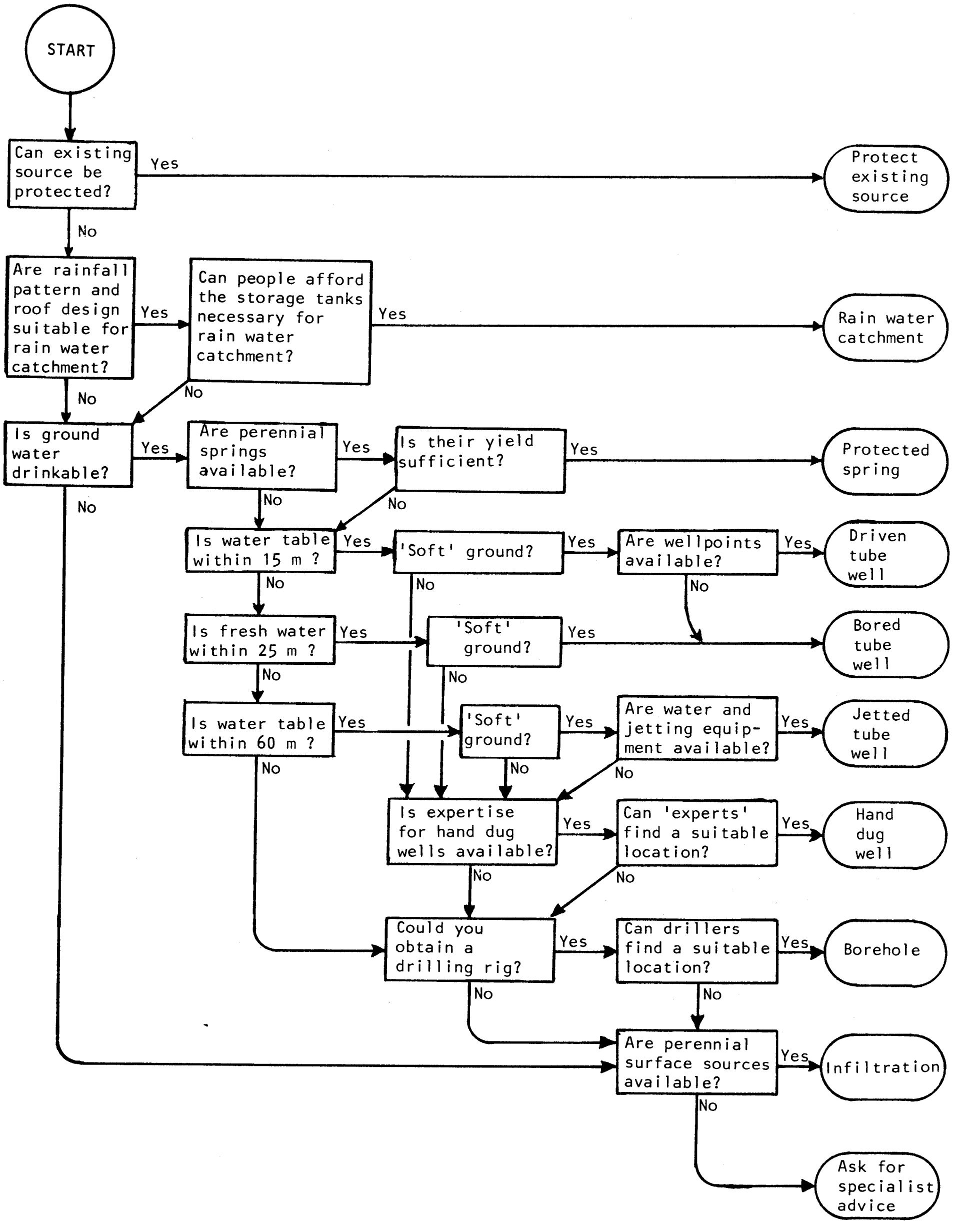


*Fig.* 2. Choosing a source of water. Follow the arrow corresponding to your answer to the question in each box.

surface water from streams, rivers or dams. Except in very sparsely populated areas, these sources are liable to serious pollution, and purification of some kind will normally be required before they are safe for human consumption.

The process of choosing a source of water can be very complicated as it depends on many aspects of the local conditions. If you are in doubt, it is advisable to ask for guidance from someone experienced in this work. Figure 2 illustrates the process by a flow diagram. It illustrates the correct approach to the problem, but should not be followed blindly.

When you have decided which source to use, you should check that it can provide enough water for the community to be served (that is, check its 'yield') and preferably test its quality. Techniques for doing this are described in Appendices A and B.

## 2.2 RAIN WATER

Rain water can be collected from roofs made of tiles, slates or sheeting (galvanised iron, aluminium or asbestos) but not of thatch or lead. Bituminous surfaces such as roofing felt are likely to make the water unpleasant to taste, rather than dangerous to drink. The guttering should slope evenly towards the downpipe, because if pools form where it sags, they can form breeding places for mosquitoes. Dust, dead leaves and bird droppings may fall on the roof during dry periods, and be washed down by the first rain. A wire mesh should be placed over the top of the downpipe to prevent it from becoming clogged with this material. It may also be helpful to arrange the pipework so that it can be detached from the water storage container and the first water from each shower allowed to run to waste. The roof and gutters should be cleaned regularly. It may be convenient to keep the water for domestic use in a storage tank beside the house, and run the overflow to an underground tank for other purposes such as washing or irrigation. Rain water will corrode steel storage tanks unless they are well galvanised. Storage tanks are discussed in Section 5.3.

You can estimate how much rain water can be collected, from the area of the roof in plan and the yearly rainfall, as follows: one millimetre (mm) of rainfall on one square metre of roof will give 0·8 litres of water, after allowing for evaporation. So, if the building measures 5 m × 8 m, and the average annual rainfall is 750 mm, the amount of rain water which can be collected in a year is equal to:

$$5 \times 8 \times 750 \times 0{\cdot}8 = 24{,}000 \text{ litres per year}$$

$$\text{or } \frac{24{,}000}{365} = 66 \text{ litres per day on average.}$$

This can be compared with the expected requirements of the people who will use the water. The roof catchment should be able to provide on average 50% more than they will use, to allow for relatively dry years. You can also estimate how much storage is required, by working out how much they will use in the longest time which may pass without a reasonable amount of rain falling. Storage for an individual household should not, in general, be less than 500 litres and in most areas a good deal more will be required.

## 2.3 SPRINGS

Spring water usually flows from a 'water bearing layer' of sand or gravel, and comes to the surface because a layer of material such as clay or rock (an 'impervious layer') prevents it from flowing downwards. The best places to look for springs are the slopes of hillsides and river valleys. Green vegetation at a certain point in a dry area may also indicate a spring, or you may find one by following a stream up to its source. The local inhabitants, though, are the best guides, as they usually know most springs in their area.

Be sure that spring water is really seeping from the ground, and is not a stream that has gone underground for a short distance. Real spring water is usually pure, but it can become polluted if it stands in an open pool, or flows over the ground. The spring should therefore be protected with brick, masonry or concrete, so that the water flows directly into a pipe without ever being open to pollution from outside.

To protect a spring, you should dig back into the hillside to the water-bearing layer, where the water is flowing from the 'eye' of the spring, and build a collecting tank or 'spring box' around the eye, as shown in Figure 3. Be careful not to dig too far into the impervious layer, as that may let the water seep downwards so that the spring disappears or moves down the hill.

Before you build the back of the spring box, you should pile loose stones against the eye of the spring. This is partly to make a foundation for the box, and also to prevent the spring water washing soil away from the eye. Remember that the spring may sometimes flow much faster after rain than it is flowing while you work, so everything should be firmly in place. This may require quite big stones, perhaps with smaller stones, gravel and even sand laid behind them to plug the spaces between them

The outlet pipe should be at least 100 mm above the bottom of the spring box, but below the eye of the spring if possible. If the water level in the spring box is too high, silt may settle over the eye and block it up. The end of the outlet pipe inside the box should be covered with a screen, to prevent stones, rubbish and frogs from blocking the pipes. One way to make a screen is with a length of black plastic (polythene) pipe, tied off or plugged at one end, with small holes in it. There should also be an overflow pipe which is big enough to carry the maximum flow of the spring in the wet season. This pipe also should be below the eye of the spring if possible. The end of the overflow pipe inside the spring box should be covered with a screen fine enough to keep out the mosquitoes, but strong enough to hold back frogs, etc., which may block the pipes.

The top of the spring box should be at least 300 mm above the ground, to prevent surface water running into it. The box should be covered with a concrete slab, but it should preferably have an access hole so that it is possible to get inside and clean it. The hole should have a raised edge to prevent surface water running into the box. The cover should be lockable, or so heavy that it can only be opened with a lever or a manhole key, to stop anyone from interfering with it. A third pipe for cleaning out silt from the bottom of the spring box is also useful. This pipe should have a cap fixed on the end firmly enough to stop children removing it.

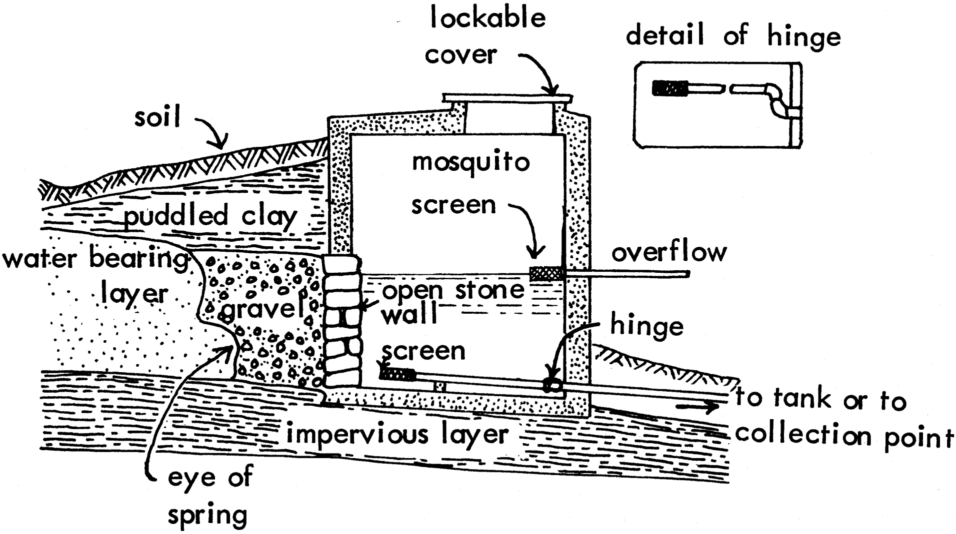


*Fig. 3.* A spring box; the inset detail shows a hingemode with two pipe bends, enabling the screen to be lifted above the water for cleaning.

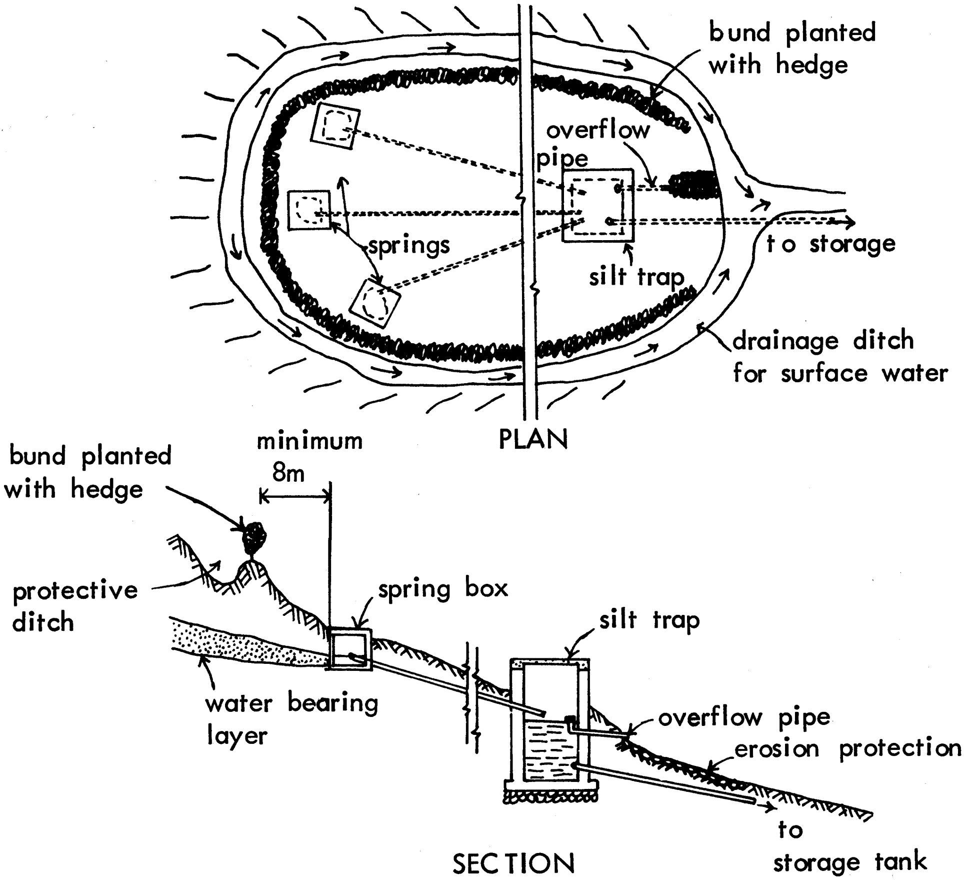


*Fig. 4.* Three protected springs connected to a silt trap.

If it is not possible to dig deep enough for the bottom of the spring box to be at least 100 mm below the outlet pipe, then you could use an outlet pipe at least 50 mm in diameter, and lead the water to another box not more than 50 metres away, which is called a 'silt trap' (Figure 4). This box also needs a manhole cover, a mosquito-proof overflow, an outlet pipe at least 100 mm above its bottom, and a strainer on the outlet pipe. If the spring has a yield of less than 5 litres per minute,[1] the spring box may be quite small, but it should at least have an access hole and an overflow pipe. Water from several small springs may be collected in one silt trap, as shown in Figure 4. One point to watch when piping water by gravity from several springs is the danger of the pressure from one spring stopping up another. The pipelines from separate springs should only come together as separate inlets above the water level, to a reservoir or silt trap.

When the spring box is complete, the space behind it should be filled with soil. At the bottom, level with the eye, this space should be filled with gravel or sand at least as coarse as the water bearing layer. Further up it should be made watertight, to prevent surface water running down the outside wall and into the box. This can be done with cement, or with puddled clay. To make puddle clay, mix

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[1] The measurement of yield is described in Appendix B.

up some clay very well with just enough water for the mixture to wet your hands. Then put in a layer of the clay not more than 150 mm thick, and tramp about in it for ten minutes with your feet; put in the next layer, walk about in it, and so on.

New spring boxes and silt traps should be sterilised by scrubbing on the inside with bleach solution, as described for hand-dug wells in Section 2.10.

Lastly, you should dig a ditch at least 8 metres uphill and around on each side of the spring box to take surface water away from it and prevent pollution of the spring water. The soil from the ditch should be piled on the downhill side to make a ridge, or 'bund', which will also help to keep away surface water. If you put a fence or prickly hedge on top of the bund, this will help to keep people and animals away.

Spring boxes and silt traps will gradually become filled with silt. They should be cleaned out once a year.

For springs with very large flows – over about 10 litres/second – a spring box would be difficult to build and might be eventually washed away by the flow. In these cases, an infiltration gallery (Section 2.12) may be built into the side of the hillside, running across the slope.

## 2.4 DRIVEN WELLS

A driven well is made by pushing a pointed strainer called a 'well point' into the ground. A well point is a specially made metal tube with a point at the lower end, and holes or slits in the sides through which water can filter. These holes are made in special ways, to prevent them becoming clogged with soil. Homemade well points are not recommended. Brass well points do not usually last more than a year or two. Steel ones are best, but nevertheless have a limited lifetime.

As a well point is driven further into the ground, lengths of steel pipe are fixed to the top. Sometimes a well point can be pushed into the ground by twisting it, or by pumping water down the pipe ('jetting'). More usually, it is driven by hitting the top of the pipe with a heavy weight. To make sure that the pipe joints stay tight, the pipe should be twisted after each blow of the hammer. The top end of the pipe should be protected from damage while driving. This can be done with a steel end cap or a wooden block.

It may be better to line the hole first with a 'casing', a piece of pipe larger than the well point. This can be jetted into the ground or driven into a bored hole (see below). The well point is then lowered into this pipe and driven the last metre or so into the water bearing layer (see Figure 5). To install a driven well, you will first need to buy a well point, and you should ask the supplier of the well point for detailed advice on how to install it, and what equipment is required. Some suppliers of suitable equipment are listed in Appendix D.

Most well points are only 30 to 50 mm diameter, but most pumps have a mechanism known as the 'cylinder' which is inserted down the well, and is usually at least 50 mm diameter. You should therefore check when you buy one that it will make a hole big enough for you to insert a pump cylinder. The pump cylinder should not be more than 5 metres above the well point. Some pumps have the cylinder at the top of the well ('suction pumps') and they are only suitable for wells less than 8 metres deep.

## 2.5 BORED TUBE WELLS

Tube wells can be bored by hand using tools like those shown in Figure 6. You will normally need several boring tools, and connecting rods to make the handle longer as the hole gets deeper. The rods can be made from ordinary 25 mm diameter steel pipe. If you have your own boring tools made, you should aim to bore a hole 200 mm in diameter.

The first section of the hole can normally be bored with a hand auger. As it is pushed down and turned into the hole, the soil collects between the two flaps, and can be lifted to the surface because the flaps bend inwards to hold the soil as the auger is lifted. If the soil is hard or stony, a heavy iron tool on the end of the connecting rods can be used to break up the rock or soil. Then the auger can be used to remove the broken soil and rock. The auger should be brought up to the

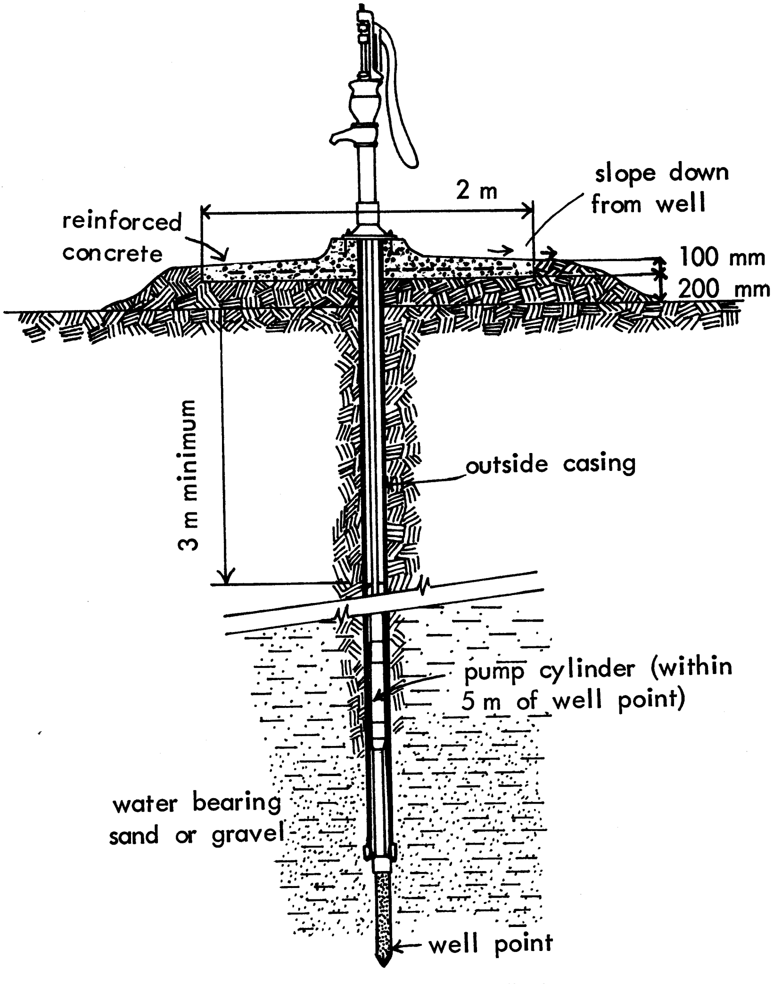
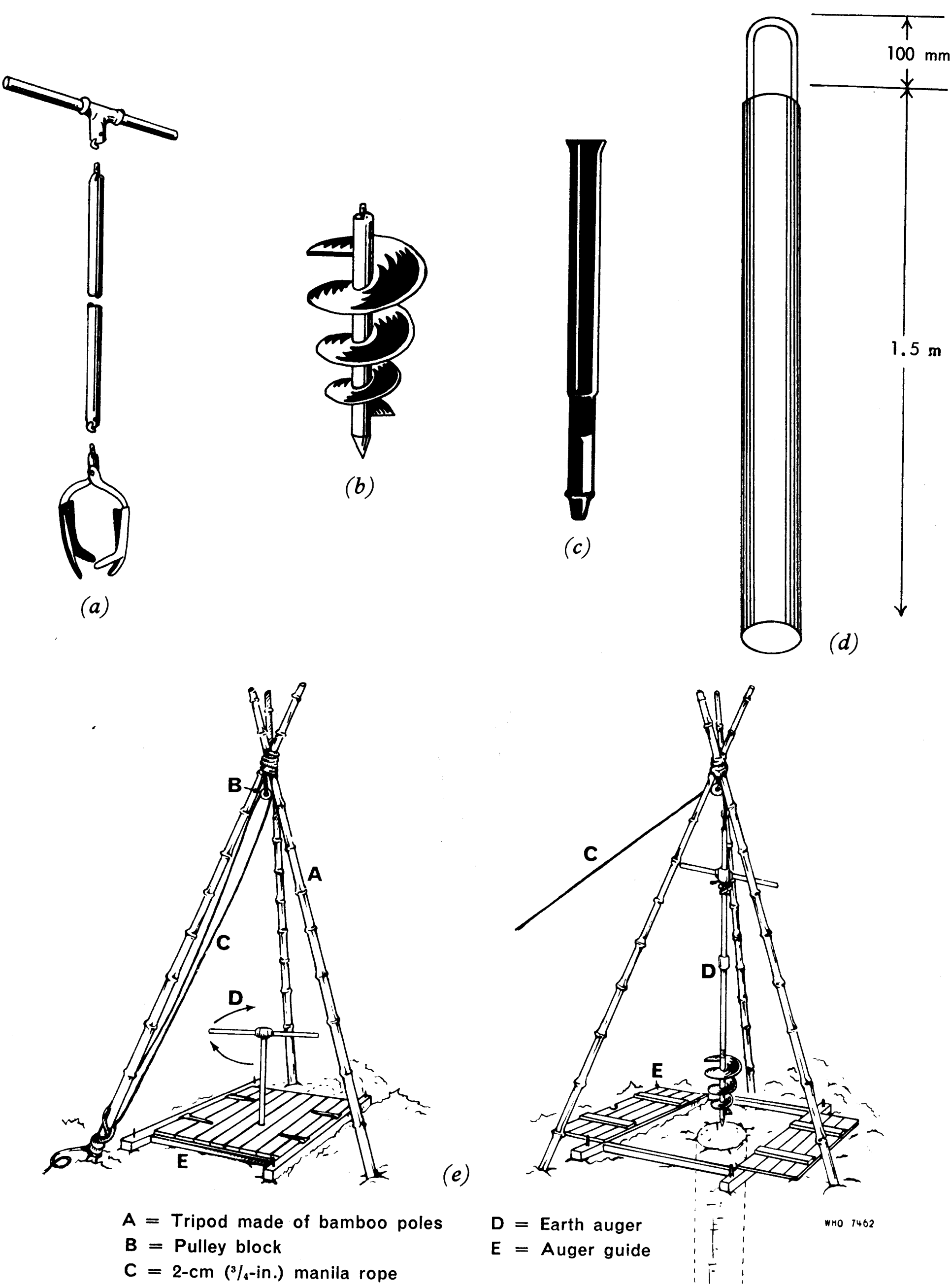


*Fig. 5.* A tube well with a driven well point.

surface and emptied frequently, to prevent it from becoming stuck at the bottom of the hole.

When you reach water, the soil will probably be too loose to come up in the auger. Loose soil can be excavated either with a spiral or fan auger, or when you have reached below the water table, with a bailer.

These tools are all shown in Figure 6. The bailer is a tube about half the diameter of the hole. If it is to be used for very loose soil such as sand, it should have a flap at the bottom which is hinged to open upwards but not downwards. It can be fixed to connecting rods or lowered on a strong rope or steel wire, and works best if it is fitted with a piston which can slide up and down inside it, and is also held on a rope. The piston is pulled up with a jerk to suck mixed soil and water into the bailer. When the piston is lowered for the next jerk the flap closes, holding the soil inside. This is repeated until the bailer is full. It is best if the bailer can be pushed down into the ground while this is being done, to help force



A = Tripod made of bamboo poles
B = Pulley block
C = 2-cm (³/₄-in.) manila rope
D = Earth auger
E = Auger guide

*Fig. 6.* Equipment for boring tube wells: *(a)* hand auger; *(b)* spiral auger; *(c)* rock chisel; *(d)* bailer; *(e)* frame for positioning auger.

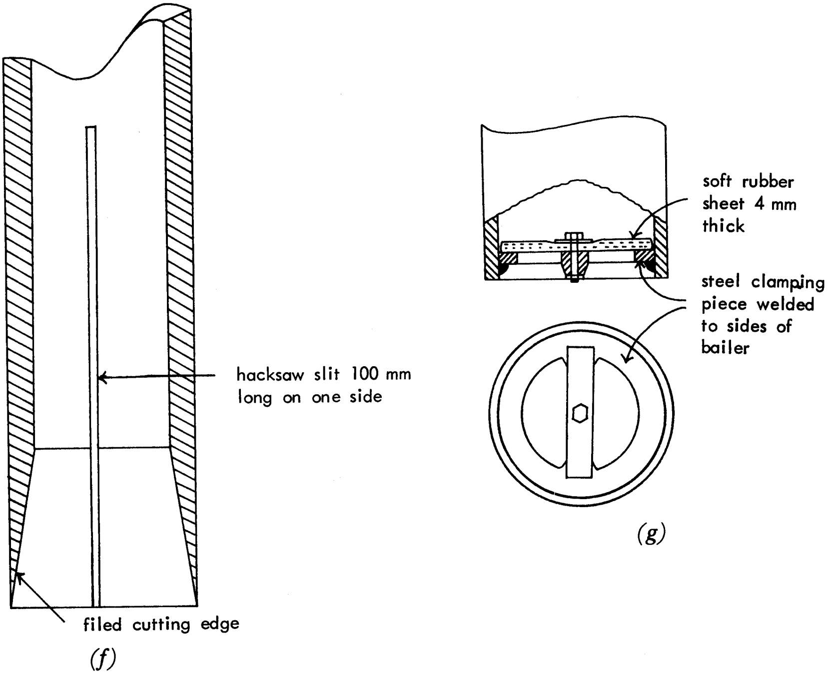


*Fig. 6. cont. (f)* and *(g)* alternative designs for bottom of bailer – *(f)* for firm soil, *(g)* for very loose soil.

soil into it. Then, when the bailer is full, it can be brought up to the surface and emptied. Full details of how to make your own auger and bailer are given in the Village Technology Handbook (See Appendix D).

In many soils, especially below the water table, the sides of the hole tend to fall in. You therefore need a 'casing' to hold them up while you bore. This is basically a strong pipe, normally made of steel or plastic (PVC), and the same diameter as the hole. Each length should be as long as possible, preferably not less than 7 metres. It should be held by at least two strong steel cables so that it can be pulled out when the well is complete. The casing is pushed down as the hole is bored deeper, usually with the connecting rods of the auger. If you need more than one length of casing, the second length should fit inside the first, and so on. So if the first piece is 200 mm in diameter, the second might be 150 mm and the third 125 mm. Remember that the auger you use must not be too large to come up inside the casing, and this means that several different auger sizes are required if more than one piece of casing is used.

Bore the hole at least 7 metres below the water table. Check the yield by measuring how much the water level in the well drops if you pump water from the hole as fast as you can for an hour or two, using the pump you intend to use, or one like it. After a while you should reach a point where the water level stays constant. You should certainly not be able to pump the hole dry with a hand pump. If the level drops a long way, it may help to bore a little deeper. More details of how to test the yield of a well and how to increase it are given in Section 2.9.

When you have drilled the hole, the next task is to make the tube which will go down it. This should be about 75 mm to 100 mm diameter, and certainly big enough for the pump mechanism which you will be using. This tube is *not* the same as the casing, which will be pulled out and can be used again. The tube will be inserted inside the casing, and the casing slowly pulled out while gravel or stones are poured into the gap between the tube and the sides of the well. The tube must be strong, straight, and have slots in it for the water to soak in. It can be made from various materials.

The tube can be bought as a ready-made metal 'well screen' from drilling equipment manufacturers, but it is expensive and has the same limited lifetime as a well point.

The tube can also be made of bamboo or areca nut tree trunk. The inside is cleaned out to make a pipe (See Section 6.2), and vertical slits cut in the side, about 100 mm long and 3 mm wide, spaced evenly around the pipe. To cut slits along the tube, a circular saw is needed. If you have no circular saw, you can cut the bamboo into strips about 10 mm wide, and then tie them together again to make a continuous pipe 100 mm in diameter. You should fix iron rings inside to act as ribs, and wind string or coir (coconut fibre) cord round and round all along the pipe, to cover it completely like string round the handle of a cricket bat. These types of tube will normally last very well below the water level, but above the water table they can be expected to rot away in 5 years or less. Plastic or steel pipe would then be necessary for the upper section of the tube, but no slits are needed in that section.

Alternatively, a clay tube can be made from sections of pipe specially made by the village potter. They should be about 100 mm in diameter and 450 mm long, with a socket and joint arrangement for each pipe to fit into the one above it (Figure 7). The best thickness for the pipe depends on the strength of the clay, but should be about 15 mm. The inside surface should be straight and smooth, and each length should have slits along it, about 100 mm long and 3 mm wide, spaced evenly around the pipe as shown in Figure 7. These slits can be cut with a knife while the clay is wet. If possible, they should be narrower at the outside of the pipe than at the inside. The clay pipes are then dried in the sun, and fired to make them as strong as possible.

When the hole is ready, the pipes are lowered into it from a tripod above the hole. The bottom of the first pipe is closed with a piece of hard wood, and the pipe hung from the tripod vertically over the hole by three wires or ropes (such as coir cord) running down the outside. These ropes or wires will be left in the well, so they should be cheap; but each should be strong enough to carry a man's weight. The second pipe is then placed on the first and lowered, the third placed on top and lowered and so on until the first pipe has settled firmly on the bottom of the hole. The last six pipes should be plain, without

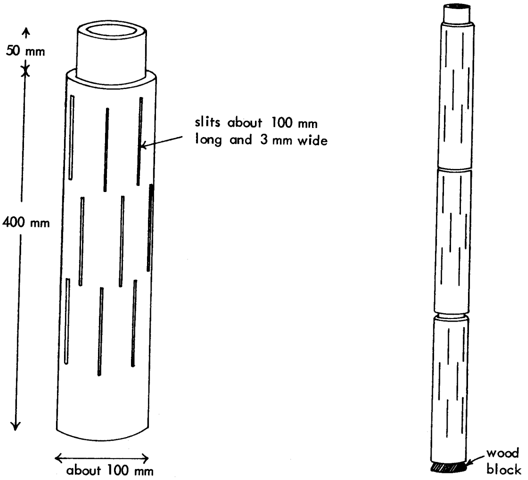


*Fig. 7.* Clay pipes for use in tube wells.

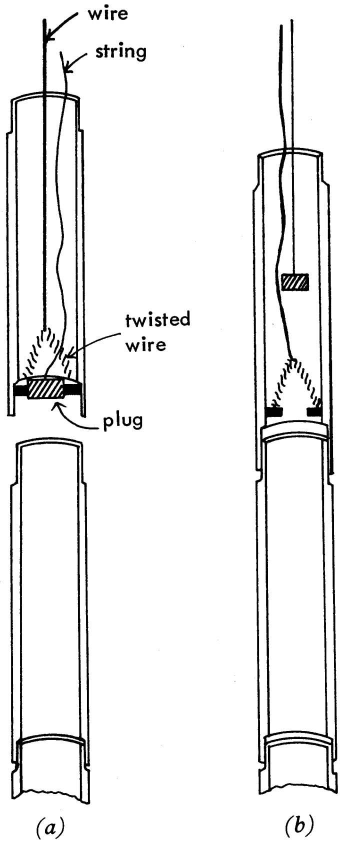


*Fig. 8.* A method for lowering clay pipes into a tube well: (a) lower pipe; (b) release plug by pulling string and withdraw carefully.

slits, to prevent seepage of unhygienic water from the surface. An alternative method, for lowering the pipes one by one, is shown in Figure 8. Each pipe is lowered on a wire, supported by two blocks held apart by a plug. The plug is removed by pulling a string, releasing the blocks. Check that you can work it without dropping the pipes, before you lower them into the hole.

Another kind of tube is a plastic (PVC) pipe, about 70 mm in diameter. If possible, the joints should be the threaded kind which screw together. The section of pipe that will be under water is cut with a hacksaw to make slits about 20 mm long and 20 mm apart, at an angle to the line of the pipe as shown in Figure 9. The lower end of the pipe is plugged either with a wood or a PVC cap and inserted into the hole.

Finally, coarse gravel is required to fill the gap between the excavated hole and the tube. It is best to use rounded gravel between about 3 mm and 10 mm in size, and the gravel should be well graded to ensure that the largest stones are not more than twice the size of the smallest. It should be washed before use to remove sand and silt. You will need about 0·3 cubic metres (6 wheelbarrows) of this material. If rounded gravel is not available then you can use well-baked clay, broken into pieces of the same size. Before you do this, though, you should test the clay by leaving it in a bucket of water for a few weeks. The clay should still be strong and hard after this time. If it has softened at all, use finer clay or bake it at a higher temperature. Unbaked clay is no use at all. The top 3 metres should be filled with moist clay to prevent pollution, as for a spring box (Section 2.3).

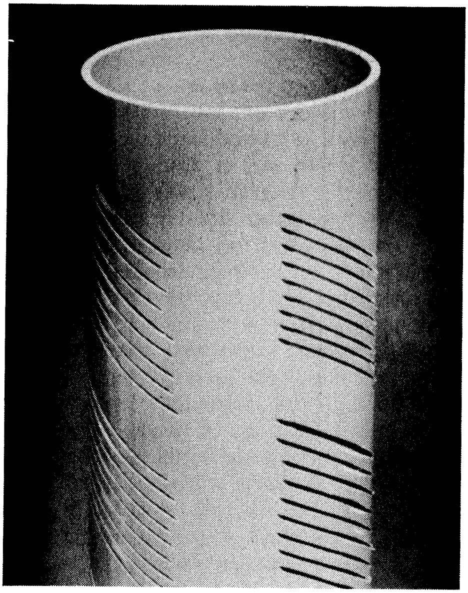


*Fig. 9.* Slotted plastic pipe. the slots can be cut with a hacksaw.

Be careful to keep the tube straight while you pour in the gravel and clay. If it is bent or pushed to one side it will be impossible to insert the pump mechanism. It is not enough to insert the pump cylinder before you place the gravel, because you will also want to remove it at times, to service or repair it. A steel pipe which just fits inside the tube may be the best way to keep it straight; it can then be removed when the gravel is in place.

An alternative method, particularly if it is necessary to insert a pump, is to make the lowest casing section of slotted plastic pipe (Figure 9) and leave the casing in place. No gravel is then required, but the bottom of this section should be plugged with a piece of wood.

## 2.6 JETTED TUBE WELLS

The simplest method of jetting is known as the 'sludger' method, and needs no pump. It is only useful in fine loose soils, such as sands and silts, and is difficult when the water level is more than ten metres deep. It is most appropriate for delta areas where the soil is suitable and ground water is near the surface.

First, a hole about a metre deep is dug by hand and filled with water. Then a piece of steel pipe, about 50 mm diameter and 4 m long, is inserted vertically into the hole. A pipe coupling, sharpened at the edge with a file, should be fixed to the bottom to help the pipe cut its way into the soil. A scaffolding of wood or bamboo is built beside the hole, and a lever fixed to it, with one end tied to the pipe by a chain (Figure 10), so that by operating the lever the pipe can be lifted up and down in the hole. The man shown sitting on the scaffolding uses his hand as a valve. As the pipe rises he holds his hand firmly over

*Fig. 10.* The palm-and-sludge method.

the end, but lets go each time the pipe is allowed to fall. Repeating this up-and-down process pumps water up the pipe, bringing some of the soil with it. The pipe will slowly sink into the ground. As it sinks, further lengths of steel or threaded PVC pipe should be added at the top.

Meanwhile, the hole should be kept full of water. If the soil is very permeable and the water table is deep, it may be difficult to keep the hole full. Adding a little cow dung to the water (about one part in twenty) will help to seal the soil and slow down the rate at which the water seeps in. The dung need not be dangerous to health as long as the well is to be properly disinfected on completion (Section 2.10). Dung should only be used for the top 5 to 10 metres, otherwise it will slow down the rate at which water seeps *into* the well when it is completed. Then surging would be required (Section 2.9).

A casing is not usually necessary with this method, except for the top 7 m. The casing diameter may be about 20 mm larger than the pipe used for jetting. When the hole is complete, the pipe is pulled out, carefully keeping the hole full of water, and a slotted tube inserted as for a bored tube well. This method needs skill and careful timing from the man using his hand, which can be learned with practice. It also needs tough hands. For larger pipes, a wood or rubber flap may be used instead of a hand.

The other jetting methods all require special equipment. Water is pumped down the pipe, and this and a twisting action on the pipe helps it to sink. This requires a pump, and a special swivel connection so that the pipe can be twisted without disconnecting it from the pump. The pipe is hung from a tripod by a pulley to keep it vertical. Usually, a special fitting is attached to the bottom of the jetting pipe. Appendix D contains details of some manufacturers of jetting equipment, who can give you detailed advice on jetting methods.

## 2.7 HAND-DUG WELLS

*Digging a well by hand can be a dangerous business for the workmen.* It is advisable to have an experienced supervisor in charge of the work, particularly for wells over 5 or 10 metres deep. If there is no previous experience of hand-dug wells in the area, you should seriously consider using a spring or a tube well instead. If you still want to go ahead, you are advised to read a good manual, such as the ITDG Wells Manual (See Appendix D) before you start work. The process is too complicated to describe adequately in this Bulletin.

It is often more appropriate to improve an existing polluted well than to dig a new one. An existing well may be polluted by any of the following means.

(i) *Surface water.* This may be washed straight down the hole if the ground surface around the well has sunk. It can be prevented by building a headwall (Figure 11) which will also help to prevent animals and people falling down the well.

(ii) *Spilt water.* If there is no headwall, or if people stand on the headwall to draw from the well, water which has splashed against their feet may fall back into the well and spread guinea worm and other diseases.

(iii) *Seepage water from the surface* through the top few metres of the well lining. The well lining should be waterproof for the top 3 metres in clay soils, and preferably for the top 6 metres in sand or gravel.

(iv) *The vessel used for drawing water.* However often these may be rinsed out, they can cause some pollution of the well. It is preferable, if possible, to use a pump of some kind, so that the well water is protected from pollution until it flows into the user's own bucket.

(v) *Polluted ground water.* This can result from the location of the well too close to pit latrines, soakaways or refuse dumps. A well should be at least 30 metres from any such source of pollution (See Section 2.1).

(vi) *Rubbish thrown down the well.* The chance of this may be reduced by preventing children from playing near the well, but the only certain way to prevent it is to fit a permanent cover over it and install a pump.

*Fig. 11a. Wrong.* This headwall is too low and too wide, and encourages people to stand on it. (From Watt and Wood).

*Fig. 11b. Right.* A headwall and rollers are provided, to prevent guinea worm transmission.

If you want to improve a polluted well, you should check the following aspects:

(i) *Location.* Look for nearby buildings and possible sources of pollution, especially on the uphill side of the well. Check that surface water will drain away from the well head.

(ii) *Yield.* Make sure that the well will in fact provide enough water. Find out how often it has run dry in the past. It may be necessary to deepen the well before you improve it, as it will be more difficult later. In any case, there may be rubbish in the bottom which should be cleaned out. It is easiest to clean out or deepen a well in the dry season, when the water level is lowest. If the yield is still unsatisfactory, it may be possible to improve it by sinking a tube well from the bottom.

(iii) *Lining.* Check that the lining is in good condition, and that water is not seeping in near the surface. It may be necessary to build a new lining, or to improve the old one. The best materials for rebuilding or improving a lining are brickwork and reinforced concrete. The use of these for lining wells is described by Watt and Wood (1977). The simplest method to make the upper section watertight is to dig out the soil around the lining and fill it in with puddled clay (Figure 12), placed in 150 mm layers as described in Section 2.3. If possible, a layer of concrete 150 mm thick and reinforced with wire mesh ('chicken wire') can be placed between the old lining and the clay.

(iv) *Well head.* The simplest, but the most important single improvement to an existing well is the construction of a well head consisting of a headwall and drainage apron. This single measure can completely prevent guinea worm transmission at a well and considerably

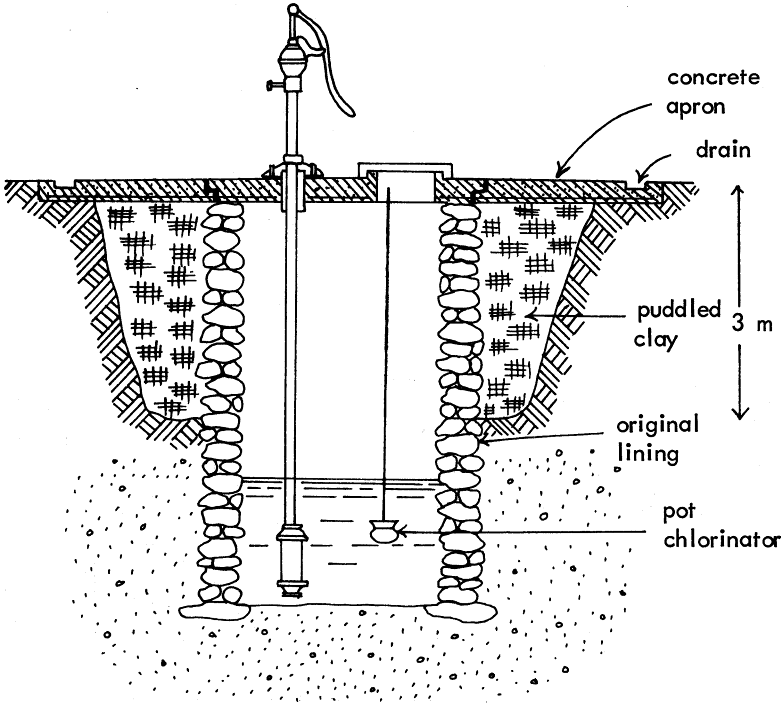


*Fig. 12.* Improving an existing well. (After Wagner and Lanoix).

reduce other health risks. It can only be done on its own in good solid ground where there is no danger of the shaft collapsing; if the ground is at all unstable you will have to build a lining first.

The drainage apron should slope down away from the well, so that spilt water will drain away to a soakaway (Section 7.2). Before constructing the apron, it is worthwhile to build up the area around the well with clay or rubble. Reinforced concrete is usually the best material for the headwall and apron, but brickwork, masonry or even cement mortar may be used.

The headwall can be fitted with rollers, a pulley or a windlass to help people pull up the bucket without leaning over the well (Figure 11). Even better protection from pollution can be gained by covering the well with a concrete slab and fitting a hand pump, like the well in Figure 12. The slab should not be made until you are ready to install the pump, and a pump should not be installed unless arrangements have been made to maintain it in the future.

You can cast the concrete cover slab on the ground beside the well, and lift it over when it has set. The slab should be at least 150 mm thick and should contain 8 mm thick steel reinforcing rods at 150 mm spacing, running both ways at right angles (Figure 13). They should be tied together with wire where they cross one another, and supported 50 mm above the ground on small stones or blocks of cement mortar. The rods must be completely surrounded in concrete, or they will rust. Extra reinforcing rods should be placed diagonally around the access hole. If the well is more than $1\frac{1}{2}$ metres in diameter, you should ask an engineer to check that the slab will be strong enough. It should have an access hole with a raised edge and a heavy cover, as for the top of a spring box (Section 2.3). Before you cast the cover slab, work out how you will move it into position, because it will weigh about a ton and may require twenty men to lift it. If you cast in six extra lifting bars as shown in Figure 13 (bolts or loops may be more convenient) you can connect them with four rope slings and lift it with two parallel pieces of steel pipe, each passing through two slings. You should also plan how to cast the pump fixing bolts into the concrete and arrange for a watertight seal between the concrete and the pipe coming up from below. This seal should be above the level of the surrounding apron.

Another way of protecting a well is to turn it into a tube well by filling the bottom part with gravel and the top with clay or other soil (Figure 14), leaving a tube in the middle for a hand pump. However, it is then almost impossible to remedy the situation if the tube becomes blocked up with silt.

Dust and dead animals can accumulate remarkably quickly in the bottom of an open

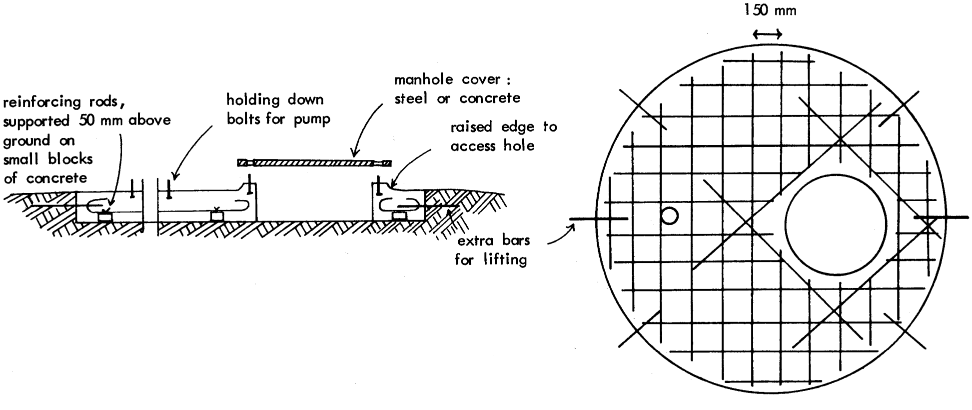


*Fig. 13.* Casting a reinforced concrete well cover. Slab thickness should be 150 mm. (After Watt and Wood).

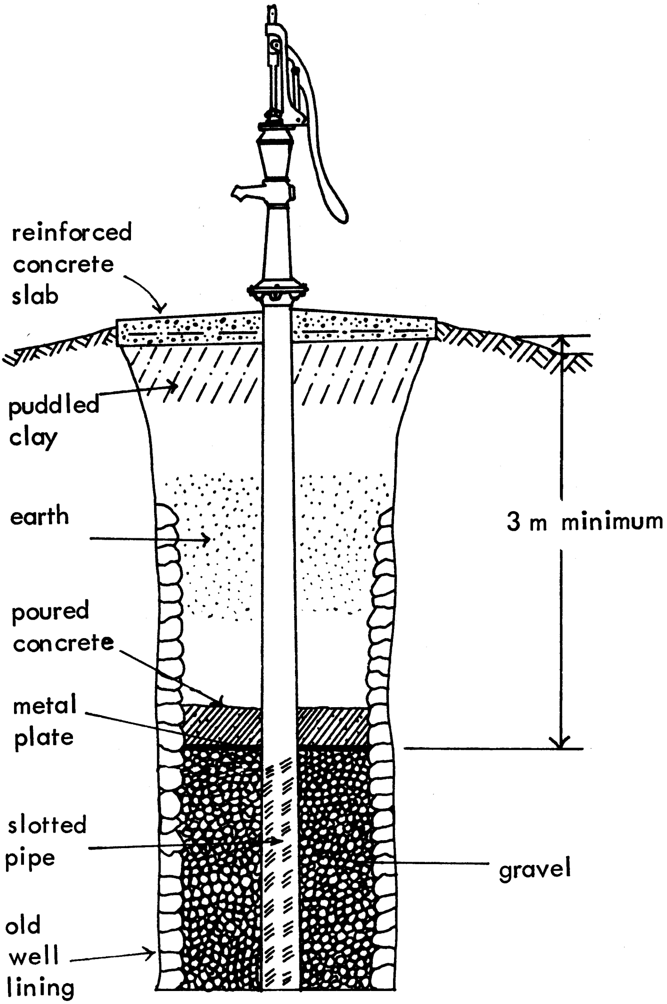


*Fig. 14.* A hand-dug well converted into a tube well. (After Wagner and Lanoix).

well. Apart from polluting the water, the accumulation of rubbish or windblown dust in a well may be sufficient to reduce its depth or block it up. Any open well should therefore be cleaned once a year in the dry season.

The lining should be checked carefully before anyone goes down, since if it has become loose it will be dangerous. The inside of a well can be inspected from the surface, using a shaft of light reflected from a mirror. A lighted candle should also be lowered into the well to test for harmful gases. Old wells, particularly if over 15 metres deep, often contain enough carbon dioxide to suffocate anyone who goes down them. If the candle flickers or goes out, the well must be ventilated before anyone goes down it. Any method of circulating air will achieve this. For instance, a large bundle of leaves or grass can be lowered into the well and quickly pulled up again; this is repeated until the well is clear of gas. Anyone going down a well should wear a safety rope which passes over a secure pulley at the top, and a team of men should stand by to pull him out quickly if necessary.

## 2.8 BOREHOLES

It is necessary to obtain a drilling rig to drill a borehole, and this is very expensive. It will therefore almost always be necessary to hire one, or to borrow one from the Government. A drilling rig is a large machine usually mounted on a truck, and may not be able to reach certain areas. You should certainly check carefully that there is no alternative to a borehole. Drilling for ground water is always a gamble, and it is advisable to take expert advice, especially on the best site for the hole.

There are two kinds of rig. The simplest is a percussion rig, which drills the hole by repeatedly dropping a heavy weight into it. The other type is a rotary rig, which drills by rotating a sharp bit in the hole. Rotary rigs are much faster, and can drill in harder rock, but they are much more expensive. The hiring rates will normally include a very high charge for any time the machine stands idle, so you should be ready for the rig when it arrives on site, and not keep it waiting.

## 2.9 CHECKING THE YIELD OF A WELL OR BOREHOLE

Once you have completed a well, of whatever kind, the first step is to check its yield. You should bear in mind that the yield of a well may drop by as much as a third, after a few months of use. The yield can be checked by pumping water out for 8 hours a day for 3 days with the pump you will be using. You should not be able to pump it dry; if a well is often pumped dry, the pump will wear out very quickly, and may break down. Pumping for a long time to check the yield will also help to increase the yield of a tube well, because it will pump out much of the finer soil particles around it, so that water can pass through more easily.

An effective way of moving these fine particles in a tube well is known as 'surging'. For this you need a plunger, such as that in Figure 15. It can be made from blocks of wood which fit easily inside the well, screwed together with pieces of leather or rubber between them which are large enough to make the plunger work like a piston in the tube of the well. Ideally, the plunger should have holes through it and a leather or rubber flap, without holes, over the top, as shown in the figure. The plunger is then pushed slowly down into the well on the end of a rod or a length of steel pipe, until it is a metre or two below the water level. Then it is repeatedly raised and lowered through a distance of about a metre, pumping water up and down in the well. This surging should be started slowly, gradually increasing the speed but keeping within the limit at which the plunger will move smoothly. You should stop every few minutes to remove soil from the well with

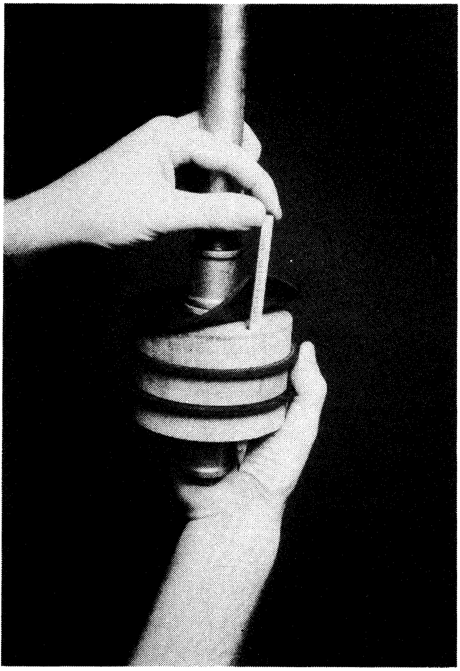


*Fig. 15.* A surge plunger for a 100 mm diameter tube well. The holes run right through the plunger, except for the top flap.

a bailer (Section 2.5.) Continue surging until no more soil comes into the well.

The yield of a hand-dug well can be increased by deepening it, by sinking a tube well downwards from its bottom, or by digging tunnels or driving slotted pipes out to either side at the bottom of the well.

## 2.10 WELL DISINFECTION

When you are satisfied that your well has sufficient yield, it should be disinfected before it is used, even if you will not be disinfecting its water in the future. This is because the well may have been polluted during construction. The pump also needs disinfection.

The easiest disinfectant to obtain is usually chlorine, which can be found in bleaching powder, High Test Hypochlorite solution (HTH), liquid bleach and javel water. Bleaching powder contains about 35% available chlorine, HTH 70%, liquid bleach usually about 5%, and javel water about 1%. To disinfect a tube well, mix up a solution of 0·2% chlorine in 25 litres of water (two bucketsful). This will require about 15 g of bleaching powder (one heaped tablespoonful), 7 ml of HTH, a litre of liquid bleach or 5 litres of javel water. If you are using a kind of bleach weaker than 5%, you should use proportionately more. Mix the solution well. If you use bleaching powder, stir it for 10 minutes, allow it to settle, and then pour off the clear liquid to avoid the white sediment left on the bottom.

When the mixture is ready, pour it down the well. Then operate the pump until the water pumped out smells distinctly of chlorine, and then wait for one hour before pumping again. Repeat this procedure of pumping and waiting several times, and then leave the well for 12 hours. At the end of that time pump water to waste until it does not smell of chlorine.

To disinfect a hand-dug well, a spring box or a silt trap, mix up 3 buckets of the solution, and scrub the inside walls with it, especially between the current water level and the highest point the water level is expected to reach. Then pour in the remainder. In the case of a well, mix up the same amount again, and pour that also into the well. Then pump several times and leave overnight as for a tube well.

Some chlorine may stay in a well for a week or more, depending on the size of the well and the pumping rate, but it will all disappear slowly in time.

## 2.11 CAPPING A TUBE WELL

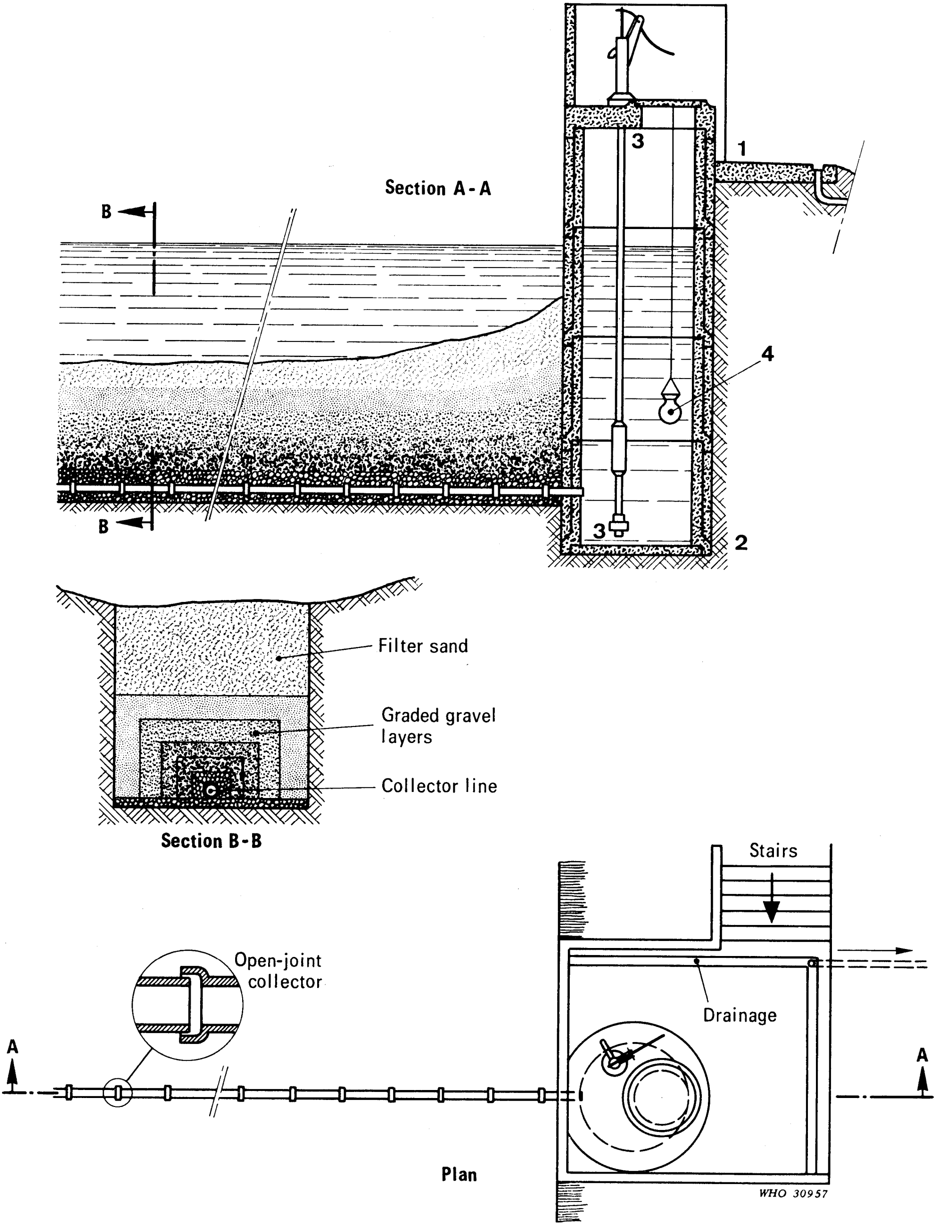
The top of a hand-dug well has been discussed in Section 2.7. Tube wells and boreholes require similar measures.

The tube of the well should protrude at least 450 mm above ground level. The ground level is then raised by 200 mm over an area at least 2 m square and levelled. This area should then be covered in concrete at least 100 mm thick, which should be reinforced with steel bars if possible. They should be at least 8 mm diameter running each way at 150 mm spacing. They should be tied together with wire where they cross each other, and supported 50 mm above the ground on small stones or blocks of cement mortar. The concrete for the platform is then placed around and over them, and smoothed with a trowel to slope gently down from the pump, so that spilt water will drain away from it. Be careful not to cover the fixing bolts of the pump, so the pump can be removed when necessary for repair. The reinforcing rods, however, should be completely covered in concrete, above and below.

An air vent is necessary in the side of the hand pump, so that surface water will not be sucked in under the platform when water is pumped out of the well.

## 2.12 SURFACE WATER INFILTRATION

Surface water is usually heavily polluted, but where there is an all year round source of surface water, such as a stream, dam or village pond, you can expect the ground water table to be very near the surface. It is preferable to use the ground water adjacent to the stream or pond than to use the surface water directly. However, in some areas the ground water may not be drinkable, or the ground conditions not suitable.



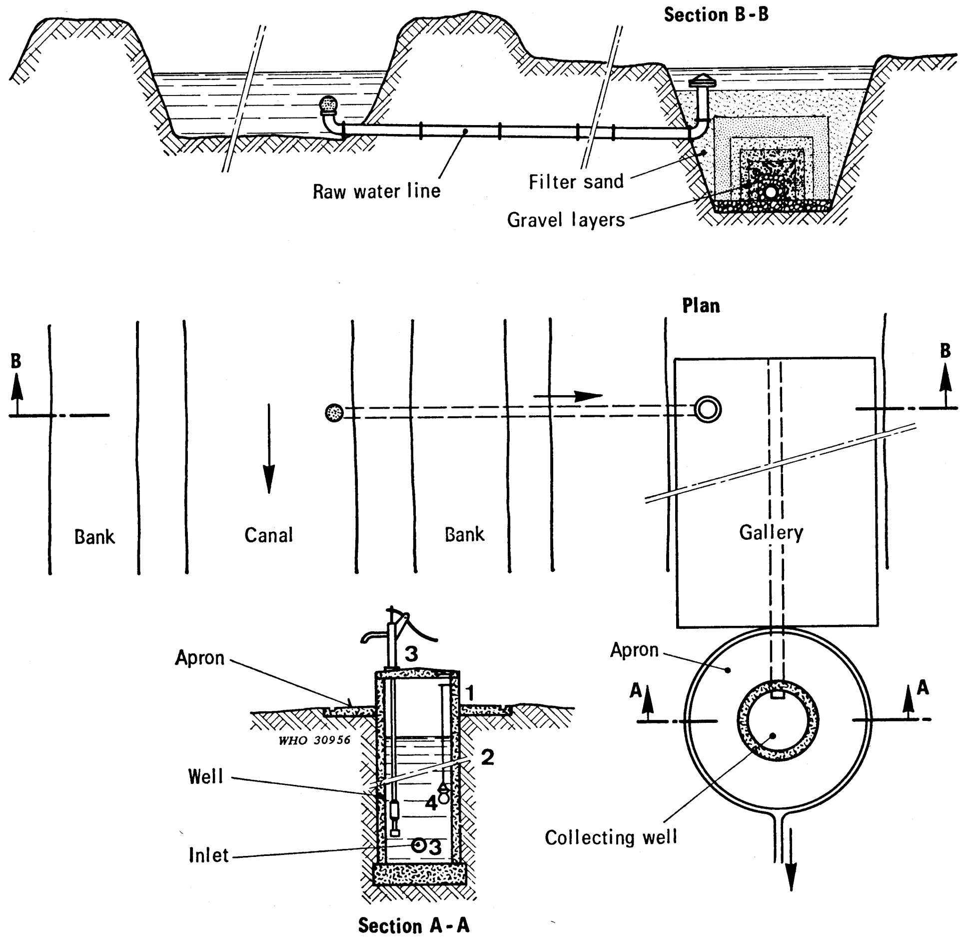
**Check list**

1. Does the collecting well extend 1 m above ground ?
2. Is the collecting well sealed watertight throughout ?
3. Are the inlet and outlet pipes well sealed in ?
4. Is the water chlorinated ?

*Fig. 16.* An infiltration gallery under a stream or village pond. (From Rajagopalan and Shiffman).

If the ground is not permeable enough for sufficient water to be extracted from a well, it may be possible to build an 'infiltration gallery' under the bed of the body of surface water. This is basically a horizontal tube well. Instead of the tube, a collector pipe is laid with its joints open so that water can drain into them (Figure 16). Gravel and sand must be carefully placed around it in layers, so that each layer is a little finer than the one inside it. This is to prevent the fine sand from running into the pipe and blocking it. The collector pipe is closed at one end, and the other end leads the water into a collecting well, from which it can be pumped in the usual way.

The difficulty with an infiltration gallery is that it is necessary to dig a trench for it more



**Check list**

1. Does the collecting well extend 1 m above ground ?
2. Is the collecting well sealed watertight throughout ?
3. Are the inlet and outlet pipes well sealed in ?
4. Is the water chlorinated ?

*Fig. 17.* An infiltration gallery under a separate channel; the gallery is built before diverting the surface water over it. (From Rajagopalan and Shiffman).

than 1 m below the water level. This normally will require continuous pumping with powerful pumps to keep the trench dry, and the sides of the trench will also need to be supported. One way to reduce this problem is to build the gallery under dry ground to one side of the stream or pond and then dig a channel to bring the water over the gallery (Figure 17).

Alternatively, you could build the gallery beside a stream and then raise the water level by a dam. This has the additional advantage that water is stored behind the dam. If you arrange that sand and gravel are deposited behind the dam, the stored water will be partially purified by seeping through the sand, and will not be lost by evaporation.

The method is as follows. The dam wall is built in the river bed during the dry season, usually of concrete so that the river can flow over it when the rains come, without washing it away. Normally, the material carried by flood water is roughly 75% silt and clay with only 25% sand and gravel. To ensure that only sand and gravel are deposited, the dam wall is built first to a height of only 2 m and is subsequently heightened in stages as the sand deposit builds up. The flood waters overflow the wall, taking most of the mud and depositing only the larger sand and gravel particles. Each stage is added as the space behind the wall fills with sand (which may require the whole of the wet season), and the full operating height of 6-12 m is reached (Figure 18).

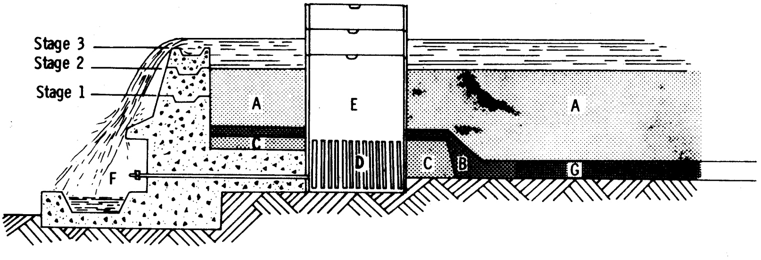
However, the construction of a sand dam, or any other kind of infiltration gallery, involves a great deal of work, and you should ask an engineer's advice before you start to build one.

An easier way to collect filtered water from a stream, or in some cases a dam, is to bury a filter such as the SWS filter (Appendix D) under the bed of the stream. This is basically a reinforced box with a slotted plate (or 'spetum') in it (Figure 19). The slots in the plate are specially made to taper towards the outside to prevent them from clogging with silt as water enters from below. When the filter has been buried, heavy pumping is then used to build up a graded bed of soil underneath it. It then works in a similar way to an infiltration gallery when an ordinary pump is fitted.

This kind of device is particularly useful for temporary use, as it can be removed and installed elsewhere. It can be used permanently under a stream bed, but if used under a body of still water such as a dam or a lake there is danger that the bed may become clogged from time to time, so that the filter has to be moved to another position. If installed under a briskly flowing stream, it may get washed out after heavy rain. The best site for a filter like this is one with a fairly sandy bed. It is usually necessary to throw away the first few litres of water when pumping starts after having stopped for more than a few hours.

## 2.13 RIVER INTAKES

If it is not possible to take water from below the bed of a body of surface water, the water



A sand deposited by floods
B fine sand filter
C coarse sand filter
D slots for water intake to well
E well
F outlet pipe
G additional sand

*Fig. 18.* The principle of the sand dam (not to scale). (From Pacey).

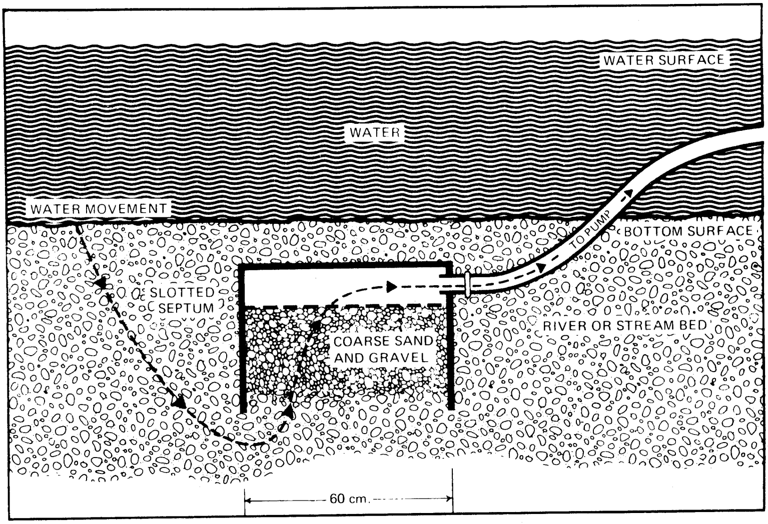


*Fig. 19.* The S.W.S. filter. (From Cansdale).

can be collected directly by some kind of 'intake' structure. But this water will usually need treatment, and the design of the intake arrangement needs careful thought. If it is at all possible, you should ask for an engineer's advice in designing an intake. A wrongly designed structure will soon be carried away by floods, clogged by silt, or left high and dry when the water level falls.

It is not a good idea simply to use a pipe sticking into a river. An intake pipe should at least be fixed firmly down by stakes driven into the bed of the river, be fixed well above the level of the river bed to prevent it becoming buried, and its end should be covered with some kind of grid or mesh to keep out dead leaves and other rubbish. Any exposed sections of the pipe should be protected from damage by trees or other debris carried downstream. This requires concrete, a pile of large rocks, or a heavy wooden frame. It is usually preferable to use a small dam or weir across the stream, and to take the water from a channel in the top of the weir or from the body of water held back by it.

In choosing a place for a river intake, it is best to choose a rocky site because streams and rivers tend to wash away their banks, and because the rockiness shows that not much silt is being deposited at that point. If there are no rocky sites, choose a straight stretch of the river. Obviously, the further upstream you go, the less pollution there is likely to be. If an upland stream is being used, it is important to keep cattle away from the intake works and preferably off the catchment area altogether. In Africa, big game may prove to be a problem.

If water is to be taken from a lake or dam, it is important to allow for variations in the water level. The intake should therefore not be too high. But it should also not be so low as to become buried in silt; most dams in the tropics fill up with silt completely in a few years. One solution to the problem is to have a flexible intake pipe fixed to a float, so as to remain a constant distance below the water level. An infiltration arrangement is much better, though. It can be built before a dam is completed, while the area is still above water.

## 2.14 UNDERGROUND CATCHMENT TANKS

In some arid places there are streams or wadis which only flow for a few hours or days in the year, but which carry large quantities of water at those times. It may be possible to slow down the flow of one of these torrents and encourage the water to seep into an underground tank. The water is extracted from a well in the middle of the tank, and the tank may be filled with sand, in which case it is easier to build because it does not need to have structural strength.

An ingenious way of building this sort of tank uses polythene sheets made into long tubes. The tubes are filled with soil-cement mixture and laid horizontally, side by side on the floor, and on top of each other to form the walls. The method is fairly cheap, and avoids the need for skilled labour, although it requires expert supervision and special polythene tubing. An example of its use is described by Moody (1969).

# CHAPTER 3 RAISING WATER

## 3.1 INTRODUCTION

Whatever device you use for raising water, it will have moving parts. These will require regular maintenance and occasional repair. No new water raising device should therefore be installed unless precise arrangements have been made to ensure that this work will be carried out.

A bewildering variety of methods are available for lifting water. Unfortunately, many of them are not suitable for small water supplies, either because they cannot lift water through a sufficient height, or because they expose the water to the risk of pollution, or because they are too expensive to install and operate. The simplest methods are often the cheapest, and can more easily be made and repaired with local materials. However, they are sometimes less durable, and usually require more maintenance by the local community. We will describe the main methods in order of increasing complexity and cost. Which of these is the most appropriate will depend on the local conditions, the funds available and the probability of regular maintenance in the future.

The first decision to make, though, is whether to use hand power for raising water, or to use a motor of some kind. Hand power is suitable for a supply where water is drawn straight from the source, such as a well, and the person drawing water operates the device. If water is to be pumped to a storage tank first, some other type of power will have to be used, such as wind, diesel or electricity.

## 3.2 HAND DEVICES USING BUCKETS

The simplest method of raising water is a bucket of some kind on the end of a rope. It is best to use rollers (Figure 11), a shaduf (Figure 20) or a windlass, so that people do not have to lean over the well to raise the bucket. It will help to prevent pollution of the well water if the bucket hangs permanently in the well, so that it is never taken home and never put on the ground. If a shaduf is designed to balance with the empty bucket in the air, this will help to prevent the bucket from being put down on dirty ground.

Various methods have been suggested for avoiding the need for anyone to touch the bucket, so that the well is better protected from pollution. An example is shown in Figure 21. However, none of these methods has yet been tried in a village for very long, and they probably need careful maintenance. A more practical method is to have a chain of buckets (Figure 22), or a 'chain and washer' pump, as in Figure 23 (Watt, 1976).

## 3.3 HAND PUMPS

The devices mentioned in Section 3.2 can often be made using materials available in rural areas. A hand pump is easier to install and may be more reliable, but will normally have been made in a factory, possibly in another country. It also requires regular maintenance (Figure 24). Some of this maintenance requires a certain amount of skill. For instance, removing the cylinder from a deep well requires great care. Simple hand pumps can be made by hand from wood and plastic. They are easier to repair in the village, but they tend to wear out quickly.

When choosing a hand pump it is wise to remember that even a cast iron pump can get broken very quickly if it is heavily used by the public. The most common part to break is the handle mechanism, so the mechanism should be strong and simple, and should not be so loose that the handle can be shaken from side to side. Most hand pumps work by moving a piston up and down in a cylinder, rather like a bicycle pump. This cylinder is normally at the bottom of the well, and the piston connected to the surface by a steel pump rod; but in a 'suction pump' it is built into the pump body at the top. Suction pumps are useful in tube wells which have an internal diameter smaller than 50 mm, as a normal cylinder will not fit down such small holes. But they will only pump in wells where the water level is less than 8 metres deep.

One other kind of hand pump (the Mono pump) uses a corkscrew mechanism in the

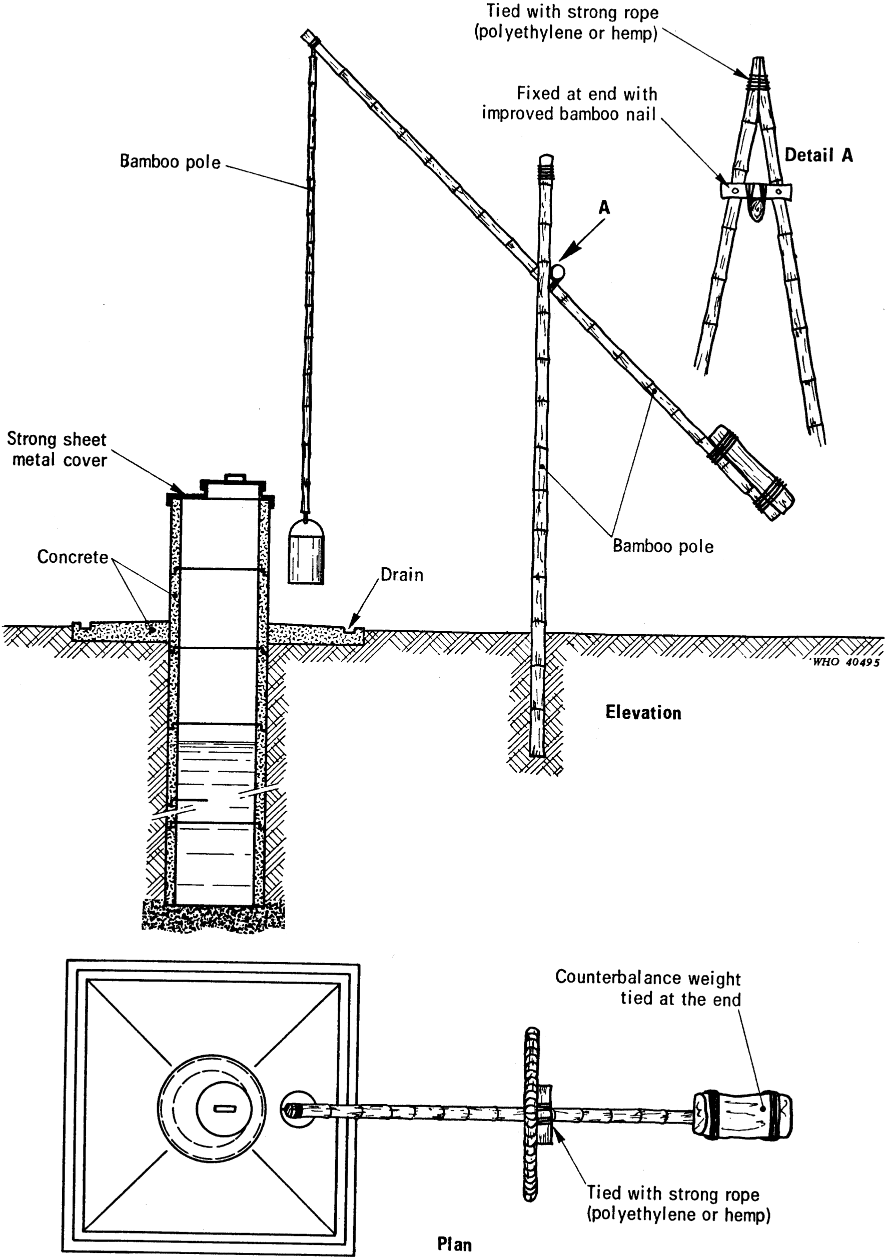


*Fig. 20.* A shaduf used over a hand-dug well. (From Rajagopalan and Shiffman).

bottom of the well. It cannot be used in wells less than 90 mm diameter and it is more expensive and more difficult to repair than most other hand pumps, but it appears to be more reliable.

Most kinds of hand pump cannot pump water from a depth of over 60 metres; you should specify the depth to the water level when you order a pump, and buy some spare leather piston washers (known as 'pump buckets') at the same time. A great deal of information on hand pumps is given by McJunkin (1977).

## 3.4 WIND PUMPS

The advantage of wind power is that wind is free. However, a windmill is necessary to use wind power, and windmills are usually rather expensive. Home-made windmills can be made cheaply, but they are not usually strong enough to last for very long under village conditions.

Before buying a windmill you should check whether the wind blows regularly enough to give a reliable supply of pumped water. Find out about any other windmills in the area. It may also help to ask about wind records at an airport, if there is one near you. In any case, you will probably need a storage tank big enough to hold at least 7 days' supply of water, to allow for up to a week without enough wind.

Most windmills drive a piston in a cylinder, like a hand pump. In fact they may be com-

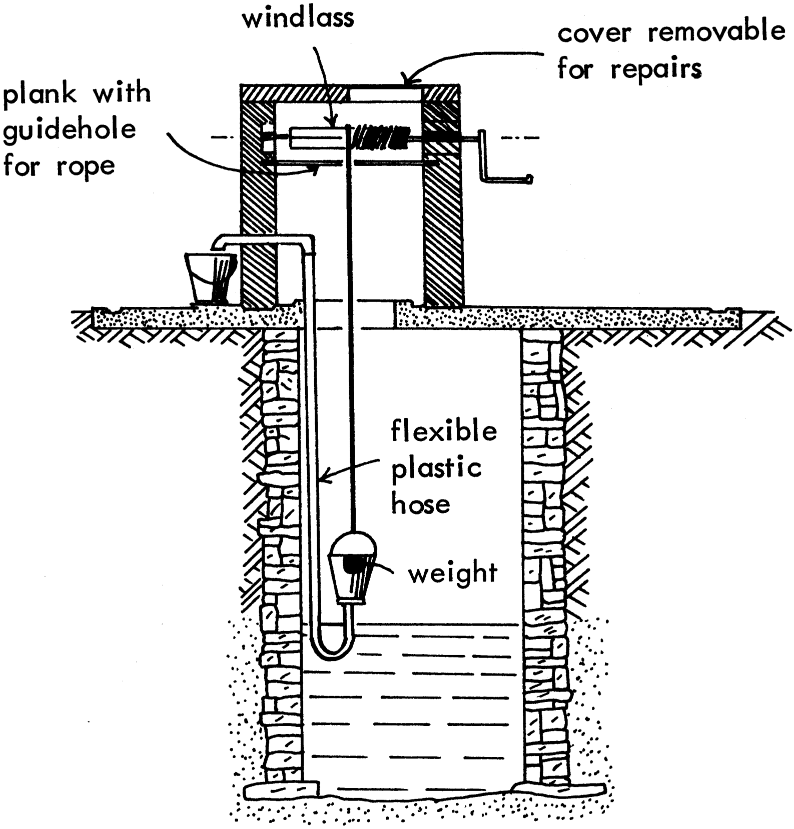


*Fig. 21.* One method of protecting a well from pollution. No methods of this kind have yet been adequately tested in the field.

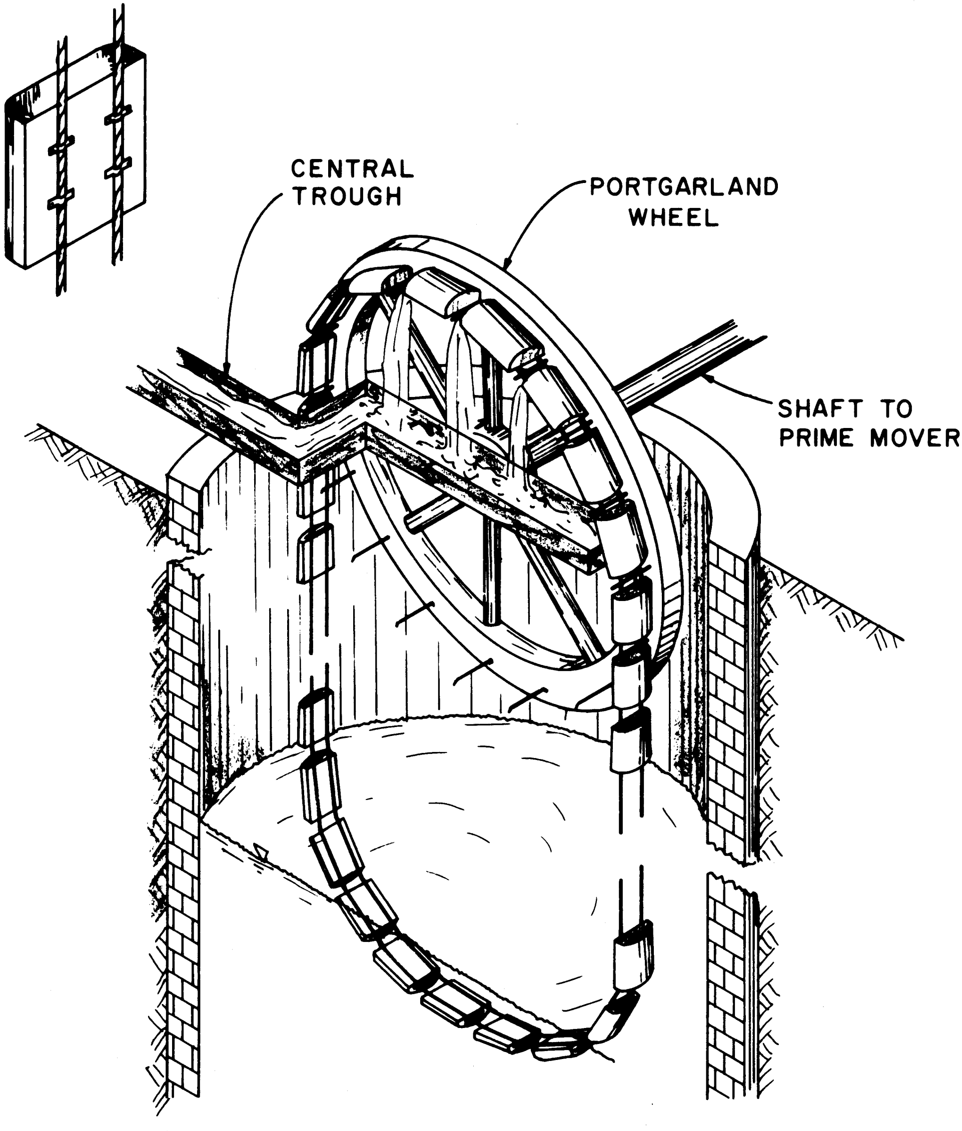


*Fig. 22. A chain of buckets (persian wheel) device for raising water, with a 'portgarland wheel' driven by a horizontal shaft. (From Wood).*

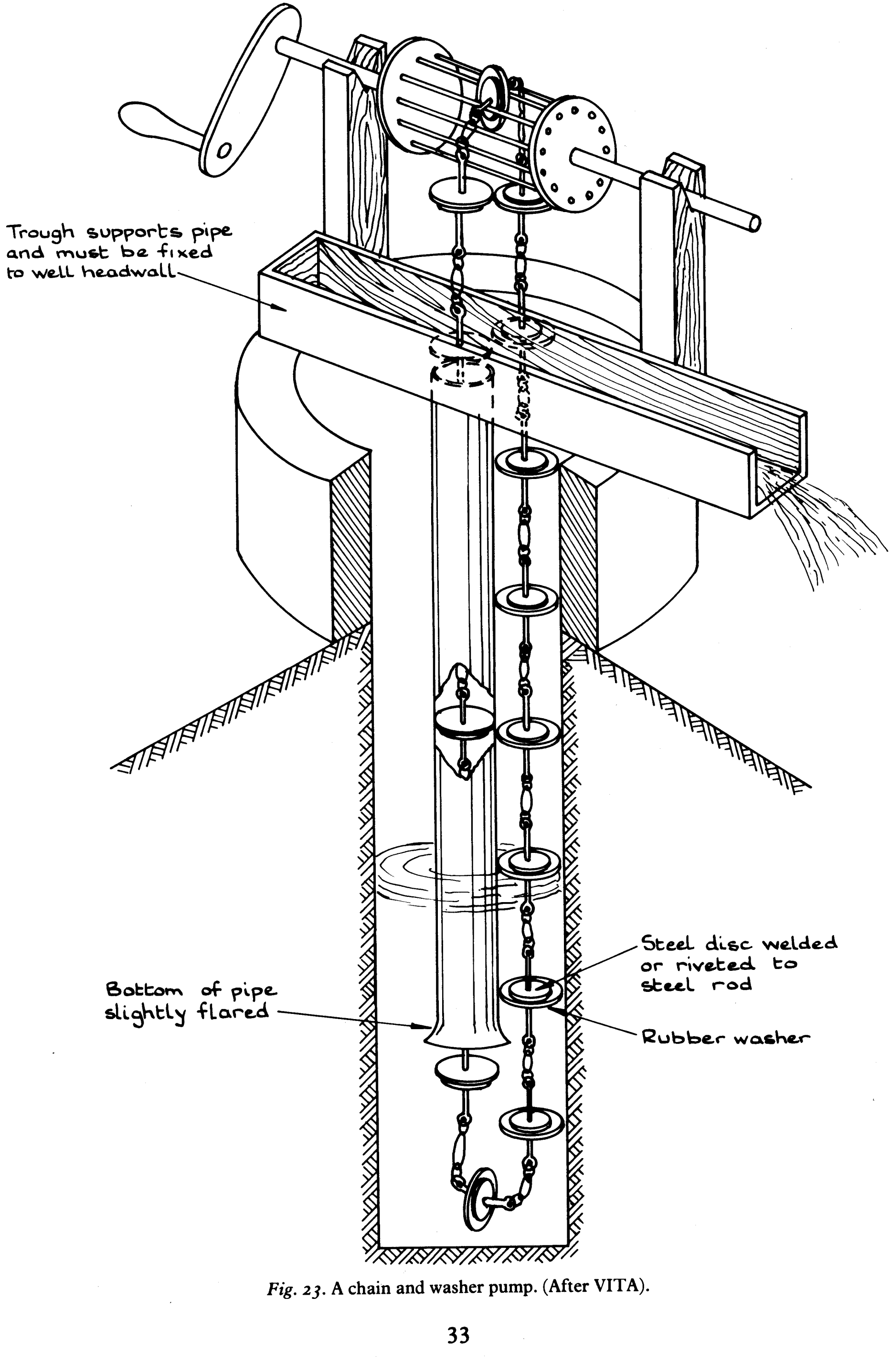


*Fig. 23*. A chain and washer pump. (After VITA).

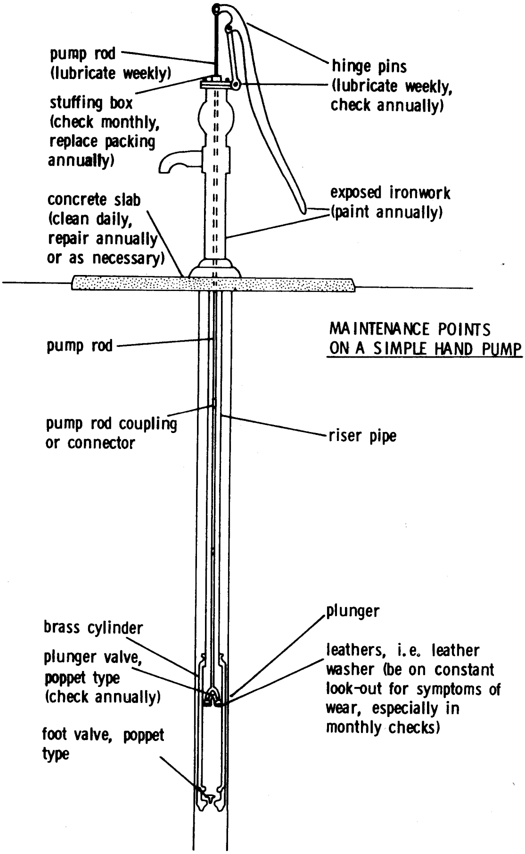


*Fig. 24.* Maintenance points on a simple hand pump. (From Pacey).

bined with a hand pump so that water can be pumped by hand if there is no wind. Alternatively, you could also provide a diesel engine for use when the windmill is not pumping.

## 3·5 HYDRAULIC RAMS AND SOLAR PUMPS

Two other types of pump also use naturally occurring sources of energy.

A hydraulic ram uses the energy of flow of a large volume of water, to pump a small proportion of that volume. It therefore requires a much larger flow of water of suitable quality than would be necessary for the community's needs alone; usually 10 to 100 times as much. This has to be quite a rapid flow to be suitable for a ram. Rams also require careful adjustment. Home-made hydraulic rams are liable to be shaken apart by vibration unless carefully designed. The address of one manufacturer is included in Appendix D.

Solar pumps are suitable for arid areas, and although they may pump as much as 6 litres per second, they require sophisticated technology and are not easy to repair. Several have been installed in rural areas of West Africa by a French company (Appendix D).

## 3.6 DIESEL AND ELECTRIC PUMPS

Most pumps can be run either by diesel or by electric motors. Electric motors need less maintenance and are usually more reliable than diesel engines, so they are preferable where a reliable supply of electricity is available.

The simplest motorised well pump works like a hand pump, but a large gear mechanism called a 'forcehead' is used at the top to turn the motor's rotation into the up-and-down motion necessary for pumping.

There are many other types of motor driven pump, mainly for pumping from a source at the surface. The larger ones are usually of the 'centrifugal' type. You should ask for an engineer's advice if you are choosing a motorised pump, but it will help to bear in mind the following points.

If you are pumping from below ground, you should remember that a pump cannot pull water from more than 8 metres below it. If the water table is more than 8 metres down, the pump mechanism should be down the well, although the motor may be at the top. In general, it is preferable for the water to flow into a pump from above. If it is necessary that the pump should draw water from below it, it may need 'priming' every time you start it, because it cannot pump air. If it is a centrifugal pump it will certainly need priming. This involves pouring water down the inlet pipe, and makes the operation of the pump more complicated. Priming can be made easier by installing a non-return valve at the bottom of the inlet pipe, and by storing water for priming in a special tank beside the pump. However, it is preferable to choose a pump which does not need priming.

Certain types of pump will wear out quickly if they are used for pumping dirty water, so it is best to do any treatment before the main pumping. This may require a separate 'low lift' pump to deliver the dirty water to the treatment site. If it is necessary to pump muddy water, you should check with the pump manufacturer that his pump is suitable for this purpose. Take a sample of the water in a bottle, and allow the sediment to settle to the bottom; measure the thickness of the sediment layer, and estimate the size of the largest particles. Tell the manufacturer your results, or give him the sample.

In choosing a pump, it is important to select one for which you will be able to buy spare parts. If there are already some pumps in your area, it is probably best to use the same kind. This also applies to the motor which will drive the pump. Most pumps have been designed for particular conditions. Before you choose a pump, you should work out the pumping capacity and the lift which you require.

The pumping capacity is simply the rate at which the pump can work, and can be calculated from the design capacity of the supply (Section 1) if you know how many hours per day you will pump. A typical time is 8 hours per day. For a supply needing 75,000 litres per day, with 8 hours' pumping per day, the pumping capacity would be 75,000/8 litres per hour, or:

$$\frac{75{,}000}{8 \times 3{,}600} = 2{\cdot}6 \text{ litres/second}$$

The lift is the vertical height the water has to be lifted. It is the sum of the depth below ground level of the water table in the well, and the difference between the ground level at the well and at the level of the storage tank to which you are pumping. The second can only be measured with surveying equipment, such as an abney level. You may be able to borrow this from the local office of the Ministry of Public Works, who can advise you how to use it.

You should specify the connections of the inlet and outlet pipes to the pump, giving the pipe diameter and type of fitting. These fittings usually use either flanges or a standard steel pipe thread. If you already have a flanged fitting, measure the position, size and number of bolt holes.

If you are considering an electric pump, check the voltage of the electricity in your area, and whether it is DC or AC. If it is AC (Alternating Current), the manufacturer should also be told the frequency in cycles per second (Hz) and the number of phases. Small motors normally use a single phase, but larger ones may need three. When the manufacturer has suggested a particular model, the electricity supply authority can tell you from its specification whether special starting switchgear will be required.

For a diesel pump, describe the type of fuel, the altitude and maximum air temperature, and tell the manufacturer if the air is unusually humid or dusty.

Motorised pumps need plenty of maintenance, and they cost money to run. It is particularly important, therefore, to be clear about who will pay for all this, and how. It is also important to decide *beforehand* exactly who will operate the pump, who will be responsible for repairing it if it breaks down, and where there is a reliable source of fuel.

These points may appear obvious, but they are all regularly forgotten and explain many of the non-functioning water supplies of the tropics.

# CHAPTER 4 WATER TREATMENT

## 4.1 INTRODUCTION

Unfortunately, there is no such thing as a simple and reliable water treatment process suitable for small community water supplies, and it is preferable to choose a source which provides naturally pure water, and then to collect that water and protect it from pollution so that treatment is not necessary. Treatment should only be considered if it can be afforded and reliably operated.

The treatment methods described in this chapter are for community water supplies. The treatment of water for individual households is described in Chapter 8.

## 4.2 STORAGE AND SEDIMENTATION

The simplest method of treatment is storage in a covered tank. If the water can be stored for at least two days, it will be free of schistosome larvae,[1] and contain considerably less bacteria. However, if the inlet and outlet pipes are too close together, some of the water may flow straight by a 'short-circuit' route directly from the inlet to the outlet, while most of the water remains still in the tank. In any storage tank, the inlet should be above the top water level, while the outlet should be about 100 mm above the bottom. It is also helpful if they can be arranged on opposite sides of the tank.

Besides the tendency of schistosome larvae to die in water after a few days, the quality of water can also be improved in a large tank by sedimentation, the process by which silt and other solid material sink slowly to the bottom of the tank. Sedimentation does not remove many of the harmful organisms from polluted water, but it helps to make silty water clearer. This is particularly useful if the water is to be filtered (Section 4.3), because silty water can block up a filter in a short time.

Sedimentation will not produce completely clear water unless a specially designed tank is used and chemicals are added to the water to help the process. If you want to do this, you should first ask for advice from an engineer.

However, a simple sedimentation tank like that shown in Figure 25 can be used without chemicals to remove grit, sand, and coarse silt from water to make it more suitable for filtering. This tank is designed for silty surface water which has already been exposed to pollution, and so requires no cover unless it presents a health danger as a breeding place for malaria mosquitoes.

For relatively large flows, up to six units like that shown can be joined together so that the water flows a zig-zag path through them all, one by one. There should then be at least one unit for every 2,000 litres per hour flowing through the tank. So, if the flow is 12,000 litres/hour, six units are required (Figure 26). Note that if water only flows through the tank for a few hours per day (for instance while a pump is running), or if some water is being run to waste from an overflow after sedimentation, the rate of flow through the tank will be higher than the average rate of consumption of the community.

The tank will have to be cleaned out regularly, and so it requires a drain pipe. Cleaning the tank will be much easier if the tank floor slopes down by at least one in fifty towards the drain.

## 4.3 FILTRATION

Some kinds of water filter can remove at least 99% of the bacteria and viruses in water if they are correctly operated, as well as some other sources of disease such as cysts, ova and schistosome larvae. Sand is the most convenient material for filtering water, but other materials such as burnt rice husks may be used. Whatever material is used, the particles should be fairly uniform in size. They should be not more than about 1 mm diameter, and preferably about 0.5 mm.

Various prefabricated filter plants using 'rapid' sand filters or 'pressure' filters are available, but are generally too complicated for operation in small communities. In this section we only consider the type known as the *slow sand filter*, which is the simplest to operate and the most effective in removing bacteria. Although the operation requires

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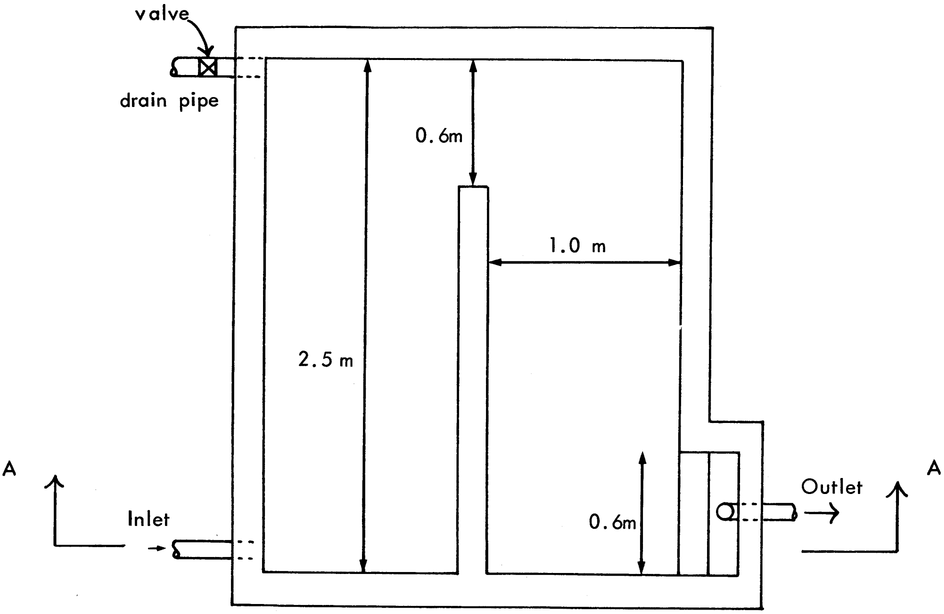
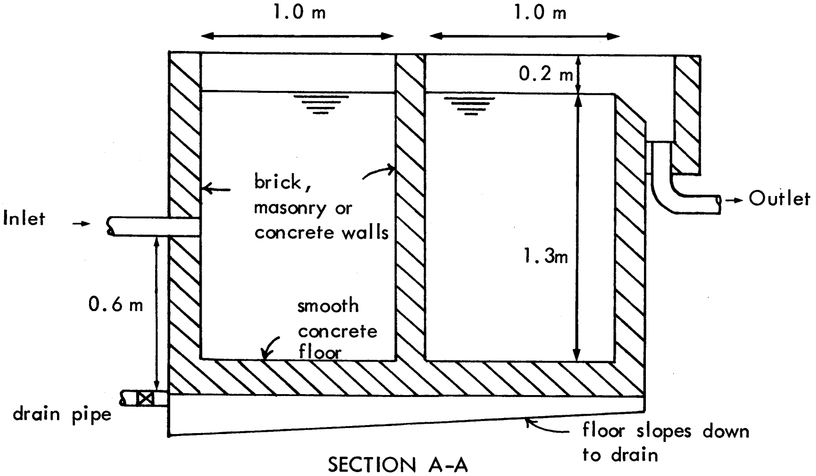
[1] Schistosomes are the worms which cause bilharzia.



PLAN



SECTION A-A

*Fig. 25.* A simple sedimentation tank for flows up to 2,000 litres/hour.

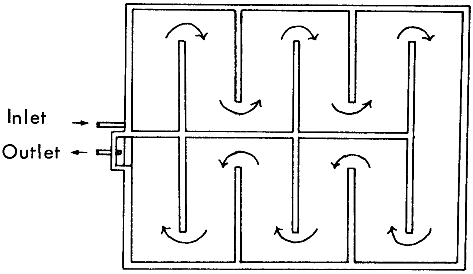


*Fig. 26.* Method of combining six small sedimentation tanks.

little skill, it does need regular attention, and it should be carefull designed.

A slow sand filter consists basically of a large tank containing a bed of sand (Figure 27). The water filters down through the sand bed to a set of drains which take it to an outlet well. The filter does not work by a simple straining process. The sand grains in the top layers of the bed become coated with a sticky deposit in which bacteria and microscopic plants multiply. These form a very fine straining mat in the topmost few millimetres, as well as killing most other micro-organisms which pass through.

The tank walls should rise 2.4 metres above the floor and the area in plan should be at least 3 square metres for each 400 litres per hour capacity. More details of how to construct a large tank are given in Section 5.3. The sand should be at least 700 mm deep, and its surface should be at least one metre deep under water. Between the sand bed and the drains there should be three or four layers of clean gravel, each 75 mm thick. The gravel in each layer should be of uniform size, and about twice as large as in the layer above. So, if the top layer were about 2 mm diameter (this could be left out if the filter sand is quite coarse), the second layer might be 5 mm, the third 10 mm and the fourth about 25 mm diameter. The drains beneath the gravel can be made of bricks laid down without cement (Figure 27), and they should not be more than 3 metres apart. The drains lead the water to an outlet chamber, a separate compartment which is kept clean. Water collects in the chamber and flows down the collector pipe, whose top should be a little above the level of the top of the sand. There should be a valve on the inlet and the outlet pipe, and a drainpipe so that the filter can be emptied when necessary.

If the water being treated is reasonably clear, a slow sand filter may run for weeks or even months without cleaning. If the water going into the filter is very dirty, it is advisable to try to improve it beforehand. This may often be done by sedimentation. However, if the sediment in the water is very fine, it will not settle fast enough for sedimentation to work. Check this by leaving a sample in a bottle to settle for an hour. If the water is still dirty after this time, this means that sedimentation would require special chemicals to work effectively. An alternative is to use another filter filled with coarse sand or coconut fibre instead of fine sand, or an upward flow filter (Section 8.3), before the slow sand filter.

It will become obvious when a slow sand filter requires cleaning, because the flow through the filter will slowly drop to the point where it is not enough for the community's needs. It is cleaned by raking off the top 20 mm of sand from the surface of the sand bed and discarding it. When the sand bed is only 600 mm thick, more sand is needed. The old sand can be washed in a box with water slowly piped in at the bottom. This should be continued and the sand disturbed with a spade until the water overflowing from the box becomes clean.

When the filter is first used after cleaning, the water may flow through it too fast. This can be prevented by fitting a floating regulator over the outlet pipe. A regulator

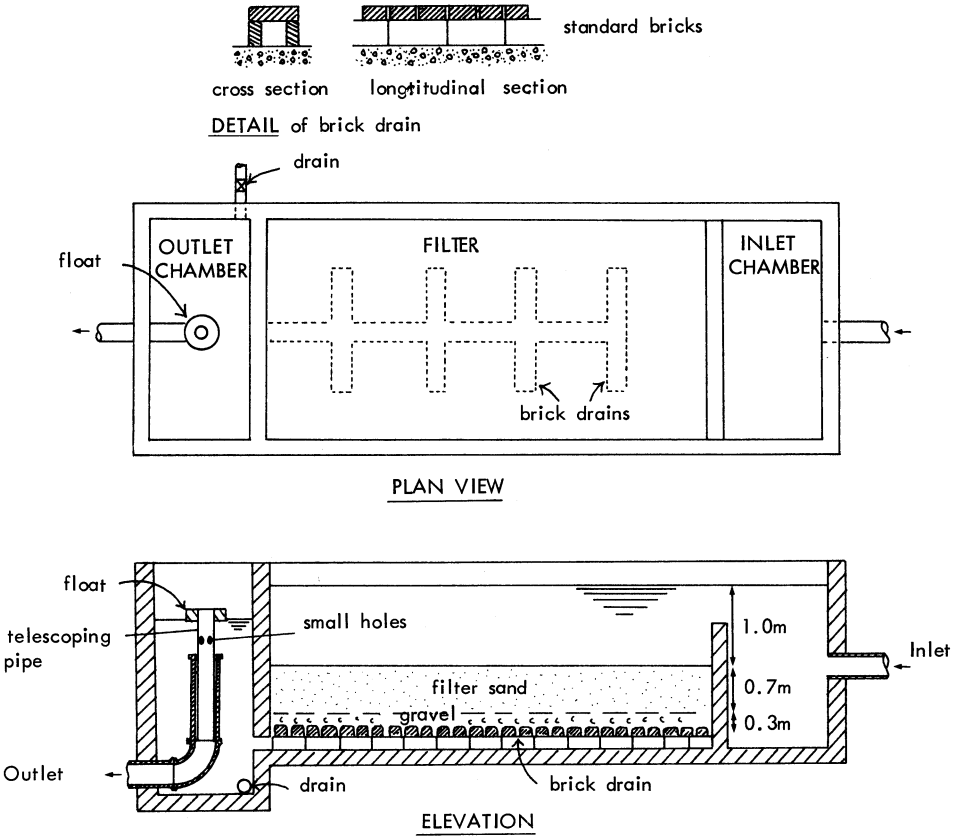


*Fig. 27.* Slow sand filter.

may be made with a piece of PVC pipe which can slide telescopically up and down inside the outlet pipe. It should be able to slide freely, but with a clearance of not more than 5 mm. It should have two or three small holes in it, as shown in Figure 27. When the pipe has slid as low as it can, the holes should sit just above the top of the fixed outlet pipe. A ring of wood or light plastic is fitted to the top end, so that the pipe floats with holes about 150 mm below the surface.

If the flow through the holes of the regulator increases, the water level in the outlet chamber will rise, and the regulator will start to float. To determine the size and number of holes required, start with only one hole less than 10 mm diameter, and increase the size and number of holes until the flow through them when the regulator is floating is fast enough. To measure the flow, shut off the inlet to the filter while it is running, but leave the outlet valve open. If the regulator is floating, the water level should start to fall at a rate of 0.2 metres per hour. During normal running of the filter, the regulator will not usually be floating, however, because it should not float when the flow is slower than this.

As this description shows, the building and operation of a slow sand filter is quite complicated, and it is best to ask for the advice of an engineer if one is available to help.

## 4.4 DISINFECTION

Larger water supplies are usually disinfected by adding chlorine, but it is often an unreliable process when used in smaller communities. The main problem is that, unless the chlorinator is filled every week or two, the chlorine will run out, and there is no easy way of knowing that the water is no longer safe. Chlorine can be obtained in pure gas or liquid form in large pressure bottles, but it is safer and more convenient for small water supplies to obtain it from liquid laundry bleach or bleaching powder. This is easier to obtain than bottled chlorine, but it rapidly loses its strength when exposed to the atmosphere or to sunlight. Even if carefully stored in sealed containers in a cool, dark place, it will lose half its strength in about a year. A stronger disinfectant is High Test Hypochlorite solution or powder, which contains about 70% available chlorine. It is slightly more stable than bleach, but should also be stored in sealed containers in a cool, dark place. Chlorine can kill bacteria, schistosome larvae, some viruses and, in higher doses, amoebic cysts. There is little danger to health from excessive dosing, but if too much chlorine is added, the unpleasant taste may drive people to use more heavily polluted water instead.

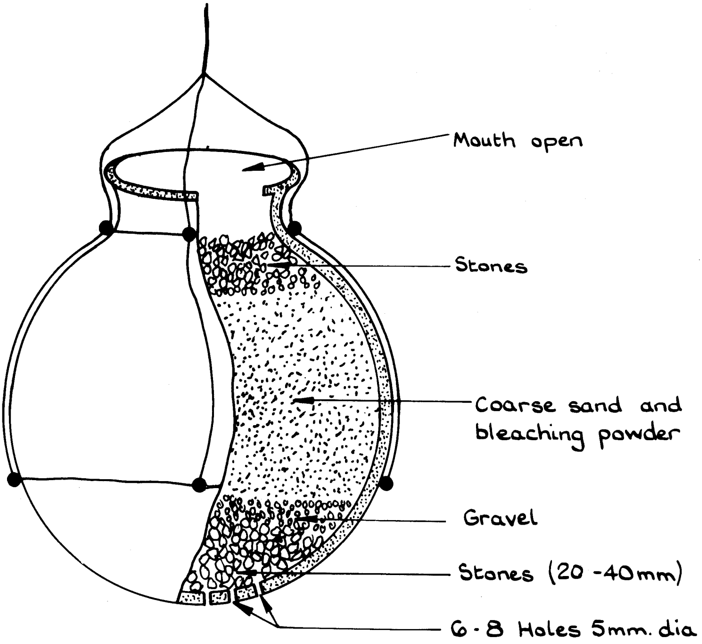
Chlorine should never be applied before slow sand filtration but filtration before chlorination will make the chlorination more effective. Dirty or cloudy water is not suitable for chlorination, because the dirt in the water will absorb the chlorine.

Simple chlorinators, which dispense a chlorine solution at a constant rate, can be bought or made with materials available in most developing countries. But it is difficult to set their adjustment correctly, and you would be wise to seek expert advice before you try to make one. Besides, regular attention is necessary to ensure they run reliably. *There is no point at all in using a chlorinator which is not reliable.*

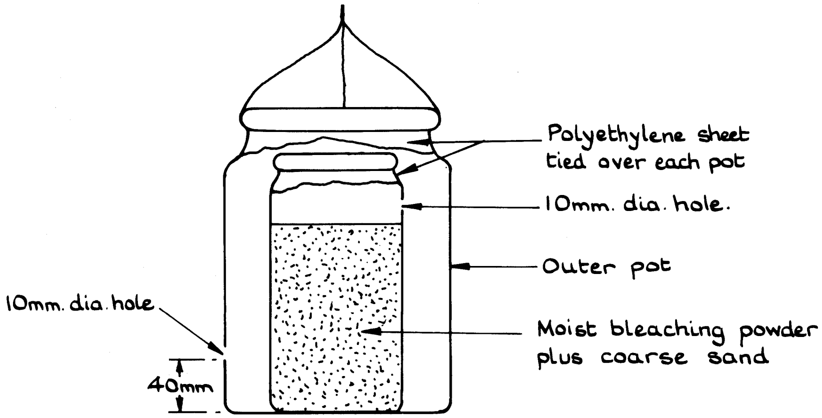
Chlorine should not be added to water flowing straight to a tap, or it will not have enough time to disinfect the water before it is used. It should be added to the water in a well or entering a storage tank, because it requires at least half an hour to act. If chlorine is being added to a water supply, the amount of chlorine in the water must be regularly checked because the amount required will vary, depending on the level of pollution. These checks should be carried out on the water as supplied, not just after chlorination. In a piped supply, the water to be tested should be taken from the tap furthest from the source. At this point the 'free chlorine residual' (the amount of chlorine still left to kill bacteria) should be at least 0.3 mg/litre (0.3 parts per million), although to achieve this will usually require an initial dose of at least 10 times as much. A residual of 2 mg/litre is required to kill amoebic cysts. Simple kits for measuring chlorine are available and include instructions for their use (Appendix D). If not enough chlorine is added, it may all be absorbed very quickly by organic matter in the water and have negligible disinfectant effect. This means that disinfection is carried out by the last few parts per million, not the first. It is therefore useless to chlorinate if you are not adding enough chlorine.

The simplest type of chlorinator is a pot containing a mixture of coarse sand and bleaching powder, which is hung underwater in a well (See Figure 12). Figure 28 shows two types of pot chlorinator. The double pot is suitable for a well serving up to 20 people and needs to be refilled with 1 kg of bleaching powder and 2 kg of coarse sand every 3 weeks. The single pot will serve up to 60 people if it holds 50% more bleach and sand, but it requires replenishing every 2 weeks. For wells serving larger communities, more pots would be required.

The next most simple type is shown in Figure 29. It can be adjusted to feed chlorine solution at a slow constant rate to water in a tank or even in a pipe if the pressure is low. The largest component is a tank holding about 200 litres; an old steel drum can be used for this. The tank is painted inside with bitumen paint, because chlorine will rust metal and even attack rubber and wood. The tank should have a drain for cleaning-out and a cover over the top to keep out light although it should not be airtight.



(a) SINGLE POT SYSTEM



(b) DOUBLE POT SYSTEM

*Fig. 28*. Pot chlorinators; two alternative designs.

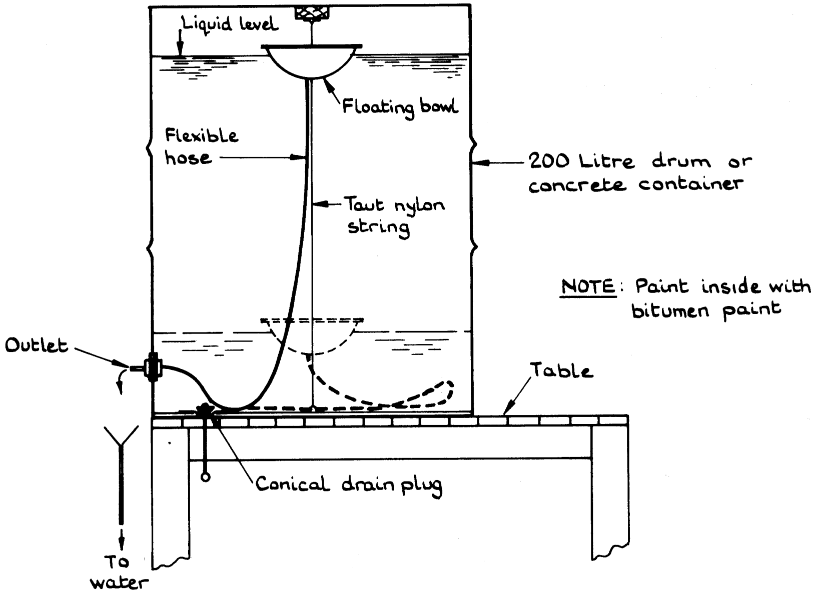


*Fig. 29.* Floating bowl chlorinator, to feed chlorine solution at a constant rate. (From McJunkin).

The tank is filled with a solution of 1% chlorine in water. This solution can be made up by adding to each litre of water in the tank either:

20 ml (almost 1 fluid ounce) of High Test Hypochlorite solution, or 20 g of powder
or
40 g (3 heaped tablespoons) of bleaching powder (chlorinated lime)
or
250 ml (one cup) of liquid laundry bleach

If bleaching powder is used, an inert sediment will settle to the bottom in a few hours, leaving the chlorine dissolved in the water.

The floating bowl arrangement, shown in Figure 30, is designed to ensure that the solution trickles out of the outlet at a constant rate. A hole in the bottom of the floating bowl is blocked with a cork or rubber stopper. At least two glass, brass or copper tubes pass through the stopper. One, about 6 mm diameter, is connected to the flexible tube which runs to the outlet. The other, not more than 3 mm diameter, is fixed with its top slightly below the liquid level in the tank, so that solution spurts up it into the bowl, and down through the other tube. You could use a plastic, enamel or glazed ceramic bowl, but the bottom half of an old plastic bottle will do just as well.

As the liquid level in the tank falls, the bowl will move down with it, always floating on the surface. It may be necessary to put stones in the bowl to make it float straight and steadily. In order to stop the bowl catching on the sides of the tank, it may be necessary to fit a third tube through the bottom of the bowl, threaded on a taut nylon string as shown in Figure 29. The flow from the chlorinator can be adjusted by carefully positioning the small tube which lets the solution into the bowl. The flow is reduced by moving it upwards to reduce the height H between its tip and the liquid level in the tank (Figure 30). It can be made easier to adjust by making the aperture smaller at the tip of the tube. With a glass tube this can be done by heating it and drawing it out. A brass or copper tube can be flattened at the tip. However, the aperture may become clogged over a period of time with chloride sediment.

To prevent the flow of chlorine solution decreasing to an ineffective level, therefore, the device needs regular adjustment and occasional replacement of the tube.

You should expect to have to add up to 1 ml of solution to every litre of water you treat, but this amount will depend on the results of your chlorine tests at the tap. The flow from the chlorinator is stopped by lifting the bowl out of the solution. The outlet should *not* be shut off, or the bowl will fill up and sink to the bottom of the tank. Accidental

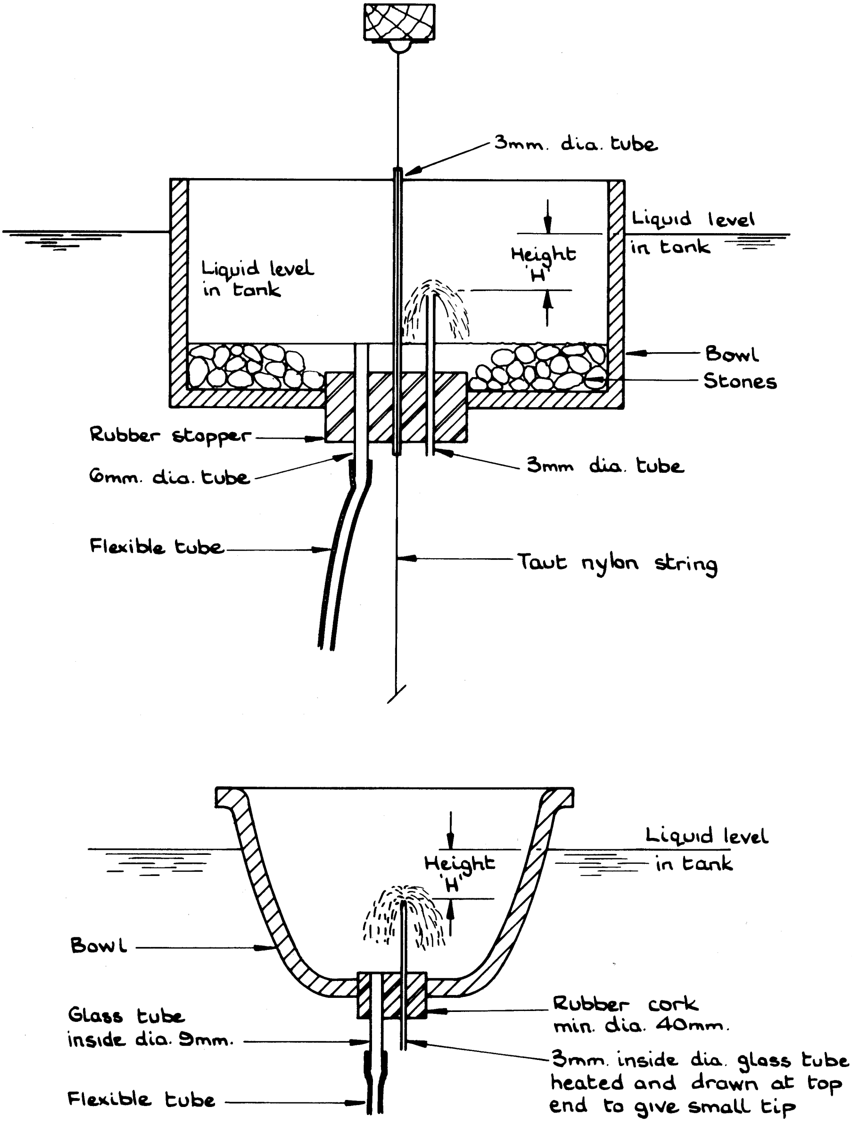


*Fig. 30.* Detail of floating bowl; two alternative arrangements. (From McJunkin).

sinking of the bowl can be avoided by fitting a float to it. Sometimes, for instance when it is unavoidable to feed chlorine into a pumping pipeline, it is necessary to stop the chlorination when the pump is not running, or at night. If so, you should make a special arrangement to ensure that no-one forgets to start it again when necessary.

The chlorinator needs careful maintenance if it is to work correctly. If rubber, rather than plastic, is used for the flexible hose, it will eventually become damaged by the chlorine and require replacement. And of course, you should make definite arrangements for regularly refilling the tank.

Chlorine can also be added through a special regulator from containers of pure chlorine under pressure. However, the regulators are expensive and require particularly careful operation, as chlorine gas can be dangerous. This method of chlorination is not recommended for small water supplies.

## 4·5 AERATION

In a few areas, heavy concentrations of iron and manganese in the ground water can give it an unpleasant taste, and give a brownish colour to clothes washed in it. In other areas various chemicals in the water, while not necessarily harmful, may make it unpleasant to taste. Other water treatment processes such as sedimentation and filtration can help to remove these impurities, but if they fail it can be a serious nuisance and even prevent people from using the water. If other processes do not succeed, these chemical impurities can sometimes be removed by aeration. Aeration

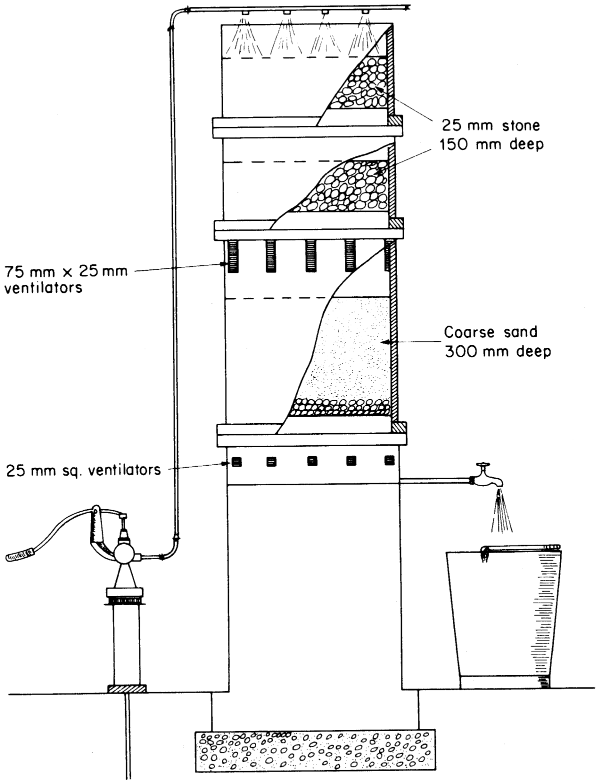


*Fig. 31.* A hand operated unit for iron and manganese removal. (From Pickford).

changes the iron and manganese so that they are no longer soluble in water, so that they form a fine dark sediment which is easily removed.

Figure 31 shows a simple unit which will aerate water, and also remove the iron and manganese sediment this produces. The unit consists of four cylinders, which could be made from 450 mm diameter cement pipes or from 200 litre steel drums, placed on top of one another. If steel drums are used, they should be rust-proofed with bitumen paint. The top three cylinders each have a mesh or sieve in the base, and ventilation slots in the side. The top two each have a layer of stones 150 mm deep, and the third has a 50 mm layer of stones covered with 300 mm of coarse sand. The unit stands on a solid brick or concrete platform. Water can be pumped in from a hand pump and is sprayed over the stones at the top. It runs down and is collected in the bottom cylinder to be withdrawn through a tap at the bottom. The water is exposed to the air as it trickles down through the stones, and the sediment is deposited on the sand lower down. The sand requires replacement roughly once a month.

## 4.6 SALT AND FLUORIDE

Salty water can be purified by various methods, but they are so expensive that they are only practicable in special cases or for limited amounts of water (Section 8.7). It is almost better to obtain another salt-free source of water, where that is possible. When ground water is salty as in some flat areas near the sea, there is sometimes fresh water lower down. If so, a deep tube well or borehole may be sunk to reach the fresh water below.

Similar considerations apply to water containing fluoride in concentrations over 4 parts per million. This cannot be tasted in water, but in the long term can damage the teeth and bones of those who drink it. It is mainly found in ground water in areas of flat dry scrubland. The local medical authorities can tell you if the ground water in your area contains a dangerous amount of fluoride. Fluoride can be removed by the addition of lime and alum, followed by sedimentation. This is known as the Nalgonda technique. It should not be used without specialist advice, because the amount of alum required depends upon local conditions.

# CHAPTER 5 STORAGE

## 5.1 INTRODUCTION

If water straight from a storage reservoir is for direct consumption, the reservoir must be protected from pollution. In particular, it must be covered over. If an open reservoir such as a dam has to be used, it should be considered as a surface source of water and would probably require treatment. It is therefore better to look for an unpolluted source which is reliable enough for this kind of storage to be unnecessary. If treatment is used, however, the treated water should only be stored in a covered tank.

This means that there are in general two types of storage reservoir. Firstly, there are large, unprotected reservoirs such as dams, whose purpose is to store water through dry periods of the year. Secondly, there are tanks for storing water ready for consumption. Because of their cost, these are usually much smaller, and normally hold only one day's supply of water. In certain cases, a storage tank should hold more than one day's supply. For instance, if water is being pumped to it by wind power, it should hold enough for a week or so.

The best shape of tank will depend on the size and the methods used to build it, but some typical dimensions for covered circular tanks are given in Table 1.

**Table 1**

**Typical Storage Tank Sizes**

| *Capacity (litres)* | *Water depth (metres)* | *Inside diameter (metres)* |
|---|---|---|
| 1,000 | 1·0 | 1·2 |
| 2,000 | 1·0 | 1·6 |
| 5,000 | 1·0 | 2·6 |
| 10,000 | 1·5 | 3·0 |
| 20,000 | 1·5 | 4·2 |
| 30,000 | 2·0 | 4·4 |
| 40,000 | 2·5 | 4·6 |
| 60,000 | 2·5 | 5·6 |
| 80,000 | 2·5 | 6·4 |
| 100,000 | 2·5 | 7·2 |
| 150,000 | 2·5 | 8·8 |
| 200,000 | 2·5 | 10·1 |

If water is to flow from a tank to a distribution system by gravity, the tank position must be carefully chosen. The tank should not be more than 60 metres above the lowest section of the pipeline if ordinary plastic pipe is used, or the pipe may burst. If the tank is more than 100 metres above the lowest pipes, you should check that the pipes you use are strong enough to withstand the pressure, or else use break-pressure tanks (Section 6.4). On the other hand, the tank should be high enough for the water to flow easily to every tap in the system. If you stand at the proposed tank position, your line of sight should fall by at least one in 50 to any point on the distribution pipelines. This can be checked with a water level, which you can make with a piece of transparent plastic tube filled with coloured liquid (Figure 32). The internal diameter of the tube should be at least 5 mm, or the column of liquid will break up. With the arms of the water level one metre apart, and your eye in line with the level of water in the near arm, the whole distribution system should be in line with a point at least 20 mm below the level of water in the far arm (Figure 33). An alternative is to use a spirit level, propped up on a box so that it lies horizontally. You should also check for a 1 in 50 fall from the source to the tank if the water is to flow to it by gravity.

## 5.2 DAMS

A reservoir of quite large capacity can be built cheaply by building an earth dam across a suitable ravine or erosion gully. However, dams can be very dangerous because if the water overflows, they can be washed away in minutes, releasing huge quantities of water onto the area downstream. The reservoir may also provide a breeding site for mosquitoes and other vectors of disease. Some reservoirs formed by damming streams become filled with silt in only a year or two. Others never fill up because the ground below them is too porous or because the water does not flow into them any faster than it evaporates from them.

For these reasons you should if possible ask an engineer for help if you plan to build a

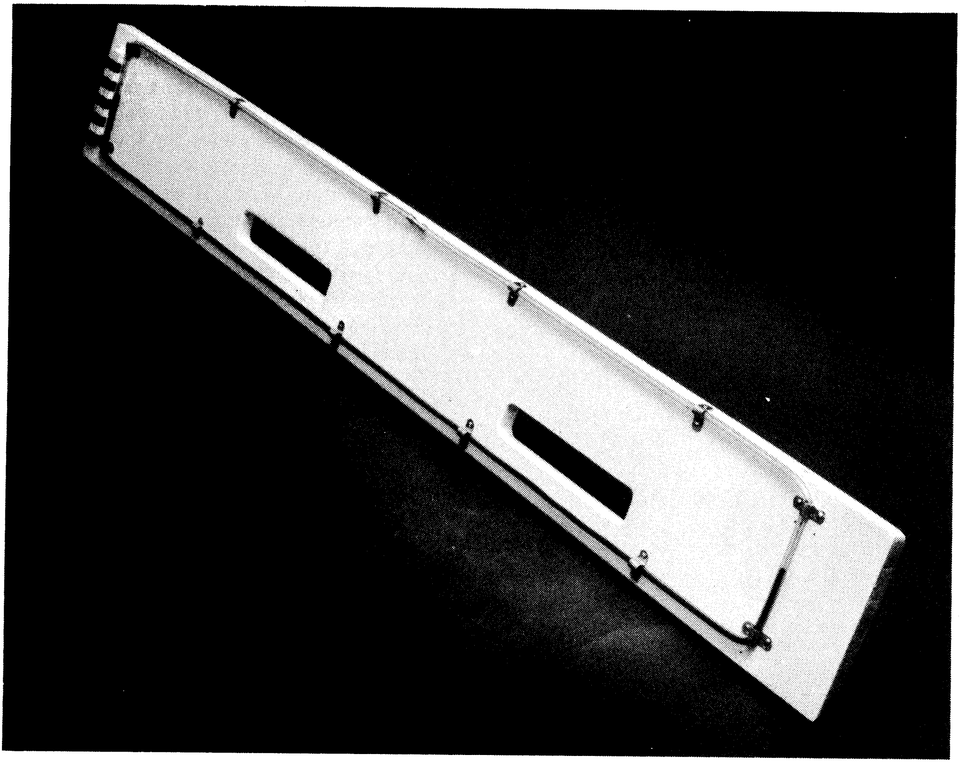


*Fig. 32.* A water level. Note that the tube is joined at the top to make a closed circle.

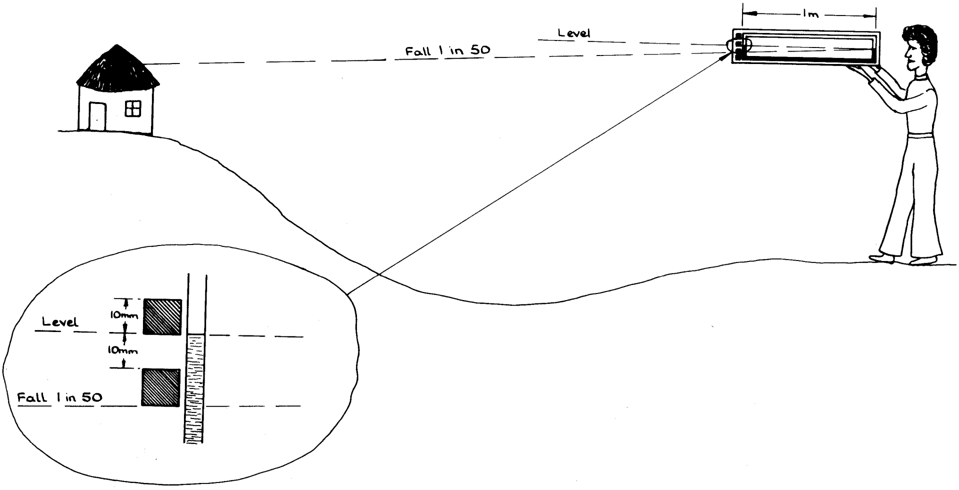


*Fig. 33.* How to use a water level.

dam, and *never* build one over four metres deep or a hundred metres long without an engineer's advice.

First, though, you should look to see if there are any suitable dam sites. The best place is a deep, narrow valley or ravine where the stream runs slowly. If the valley sides slope steeply, the dam can be short. If the stream runs slowly, that means the slope along the stream is gentle, so the water will back up a long way behind the dam. The best site is a place where a broad valley suddenly narrows. Ideally, there should be firm rock on which you can build, or at least a considerable depth of silty or sandy clay under the whole area to be flooded behind the dam. Preferably, the dam should be upstream of any houses, to minimise pollution of the water in the reservoir.

When you think you have found a suitable site, you can make a rough estimate of the volume of water which could be stored, as follows. Using a water level (Figure 32) mark the two ends of the proposed dam and measure the distance between them. The ground level each end must be the same. Stretching a string between these points on the ground, and hanging a tape from it in the middle, you can estimate the maximum height of the dam. This should be at least 2 metres. If it is less, the reservoir will dry up or silt up too quickly. Then, using the water level again, find the point upstream where the stream is level with the top of the dam, and measure how far it is from the dam. Then the volume of the reservoir is roughly:

Volume = upstream distance × length × depth × 1/6

If these distances are in metres, the volume you calculate will be in cubic metres; multiplied by one thousand, it will be in litres.

Then try to estimate the catchment area which would drain into the reservoir. This is most easily done with a map. The size of the catchment area should be at least fifteen times the area of the reservoir which would be formed. The average catchment area will drain about 1,000 litres of water for every millimetre of rainfall on a hectare; that is, about 10% of the rainfall.

When you have made these estimates, take them to an engineer for his opinion, together with any other relevant information you may have.

Another kind of dam, a sand dam, has been discussed in Section 2.12.

## 5·3 BRICK OR MASONRY TANKS

Brick or masonry tanks should only be built by an experienced builder. The standard of construction has to be better than for a normal building, because they must be watertight. Structures built using traditional methods can be made watertight by lining them with plastic sheeting, but this may be eaten by rats or insects, and it is much better to make sure that the tank structure itself does not leak. Reinforced concrete is the ideal material for this work, but brick or masonry tanks are easier to design and build.

If a tank is more than two metres across, it should be circular in plan. The circle should be set out accurately using a vertical pole at the centre. The floor should be at least 200 mm thick, preferably of concrete reinforced with steel bars, although two sheets of wire mesh (rabbit wire) will do as reinforcement. It should be laid on firm soil or rock, after the topsoil has been removed to a depth of at least 500 mm. In a shallow tank, the walls may be built on the floor, but if they are over 1.5 m high they should be supported on concrete footings lower down. To make a footing, dig a trench 600 mm wide with a level bottom, and fill it 200 mm deep with concrete containing one part of cement to three of sand and six of gravel (1:3:6 concrete).

Concrete walls should be at least 200 mm, and brick or masonry walls at least 300 mm thick. If more than 1 metre below the top water level but not supported by earth on the outside, they should be thickened by an extra 100 mm. Brick and masonry walls should be strengthened by laying galvanised wire mesh horizontally between the courses of brick or stonework at every 300 mm. The walls (and the floor if not of concrete) should be plastered inside with two coats of mortar, each 10 mm thick. The mortar used for bricklaying and plastering should contain one part of cement to 3 of sand by weight.

Tanks are often built underground so that the surrounding soil will help to support the sides. They then also keep the water cooler in hot weather. However, the roof of a tank should always be at least 300 mm above ground level, to prevent the danger of surface water running into it. If a tank is built above ground, the walls can be strengthened by placing an earth bank against them, sloping down away from the holes at not more than a one in two gradient. The earth of this bank should be placed in layers 150 mm thick, each layer being well tamped down.

It is sometimes necessary to build an elevated tank in order to develop enough pressure in the distribution system. Tanks should not be elevated more than 2 m without specialist technical guidance, but a platform up to 2 m high can be built of brick or masonry. A circular wall is built with its inside diameter slightly larger than the tank, and the enclosed space is filled with rubble or clean sand, placed in layers 200 mm thick and thoroughly tamped down. If sand is used it should be completely free of clay and vegetable matter to prevent settlement, and should be placed with water to make it as firm as possible. A drain is necessary at the bottom to allow all water to escape from the filling. Finally, the filling should be covered with a layer of concrete, level with the top of the wall, and the tank built on top of this.

In firm ground, it is possible to build an underground tank using the polythene tube method (Section 2.14), but it would be best to ask for specialist advice before doing so.

The roof of the tank should be adequate to keep out rats and mosquitoes, and should slope enough to throw off rainwater. If steel sheets are used, they should be firmly bolted together. A concrete roof needs careful design and strong shuttering to support it until the concrete has set, but the advantages of steel and concrete may be combined as follows. Steel rails are laid as joists at 1 m spacing, and flat arches are made between these with No. 26 gauge corrugated galvanised iron sheet, bent to a radius of about 2 m and resting on the rails. This is then covered with 1:3:6 concrete to a minimum depth of 80 mm.

The tank roof should have an access hole with a concrete or iron cover, which is lockable or heavy enough to prevent people from tampering with it. Steps built into the walls below the access hole will make it easier to climb in and clean the tank.

The outlet pipe should be at least 100 mm above the bottom of the tank. But there should also be a drain pipe at the bottom so the tank can be completely emptied when necessary for cleaning, and if possible the floor of the tank should slope gently towards this drain. The drain should *not* be connected to a sewer pipe. It should not be possible to open this drain by a valve which is easily reached by inquisitive people or vandals.

There should also be an overflow pipe with a mesh over its inside end to keep out mosquitoes. The overflow should be at least as large as the inflow, and positioned 200 mm below the reservoir roof to allow an air space above the water surface. The inlet pipe should be *above* the surface of the water, even when the tank is full to overflowing. There should also be a screened ventilation pipe from the tank. If the overflow pipe is short, it can serve for this purpose.

Arrangements should be made to prevent any overflowing water from causing a boggy area, creating mosquito breeding sites or starting an erosion gully. Some supplies have surplus water overflowing almost all the time, which can be used for irrigation.

The possibility of using storage tanks to improve the quality of the water is discussed in Section 4.2. Storage tanks require a small amount of maintenance. They should be emptied and cleaned out once a year, and leaks repaired. Small leaks in a tank above ground may not be serious, but in a buried tank they may lead to pollution entering the tank from the surrounding ground water. Leaks should be plugged from the inside if possible. All cement or concrete around the leak should be chipped away with a chisel, for at least 10 mm to each side of the crack, and 50 mm deep from the surface. This space should then be filled with fresh cement or with bitumen.

In particularly arid areas, one unusual type of tank is worthy of consideration. This is the baobab tree, whose trunk can be hollowed out to store water, and a hole cut in the side to fill it and draw water. Other holes may be cut to catch rainwater running down the branches. An average tree holds about 1,000 litres, a large one up to 5,000.

A new tank should be disinfected before use. To disinfect a tank up to 50,000 litres capacity, mix up 3 bucketsful of 0.2% chlorine solution (See Section 2.10). Scrub the walls and floor with it, and rinse out the tank with clean water. Fill the tank, pour in another 3 bucketsful, and leave it overnight.

# CHAPTER 6 PIPES

## 6.1 INTRODUCTION

Water for domestic use should not be allowed to run in open channels or ditches, as it is liable to become polluted like any other surface water. To protect its quality, it should flow only in pipes. Leaking pipes can cause pollution of the water in them. Even where the pressure is high for most of the time, it may drop when the water is flowing, sufficiently to suck in pollution from outside.

Pipes can be made of plastic (PVC or polythene), steel or bamboo. PVC and bamboo pipes are brittle and should only be used where you can be sure they will be laid in a trench with a firm smooth bottom, and well covered with soil. Bamboo pipes can take hardly any pressure and should normally only be used where they slope evenly and the water is not shut off at the bottom, but is flowing continuously. They do not normally last more than five years.

Of the other types, the cheapest and easiest to lay are polythene pipes. If they have to withstand very high pressures, for instance if some taps are to be more than 60 metres below the storage tank, then steel or high density polythene pipes should be used. These cost about the same as each other, but high density polythene pipes are better than steel for most conditions.

## 6.2 BAMBOO PIPES

Bamboo pipe is made from lengths of bamboo of the desired diameter by boring out the dividing membrane at the joints with a piece of sharp steel. This is made by flattening the end of a 12 mm diameter steel bolt or rod with a hammer against an anvil and sharpening the edges. A vice or a heavy axe head would also serve if no anvil were available. The sharpening can be done with a grinding wheel or a file. The trick is to grind the two cutting edges in parallel directions so that each is cutting properly when the blade is rotated (Figure 34). This bit is then fixed to a piece of 12 mm steel pipe or a piece of bamboo. A 4 mm hole is drilled through the

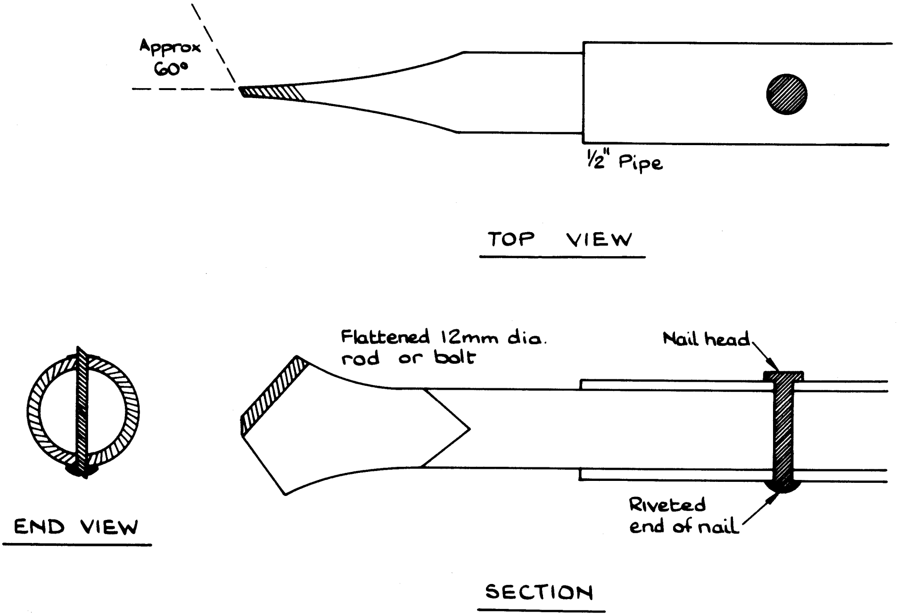


*Fig. 34.* Drill bit for preparing bamboo pipes (not to scale). (From Morgan).

bit and the handle, and a nail pushed through and cut off to leave about 4 mm sticking out. The head of the nail is pressed down on the anvil and the other end hammered flat like a rivet. The tool is now ready for use. It can then be pushed into the pipe by a larger piece of bamboo with the membrane still unbroken, and turned with a spanner.

Joints can be made in various ways (Figure 35). Instead of a larger piece of bamboo you could use a piece of motor tyre inner tube, tied with wire or jubilee clips. This kind of joint is particularly useful at bends, but it *must* be watertight or pollution may be sucked into the pipes.

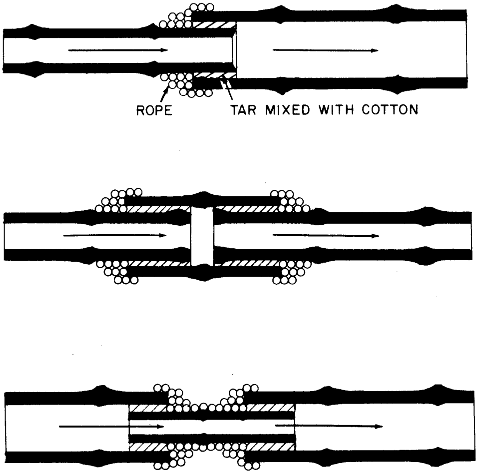


*Fig. 35.* Construction of joints in bamboo pipe; three possible methods. (From McJunkin).

Bamboo pipes do not normally last more than five years. They can be made to last longer by using green bamboo and soaking them for several hours in a solution of boric acid and borax. Boric acid and borax are mixed in equal parts by weight, and dissolved in 20 parts of the mixture. When the pipe is first used, it will give the water an unpleasant smell, but this will disappear in a few weeks.

If chlorine is used to disinfect the water, it will be absorbed by the bamboo. If the supply is polluted through leaks in the pipe, there will therefore be no chlorine left to deal with it.

## 6.3 PIPE SIZE

The size of pipe required depends on the amount of water it is to carry, the material it is made of, and the slope down which the water is to run if it is driven by gravity. However, between the flattest and the steepest slopes likely to be found in a small water supply – 1 in 50 to 1 in 5 – the slope makes a difference of only plus or minus 25% to the pipe diameter. Table 2 gives pipe sizes for various materials and for slopes in two ranges of steepness. 'Steep' slopes are those steeper than 1:15. The flow required should be calculated as described in Section 1. If a slope of less than 1 in 50 is unavoidable, you should ask an engineer for advice on the pipeline design.

**Table 2**

Pipe Diameter (mm)

| *Flow* | *Steel* | | *Polythene* | | *Bamboo* | | *PVC* | |
|---|---|---|---|---|---|---|---|---|
| *(l/sec)* | *Flat* | *Steep* | *Flat* | *Steep* | *Flat* | *Steep* | *Flat* | *Steep* |
| 0·10 | 19 | 19 | 12 | 12 | 25 | 19 | 19 | 12 |
| 0·15 | 25 | 19 | 19 | 12 | 32 | 25 | 19 | 19 |
| 0·20 | 25 | 19 | 19 | 12 | 32 | 25 | 25 | 19 |
| 0·30 | 32 | 25 | 25 | 19 | 32 | 25 | 25 | 19 |
| 0·40 | 32 | 25 | 25 | 19 | 37 | 32 | 25 | 25 |
| 0·60 | 37 | 32 | 32 | 25 | 50 | 32 | 32 | 25 |
| 0·80 | 50 | 32 | 32 | 25 | 50 | 37 | 37 | 32 |
| 1·00 | 50 | 37 | 37 | 32 | 62 | 50 | 37 | 32 |
| 1·50 | 62 | 50 | 50 | 32 | 76 | 50 | 50 | 37 |
| 2·00 | 62 | 50 | 50 | 37 | 76 | 62 | 50 | 37 |
| 3·00 | 62 | 50 | 62 | 50 | 76 | 62 | 62 | 50 |

'Flat' is < 1:15
'Steep' is > 1:15

## 6.4 PIPELINE DESIGN

If the water in the pipes is under too much pressure, they will burst. The strength of a particular kind of pipe – the pressure it can contain – can be expressed in 'metres head of water'. Roughly:

1 pound per square inch (psi) = 0.7 metres head
1 bar = 1 kg per square cm ($kg/cm^2$) = 10 metres head
1 kilopascal (kpa or $kN/m^2$) = 0.1 metres head

If a type of pipe can hold so many metres head, the pipeline should not drop more than that number of metres below its highest point, unless it is open at the bottom end, so that pressure cannot build up. Even if the pipe is open (as with a gravity main from a spring to a storage tank which is allowed to overflow when it is full) you should be careful if the pipe has to dip very low in a U, for example to cross a river. If the lowest point of the U is far below the outlet, the pressure there will be high. It is better to lay pipelines to slope up or down evenly and gently, even if this makes them a little longer.

If there is a danger of too much pressure in a gravity pipeline, you can avoid it by building 'break pressure tanks' at intervals. A break pressure tank is just like a silt trap (Section 2.3). The maximum head in the pipeline is its vertical distance below the break pressure tank, not below the original source. But a break pressure tank should not be too low, or water will not flow from it. As with a reservoir (Section 5.1), you should check that there is at least a 1 in 50 fall from the tank to any point on the pipeline below it. If it is impossible to ensure a 1 in 50 fall, the supply will have to be surveyed with special instruments and larger pipes must be used.

Whenever a pipeline branches in two, you should fit valves so that the branches can be closed off independently. There should also be valves to drain a tank and to shut off all pipes coming from it, and to shut off the supply to each main part of the area supplied, if there are more than five taps. The pipes carrying water from the storage tank to the taps should preferably form a ring; then if a pipe on one side breaks, it can be shut off and the other side used until it is mended.

## 6.5 PIPE LAYING

Pipe manufacturers usually print free instruction books on pipe laying, and you should ask for a copy and follow them. One or two points are especially important.

Pipes should be laid at least 0.3 m deep, and preferably 1 m deep when there is a chance of their being exposed by ploughing or soil erosion. The soil around the pipe should be free of stones, and well compacted in 100 mm layers by stamping it with your feet or, preferably, with a flat, heavy object. If there is any danger of the replaced soil being washed away, it should be compacted after placing each layer up to the surface. The soil should be filled back at least to the surface level and built up to make a small mound, because if there is a depression in the ground above the pipeline, rainwater will run along it and wash away the soil. If you place cuttings from thorn bushes along it, this will help to keep goats away and allow grass to grow, protecting the soil from erosion. Another way to protect the pipeline is to put small logs or ridges of earth across the line of the trench at intervals, to make the surface water run off to one side.

If pipes cannot be buried below ground they should be laid in a soil embankment with gently sloping sides covered with carefully placed stones, or wrapped in some kind of padding to protect them from animals, and (in high altitudes) from frost which can burst them.

Pipelines should always be completely watertight, as even the smallest leak is a potential source of pollution. A new pipeline should be checked for watertightness, especially at every joint, before the trench is filled in.

Someone should walk along every pipeline at least once a year to check it for leaks and soil erosion. It will help if the route of the pipe has been marked with permanent markers.

# CHAPTER 7 WATER DISTRIBUTION

## 7.1 HOUSE CONNECTIONS

There are great advantages in piping water into individual households, rather than providing it for collection from public water points. It may be essential to do this to obtain any health benefit from the water supply, for instance.

Each household may be provided with a single tap, fitted with a valve which delivers up to a fixed volume of water each time it is operated. This helps to avoid waste, and reduces peak flows so that 12 mm pipe may be used for house connections. The cost of a supply with such individual connections depends on how close together people live, but is typically less than twice the cost of a supply to public water points.

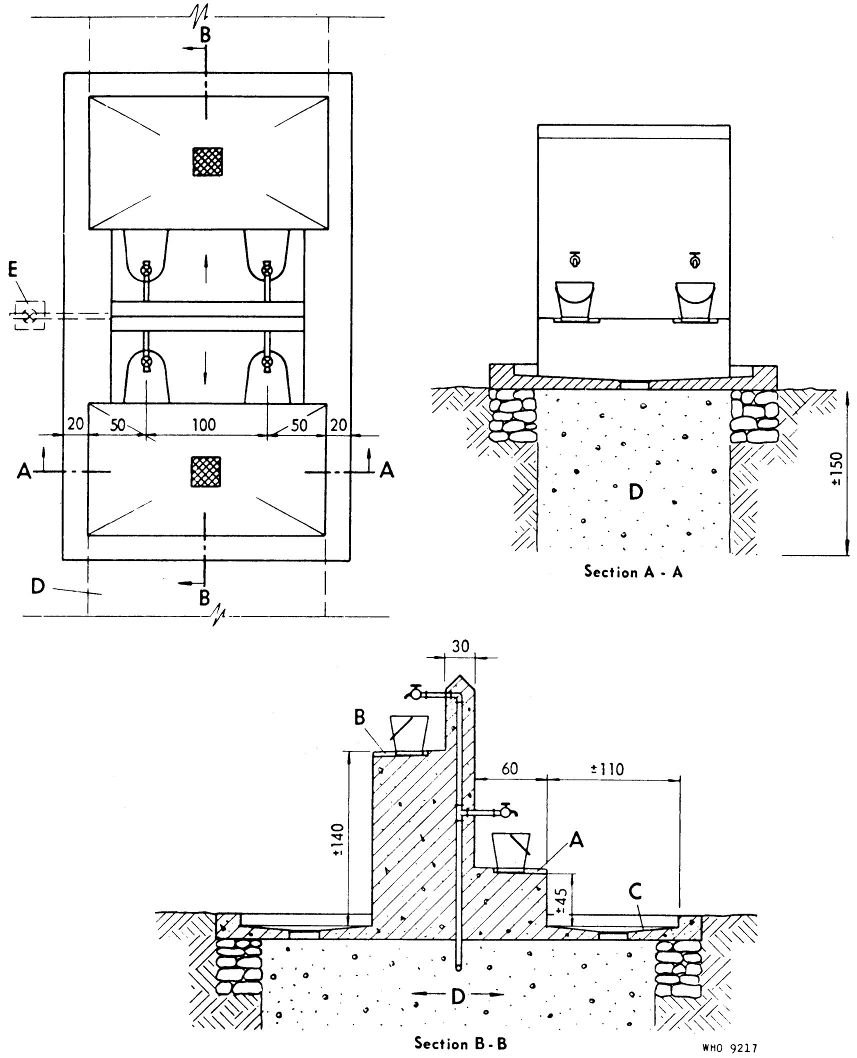
## 7.2 PUBLIC WATER POINTS

If water is to be collected from public water points, they should be made as strong and durable as possible. Public water points break down more often than almost any other part of a village water supply, and need regular maintenance. The simplest type of water point is the end of a pipe from which water flows continuously. A protected spring with a pipe like this is very cheap and can provide good quality water. However, this continuous flow is very wasteful unless the water is flowing by gravity from a strong enough spring. In that case, provision must be made for the water to drain away without causing soil erosion or a health risk.

Taps, when they are used, are the most frequent component of a water point to break down, and they should be the strongest type available. Someone living near to the water point, preferably someone whose family collects water from it, should be issued with spare washers and a spanner and shown how to replace old washers. Various ingenious devices have been invented to reduce waste from taps left running. However, much waste is actually caused by leaking taps, and before buying one of these devices, you should check whether waste is in fact a serious problem and is really due to carelessness. Some waste-saving taps do not last very long when used for public water points, as frustration with them leads to mistreatment and vandalism.

The design of a water point should allow for local methods of carrying water. If water is customarily carried on the head, it will be convenient to provide a loading platform about 1.4 m above the ground, to avoid unnecessary lifting. It is then advisable to provide a second, lower platform about 0.45 m from the ground, for children and old people to use, and to allow clothes washing under the tap. The taps should be high enough above the platform for containers to fit beneath them. Where jugs with round bottoms are used, there might be a depression in the platform to give firmer support.

Spilt water lying in puddles around water points can be a nuisance and can discourage people from using them. It can also provide sites for mosquitoes to breed. Every water point should be designed so that spilt water drains directly to a soakaway. A soakaway is a pit in the ground about 1.5 metres deep, filled with gravel and preferably covered over with soil or concrete. A drainpipe or channel is necessary to lead spilt water to the top of the gravel. Figure 36 shows a typical design of water point. It may also be desirable to add facilities for washing clothes or for personal washing at some of the water points.



Measures are in centimetres.

**A** = Platform level at about knee height
**B** = Platform level at about shoulder height
**C** = Hard-surface floor
**D** = Soakage pit : length may extend
beyond limits of fountain
**E** = Control valve

*Fig. 36.* Possible design of public water point. (From Wagner and Lanoix).

# CHAPTER 8 PURIFICATION ON A DOMESTIC SCALE

## 8.1 INTRODUCTION

When purifying water on a domestic scale, it is not usually necessary to purify water for all domestic uses. It is often more practical to purify fully only the water required for human consumption. However, water which may contain schistosome larvae[1] should not be used for personal washing or for laundry, and turbid water may not be acceptable. Schistosomes can be killed by storing the water for two days, and water can be made clearer by almost any simple filter. This chapter describes methods of purification to drinkable quality.

The simplest and cheapest method of purifying water on a small scale is filtration. Disinfection by boiling or chemicals can be used after filtration or instead of it, but should not be used before it.

## 8.2 CANVAS FILTER

The simplest type of filter to use is a canvas bag. The bag is filled with water, and the water collected as it seeps out of the bag. This will remove a few pathogens, but it has the more important effect of rendering the water clearer so that chemical disinfection can be used effectively. It is therefore suitable for use, together with chlorine tablets, for travellers who may have to treat water of very poor quality. Bags are available which have been specially treated to prevent them from rotting (Appendix D).

## 8.3 HOUSEHOLD SAND FILTER

A household sand filter is easy to build, but if it is not carefully operated it can produce water with more bacteria than before filtering. It should only be used, therefore, where you are sure it will be well maintained and regularly cleaned. Even if reliably run, it is not certain to remove all bacteria, though it will remove cysts, ova, schistosome larvae and other large organisms, as well as most of the silt. If the raw water is very silty, though, it should be allowed to stand in a large tank before it is passed through the filter.

Some household filters contain charcoal, but this serves only to remove certain unpleasant tastes, and has to be renewed at least every two months. Charcoal filters absorb organic matter, which can then provide a nutrient for undesirable bacteria to breed. They are therefore not recommended.

The bed of sand in a household sand filter should be at least 600 mm deep, preferably 750 mm deep, and it should be at least 0.5 metres across. A filter can be made from a 200 litre steel drum. Drums which have previously been used for oil or chemicals should not normally be used as they may still contain enough poison stuck to the sides to be dangerous. Remove the lid, make a hole in the side near the bottom and fit a tap to it. The drum should also have two holes in the side near the top for an inlet and an overflow. The overflow hole should be 50 mm above the inlet and should be connected to a short length of pipe, covered over by a mesh to keep out mosquitoes.

Clean out and disinfect the drum thoroughly with bleach. Next, place a layer of small stones, about pea size, in the bottom of the drum to a depth of about 50 mm above the outlet hole, and fill the drum to within 100 mm of the top with fine, clean sand (Figure 37a). Sand size 0.1 to 1 mm may be used, but 0.2 to 0.5 mm is preferable. Section 4.3 describes how sand can be washed. Fill the filter with a well-mixed solution of one part of 1% chlorine solution (Section 4.4) to 3 parts water, and leave it to stand for 12 hours. This water will then have to be flushed out by running water through the filter for some time until it no longer smells of chlorine. A taste of chlorine will remain for a few days, but will disappear eventually.

To operate the filter, the tap should be almost closed to give a flow of 1 litre per minute, which should flow to a covered tank. The outlet pipe should be brought in a loop up to the level of the top of the sand. The filter should have a tight cover. It should be mounted above the storage tank, and the tap

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[1] These are tiny worms which can penetrate the skin and cause schistosomiasis (bilharzia).

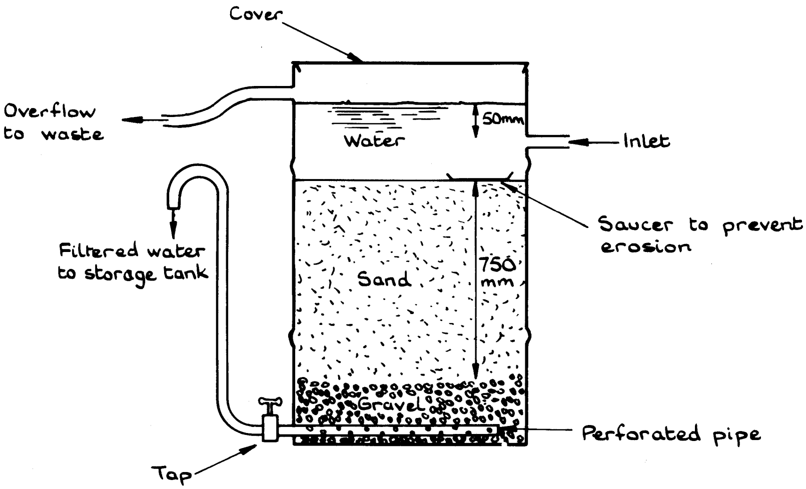

*Fig. 37a.* A household sand filter, capacity 1 litre/min.

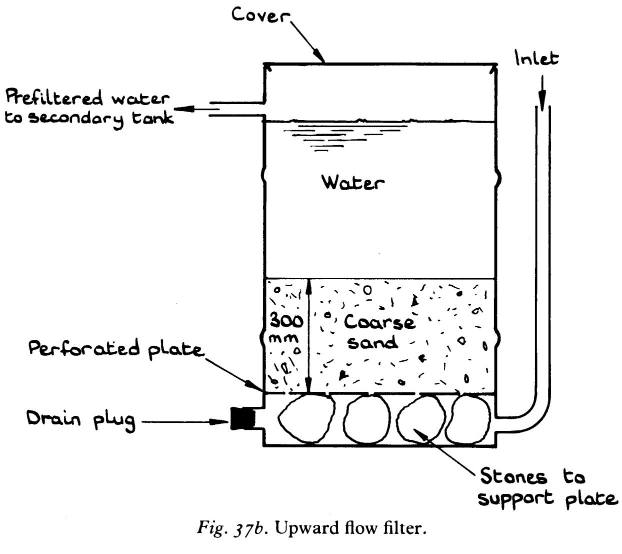

*Fig. 37b.* Upward flow filter.

at the bottom protected to prevent children playing with it. A continuous flow of water should run in at the top of the filter, just sufficient to keep it filled, with a slight overflow. It may be necessary to place a saucer on the surface of the sand below the inlet to prevent a hollow forming in the sand.

The filter should be cleaned when the flow becomes too small, normally after a few months. To clean the filter, drain out the water and scrape off a very thin layer, about 10 mm thick, from the sand surface and throw it away. Then lightly rake or scratch the sand surface to leave it loose. After several such cleanings, the sand bed must be topped up to its original level with clean sand.

If the filter has to be cleaned very often, the water is too silty and should be allowed to stand in a large tank or prefiltered beforehand. For prefiltration, an upward flow filter is useful (Figure 37b). An upward flow filter made from a 200 litre steel drum can filter 200 litres per hour, but the flow must be carefully controlled to avoid lifting the sand bed. The bed of coarse (3 to 4 mm) sand is supported on a plate pierced all over with 2 mm holes 50 mm apart. The advantage of the upward flow filter is that it is easy to clean the sand bed once a day by shutting off the flow and pulling out the drain plug.

## 8.4 CERAMIC AND PAPER FILTERS

The other simple kind of filter uses a porous porcelain hollow 'candle' or a paper cartridge. The very small pore sizes of these materials do not allow most bacteria to pass through, and the filter is sometimes impregnated with silver to kill the bacteria which are held back on its surface. There is also evidence that a silver-impregnated filter can remove some viruses.

The ceramic candle should be cleaned and boiled at least once a week, even if it has not clogged. If it has become clogged, it should be scrubbed under running water with a stiff brush free from soap, grease or oil, and then boiled for 20 minutes. The filters containing silver do not need boiling however. A paper cartridge needs to be replaced from time to time.

If the ceramic candle is cracked or the paper cartridge pierced, there is a danger that water will pass through without being purified. The filter should be regularly checked by eye to make sure it is intact.

The paper cartridge filters are cheaper to buy, but are more expensive to run as they need a supply of replacement cartridges. They are generally lighter and less fragile than the ceramic filters, but if allowed to dry they may shrink and crack, and so become ineffective. Where a range of candles is available, the finest-grained should be used. Some suppliers of this equipment are listed in Appendix D.

## 8.5 CHEMICAL DISINFECTANTS

Chemical disinfection is only effective on clean water. If the water is very dirty, it should be filtered first. Chlorine is the disinfectant normally used for community water supplies (Section 4.4), and can also be used on a domestic scale. It is contained in liquid hypochlorite solution, in powdered chloride of lime, and in special water sterilizing tablets.

Directions for using the tablets are on the packets. Chlorine solution can be applied by a small chlorinator (see Section 4.4), or by hand. To chlorinate by hand, mix up a 1% solution of chlorine in water, as described in Section 4.4. Add 3 drops of this solution to each litre of water to be treated, mix it thoroughly and allow it to stand for 20 minutes or longer before using the water. The amount to add will in fact vary depending on the strength of the bleach. If you do not know how much to add, add chlorine till you can taste it.

Iodine works in a similar way to chlorine. It can be bought as a tincture about 2% strong from chemists, and should be added at a rate of 2 drops per litre and left for half an hour to act before using the water. It is suitable for occasional use, but should not be used continuously for a long time lest it cause any unpleasant side effects.

## 8.6 BOILING

Boiling is effective in clean or cloudy water, and destroys all forms of disease-producing organisms usually found in water, including bacteria, viruses, spores, cysts and ova. However, it is expensive (roughly 1 kg of wood is required to boil a litre) and the water takes a long time to cool to a suitable temperature for drinking.

To be safe, the water should be boiled violently (not gently simmered) for at least five minutes. The appearance of small bubbles or of steam is not necessarily a sign of boiling. Boiling makes the water taste 'flat', but if it is left for a few hours in a partly filled, covered container, it will absorb air and lose its flat taste. The water should be kept in the same covered container as was used to boil it, to avoid recontamination. You will need at least two of these containers, which should only be used for this purpose.

## 8.7 DESALINATION

As for a community water supply, it is usually best to choose a source of salt-free water, because the removal of salt is normally very expensive. Where it is inevitable, the simplest and cheapest method, when possible, is distillation using the sun's heat.

This may be done with a still like that shown in Figure 38, or an equivalent device like a tent made from transparent plastic sheet (the roof) and black plastic sheet (the floor). A glass roof is more efficient, however. The silty water to be treated is poured into the central area and the troughs at each side should slope slightly so that the distilled water will drain to a storage tank. A unit 1 metre wide by 10 metres long was found in the Sudan to produce about 30 litres per day.

## 8.8 STORAGE IN THE HOME

No matter how much care you take to produce safe water, it will have been useless if the water is polluted after treatment. It is therefore very important to protect stored water from contamination. The containers used for storage must be kept clean and regularly rinsed with boiling water or washed out with a bleach solution (1 part liquid bleach to 5 parts water), which is later

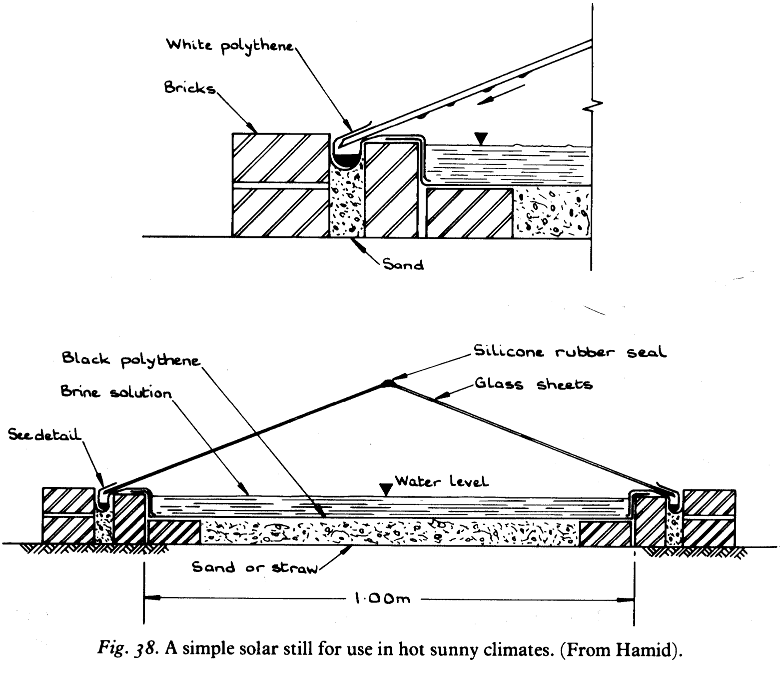

*Fig. 38.* A simple solar still for use in hot sunny climates. (From Hamid).

removed by rinsing with pure water. Each container should have a cover which fits closely enough to keep out insects, dust and other impurities. When possible, it is best to use containers with small mouths so that cups or hands cannot be dipped in the water. The best way to draw water is from a tap at the bottom of the container. Otherwise, arrangements should be made for easy pouring, either by tipping or by rolling the vessel.

# APPENDIX A: BACTERIAL ANALYSIS OF DRINKING WATER

by Duncan Mara, University of Dundee, Scotland

## A1 INTRODUCTION

The number of disease-causing organisms that can be found in polluted water is very large indeed. It is simply not possible to examine a water sample for the presence or absence of all of these organisms. Moreover they may often be only occasionally present in a water, even though the water is being polluted continuously. Therefore we look for the presence or absence of special bacteria which are *always* present in faeces and whose normal habitat is the intestine of man and higher mammals – bacteria which are therefore indicators of faecal pollution. One such bacterial group is the 'faecal coliform' bacteria (sometimes referred to as *Escherichia coli* or *E. coli*).

Faecal coliforms are not usually harmful to man; but if a water sample is shown to contain these organisms, then we know that the body of water from which it was obtained has been polluted with human or animal wastes. The water may therefore contain disease-causing organisms which *may* cause illness in those who drink it.

### A1.1 Bacteriological Tests

There are basically two techniques available for counting the numbers of faecal coliform bacteria present in a sample of drinking water: (1) the membrane filtration technique and (2) the multiple tube fermentation technique. The membrane filtration technique is undoubtedly the more accurate method and, for a skilled bacteriologist, somewhat easier; but the multiple tube test requires less specialised equipment, is cheaper and, for a person with little experience in practical bacteriology, much easier to do. The multiple tube test described below involves examining only five 10 ml portions of the sample; it is thus the simplest of the multiple tube tests but, since 'the absence of gas in all tubes, when five 10 ml portions are examined by the multiple tube method... is generally considered to meet the United States Public Health Service drinking water standards',[1] it is by no means *too* simple.

The collection and multiple tube analysis of water samples is described below as a series of simple instructions to a laboratory technician. A short description of the membrane filtration method is given at the end of this Appendix.

## A2 SAMPLE COLLECTION

Samples must only be collected in sterile bottles; see the next section for details of how to sterilize the sampling bottles.

### A2.1 Sampling from a Stream

1. Stand in the middle of the stream and face upstream. If necessary, wear waterproof boots and gloves to protect yourself against schistosomiasis.
2. Carefully remove the cap from the bottle. You must *not* touch the screw thread at the top of the bottle nor the inside of the cap. (If you should touch these parts of the bottle by accident, discard the bottle and use another one; the first one must be sterilized before it is used again. You should always carry a spare sampling bottle.)
3. With the mouth of the bottle facing upstream, lower the bottle into the stream and allow it to fill. Tilt the bottle upwards to let it fill completely. *Carefully* replace the cap.

### A2.2 Sampling from a Well

1. Tie a sample bottle on to a weighted length of rope or *strong* string. Use a stone or piece of metal weighing about 500 g as the weight and attach the bottle just above the weight. A convenient arrangement is shown in Figure A1.
2. Carefully remove the cap from the bottle and lower the bottle into the well to a depth of about 1 m. When no more air bubbles rise to the surface, raise the bottle out of the well and carefully replace the cap.

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[1] Standard Methods for the Examination of Water and Wastewater, 13th Edition, 1971.

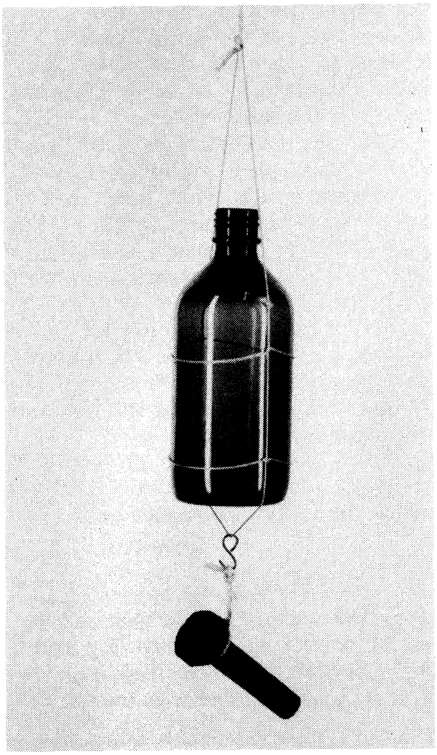

*Fig. A1.* A weighted bottle for sampling from wells.

## A2.3 Sampling from a Tap

1. Make sure the tap is clean, especially on the inside.
2. Turn the tap full on and allow the water to run to waste for 1 minute.
3. Close the tap until only a slow trickle of water is coming out.
4. Carefully open the sampling bottle.
5. Fill the sampling bottle with the water and carefully replace the cap. Screw it on tightly.

## A2.4 Sampling a Chlorinated Supply

When sampling a chlorinated supply it is necessary to neutralise any residual chlorine in the water, otherwise this chlorine will prevent any bacteria present from growing. Dechlorination is achieved by adding a small volume of sterile sodium thiosulphate solution to the water. The procedure is as follows:

1. Take a bottle of sodium thiosulphate in the form of white crystals ($Na_2S_2O_3.5H_2O$), and make up a 1% solution by adding 1 g of crystals to 100 ml of water.
2. Add this solution to the sampling bottles so that 0.2 ml of thiosulphate solution will be mixed with 100 ml of water sample. In other words, to a 100 ml bottle add 0.2 ml, to a 200 ml bottle add 0.4 ml and so on.
3. Sterilize the sample bottles containing the sodium thiosulphate, as described in Section A 3.2, and collect samples as described above.

This will ensure that the water samples are mixed with sterile sodium thiosulphate which will neutralise the chlorine in the water samples.

## A2.5 Frequency of Sampling

As well as testing water from any sources you are considering for a new water supply, you should also test the water from the supply after it is built, and preferably every few months after that. A hospital or clinic water supply should be tested at least every two months. Samples should be taken on each occasion at the point of abstraction, as the water leaves the treatment works (if any) and at various points in the distribution system (private connections and public standpipes).

# A3 PREPARATIONS FOR THE TEST

## A3.1 Making up MacConkey Broth

MacConkey broth is a special mixture of chemicals in water (properly called a 'medium') which is used to determine whether faecal coliforms are present in a water sample or not. To prepare 500 ml of double strength MacConkey broth (sufficient for 10 tests), proceed as follows:

1. Weigh out 40 grams of dehydrated Oxoid 'MacConkey broth (purple)' powder. This powder (reference number CM5a) is available from Oxoid Ltd., Wade Road, Basingstoke, Hampshire, U.K. Other companies

market a similar medium – e.g. Difco Laboratories Inc., Detroit, Michigan 48201, U.S.A. and Baltimore Biological Laboratories, Cockeysville, Maryland 21030, U.S.A. However with the Difco and BBL MacConkey broth you should use only 35 grams.

MacConkey broth powder is available in preweighed packs from Mast Laboratories Ltd. (38 Queensland Street, Liverpool, England). Use the '10 × 1 litre' packs and add the contents of one envelope to 500 ml of water to make double strength broth. These cost the same price as the bulk product from Oxoid and Difco. The use of preweighed packs means that a balance is unnecessary and weighing mistakes are avoided. The only drawback is that these prepacks are not generally available and would have to be specially ordered from Britain.

2. Fill up a graduated 1 litre beaker to 500 ml level with clear drinking water and add the 40 grams of MacConkey broth powder. Stir to dissolve. This solution is double strength MacConkey broth. It is of course possible to make up MacConkey broth from the individual constituents. But this is a tedious process and it is not usually possible to ensure that each batch of medium is identical – this can lead to significant errors in the test results. Dehydrated, powdered broth overcomes these disadvantages.

3. When the powder has dissolved, measure 10 ml of MacConkey broth into each of fifty screw-capped bottles (either 'universal containers' or 'McCartney bottles'), with capacity 28 ml (1 fluid ounce). A 10 ml tilting pipette is a convenient means of dispensing the solution.

4. Add to each bottle an inverted Durham tube; this is a small test tube which is used to detect gas production (see Figure A2). Make sure that the open end of the Durham tube is at the bottom of the bottle.

5. Screw the caps on to the bottles. Do NOT tighten the caps but leave them loose. Sterilize the bottles as described below.

### A.3.2 Sterilization

Before a water sample can be analysed, all the bacteria present in the glassware and the MacConkey broth must be killed; if they were not, they would interfere with the test on the

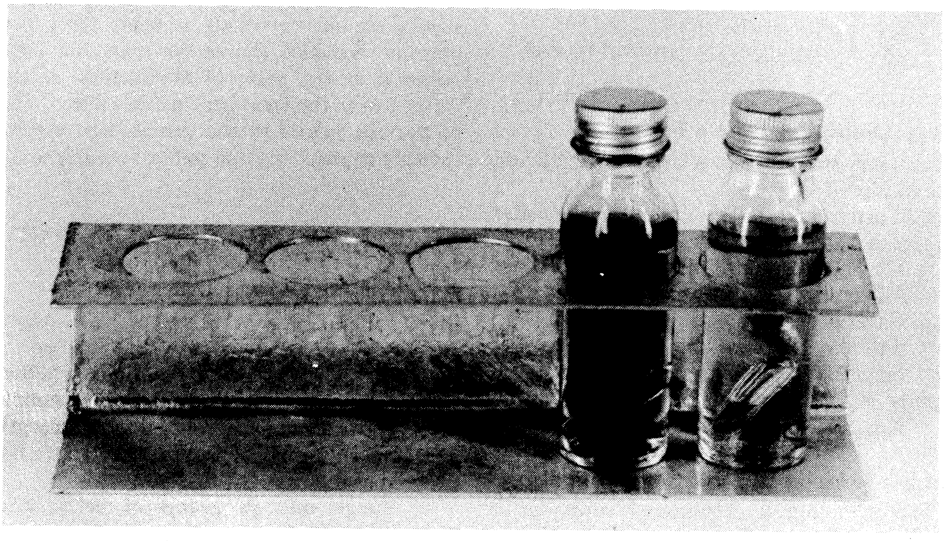

*Fig. A2.* Multiple tube technique. In the right hand bottle the MacConkey broth has turned yellow and gas has collected in the Durham tube inside. The picture also illustrates a simple bottle rack to hold the five bottles required for the test.

sample – we are only interested in the bacteria in the water sample, not those on the surfaces of the glassware or those on your hands. The process of killing bacteria is called sterilization.

The following items need to be sterilized:

(a) Sampling bottles.
(b) Screw-capped bottles containing Durham tubes and MacConkey broth.
(c) 10 ml measuring cylinders and 10 ml beakers – these are used to transfer 10 ml of the water sample to each screw-capped bottle (see next section on Test Procedure); the 10 ml beaker is placed over the open end of the cylinder in order to protect the inside of the cylinder from becoming contaminated after it has been sterilized.

An ordinary domestic pressure cooker is recommended as the sterilizer. The temperature of the steam inside the pressure cooker reaches 120°C which, when maintained for 15 minutes, kills all the bacteria which are likely to interfere with the test.

To use the pressure cooker, follow the manufacturer's instructions. The items should be 'cooked' for 15 minutes at 120°C (this temperature is achieved at a steam pressure of 15 pounds per square inch). Bottle caps should only be screwed on loosely – otherwise they may explode. Make sure that the 10 ml cylinders are fitted with 10 ml beakers. When the bottles have cooled after being sterilized, screw the caps down tightly.

### A.3.3 General Cleanliness

The work area set aside for analysing water samples should always be kept very clean. Try to choose an area free from both dust and draughts. Always wash your own hands before you start to analyse a sample. Rinse out all glassware with clean water immediately after use.

## A.4 TEST PROCEDURES

There are two tests: The 5 × 10 ml test and the 5 × 1 ml test. They are very similar – the only difference being the range of counting: the 5 × 10 ml test can count up to 16 faecal coliforms per 100 ml whereas the 5 × 1 ml test can count up to 160 per ml. Always use the 5 × 10 ml test first and only use the 5 × 1 ml on subsequent samples from the same source if the faecal coliforms count is more than 16 per 100 ml (see below for further details).

It is not always necessary to do the 5 × 1 ml test and your laboratory may not have the extra equipment required for it. The 5 × 10 ml test is the more important one.

### A.4.1 The 5 × 10 ml Test

1. Vigorously shake the sampling bottle to mix its contents thoroughly.

2. Pour the sample into a sterile 10 ml measuring cylinder to the 10 ml mark. Remember not to touch the top of the sampling bottle, nor the top of the cylinder.

3. Add this 10 ml of the sample to a screw-capped bottle which contains 10 ml of sterile double strength MacConkey broth and an inverted Durham tube.

4. Using the same measuring cylinder repeat steps 2 and 3 four more times. You should now have 5 screw-capped bottles each with 10 ml of the sample.

5. Make sure that the inverted Durham tube is full of liquid. If there is any air trapped inside it, tighten the bottle cap and turn the whole bottle upside down. The air will now rise up out of the Durham tube; when this has happened, quickly turn the bottle upright again.

6. Place the 5 bottles in a bottle rack (such as the homemade one shown in Figure A2) and place the rack in a water bath which has been set at *exactly* 44°C (see below for the reasons for choosing an incubation temperature of 44°C rather than 35° or 37°C). The caps on the bottles should only be screwed on loosely.

7. After 24 hours remove the rack from the water bath and examine each bottle for the production of acid and gas.

Acid production: If acid has been produced the colour of the MacConkey broth will have changed from red or purple to yellow.

Gas production: If gas has been produced, some of it will have been trapped in the Durham tube where it will be visible (Figure A2). If necessary, tilt the bottle so that the

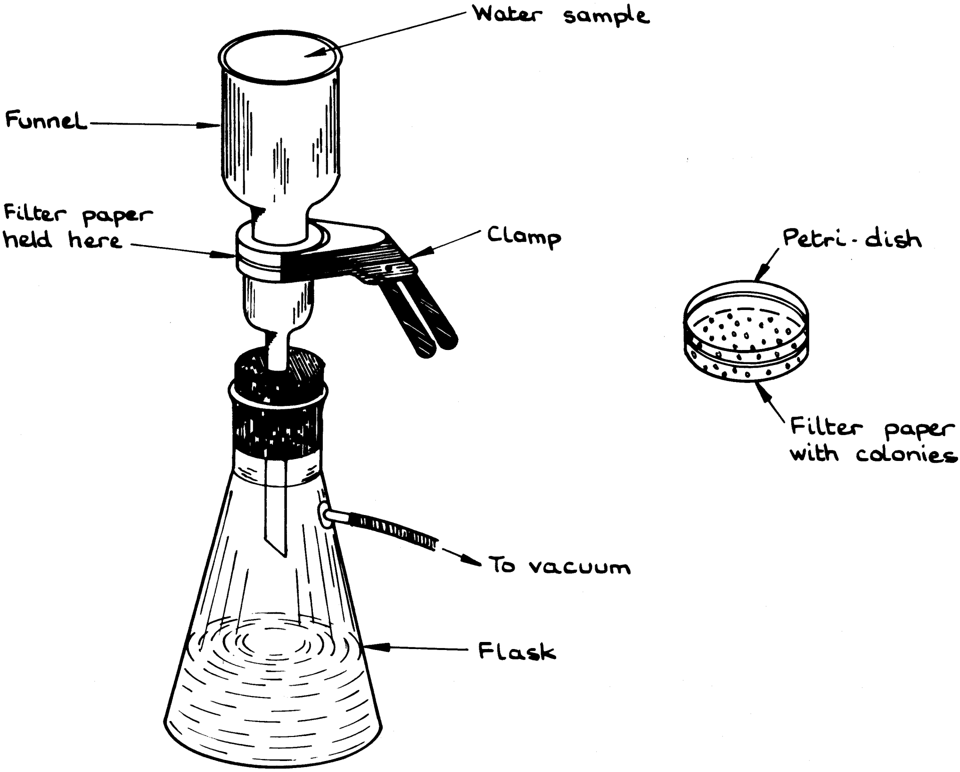

*Fig. A3.* Membrane filtration assembly.

Durham tube is next to the bottle wall – this allows you to see the gas more easily.

8. Count the number of bottles in which both acid and gas have been produced. Read off the most likely faecal coliform count from the following table (this count is often called the 'most probable number' or 'MPN' of faecal coliforms in 100 ml of the sample):

| Number of positive bottles (acid and gas production[1]) | Most likely faecal coliform count per 100 ml of the water sample |
|---|---|
| 0 | 0 |
| 1 | 2 |
| 2 | 5 |
| 3 | 8 |
| 4 | 16 |
| 5 | >16 |

9. Sterilize all the bottles and their contents before cleaning them. This is to ensure that large numbers of live bacteria do not escape into the environment.

10. If all 5 bottles are positive it is not possible to obtain a faecal coliform count. Use the 5 × 1 ml test for the next sample taken from the same source.

### A.4.2 The 5 × 1 ml Test

This test is identical to the 5 × 10 ml test except that 1 ml quantities of the sample are added (by means of a sterile 1 ml pipette) to screw-capped bottles which contain 5 ml of

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[1] Acid production without gas production is a negative result.

single strength MacConkey broth (the bottles are also fitted with smaller Durham tubes).

Single strength MacConkey broth is most conveniently obtained by mixing together equal parts of the double strength broth and water before sterilization.

The 1 ml pipettes should be individually wrapped in aluminium foil and placed in the oven of a domestic electric or gas cooker for 1 hour at 160°C. If such a cooker is not available then pre-sterilized disposable pipettes must be used (e.g. Sterilin Ltd., 43 Broad Street, Teddington, England). When you use the pipette, be careful not to touch its tip or any part which comes in contact with the water sample.

The test procedure is otherwise the same as that for the 5 × 10 ml test. The faecal coliform count is obtained from the following table:

| Number of positive bottles (acid and gas production[1]) | Most likely faecal coliform count per 100 ml of the water sample |
|---|---|
| 0 | 0 |
| 1 | 20 |
| 2 | 50 |
| 3 | 90 |
| 4 | 160 |
| 5 | >160 |

If a water source consistently has more than 160 faecal coliforms per 100 ml, it is possible to do a 5 × 0·1 ml test. This is the same as the 5 × 1 ml test except that 0·1 ml quantities are used; the 1 ml pipettes are graduated to 0·01 ml so they may be used to deliver 0·1 ml – some considerable care is needed however to deliver a volume as close to 0·1 ml as possible. The results may be obtained from the table for the 5 × 1 ml test; however multiply the count given in the table by 10.

### A.4.3 Incubation Temperature

Usually we incubate MacConkey broth cultures at 35°C or 37°C to obtain a total (i.e. faecal+non-faecal) coliform count and then we examine any positive tube to determine if the result was due to faecal coliforms. This is a satisfactory procedure only in temperate climates; too many saprophytic lactose-fermenting bacteria grow from tropical water samples if the incubation temperature is 35-37°C. These organisms have no sanitary significance and to avoid a high incidence of false positive results an incubation temperature of 44°C is chosen. At this temperature false positive reactions can occur due to the growth of anaerobic spore-forming bacteria, but the incidence of these false reactions is likely to be significantly less than those occurring at the lower temperatures. Preincubation for 2-6 hours at 30-35°C, while usually advisable in temperate climates, is not considered necessary in the tropics.

## A.5 EQUIPMENT

The room in which the tests are done must be provided with electricity (to operate the pressure cooker and the water bath). It should also be provided with a sink and cold water (to wash glassware after use). The equipment required for the tests is listed on p. 68. The most important piece of equipment is the water-bath; it is essential to maintain the incubation temperature to within $\frac{1}{2}$° of 44°C. The electric hotplate is not essential; for example a simple charcoal stove is a perfectly satisfactory alternative.

## A.6 MEMBRANE FILTRATION

The principle of membrane filtration is very simple indeed: a known volume of the water sample is filtered through a filter paper which has a pore size smaller than bacteria: thus all the bacteria in the water sample are retained on the filter paper which is then transferred to an absorbent pad soaked in nutrients; the bacteria then grow on the surface of the filter paper into colonies, just as they do on the surface of an agar medium in a Petri dish. The special 'membrane' filter paper is commonly 47 mm in diameter and has a pore size of just under 0·5 μm; a special membrane

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[1] Acid production without gas production is a negative result.

## List of equipment required for multiple tube analysis of drinking water samples

| *Operation* | *Quantity*(a) | *Item* | *Source*(b) *& Reference No.* | *Cost*(c) |
|---|---|---|---|---|
| Sampling | 30 | 125 ml polypropylene bottles(d) | Gallenkamp: BTK-270-070T | 3·60 |
| Media preparation | 1 | 'Speedscale' balance(e) | Gallenkamp: BCJ-260-X | 46.65 |
| | 10 | 150 ml polypropylene beakers(e) | Gallenkamp: BNH-700-070J | 2·10 |
| | 5 | 1000 m polypropylene beakers | Gallenkamp: BNH-700-130R | 2·35 |
| | 3 | 10 ml automatic tilting pipettes | Gallenkamp: PMR-780-080P | 7·20 |
| | 3 | 5 ml automatic tilting pipettes(f) | Gallenkamp: PMR-780-070S | 6·75 |
| | 1 gross(g) | 1 oz McCartney bottles | Gallenkamp: BTS-300-052F | 15·40 |
| | 1 gross(g) | 50 mm Durham tubes | Gallenkamp: TEW-380-070R | 2·17 |
| | 2 gross(g) | 30 mm Durham tubes(f) | Gallenkamp: TEW-380-030G | 12·81 |
| Sterilization | 1 | Pressure cooker | Prestige: 6185 | 11·40 |
| | 1 | Electric hotplate | Gallenkamp: HPS-340-010L | 18.70 |
| Inoculation | 20 | 10 ml measuring cylinders | Gallenkamp: CYL-300-032X | 10·60 |
| | 20 | 10 ml beakers | Gallenkamp: BNB-300-030V | 3·80 |
| | 20 | 1 ml pipettes(f) | Gallenkamp: PMF-670-040B | 6·80 |
| Incubation | 1 | Water bath, with lid | Grant: JB2 and LJ2 | 71·20 |
| | 3 | Thermometers −10°C — 50°C | Gallenkamp: THL-210-030C | 3·75 |
| Miscellaneous items | | Bottle racks<br>draining racks, etc. | | approx. 10.00 |
| | | | Total | £235.00 |

### Notes

(a) The quantities quoted are in many cases higher than the minimum required. This is to permit an initial stock and so allow for breakage.

(b) Gallenkamp: A. Gallenkamp & Co. Ltd., Christopher Street, London EC2P 2ER, UK.
Prestige: Prestige Group Ltd., 14/18 Holborn, London EC1N 2LQ.
Grant: Grants Instruments Ltd., Barrington, Cambridge CB2, UK.
These firms have been chosen because their catalogues are readily available as reference volumes to identify the items required. Other firms of course market the same or similar items, possibly at lower cost.

(c) UK sterling prices in April 1977.

(d) Polypropylene is a plastic which does not melt at 120°C; most other common plastics do melt at this temperature. If polypropylene is unavailable, use glass bottles.

(e) These items would not be required if preweighed packs of MacConkey broth were used.

(f) These items are only required for the 5 × 1 ml test.

(g) Minimum quantities available (1 gross = 144). These items could of course be shared between several laboratories.

filtration unit is used – one of these is shown in Figure A3.

The principal disadvantage of the membrane filtration technique is cost: the membrane filters cost about £0·12 each, although the National Environmental Engineering Research Institute in Nagpur, India, manufactures them at about a tenth of this price. However the ancillary equipment – filtration unit, special forceps, absorbent pads, small Petri dishes – is also expensive. Moreover, even though a skilled bacteriologist finds this a simple method in practice, an inexperienced operator is almost certain to have considerable difficulty in handling the filter and the rest of the apparatus with a sufficiently rigorous aseptic technique. In the examination of small supplies the simple multiple tube tests described in this Appendix are much more likely to give reproducible results, and at lower cost.

## A.7 INTERPRETATION OF RESULTS

Ideally, of course, all five bottles should be negative as drinking water should preferably contain no *E. coli* at all. But in rural areas, villages and small towns, the provision of drinking water with zero *E. coli* is often impossible. It is impossible to lay down a rigid standard of bacteriological water quality for general application, and the results of these tests should mainly be used for comparing alternative sources, and for monitoring against any deterioration over a period of time. However, as a basis for the preliminary examination of water quality, we offer the following interim 'standards' for use with the 5 × 10 ml test on chlorinated supplies, for which bacteriological tests serve mainly as a check on the chlorination system:

### Chlorinated Supplies (samples taken before entering the distribution system)

(a) In not less than nine tenths of the number of tests done over a twelve month period, there should be no positive bottles in each test; i.e. for 90% of the time *E. coli* should be absent.

(b) In no test should there be more than two positive bottles; i.e. the *E. coli* count should never exceed 5 per 100 ml.

### Unchlorinated Supplies

It is impossible to set standards for unchlorinated supplies to small communities in the tropics which would have any general applicability. Most, if not all, untreated supplies contain faecal bacteria and, in villages without piped supplies, levels of 1000 *E. coli* per 100 ml are not uncommon. If the supply uses ground water and is well constructed (e.g. a boxed spring, sealed well or tube well) it might be appropriate to aim for the following goals:

(a) In any twelve month period the average number of positive bottles in each test (on samples from the same source) should not be more than three: i.e. the average *E. coli* should be less than 8 per 100 ml.

(b) In no test should there be more than 50 *E. coli* per 100 ml, i.e. not more than two positive bottles in the 5 × 1 ml test.

The local water engineer or health authorities should be informed about any improved water supplies which consistently fail to meet these standards, so that they will be able to investigate the cause of the pollution and thus be in a better position to improve the quality of the water. In the case of potential sources for a proposed water supply, the quality of the water will affect the choice of the type of source (e.g. protected springs versus streams). It has been pointed out elsewhere in this Bulletin that it is preferable to choose a source of good quality and protect it, than to use a poor quality source and treat it.

In the choice between alternative sources of the same type, quality will tend to be less important than the distance or reliability of the various sources.

## BIBLIOGRAPHY TO APPENDIX A

D. D. Mara, *Bacteriology for Sanitary Engineers,* Churchill-Livingstone, Edinburgh, 1974.

Millipore Corporation, *Biological Analysis of Water and Wastewater,* Application Manual AM302; available from Millipore Intertech Inc., P.O. Box 255, Bedford, Mass. 01730, USA.

National Environmental Engineering Research

Institute, *Membrane Filter*, Technical Digest No. 14, February 1971; available from NEERI, Nehru Marg, Nagpur 20, India.

**Note:** This Appendix is largely based on the author's article in *Appropriate Technology*, November 1976, pp. 7-10.

# APPENDIX B: THE GAUGING OF YIELD

## B.1 INTRODUCTION

When choosing a source of water to supply a community, you must be sure that it will provide enough water. This means you will sometimes have to measure the water available or flowing from the source (the 'yield' of the source). Remember that most water sources flow much more slowly during dry seasons of the year. It is best to measure their flow towards the end of the dry season, or at least after a period without much rain. Some of the springs which flow most powerfully after rain are the first to dry up in dry weather. There is certainly no need to make very accurate measurements. If a source provides only just enough water, that probably means it will not be sufficient in the long term, so you should allow a wide margin of safety. It is also helpful to ask the local inhabitants, if it is a spring, stream or existing well, how often it has dried up in the past.

## B.2 SPRINGS

In order to gauge a spring, you will need to gather the flowing water together, perhaps with a small earth dam. In some cases, you

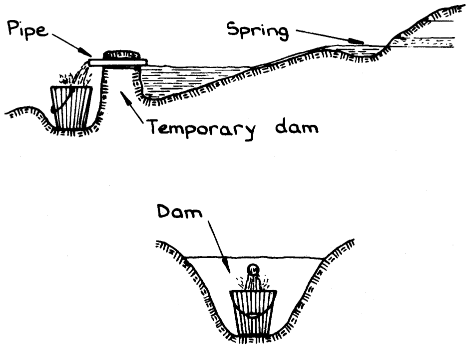

*Fig. B1.* Gauging the flow from a spring using a pipe and a temporary dam.

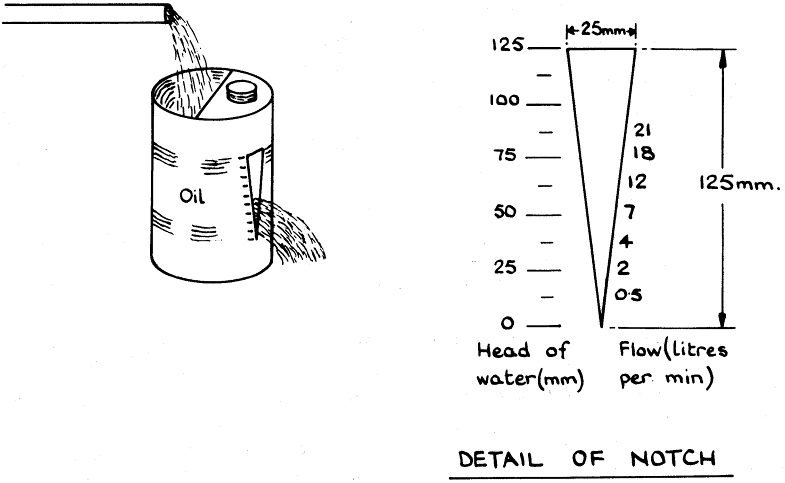

*Fig. B2.* Using a box or old oil can as a V-notch gauge.

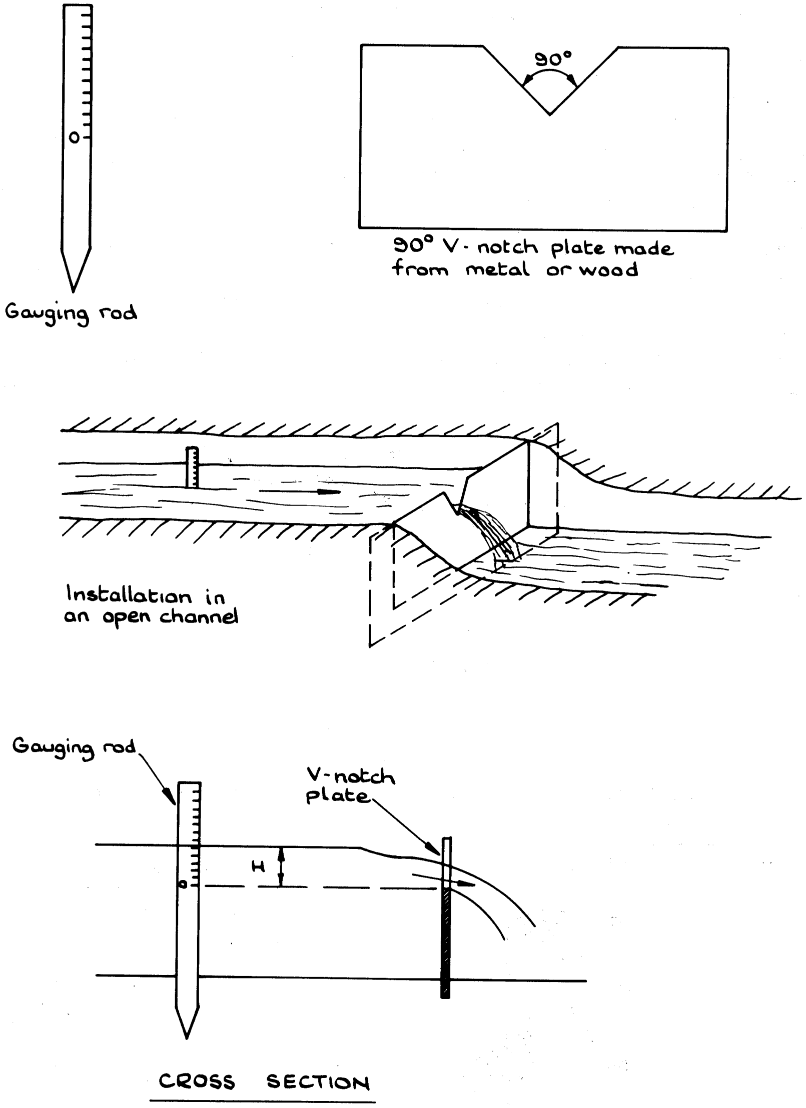

*Fig. B3.* Using a 90° V-notch to measure flow.

will find that the water from the spring overflows from a small pool. If the flow is very small, you may be able to bale a measured volume out of the pool with a bucket, and measure how long the pool takes to fill up again. Otherwise, you may be able to arrange for all the water to flow through the dam by a pipe (Figure B1) or, if the flow is larger, through several pipes. In that case, you measure the flow in each, and add them up to get the total.

The simplest method of measuring the flow from a pipe is to see how long it takes to fill a bucket whose size you know. If it takes less than 5 seconds, you should use a larger bucket or divide the flow through several pipes, or use another method. You can measure the volume of water the bucket holds by weighing it empty and full, and calculating the difference, the weight of water. One litre of water weighs 1 kg. Measure the time taken to fill the bucket three times and take the average. The flow in litres per second is then the volume of the bucket in litres, divided by the time in seconds.

Another method is to use a V-notch. Figure B2 shows how a V-notch can be cut in the side of a 5-litre oil can. The notch must be cut accurately with straight sides. The flow in litres per second is read from the scale of the side. For larger flows, a V-notch with a 90° angle can be cut in a thin sheet of metal or plywood, and placed in the middle of a dam so the water flows over it. The water level must then be measured well back from the notch. A gauging rod can be used to do this (Figure B3). The zero point on the rod should be level with the bottom of the notch. Table B1 shows the flow in litres per second for a given height of water above the zero.

**Table B1**

*Flow over a 90° V-notch*

| *Height of water H (mm)* | *Flow (litres/second)* |
|---|---|
| 50 | 0·8 |
| 60 | 1·2 |
| 70 | 1·9 |
| 80 | 2·6 |
| 90 | 3·4 |
| 100 | 4·5 |
| 110 | 5·6 |
| 120 | 7·0 |
| 130 | 8·6 |
| 140 | 10·3 |
| 150 | 12·3 |

If the flow from a pipe is too fast for the bucket or the V-notch method, you can measure it by placing the pipe horizontally, and measuring the stream of water flowing from it with a straightedge (Figure B4). The pipe should be straight and have a constant diameter for the last metre before the end. The flow can be read from Table B2.

**Table B2**

*Water flow from horizontal pipes (litres/second)*

| Horizontal distance, x (mm) – see Fig. B4 | Nominal pipe diameter (mm) | | | | |
|---|---|---|---|---|---|
| | 25 | 32 | 37 | 50 | 62 |
| 100 | 0·36 | 0·6 | 0·8 | 1·4 | 2·0 |
| 125 | 0·45 | 0·8 | 1·0 | 1·7 | 2·5 |
| 150 | 0·54 | 0·9 | 1·3 | 2·1 | 3·0 |
| 175 | 0·6 | 1·1 | 1·5 | 2·4 | 3·5 |
| 200 | 0·7 | 1·2 | 1·7 | 2·8 | 3·9 |
| 225 | 0·8 | 1·4 | 1·9 | 3·1 | 4·4 |
| 250 | 0·9 | 1·5 | 2·1 | 3·5 | 4·9 |
| 275 | 1·0 | 1·7 | 2·3 | 3·8 | 5·4 |
| 300 | 1·1 | 1·8 | 2·5 | 4·2 | 5·9 |
| 325 | 1·2 | 2·0 | 2·7 | 4·5 | 6·4 |
| 350 | 1·3 | 2·1 | 2·9 | 4·9 | 6·9 |
| 375 | 1·3 | 2·3 | 3·1 | 5·2 | 7·4 |
| 400 | 1·4 | 2·5 | 3·3 | 5·5 | 7·9 |

## B.3 STREAMS

To measure the flow in a large stream, find a stretch of the stream which is straight, of fairly constant width, and clear of obstructions for a distance at least 6 times the average water depth. The stream should be at least 300 mm deep. Measure out a length along the bank and throw a floating object into the centre of the stream at the top end of this length. An orange is handy for this. Time how long it takes to reach the bottom end. Repeat this three times and take the average time in seconds.

Then the flow in the stream in litres per second is roughly:
850 × measured length × width of stream × average depth/average time, where all the lengths are in metres.

For smaller streams, you should build a dam of earth across the stream and then gauge it as for a spring (Figure B1).

## B.4 WELLS AND BOREHOLES

The yield of a well or borehole can only be measured by pumping a measured flow of water from it and observing the drop in the

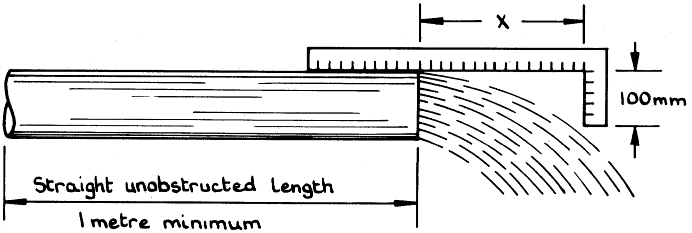

*Fig. B4.* Measurement of flow from a horizontal pipe.

water level inside the well. The depth to the water level can be measured with a weight on the end of a piece of dry string. Lower the weight till it is underwater, mark the point at ground level on the string and then pull up the weight and measure the length of string from the marked point to the highest wetted point. The flow from the pump can be measured using one of the methods described above for springs.

Find how fast you can pump for the water level to settle down to a fixed level. This is the pumping yield. Then stop pumping and check that the water returns to its original level.

# APPENDIX C: IMPERIAL UNITS

## *Length*

No lengths quoted in this Bulletin have to be copied exactly. If you are working in Imperial units (inches, feet and yards), the following rough working rules will be sufficiently accurate:

| *Metric* | *Imperial equivalent* |
|---|---|
| 25 mm | 1 inch |
| 0·1 m = 10 cm = 100 mm | 4 inches |
| 0·3 m = 30 cm = 300 mm | 12 inches = 1 foot |
| 1 m = 100 cm = 1000 mm | 3 feet = 1 yard |

| *mm* | *inches* | *mm* | *inches* |
|---|---|---|---|
| 1 | 1/32 | 7 | 9/32 |
| 2 | 1/16 | 8 | 5/16 |
| 3 | 1/8 | 9 | 3/8 |
| 4 | 5/32 | 10 | 13/32 |
| 5 | 3/16 | 11 | 7/16 |
| 6 | 1/4 | 12 | 1/2 |

For smaller lengths, the following approximate conversion table may help:

## *Volume*

Roughly,
1 litre = 1000 ml
= 2·1 US pints
= 1·8 Imp. pints
100 litres = 26 US gall.
= 22 Imp. gall.
1 cubic metre = 1000 litres
= 264 US gall.
= 220 Imp. gall.

## *Flow,*

Roughly,
1 litre/sec. = 16 US gall./minute
= 13 Imp. gall./minute
= 950 US gall./hour
= 790 Imp. gall./hour
= 22,800 US gall./day
= 19,000 Imp. gall./day
= 86,400 litres/day
= 86·4 cubic metres/day

# APPENDIX D: FURTHER INFORMATION

## D.1 USEFUL ADDRESSES

**For books, advice and information:**

ITDG (Intermediate Technology Development Group)
9 King Street,
London WC2E 8HN,
England.

USAID,
Health Service,
Office of War on Hunger,
Agency for International Development,
Washington DC 20523,
USA.

VITA (Volunteers in Technical Assistance),
3706 Rhode Island Avenue,
Mount Rainer,
Maryland 20822,
USA.

WHO International Reference Centre for Community Water Supply,
PO Box 140,
Leidschendam,
Netherlands.

Any of these will send a list of publications if requested; some of their publications are listed in Section D2 below.

**For 'Millbank' water filtering bags:**

Johnson-Progress Ltd.,
Carpenters Road,
Stratford,
London E15 2DS,
England.

**For chlorination tablets and iodine:**

The Boots Co. Ltd.,
Nottingham, NG2 3AA,
England.

Wilkinson & Simpson Ltd.
57 Queensway,
Team Valley Trading Estate,
Gateshead,
Tyne & Wear NE11 0NS,
England.

Wilkinson and Simpson also sell equipment for measuring the chlorine content of water. For accurate measurement, you would require a box of tablets, a Lovibond 1000 comparator with one or two spare test tubes, and comparator disc no. 3/40A. This will cost about £30 altogether. A much cheaper alternative would be to buy only the tablets and a colour chart, also available from Wilkinson and Simpson.

**For drip-feed chlorinators:**

A. Bell & Co. Ltd.,
Kingsthorpe,
Northampton NN2 6LT,
England.

**For paper cartridge filters:**

Victoria Industrial Contracts Ltd.,
443-445 Holloway Road,
London N7 6LW,
England.

**For silver impregnated ceramic candle filters:**

Portacel Ltd.,
Cannon Lane,
Tonbridge,
Kent TN9 1PP,
England.

C. M. Wales Ltd.,
Findrassie,
Nether Lane,
Nutley,
Sussex TN22 3LA,
England.

Doulton Industrial Products Ltd.,
Stone,
Staffs. ST15 0PU,
England.

**For boring and jetting equipment:**

Duke & Ockenden Ltd.,
River Road,
Littlehampton,
West Sussex,
England.

English Drilling Equipment Co. Ltd.,
Lindley Moor,
Huddersfield,
Yorkshire HD3 3RW,
England.

Engineering Laboratory Equipment Ltd.,
Frogmore Road,
Hemel Hempstead,
Herts HP3 9RL,
England.

**For hand pumps:**

Consallen Structures Ltd.,
291 High Street,
Epping, 0378 74677
Essex CM16 4BY,
England.

H. J. Godwin Ltd.,
Quenington, COLNE ST ALDWYNS
Cirencester, 271
Glos GL7 5BX,
England.

Lee, Howl & Co. Ltd.,
Alexandra Road,
Tipton,
West Midlands DY4 8TA,
England.

253 8911

Mono Pumps Ltd.,
Sekforde Street,
Clerkenwell Green,
London EC1R 0HE,
England. E530
HOLMAN,

~~BARNABY CLIMAX LTD~~
~~WHITE LADIES CLOSE~~
~~LITTLE LONDON~~
~~WORC. WR1 1PZ~~

**For hydraulic rams:**

John Blake Ltd.,
PO Box 43,
Royal Works,
Accrington,
Lancashire BB5 5LP,
England.

**For solar pumps:**

Sofretes,
B.P. 163,
45203 Montargis,
France.

**For SWS filters:**

Sea Water Supplies Ltd.,
North Parade,
The Promenade,
Skegness,
Lincs PE25 1DB,
England.

## D.2 FURTHER READING

**For guidance on methods of construction:**

*Small wells manual,* by G. P. Gibson and R. D. Singer, published by USAID, 1969. A technical manual for tube wells and boreholes.

*The introduction of rainwater catchment tanks and micro-irrigation to Botswana,* by P. Moody, published by ITDG, 1969. A case study of the polythene tube method of tank construction.

* *Village technology handbook,* published by VITA, 1970. Full of suggestions for simple technology, with an emphasis on how to make things.

*Water Supply for rural areas and small communities,* by E. G. Wagner and J. N. Lanoix, published by WHO, 1959. A very thorough, but rather expensive and dated, survey of the subject.

*Chinese chain and washer pumps,* by S. B. Watt, published by ITDG, 1976. Brief descriptions of a wide variety of these pumps.

* *Hand-dug wells and their construction,* by S. B. Watt and W. E. Wood, published ITDG 1977. A cheap and comprehensive practical manual, with a good annotated booklist on water supply.

*Hand pumps,* by F. E. McJunkin, published by WHO International Reference Centre for Community Water Supply, 1977. A very detailed handbook.

**For more general background reading:**

*A bibliography of low-cost water technologies,* compiled by G. H. Bateman, published by ITDG, 1974.

*Water, wastes and health in hot climates,* edited by R. Feachem, M. McGarry and D. Mara, published by John Wiley and Sons, 1977.

*Drawers of Water: domestic water use in East Africa,* by G. White, D. Bradley and A. White, published by University of Chicago Press, 1972.

The addresses of ITDG, VITA and USAID are given in Section D.1 above.

# PUBLICATIONS OF THE ROSS INSTITUTE

| | | |
|---|---|---|
| | *The Preservation of Personal Health in Warm Climates*<br>(A handbook for those going to the tropics for the first time) | ISBN 0 900995 01 7 |
| | *Ross Institute Bulletins*:- | |
| (1) | Insecticides.<br>(Revised) July 1976. | ISBN 0 900995 02 5 |
| (2) | Anti-malarial Drugs.<br>(Reprinted) April 1975. | ISBN 0 900995 03 3 |
| (3) | (Out of print) | |
| (4) | Tropical Ulcer.<br>(Revised) August 1973. | ISBN 0 900995 04 1 |
| (5) | The Housefly and its Control.<br>(Reprinted) August 1974. | ISBN 0 900995 05 X |
| (6) | Schistosomiasis.<br>(Reprinted) May 1974. | ISBN 0 900995 06 8 |
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| (10) | Small Water Supplies.<br>(Rewritten) January 1978. | ISBN 0 900995 10 6 |
| (11) | Anaemia in the Tropics.<br>(Reprinted) June 1974. | ISBN 0 900995 11 4 |
| (12) | Protein Calorie Malnutrition in Children.<br>(Reprinted) June 1974. | ISBN 0 900995 12 2 |

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