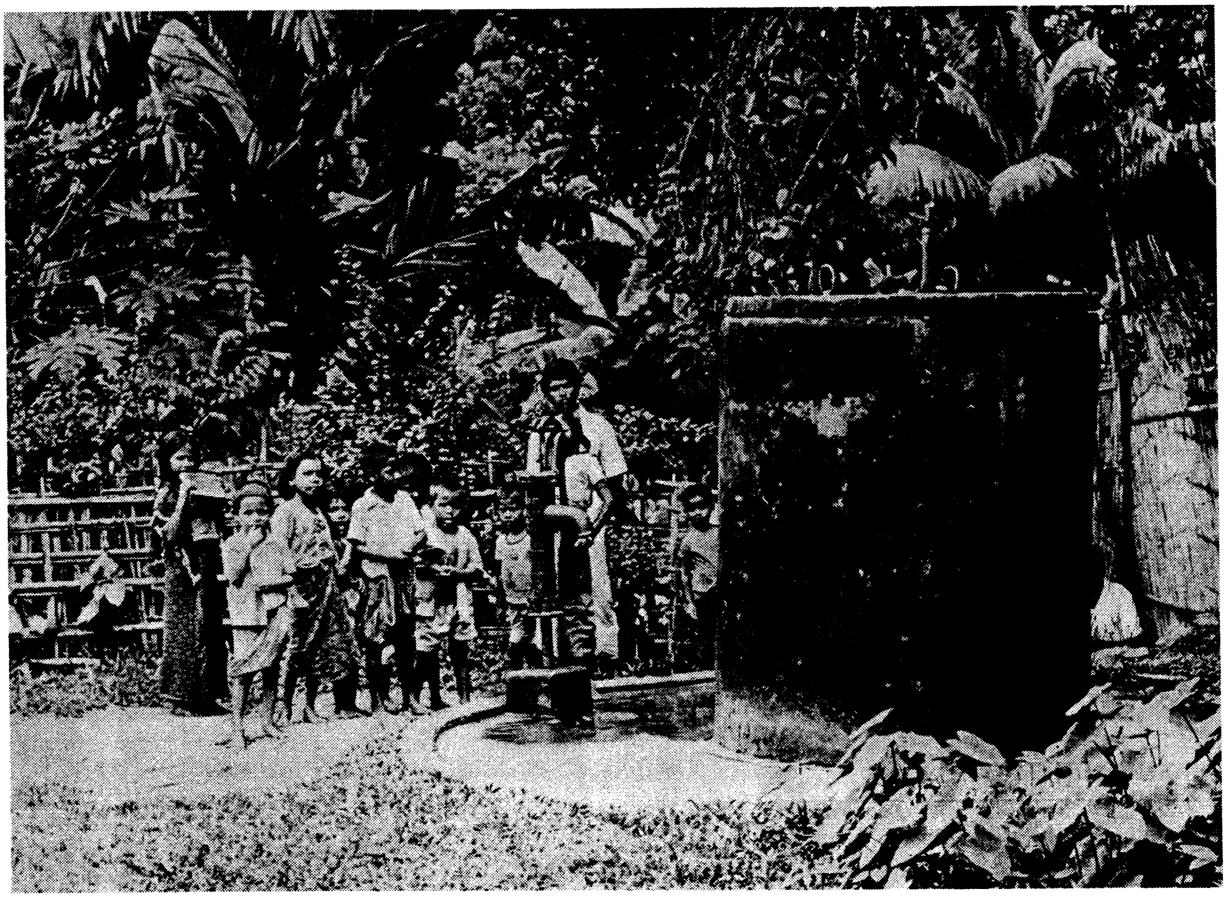
overseas building notes

Information on housing and construction in tropical and sub-tropical countries

No 178 February 1978

VILLAGE WATER SUPPLIES

by A M Cairncross



A hand pump installed on a hand dug well. The access cover is out of reach of children and too heavy for them to tamper with.

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VILLAGE WATER SUPPLIES

by A M Cairncross, MA, PhD (Cantab)

INTRODUCTION

At least one in four of the rural water supplies in most developing countries is out of order, and has frequently been broken down for some time. Very often the reason a rural water supply has not been repaired is connected with organisational problems, particularly at village level, but there are usually technical reasons why it broke down in the first place. These technical reasons may at first sight appear to be problems of poor standards of workmanship due to a shortage of skilled and supervisory staff. But these problems are almost inevitable in most developing countries, and the engineer who blames them for poor breakdown rates is rather like a workman blaming his tools. Good engineering requires designs which can be built, and technology which can be made to work, *with the labour and materials currently available.*

For instance, the engineer cannot usually rely on high standards of pipe laying to regular falls, with full compaction of the soil replaced around and above the pipe. The slopes on pipelines should be large enough to allow for air locks due to uneven gradients, and for errors in the original survey.

This can be turned into an advantage, because if it means that the minimum permitted gradient for a gravity-fed pipeline is, say, 1 in 50, then the maximum possible size of pipe required for a given flow is only 60 per cent larger than would be required for a very steep slope of 1 in 5. For a given flow capacity, therefore, the pipe size required for any likely slope can be chosen from a range of only two or three. This means that pipe sizes can be selected from a table like Table 1 by a technician who would be likely to find a Hazen-Williams pipe flow chart confusing.

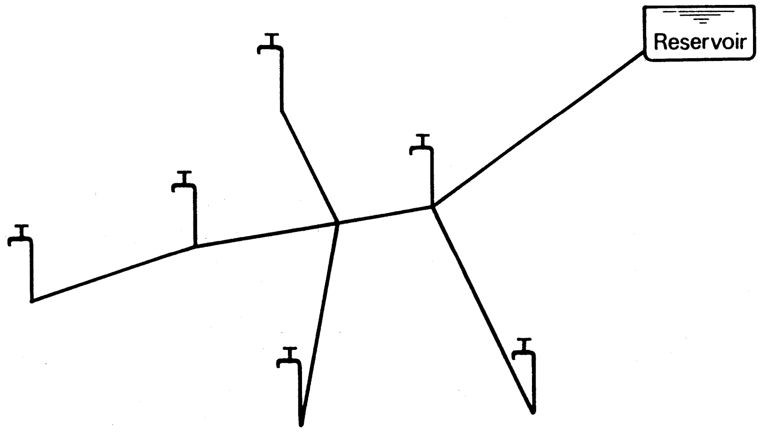
If it is important for water supply technology to be designed so that it can be made to work under the existing construction conditions, it is even more important that it should continue to work under the prevailing maintenance conditions. Water treatment plant, for example, generally requires a level of attention and skill in operation quite unattainable in a small community. Since there is little point in installing water treatment facilities if they will not be reliably operated, it is almost always preferable to find a source of good quality water and protect it from pollution, rather than to take water from a doubtful source and treat it. Pumps, too, of any kind, frequently break down or fall into disuse in rural areas. Motorised pumps, especially, should only be installed where adequate arrangements have been made to pay for their running costs. It is often preferable to choose a source of water high enough to permit a gravity-fed supply, rather than to take water from a source where pumping is required.

It is best to try to build a 'fail-safe' character into rural water supplies so that one small fault is not likely to put the whole system out of action. For example, a ring main is preferable to a 'dendritic' distribution system (Figure 1), so that if a pipe is broken the whole community is not necessarily deprived of water. Again, a

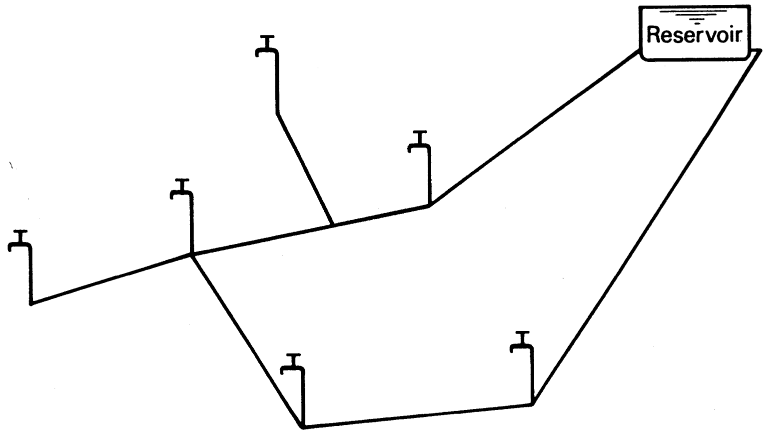
Table 1 Pipe diameter in millimetres

Flow Litre/second	Steel		Polythene		Bamboo		PVC	
	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

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



(a) 'Dendritic' system



(b) Ring main

Figure 1 Alternative village water supply distribution systems. (a) 'Dendritic system. (b) Ring main.

series of hand pumps on tubewalls may have the advantage over a piped supply from a distant water source, because if one pump breaks down the villagers can continue to use the others until it is repaired.

As a general rule the cheaper and simpler the technology, the less maintenance it requires, the more reliable it is in practice and the easier to repair under village conditions. The major exception is in the choice of hand pump, where the more robust and reliable pumps are usually more expensive and more difficult to repair; here the choice will depend not only on technical considerations but also on factors such as the amount of community participation which can be expected.

SOURCES OF SUPPLY

Because of the unreliability of treatment plant under most rural conditions, the best sources of water are those which do not need treatment.

Rainwater collected from a metal roof is relatively pure, and is of course available close to the users if the roof is theirs. However, many rural houses are roofed with other materials than metal, such as thatch, and rainfall patterns may require large and expensive storage tanks to guarantee a supply all the year round.

Surface water may be readily available and easy to collect, but it is often of inferior quality. In some sparsely populated upland areas, streams may be of a quality good enough for domestic use, but in most regions all streams large enough to flow all year round are subject to substantial faecal pollution.

Where it can be extracted reasonably easily, ground water is normally preferable to surface water because it is purified by the filtering action of the soil through which it flows. Nevertheless, ground water in some areas may contain salt, fluoride, iron and manganese, or other substances which make its use undesirable or unpleasant, and the use of surface sources may be unavoidable.

Sufficient quantities of ground water to supply a rural community may be collected from a spring or extracted from a well of some kind.

Springs

Springs, where they exist and have a reliable flow, can make ideal sources of water for a community water supply. No pumping is required to extract water from them, and all that is usually necessary to obtain water of good quality is to collect it and protect if from pollution. This is done by building a box of brick, masonry or concrete around the spring so that water flows directly out of the box into a pipe without ever being exposed to pollution from outside (Figure 2). In building a spring box, there are several points to watch.

The water emerging at a spring has generally been forced to the surface by meeting an impervious layer of soil or rock: a layer through which water cannot pass. In excavating the foundations for a spring box it is important to avoid digging through this layer, or the water may seep downwards so that the spring disappears or moves downhill.

The point where the water emerges, known as the 'eye' of the spring,should be covered with carefully selected sand or gravel. If this material is too coarse, the spring water may erode the soil behind it, but it should not be finer than the existing soil behind it or it may block the flow. If there is a danger that it too could be washed away, then still coarser gravel should be placed in front of it, with the gravel progressively increasing in size to the stones of the spring box wall. A spring may sometimes flow very strongly for brief periods after rain, and the whole structure must be sound enough to resist erosion.

A certain amount of fine sediment is suspended in the water from most springs. A spring box therefore should be built so as to prevent this sediment from settling over the eye of the spring and blocking its flow. This is best done by ensuring that the overflow pipe is not above the eye (Figure 2). It is also important for the spring to have a removable cover, so that it can be cleaned out from time to time. Alternatively, several small springs may be connected to a single 'silt trap' (Figure 3) where the silt is allowed to accumulate and is periodically cleaned out.

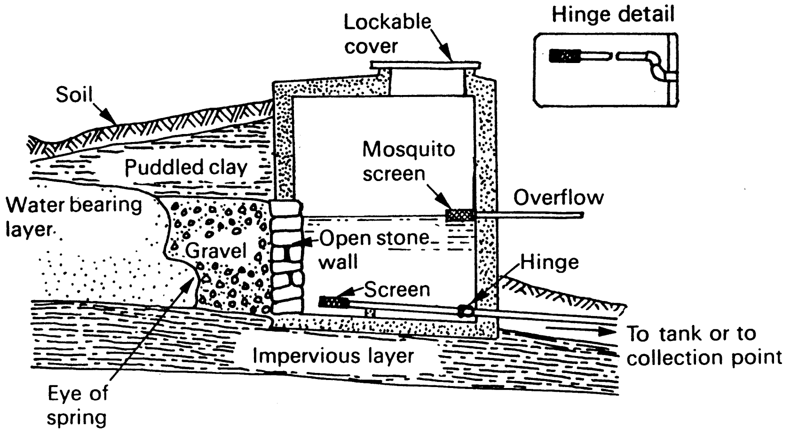


Figure 2 A spring box. The inset detail shows a hinge made with two pipe bends, enabling the screen to be lifted above the water for cleaning.

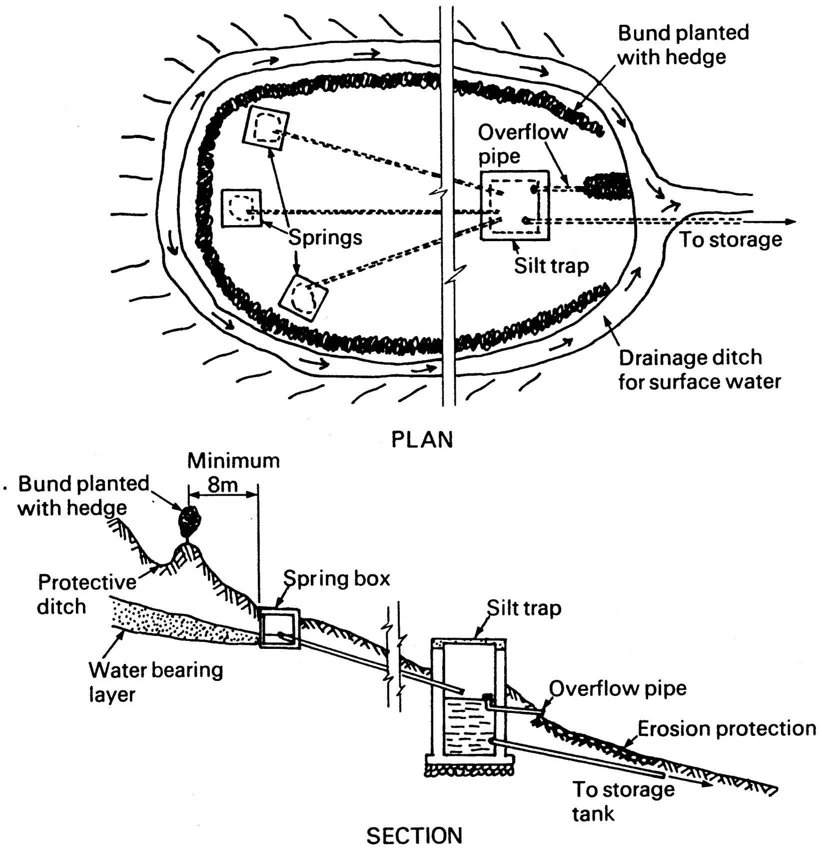


Figure 3 Three protecting springs connected to a silt trap.

Care is required to prevent surface water from running into the spring box and polluting the water in it. Puddled clay should be used to backfill behind the box to seal the ground against infiltration. The top of the spring box should be at least 300 mm above the ground, and the access hole should have a lip around it and a cover which is not easily removed. In addition, a ditch may be dug on the uphill side of the spring, and the excavated soil thrown up into a bank or 'bund' (Figure 3) to divert surface water. Finally, a fence or prickly hedge set on the bund will help to keep people and animals away.

Wells

Wells can be sunk in a wide variety of ways. Briefly, the basic methods most suitable for small community water supplies are illustrated schematically in Figure 4, and listed below.

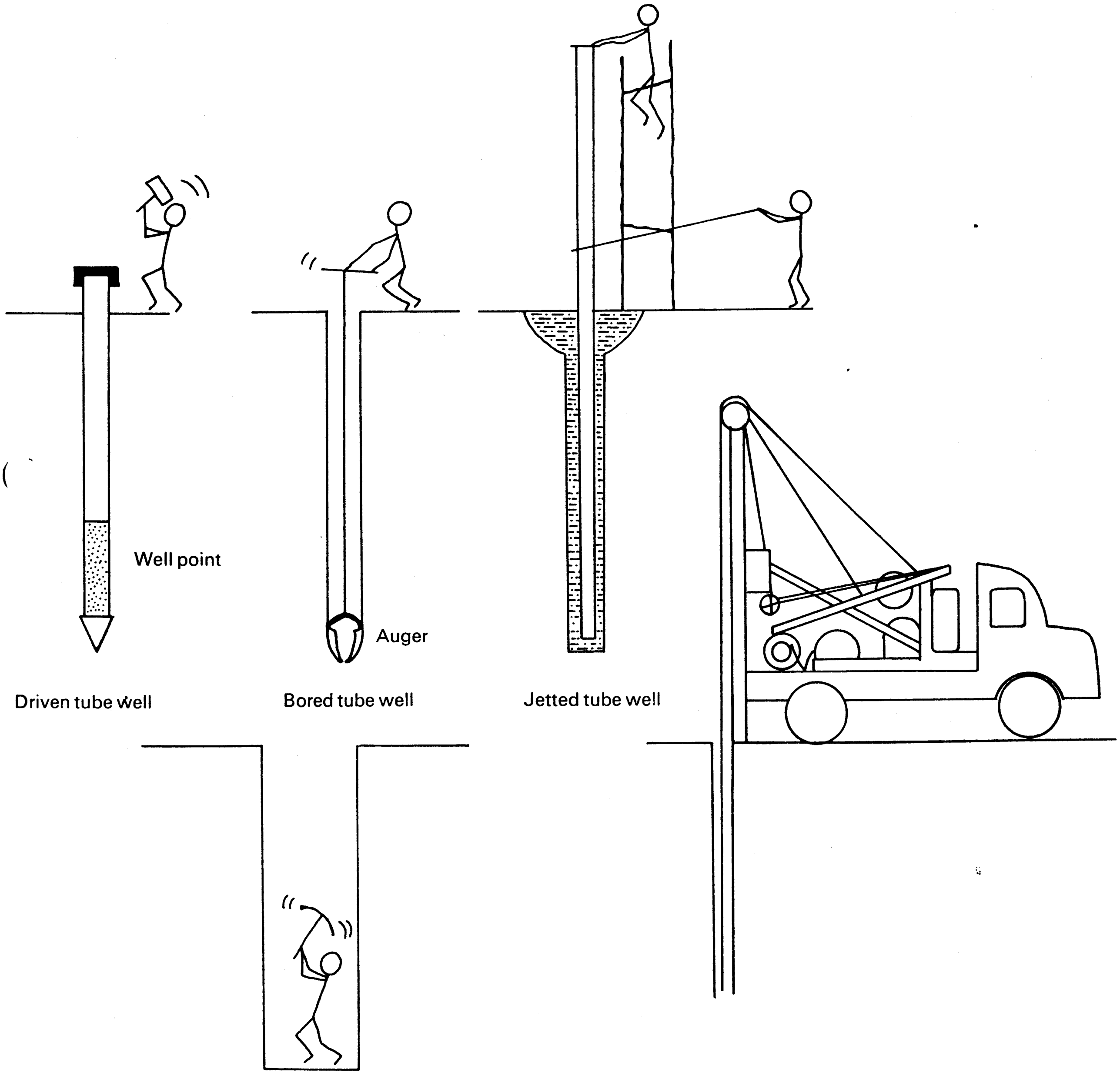
(i) **The driven tube well,** in which a specially perforated tube known as a 'well point' is driven into the ground. The well point is re-usuable, but is expensive and normally lasts only about 5 years.

(ii) **The bored tube well,** which can be sunk by hand to depths up to 25 metres with an 'auger', a simple tool twisted by hand in the ground.

(iii) **The jetted tube well,** in which a pipe is sunk into soft ground while the soil is loosened and removed by water pumped down (or up) the pipe and the surrounding hole is kept full of water. The cartoon in Figure 4 illustrates the simplest method of jetting known as the 'palm and sludger' method, in which the pipe is moved up and down by a lever, and a man's hand or a wooden flap on the top of the pipe is used as a valve to pump upwards.

(iv) **The hand dug well,** the most common method of extracting water from the ground. It can be dangerous to build unless the necessary skills are available locally. But if they are, it can be constructed cheaply with simple tools.

(v) Various methods of jetting and drilling a tube well or borehole require a special **drilling rig** which may be trailer or truck mounted for use in rural areas.



Driven tube well

Bored tube well

Jetted tube well

Hand dug well

Borehole

Figure 4 Schematic illustration of five basic methods of groundwater extraction

The construction of these various types of well is described in a few well-written technical manuals (Watt and Wood, 1977; Gibson and Singer, 1969; VITA, 1970) which are listed in the Bibliography at the end of this paper.

Pollution of wells

Tube wells and boreholes are protected from pollution from the surface by a concrete apron 2 m across, used as a base for the pump. Open hand dug wells, however, are more liable to pollution. An open well can be polluted by any of the following means, but only the first two normally affect tube wells.

(i) **Polluted ground water.** This can result from location of the well too close to pit latrines, soakaways or refuse dumps, whose influence may extend up to about 30 metres in a typical soil. In some kinds of strata such as limestone, ground water may flow in underground rivers rather than seep through the ground, and so carry faecal pollution much longer distances.

(ii) **Seepage water from the surface** may enter through the top few metres of the well lining if it is not sufficiently water-tight near the surface.

(iii) **The vessels used for drawing water.** However often these may be rinsed out they can cause some pollution of the well. An improvement can be achieved be having a bucket permanently hanging in the well, probably from a windlass, so that it is never taken home and never put on the ground (Figure 5). Pollution can only be completely avoided by installing a pump of some kind though this may cost as much as the original construction of the well.

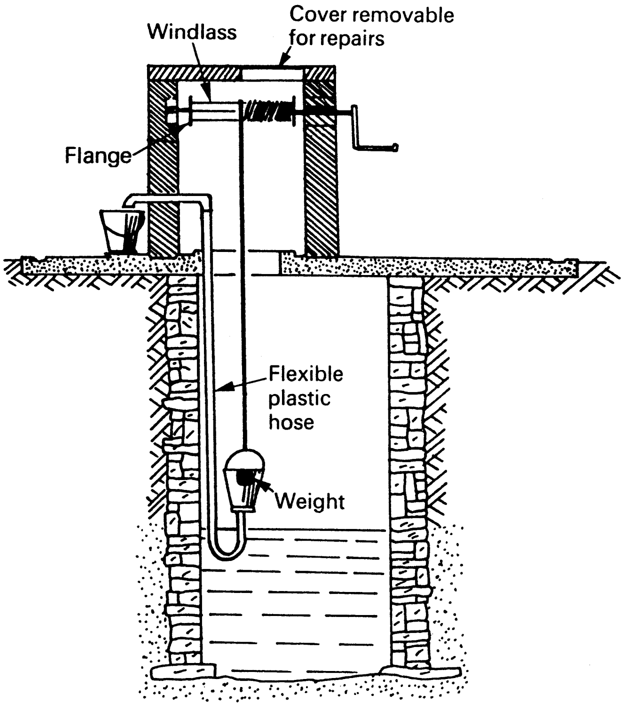


Figure 5 One method of protecting a well from pollution. No methods of this kind have yet been adequately tested in the field

(iv) **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 the well and install a pump.

(v) **Surface water.** This may be washed straight down the well, especially if the ground surface has sunk, as is often the case when the well does not have an adequate lining. It can be prevented by building a headwall (Figure 6), which will also help to prevent animals and people falling into the well.

(vi) **Spilt water.** Lastly, but probably the most important in some countries, is the water spilt by people collecting water. If there is no headwall, or if people stand on the headwall to draw water, water which has splashed against their feet can fall back into the well.

Avoidance of pollution by spilt water is particularly important in arid savannah regions of West Africa and the Middle East, where guinea worm *(Dracunculus medinensis)* is endemic. Guinea worm kills few people but causes debilitating pain, usually in the planting season, and so can have far-reaching economic effects by reducing the ability to work of almost the whole population. In some places the worm is transmitted chiefly through domestic water supplies, in the following way.

The body of the mature female worm lies under the skin of the leg with its genital pore beneath a sort of blister near the sufferer's ankle. When this blister is immersed in water or when water splashes over it, as when water is being drawn from a well or water-hole, it bursts and releases a cloud of *Dracunculus* larvae which are likely to be washed down into the well or pool. The larvae then infect cyclops, tiny crustaceans that are found in many small bodies of water, and develop inside their new hosts. Cyclops are only 2 mm long, and so are easily consumed inadvertently in water from an infected well. The cyclops themselves are not dangerous to drink, but the worms they contain develop in the human host and the female *Dracunculus* makes its way to the legs and forms blisters, ready to start a new cycle.

Because of this, and because of the importance of surface and spilt water in causing well pollution in general, the most important single improvement which can be made to an existing well (although among the simplest to make) is the construction of a well head consisting of a headwall and drainage apron to take spilt water to a soakaway. This single measure can completely prevent guinea worm transmission at a well, and considerably reduce other health risks. However, it can only be done on its own good solid ground where there is no danger of the well shaft collapsing. When the ground is at all unstable, it is necessary to build a lining first.

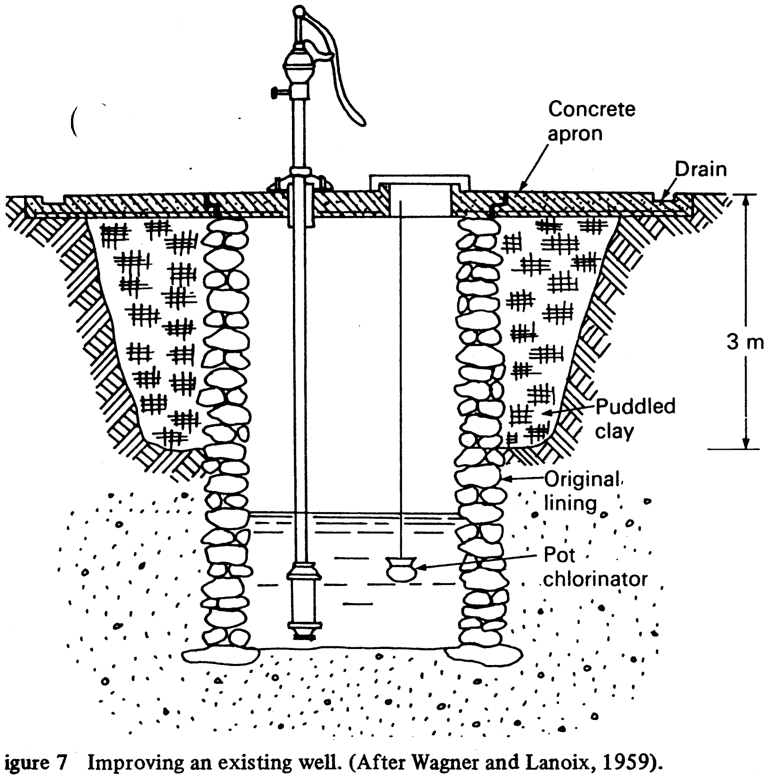
e headwall can be fitted with rollers, a pulley or a dlass to help people pull up the bucket without ning over the well (Figures 5 and 6). Even better tection from pollution can be gained by covering well with a concrete slab and fitting a hand pump gure 7). But of course this increases the cost of the ll, and a pump should not be installed in any water ply unless arrangements have been made to main- n it.

vell itself requires maintenance too. Dust, rubbish and d animals can accumulate remarkably quickly in the ttom of an open well. Apart from polluting the water, the accumulation of rubbish or wind-blown 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 when the water level is low.

RAISING WATER

Methods of lifting water are numerous and varied. Unfortunately many of them are not suitable for small water supplies, either because they cannot lift water through a sufficient height, or they expose it to the risk of pollution, or because they are too expensive to install and operate.

gure 6 An open well with headwall. Note the metal bars used as rollers, which reduce the need to stand on the headwall to lift buckets. The basins at each side are for watering animals.



igure 7 Improving an existing well. (After Wagner and Lanoix, 1959). Details of pot chlorinator are shown in Figure 11.

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. The main methods are described below, roughly in order of increasing complexity and cost. Which of these is most important will depend on the local conditions, the funds available and probability of regular maintenance in the future.

The first decision to make 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.

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 5), a shaduf (Figure 8) or a windlass, so that people do not have to lean over the well headwall to raise the bucket. If the 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.

However, these devices are not suitable for tube wells, or for very deep hand dug wells, and for these a hand pump may be required. A hand pump also enables the water to be protected from pollution until it enters the user's bucket, but it cannot usually be made in the village, and may have to be imported. It also requires regular maintenance (Figure 9). Simple hand pumps can be made locally from wood and plastic. They are easier to repair in the village, but they tend to wear out quickly (McJunkin, 1977).

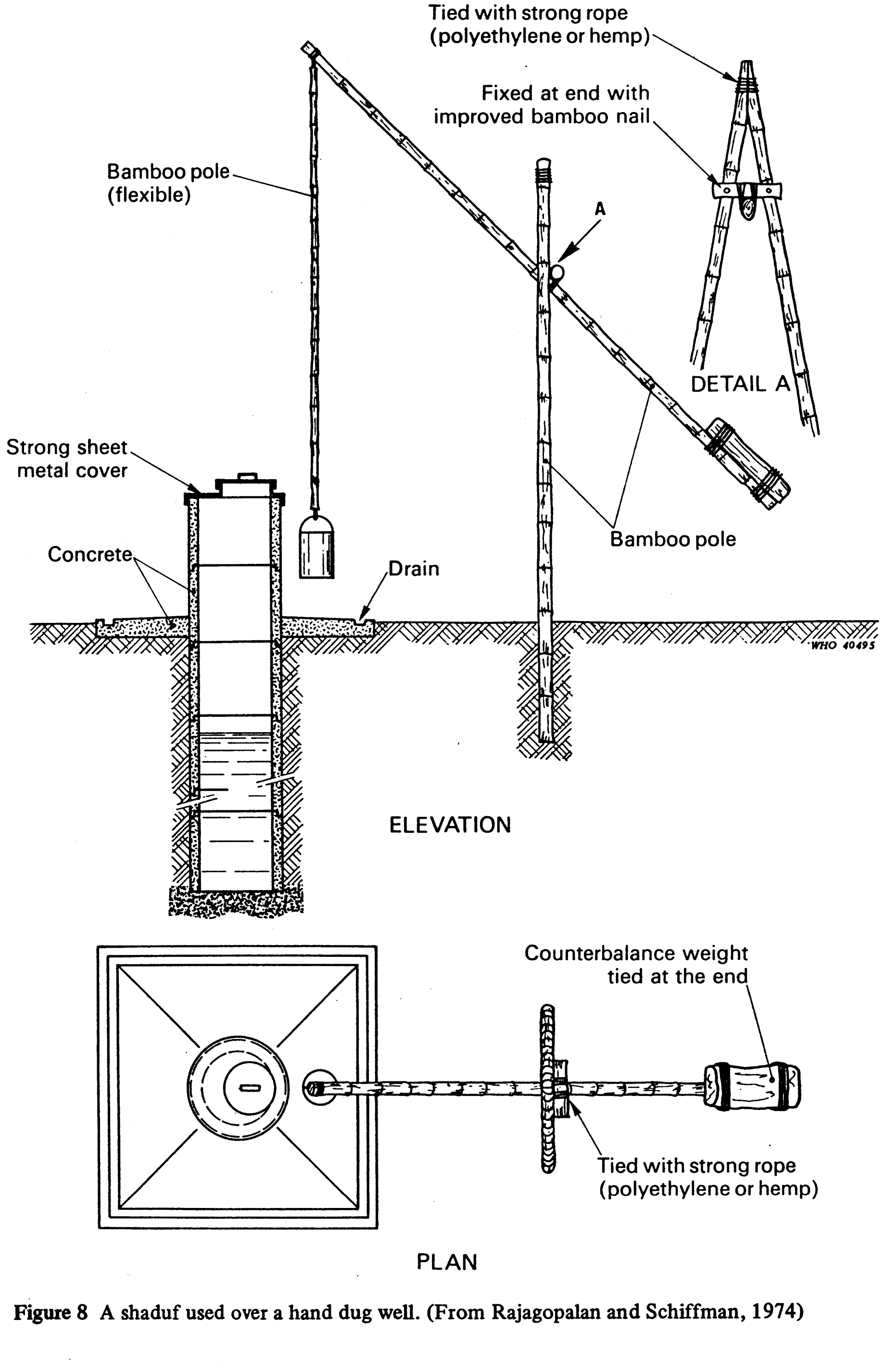


Figure 8 A shaduf used over a hand dug well. (From Rajagopalan and Schiffman, 1974)

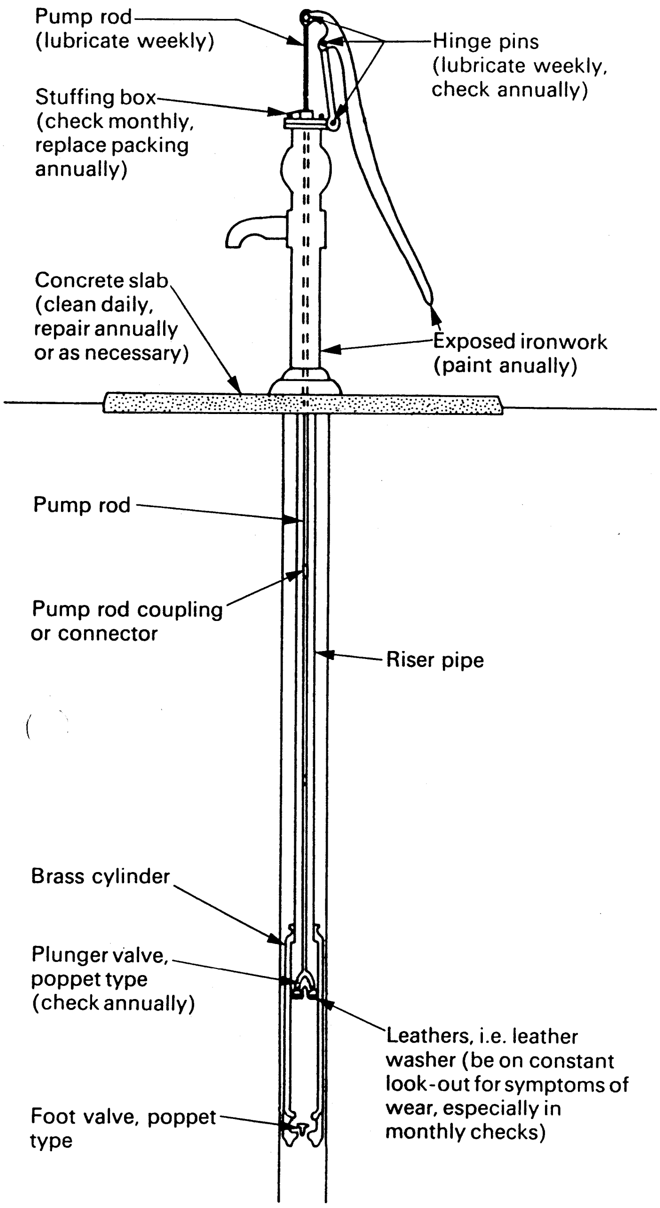


Figure 9 Maintenance points on a simple hand pump. (From Pacey, 1977)

Wind power may also be used for raising water, with the advantage that wind is free. However, a windmill is necessary to harness wind power, and windmills are usually rather expensive. A large and expensive storage tank is also necessary to ensure a reasonably reliable supply over windless periods. Even in a quite windy region, storage capacity for seven days' water will be required.

Two other types of pump use naturally occurring sources of energy: the hydraulic ram and the solar pump. 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. It also requires careful adjustment (Watt, 1975). Solar pumps are suitable for arid areas, and although they can pump as much as 10 litre/second, they require very sophisticated technology. Several have been installed in rural areas of West Africa by a French company.

Pumps may also be driven by diesel or electric motors. Electric motors need less maintenance and are usually more reliable than diesel engines, so they are preferable where 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 vertical motion necessary for pumping, which is transmitted down the well by a steel rod. In general it is best to have the motor at the surface where it is accessible for maintenance, but to keep the pump mechanism below the surface to avoid the need for 'priming'. Priming is sometimes necessary when a pump has to suck water from below it, and involves pouring water down the inlet pipe to start off the pumping. Water of adequate quality will often not be available for priming, and priming will become more and more difficult in a poorly maintained pump.

For applications where both pump and motor can be on the surface, the choice of pump is dealt with by conventional textbooks on water engineering, such as Twort et al (1974). However, there are a few particular points to note when choosing pumps for village water supplies. Spare parts should be readily available: this can be helped by standardisation on one or two basic designs. Motors should be simple to maintain, and be able to run with locally available lubricants and local fuel or electricity. The water pumped for a village water supply may be quite silty: if so, the type of pump used should not be liable to wear out too quickly under these conditions. Finally, in view of the difficulty of assessing village demand, it will help if the pump cylinder or, on a centrifugal pump, the impeller can be changed for a larger one if necessary.

STORAGE AND TREATMENT

General

When designing storage tanks for village water supplies, it is often tempting to use familiar materials such as reinforced concrete or corrugated steel sheet, as these are easier to make reliably water-tight. But a few small leaks in a tank above ground may not be serious in village circumstances, and perfectly adequate tanks may be built of local building materials such as brick or masonry, especially if galvanised wire is laid between courses to give the walls horizontal reinforcement.

Small earth dams, too, do not need to be of sophisticated design with clay cores and rip-rap, although certain basic safety requirements are of course required. A good account of small dam construction is given by Wagner & Lanoix (1959).

Care should be taken to prevent tanks and reservoirs from becoming breeding places for malarial mosquitoes, especially in seasonally arid areas where malario transmission decreases during the dry season. The creation of any permanent water surfaces accessible to mosquitoes may promote their breeding in the dry season, unless special precautions are taken. Storage tanks should therefore be covered, and ventilation pipes screened with mosquito-proof mesh. Ponds and dams may need special measures to prevent their banks becoming overgrown with weeds, for instance by paving them at water level.

Unfortunately, there is no such thing as a simple and reliable water treatment process suitable for small community water supplies. Therefore it is preferable to collect rainwater or to choose a source of naturally pure water such as ground water, and protect the water from pollution so that treatment in unnecessary. Treatment of village water supplies should only be considered if it can be afforded and reliably operated in the future, and if the quality of the water is very poor. Simple methods of testing water quality are given in Cairncross and Feachem (1977).

The simplest method of treating water is to store it in a covered tank. Some treatment may be obtained by careful design of storage tanks to ensure a slow and even movement of water from the inlet to the outlet, as in a sedimentation tank. This will permit some silt to settle out, and allow time for some disease organisms to die off. If water is stored for at least 48 hours, for instance, any schistosome larvae in it will die before it leaves the tank.

For larger communities it may be useful to build a small sedimentation tank like that shown in Figure 10, although it will not usually be possible to arrange for coagulant chemicals to be added to the water to assist the sedimentation. Sedimentation does not remove many of the harmful organisms from polluted water, but it helps to clarify water for treatment by filtration or chlorination.

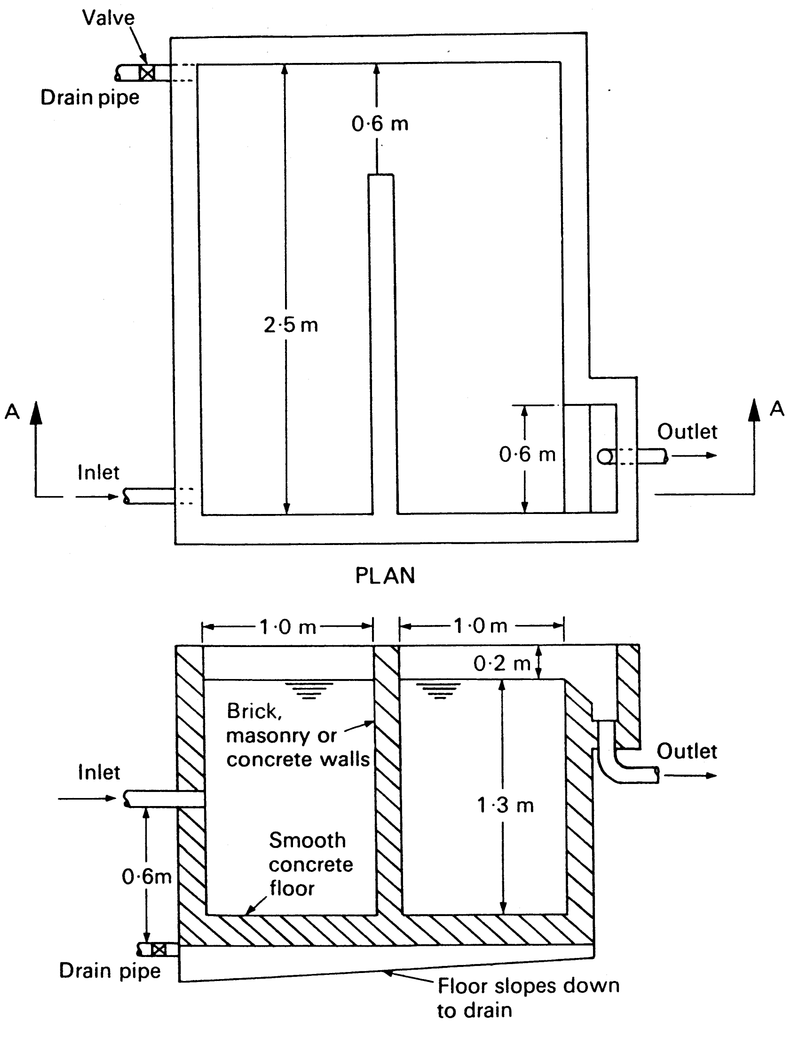


Figure 10 (a) A simple sedimentation tank for flows up to 2000 litre/hour. Several of these may be combined for larger flows.

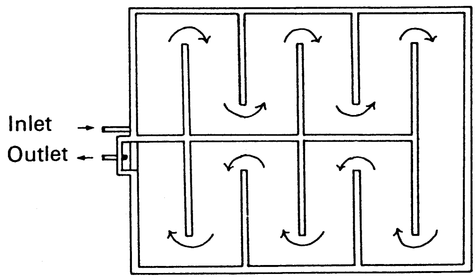


Figure 10 (b) Method of combining six small sedimentation tanks. One tank is required for every 2000 litre/hour.

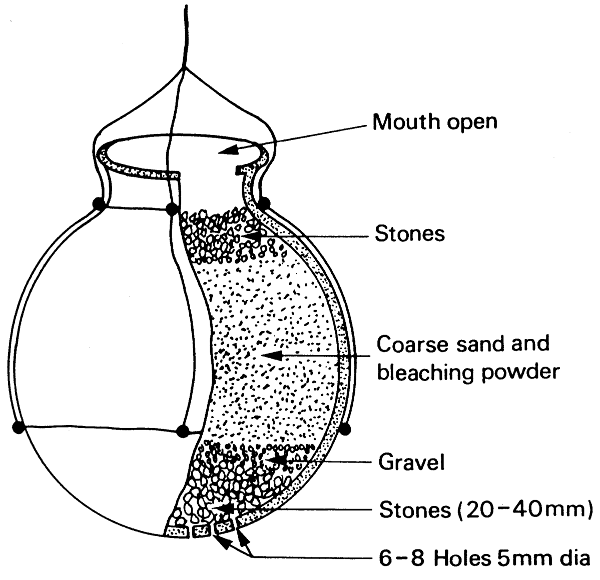
Filtration and chlorination

Filtration and chlorination are not usually suitable for village conditions. One method of chlorination, however, may be appropriate for hand dug wells. It involves a pot containing a mixture of coarse sand and bleaching powder, which is hung underwater in a well (see Figure 7). Figure 11 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 bleach and 2 kg of sand every three weeks. The single pot will serve up to 60 people if it contains 50 per cent more bleach and sand, but it requires replenishing every fortnight. The trouble with these pots is that they sometimes make the water taste unpleasant for the first few days after refilling. There is no point at all in a water disinfection process which is not reliably operated or which drives people to use water of worse quality. However, if the use of these pots does not deter consumers, and if their regular refilling can be guaranteed, they are a cheap and simple method of disinfection.

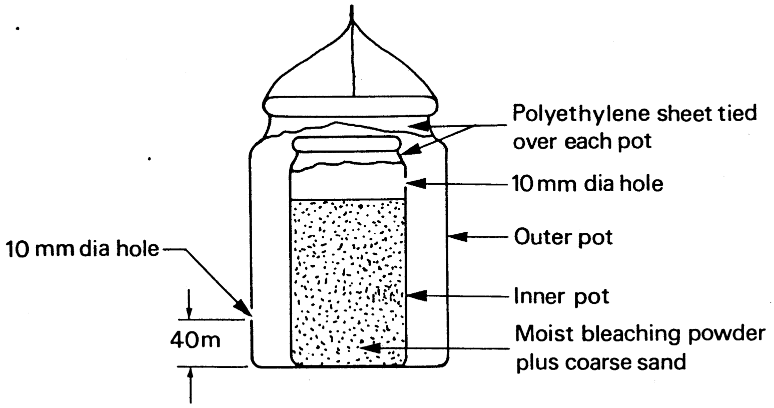
Removal of mineral impurities

In a few areas, heavy concentrations of dissolved iron and manganese in the ground water can give it an unpleasant taste, and give a brownish colour to food and clothes. Other chemicals in the water, while not necessarily harmful, may also make it unpleasant to taste. These chemicals can be a serious nuisance, and may even prevent people from using the water. If so, they can often be removed by aeration, for instance when the water falls into a storage tank from the inlet. Aeration causes the iron and managnese to become insoluble so that they form a fine dark sediment which is more easily removed.

Figure 12 shows a simple unit for the thorough aeration of water, which will also remove the iron and manganese sediment produced. It is made of four cylinders, the top three of which each have a mesh or sieve in the base, and ventilation slots in the side. The top two have a layer of stones 150 mm deep, and the third has a 50 mm layer of small stones, covered with 300 mm of coarse sand.



(a) Single pot system



(b) Double pot system

Figure 11 Pot chlorinators: two alternative designs
(a) Single pot system (b) Double pot system

The unit stands on a solid brick or concrete platform. Water is sprayed over the stones at the top 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.

Other chemicals in water, particularly salt, fluorides and nitrates are less easily removed under village conditions. The simplest fluoride removal process, for example, requires the regular addition of alum (potassium aluminium sulphate) to the water, and some kind of settling process. The alum is not always available, and since the fluoride is present only in imperceptible amounts the villagers are not strongly motivated to treat the water or conscious if it has not been treated. It is usually preferable to look for alternative sources of water. For instance, when ground water is salty in flat coastal areas, it is sometimes possible to find sweet water lower down, by sinking tube wells several hundred feet deep.

Most of the chemicals in a water source will make it unpalatable before they constitute a health hazard. The national or regional health or water authorities can advise if the ground water in a particular area may contain hazardous chemicals.

WATER DISTRIBUTION

Some aspects of pipeline design for rural water supplies have been discussed in the Introduction. This section deals with the design of rural water points.

Many of the potential health benefits from rural water supplies result from an increased use of water, possibly more than from improved quality. There is therefore good reason for designing water points so as to encourage the maximum possible water use, particularly for hygiene. Ideally, water would be provided inside each house, as the amount of water used usually increases by several times if this is achieved, even to only a single tap in each house. The tap can be fitted with a special valve which delivers up to a fixed volume of water, usually a litre, each time it is operated. This keeps waste and peak factors down, to the extent that 12 mm pipes can be used for each house connection.

The cost of a water supply with such individual connections will depend on the density of village housing, but is typically not more than twice the cost of a supply to public water points. It is also possible to raise revenue from private subscribers, a thing very difficult to do with public water points.

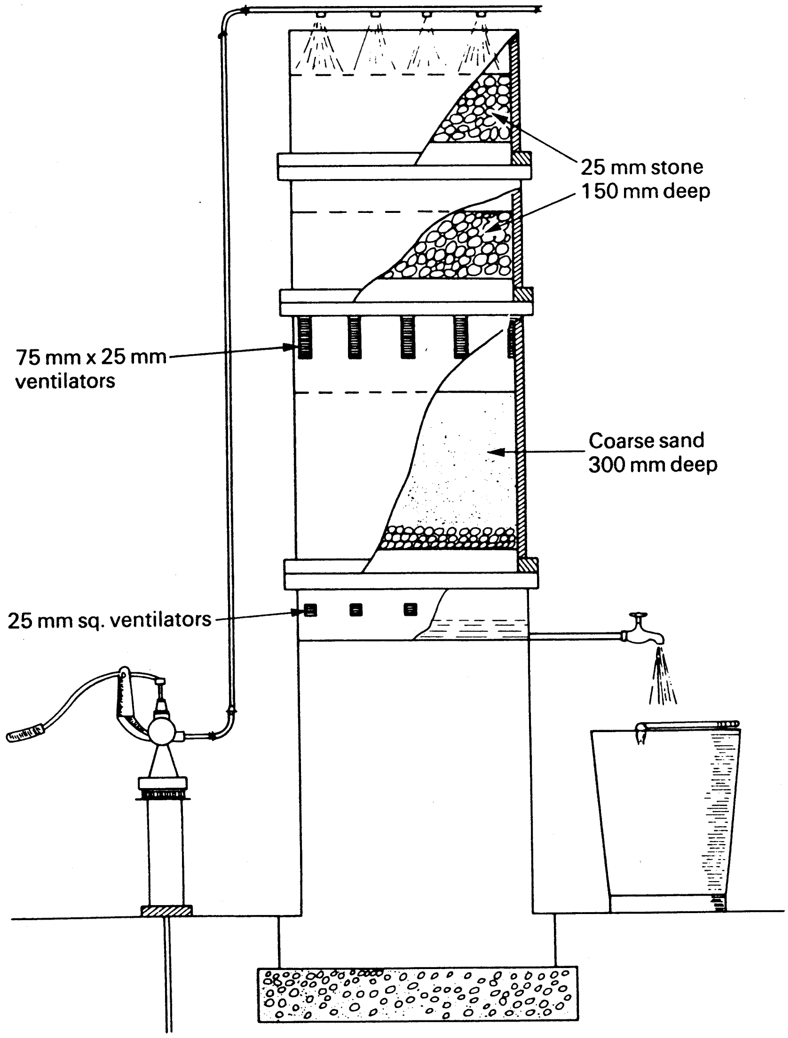
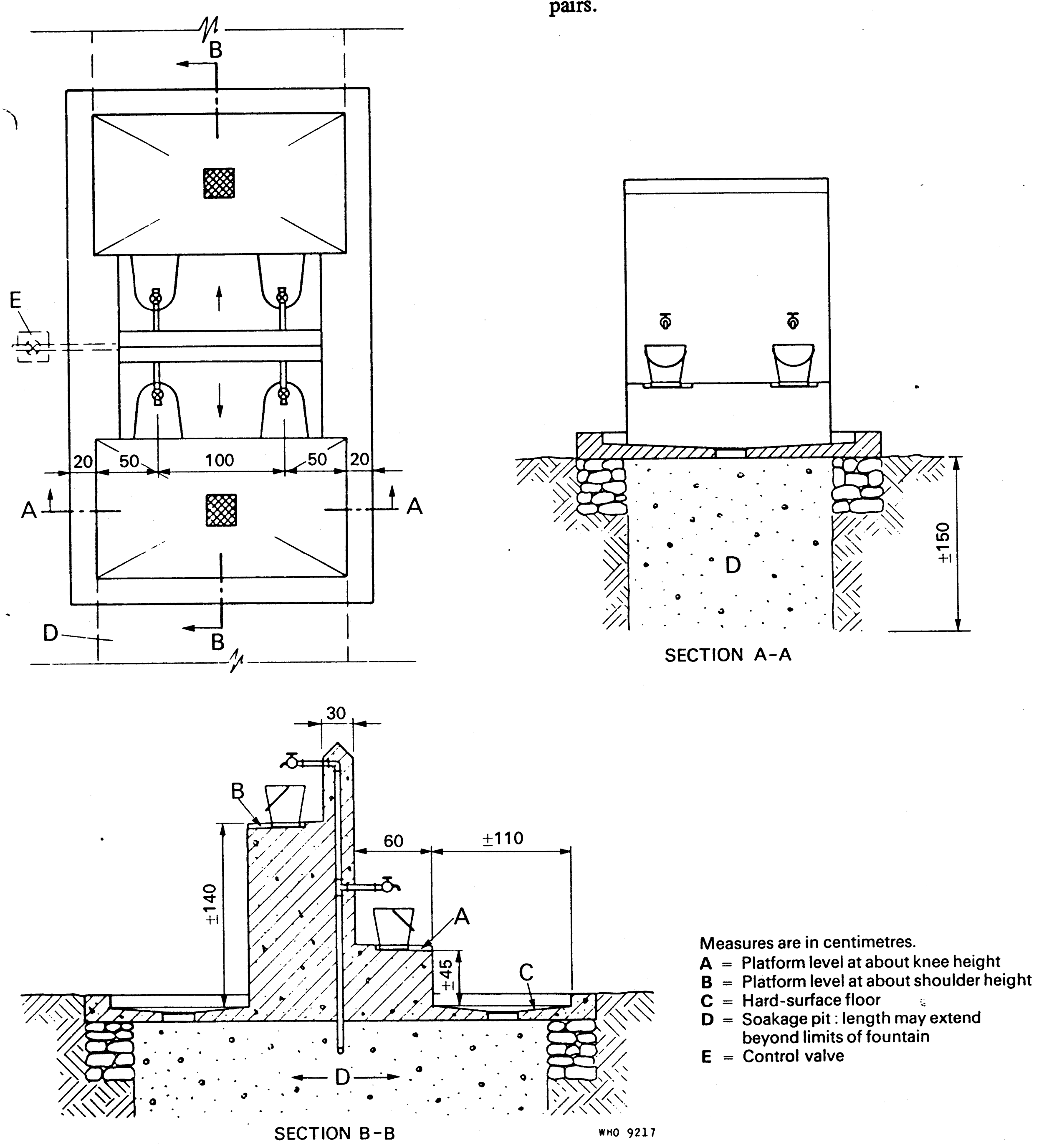


Figure 12 A hand operated unit for iron and manganese removal. (After Pickford, 1977).

When individual connections cannot be afforded, the alternative is to provide public water points. In addition, showers, clothes washing facilities and possibly toilets may be constructed and connected to the piped water supply. These would be provided on a communal basis, but if one shower and toilet cubicle is reserved for each family, this will help to encourage good maintenance by the users.

The best design for a public water point may depend upon traditional methods of carrying water. Where water is carried on the head, it may help if buckets can be stood on a platform at shoulder height to be filled (Figure 13). In that case, a lower tap should also be provided to allow clothes washing under the tap and to permit water collection by children and old people. In designing a water point, provision should be made for the disposal of spilt water and waste water used for washing at the water point. Areas on which water will be spilt should be paved, preferably with concrete, and the waste water taken to a soakaway such as a pit filled with stones and covered over with a layer of soil.

One serious problem is damage to water points through heavy use, or sometimes through vandalism. The most common component to break is the tap, and this should be as durable as possible. But it should not be too hard to operate; much 'vandalism' to rural water supplied is in fact the product of frustration. In any case, arrangements should be made for the regular inspection and maintenance of public water points, and for villagers to report faults they cannot repair themselves. For instance, villagers can be issued with a set of prepaid post cards illustrating a water point. When a component is broken, the card can be marked to indicate this, and posted to the agency responsible for helping the village with repairs.



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

Figure 13 Possible arrangement of public fountain. (From Wagner and Lanoix, 1959)