CHAPTER 8

Water Supply

Edited by BARRETT HAZELTINE
Brown University

WATER SUPPLY

Based on Surface Water Treatment by Roughing Filters—A Design, Construction and Operation Manual, *Text Revisers: Sylvie Peter, Brian Clarke, ISBN: 3-908001-67-6, Swiss Centre for Development Cooperation in Technology and Management (SKAT), CH-9000 St. Gallen, Switzerland*

The quantity of water available to users has a direct bearing on their health. Five liters per person per day is considered the minimum consumption level, although desert dwellers exist on less. More than 50 liters per person per day, it has been estimated, gains no further health benefits. Twenty-five liters per person per day may become an acceptable goal in places where piped connections to individual houses are not feasible. An article in the Health chapter discusses water-borne diseases and is recommended as background to the present article. The "Building" article in the Construction chapter also discusses water problems—focusing on sanitation.

Here are the chief potential sources of water listed in their approximate order of preference based on cost, quality of water, need for equipment and supplies.

- *Springs.* If there are year-round springs nearby, they can usually be developed to supply clean water. This water can often be conveyed through pipes without the expense of pumps or water treatment. Springs can most often be found in hilly or mountainous regions.
- *Wells.* Because there is water at some depth almost everywhere beneath the earth's surface, a well can be sunk (using the appropriate technique) almost anywhere. The water that comes into the bottom of a well has filtered down from the surface and is, in most cases, cleaner than water that is exposed on the open ground. A separate article in this chapter deals with well construction.
- *Rainwater.* Collection and storage of rainwater may provide another source where surface and underground water supplies are limited or difficult to reach. Normally, except in the

rainiest regions, rainwater will not supply all the water needs of a locale; however, as a supplement, it can be collected from roofs or protected ground runoff areas, and stored in covered cisterns to prevent contamination. A separate article in this chapter deals with rainwater collection.

- *Surface water.* Streams, rivers, and lakes are all commonly used as sources of water. Although no construction is needed to enable them to supply water, the quality of the water is almost always poor. Only clear mountain streams flowing from protected watersheds could be considered as fit for human consumption without treatment. An article cited in the References section of this article describes a water supply project in Malawi using mountain stream water. Village people learned to plan and construct a water system to bring mountain stream water down to public standposts in the villages.

This article discusses water supplies using surface water.

From the technical point of view, the following three questions must be answered during the planning phase of a water supply scheme.

- Which raw water source should be used for the water supply scheme?
- If treatment is necessary, what type of treatment scheme should be favored?
- How much water should be distributed to the consumers, and at what service level?

Layouts of some possible water supply systems, all using surface water, are shown in Figure 1. As shown in Figure 1, surface water has to be collected, treated, and stored before it reaches the consumer.

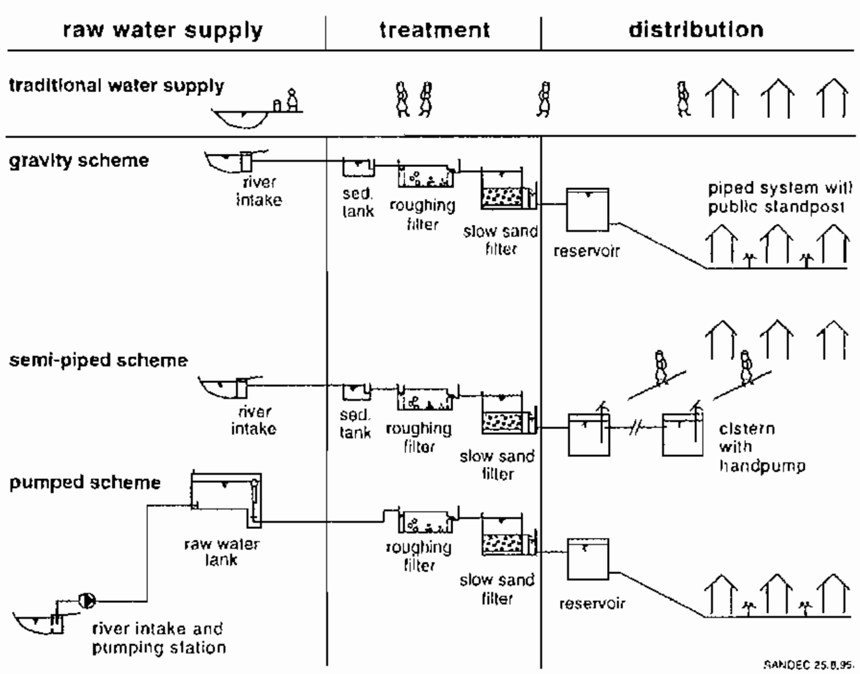

FIGURE 1
Possible water supplies using surface water.

SOURCE AND TREATMENT OF WATER

Source selection is a very basic decision entailing numerous consequences for the future water supply scheme. The different local water sources have to be evaluated with respect to their quantity, quality, and accessibility. The future water demand must be covered by the selected source with the best possible water quality and located as close as possible to the supply area.

Since water treatment is usually the most difficult element in any water supply scheme, it should be avoided whenever possible. The general statement that no treatment is the best treatment especially applies to rural water supply schemes. The use of the best available water quality sources is, therefore, an alternative that should always be taken seriously. If no other alternative is available, rural water treatment must improve the bacteriological water quality by locally sustainable treatment processes.

DISTRIBUTION

Water distribution systems depend on the type of water source used, on the topography, and on the provided supply service level. Individual water supplies, such as rainwater harvesting and shallow groundwater wells equipped with hand pumps, usually do not need piped supply systems. Treated surface water, however, is normally distributed by a piped system. A suitable topography often allows the installation of a gravity system that will improve reliability and supply continuity. Since pumped water supply schemes depend on a reliable supply of energy and spare parts, they are very susceptible to temporary standstills. Finally, the service level of water supply strongly governs water demand. Water usage increases drastically as the service improves: public standpost, yard connection, multiple-tap house connection. The article "Saving and Reusing Water" discusses this increase in consumption with an increase in convenience. Two pumped systems are shown in Figure 2.

Water supply is always interlinked with wastewater disposal. Wastewater disposal is described in the "Sanitation" article. The health situation of a community newly supplied with treated water does not necessarily improve, especially if public health and wastewater disposal issues are neglected. The main components necessary to significantly improve the public health situation

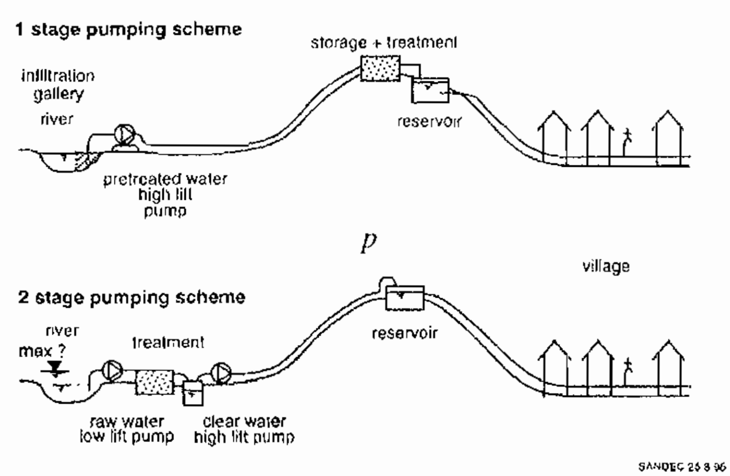

FIGURE 2
Pumped water supply schemes.

of a community are therefore a reliable and safe water supply, an adequate waste disposal system, and a comprehensive hygiene education program.

HYDRAULIC PROFILE

Selection of how to move the water is a basic criterion when planning a water supply scheme. First choice must be given to gravity supply systems, since they guarantee reliable operation at low running costs. Schemes that integrate the use of handpumps are a second choice. (Water pumps are discussed in a separate article.) The installation of mechanically driven pumps should be chosen as the last option and only applied in special cases where a reliable and affordable energy supply and the infrastructure for pump maintenance and repair work is guaranteed. Hydraulic rams—described in an article of the same name in this section—that make use of the potential energy of a large water volume to pump a small fraction of this water volume to a higher level, may be an appropriate option where abundant water is flowing.

Water treatment plants should, whenever possible, be operated by gravity and with open channels to minimize water pressure on the structures. The total head loss through the treatment plant will amount to 2 or 3 m. As noted, any type of water lifting, except through handpumps, should be avoided, since the supply of euergy and sophisticated spare parts is generally unreliable. If water lifting is absolutely necessary for topographical reasons, the number of pumping steps must be limited. A one-stage pumping scheme, illustrated in Figure 2, should be chosen for raw water to be pumped to an elevated site where the treatment plant and reservoir are located. Such a one-stage pumping scheme has a great advantage over a two-stage scheme because it increases its reliability by a factor of 2. Moreover, the risk of flooding in lowland areas can often not be excluded entirely. Protecting a high-lift pumping station against floods is easier than a full-sized treatment plant. A two-stage pumping system, however, is unavoidable for a piped supply on a flat area devoid of natural elevation and in the case of serious raw water quality fluctuations, such as heavy sediment loads during the monsoon. In such a situation, installation of a low-lift raw water pump is recommended. It may consist of an irrigation unit of low efficiency but of simple design to limit high lift pumping for treated water and protect impellers and seals from damage. Hence, high-lift pumps should be used for treated water or raw water pumped from infiltration galleries or similar intake systems.

Treatment Steps

Surface water has to undergo a step-by-step treatment. Coarse solids and impurities are first removed by pretreatment, then the remaining small particles and microorganisms are separated by the ultimate treatment step. Under special local conditions, raw water collection and pretreatment may be combined in a single installation, such as intake or dynamic filters or, alternatively, by infiltration galleries. The required water treatment scheme is mainly dependent on the degree of fecal pollution, characteristics of the raw water turbidity, and the available type of surface water.

Removal of Coarse Material

Separation of coarse solids from the water is preferably carried out by a sedimentation tank (grit chamber), since sludge removal from such tanks is less troublesome than from roughing filters. Simple sedimentation tanks should be designed for a detention time between one and three hours. Such a tank is shown in Figure 3.

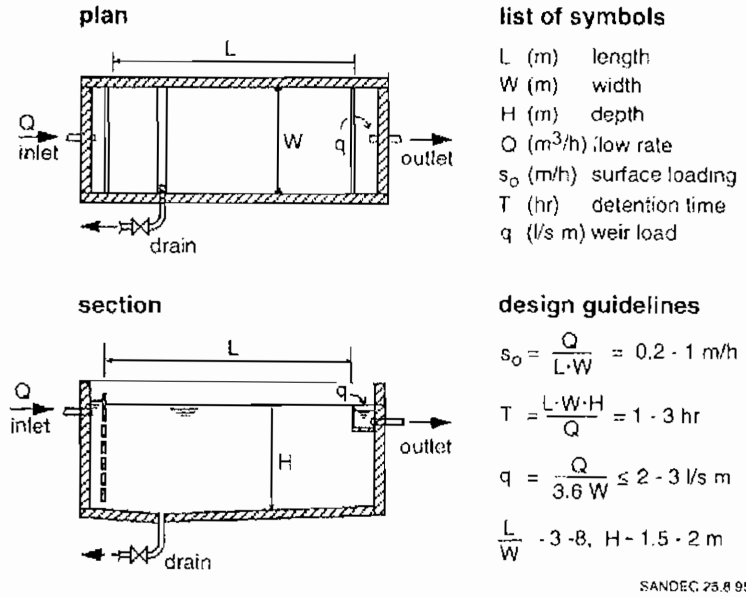

FIGURE 3
Layout and design of a sedimentation tank.

Use of one sedimentation tank should be sufficient for a small-scale water supply scheme. The accumulated sludge can be removed during periods of low silt load. A bypass is required to maintain operation of the treatment plant during cleaning periods. In order not to interfere too much with normal operation of larger water treatment plants, two or more sedimentation tanks operating in parallel should be provided to allow cleaning, maintenance, and repair of one tank.

Aeration

The water's dissolved oxygen content plays a key role in the biology of the slow sand filtration process. Although physical processes are the main mechanisms in roughing filtration, biochemical reactions may also occur in the prefilters, especially if the raw water contains high organic loads. The activity of the aerobic biomass decreases considerably if the oxygen concentration of the water falls below 0.5 mg/l. Furthermore, nitrification of ammonia is associated with a significant consumption of oxygen—for example, 1 mg NH_4 uses 4.5 mg O_2. Hence, adequate oxygen content in the water to be filtered is of prime importance. Since turbulent surface waters are generally well oxygenated, they do not require additional aeration. Still water, however, can exhibit low oxygen contents, especially when drawn from the bottom of polluted surface water reservoirs. Multilevel draw-offs—"waterfalls"—are recommended as intake structures for stratified water bodies. Stagnant raw surface waters should be aerated.

Cascades, where water cascades from a pool at one level to a pool at a lower level, are simple but efficient aeration devices. Three or so cascades should be put in series. The cascade should preferably precede filters to meet the possible oxygen demand in the filter.

ROUGHING FILTRATION AS PRETREATMENT

In the "Filtration and Disinfection," article in this chapter the term *rapid filter* is used to mean roughing filters. Roughing filtration mainly separates the fine solids that are not retained by the preceding sedimentation tank. The effluent of roughing filters should not contain more than 2–5 mg/l solid matter to comply with the requirements of the raw water quality for slow sand filters.

Coarse gravel filters mainly improve the physical water quality as they remove suspended solids and reduce turbidity. A bacteriological water improvement can also be expected as bacteria and viruses are solids also, ranging in size between about 10 to 0.2 mm and 0.4 to 0.002 mm, respectively. Furthermore, these organisms get frequently attached by electrostatic force to the surface of other solids in the water. Hence, a removal of the solids also means a reduction of pathogens (disease-causing microorganisms). The efficiency of roughing filtration in microorganism reduction may be in the same order of magnitude as that for suspended solids—for example an inlet concentration of 10–100 mg/l can be reduced by a roughing filter to about 1–3 mg/l. The bacteriological water quality improvement could amount to about 60 to 99 percent. Larger-sized pathogens (eggs, worms) are removed to an even greater extent.

Roughing filters are used as pretreatment step prior to slow sand filters. Slow sand filtration may not be necessary if the bacteriological contamination of the water to be treated is absent or small, particularly in surface waters draining an unpopulated catchment area or where controlled sanitation prevents water contamination by human waste. Physical improvement of the water may be required because of permanent or periodic high silt loads in the surface water. Excessive amounts of solids in the water lead to the silting up of pipes and reservoirs. For technical reasons, roughing filtration may therefore be used without slow sand filtration if the raw water originates from a well-protected catchment area and if it is of bacteriologically minor contamination: in the order of less than 20–50 *E. coli*/100 ml.

For operational reasons, at least two roughing filter units are generally required in a treatment plant. Since manual cleaning and maintenance may take some time, the remaining roughing filtration unit(s) will have to operate at higher hydraulic loads. A single prefilter unit may be appropriate in small water supply schemes treating water of low turbidity.

SLOW SAND FILTRATION AS MAIN TREATMENT

The substantial reduction of bacteria, cysts, and viruses by the slow sand filters is important for public health. Slow sand filters also remove the finest impurities found in the water. For this reason they are placed at the end of the treatment line. The filters act as strainers, since the small suspended solids are retained at the top of the filter. However, the biological activities of the slow sand filter are more important than the physical processes. Dissolved and unstable solid organic matter, causing oxygen depletion or even causing fouling processes during the absence of oxygen, is oxidized by the filter biology to stable inorganic products. The biological layer on top of the filter bed, the so-called "Schmutzdecke," is responsible for oxidation of the organics and for the removal of the pathogens. A slow sand filter will produce hygienically safe water once this layer is developed.

WATER DISINFECTION

Water from a slow sand filter with a well-developed biological layer is hygienic and safe for consumption. Any further treatment, such as disinfection, is therefore not necessary. As documented by numerous examples in many developing countries, provision of a reliable chlorine disinfection system in small rural water supply schemes is often not practicable. A regular supply of mostly imported chemicals and accurate dosage of the disinfectant are the two main practical problems encountered.

However, as regards disinfection, one has to differentiate between small (rural) and large (urban) water supply schemes. Large distribution systems with often illegal connections present a risk of recontamination, especially if the supply of water is intermittent. In large urban water supply schemes, final water chlorination is recommended as a safeguard. Residual chlorine, however, will be too low and contact too short to deal with serious contamination introduced by infiltration of highly contaminated shallow groundwater in intermittently operated water supply systems. In rural water supply system, implementation of a general health education program with special emphasis on correct water handling is a more effective measure than preventive disinfection.

WATER STORAGE

To make full use of the treatment capacity and to avoid interference of the treatment process by intermittent operation, water treatment installations should preferably be operated uninterruptedly on a 24-hour basis. Particularly, slow sand filters should be operated continuously to provide the biological layer with a permanent supply of nutrients and oxygen. Roughing filters are less sensitive to operational interruptions, although careful restarting of filtration should be observed in order not to resuspend the solids accumulated in the filter. Water supply schemes, operated entirely by gravity, can easily handle a 24-hour operation. Pump operation, however, is often reduced to 6 to 16 hours a day in water supply systems requiring raw water lifting. In pumped schemes, constructiou of a raw water tank may offer an economically and technically sound option, since it enables continuous operation of the treatment plant and also acts as a presedimendation tank.

Water storage capacity must be provided to compensate for daily water demand fluctuations. In rural water supply schemes, peak water consumption occurs generally in the morning and evening hours. Therefore, a storage volume of at least 30 to 50 percent of the daily treatment capacity should be provided to compensate for the uneven daily water demand distribution.

DISTRIBUTION SYSTEM

Water accessibility rather than water quality is the most important criteria for the consumer, since her or his main concern is the walking distance between home and the water point. Consequently, treated or better quality water has to be brought nearer to the homes than the existing water sources. Treated river water is likely, for instance, to be more readily accepted if the original walking distance to the river is reduced substantially by the installation of a water supply system.

A water distribution system will therefore have to be constructed. The service level of a piped system is dependent on the economic situation; construction costs of a distribution system normally amount to 50 to 70 percent of the total investment costs of a water supply scheme, including a water treatment plant. Gravity schemes should be installed whenever possible. In many instances, however, topography is unfavorable, and differences in altitude must be overcome by water lifting. Pumps require, however, relatively high investment and operating costs, spare parts, and, particularly, energy—an aspect that will in the future gain increased importance. In rural water supply schemes, pumped systems should therefore be iutroduced only after careful consideration and in exceptional cases.

Figure 1 illustrated different hydraulic layout possibilities. On the raw water side, the water flows by gravity directly to the treatment plant or, if pumped, preferably first to a raw water balancing tank. After passing through the treatment plant it is stored in a reservoir and later distributed to the consumers by a piped gravity scheme close to the houses. In a semipiped scheme, the water flows by gravity through the treatment plant into the reservoir equipped with handpumps, or as an extended alternative, the reservoir is connected to a system of cistern located between treatment plant and village. Treated water is now supplied by gravity to these cisterns equipped with handpumps. Each cistern acts as reservoir and water point.

Such distribution systems may increase sustainability and reliability of a water supply as the consumers keep the water supply system running at low operating costs and at village maintenance level. The system of storage tanks equipped with handpumps can best control excess water usage, prevent contamination and avoid wastewater disposal problems. The consumer, however, may require higher service levels than the "handpump option." On the one hand, higher service levels imply increased water consumption and wastewater disposal problems; on the other, collection of water charges may become easier if the distribution level is shifted from public to individual supply.

The following per capita daily water demand values are generally used:

Supply with public handpumps	15–25 l/person day
Supply with public standpipes	20–30 l/ person day
Supply with yard connections	40–80 l/ person day
Supply with multiple tap house connections	80–120 l/ person day

The effective values for the supply with public handpumps or standpipes are greatly influenced by transport distance, ranging from a few dozen to 300 and more meters. For yard and house connections, water use will be influenced by the level and manner in which the water charges are levied (such as a monthly lump sum or on an effectively used water volume basis). Furthermore, use of drinking water for backyard garden irrigation leads to an enormous water demand and should therefore be prohibited.

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WATER HARVESTING AND SPREADING FOR CONJUNCTIVE USE OF WATER RESOURCES

Frank Simpson

Girish Sohani

INTRODUCTION

What is the best way to plan a strategy for obtaining a year-round water supply in a rural dryland area with rainfall largely restricted to a few weeks within a four-month period of monsoon? What are the most appropriate technologies for provision of a domestic water supply in a setting of rapidly dwindling surface water, where shallow aquifers are scarce and seldom found near the locations of greatest need? What is to be done about these problems when the people in need are destitute and conditioned by life in a harsh environment to think only about survival in the short term?

The first steps in such a strategy involve collecting rain (water harvesting) to satisfy the immediate water needs of village families. A more lasting solution to the problem requires significant reduction in the amount of monsoon water leaving the area as runoff. There are limits to the effectiveness of check dams and other barriers across the valleys of ephemeral streams, in this particular regard, even though these structures are essential parts of an overall strategy. The most far-reaching effects (water spreading) come from artificial reductions in the slope of the hillside, augmented by systems of ridges and trenches, configured so as to direct the surface runoff underground. The technologies employed to these ends should be cheap, small in scale, and easily replicated.

The purpose of this account is to describe the main technologies for water harvesting and spreading, employed in the research project, titled *Conjunctive Use of Water Resources in Deccan Trap, India.* The project involved Bharatiya Agro Industries Foundation (BAIF), Pune, India, and University of Windsor Earth Sciences, Windsor, Ontario, Canada, working in partnership with the tribal and rural people of Akole *Taluka*, Maharashtra. It ran from 1992 to 1996 and achieved sustainable results for the villagers of Ambevangan, Manhere, and Titvi. The authors were the Canadian (FS) and Indian (GS) project leaders.

A detailed account of the project research is given by Sohani, Simpson, et al. (1998). A summary of the main benefits, derived from the project by the three partner villages, is presented by Simpson and Sohani (2001). The main factors that set the scene for participatory management and evaluation of the project are discussed by Simpson and Sohani (in the Planning and Implementation chapter). This last mentioned article also includes a general description of the terrain and climate in Akole *Taluka* and the living conditions of the tribal and rural people, which is not repeated here.

ASSESSMENT OF TECHNOLOGIES

The tribal and rural people shared elements of local knowledge systems pertinent to the use of water and soil. This indigenous technical knowledge included information on botanical indicators of shallow ground water, such as the tree *Ficus glomerata*, known locally as *umbar*, and the associated bottomland flora. This information tended to be supported by accounts of ancient, Indian hydrology, such as the *Brahat Samhita*, written by Varaha Mihira in the sixth century (see Tagare 1992) and by modern field observations. In addition, the people provided useful information on the relationship between terrain features and groundwater discharge, local strategies of land use, and a local classification of soils.

Indigenous technical knowledge was combined with project research on hydrology and hydrogeology in the assessment of technologies for possible introduction into the area and in the selection of sites for demonstration purposes. The research involved field and laboratory study of the soils, weathered bedrock, and underlying basalt lavas making up the bedrock, as well as water from streams, springs and seepages, and shallow wells. Imagery from earth satellites in orbit was employed in the mapping of straight-line ground features (lineaments), many of which coincided with the traces of vertical fractures in the bedrock. These formed conduits for the circulation of ground water and also coincided with several of the more persistent springs.

A high priority was assigned to the selection of technologies for water harvesting and spreading that were easily understood by and acceptable to the people. In addition, it was important that the technologies under consideration were compatible with existing approaches to land use. A wide range of alternative approaches to water harvesting and spreading was considered. These were documented from other dryland regions of India and elsewhere. They included ancient technologies, such as those used in the Negev Desert by the Nabotean culture and its predecessors, more than four millennia ago (Nessler 1980).

WATER HARVESTING

Water harvesting refers to the collection and storage of water from a surface on which rain falls. Ideally, the catchment or water-collecting surface is impervious to water and may be located on natural or artificial materials. Alternatively, it may be on natural materials that have been treated so as to increase the amount of runoff associated with precipitation events. The water is contained in a storage tank, which may be connected to the catchment area by means of a pipe. A reservoir, receiving water by overland flow from the slopes of an adjacent catchment area, is also part of a water-harvesting system. Rainwater collection from buildings is described in the "Rainwater Collection" article in this chapter.

The tribal and rural people gave a high priority to a year-round water supply for domestic use. Roof water harvesting was introduced into the villages as a partial response to this need (see Figure 4). The houses in the villages are made of stone and mud and have tiled roofs, which make effective catchments. In each system, gutters, made of galvanized iron sheets, were added to the sides of the roof and connected by means of PVC pipe to a ferrocement storage tank, equipped with a tap and mounted on a stone platform. In general, a 2,500-liter tank proved adequate for the needs of a family throughout much of the year.

Check dams were constructed across the valleys of ephemeral streams. Straight stretches of the valley with low gradient on the up-slope side of the dam and shallow bedrock for its foundation provided optimum conditions. Masonry check dams, gabiou structures, and gabion structures with impervious, ferrocement barriers were employed at different locations. The gabion structures were held together by galvanized iron chain liuk. The impervious barriers were constructed in trenches, excavated in the bedrock, and situated at the center of the dam site or on the up-slope side (see Figure 5).

The waters of selected springs were collected in stone storage tanks equipped with taps. A gravel filter was installed at the inlet of each tank. At one location, groundwater was contained for village use on the up-slope side of an underground stone dam, extending down to the bedrock. A barrier of ferrocement was included in the structure.

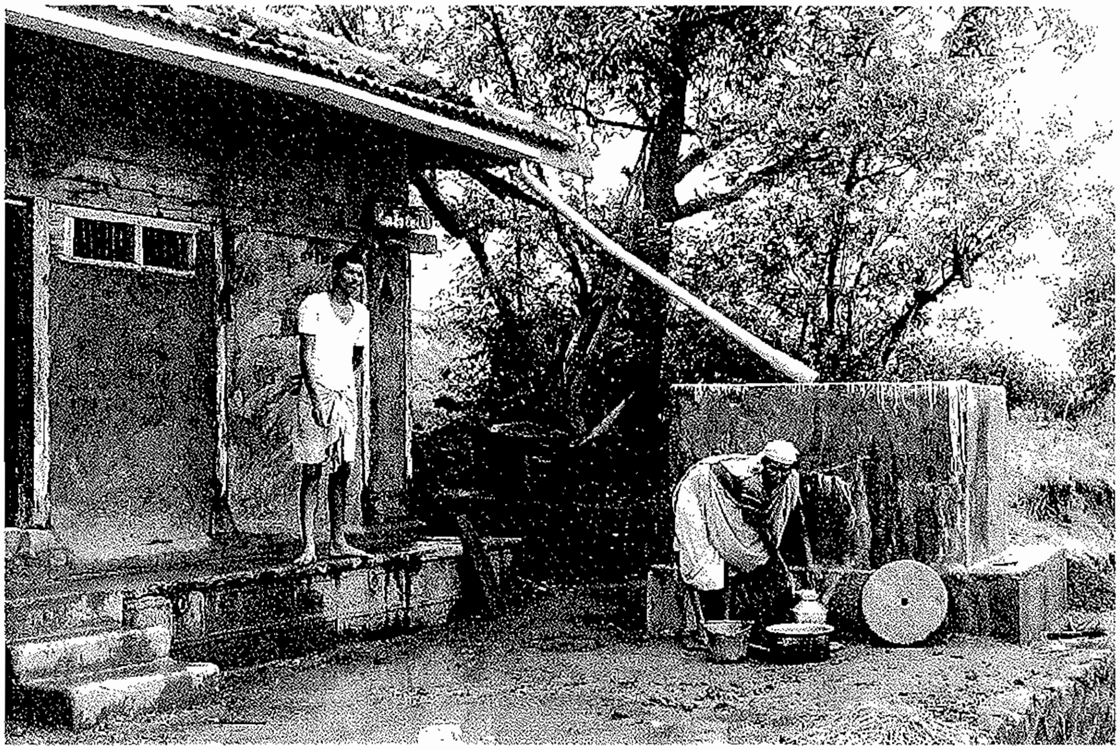

FIGURE 4 Roof water harvesting
Manhere Village, Akole *Taluka,* Ahmednagar District, Maharashtra State, India.

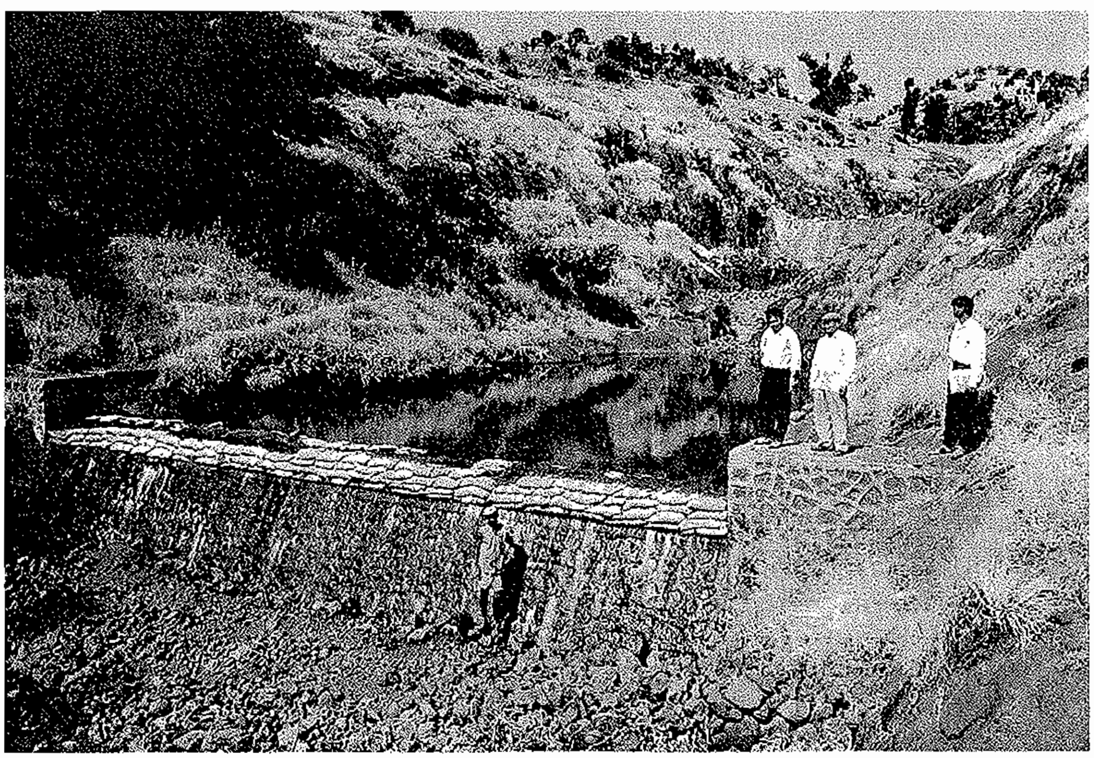

FIGURE 5 Lowermost check dam and reservoir in gravity-flow system of three reservoirs, close to completion
Middle and uppermost check dams of system also visible. Near Manhere Village, Akole *Taluka*, Ahmednagar District, Maharashtra State, India.

WATER SPREADING

Water spreading involves arresting the down-slope motion of overland flow by means of artificial reductions in the angle of slope, which may be augmented by low ridges of soil. The ridges are constructed parallel to the contours of elevation, generally along the outer margins of the areas of reduced slope. The water spread out by these means infiltrates into the soil and makes additions to soil moisture. It also may recharge shallow ground water. Infiltration may be improved through the excavation of strategically located, shallow pits and trenches, elongated parallel to contours of elevation. Infiltration at different levels on the hillside may be controlled sequentially by means of spillways.

Various approaches to slope modification were employed. The existing system of hill terraces was expanded, notably for orchard development. Contour trenches were dug close to their down-slope margins. Terrace-margin bunds (soil ridges) were built up from the excavated soil. Spillways were introduced at breaks in the bunds, with stone aprons to give protection against soil erosion. Farm ponds are rectangular excavations, located at the lower terrace levels, so that the removed soil forms a ridge on the down-slope side (see Figure 6).

Dry stone bunds were constructed at the upper reaches of slopes, parallel to contours of elevation, to reduce the velocity of surface runoff and minimize soil erosion. Gully plugs were positioned across incipient gullies to trap eroded soil. They serve the additional function of promoting the infiltration of trapped surface runoff (see Figure 7). Vegetative, ecological techniques were also applied, in support of these inorganic approaches to soil conservation. These included the planting of forestry and fruit trees, as well as shrubs and grasses, along terrace-margin bunds and soil ridges, associated with farm ponds.

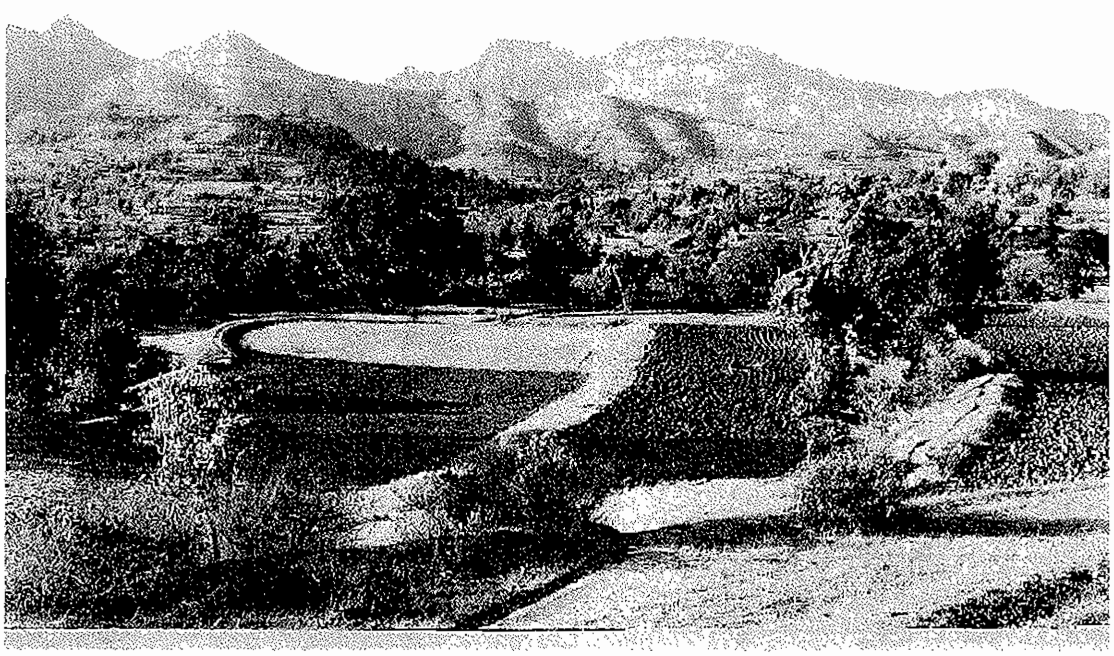

FIGURE 6 Hillside terraces with marginal bunds
Near road between villages of Ladgaon and Titvi, Akole *Taluka*, Ahmednagar District, Maharashtra State, India.

FIGURE 7 Contour bund with contour trench and farm pond on upslope side
Near road between villages of Manhere and Ambevangan, Akole *Taluka*, Ahmednagar District, Maharashtra State, India.

Infiltration trenches and pits were excavated in the vicinity of selected dug wells, many of which also were deepened to improve their yields. Particular bore wells were given workovers for the same reason.

CAPACITY BUILDING

Villagers were involved in the introduction of the various technologies at demonstration sites. In addition to learning the techniques required, they developed basic management skills and, in some cases, demonstrated leadership qualities. In each of the three partner villages, additional training in the application and maintenance of water-harvesting and -spreading technologies was provided for interested individuals (see Figure 8).

ACKNOWLEDGMENTS

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The phenomenal success of the project was the result of teamwork and the commitment of many individuals. In particular, reference must be made to the roles of the BAIF field staff, members of the Canadian and Indian project teams, and the numerous individuals at the BAIF office in Pune and at the University of Windsor, who also made contributions.

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FIGURE 8 Demonstration of teamwork in use of A-frame for excavation of contour bunds and trenches
Manhere Village, Akole *Taluka*, Ahmednagar District, Maharashtra State, India.

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RAINWATER COLLECTION

Based on "Rainwater Reservoirs Above Ground Structures for Roof Catchments," Rolf Hasse, A Publication of Deutsches Zentrum für Entwicklungstechnologien–GATE in: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH—1989

An approach to supplying clean water is to collect rainwater, usually from a roof. Systems for doing this are used presently in Thailand, New Zealand, and other places. A major design question is the size and construction of the storage tank. In Thailand, for example, large baskets are coated with cement to give tanks of 1000-gallon capacity. Figure 4 in the previous article shows a system.

ADVANTAGES OF HARVESTING RAINWATER

- Provides very high-quality water (in most areas), soft and low in minerals, so less soap is required
- Reduces mineral deposits on fixtures, pipes, and water heaters
- Offsets the need for pumping groundwater; reduces energy needed for deep well pumping and water softening
- Conserves irrigation water because plants often respond better to rainwater than groundwater, increasing yield
- Reduces erosion and flooding typically created by runoff
- Reduces silting and contamination of waterways from runoff

COMPONENTS OF A ROOFTOP RAINWATER HARVESTING SYSTEM

- Catchment Area—another potential function of a roof
- Gutters and downspouts—can include leaf screens and roof washers
- Storage tanks/cisterns—prefabricated: galvanized steel, fiberglass, polyethylene, polypropylene, PVC bladders; partially prefabricated: series of drums, cans or barrels; site built: ferrocement, stone, poured concrete, mortared block and rammed earth

A house with rainwater gutters and a cistern is shown in Figure 9.

Roof Type and Catchment

The shape of a catchment area has a considerable influence on the catchment possibilities. Of the most common roof types shown in Figure 10, the single-pitch roof is the most appropriate for rainwater harvesting, since the entire roof area can be drained into a single gutter on the lower side and one or two downpipes can be provided, depending on the area. A more difficult roof for rainwater catchment is the tent roof. It requires a gutter on each side and at least two downpipes on opposite corners. If a tent roof is large enough, it could be drained into four tanks located at each corner of the house. The main problem is always the corner. A 90-degree angle in the gutter should be avoided. It is extremely difficult to adjust gutters in such a way that water really flows easily. A gutter seldom works well when downpours occur, and it is the heavy downpours that should be caught. The hip roof is not very efficient either, since it also needs gutters all around the building. Flat roofs can be used for catchment if they are furnished with an edge, keeping the water on the slab until it has drained through the gutter or downpipe. However, using a flat roof for rainwater harvesting is not very efficient because of the extended runoff time and the evaporation losses. One way to improve the catchment is to provide the slab with a sloping cement screed. Constructing a waterproof edge on a flat roof is rather difficult because of the temperature expansion.

Roof Finish

Not all materials used for roofing finishes are equally good, but the most commonly used material, metal sheeting (corrugated galvanized iron and aluminum sheets), is very suitable for rainwater catchment. Likewise brick tiles of all variations and also thatch can be used, but these are less efficient. Lead, sometimes employed in soldering gutters or channels, should not be used.

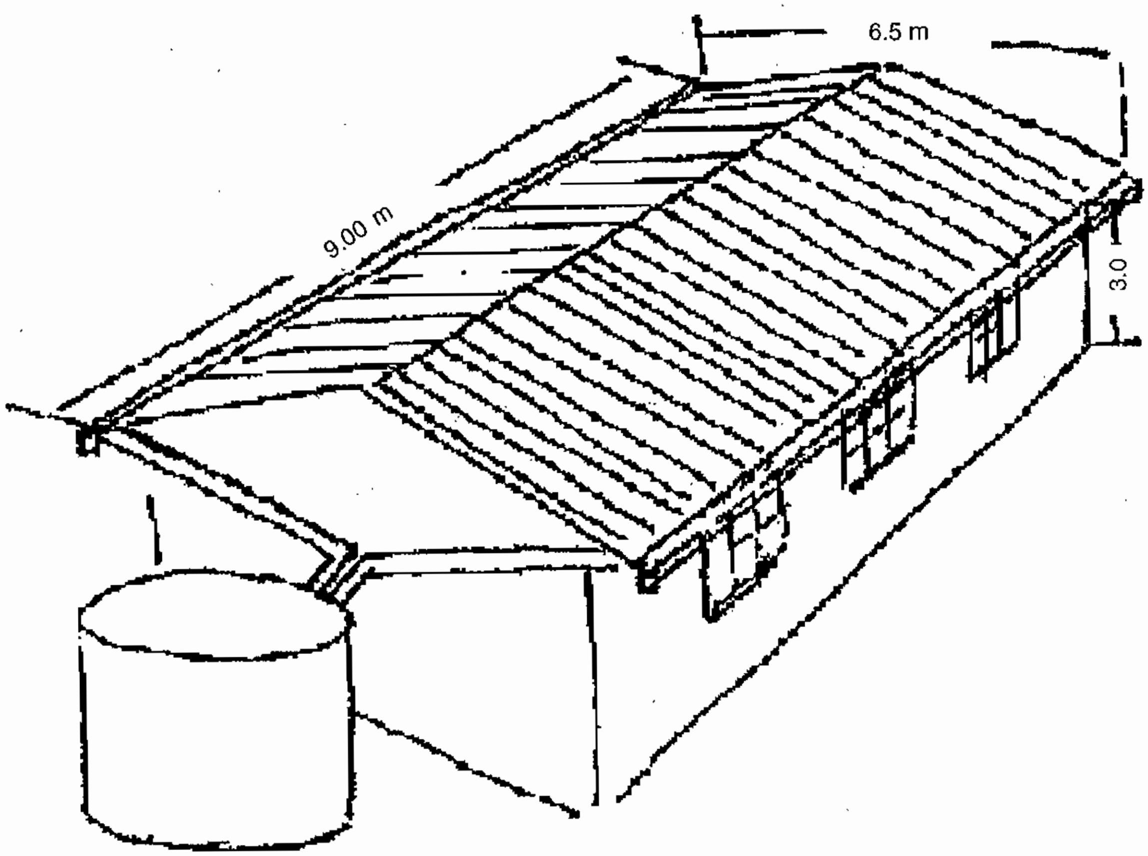

FIGURE 9
Rainwater collection.

ROOF WASHERS

The water from a roof during the first few minutes of a rainstorm will rinse dirt—often mostly bird droppings—off the roof and will be dirty. A design question, then, is how to divert that water from the storage tank if clean water is needed. One device uses a bucket to take the first flow; when it is full, it tips over, directing the rest of the flow to the storage tank (see the report by the Institute for Rural Water in the References). Another device is a vertical standpipe in the gutter between the roof and the downspout leading to the storage cistern. This standpipe extends to the ground and has a normally closed stopcock at the bottom. The first rain in a storm will flush dirty water into the standpipe. Only after the standpipe is full will rainwater go to the downspout leading to the cistern. The standpipe should hold 10 gallons of water for each 1,000 ft^2 of roof. A six- or eight-inch PVC pipe is usually suitable. The water in the standpipe can be used for irrigation between rainstorms. A screen over the gutter will keep leaves out.

DIFFERENT TYPES OF RESERVOIRS AND THEIR ADVANTAGES

In many cases in developing countries the availability of building materials outweighs the economic factor in selecting a type of reservoir.

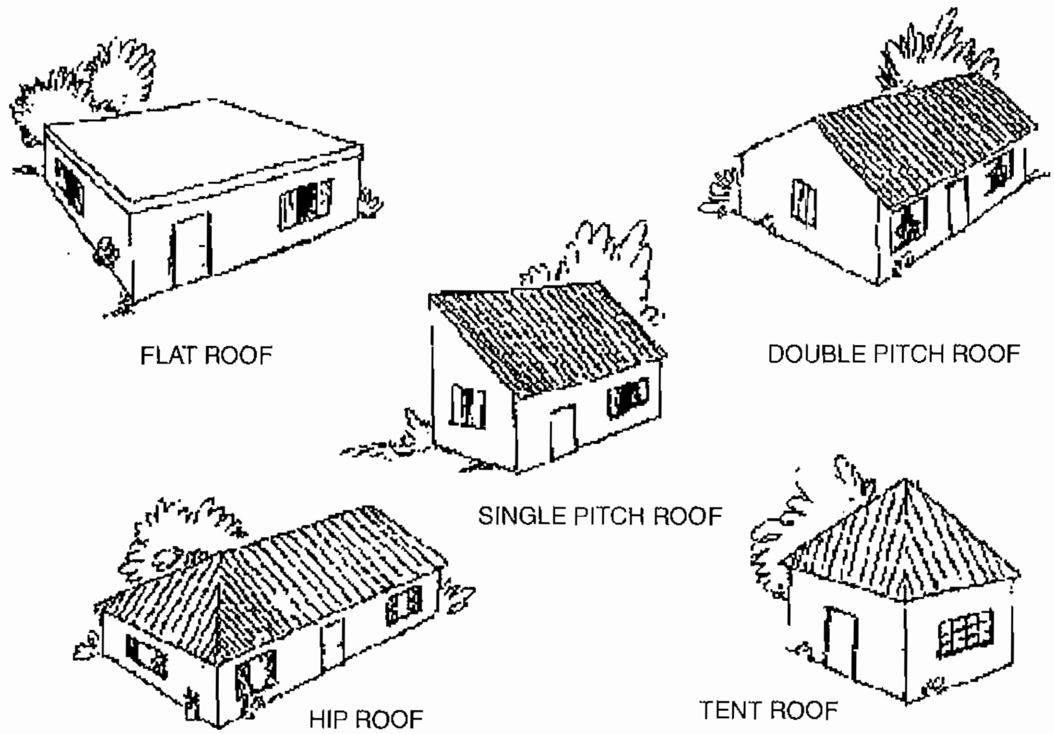

FIGURE 10
Types of roofs.

The Corrugated Iron Tank

This is an industrial product manufactured in many countries. Where the material for this tank is available, there are at least three capacity sizes: 2.25, 4.5, and 9.0 m^3. Although iron tanks are usually the most economical, prices have to be compared with other suitable materials; the transport aspect can also increase costs substantially. The advantage of this tank is mainly the price but certainly also the fast installation. The disadvantage is the limited lifetime due to corrosion, although this can be improved by painting. One should remember at all times that the corrugated iron tank is vulnerable to manual force. Experience has shown that this tank should not be used at public places, especially not at schools, since vandalism is likely to damage the tanks beyond repair.

The PVC Foil Tank

Several industrial producers offer tanks of PVC foil. The foil is fixed inside a reinforcement mesh framework or galvanized sheet cylinders, screwed together from sections. The tanks are available from about 5 m^3 up to 430 m^3. Their considerable advantage lies in fast assembly and low transport costs. A reservoir of 9.25 m diameter (capacity 81.0 m^3) can be transported on a small van and be assembled within a couple of hours. No foundation is needed. Dismantling and reassembly at another place can be carried out within a day or two. Apart from this advantage, which is very valuable for cases requiring immediate action—for instance, improvising a village water supply—the system has some weak points. Tanks of large capacity are uncovered, so evaporation is high and there is a danger of pollution. More important for permanent use is the problem of ultraviolet ray influence on the PVC foil. Systems in use show signs of ultraviolet light effect on the material after just a few years. Otherwise, the vulnerability to external force is great, and tanks should always be fenced in. For permanent rainwater catchment, although relatively cheap, this technique has its limitations.

The Ferro-Cement Tank Without Mold

This technique depends on the availability of welded reinforcement mesh. Since this is not to be found everywhere, other methods can be substituted. There are many examples of such reservoirs in Kenya. Ferro-cement is described in the "Boats" article in the Transportation chapter.

First, close attention must be given to the cost of the material and the transport to the site. The height of the tank will be the width of the roll of mesh or mats, about 1.80 m. This is certainly a restriction. Theoretically, it is possible to extend the height of the wall by using one and a half widths of the mesh, overlapping it a minimum of three fields, and tying it together with the bottom circle, but such is not recommended. The entire structure becomes unstable, and any vibration during the process of plastering will make the work very difficult. In addition a scaffold is needed, which might not always be available. The fixing of the scaffold requires skilled workers.

The Ferro-Cement Tank with a Factory-Made Mold

The technique has considerable advantage for rainwater storage where all tanks are of the same size. Several examples are found in Botswana.

This construction method can only be chosen if a factory or experienced workshop provides the facilities for bending corrugated sheets and welding them neatly together. The technique is highly appropriate in areas where a series of tanks are to be built, such as when new buildings, like schools, are put up and design of the buildings already includes provision for rainwater catchment.

The mold can be used 10 to 15 times, depending on the experience and careful handling of the staff. For larger projects it is advisable to have at least two molds at the site. With two molds, the work can be organized with three crews. The first crew starts preparing the ground and then casts the foundation slab. The second erects the mold and reinforces it, and the third crew does the plastering. The roof slab can be made by a fourth crew or by the first, depending on the amount of ground to be cleared. This technique will be too expensive where only four or five reservoirs have to be constructed.

The Ferro-Cement Tank with a Made-on-Site Mold

This approach should be chosen where only a few tanks are required, or even jnst one—in other words, where prefabricated molds do not make sense and welded reinforcement mesh is not available. All that is needed, in addition to the normal building materials for a ferro-cement structure, is some additional timber for the framework and a few corrugated iron sheets for shuttering. Fencing mesh is an additional reinforcement but could be replaced by other available mesh material.

The Reinforced Brickwork Tank

The reinforced brick tank is more expensive than the ferro-cement tank, although the cost per m^3 reduces with increased capacity. A brick tank costs about twice as much as a ferro-cement tank. For this reason this tank should be chosen only when the capacity needed is above 30 m^3 or the life of the structure is expected to be 20 years and more. The advantage of the construction method is the adaptability to the building design. Structures above 1.80 m in height can be built without problems, although plastering has to be done with great care. Especially at public buildings, which are usually higher than residential houses, it is possible to use the height between gutter and ground, avoiding large diameters and thus saving space.

HOW TO CHOOSE THE SIZE OF A RESERVOIR

The size of storage capacity is based on the mean annual rainfall, but it should be greater if funds allow. To calculate the rainwater amount that can be harvested, the mean annual rainfall figure is commonly used. Mean annual is the statistical average calculated on the basis of measured rainfall over many years. Not only the average rainfall needs to be considered but also the uniformity. If the rainfall is fairly uniform year-to-year then the average is a useful estimate. But the average is less helpful if the rainfall pattern in a given area is erratic, which is quite common in countries with drought periods. It can happen that the mean annual is not reached. It can certainly happen the other way round that considerably more rain falls than the mean annual. This makes the calculation of the storage capacity rather difficult.

As an example, let us consider the roof of the building in Figure 9 with a rainfall of 450 mm. We assume that less than 100 percent of the calculated amount of water will be collected. This is due to unavoidable small leakages in the gutter downpipe system, or rainfalls that are too light to produce sufficient runoff, or a possible overflow of gutters in the case of an extreme downpour. For these reason we can generally assume that only 90 percent of the rainwater can be collected.

For calculation we take the following formula.

$$\text{Mean annual rainfall in mm} \times \text{area in m}^2 \times \text{runoff factor} = \text{collected rainwater in liters.}$$

In our example this means the following

$$450 \times 6.5 \times 9 \times 0.9 = 23{,}700 \text{ liters}$$

The height from the ground to the gutter outlet is 3 m. A reservoir of 4-m diameter on a filling height of 1.80 m has a storage capacity of 23,000 liters. This means that one reservoir built at the gable side of the house would be sufficient for nearly all the rainwater that can be collected if average rainfall occurs. We assume that the rainfall pattern makes it unlikely that all the year's rain will occur within a short time period. Two gutters along the sides of the building should be connected with downpipes fixed to the gable wall and then bridged into the tanks.

For this storage capacity a ferro-cement tank would be less expensive than a reinforced brick tank and serves the same purpose. But if a smaller storage capacity would be sufficient, or if funds are very limited, two corrugated iron tanks, 9,000 liters each, would be cheaper and more effective.

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SAVING AND REUSING WATER

Based on "Rainwater Reservoirs Above Ground Structures for Roof Catchment." Rolf Hasse, A Publication of Deutsches Zentrum für Entwicklungstechnologien—GATE in: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH—1989

Saving water in semidesert countries is essential and should be encouraged as much as possible. To support saving, it is first important to understand how water is wasted. By way of example, let us consider a self-help housing area in Botswana. This area is supplied through standpipes on the side of streets, never more than 100 meters away from a house. Tenants are supposed to build pit latrines before they construct dwelling rooms. People fill containers several times a day and carry the water home. Although the supply of water is much better than in villages and distances are much shorter, the water still has to be carried. When you have to carry water to the point of use, you learn quickly not to waste it. It was observed that people became used to collecting their washing water after use and watering their plants in the courtyard. Water bills in Lobatse showed that consumption of water per standpipe, used by 7–10 families, in self-help housing areas is lower than the consumption for one high-cost house. It appears that the consumption in residential houses rises with the number of taps and other sources connected to the central supply. The conclusion should not be to require public standpipes. The general conclusion should only be that the convenience of access to water raises consumption. We should have a close look at possibilities of saving domestic water.

DOMESTIC WATER SAVING

In domestic water use the water-borne toilet system, in general, is the highest consumer of water. Moreover, the water used is not fit for reuse and goes into the sewers. Recycling of sewer water is possible but expensive and can only be done in special ponds. Toilets are discussed in the "Sanitation" article in this section. At a school with water closets—12 toilets, each consuming 10 liters per flush—the consumption of these flush toilets is higher than the consumption of 1,000 pupils and their teachers for drinking, cooking one meal a day, and washing the dishes. Consumption reduction means first reducing the consumption by the toilets. Flushing valves consume less than flushing cisterns, but they are not appropriate, since they require a permanent high water pressure not always available in developing countries. There are producers of toilets consuming 4 liters of water per flush in Sweden, Great Britain, and West Germany. In the United States all new toilets are required by federal law to use a minimum amount of water. Imports of this highly appropriate system into developing countries, where there is a real need to save water, should be encouraged.

Introduction of a new system—low water consumption toilets—takes time, since people have to be convinced that the higher investment really brings returns. But there is also something that can be done about the existing highly wasteful cisterns—toilet tanks. Some can be adjusted to lower levels of filling by bending the bow of the cistern float downwards. This results in stopping the filling water at a lower level. It is also possible to put stones in the cistern. The volume of the stones (blocks) will be the volume of water saved. Depending on the type of cistern, the consumption can be reduced to 7 or even 6 liters, but the cleaning effect of flushing may be reduced, since the toilet bowl is not designed for such low consumption.

BATH OR SHOWER

It is often not realized that the amount of water consumed for one bath is sufficient for three showers. In consequence, houses should be furnished with showers rather than with baths. But baths have become a status symbol in many countries, and a high-cost house must be furnished with a bath. The odd thing is that baths in Europe are rather out of fashion and much less used than showers, which produce savings in both water and time. From the hygiene point of view showers are better than baths. When a bath is installed, it should always be done that the bath can also be used for showers. At the same time the built-in bath should be chosen carefully, since the capacity varies substantially.

Several devices designed to reduce water consumption are on the market. Spray nozzles for showers, push button taps, and so on might reduce consumption but should be studied before use. When deciding on water saving equipment one has also to consider the lime content of the water. Lime precipitates at 60° C. This means that sensitive equipment in hot climates will soon clog.

REUSE OF DOMESTIC WATER

Major sources of water consumption in residential houses are the kitchen sink, the bath and/or the shower, the basin in the bathroom, and the toilet. While for obvious reasons the reuse of water from the toilet is not possible, the bathroom water, although contaminated by soap and through laundry by washing powder, can be used for cultivation, even for vegetables, if directed at the soil. Such a system is sometimes called "graywater" recycling—"blackwater" would be water from a toilet. One vegetable gardening area of 150 m at a clinic in Lobatse was only irrigated with water from sinks and hand basins for a period of one year and showed very successful results. At this clinic one sink was used for washing drug containers and equipment used for medical tests. This wastewater was drained into the sewer. All other wastewater was drained into drums dug into the ground (see Figure 11). The water was then extracted with buckets and used for gardening.

Experiments at private residential houses have shown that the reuse of water for gardening does not affect the plants. One should be careful with water running out of the kitchen sinks. Water from dishwashing usually contains much grease and is therefore not suitable for most plants or for vegetable gardening. But this water can be successfully used, for example, for cultivation of banana plants. Bananas should not be planted closer than 15 meters to a residential house because of mosquito breeding. A simple sand filter can be built to remove the grease. The cleaning material used in the household should be chosen carefully. Soaps contain fewer harmful chemicals than detergents. Boron is especially harmful to plants. It is necessary that the area of soil receiving the graywater be large enough to absorb it all—sandy soils are more absorbent than clay soils and a smaller area is necessary.

There are two ways to reuse domestic water. The first, as stated, is to disconnect the pipes of the sink outlets and fit hoses draining the water into drums dug into the ground. These drums must be provided with lids because of the danger of mosquito breeding. Water is then lifted out with buckets. The other and more convenient method is to connect long hoses direct to the

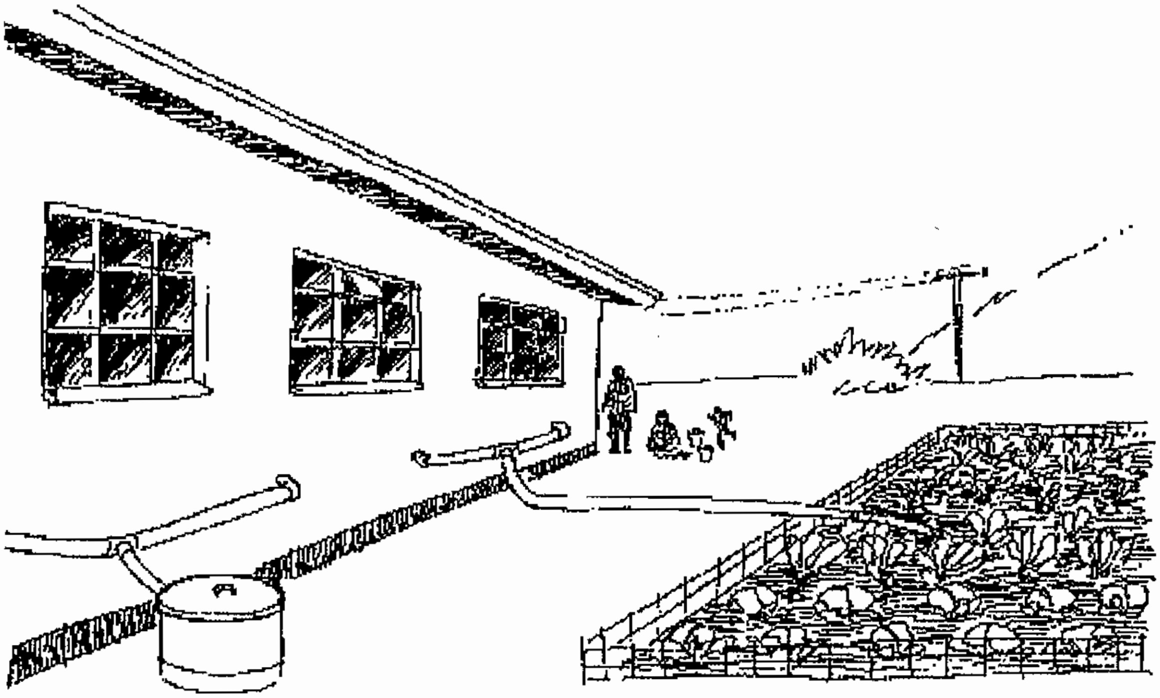

FIGURE 11
Water recycling.

outlets and draw the water straight to the place of use. See Figure 11. Attention must be paid, of course, to matching the amount of water from the drains to the needs of the garden.

Where rainwater is available and not used for the household as drinking water because of an existing centralized supply, it should be used for vegetable gardening and the waste water for cultivation of trees and other plants. It is probably best not to use graywater for irrigating root crops and not spray the water on edible leaves. Soaps and detergents are alkaline, and some plants, such as broccoli, cantaloupes, and tomatoes, thrive on alkaline soil. Beans, apricots, and peaches do not.

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WELLS: HAND DUG AND HAND DRILLED

Based on "Wells Construction: Hand Dug and Hand Drilled," Peace Corps Information Collection & Exchange, Manual M0009, Written by Richard E. Brush, September 1982

There is water at some depth almost everywhere beneath the earth's surface. A well is a dug or drilled hole that extends deep enough into the ground to reach water. Wells are usually circular and walled with stone, concrete, or pipe to prevent the hole from caving in. They are sunk by digging or drilling through one or more layers of soil and rock to reach a layer that is at least partially full of water, called an aquifer. The top of the aquifer, or the level beneath which the ground is saturated with water, is called the water table. In some areas there is more than one aquifer beneath the water table. Deep wells, such as those sunk by large motorized equipment, can reach and pull water from more than one aquifer at the same time. However, this article will only discuss sinking wells to the first usable aquifer with hand-powered equipment.

SITE CHOICE

The well should be located at a site with the following characteristics.

- Water bearing
- Acceptable to the local community
- Suitable to the sinking methods available
- Not likely to be easily contaminated

It is not always possible for a site to meet all of these guidelines. Therefore, a site will need to be chosen that best approximates the guidelines, with particular emphasis on the likelihood of reaching water (see Figure. 12). Where there is an equal chance of reaching water at several different locations, the one closest to the users is preferable.

WHERE IS WATER LIKELY TO BE FOUND?

Choosing the site for a well can be difficult because easily available and abundant water can never be guaranteed. Even professionals, before a well is sunk, rarely know where they will reach water and how much will be available. However, there are a number of guidelines that can be very useful in providing information about possibly successful well sites. Where possible, a well can be located near a past or present water source. By doing so, you are likely to reach water at approximately the same depth as the other source.

If no other sources exist or have ever been developed nearby, you must be more cautious in choosing a well site. Unless you have the benefit of detailed geological information, it is best simply to look for the lowest spot nearby. Both surface and groundwater are likely to collect here. In some cases, plants can be indicators of the presence of groundwater—perennial plants and trees often tap into groundwater. Be careful, however, not to build in a place so low that the well would be susceptible to flooding in heavy rain.

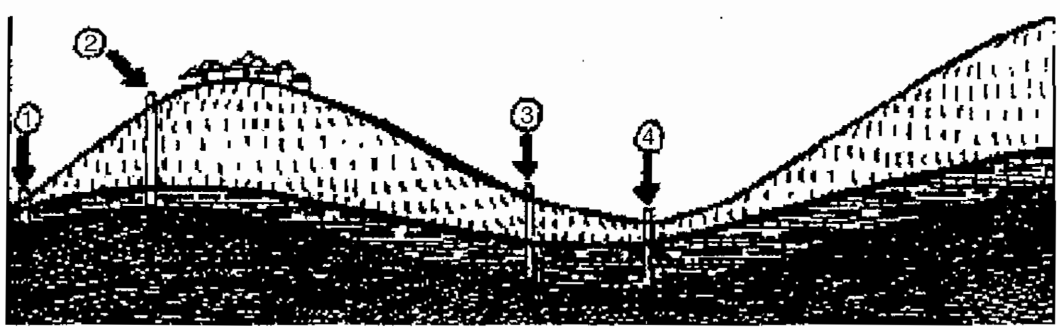

FIGURE 12
Possible well sites.

FIgure 12 Shows four possible sites and their suitability.

1. Limited water would be available at this site because the impermeable rock layer is close to the ground surface, allowing slight fluctuations in the water table to drastically affect water availability.
2. This is the closest site to village and therefore the best site if it is possible to dig down far enough to reach water.
3. At this site, there would be a better chance of reaching more water than at site 2, but the site is farther from the village.
4. This is the site where water is most likely to be reached by a well, although it is some distance from the village. Because it is in the absolute bottom of the valley, it may be subject to flooding.

OTHER CONSIDERATIONS

Other considerations involve being acceptable to the local community, suitable to the sinking methods available, and not likely to be easily contaminated. If the most likely site would require that the well penetrate a layer of rock, and if there are no tools available to do such a difficult job, the site is not an appropriate one. The most important contamination factor is that the well not be located within 15 meters of a latrine or other sewage source. This would also include not placing the well where it might be damaged or inundated by a flood or heavy rain.

The only way to design a well to prevent water contamination is to seal it so that water can enter only through the bottom section. Dug wells need to be covered with a permanent cover through which a pump is installed to draw water. All wells should have a platform around them that is at least 1 meter wide, one that water will not penetrate. This platform ought to be sloped in such a way that any spilled water runs off away from the well.

TYPES OF WELLS

In general, there are two types of wells: dug wells and drilled wells. The obvious difference between the two is the size of the holes. Dug wells are sunk by people working down in the hole to loosen and remove the soil. The wells need to be at least 1 meter wide to give the diggers room to work. Drilled wells, on the other hand, are sunk by using special tools that are lowered into the ground and worked from the surface. These wells are normally less than 30 centimeters (cm) in diameter and usually are less than 15 cm; it is difficult to drill wide diameter holes with hand-powered tools.

WELL SECTIONS

Every well, whether drilled or dug, has three sections: top, middle, and bottom. Each of these sections varies in construction because each must function differently.

- Top section—that part of the well at or above the ground surface level. It should be designed to allow people to get water as easily as possible and, at the same time, to prevent water, dirt, and other contaminants from entering.
- Middle section—that part of the well that is between the ground surface and the water. This section is usually a circular hole. It is reinforced with some kind of lining to prevent the walls from caving in.

- Bottom section—that part of the well that extends beneath the water table into the aquifer. It should be designed to allow as much water as possible to enter and yet prevent the entrance of soil from the aquifer. Its lining will have holes, slots, or open spaces, allowing water to pass through.

Lining and casing refer to the same part of the well. Lining is used with a dug well, while casing refers to the pipe used to reinforce a drilled well. The three sections are shown in Figure 13.

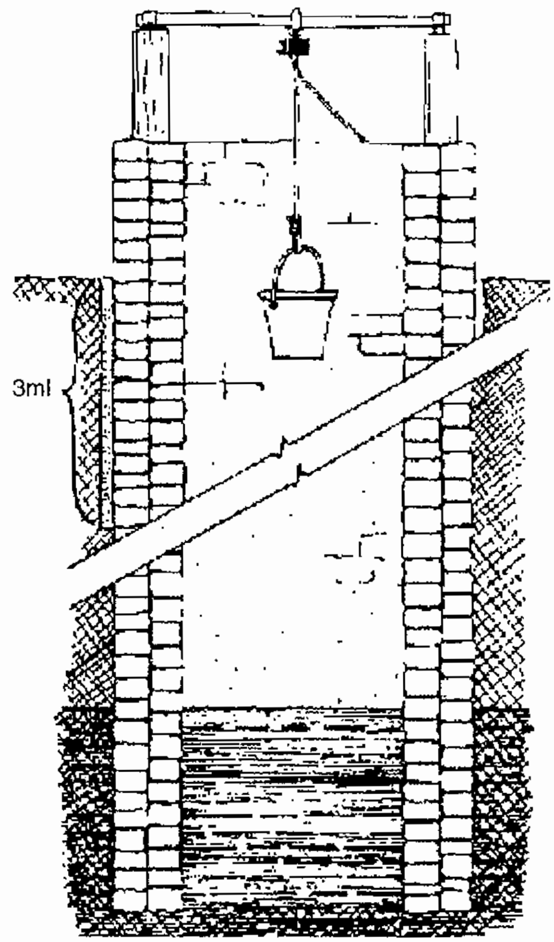

FIGURE 13
Rock-lined dug well.

A head wall should be built on all wells that will not be fitted with a permanent cover and a pump, as a inexpensive safety feature, which will prevent people and animals from accidentally falling in. It is simply a wall that extends above the surface of the ground far enough to prevent most accidental entry of people, particularly children, and animals. Its external dimension is dependent on how thick you want the head wall to be. A head wall that is unnecessarily thick will encourage people to stand on it to draw their water, creating an unsafe situation. The easiest and best way to construct the head wall is as an extension of the lining as the equipment and supplies construction will be on site. The head wall should extend 80 to 100 cm above the ground surface or apron, if there is one.

A drainage apron is most often a reinforced concrete slab 1 to 2 meters wide, which surrounds a well and, because of its slight slope, channels surface water away from the well. Wire mesh reinforcing may be used if it is available. By forcing water to flow away from the well, the apron serves two functions: It prevents contaminated surface water from flowing back down into the well before it has had a chance to be sufficiently filtered by the earth, and it prevents the formation of a mucky area immediately around the well, which can be a breeding ground for disease and a source of contaminants to the well water.

All wells, except those drilled through rock, can be expected to cave in with time unless a lining is installed to support the well. The lining thus helps to keep the well open. Another function of the lining is to prevent contamination of the water. Occasionally slight ground shifts can put pressure on linings, causing them to split and separate if not strongly built. Geologists can usually predict where such shifts are likely to occur. If no such information is available, it is recommended that you build the lining strongly enough to withstand normal earth stresses.

Depending on ground conditions, you may or may not be able to dig the complete hole and then line it. In very loose, sandy soil, for example, the sand from the walls of the hole will frequently cave into the hole, seriously hampering efforts to deepen the hole. In this case the hole is lined after 1 meter or so—certainly less than 5 meters—have been dug.

Designing the lining for the middle section is largely a matter of assessing the ground conditions and materials availability to determine the lining materials and method most appropriate for the situation. The lining of a dug well can be built of reinforced concrete, concrete without reinforcement, cement alone, bricks, rocks, even wood or bamboo. Drilled wells are almost always lined with pipe. If concrete is used, the lining can be formed above ground and lowered into the well or made in place.

The purpose of the bottom section is to allow as much water as possible into the well without permitting any of the fine soil particles from the surrounding aquifer to enter the well. There are three commonly used methods of allowing water to enter the well.

- Through a porous concrete lining—lining rings sunk into the bottom section can be made of porous concrete, which acts as a filter to prevent soil particles from entering the well.
- Through angled holes in the lining—holes can be punched in a freshly poured concrete ring that, when cured, can be sunk into the bottom section. These holes are more effective at preventing soil entry if they are slanted up toward the middle of the well.
- Though the bottom—the bottom of the well should always be constructed to allow water to come up through it. Often the bottom is simply left open and uncovered, but it is preferable to prevent soil entry which will gradually fill up the well. A perforated concrete slab can be used at the bottom of the well.

MATERIALS

The two most important sections of the well are the lining (or casing) and the bottom (or intake) section. While it is not necessary that both be built of the same material, it is often cheaper and more convenient to do so. Almost all modern well linings are made of either concrete or pipe (metal or plastic). Nowadays, concrete is used most often in the lining of hand-dug wells. It can be easily mixed from cement, sand, gravel, and water, and cast in place in the well. Reinforcing bars can be added to either mortar or concrete to make a much stronger and more durable lining.

Metal pipe is normally used in the construction of drilled wells. It can easily be shaped to make the necessary tools with which to sink the well and can also serve as the permanent casing and bottom section. Plastic pipe is too soft to use during drilling but is in many situations a better casing than metal pipe because it will not rust or corrode. Large-diameter concrete pipe can be used to line dug wells. Cement and pipe are available in most countries and usually in all but the most remote regions. When both materials are available, consider such factors as transportation, type of well, depth, ease of construction, and adaptability to local practices before deciding which is more appropriate.

In emergency situations, when the best water available is immediately needed, a number of substitute materials and techniques can be used. For example, wood lining can be used instead of cement. Wells built with wood or other substitute materials and techniques will supply acceptable water for a short period of time. However, they cannot now or in the future be converted into permanent sources of clean water without rebuilding major portions of the structure.

SINKING METHOD

A sinking method is the way of sinking a well. Wells may be dug by hand, drilled with hand tools, or drilled with motorized equipment. Many methods and techniques are used. The particular choice depends on the available materials and equipment, the expected ground conditions at the well site, and the user's experience with a specific sinking technique.

DUG WELLS

Hand-dug wells are sunk by digging a hole as deep as is necessary to reach water. Once the water-bearing layer is reached, it should be penetrated as far as possible. The process is always basically the same, with only minor variations because of the particular tools and equipment available and the variety of ground conditions—see Figure 14.

The following are the advantages of dug wells.

- The procedure is a very flexible one. It can be easily adapted with a minimum of equipment to a variety of soil conditions as long as cement is available.
- Because the resnlting well is wide-mouthed, it is easily adaptable to simple water-lifting techniques if pumps are not available or appropriate.
- It provides an underground reservoir, which is useful for accumulating water from ground formations that yield water slowly.

The following are the disadvantages of dug wells.

- A hand-dug well takes longer to construct than a drilled well.
- It is usually more expensive than a haud-drilled well.

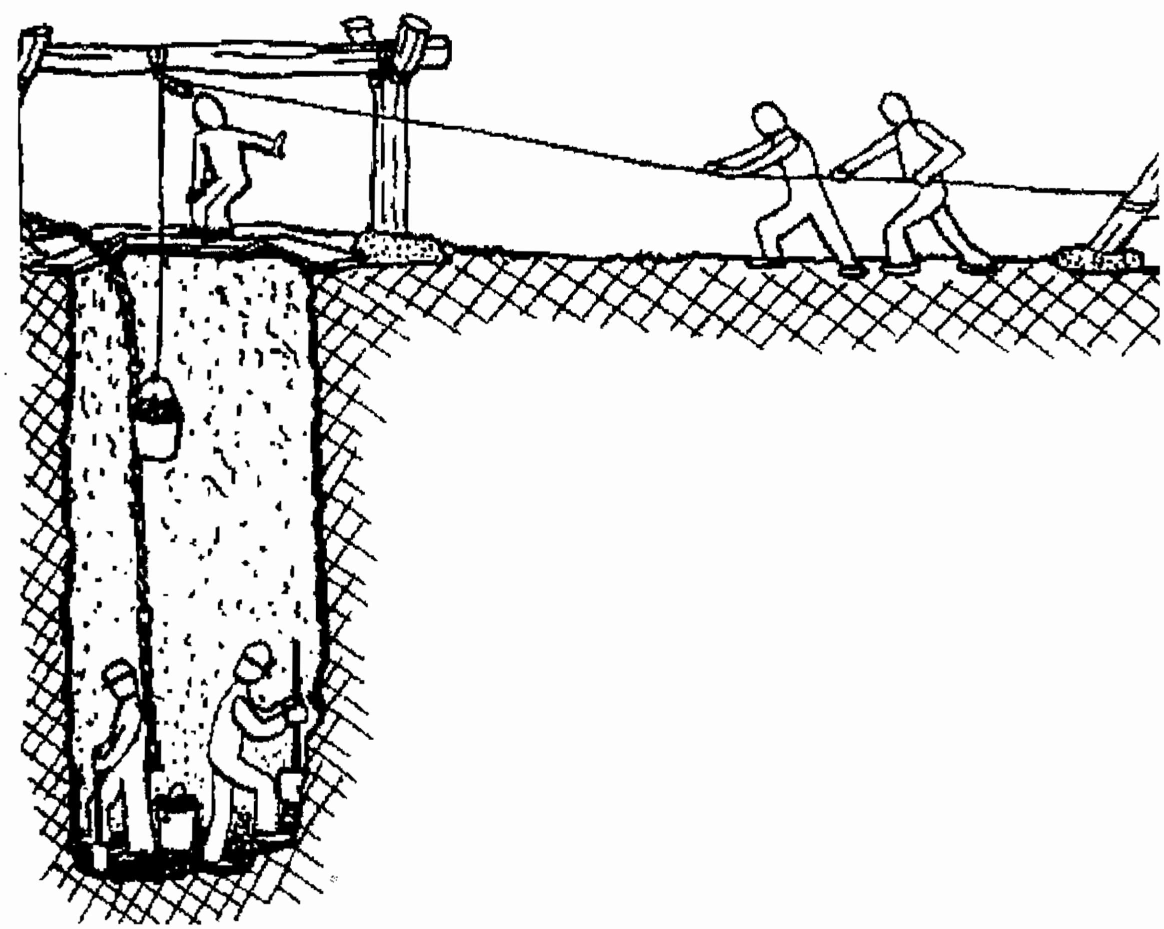

FIGURE 14
Digging a well.

- It cannot easily be made into a permanent water source without the use of cement.
- Hand digging cannot easily penetrate hard ground and rock.
- It may be difficult to penetrate deeply enough into the aquifer so that the well will not dry up in the dry season.

Compared to other well-sinking methods, digging a well by hand takes a long time. An organized and experienced construction team, consisting of five workers plus enough people to lower and raise loads in the well, can dig and line 1 meter per day in relatively loose soil that does not cave in. However, the bottom section is likely to take two or three days per meter because of the difficulty in working while water continually enters the well. Depending on how the well is developed, the top section can take anywhere from a day or two to several weeks. An experienced team sinking a 20-meter well and installing pulleys on the top structure could easily take five weeks, including occasional days off (this, of course, assumes no major delays). A new or inexperienced group would be expected to take twice that time.

Hand-dug wells should be dug during the dry season when the water table is likely to be at or near its lowest point. The well can be sunk deeper with less interference from water flowing into it. The greater depth should also ensure a year-round supply of water. If the well cannot be dug during the dry season, plan to go back to it at the end of the dry season to deepen it.

DRILLED WELLS

Drilled wells are sunk by using a special tool, called a bit, that acts to loosen the soil or rock at the bottom of the hole. It is connected to a shaft or line that extends to the ground surface and above. The part of the shaft or line extending above the ground can then be rotated to operate the bit—see Figure 15.

The following are the advantages of drilled wells.

- Construction is fast.
- Where cement is not available, wells can be sunk with locally made drilling equipment and lined with local materials.
- While not easy, it is possible to penetrate hard ground and rock formations that would be very difficult to dig through.
- Drilling usually requires fewer people than hand digging.
- It is especially suitable for use in loose sand with a shallow water table.

The following are the disadvantages of drilled wells.

- Special equipment is required. There are a number of different hand-drilling techniques that are suitable for a wide range of ground conditions.
- Pumps almost always have to be used because buckets are too large to be lowered into the well.
- Limited depth can be reached with hand-powered drilling equipment.

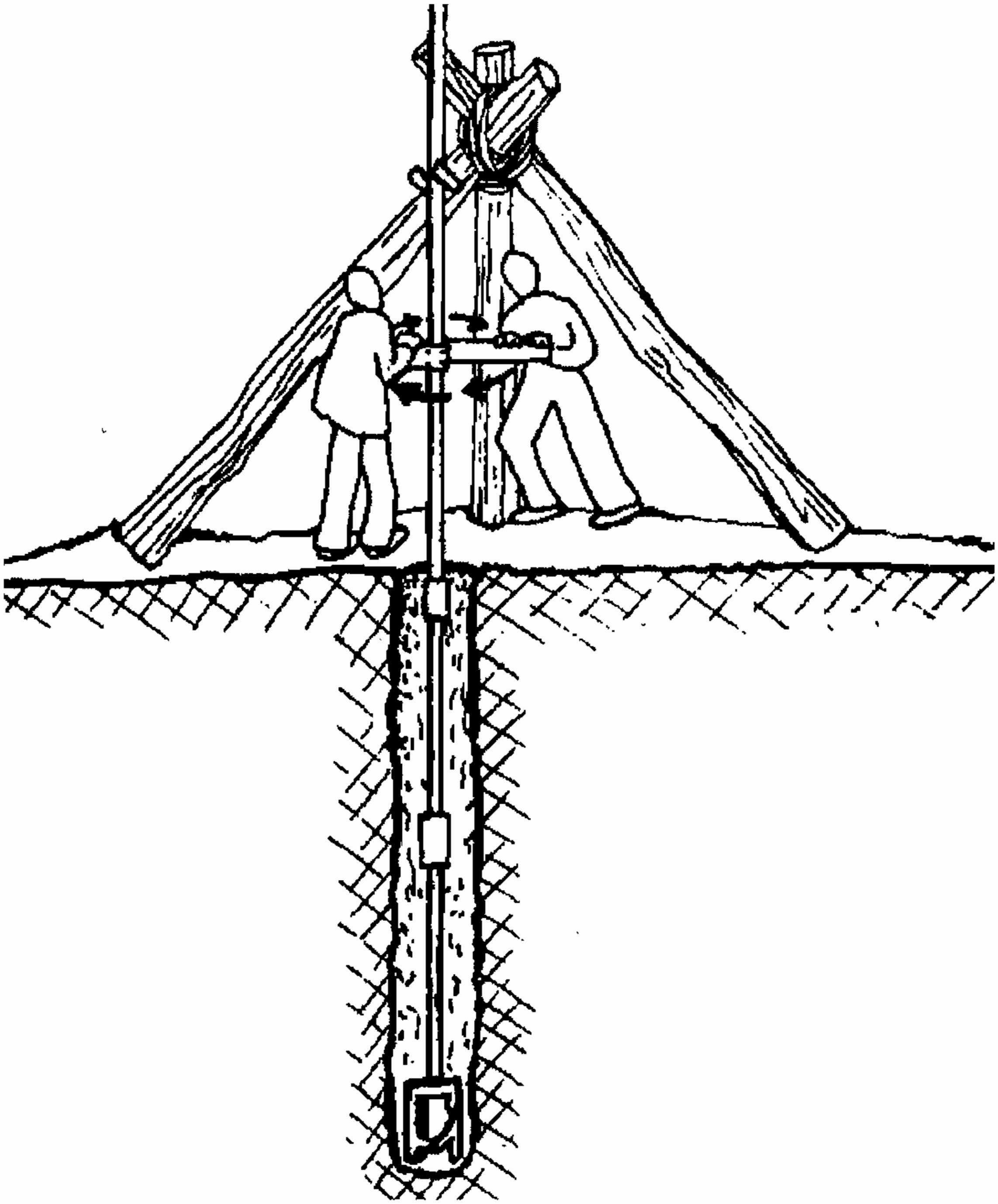

FIGURE 15
Drilling a well.

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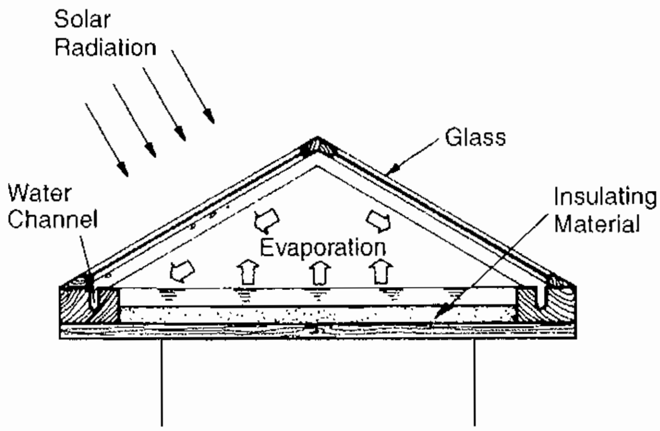

FIGURE 16
Solar still. (From *More Other Homes and Garbage.*)

SOLAR STILLS

Water is purified by distillation. If the water is very poor quality—for example, from stagnant pools or from the ocean—distillation may be the only practical way to make it drinkable. Small solar stills are fairly easy to make. One is shown in Figure 16. The sun's energy goes through the glass windows and evaporates the impure water in the pool at the bottom of the still. The evaporated water condenses on the glass windows and flows along them into the channels at the bottom, where it is collected. As long as the glass is tilted at least 20 degrees, the water will flow along it rather than drip back into the pool of impure water. Still performance improves if the temperature inside is increased, so the joints should be tight and the sides and bottom insulated. A reasonable size still—10 ft^2—will supply sufficient water for one adult, so they are useful in emergencies, but probably are not practical for a village water supply. In the Kalahari Desert village well water was much too salty to be drunk. A solar distillation facility was established that earned cash by selling the salts remaining after distillation as well as produced drinking water.

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FILTRATION AND DISINFECTION

Based on "Simple Methods for the Treatment of Drinking Water," Gabriele Heber A Publication of the Deutsches Zentrum für Entwicklungstechnologien—GATE in: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, 1985

Filtration is the deliberate passage of polluted water through a porous medium, utilizing the principle of natural cleansing of the soil. This widely used technique in water treatment is based on several simultaneously occurring phenomena.

- Mechanical straining of undissolved suspended particles (screening effect)
- Charge exchange, flocculation adsorption of colloidal matter (boundary layer processes)
- Bacteriological-biological processes within the filter

Filters may be divided into two principally different types

- Slow sand (or biological) filtration (filtration rates = 0.1 to 0.3 m/h)
- Rapid filtration (filtration rates = 4 to 15 m/h)

Generally, a filter consists of the following components:

- Filter medium (inert medium: quartz sand; chemically activated medium: burned material)
- Support bed (gravel) and underdrain system, influent and effluent pipes, wash and drain lines, control and monitoring appurtenances

RAPID FILTRATION

Rapid filtration is mainly based on the principle of mechanical straining of suspended matter due to the screening effect of the filter bed (sand, gravel, etc.). The particles in the water pass into the filter bed and lodge in the voids between grains of the medium.

Also operative to some degree in rapid filters are boundary layer and biological mechanisms. Their extent largely depends on the filtration rate, filter medium, depth of the filter bed, and quality of the raw water. Cleaning of the rapid filter is facilitated by backwashing—reversing the flow direction. A backwash may be conducted simply with water or a water-air mix (upward air scour). The impurities are thus dislodged and removed from the filter bed.

The performance of a rapid filter regarding the removal of suspended matter is determined by the following filtration process variables and parameters.

- Filtration rate
- Influent characteristics: particle size, distribution, and so on
- Filter medium characteristics that control the removal of the particles and their release upon backwashing.

Generally, it is true that the treatment effect can be improved by the following.

- Reduced filtration rates
- Smaller granulation size of the filter medium
- Increasing depth of the filter bed

HOUSEHOLD SIZE RAPID FILTERS

Household filters can be made from sand or gravel of different grain sizes, from ceramics, porcelain or other fine porosity materials. They basically operate on the principle of mechanical straining of the particles contained in the water. The filter performance depends on the porosity of the filter medium. Through additives in the filter material, additional effects can be obtained (adsorption, disinfection).

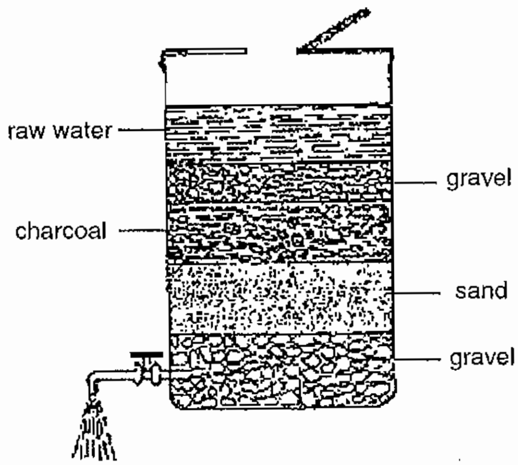

FIGURE 17
A multiple layer rapid filter.

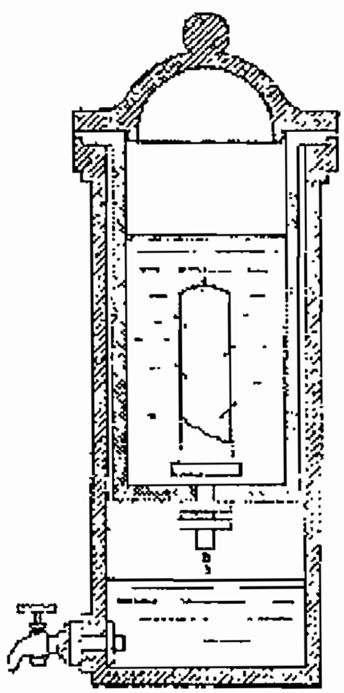

FIGURE 18
Household filter with candle.

Simple household filters can be put together using metal drums, plastic containers, or clay vessels and filling them with several 10 cm layers of sand, gravel, or charcoal. They do not perform well at removing pathogens, though. After filtration, the water therefore needs to be disinfected. A multiple-layer filter is shown in Figure 17.

Charcoal adsorbs organic substances that cause disagreeable color and taste. The effect can only be sustained, however, if the charcoal is frequently renewed. If this is not possible or if the filter (empty or filled with water) is left unused for some time, the charcoal can become a breeding ground for bacteria. The result is that the filtered water exhibits a higher bacteria count than the raw water. Monitoring of the filter condition is rendered more difficult because there is no visual indication given for the point when the charcoal should be replaced. Charcoal cannot be regenerated. It is for these reasons that the use of filters with charcoal media is not recommended.

Ceramics filters may be used for the purification of drinking water. If there are native potters, the filter can be manufactured locally. Otberwise they can be readily obtained from various commercial manufacturers. The purifying agent is a filter element, also called a candle, through which the water is passed. Suspended particles are thus mechanically retained and, depending on the size of the pores, also pathogens. Ceramics filters should only be used if the water is not too turbid, since the pores clog rather quickly. A ceramic filter is shown in Figure 18.

Ceramics filter elements can be made from various different material compositions (diatomaceous earth, porcelain); they have pore sizes of between .3 and 50 microns. If the pore size is smaller than or equal to 1.5 microns, all pathogens get removed with certainty. Posttreatment of the water prior to consumption is then unnecessary. Filters with larger pores only retain macroorganisms such as cysts and worm eggs—the filtered water must be boiled subsequently or otherwise disinfected

The candle should be cleaned because the impurities held back deposit on the candle's surface. At regular intervals—six months or so—this coating can be brushed off under running water. After the cleaning, the candle should be boiled. Ceramics filters must be handled with care. From time to time they must be checked for fissures to prevent the water from passing through the medium without being filtered.

Candles made from diatomaceous earth that contains silver have the advantage that recontamination of purified water due to infestation of the filter material with bacteria-laden washing water is avoided. Other filter inserts can be treated as follows.

> Prepare a solution of 6.1 ml colloid silver in 200 ml of clean water and lay it on the filter element by means of a brush or a sponge. Let the filter dry for 24 hours. The first two filter runs should be discarded.

In this case, silver is the only component that must be imported. Though it is the most expensive part of the filter, it does achieve disinfection. Filters operating at atmospheric pressure exhibit a very slow rate of percolation. This can be increased considerably by forcing the water through the medium.

SLOW SAND FILTRATION

Slow sand filtration is accomplished by passing raw water slowly, driven by gravity, through a medium of fine sand. On the surface of the sand bed, a thin biological film develops after some time of ripening (the film makes the filter different from the rapid filter). This film consists of active microorganisms and is called "Schmutzdecke," or filter skin. It is responsible for the bacteriological purification effect.

These are the principal purification processes that take place during slow sand filtration.

- Sedimentation—the water body sitting on top of the filter bed acts as a settling reservoir. Settleable particles sink to the sand surface.
- Mechanical straining—the sand acts as a strainer. Particles too big to pass through the interstices between the sand grains are retained.
- Adsorption—the suspended particles and colloids that come in contact with the surface of the sand grains are retained by adhesion to the biological layer, by physical mass attraction (Van der Waals force), and by electrostatic and electrokinetic attractive forces (Coulomb forces).

Because of these forces, an agglomerate of oppositely charged particles forms within the top layer of sand. This process needs some ripening time to fully develop.

Several biochemical processes take place in the biological layer.

- Partial oxidation and breakdown of organic substances forming water, CO_2, and inorganic salts
- Conversion of soluble iron and manganese compounds into insoluble hydroxides, which attach themselves to the grain surfaces
- Killing of *E. coli* and of pathogens

Organic substances are deposited on the upper layer of sand, where they serve as a breeding ground and food for bacteria and other types of microorganisms (assimilation and dissimilation). These produce a slimy, sticky, gelatinous film, which consists of active bacteria, their wastes and dead cells, and partly assimilated organic materials. The dissimilation products are carried away by the water to greater depth. Similar processes occur there. The bacterial activity gradually decreases with depth. Different types of bacteria are normally found at various depths.

Algae can contribute to the breakdown of organic material and bacteria. They can improve the formation of the biological layer (filter skin). In uncovered filters, growth of algae is driven by photosynthesis. The presence of large amounts of algae in the supernatant reservoir of a filter generally impedes the functioning of the filter. Dead cell material may clog the filter. Increased consumption of oxygen due to the presence of dead cell material increases the possibility that anaerobic conditions will occur. There is always a diurnal variation in the oxygen content due to growth and decay of the algae mass. When algae growth is strong, the algae must be either removed regularly or the filter must be covered.
The conditions necessary for those biochemical processes are the following.

- Sufficient ripening of the biological layers
- Uniform and slow flow of water through the filter, approximately .1 to .3 m/hr
- Depth of the filter bed of at least 1 m (.5 m is needed solely for the biochemical process) with specific grain sizes
- Sufficient oxygen in the raw water (at least 3 mg/l) to induce biological activity.

HOUSEHOLD SLOW SAND FILTERS

Some selected slow sand filters suitable for household use are described in the following paragraphs. Because these filters are simple to build, they may be less effective biologically—necessary conditions for effectiveness are slow inflow and uniform throughflow. A pure and clean appearance of filtered water is no assurance of sufficient bacteriological quality.

A household filter can be simply made from a used metal drum, as in Figure 19. A thorough cleaning and disinfection (for example with NaOCl) is necessary prior to its use as a filter casing. A drum previously filled with oil or chemicals should not be used. The filter output is 60 l/h (as compared to up to 230 l/h for the rapid version). The filter medium is sand. The depth of supernatant is .1 to .3 m to facilitate steady flow conditions. The collection of the filtered water is in a gravel layer. Effluent discharge is through a riser pipe, which is partly perforated. The effluent pipe, mounted with a stopcock, rises just above the level of the filter bed to prevent the filter from running dry. The filtration rate is set through the effluent stopcock. The filter is cleaned whenever necessary or whenever the filtration rate is inconveniently slow. In case of high turbidity, pretreating the water is recommended by means of a rapid filter.

A two-stage coconut fiber/burnt rice husk filter is shown in Figure 20, where water flows right to left. This type of filtration plant was developed and tested in Southeast Asia, where it is widely used. Two filters are operated sequentially. The first one acts as a coarse filter, while the second one operates similarly to a slow sand filter. The filtrate is free of color, disagreeable odor, and taste. The turbidity is greatly reduced; surplus iron and manganese is removed. Since pathogen removal is not as high as using a slow sand filter, subsequent disinfection (such as chlorination in the storage tank) is recommended.

Because the plant is mostly made from locally available materials and residues, the initial capital cost and the operating cost are low. For filter vessels, clay jars or containers made of concrete, metal, or zinc-plated sheet metal can be used. Feasible operating capacities range between 1 and 15 m^3/h, depending mainly on the size of the system. The depth of filter bed is .6 m to .8 m; the depth of unfiltered water is 1 m above filter bed. The entire medium should be replaced every three to four months.

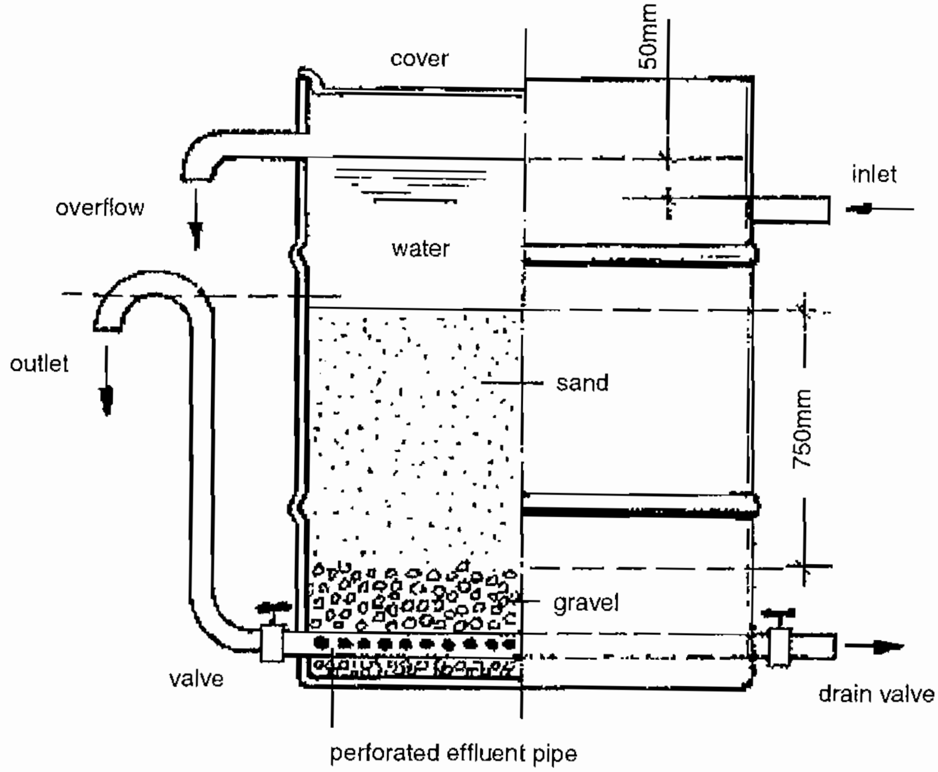

FIGURE 19
Slow sand filter in household size.

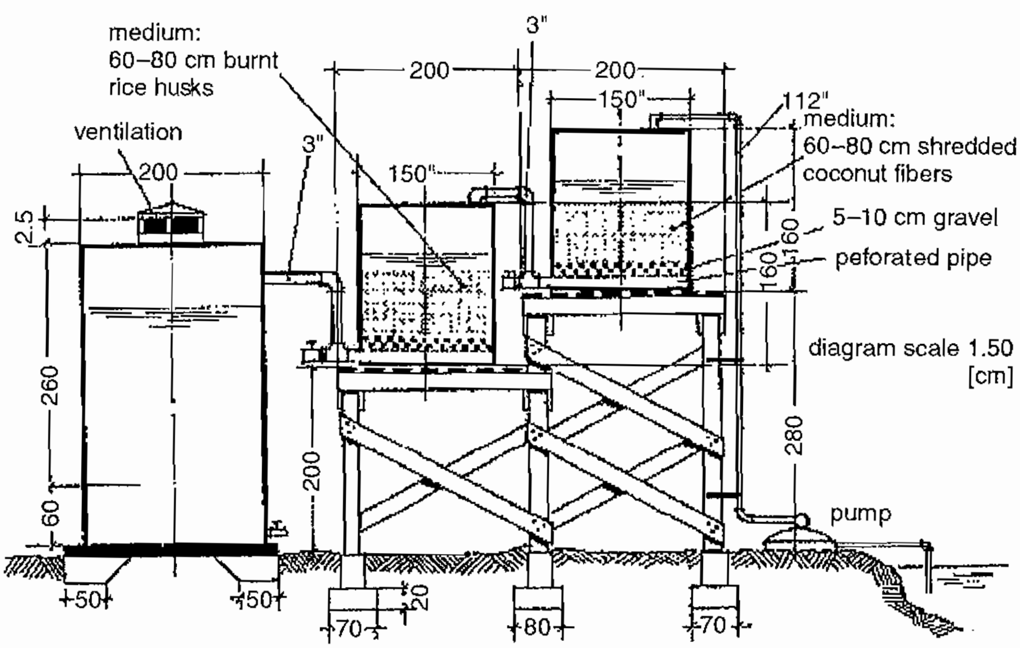

FIGURE 20
Two-stage filter.

A LARGER HORIZONTAL SAND FILTER

This type of filter, shown in Figure 21, is constructed by excavation of an earth basin, which is subsequently filled with sand. A biological skin develops at the surface of the sand around the inlet point. The inlet trough, perforated to let the water flow into the sand bed, protects the sand from disruption by the force of the incoming water. The filtration rate of the water percolating through the sand body is controlled by the filter resistance and the head differential between inflow and outflow. The filtration rate corresponds to .2 to .4 meters/hour of water—that is, .2 m^3 of water per m^2 of area. The retention time in such filters is between 36 hours and 30 days. The effect of filtration is reduction of bacteria count, turbidity, and organic content. The filter basin has a watertight lining (with plastic sheets), a depth of between .5 m and 1.0 m, a length of 5 m, and a bottom slope of 1:10 to 1:20

When the filter starts clogging, the point of inflow is simply switched. As soon as the water has drained from the clogged inflow trough, the top sand layer is scraped off. The point of inflow can then be switched back. This technique offers the possibility of uninterrupted operation.

Figure 21 shows the following features of the filter.

1. Inlet pipe
2. Inlet trough to prevent scouring
3. Barriers
4. Gravel, 50 mm
5. Outlet trough
6. Flow direction

DISINFECTION

It is essential that drinking water be free of pathogenic organisms. Storage, sedimentation, and filtration of water, both individually and jointly, reduce the contents of bacteria in water to a certain extent. None of these methods can guarantee the complete removal of germs. Disinfection is needed at the end. Water with low turbidity may however be disinfected without any additional treatment for bacteria removal.

Groundwater abstracted from deep wells is usually free of bacteria. Surface water and water obtained from shallow wells and open, dug wells generally need to be disinfected.

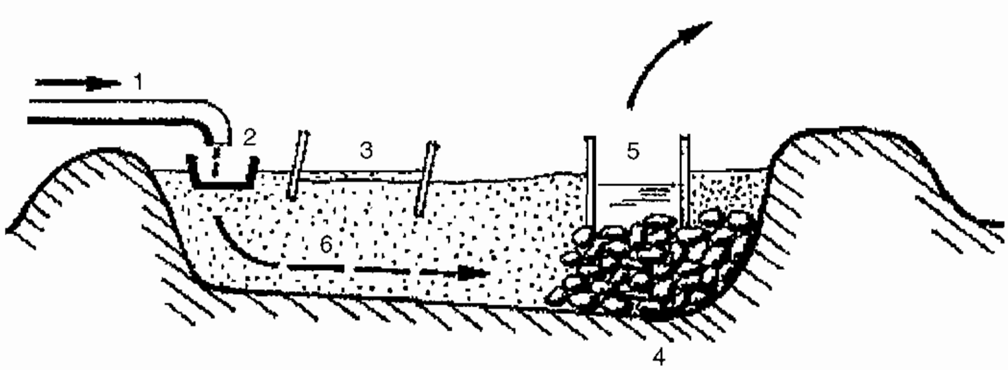

FIGURE 21
Horizontal flow sand filter.

The degree or efficiency of disinfection depends on the method employed and on the following factors influencing the process.

- Kind and concentration of microorganisms in the water
- Other constituents of the water that may impede disinfection or render it impossible
- Contact time provided (important for chemical disinfectants, since their effect is not instantaneous, a time of contact is necessary)
- Temperature of the water (higher temperatures speed up chemical reactions)

Water disinfection can be accomplished by several means.

- Physical treatment: removal of bacteria through slow sand filtration, application of heat (boiling), storage, and so on
- Irradiation, such as UV-light
- Metal ions, such as silver (and copper)
- Chemical treatment, use of oxidants (halogens and halogen compounds—chlorine, iodine, bromine, ozone, potassium permanganate, hydrogen peroxide, and so on)

A good chemical disinfectant should have the following abilities.

- Destroy all organisms present in the water within reasonable contact time, the range of water temperature encountered, and the fluctuation in composition, concentration, and condition of the water to be treated
- Accomplish disinfection without rendering the water toxic or carcinogenic
- Permit simple and quick measurement of strength and concentration in the water
- Persist in residual concentration as a safeguard against recontamination
- Allow safe and simple handling, application, and monitoring
- Ready and dependable availability at reasonable cost

Just as important as the proper choice of the disinfectant is that the agent be added to the water in a safe and controllable fashion.

CHLORINATION

The application of chlorine and its compounds for the purpose of water disinfection is the best and most tested compromise. Several chlorine compounds that have various active chlorine contents are easily used. In some form or another they are available virtually anywhere. Chlorine gas and chlorine dioxide are widely used in large-scale water treatment on account of their high efficiency and ease of application. Handling and transport, however, are too demanding and hazardous for the purposes described here. Some chlorine compounds are described next. Advice on amounts to be used will normally be given by the manufacturer.

Sodium hypochlorite ($NaOCl$) is commonly known as bleach or Javelle water. It is generally available in dissolved form. Its commercial strength in terms of active chlorine is between 1 and 15 percent. It is stored in dark glass or plastic bottles. The solution loses some of its strength during storage. Prior to use, the active chlorine content should be tested. Sunlight and high temperatures accelerate the deterioration of the solution. The containers therefore should be stored in cool, darkened areas. The stability of the solution decreases with increasing contents of available chlorine. A 1 percent solution is relatively stable but is not economical to store. Even though hypochlorite solutions are less hazardous than chlorine gas, every precaution should be taken to avoid skin and eye contact and to protect containers against physical damage.

Chlorinated lime, or bleaching powder, is readily available and inexpensive. It is stored in corrosion-resistant cans. When fresh, it contains 35 percent active chlorine. Exposed to air, it quickly loses its effectiveness. It is usually applied in solution form that is prepared by adding the powder to a small amount of water to form a soft cream. Stirring prevents lumping when more water is added. When the desired volume of the solution has been prepared, it is allowed to settle before decanting. Solutions should have concentrations between 5 and 1 percent of free chlorine, the latter being the most stable solution. Some 10 percent of the chlorine remains in the settled sludge. The precautions given previously pertain also to the storage of dissolved chlorinated lime.

High-test hypochlorite (HTH) is a stabilized version of calcium hypochlorite ($Ca\ (OCl)_2$) containing between 60 and 70 percent available chlorine. Under normal storage conditions, commercial preparations will maintain their initial strength with little loss. Even though HTH is expensive, it may be economical, thanks to its properties. It is available in tablet or granular form (commercial names: Stabo-Chlor, Caporit, or Para-Caporit).

These chemicals must be handled with great caution. They are caustic, corrosive, and sensitive to light. Chlorine corrodes metal and, to a less extent, wood and some synthetic materials. Metal parts that come in contact with the chemicals should be resistant.

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SANITATION

Based on "Appropriate Technology for Water Supply and Sanitation," A Sanitation Field Manual, *John M. Kalbermatten, DeAnne S. Julius, and Charles G. Gunnerson, The World Bank, Washington, D.C., 1980*

The proper disposal of human and animal wastes is a major sanitation problem in the Third World and elsewhere. Methane digesters, described in the Energy chapter, are an approach to the animal waste problem but are less effective in killing the pathogens of human wastes, which are a bigger health problem. If they get into the water supply, pathogens from human wastes can cause cholera and hepatitis, as well as diarrhea. Flies can also spread disease by carrying germs on their feet when flying from feces to food. An article in the Health chapter, "Water and Health," discusses pathogens that affect human health. The "Building" article in the Construction chapter includes rules of thumb for sewer systems.

Most people in the world probably want flush toilets emptying into septic tanks or sewers, but the cost of providing such systems to everyone in the world makes such toilets presently out of the question. Estimates are that 2 billion people worldwide need improved sanitation facilities. The cost of providing sewers would be about $500 per person, and the annual per capita income of half of these people is less than $200. Septic tanks would not be appreciably cheaper.

The common approaches to sanitation in the Third World are as follows.

- Ventilated improved pit (VIP) latrines
- Composting toilets
- The Benjo—a toilet enclosure over a stream
- Pour-flush toilets
- Aquaprivies
- Soakaways, septic tanks, and drain fields

CULTURAL ISSUES

Float Kidha, a public health specialist in Africa, reports the following.

> There are customs and beliefs about human waste disposal and even where people know the connection between human waste and diseases, they have difficulty overcoming their beliefs. Health workers have failed to reduce diarrheal diseases by forcing people to build latrines. People have built latrines for fear of the authorities but not because they understand why they must build them. The result is that nobody used them. Health education is the key. But the health educator must *know* and appreciate the culture of the people and educate them in the context of that culture. In many cultures it is believed that using a pit latrine is like being buried alive. They believe that human waste must go back to the land and fertilize it. For this reason the bush is used more often. People can be taught to bury their waste if they will not use pit latrines. Another belief is that a man would get ill and even die if he used the same latrine that has been used by a woman who is menstruating. A young woman would never use the same latrine which her mother and father-in-law use. Human waste is used for manure in many cultures. It is, therefore, not fact to assume that one's own pit latrine will ensure reduction in diseases due to poor sanitation.

People built latrines but never use them for various reasons. In one village in Kenya, health workers forced people to build latrines during a cholera outbreak. When the health workers returned to the village two weeks later everyone had a latrine, which the health workers duly noted. It turned out later that the round "huts" had holes, which were only three feet deep and were not being used as latrines but stores for illegal brew! People did not believe latrines were useful for health purposes but they did need a place to store the homemade distilled beer. Education and recognition of local customs are essential for success.

Another important cultural issue is whether people will use fertilizer processed from human waste on plants for human consumption.

POUR-FLUSH TOILETS

Two pour-flush toilets are shown in Figure 22. One or two liters of water are poured in by hand to flush the excreta into the pit. (The "soakaway" shown in the figure is discussed below.) Note the water seals in both models, which prevents odor development and mosquito breeding. An advantage of the offset pit design is that the toilet can be inside the house and the pit outside. If two pits are built, they are used alternately. When the first pit is nearly full, the second is connected to the toilet. During the period the second pit is being used, a year or so, the waste in the first pit decomposes into a humus suitable for fertilization. Such a system can be easily upgraded by attaching to a sewer line. The chief disadvantages are the amount of water that must be used—3 to 6 liters per person per day—and that the pits must be emptied annually.

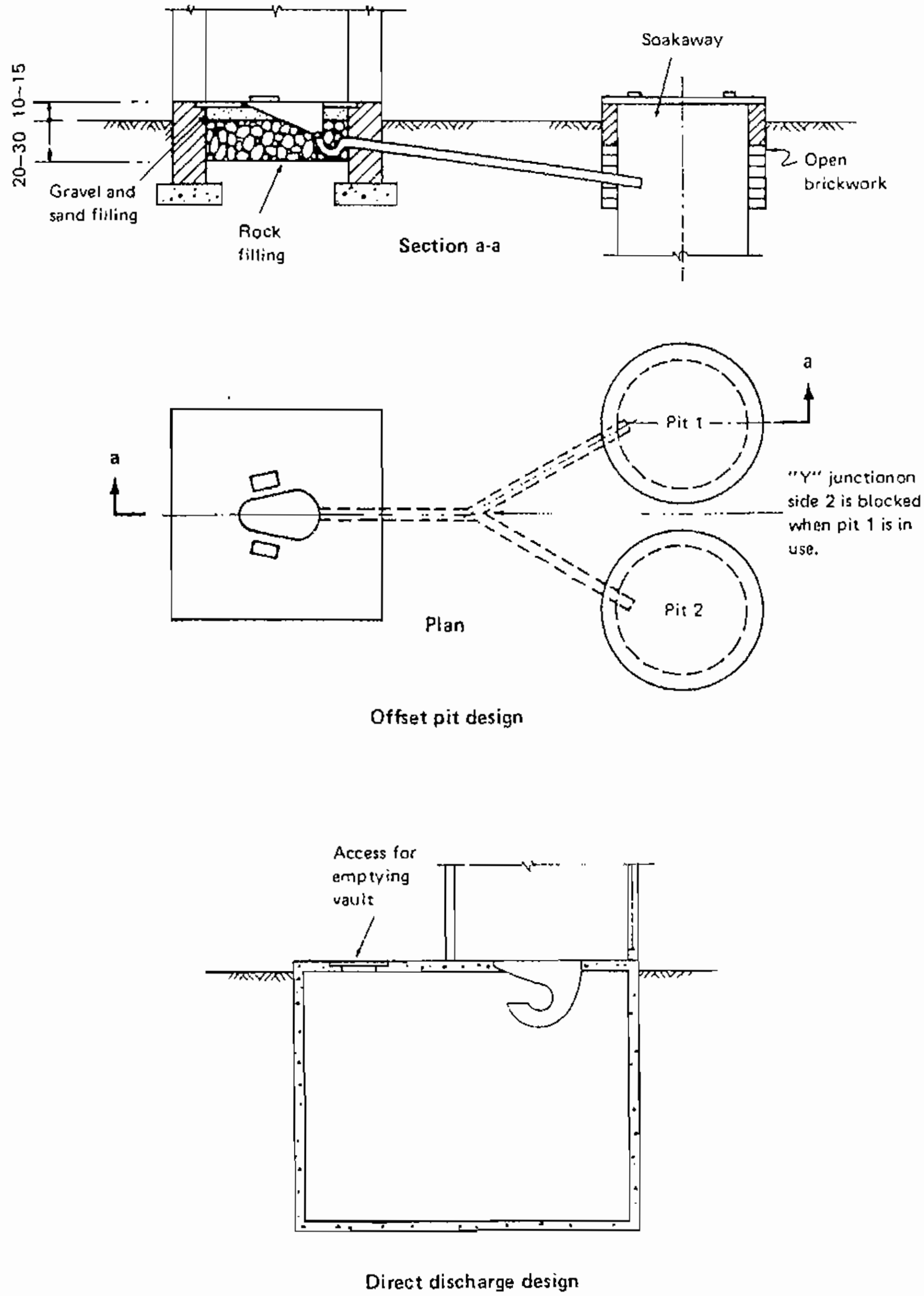
The volume of the pit is approximately .05 cubic meters—or 1.75 cubic feet—times the number of people using the pit, if the pit is emptied annually. The maximum length of the connecting pipe is 8 meters—26 feet or so—and the slope should be at least 1 in 40. All the parts except the water seal can be easily made, and even the water seal can be constructed by local artisans with experience. Maintenance is minimal.

AQUAPRIVIES

An aquaprivy is shown in Figure 23. Here the waste goes into a pool of water. To avoid odors and mosquito breeding, the water level must be maintained high enough for a seal so the tank will not leak, and water must be added regularly. The waste decomposes anaerobically in the tank, but a sludge is formed that must be removed every two or three years. The volume of the tank is approximately .12 cubic meters per user but not less than 1 cubic meter. Construction of such a leakproof vault requires skill. The depth of the water is normally 1.0 to 1.5 meters. The volume of effluent flowing to the soakaway is about 6 liters per person per day, corresponding to 1.5 liters excrement and 4.5 liters for cleansing and "flushing." Aquaprivies can be upgraded to sewer systems easily. In practice, maintaining the water seal has been difficult, thus, some specialists do not recommend aquaprivies.

SOAKAWAYS, SEPTIC TANKS, AND DRAIN FIELDS

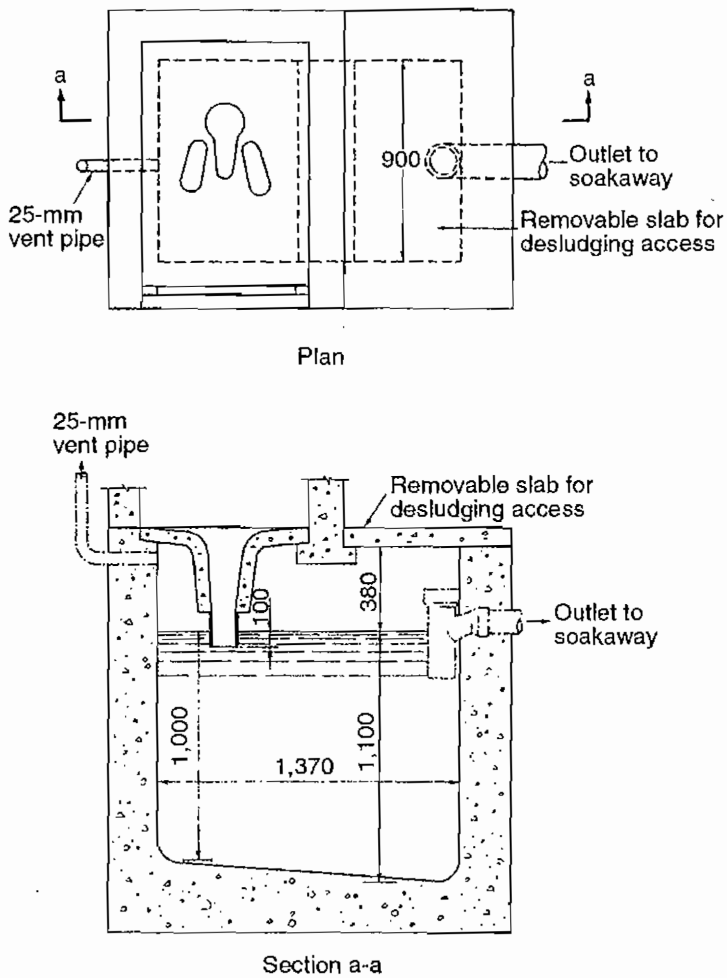
A soakaway pit is shown in Figure 24. The purpose of the soakaway is to allow waste to soak gradually into the soil. For normal soil types the infiltration of water to the soil will be 10 liters or more per day per square meter. The pit should be designed with this much area on the sides, since the bottom will probably be clogged by sludge. A pour-flush toilet used by a family of



Note: In the offset pit design, the pit is placed at site of "Y" junction if only one pit is installed.

FIGURE 22
Pour-flush toilets.

eight people would be designed to receive about 48 liters a day, so the area of the sidewalls should be about 5 meters. If the depth is 1.5 meters, the corresponding diameter of the pit is about 1.1 meters. Soakaways should be located at least 15 meters—50 feet—from wells, more for sandy and gravelly soil, and 30 meters—100 feet—from streams. They should be 3 meters from buildings or large trees, whose roots can infiltrate and damage the pit. Soakaways will not



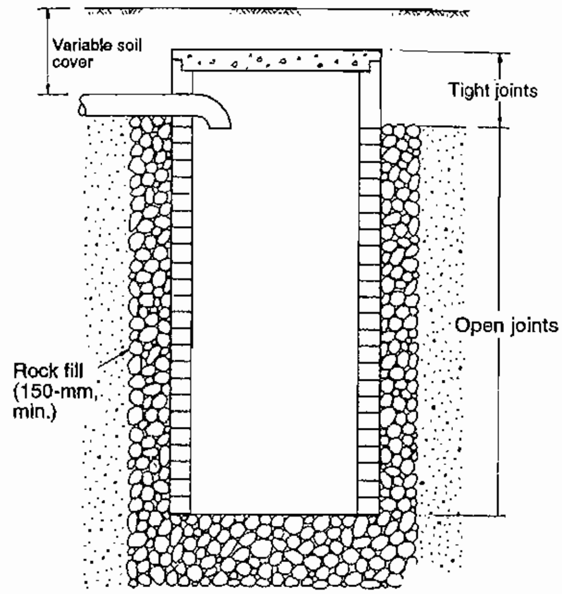
Source: Adapted from Wagner and Lanoix (1958).

FIGURE 23
Aquaprivy.

work with an impervious soil. Systems using soakaways require a fairly large distance between homes or a low housing density. More design guidelines are given in the "Building" article in the Construction chapter.

A septic tank is shown in Figure 25. A septic tank is used with flush toilets. It also receives wastewater from sinks, kitchens, and other household appliances. The retention time is three to five days. During this time the solids settle to the bottom of the tank, where they decompose. Most of the decomposition products—water and methane gas—flow out with the effluent, but sludge does remain, and a scum is formed on the surface of the water. Sludge should be emptied from a septic tank every five years or so. The effluent does contain harmful pathogens and should not be discharged directly to open streams or into drinking water supplies. The effluent should go to a soakaway or, alternatively, a drain field. The two chambers shown in the figure are a preferred design because they allow lighter waste particles to separate from the heavier ones. The lighter particles move into the second chamber where they can decompose more thoroughly in the absence of gas bubbles created from the heavier material. Septic tanks cost about as much as sewers and are equally attractive to users, so systems would probably not be upgraded unless the density of housing in the neighborhood increased to the point where insufficient area is available for the drain field or soakaway.

A drain field is made of two or three parallel trenches containing tile pipes with open joints. The pipe usually rests on a gravel bed. The trenches are about .5 meter deep. The length is determined by the infiltration rate of the effluent—generally 10 liters per square meter—where the area infiltrated by the effluent is the total length of the parallel trenches multiplied by the trench depth (.5 meter or so) and multiplied by 2—because the effluent infiltrates the soil on both sides of the trench. Again, the drain field should be located at least 30 meters from drinking water sources. Drain fields are effective but use much area—more than soakaways.

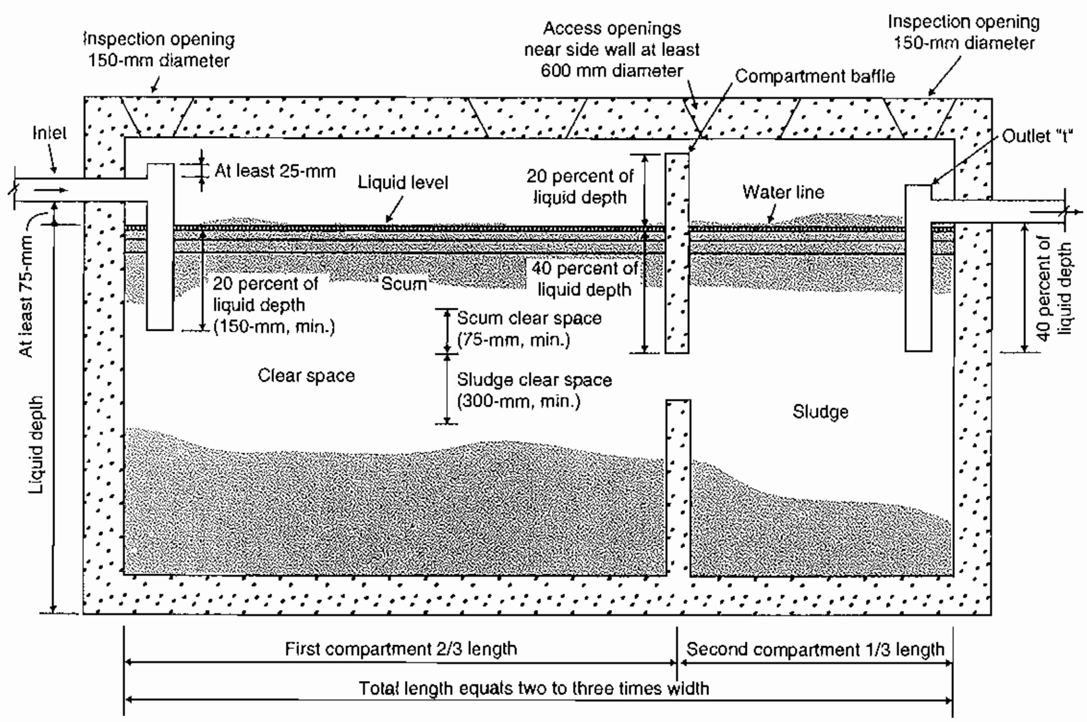


Source: Adapted from Wagner and Lanoix (1958).

FIGURE 24
Soakaway.

CHOICE OF SYSTEM

Besides the systems described in this article, VIP latrines and composting toilets, described in separate articles, should be considered. VIP latrines work well and are the least



Note: If vent is not placed as shown on figures 13—2, 3, and 4, septic tank must be provided with a vent.

FIGURE 25
Septic tank.

expensive in terms of initial cost and maintenance but do need to be emptied after five years or so, and an improperly placed latrine can contaminate groundwater. Composting toilets produce a usable composted humus, but their operation requires significant user attention.

These are some questions to ask when choosing a system.

- Is it likely that the system will be upgraded to sewer-based sanitation?
- Is the decomposed excreta wanted for fertilizer?
- Are the plot sizes large enough and the soil sufficiently permeable for onsite disposal of effluent?
- Is sufficient water available for pour-flush toilets?
- Are municipal or private mechanisms available for emptying latrines?
- How do the costs compare?

REFERENCES

Leckie, Jim, Gil Masters, Harry Whitehouse, and Lily Young. (1981). *More Other Homes and Garbage*. San Francisco: Sierra Club Books.

Pickford John. (1991). *The Worth of Water, Technical Briefs on Health, Water and Sanitation,* IT Publications, 103–105 Southampton Row, London WCIB 4HH, UK. Tel.: 44 171436 9761. Fax: +44 171436 2013. orders@itpnbs.org.uk. In the U.S.: Stylus Publishing, PO Box 605, Herndon, VA 20172-0605. 800-232-0223. Fax: 703-661-1501. *Styluspub@aol.com.*

VITA. (1988). *Village Technology Handbook.* Volunteers in Technical Assistance, 1815 North Lynn Street, Washington, DC 22209, USA.

LATRINES

The ventilated improved pit (VIP) latrine described here and in the World Bank reference was developed in Zimbabwe for rural use. It costs about $100. Even a more substantial version—for example, one useful in a settlement on the edge of a city—can be built for $150. Compared to other toilets they are low cost, easily built and maintained, and use minimal water. A principal danger is that they may pollute groundwater, so placement must be done carefully. VIP latrines are sometimes called "Blair" toilets, after their designer. An Appendix to this article is a set of plans used in a rural school in Malawi for teaching purposes.

DESIGN OF VENTILATED IMPROVED PIT LATRINE

A conventional pit latrine consists of a pit, a squatting plate, and a superstructure. The problems with a conventional pit latrine are odors and insects. The ventilated, improved pit latrine shown in Figure 26 does away with these problems. The vent pipe is the key component. The vent pipe, which is painted black, is heated by the sun so the air rises. Wind blowing across the top of the vent also pulls air out of the pipe. Air is thus pulled down the squat hole through the pit and out the vent. Inside the superstructure no odor exists because of the direction the air is moving. A way of augmenting this airflow is to locate the door opening so the prevailing wind will be caught to blow air into the pit.

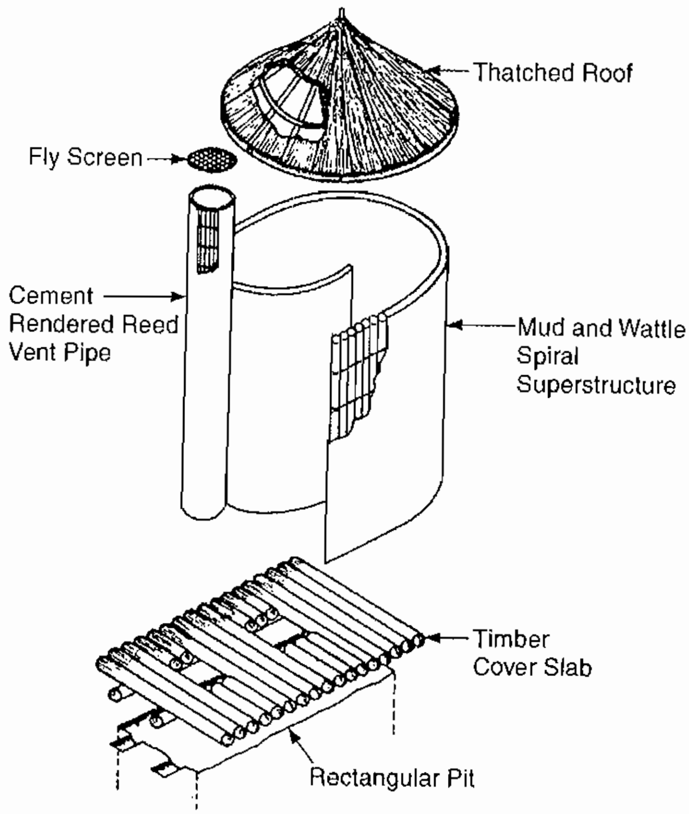


FIGURE 26
VIP latrine in Zimbabwe. (From *Ventilated Improved Pit Latrines: Recent Developments in Zimbabwe.*)

The vent pipe is screened at the top. This prevents insects from escaping and also keeps them from coming down the vent. Some flies will get into the pit through the squat hole and lay eggs. The emerging flies, though, will be attracted to the light and will fly up the vent pipe and be caught at the screen. The other troublesome insects are mosquitoes. If the pit is dry, mosquitoes are not attracted, but if the pit is wet—that is, if the level of groundwater is above the bottom of the pit—mosquitoes will breed there. Mosquitoes are not attracted as strongly to light as flies, so some will go out the hole. In this case the hole should be covered with a removable screen. It is important, of course, not to interfere with the circulation of air through the system by covering the hole with a solid cover.

It must be relatively dark inside the superstructure so flies are attracted to the vent pipe. If social custom favors an illuminated superstructure, then some type of opaque cover will be needed over the hole. This cover should be raised from the floor to allow as much ventilation as possible, using screening to keep insects in the pit. If the entrance to the latrine faces east or west, the morning or evening sun may shine into the latrine, so shading may be necessary. If wind conditions permit, north or south orientation should be used.

Lighting is an important issue. When VIP latrines were built near a health clinic in Kenya, care was taken to make them very dark inside. Snakes then found the superstructures desirable places to live. The local people in turn refused to use the latrines. One lesson is that a design must meet local conditions.

If the pit is above the groundwater level, the pit will be dry and the wastes will decompose in the pit. If the pit is below groundwater level, the pit will have water in it and some of the wastes will seep away into the ground, just as they do in septic systems not connected to sewers. In this case, wells for drinking water should be at least 150 feet from the latrine.

A dry pit 10 feet deep and 3 feet long in either direction should last a family of six for about ten years. The useful life will be twice as long if the pit is wet. (In designing one should allow for about 1.5 cubic feet of waste per person per year.) The VIP latrine is so simple to build that one might just start over somewhere else when the pit is full. Alternatively, one could build a double pit latrine and use each pit alternately for a year. At the end of a year, the material in the unused pit will have decomposed and could safely be removed and used as fertilizer, if social customs permit.

CONSTRUCTION OF THE RURAL VIP LATRINE

The basic rule is to make the construction as similar as possible to other structures in the village, so the model shown in Figure 26 would be used when the surrounding buildings are made of mud and wattle. The vent pipe is made of a reed mat, 8 feet by 3 feet, rolled up into a cylinder about 11 inches in diameter and then plastered with a mortar made with cement. Ordinary corrosion-resistant screening can be used at the top. The rest of construction is obvious. The roof thatching has to be dense to keep the interior dark. Of course, people who use thatching regularly will have no trouble with this. The walls should not have light leaks either. The people building the structure, again, will have had experience in making tight walls. If the soil crumbles easily, the top three feet or so of the pit should be lined with cement. The logs supporting the timber cover slab should extend a foot or so in each direction beyond the pit hole. They should be treated with a wood preservative. The slab itself should also be painted to protect the wood.

In areas where wood is scarce, the superstructure can be built of thatching or of locally made bricks. In more urban areas, cement over a wire frame can be used, and the squat plate can also be cement. A latrine with a cement squat plate in a refugee camp is shown in Figure 27. The latrine

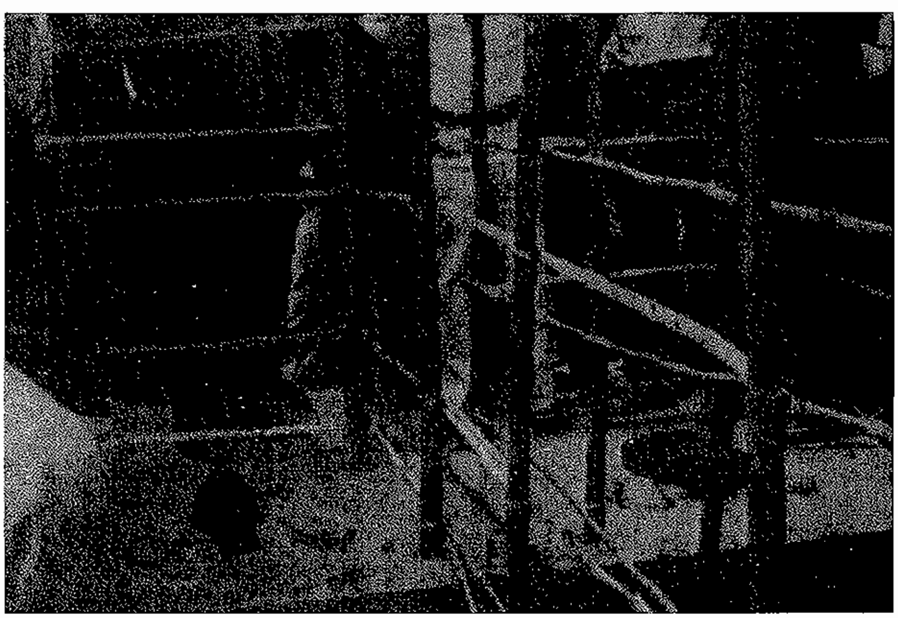


FIGURE 27
Latrines under construction.

TABLE 1
Cost of a VIP latrine

Material	Amount	Cost
Cement for pit lining and vent pipe	55 lbs.	$2.00
Cement for superstructure	55 lbs.	2.00
Wire	150 ft.	0.70
Fly screen	1 ft × 1 ft.	0.20
Nails		1.00
Paint		1.00
TOTAL		$6.90

is under construction, and the squatting holes are covered with mud or bricks. The vent pipe can be asbestos cement or PVC; cast iron corrodes.

Table 1 shows estimated costs of the VIP latrine. It would take there people about one week to build the latrine

SLOPING PIPE VIP LATRINES

A variation of the VIP latrine uses a sloping pipe from the squatting plate to a pit located behind the superstructure. The advantage of this configuration is that the toilet can be inside the house and the pit outside. A removable cover can be built over the pit so it can be emptied every few years, since the toilet room will be an integral part of the house. The pipe can clog, so it may have to be cleaned regularly with a long-handled brush. Typical pipe diameters range from 150 mm to 200 mm—6 to 8 inches.

SUCCESS OF VIP LATRINES

These latrines have worked well in Zimbabwe, where 20,000 were in use in 1982. Perhaps one reason for their success is that they represent a relatively small change from what had been in use before. Another reason is probably the extensive education program that the government of Zimbabwe used, including films, instruction leaflets, and demonstration models.

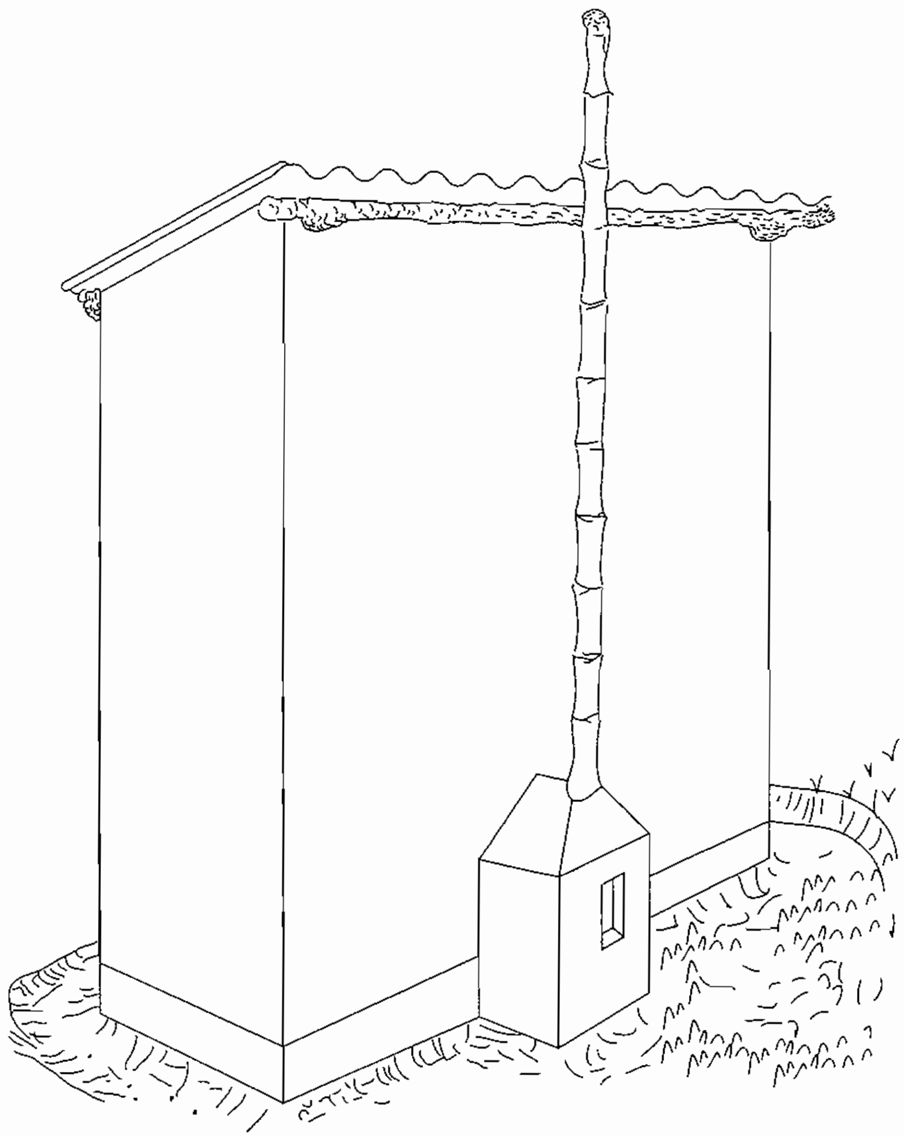
REFERENCES

Morgan, Peter R., and Duncan D. Mara. (1987). *Ventilated Improved Pit Latrines: Recent Developments in Zimbabwe.* Technology Advisory Group, The World Bank, Washington, DC 20433.

VITA. (1988). *Village Technology Handbook.* Volunteers in Technical Assistance, 1815 North Lynn Street, Washington, DC 22209, USA.

APPENDIX

Plans from Evergreen Secondary School, Phulula District, Malawi. Further information from Henry Ngaiyaye, University of Malawi—The Polytechnic, Private Bag 303, Chichiri, Blantyre 3, Malawi.



HOW TO BUILD A LOW COST PIT LATRINE

By

Henry Ngaiyaye

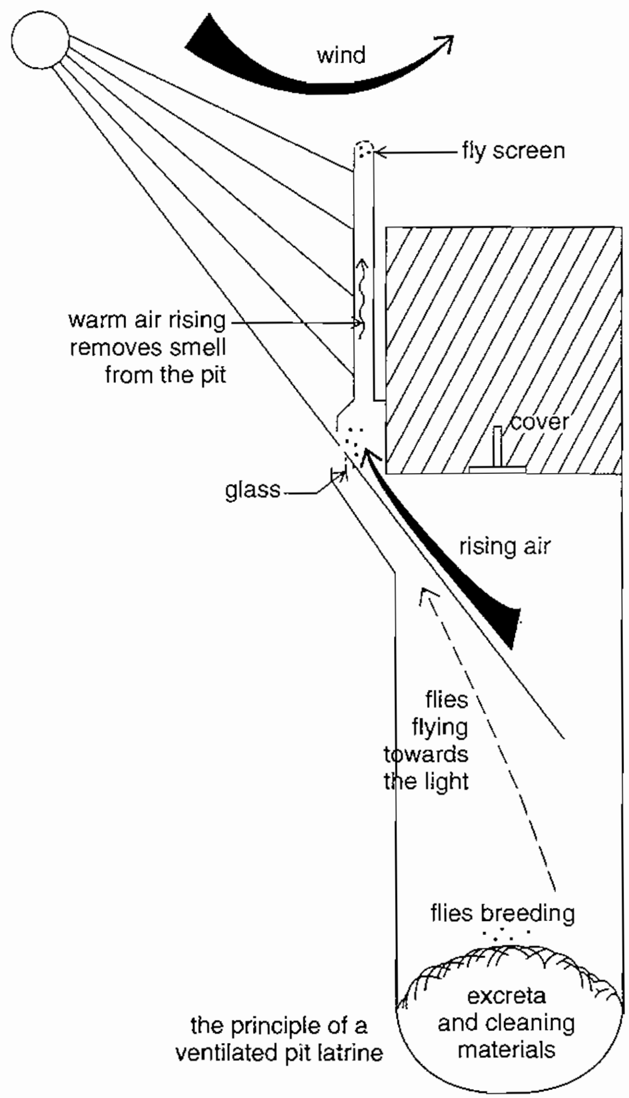
INTRODUCTION

The Rural Housing Project has designed a ventilated improved pitlatrine that is cheap and long lasting. In this pamphlet, you can learn how to build your own pitlatrine.

The floor of the pitlatrine is held up by a brick vault. This method is not only cheaper than a reinforced concrete slab and longer lasting than the traditional slab made of timber and mud, but it is also safer.

All measurements used for the illustrations are in millimeters (mm) if not otherwise stated.

BEFORE STARTING TO BUILD, PLEASE READ THE WHOLE PAMPHLET CAREFULLY!



the principle of a ventilated pit latrine

VENTILATION

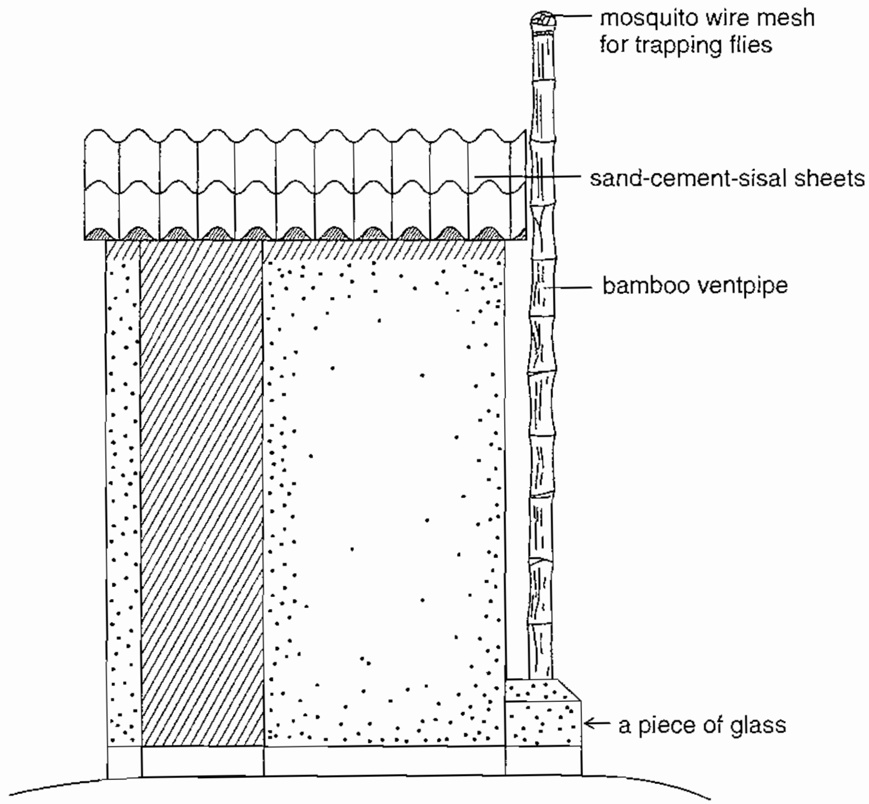
The purpose of the ventilated pitlatrine is to; (1) keep the bad smell away and, (2) to get rid of flies by leading light into the pit. When flies see the light they fly towards that instead of the squatting hole and will be trapped against the glass or at the top of the ventpipe in the mosquito mesh fly trap.

The ventpipe should reach at least 500 mm above the highest point of the roof. Wind passing across the top of the ventpipe creates a suction within the pipe so that the air in the pit flows out through the ventpipe.

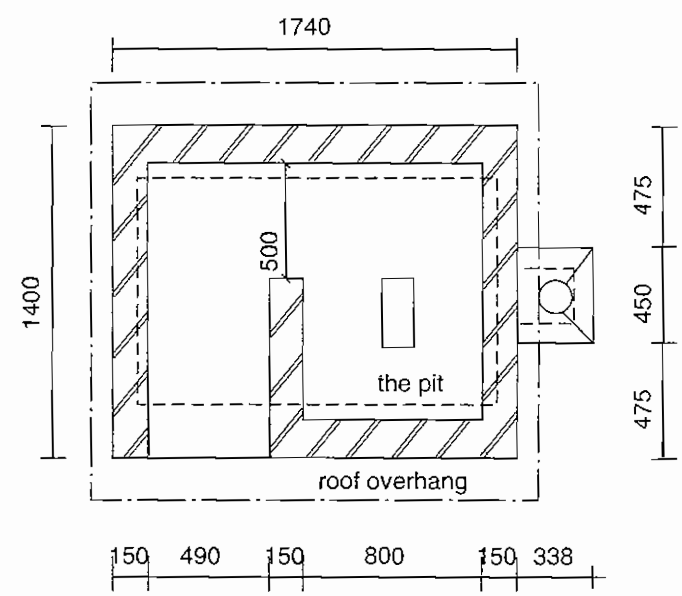
The ventpipe should ideally face north or south in order to allow the sun to heat the pipe and the air inside. The air will rise and help to ventilate the pit.

A cover must be placed over the squatting hole in order to reduce access for escaping smell, flies and minimise mosquito breeding in the pit.

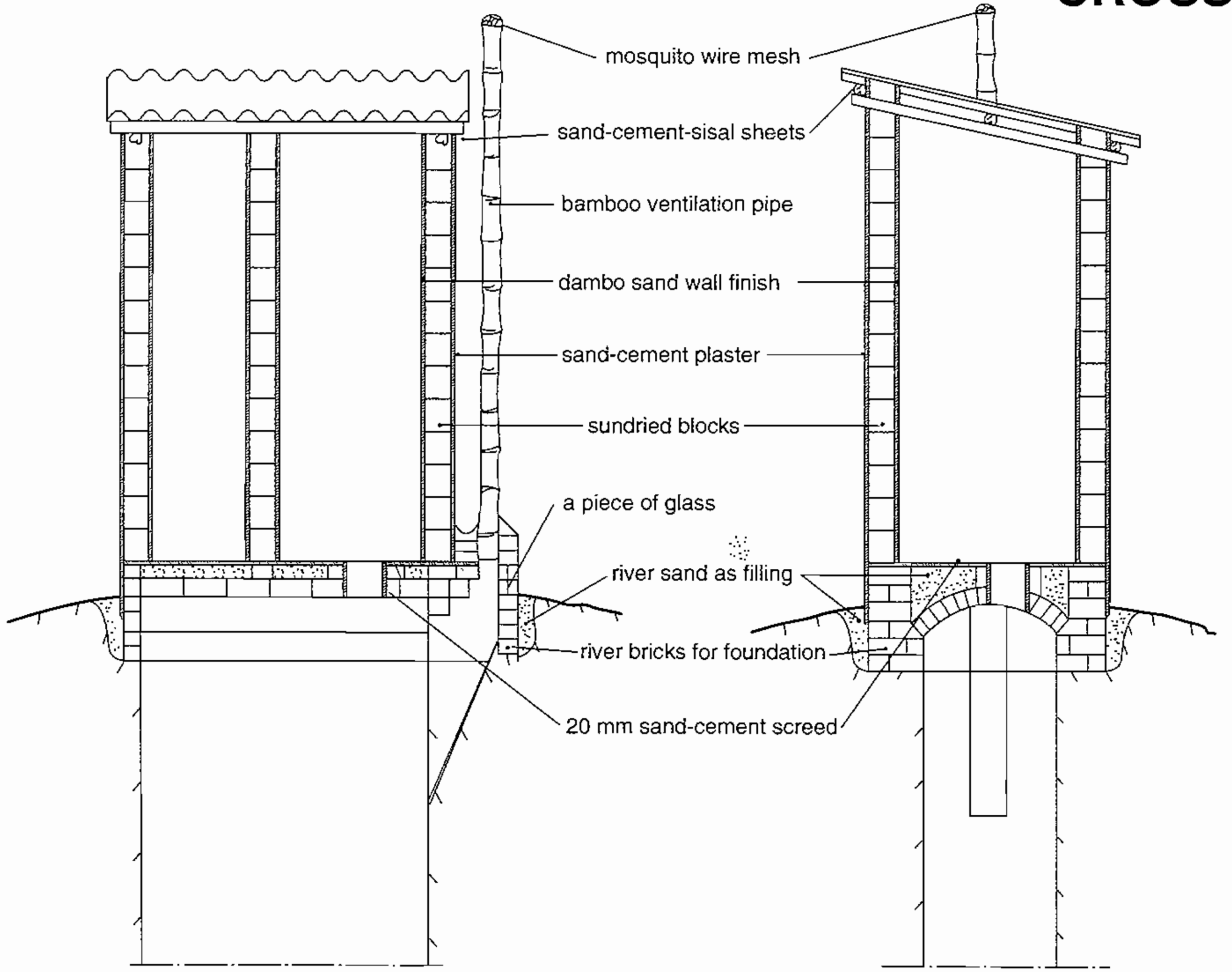
ELEVATION AND PLAN



FRONT ELEVATION



CROSS SECTIONS



MATERIALS NEEDED

500 Burnt bricks (235 mm x 112.5 mm x 85 mm)
250 Sundried blocks (300 mm x 150 mm x 150 mm)

1.5 Bags of cement

0.5 Kg Sisal

0.5 Litre bitumen paint

0.5 Litre solignum

0.5 Bag of lime

0.5 Tonne of river sand

0.5 Tonne of dambo sand

150 mm x 150 mm mosquito wire mesh

1 Big bamboo

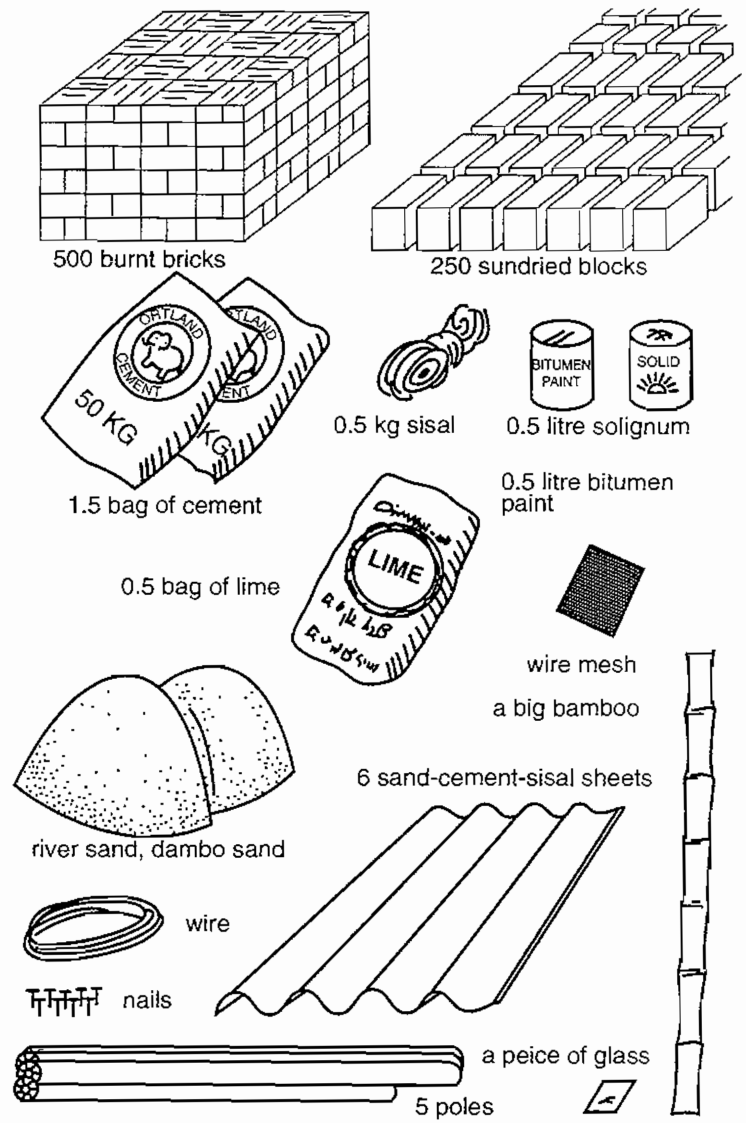
1 Piece of glass minimum 150 mm x 150 mm

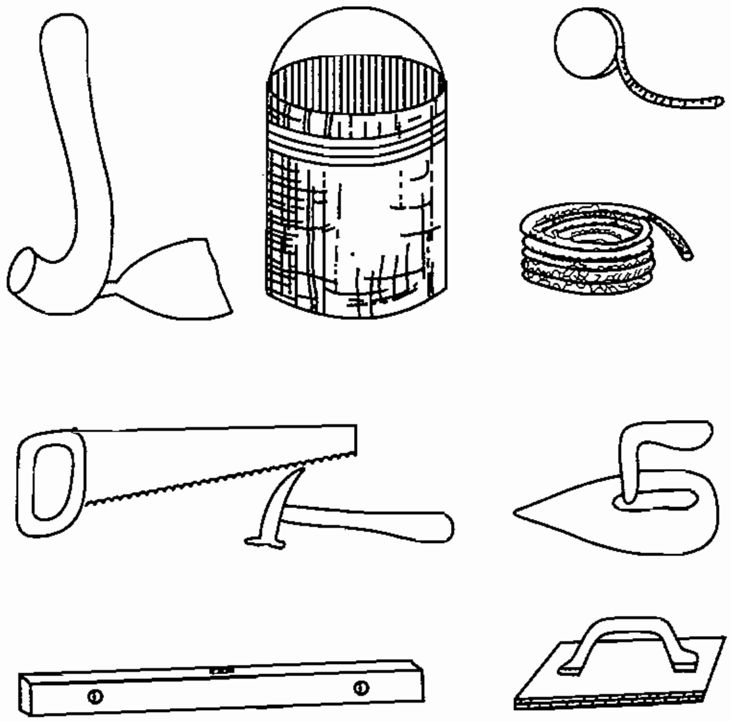
6 Sand-cement-sisal roofsheets

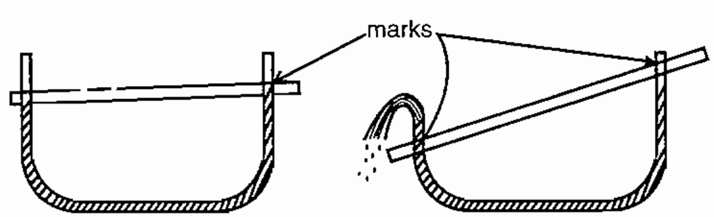
5 Poles (three 1.8 m and two 1.6 m long)

5 m Wire

0.3 Kg nails 4" (and 8 nails 1")







in level—the
water stays at the marks

not in level—
water pours out

TOOLS NEEDED

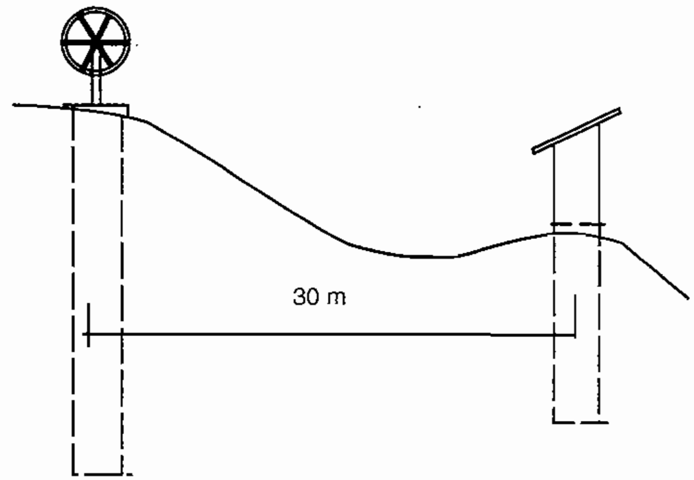
HOE
BUCKET
ROPE - 5 m long
SAW
HAMMER
TROWEL
WOODEN FLOAT
SPIRIT LEVEL
MEASURING TAPE

Instead of a spirit level you can use a transparent plastic hosepipe 3 m long. Put two marks, 15 cm from the ends; and fill the hosepipe with water up to the marks.

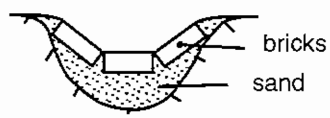
When leveling, you need to have two persons, one holding each end of the hosepipe against the part that is to be leveled. If the water is above one of the marks you have to lift that end or lower the opposite end.

WHERE TO PLACE IT

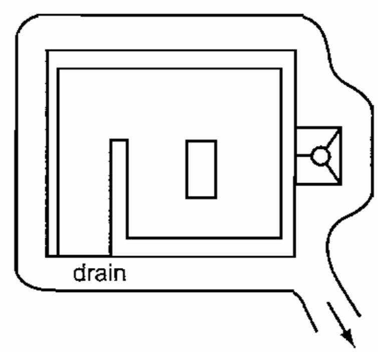
To prevent pollution, the pitlatrine should be placed down hill from a well, at a distance of not less than 30 meters.



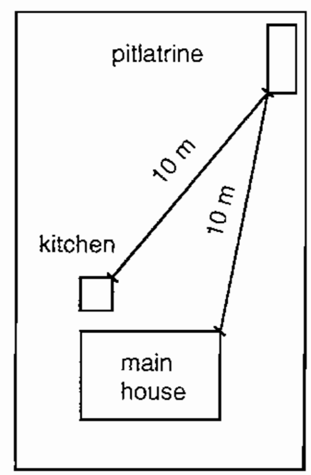
To avoid flooding the pit by rain, the ground should slope away from the pitlatrine on all sides. Where this is not possible, a drain should be placed as shown in the drawing.



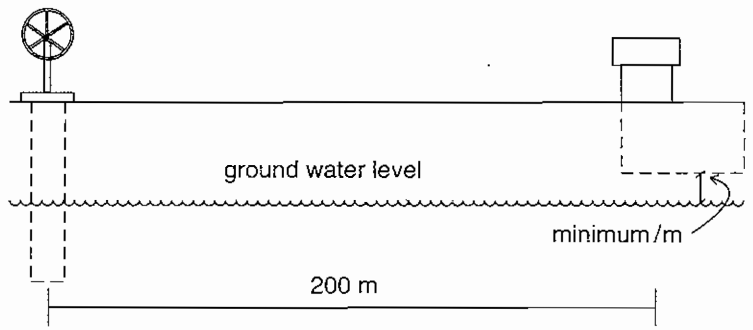
Drain, cross section

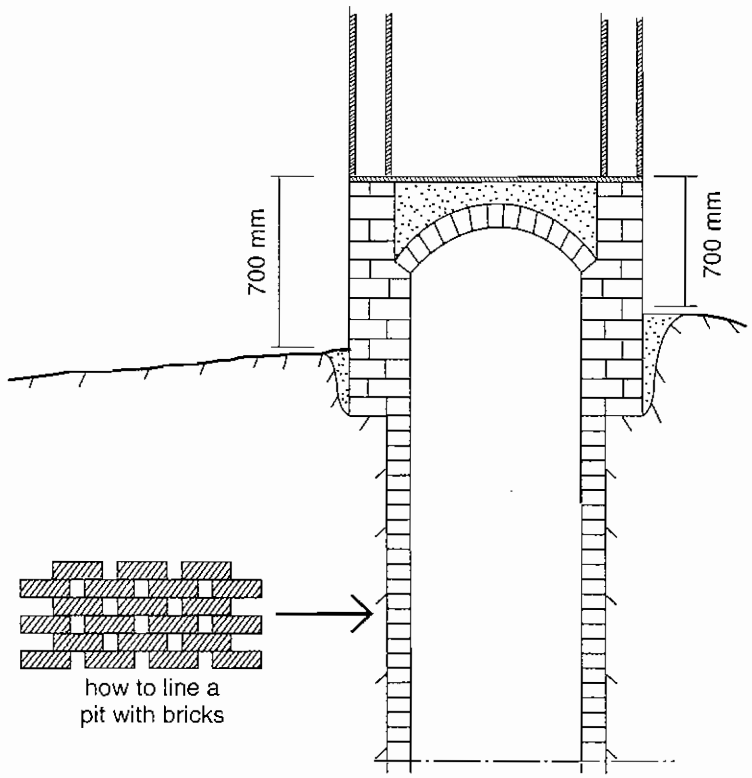


The pitlatrine must be at least 10 m from nearest house or kitchen.



There should be a clear space of not les than 3 m around the pitlatrine.





HIGH WATER TABLE

Where the water table is very high, the latrine must be down hill of any well at a distance of not less than 200 m.

The safe rule is that the bottom of the pit should not be less than 1 m above the highest level of the ground water level.

In some cases of high ground water, the height of the floor should be raised (700 mm) above the highest point of ground.

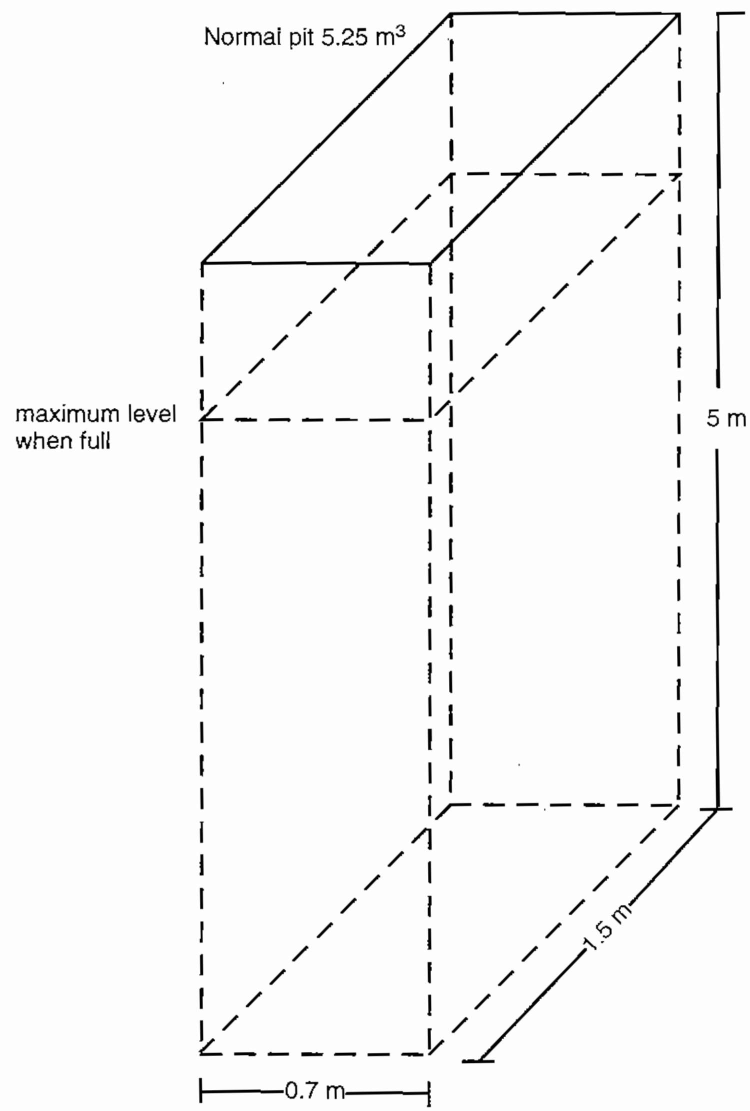
SIZE OF THE PIT

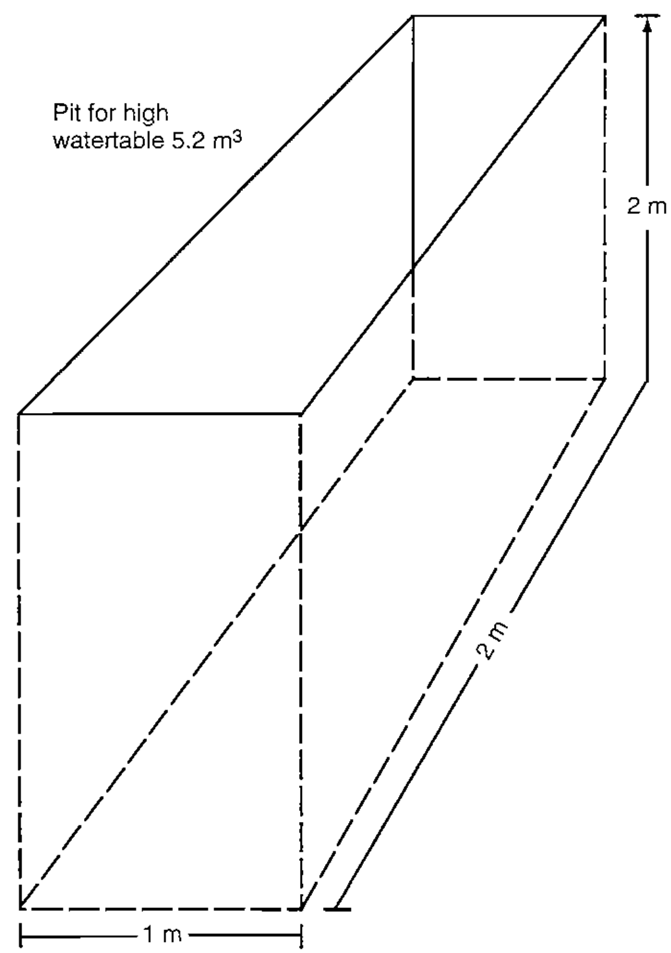
NORMAL PIT- stable soil and low ground Water level. Width 700 mm, depth 5 m Length 1.5 m

If there is no problem with the ground-water level and the soil stability, then 5 m is a good depth.

Our normal pit is 1.5 m long and is Suitable for a pitlatrine house without a door. However, different types of houses can be used.

The life of the pit depends on the number of users. It will last for about 5 years if 6 people are using it. (0.06 m^3/per person per year plus 0.03 m^3 for cleansing material.





SIZE OF THE PIT

High ground water

Where there is a very high water table a different size of pit should be used to avoid the pit entering the ground water and causing pollution.

A pit 2 m long, 1 m wide and 2 m deep with the floor of the latrine 600 mm above the highest ground level will give a size equal to the normal pit.

Unstable soil condition

Under unstable soil conditions, either line the pit with bricks to normal depth, or use dimensions for high ground water conditions, so as to get a size equal, or nearly equal to a normal pit.

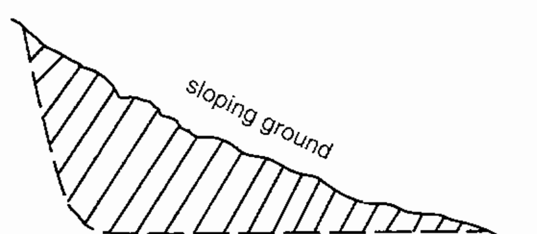
See drawings on page 786:

SETTING OUT

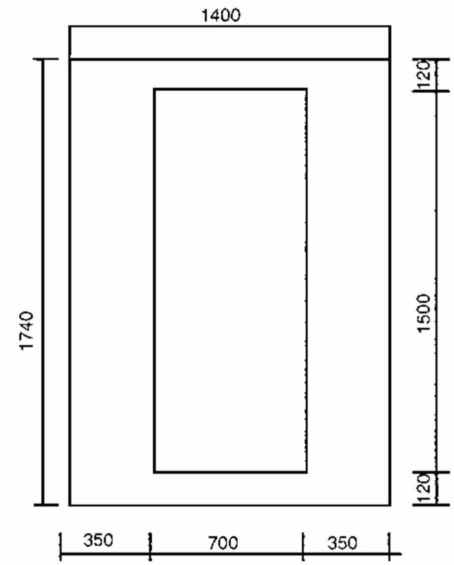
Before setting out, make sure that the ground is level.

You can use either pegs and a string or make a wooden frame. You "draw" the line on the ground. The measurements are shown on page 781.

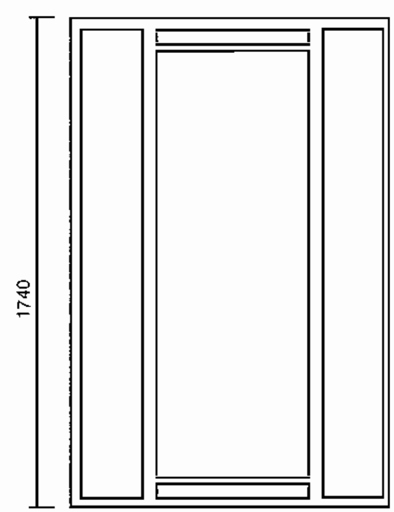
Make sure you have right angles, check with a square and/or measure the diagonals, they should be equal.



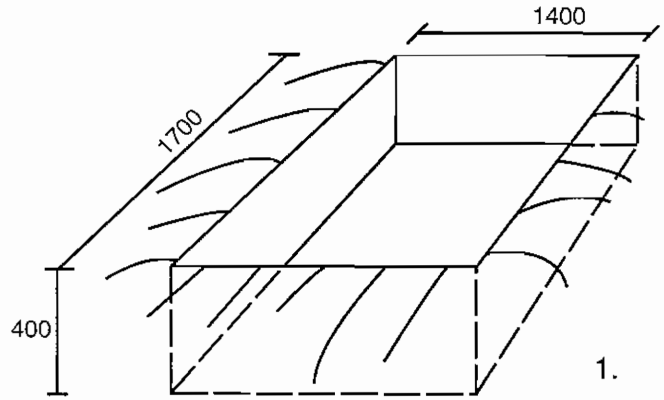
dig out the marked earth before setting out



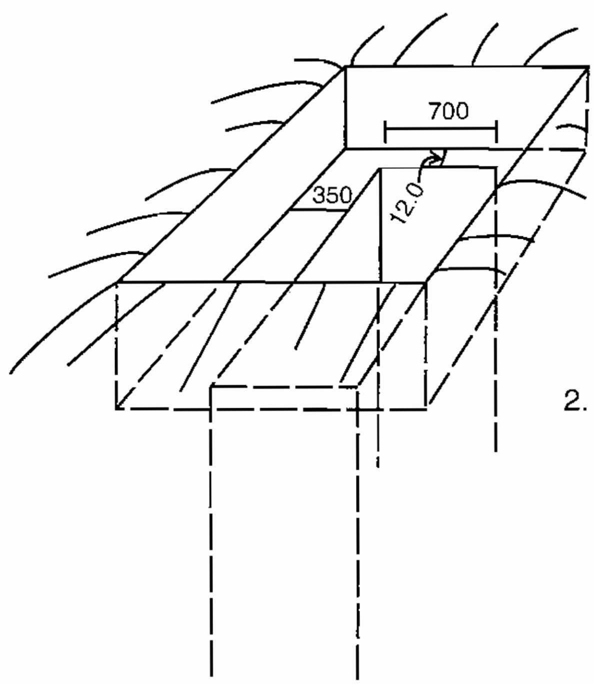
plan for setting out



a wooden frame for setting out



1.



2.

DIGGING THE PIT

Start digging a pit 1400 mm wide, 1740 mm long and 400 mm deep as shown in drawing 1.

Then dig the actual latrine pit 700 x 1500 mm and 5000 mm deep as shown in drawing 2.

When you have dug about 1000 mm of the actual latrine pit, stop and start building the base and make preparations for the vault mould.

THE BASE

The base is made up of 3 courses done in English bond as shown on the drawing.

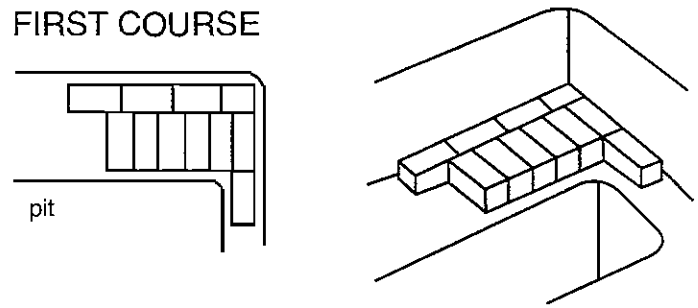
Use cement mortar 1: 5 — one part cement to 5 parts clear river sand.

All courses must be level.

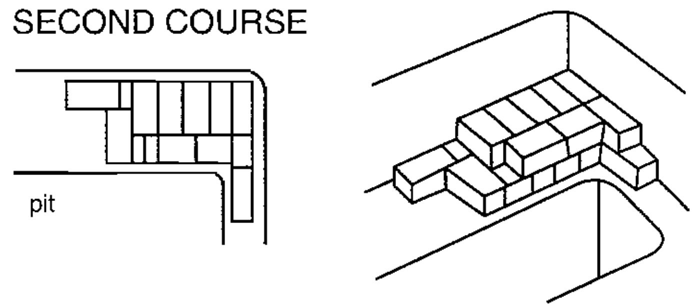
Cut the bricks for the third course carefully. It must be the correct angle to support the vault fully. Different size vault need different cut angles.

Normally the arch of the vault is fixed by a radius of 350 mm. A wooden mould will help in the building of the arch.

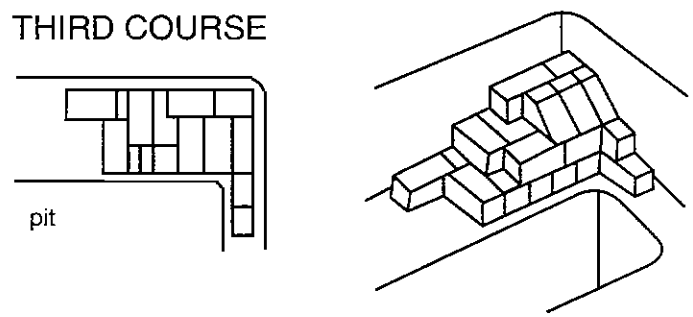
FIRST COURSE



SECOND COURSE



THIRD COURSE



COMPOSTING TOILETS

Based on "The Composting Toilet System Book A Practical Guide to Choosing, Planning and Maintaining Composting Toilet Systems, and Alternative to Sewer and Septic Systems" David Del Porto and Carol Steinfeld, The Center for Ecological Pollution Prevention (CEPP), 1999

Composting toilets (also known as dry, waterless, and biological toilets and nonliquid saturated systems) are one of the most direct ways, among wastewater treatment technologies, to avoid pollution and conserve water and resources.

Composting toilet systems contain and control the composting of excrement, toilet paper, carbon additive, and, optionally, food wastes. Unlike a septic system, a composting toilet system relies on unsaturated conditions (material cannot be fully immersed in water), where aerobic bacteria and fungi break down wastes, just as they do in a yard waste composter. Sized and operated properly, a composting toilet breaks down waste to 10 to 30 percent of its original volume. The resulting end-product is a stable soil-like material called "humus," which is used as a soil conditioner on edible crops in many parts of the world, although in the United States such use is illegal. Humus is removed after usually a year's retention.

The main components of a composting toilet are (1) a composting reactor connected to one or more dry or micro-flush toilets; (2) a screened exhaust system (often fan-forced) to remove odors, carbon dioxide, water vapor, and the by-products of aerobic decomposition; and (3) a means of ventilation to provide oxygen (aeration) for the aerobic organisms in the composter. Other components include process controls, such as mixers, to optimize and manage the process, and an access door for removal of the end-product. The composting reactor should have a volume of 0.2 cubic meters per year per person. A composting toilet is shown in Figure 28. When a single reactor toilet like this is used, then the humus can be removed regularly from the bottom of the pile, but only material that has been in the reactor for a year or so should be removed. A double vaulted composting toilet, described later in this article, is safer because the contents of one vault can decompose during the time—often one year—that the other vault is being used.

THE AEROBIC DECOMPOSITION AGENDA

Decomposition requires aeration, a suitable moisture level, a suitable temperature, and a proper carbon/nitrogen ratio.

Aerobes require oxygen. The ventilation system in a composter should draw sufficient air across and through the decomposing material. A key factor, then, is the surface area to volume ratio of the composting substrate (which includes the microbial population) because surface area allows direct contact with oxygen. Mixing, tumbling, forced aeration, and container design are ways composters provide a good surface to volume ratio. To make the composting process work best, the materials being composted should have a loose texture to allow air to circulate freely within the pile. If the material becomes matted down, compacted, or forms too solid a mass, the air will not circulate, and the aerobic organisms will die.

Here are some ways of ensuring adequate aeration.

- Add bulking agents, such as wood chips, stale popped popcorn, and so forth to increase pore spaces that permit air to reach deep into the biomass and allow heat, water vapor, and carbon dioxide to be exhausted. Earthworms also create pores as well as help break down wastes.

- Maintain adequate airflow through the material by proper ventilation (such as pressurized air, using convection, or forced air by a fan) and/or by frequently mixing.
- Provide aerators, such as mixers, mesh, grates, air channels, and screened pipes to help increase the surface area of the composting mass that is exposed to air.

However, too much airflow can remove too much heat and moisture

The microbes in the composter need the right amount of moisture to thrive. Too much water (saturated conditions) will drown them and create conditions for the growth of odor-producing anaerobic bacteria. In optimum conditions the composting mass has the consistency of a well-wrung sponge—about 45 to 70 percent moisture,

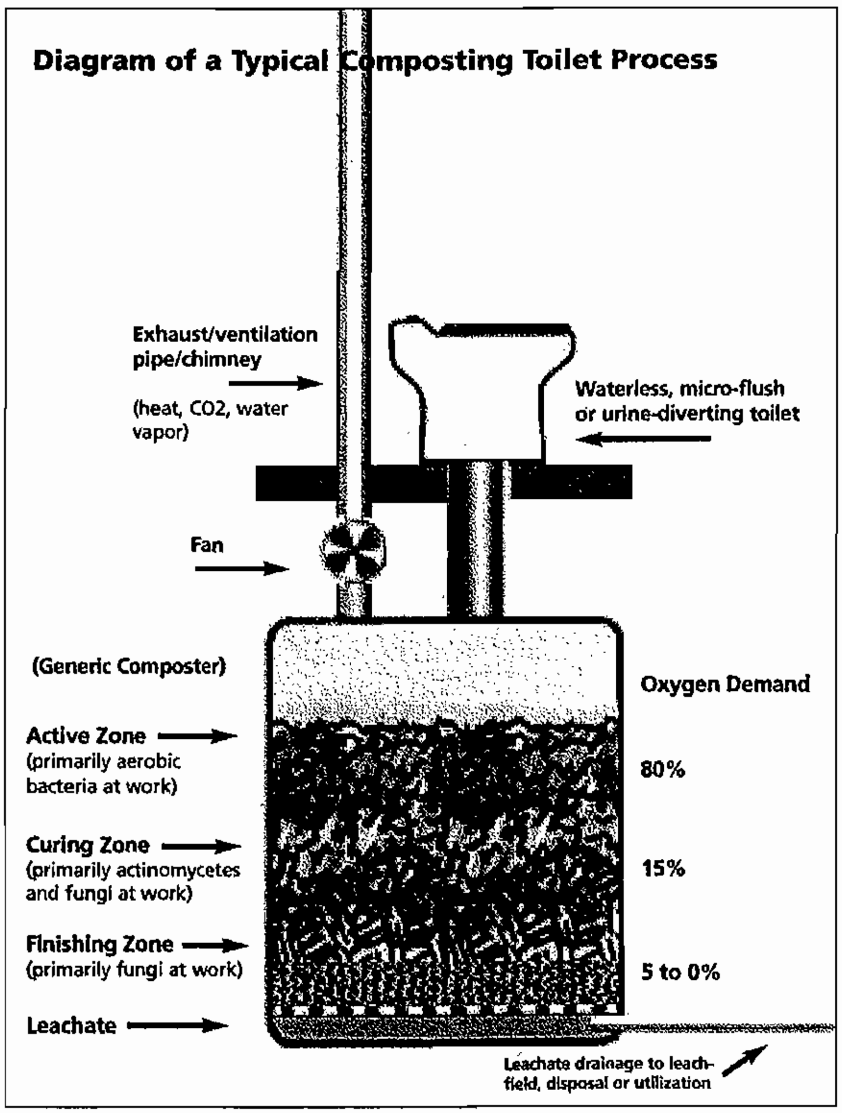


FIGURE 28
A composting toilet.

When the moisture level drops below 45 percent, it can become too dry for composting. Also, excrement, toilet paper, and additives will dry out but not decompose, thus prematurely filling the toilet (a good indicator that the mass is too dry). If the moisture level is higher than 70 percent, leachate will pool at the bottom of the composter. In this case, the leachate must be drained or evaporated; otherwise, it will drown the microbes. Urine and/or water from micro-flush toilets contributes most of the moisture in a composter and may not be distributed evenly over the mass. Fresh rainwater (which has little or no dissolved minerals) is best for moisture control, but fresh groundwater from the tap (which may contain significant dissolved minerals) will do as well. If the material is too dry, spray the compost mass with water or add a cup of water periodically.

The ambient temperature for acceptable biological decomposition is 78° to 113°F. A composter at less than 42°F will only accumulate excrement, toilet paper, and additive until the temperature rises. Generally, the rate of processing in a biochemical system is directly proportional to the increase of temperature (within certain limits, the rate doubles with every 18°F increase). The warmer the process, the more capacity in a composter. The cooler the process, the slower the rate, and more capacity needed for processing.

Microorganisms require digestible carbon as an energy source for growth and nitrogen and other nutrients, such as phosphorous and potassium, for protein synthesis to build cell walls and other structures (in the same way humans need carbohydrates and proteins). When measured on a dry weight basis, an optimum C:N ratio for aerobic bacteria is 25:1.

Human urine has a low C:N ratio (0.8:1). Therefore, oxidizing all of the nitrogen urinated into the toilet would require adding digestible carbonaceous materials on a regular basis. However, the practical fact is that urine, which contains most of the nitrogen, settles by gravity to the bottom of the composter, where it is drained away or evaporated. In either case, the nitrogen passes through the decomposing material and is lost to the process. For that reason, adding large amounts of carbon will not help process the nitrogen and will just fill up the composter faster.

Adding a small handful of dry matter per person per day or a few cups every week is a good rule of thumb to maintain a helpful C:N ratio, absorb excess moisture, and maintain pores in the composting material. The primary reason to add carbon material is to create air pockets in the composting material (that's why carbon additive is called "structure material"). Digestible carbonaceous materials include carbohydrates (sugar, starch, toilet paper, popped popcorn), vegetable or fruit scraps, finely shredded black and white newsprint, and wood chips.

LOCATING THE COMPOSTER FOR WARMTH

For solar heating, you need available solar energy, such as a clear, unobstructed south-by-southeast opening, unblocked by trees or other buildings. In most North American communities, nine square feet of solar collection area all year long will sufficiently warm a composter. There are many designs for heating small outhouses with composters in them. Some direct solar heat right onto the composting mass through a window, some on the leachate, some on the composter. (Remember that direct solar heat can dry out the surface of the mass, creating a crust that insulates the center, so you may actually need more heat. Turning the material and adding water helps.)

VENTILATION AND EXHAUST

Ensuring that air enters and exits the system in the right direction is critical for maintaining composting and preventing odors from entering the home. If your toilet room is on the side of the house opposite the prevailing winds, remember that wind pressure on the windward side of the house pulls a vacuum on the opposite, or leeward, side. So when you open your bathroom window on the leeward side, odor will be pulled from your toilet. You will know that this is the case if the window curtains blow out. If they blow into the toilet room, then the toilet is pressurized, and no odor will come into the room. Wind turbines work in areas with steady strong winds but can actually impede airflow at wind speeds of less than 10 to 15 mph. A simple plumbing T at the top of the pipe both keeps out the rain and allows the wind to suck air out of the pipe. The primary question with fan speeds is managing odor.

PULLING ODORS FROM THE COMPOSTER

Some assume that the wider the pipe from the toilet to the composter, the less chance of "skid marks" from stuff going down it. That's probably true but this connecting pipe can act as a chimney through which odors can back up into the toilet. The larger the diameter of the connecting pipe and toilet seat opening, the greater the chance of odor. To reduce this toilet-as-chimney effect, make sure that there is not a negative pressure in the toilet room so air is not pulled up the connecting pipe. Be aware that fireplaces can pull odor from the composter into the building.

Also, if the opening diameter of your toilet is large, insects have better access to the composter, and pets, toys, and infants could fall in (although we have yet to hear of a child falling into a composting toilet system). If it is too small, the pipe can get caked with excrement and may discourage ventilation/exhaust and require frequent cleaning. A good size is 8 to 12 inches.

OUTSIDE ODORS FROM THE EXHAUST PIPE

Outside, the odor from the composter will be not normally noticed on the ground if the exhaust pipe terminates at least 12 inches above the peak of the roof. Lower than the roof peak, odors from the exhaust pipe may be swept to the ground through wind downdrafting.

TOILET LOCATION

In a waterless situation, gravity is the only way to convey excrement from toilet to composter, so the composter must be almost directly under the toilet, although it can be several floors down. There should be few, if any, angles. Do not underestimate the stickiness of excrement! If this location won't work, or if you decide that aesthetic and lifestyle issues dictate a barrier between you and the composter, a micro-flush toilet or a vacuum system are alternatives.

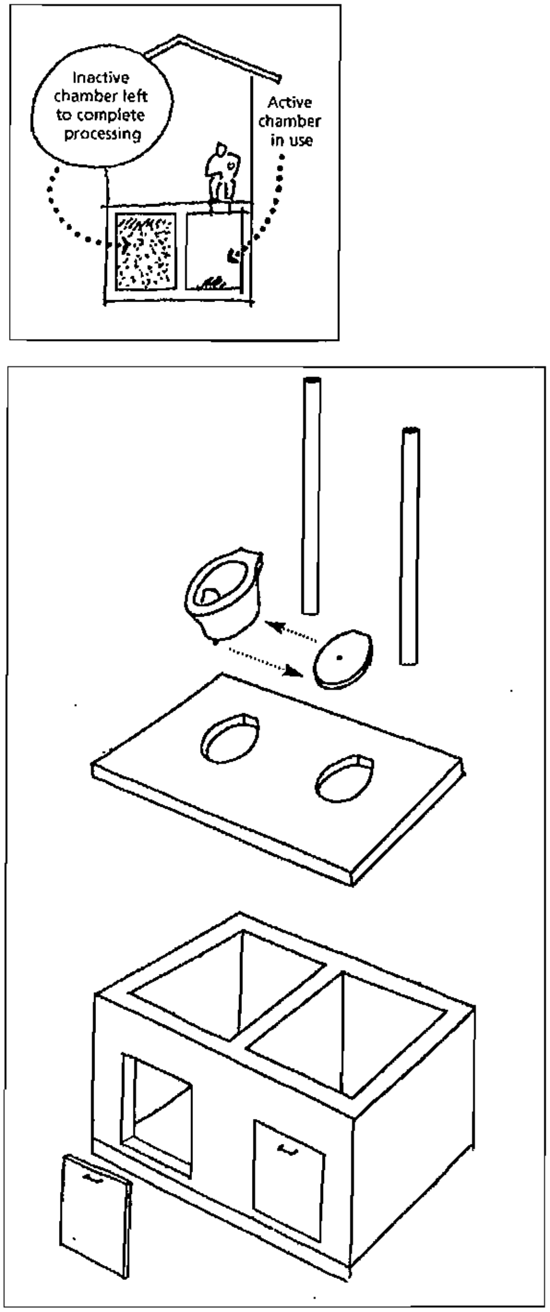


FIGURE 29
Double vault system. Adapted from graphics by César Añorvé.

DOUBLE VAULT SYSTEM

A double vault system—used in Mexico—is shown in Figure 29. Like most double-vault systems, one side is used at a time. When one side fills, the toilet stool is moved to the other side. The unused vault is covered and the waste therein decomposes. The decomposed excrement is removed, usually after a year or two, and occasionally used on farm fields.

USEFULNESS IN THE THIRD WORLD

Combusting toilet sanitation systems have been successful in the Third World. They do require care in operation—particularly ensuring that the waste is at an appropriate temperature and has an appropriate moisture level. Users must be educated about proper operation. Composting toilets offer particular advantages where human waste is presently recycled to gardens and where location of a latrine away from sources of drinking water is difficult.

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WATER PUMPS

Most water supply systems rely on water pumps that raise water from ponds or streams or from underground. In addition to the pumps described in this article, a so-called ram pump, described in a separate article, can be used to lift water.

POWER SOURCES

Many types of power sources can be adapted to driving pumps. Human-powered pumps are probably the most prevalent worldwide. They can provide a moderate supply of fresh water on demand, are well understood, and are easily implemented. The simplest human-powered pump is "cranked" up and down. To power larger pumps the operator walks in a circle pushing a horizontal bar attached to a capstan. If the pump requires a reciprocating—up and down—motion gears or pulleys with a connecting rod can be used between the capstan and the pump.

If more water is required than a human-powered pump supplies, animals can be used to provide the muscle, since they do not balk at pushing a pump all day. A common configuration has the animal(s)—donkey, horse, mule, or ox—walking in a circle, pushing a horizontal rod connected to a vertical shaft. An animal-powered pump made by the Rural Industries Innovation Centre in Botswana can replace a pump driven by a small diesel engine. Through gearing the pump shaft can rotate as fast as 1,600 rpm—fast enough to power a centrifugal pump. Up to eight oxen can be used. The address of the Rural Industries Innovation Centre is given in the References section.

Wind power to drive water pumps was commonly used in the United States before electric power was available. Water pumping is an appropriate use for wind because wind's erratic nature is usually not a problem—pumped water can easily be stored. Irrigation water is effectively stored when it is applied to the field so it is not usually stored in tanks. Wind power is discussed in an article in the Energy chapter of this book.

If wind power is to be used, a design question is how big a rotor is needed. The "Wind Power" article shows how the power and the diameter of the rotor are related. Here we estimate the power required to irrigate a 1-hectare field if the water must be raised 12 meters. The power required to raise a 1 cubic meter of water 1 meter in 1 second is 9,800 watts—the explanation of this relationship uses basic mechanics and the gravitational constant in metric units. We assume 5 mm of water are required per day on the 1-hectare field. The total amount of water required, then, is 50 cubic meters per day, or 0.000579 cubic meters/second. Raising this much water requires 68 watts. Using the relationship given in the "Wind" article and making a reasonable assumption about wind speed, the diameter of the rotor can be estimated to be about 7 feet.

The familiar fan-type rotor used in the United States in water pumping applications is a well-tested technology. These "wind-mills" are reliable—they were designed for unattended operation. They normally use gears to reduce the rotor speed to a speed more suitable for displacement pumps. Scrap automobile gears may be appropriate or local machine shops may be able to make suitable gears. Other wind-powered machines are described in the "Wind" article, and the simpler machines would be suitable for water pumping. An article in the VITA handbook points out that many wind machines were installed in Third World countries in the past, and these may be available on the surplus market, since electric power was brought to commercial farms. The Rural Industries Innovation Centre makes two models of "windmills."

A seemingly attractive idea that does not seem to have caught on in the Third World is solar-powered irrigation pumps—the usual proposed configuration employs photovoltaic cells. Probably the reason photovoltaic powered systems are not widely used in the Third World is the cost of the solar panel compared to the cost of human and animal power. In the United States, where labor costs are greater and photovoltaic costs smaller, solar-powered irrigation systems have been deployed. One system in Texas uses both wind and solar—wind is erratic in the summer when the sun shines brightest, so the two systems complement each other. Another article in the VITA handbook shows how a reciprocating wire can transfer mechanical power from a water wheel to a water pump half a mile away. Amish people in Pennsylvania have used such a system for many years.

TYPES OF PUMPS

It is helpful to consider two types of pumps: lift (suction) pumps and force pumps. Lift pumps pull the water up from the well. Actually it is the pressure of the atmosphere at the bottom of the well that pushes the water up. The pump really only removes water from the top of the pipe, so more water can be pushed up. A lift pump is located at the top of the well and is limited to a lift of 6 to 7 meters, corresponding to atmospheric pressure. Force pumps actually push the water up from the bottom of the pipe.

DISPLACEMENT PUMP

The most familiar and ubiquitous pump is probably the displacement pump—a lift pump. At the beginning of the twentieth century, windmills drove millions of displacement pumps. When one thinks of early farms in the United States the image of people pushing up and down on the pump handle comes quickly to mind.

Figure 30 shows a cutway of a typical two-cylinder displacement pump. On the upstroke the plunger valve closes and the foot valve opens. Atmospheric pressure pushes the water up the

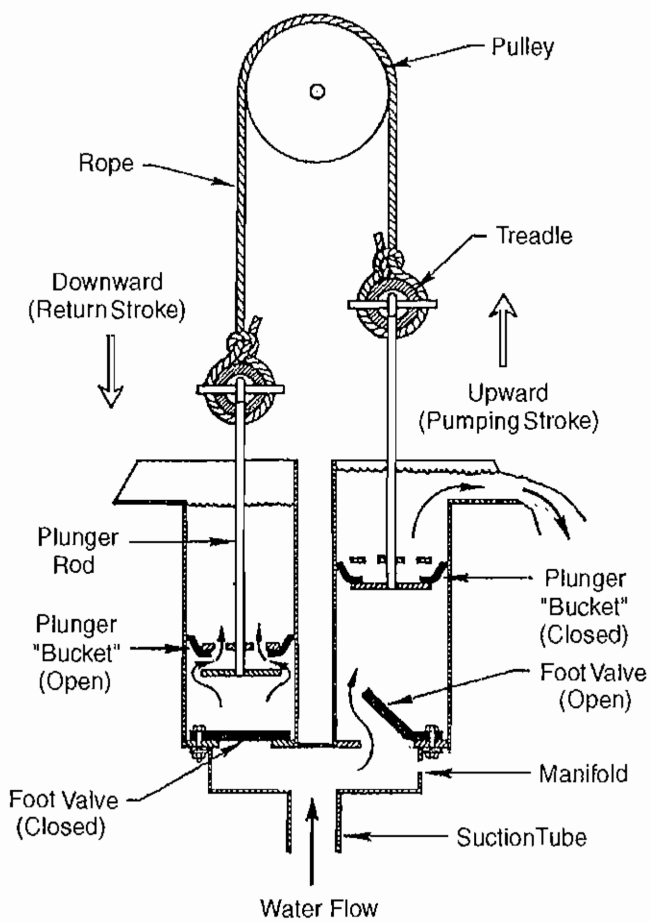

FIGURE 30
Displacement pump.

suction tube. On the downstroke, the foot valve flaps close and the plunger valve opens, allowing the piston to pass through the water already in the cylinder. On the next upstroke more water is pushed up the suction tube, and the water already in the cylinder is lifted and forced out the spout. A one-cylinder displacement pump, probably more common, is simply half of the one shown in Figure 30; water comes from the pump only half the time.

If the pump seals and valves are in good condition, this pump does not need to be primed. Perhaps an explanation of priming is in order. When a pump is not in operation, the water in the cylinder and suction tube may leak back to the well so the valves do not seal. Adding water to get the pumping started is called priming. A well-designed displacement pump is capable of pumping the air out of its system, so it does not need priming.

TWIN TREADLE PUMP

The twin treadle pump is shown in Figure 31. The prime mover is a person pedaling. The pump is actually a pair of pumps very similar to the standard displacement pump. Twin cylinders, operated alternately, provide a steady discharge, as opposed to a single cylinder that discharges only on the upstroke. A practiced treadle pump operator can work a two-hour stint; producing 2 to 3 liters per second at 2 to 4 meters lift. (The lift, or head, is the distance from the water level to the discharge spout.)

Most of the materials necessary to construct the pump will be locally available. The frame, treadles, and pipes can all be made of bamboo. The cylinders are made from sheet metal, PVC tube, cast iron, or concrete. The imported items—axles, seals, pistons, and rods—are readily available because they are replacement parts for widely used pitcher pumps. A good team of two or three people can make the bamboo pipes, strainers, and frame and sink, and install a pump in a day. The cost of a complete pump installation is around $15 to 20, which puts it within reach of all but the poorest farmers. A similar pump is made by ApproTec in Kenya—the address is given in the References.

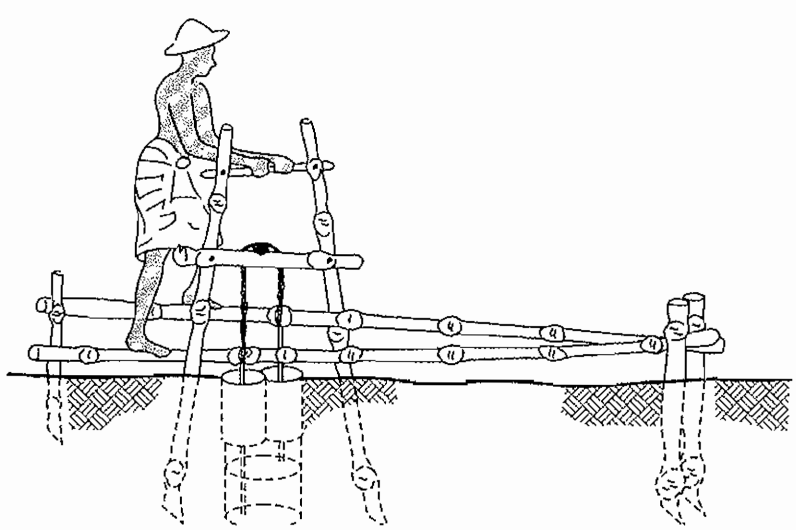

FIGURE 31
Twin treadle pump.

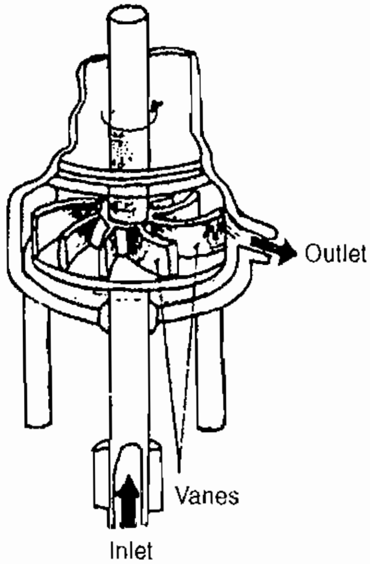

FIGURE 32
Centrifugal pump.

FORCE PUMPS

Force pumps are located at the water level—usually below ground level—and push the water up from the well. Actually most lift pumps will function as force pumps if they are submerged, but, of course, they must get power from the surface. Examples of force pumps are centrifugal pumps, rotary pumps, jet, and chain pumps.

Centrifugal pumps operate by throwing water from the center of the pump to the outlet located on the outer casing. Figure 32 shows a centrifugal pump. At the center of the impeller there is a low-pressure area, which draws more water up the suction tube. Initially water must be in this center area if low pressure is to be produced when the impeller rotates—so a dry pump must be primed. To avoid having to prime the pump before each use, a check or foot valve is installed in the suction tube. This valve prevents water from flowing back into the well—that is, water can only flow in one direction. Centrifugal pumps have a five- to ten-year lifetime, they require little maintenance, and in large installations, they have an efficiency of 80 percent, with 50 to 70 percent in smaller ones.

Axial or rotary pumps come in several variations. The best known is the Archimedes screw, which is a broadly threaded screw rotating in a snugly fitting tube. Another axial pump is made by mounting a marine propeller in a pipe. When the propeller is driven, it forces the water to the outlet. Figure 33 shows an axial pump. Axial pumps are useful in low-lift, high-volume applications. They are relatively insensitive to sediment in the water.

A jet pump, shown in Figure 34, is really two pumps. The secondary pump provides water to the primary pump. The primary pump has no moving parts; it is merely a nozzle whose outlet is a high-velocity stream inserted in a tube. The nozzle creates an area of low pressure that draws more water into the tube. Jet pumps are a good choice when the lift is more than 8 meters or the bore of the well is narrow. Their efficiency is somewhat less than that of a centrifugal pump.

A chain pump has vanes mounted on an endless chain, which push water up a channel. These are fairly easy to build but require much energy to operate. Small buckets can be substituted for the vanes.

The choice of a pump for a water supply system is based, like most appropriate design decisions, on local conditions, particularly needs and available resources. The purpose of the water (domestic, livestock, and/or irrigation), power sources, local customs, water source (shallow or deep), economic resources, climate, and local expertise all have an impact on the success of a water project. Cultural factors are significant; a pump was not accepted in the Sudan because the users thought the operators would sit in an undignified position—use of the pump violated local custom.

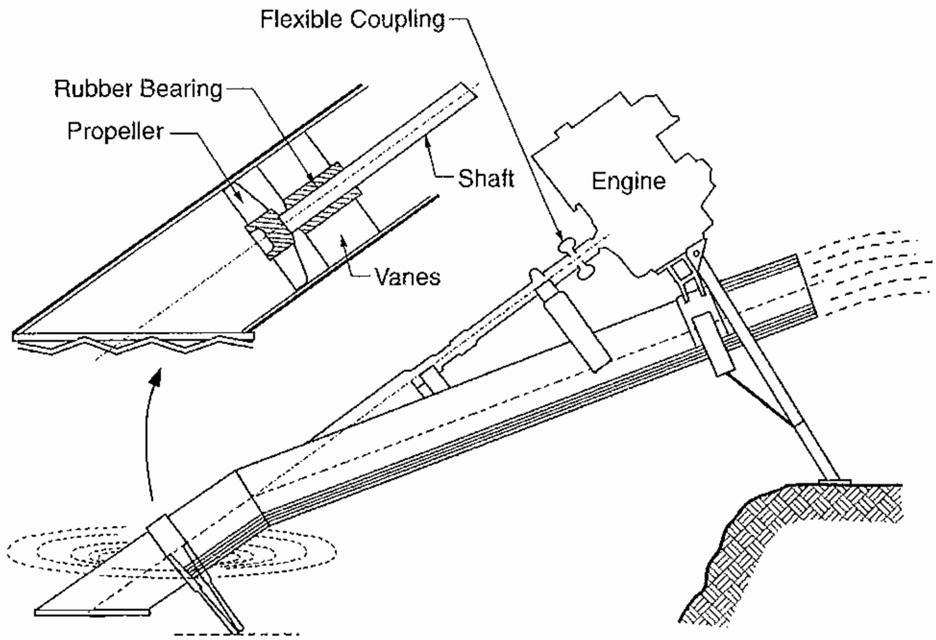

FIGURE 33
Axial pump.

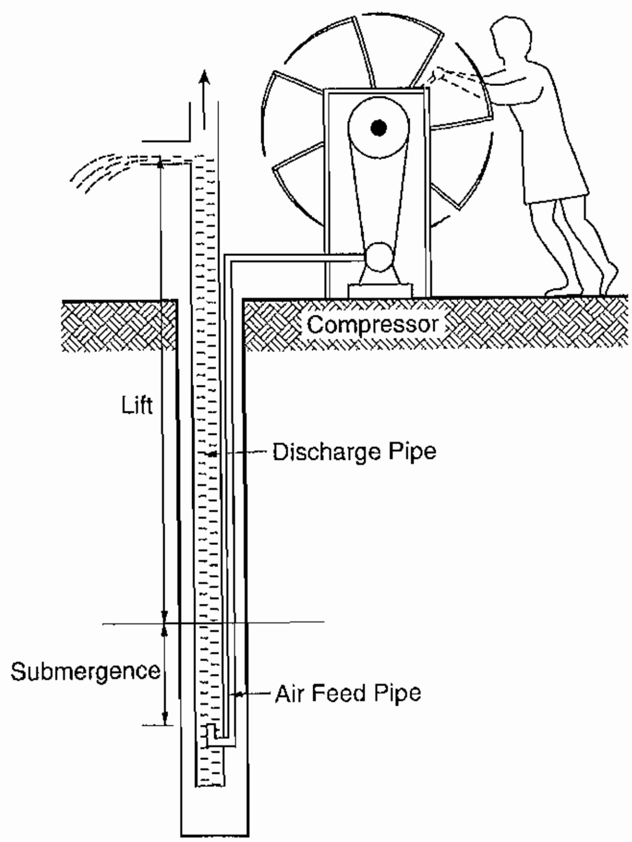

FIGURE 34
Jet pump.

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HYDRAULIC RAM

A hydraulic ram, shown in Figure 35, is a simple device that uses the energy in a stream with high volume but low head to lift a small volume of water to a large height. It could be used, for example, when we have a stream with a 1-foot drop carrying 100 cubic feet per minute of water and wanted to raise 2 cubic feet of water 8 feet to a storage tank on a roof to supply a kitchen and bathroom with running water. They require essentially no maintenance and so are useful in isolated installations where a fairly small amount of water is needed.

The only part of the ram in Figure 35 that is not obvious is the two valves. They are made with weights that normally push them open or closed, depending on the position of the weight. In particular the delivery valve in Figure 35 is normally closed—that is, horizontal—but can open up when water pushes from below. It closes when water pushes from above. Similarly, the waste valve in the same figure is normally open—that is, vertical—but close when water pushes up from the bottom.

It is probabbly easiest to understand how the hydraulic ram works if we go through the operation step by step. Initially, the delivery valve is closed and the waste valve is open.

1. Water from the stream flows down the input pipe, forcing the delivery valve open and the waste valve closed. Water, thus, can only flow into the compression chamber.
2. The momentum of the large amount of water from the input brings much water into the compression chamber, compressing the air on top.

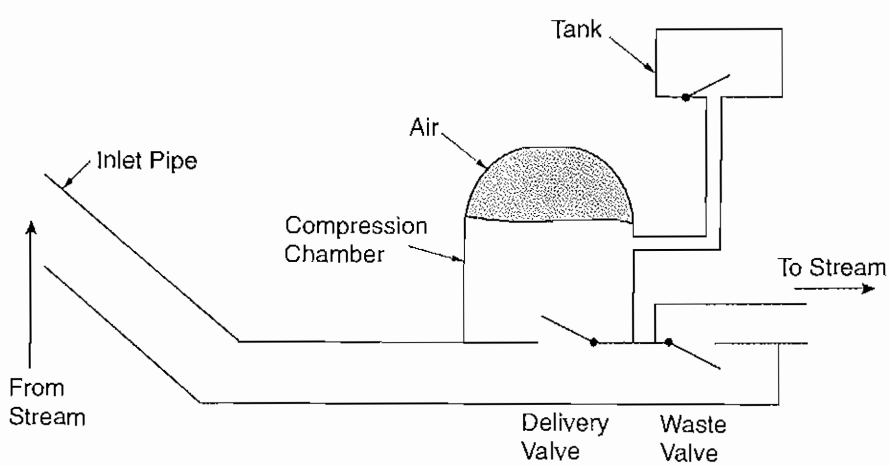

FIGURE 35
Hydraulic ram.

3. Because the water is flowing into the chamber, the pressure on the waste valve is small, so the waste valve falls open.
4. When the air in the compression chamber is sufficiently compressed, it pushes back on the water, closing the delivery valve.
5. The compressed air pushes on the water in the chamber, forcing it up to the tank.
6. Simultaneously, the water from the input, having no other place to go, flows out the waste valve, pushing it closed.
7. Meanwhile, the pressure on top of the compression chamber has decreased as water goes to the tank, so the delivery valve opens.

Now the process repeats itself, the situation being the same as it Step 1: delivery valve open, waste valve closed.

Hydraulic rams have essentially no parts rnbbing against each other as many other pumps do, so they last a long time—several decades at least.

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IRRIGATION

Based on "Small-Scale Irrigation Systems," Prepared for the United States Peace Corps by Development Planning and Research Associates, Inc., Information Collection & Exchange/Peace Corps, 1111 20th Street N.W., Washington, DC 20526, USA, September 1983

Irrigation is used for four distinct purposes.

- To enable crops to be grown where natural rainfall is too low to grow normal crops
- To provide additional water throughout the growing season, or at critical times during the crop season, when rainfall is inadequate to provide optimum crop production
- To extend the growing season
- To flood land for growing rice to prevent growth of weeds

Rice production, with some advice about irrigation, is discussed in the article "Growing Rice" in the Food chapter.

In areas where lack of natnral rainfall or lack of rainfall during the cropping season limits crop production, supplemental irrigation may significantly increase yields or permit farmers to grow crops with higher yield potential or value. For example, in much of Africa sorghum and millet are traditional cereal food crops. With supplemental irrigation, yields of those crops can be increased or maize (corn) may be grown. Maize has a potential for 50 to 100 percent higher yield than sorghum or millet under optimum water availability and agronomic practices. In certain situations, the production of high value crops such as vegetables or melons may be feasible with irrigation.

Rice is probably the most valued cereal food. Supplemental irrigation may allow it to be produced in areas where it cannot be grown with natural rainfall. The capacity to keep the rice flooded during most of the growing period will increase yields and greatly reduce labor required to control weeds.

Irrigation increases a farmer's income, but developing and managing an irrigation system is expensive in labor and money and creates risks. Supplemental irrigation may allow the production of high value crops "off-season" when demand, and price, is particularly high. The system can be justified only by drastically increased crop yields or crop values. Growing crops such as fruits and vegetables might not be possible with normal rainfall but might be profitable, or socially desirable, with irrigation. If the project is only profitable if produce is sold outside of the immediate area, then the reliability of transportation is important—for one thing, will roads be passable when the crops are ready?

In general, traditional rainfed crops that suffered from lack of moisture will require, when irrigated, higher seeding rates and more fertilizer to produce optimum yields. Exact recommendations on seeding rates and fertilizer applications are "site specific," so local agronomists should be consulted for specific crop recommendations. The availability of such inputs as fertilizer must be assured. If fertilizer is not readily available when needed, the irrigation project will fail. Weed control will probably be more difficult with irrigation, so additional labor will be needed during the growing season.

Occasionally a major benefit of irrigation may be to shift or extend the growing season. For example, a short rainfall season may preclude growing maize. Also, longer season crop varieties usually have greater yield potentials. A light irrigation just to cause germination and supply the limited water requirements of young plants might bring the period when water requirements are greatest into the rainy season. One should, however, ascertain that long-season, adapted varieties or hybrids are available before building.

The economic feasibility of irrigation should be evaluated before any physical development actions are taken. If in doubt, as, for example, about the amount of water available, the optimum planting and fertilizing rates, or crops to irrigate, start with a small pilot project so the risk is not great. Economic evaluation is handled separately from the social factors, but social and cultural factors cannot be overlooked in arriving at a conclusion regarding the feasibility of an irrigation project. If it is traditional for women to weed crops, men might expect women to handle the irrigating causing a disruption of other family and household responsibilities.

AMOUNT OF WATER REQUIRED

Crops vary in the amount of water required. Typical requirements vary from 3.3 mm/day for sorghum in Pakistan to 5.3 mm/day for cotton in Hyderabad. Rice takes more, perhaps 8 mm/day. Water requirements depend on the growth stage of the plant. During early periods of plant growth, while much of the soil surface is exposed to sun and wind, the moisture loss by evaporation predominates. At later stages of crop maturity, much of the soil surface is shaded and protected from wind. Then transpiration water requirements predominate. Evaporation losses are much larger in climates where the relative humidity is low. Of course, when planning the irrigation system allow for the amount of water expected from rain.

SOURCES OF IRRIGATION WATER

Large irrigation systems usually depend on large streams or rivers for the water source. If the large streams have a constant year-round flow, water may be taken from them by building low diversion dams to raise the water level enough to allow water to be removed by gravity flow through canals. Pumps also may be installed to raise the water level to the distribution canals.

When you consider a stream as an irrigation source, first contact local residents who will know if the stream frequently "dries up." If it ceases to flow as often as one year in five, it is of questionable value for long-season crops. If stream flow is much less than desired during the dry season, high dams can be used to store water from the wet to dry season. The design of high dams requires significant expertise—such projects are not for the inexperienced.

Underground water supplies are widely used as a water source, and large projects use mechanically powered pumps to raise the water to the surface. Small projects use hand or animal powered pumps. These systems are frequently called "tube well" systems. Since the systems vary widely in size, they may be publicly or privately owned. Wells and pumps are discussed in separate articles in this chapter.

Springs that continue to flow during the dry season are ideal water sources for small private irrigation projects. The spring is at the surface and water will flow by gravity to lower elevations where it can be used. To determine the spring's potential as a water source, the quantity of flow should be measured during the season when irrigation will be required.

Small privately or community-owned ponds to store water for irrigation may be made by damming small streams. Some major advantages are the following.

- Small ponds (microdams) can be placed in almost any location.
- Gravity flow can usually be used to distribute the water.
- Local labor can be used for construction.
- The water can be used for animals or household purposes.

The following are some major disadvantages.

- Silting is frequently a problem because runoff from natural rainfall contains eroded soil. It is less of a problem where forests or good grass vegetation exists above the pond.
- The soil at the pond site should be relatively impervious (probably one of the clay types) to prevent excessive water loss through the bottom of the pond or the dam.
- Erosion around the end of the dam from excess water can be so severe that a masonry structure is required to lower excess water to the normal stream level below the dam.
- Some capital investment is required to purchase the pipe and valve required to drain water from the pond.
- Ponds should be fenced to protect them from livestock.
- Evaporation will be rapid from the pond surface during the dry season, reducing the amount of water available for other purposes.

Before making a final decision on a water source, determine if there are legal, longstanding customs or community constraints against developing the particular source. Contact the Ministry of Agriculture or Land Development officials for information about constraints that most likely apply to using water from streams. A good spring may be considered a community resource for animals and households. Using the spring water for irrigation, particularly for a private project, could cause friction in the community. Development of underground water is less likely to encounter legal or community restrictions.

WATER DISTRIBUTION

For most water sources, some sort of a distribution system is required to transfer the water from the source to the area to be irrigated. Most small irrigation systems use small ditches and canals, and the water flows by gravity.

Unlined ditches dug in ordinary soil lose a large amount of water by seepage into the surrounding earth. Part of the seepage might be recovered by growing crops along both sides of the unlined channels. Seepage losses can be reduced by using linings of masonry, concrete, or plastic sheets, but they are seldom used on small projects in developing countries. Obviously, pipes would prevent losses from seepage and evaporation, but the cost of pipes usually prevents them from being used.

Several critical requirements must be met when designing a channel to distribute water. To reduce seepage losses, the soil should not be too permeable. If the ditch must traverse an area of very permeable soil, a lining of a heavier soil type might be feasible.

The channel must have enough slope and area to convey the quantity of water required. The quantity of water depends on the cross sectional area of the channel and the velocity of the water flow. The velocity of flow in a channel is a function of the following channel characteristics.

- Cross-sectional shape
- Slope (actually the square root of the slope—to double the velocity, the slope must be quadrupled)
- Roughness

Formulas can be used to estimate the water flow through particular channels, but they are complicated and uncertain, so one should probably make estimates on the basis of observations of the flow through channels with similar soil.

For very small flow rates, channels may be of V or semicircular cross section; for larger capacities, trapezoidal cross sections are generally used. The side slope on a triangular or trapezoidal cross section will depend upon the soil type. Side slopes that are too steep will cave off into the channel. The U.S. Bureau of Reclamation recommends a side slope of 3:1 (horizontal: vertical) for sandy soil, about 2:1 for loams and clay loams, and as steep as 1:1, or vertical, on heavy clay soils. Masonry-lined channels can have vertical sides if they are properly reinforced. Designing a trapezoidal channel—determining its cross-sectional area—usually requires a trial-and-error solution.

The velocity in the channel must not be so fast that it causes excessive erosion. When slope is great enough to allow the maximum velocity to be exceeded, two solutions are possible. A wider and shallower channel can be built, or a wood or masonry drop can be installed at some point so the slope along the remainder of the channel will be reduced. The flow velocity will be very high just below the structure and will cause severe erosion on the lower side. An apron must be provided to dissipate the energy in the falling water.

Very low velocities may cause a different problem. Water from a rapidly flowing stream could be high in sand, silt, and clay carried along by the flow. Such water diverted to a slow-moving irrigation canal would settle out sediment, requiring that the canal be cleaned periodically.

Starting at the source, a survey should be made to provide a line for the ditch. It will be almost always be on a contour from the source to the field. If the contour line is quite crooked, the channel may be "smoothed" or straightened by digging deeper through high points or by filling in low areas with extra earth to build the berms higher.

FIELD IRRIGATION SYSTEMS

Basin irrigation is widely practiced where rice is irrigated. Rice (unlike most crops and most weeds) can grow when the soil is completely saturated. The basin is formed by leveling the area completely and enclosing it with berms, or levees. The side berms will run essentially on the contour. If the land is very sloping, the berms become terraces, and a large amount of earth must be moved from the upper side to the lower side. On very steep slopes, the basin will be fairly narrow to reduce the amount of leveling required. Drop structures are required to lower water from one level to another.

Border irrigation is done by laying out the land with side berms running downhill on a slight slope. The land is leveled between side berms to make the irrigation water run in a narrow sheet from the upper to the lower end of the field. When irrigation starts, the infiltration rate is high at the upper end of the border, but as the soil becomes saturated, the leading edge of the water continues to move downhill. To provide enough water at the lower end of the field without overwatering the upper end, a high berm is constructed at the lower end to hold back a pool of water. Determining the correct length and slope of a border system is by trial and error. Distributing water uniformly across the width of the border strip requires that the field be very flat (level). If the border is wide, water should be supplied at more than one point from the distribution channel. Water may be discharged from the supply channel to the border by gated pipes through the channel berm or by siphons over the berm. The border system is well adapted to watering forage crops or other crops that cover the ground entirely.

Crops normally grown in rows, such as grain or vegetable crops, are more frequently irrigated with furrow systems—a series of furrows and ridges with about 75 to 100 cm between furrows and 15 to 20 cm deep. The furrows run downhill, as with borders. Where the furrows are constructed 15 to 20 cm deep, it is possible to irrigate a field with a significant amount of side slope. As shown in Figure 36, rows of tall-growing crops like maize are planted on the ridges. Two rows of low-growing crops like onions may be planted on each ridge.

One problem that may affect row placement on the ridge is having enough soil moisture to germinate seed. In areas that normally have sufficient rain during the planting season, rainfall should provide moisture for seed germination. In drier areas, the field may be very heavily irrigated just before or after seeding so enough moisture moves sideways and up by capillary action to germinate the seed. But it is usually best to place seeds into moist soil. In severe problem cases, such as a sandy soil and low rainfall, seed may be planted on the side of the ridge so they are closer to the wetted area. Once the seedling root system develops a few inches, there should be no further problems.

As with border systems, the slope along the furrow in furrow systems must be flat enough to prevent erosion but steep enough to allow water to reach the end of the furrow so infiltration is relatively uniform the full length of the furrow. The more permeable the soil, the steeper and/or shorter the furrows must be. In general, furrow slopes should range from .1 to 2 percent. If the distribution channel is run on a very slight grade, essentially on the contour, then the furrows can be supplied and laid out on the downhill side of the channel, although they need not run perpendicular to the channel.

Because of the many variables involved, a good operating rule is that water should reach the end of the furrow within 25 percent of the total time for one irrigation. That will provide about 25 percent more irrigation at the top of the field than at the lower end. Water to irrigate a furrow can be applied at a high rate at the beginning of the period and then reduced as the soil becomes wetted. That reduces the time required for water to reach the end of the furrow and prevents excessive loss later from the end of the furrow. Also, a dam may be placed at the end of the furrow to pond water and increase infiltration rate.

Sprinkler systems are useful when evaporation is extremely high. Efficient use of irrigation water and minimum land leveling are characteristics of sprinkler systems but operating and investment costs are higher than for gravity flow systems. Pressures must be matched to sprinkler size, and manufacturers' representatives should be consulted to design the systems.

Drip irrigation is a relatively new development. Water is piped under pressure, and small outlets are located at each plant to be watered. The system is usually applied to trees, but large

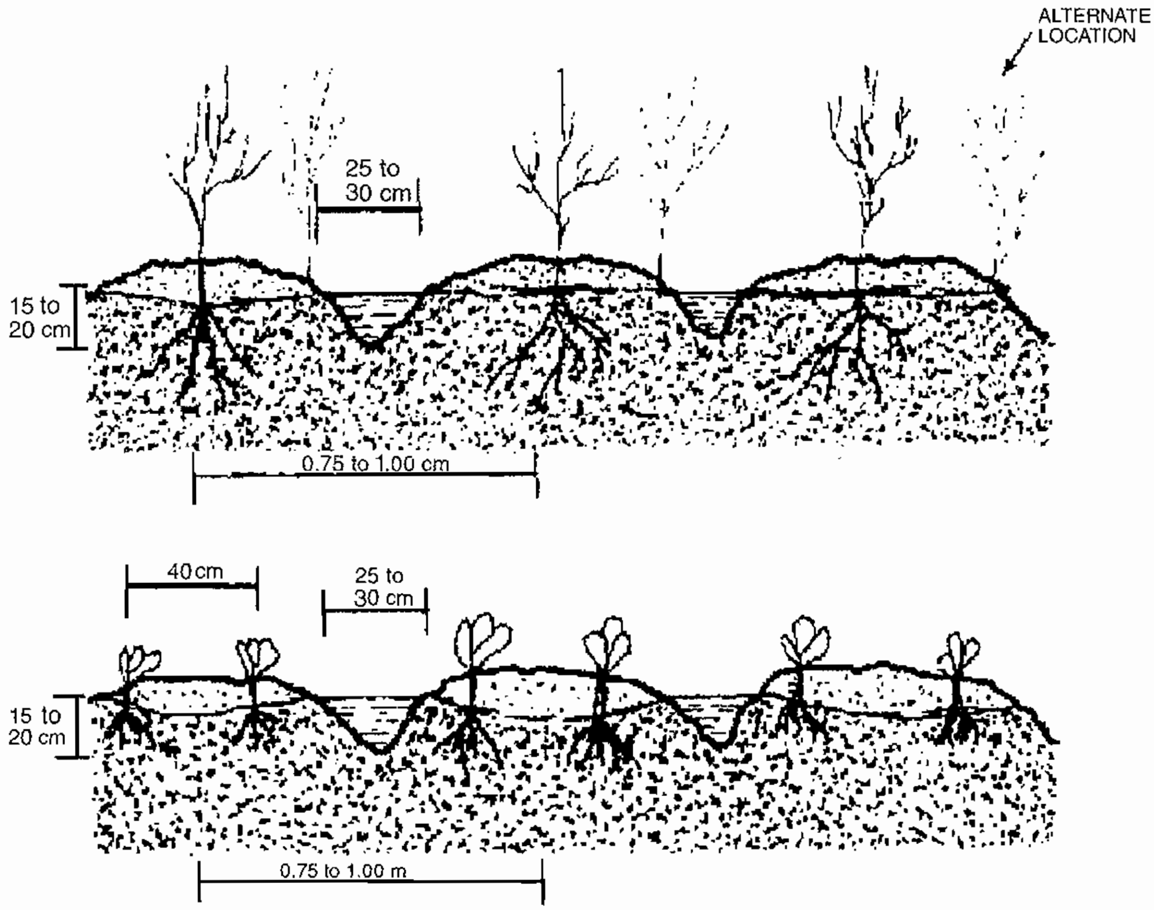

FIGURE 36
Furrow irrigation.

plants like tomatoes may be irrigated. The system is designed to apply water very slowly at a rate a specific plant needs. Other areas are not watered. Major disadvantages of the pressure system are its cost and small holes plugging up with foreign material.

In the wild flooding system, water is released from a distribution channel at the top of a field that has had little, if any, leveling. Water distribution will be very nonuniform. The system should be used only where there is a permanent ground cover such as alfalfa or grass to prevent erosion.

MAINTENANCE

Channels to and within a field require regular routine maintenance to remove weeds that reduce water velocity and cause additional evaporative losses. Some erosion will occur along channels and furrows, and some silt deposits will have to be removed to maintain channel cross-section area. With time, berms will erode and require some maintenance to maintain their height. Small leaks, particularly through or over berms, should be repaired promptly before water erodes them severely. Watch for holes made by animals through berms.

In some countries, large animals, such as water buffaloes, pose a significant threat to canal systems, since it is virtually impossible to prevent the animals from wallowing in water and thus destroying the canal bank. Consideration will need to be made for possible crossings for the animals and perhaps for policies regarding grazing alongside the canals as well.

Some leveling of basins and border systems will be required, originally and with time. High and low points should be marked when water covers the surface. Using a large plane of water is a more rapid way to locate high and low spots than using a surveying instrument.

Erosion during a rainy season can cause serious damage unless the area is well protected with drainage ditches or terraces that divert surface flood-type flow. Drainage is discussed in the next section.

DRAINAGE

Drainage is the removal of excess water from the land to prevent crop damage and salt accumulation, allow earlier planting of crops, increase the root zone, aerate the soil, favor growth of soil bacteria, and reclaim arable low-lying or swamp areas. Practically every valley where irrigation has been carried on for a considerable length of time has lands needing drainage.

These are some indications of drainage problems.

- Standing water or salt deposits on the soil's surface
- Scalding of crops by summer water ponding
- Propagation of mosquitoes in irrigated fields
- Soil compaction and resulting poor water penetration
- Difficulty in carrying on farm operations because of poor tractor footing
- Minerals accumulating in the soil
- Poor root growth due to a high water table
- Plant root diseases

A combination of field ditches and land leveling is most practical. It takes an unreasonably large network of field ditches to do a good job of moving water from most fields without land leveling. Deep channels to carry the final collection into an accepted area are often constructed on field boundaries.

To protect roads, irrigation systems, buildings, and fields, maximum rate of runoff for all drainage systems should be determined. Most structures can be flooded for a short time, but peak rainfall intensities and runoff data should be determined so that the system (bridges, culverts, etc.) can be designed to handle the runoff. It may be most economical to design the structures on a 10- to 25-year recurrence expectancy; that is, the expected runoff would be exceeded only once every 10 to 25 years.

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