6.

Technical interventions

6.1 Prevention and remedial measures

Surveillance is the process of gathering systematic information on hazards in water supplies. It enables appropriate preventive measures to be taken before failure or contamination occurs. Quality control and sanitary surveys are integral parts of surveillance which, for most community supplies, is still a medium-to-long-term undertaking. Surveillance planners and coordinators must look beyond the day-to-day problems and begin to develop infrastructures and policies that address the causes of water-supply failure and contamination.

Remedial measures include all those technical and social interventions designed to improve the water-supply service. This chapter deals with interventions of a technical nature, while social issues are addressed in Chapter 7. Interventions to improve water-supply service should include community education and management training; advising on all types of remedial action, not just technical interventions, is a key role of the surveillance agency.

Economic analysis shows that it is more cost-effective to carry out regular and diligent preventive maintenance than simply to operate equipment until it breaks down and needs expensive repairs. For example, a pump that undergoes regular maintenance such as greasing and tightening of nuts will last longer and perform better than one that is not maintained, breaks down, and requires spare parts. The cost of spare parts and skilled labour is always greater than that of a pot of grease. Complete breakdowns in supply lead to reductions in water availability and sometimes also in quality, which jeopardize the health of the community.

In some countries, preventive maintenance can only be really effective if the community is also involved. However, this does not mean that governments should abrogate their responsibilities for providing support to communities that take on the burden of maintenance. A systematic approach to maintenance is needed, taking account of environmental conditions, local culture, affordability and user involvement. For example, as a general rule, the cheaper and simpler the equipment the less maintenance it requires, the more reliable it is in practice, and the easier it is to repair. Apart from the choice of equipment, other factors that need to be considered collaboratively in choosing a maintenance system include institutional responsibilities and legal obligations, logistics, financial viability, manpower training and support, and monitoring and control. The involvement of users in decision-making with regard to level of service, type of equipment, and operational system is essential to successful maintenance. Advising on the types and suitability of the remedial action to be taken should be the responsibility of the surveillance agency.

Even with adequate maintenance, surveillance and quality control will at times reveal the need for corrective action. Some sanitary deficiencies may be easy to remedy, and it may be well within the capacity of the community to take the necessary action; others may require measures that would be costly or difficult for the community to take without external financial or technical support. It is the responsibility of the sanitary inspector to correctly determine the most appropriate body to take remedial action and the urgency with which it should be undertaken. The relative urgency of some typical preventive and remedial measures is shown in Table 6.1.

Where water quality is so poor that there is an immediate threat to public health, it may be necessary to recommend emergency precautions such as boiling drinking-water or to supply chlorine tablets for disinfection at household level. The water supplier or surveillance agency should ensure that remedial measures are promptly executed, and then carry out a bacteriological analysis of the supply to determine whether it is safe to use.

Water-supply agencies should systematically evaluate maintenance practices in order to pinpoint difficulties and find the most effective maintenance system. An overview of the principal maintenance requirements of different types of water-supply system is necessary to assist in the selection of equipment. Where users are directly responsible for their water supplies, there should be an adequate community-based management system based on local organizational structures and integrated into the institutional hierarchy of the water-supply agency.

6.2 Protecting water sources

If water supplies are to remain potable, both the source and the catchment need protection. A watershed that is used to supply untreated surface water should be sparsely inhabited and should consistently yield clean, clear water. Every effort should be made to site the abstraction point above sources of pollution; if this is not possible, appropriate forms of treatment must be applied (see section 6.6). An example of a sanitary inspection form for a simple, preliminary type of sanitary inspection of surface-water abstraction is given in Annex 2.

6.2.1 Catchment protection

A survey of the catchment area should reveal potential sources of contamination. Surface waters and groundwaters are both vulnerable. Whereas raw-water reservoirs may be protected from large-scale human activity, rivers may pass through heavily populated areas and be contaminated by both domestic and industrial discharges. Groundwaters may be contaminated by the seepage of industrial

Table 6.1 ***Preventive and remedial measures***

Source and mode of supply	Evidence or information available	Immediate remedial measures	Preventive action for avoiding recurrence
Untreated community rainwater collection systems	Localized epidemic of enteric infection	Chlorinate water in collection reservoir (tank, container, etc.) or recommend boiling or disinfection in the home	(a) Ensure that collection surfaces are in a sanitary condition and that bypass for initial collected water is properly operated (b) Promote community education and participation
Open dug wells	Findings of sanitary inspection unsatisfactory	(a) Clean well if necessary and shock-chlorinate, followed by continuous chlorination	Convert to a protected, covered well with hand-pump or device for raising water isolated from the user; discourage construction of new open dug wells; promote community education and participation
	Localized epidemic of enteric infection	(b) Recommend boiling of drinking-water, use of disinfectants and/or filters in the home	
Unpiped supplies from covered wells or shallow or deep tubewells with hand pumps or motorized pumps	Findings of sanitary inspection unsatisfactory	Confirm bacteriological quality and if necessary recommend boiling or use of disinfectant and/or filters in the home	Eliminate pollution sources and/or repair well if necessary to remedy shortcomings found in sanitary inspection.
	Localized epidemic of enteric infection	(a) If an alternative safe supply is not available, recommend boiling or use of disinfectants in the home (b) Confirm bacterial quality (c) Conduct a detailed sanitary inspection and remedy shortcomings found	(a) Take opportunity to promote community education and participation (b) Feed information on the episode and sanitary survey results back to the water-supply agencies to help in deciding whether the technologies used and the codes of practice are appropriate

Untreated piped supplies	Findings of sanitary inspection unsatisfactory	Confirm bacteriological quality and if necessary recommend boiling or use of disinfectant and/or filters in the home	Eliminate pollution sources and/or repair system if necessary to remedy shortcomings found in sanitary inspection
	Unsatisfactory bacteriological quality of water at source	(a) Chlorinate supply if feasible or recommend boiling or disinfection in the home (b) Conduct a detailed sanitary inspection and remedy shortcomings found	Protect the source and its catchment (this is very important)
	Unsatisfactory bacteriological quality of water in the distribution system	(a) If source is unsatisfactory, proceed as above (b) If source is unsatisfactory but distribution system is suspected, chlorinate supply or recommend boiling or disinfection in the home (c) Conduct a detailed inspection of distribution system and remedy shortcomings found	Frequent and improved supervision of the distribution system and prompt repair and maintenance are essential, especially for intermittently operated systems
	Localized epidemic of enteric infection	(a) Take sample for bacteriological quality determination; without waiting for this result, chlorinate general water supply or recommend boiling or disinfection in the home (b) Conduct a detailed sanitary inspection of source and distribution system, and remedy shortcomings found	Frequent and improved supervision of the source and distribution system is necessary; careful operation and maintenance of such systems are essential, especially for intermittent systems

Table 6.1 (continued)

Source and mode of supply	Evidence or information available	Immediate remedial measures	Preventive action for avoiding recurrence
Treated piped supervision supplies	Findings of sanitary inspection of source, treatment plant, and/or distribution system unsatisfactory	Confirm bacteriological quality and if necessary recommend boiling or use of disinfectant and/or filters in the home	(a) Frequent and improved of the whole system is necessary; careful operation and maintenance are essential for intermittent systems (b) Ensure that routine sanitary inspections are carried out (c) Feed information back to the water-supply agencies
	Unsatisfactory bacteriological quality of water after treatment or in the distribution system	(a) Ensure adequate chlorination of general supply or recommend boiling or disinfection in the home (b) Conduct a detailed sanitary inspection of the whole system and remedy shortcomings found	(a) Frequent and improved supervision of the whole system is necessary; careful operation and maintenance of such systems are essential, especially for intermittent systems (b) Ensure that routine sanitary inspections are carried out (c) Feed information back to the water-supply agencies
	Localized epidemic of enteric infection	(a) Take sample for bacteriological quality determination; without waiting for this result, chlorinate general supply or recommend boiling or disinfection in the home (b) Conduct a detailed sanitary inspection of source and distribution system, and remedy shortcomings found	(a) Frequent and improved supervision of the whole system is necessary; careful operation and maintenance of such systems are essential, especially for intermittent systems (b) Ensure that routine sanitary inspections are carried out (c) Feed information back to the water-supply agencies

wastes buried in the ground or in abandoned wells, and by chemicals discharged accidentally onto the land. Both surface waters and groundwaters are at risk from agricultural pollution in rural areas.

Where possible, protection zones should be clearly demarcated, and activities that may affect water quality should be restricted or prohibited within their boundaries. Such activities may include the dumping of toxic waste, the discharge of undesirable effluents, drilling, mining, quarrying, and the use of agricultural fertilizers and pesticides. Where restrictions are imposed, it is important to publicize the conditions under which normal activities, e.g. housing developments, farming, mining and manufacturing, are permitted within protection zones.

In some parts of the world, risk assessment of water sources and catchment areas is based on systems that take into consideration the hydrogeology, and the hydraulic loading of contaminants at and below the surface. Some governments are beginning to introduce legislation on groundwater protection zones under which housing, industrial and certain agricultural activities will be excluded from specified parts of catchment areas.

Water suppliers are beginning to recognize three protection zones for groundwater, as follows:

1. The area surrounding the source most at risk from contamination by pathogens. This is often the 50-day isochron (the area within which pathogens would reach the source in 50 days or less).
2. The area surrounding the source most at risk from chemical contamination. This will vary greatly and will depend on aquifer type and abstraction rate as well as on industrial and agricultural activity in the area.
3. The total catchment area.

The establishment of protection zones requires intersectoral agreements involving various authorities and ministries such as those concerned with health (surveillance), agriculture, forestry, housing, and environmental protection, as well as the water suppliers. The demarcation and acceptance of protection zones should be considered by governments of countries where groundwater accounts for a significant proportion of the water supply. For further information on the theoretical basis and practical application of groundwater protection zones, see p. 145, “Selected further reading”.

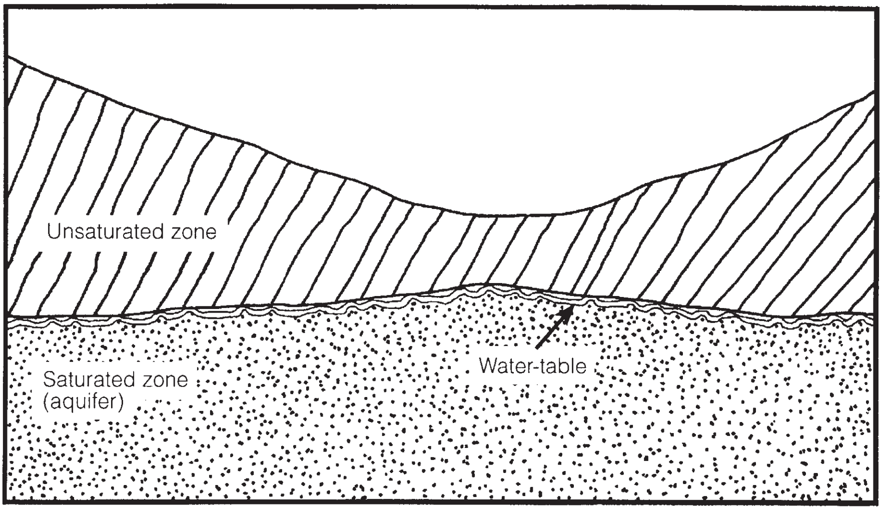
6.2.2 Groundwater protection

The most significant risk to human health related to drinking-water quality is from microbiological—particularly faecal—contamination. Health protection thus demands that sources of microbiological contamination are located sufficiently far from drinking-water sources as to minimize or eliminate the health risk.

When abstraction from a water source for human consumption is being considered, the minimum safe distance (MSD) for all potentially polluting activities should be fixed during the planning stage. Both surface and groundwater sources of drinking-water require protection. However, groundwater in its natural state is generally of good quality, and because subsurface water movement is relatively slow, it is usually easier to control sources of contamination of groundwater than it is for surface-water sources. For community supplies, the commonest sources of microbiological contamination are on-site sanitation and sewage-treatment facilities, open wells and other open surface sources of water (e.g. borrow pits), and concentrated animal husbandry.

The MSD should be determined from the time taken by contaminants to travel from their source to the source of drinking-water. This will depend on local conditions, the most important of which are the geological and hydrogeological conditions of the area, the quantity of faecal matter likely to be discharged, and the number of existing and planned sources of contamination. It is therefore very difficult to specify a universally applicable minimum distance between the location of, for instance, pit latrines and a water source. In an area where the aquifer is highly permeable and the overlying unsaturated zone (see Fig. 6.1) thin and permeable, the MSD for a latrine will be far greater than in an area where a relatively thick and impermeable unsaturated zone overlies an aquifer of relatively low permeability.

Fig. 6.1 Groundwater terminology



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In areas of fissured rock aquifers (where water is held in cracks and joints in the rock), the velocity of groundwater movement, and therefore of contaminants, will be high and must be taken into consideration when MSDs are set. This is particularly important for planning on-site sanitation where a thin, unsaturated zone of relatively low permeability overlies a fissured rock aquifer, e.g. in a karstic (weathered limestone) area. As the unsaturated zone is where the majority of microbial removal takes place, no direct source of contamination should come into contact with the water-table at its highest level.

The direction of flow of groundwater in an area will also influence the MSD. As a general rule, shallow groundwater movement reflects surface topography; sources of contamination should therefore be located downhill of drinking-water sources wherever possible.

The concentration of contaminating activities in the area concerned also affects the MSD and is particularly important where on-site sanitation or nonconventional sewage treatment is used. In areas where there are very large numbers of sources of microbiological contamination, such as low-income urban areas using on-site sanitation, there may be a build-up of nutrients in the unsaturated zone and, possibly, the aquifer. This may increase the survival time of microbes and so extend the MSD.

It is often difficult to obtain hydrogeological data in rural areas, and in community-based programmes it may not be possible to conduct thorough surveys in each area. An MSD can still be determined, however, although it may be less accurate than in other areas.

When MSDs for an area are being established, the information that will be required on the local soil and geology can be obtained by drilling or auguring to the water-table and carefully recording changes in soil and rock type, particularly changes in grain size, compaction, and the location of saturated layers. This information should then be recorded in the form of a log in which soil and rock type are plotted against depth. It is also important to carry out an infiltration test, which will give an indication of the permeability in the area. If the supply is to be a well, this can be done during test drilling (whether mechanical or by hand); where other groundwater sources, such as springs, are to be used, the infiltration test should be done in the surrounding area when the yield is tested.

Combining information from the log with data from the infiltration test will provide a good indication of the risk to the water source. Guidance on infiltration tests, infiltration rates in different types of rock, and corresponding MSDs is given in Annex 2.

Precise demarcation and enforcement of protection zones are not easy, especially where low-volume abstraction, for instance by means of hand-pumps, is practised. In these conditions, providing adequate sanitary protection of the water source and its immediate environment is likely to be easier and more effective. In much of this chapter, therefore, attention is focused mainly on the technical interventions that may be used to reduce or remove the sanitary hazards revealed by sanitary inspection on or close to the water-supply installation.

6.3 Wells

6.3.1 Dug wells

Open or poorly covered well heads pose the commonest risk to well-water quality, since the water may then be contaminated by the use of inappropriate water-lifting devices by consumers. The most serious source of pollution is contamination by human and animal waste from latrines, septic tanks, and farm manure, resulting in increased levels of microorganisms, including pathogens. Contamination of drinking-water by agrochemicals such as pesticides and nitrates is an additional and increasing problem for small-community supplies.

Dug wells are generally the worst groundwater sources in terms of faecal contamination, and bacteriological analysis serves primarily to demonstrate the intensity of contamination and hence the level of the risk to the consumer. As indicated in Annex 2, an on-site inspection can effectively reveal the most obvious sources of contamination, and can be used to promote well-head protection.

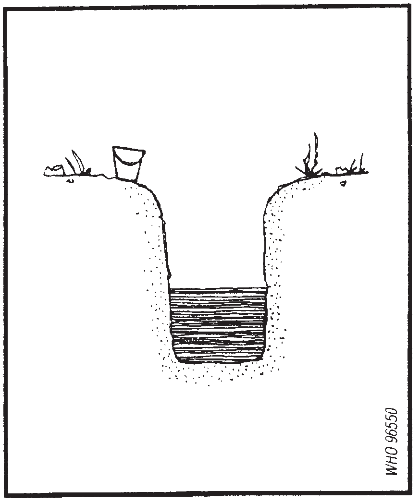
Various types of hand-dug wells are shown in Fig. 6.2, ranging from poorly protected to well protected; all types should be included by the surveillance agency in the inventory. The upgrading of unprotected wells and the construction of protected wells for community use should be strongly promoted.

Many tens of millions of families worldwide still depend on private and public dug wells; technical assessment and improvement of these wells is therefore very important. The commonest physical defects leading to faecal contamination of dug wells are associated with damage to, or lack of, a concrete plinth, and with breaks in the parapet wall and in the drainage channel. However, the most hazardous gross faecal contamination is most commonly associated with latrines sited too close to the well. Emergency relocation of either the latrines or the water source is essential when such serious problems are encountered.

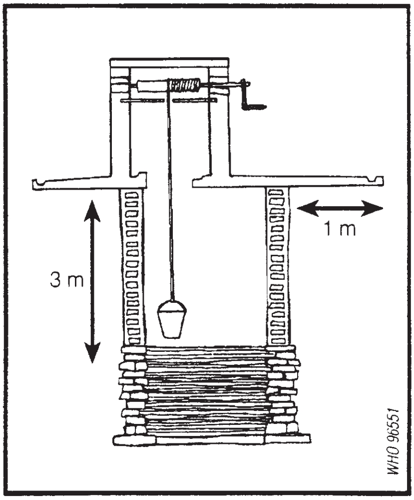
An open dug well is little better than an unprotected hole in the ground if the above-mentioned physical barriers to surface-water contamination are not regularly maintained. The majority of open dug wells are contaminated, with levels of at least 100 faecal coliforms per 100 ml, unless very strict measures are taken to ensure that contamination is not introduced by the bucket. A community dug well with a windlass whereby *one* bucket is suspended over the well in a narrow opening is an improvement on each individual using his or her own bucket.

Water quality should be greatly improved by the installation of a hand-pump and the fitting of a sanitary cover to an open dug well, access being restricted by a lockable sanitary lid, which prevents any contamination of the well by buckets. However, even this relatively costly improvement may fail to reduce contamination significantly unless the well lining is made watertight down to the dry-season water-table. If faecal contamination persists, the community may have to resort to pot chlorination (see section 6.6.11), but this requires considerable organization and management to be successful; effective physical protection of the source is generally preferred.

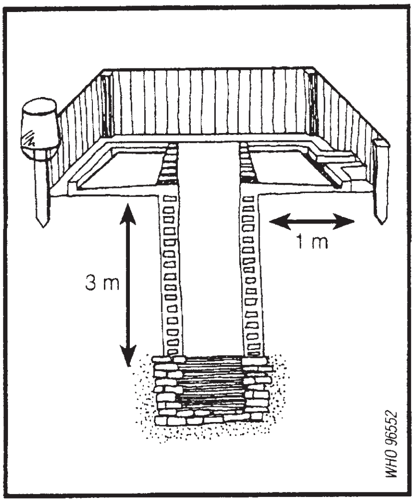
Fig. 6.2 Types of hand-dug wells



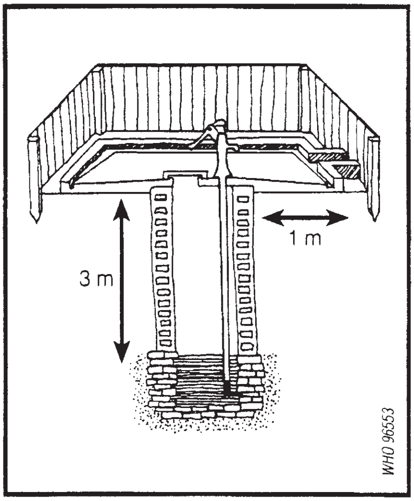
Unprotected waterhole



Dug well with windlass



Open dug well



Converted hand-pumped dug well

Occasionally the aquifer itself may be contaminated; in these circumstances the only option may be to routinely disinfect the groundwater source or resort to a deeper aquifer and mechanical pumping.

6.3.2 Hand-pumped and mechanically pumped wells

In about 85% of cases, shallow or deep tubewells with hand-pumps and proper sanitary protection will supply water that contains few, if any, faecal indicator bacteria. Where indicator bacteria are identified, the source of faecal contamination can usually be detected by an on-site sanitary survey at and around the well-head (except where the aquifer itself is contaminated). Detailed checklists (see Annex 2) for use in inspections have been drawn up for point-source supplies in rural areas. Sanitary inspections are a useful monitoring tool and are sometimes the only affordable means of identifying water sources at risk of contamination.

To ensure that the sanitary protection of a tubewell is adequate, a reinforced concrete plinth should be built on to the well-head; its diameter should be greater than that of the riser. The plinth should be sound and drained, and the hand-pump should be located and sealed in it in a sanitary manner above the surrounding plinth and ground level. A concrete apron should be laid around the well-head and plinth, at least 2 metres in diameter and sloped towards the drainage channel, which should run to a soakaway located away from the tubewell. Additional sanitary protection should be provided by fencing the well site to keep animals out.

The area immediately surrounding the tubewell should be managed in such a manner as to reduce the risk of contamination. Latrines should be located downhill from the well and a minimum of 10 metres away from it, sources of pollution, such as open dug wells, within 15–20 metres of the tubewell should be filled in, and animals should be kept at least 10 metres away. It is difficult to define protection zones for individual tubewells as the resources are rarely available for a full study of the properties of the aquifer or for comprehensive pumping tests.

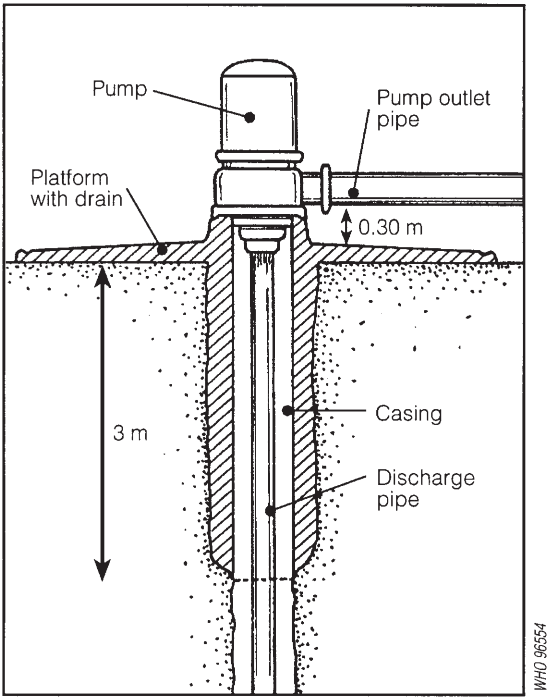
Tubewells sometimes show evidence of persistent contamination, even though sanitary inspection has revealed few local hazards. This may be the result of aquifer contamination, which is a particular problem where fissured geological strata are combined with thin top soil, and is on the increase, notably in urban and periurban areas. Under these conditions, it will be necessary either to disinfect the water supply continuously, or to locate a deeper aquifer, sink a deep borehole, and use mechanical pumping. Mechanical pumping from a deep borehole is a conventional technology more usually associated with urban settlements and developed countries because of the operation and maintenance requirements. The same principles of sanitary protection apply, and it is generally appropriate to define protection zones for the borehole because the output is much higher than that of a hand-pumped tubewell and can serve a greater population, the area of the aquifer exploited is correspondingly larger, and adequate resources are more likely to be available.

Drilling a borehole makes it possible to reach deep aquifers that are less likely to be affected by pollutants originating from the land or surface waters. Water from deep boreholes is normally free from microbiological contamination and may be used by small communities without further treatment. However, certain structural precautions are essential when wells and the associated pumps are installed. The pump casing should extend approximately 30 cm above ground and downwards to the parent rock. Concrete aprons and platforms should be constructed as for shallow wells, and the concrete sanitary seal should extend down into the space (annulus) between the casing and the excavation.

Figure 6.3 shows the sanitary protection below the pump of a deep borehole. A sanitary inspection form for this type of installation is shown in Annex 2.

Fig. 6.3 Sanitary protection of a deep borehole

Notes: The well casing extends down to the aquifer, but the concrete sanitary seal only to a depth of 3 m. The platform (plinth) drains away from the well.



6.4 Springs

If a spring is to be used as a source of domestic water:

- it should be of adequate capacity to provide the required quantity and quality of water for its intended use throughout the year;
- it should be protected to preserve its quality.

A spring encasement consists of the following features (see Fig. 6.4 and Annex 2):

- spring box (watertight tank), which intercepts the source and extends downwards to an impermeable layer, or a system of collection pipes and a storage tank;
- a cover that prevents the entrance of surface drainage or debris into the storage tank;
- a protected overflow outlet;
- a connection to the distribution system or auxiliary supply;
- an impermeable layer (e.g. of concrete or puddled clay) behind the box and above the eye of the spring to prevent the infiltration of contaminants.

Provision must be made for the cleaning of the tank and the emptying of the contents.

Exposed springs are vulnerable to contamination from human and animal activities (see Figs 6.5 and 6.6). The usual method of protecting springs is to collect the water where it rises by enclosing the eye of the spring in a covered

Fig. 6.4 Protected gravity spring

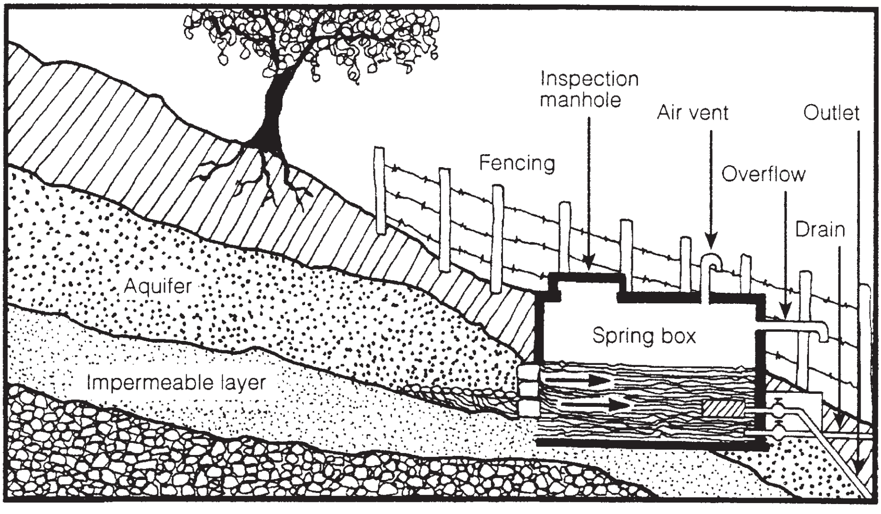


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Fig. 6.5 Unprotected gravity spring

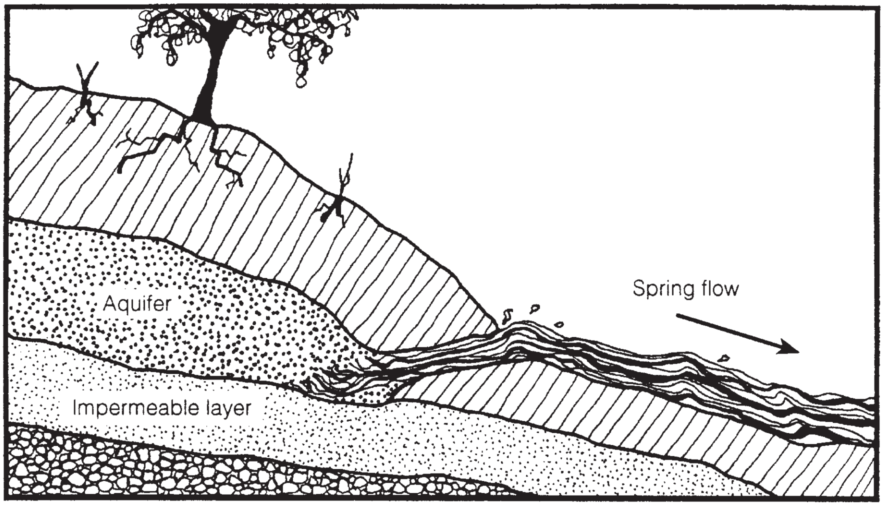

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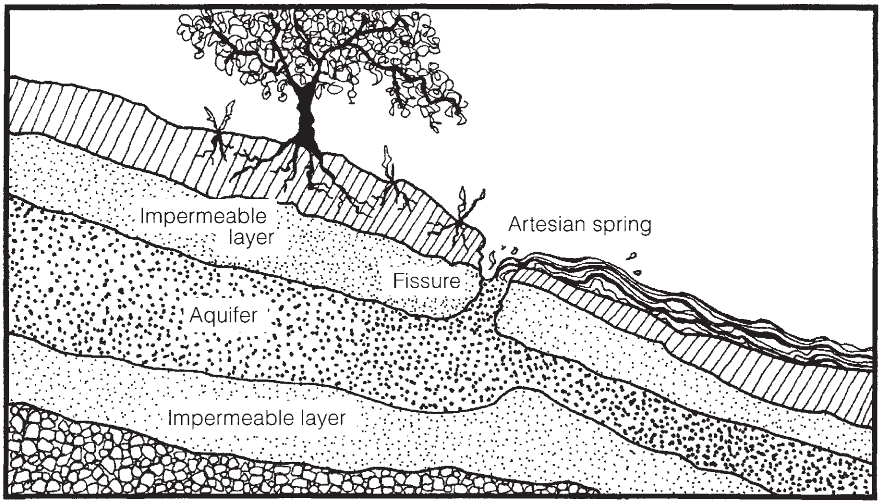
Fig. 6.6 Unprotected artesian spring



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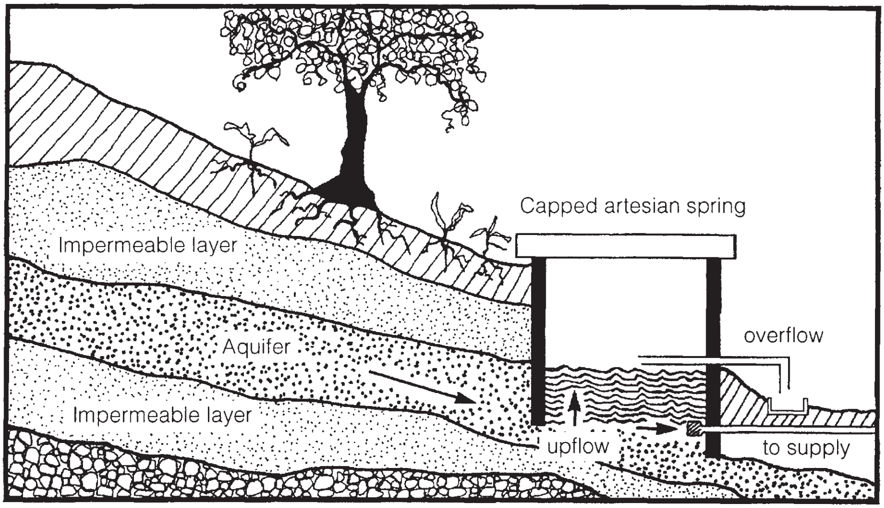
chamber or box with an outlet near the bottom to allow water to flow away from the original site of the spring; in this way the natural spring is disturbed as little as possible. The exact procedure will depend on the type and site of the spring (see Figs 6.4 and 6.7). The hillside must be excavated to a sufficient depth to tap

Fig. 6.7 Protected artesian spring



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the aquifer even when the water level is low and, for a protected gravity spring, to ensure that the collected water does not exert a back-pressure on the eye of the spring. The intake structure should be designed, and the excavated area backfilled with graded gravel, to prevent the inflow of sand and silt with the water into the spring box; this will form the back wall of a gravity spring and the floor of an artesian spring. The intake and gravel backfill should be covered by an impermeable cap (of concrete or puddled clay for example) to prevent surface-water infiltration. To ensure that the collected water is not contaminated, an adequate conduction pipeline and storage tank, if required, should be provided. The spring box should have a lockable inspection cover. Air vents, drains, and overflows should be fitted with mesh screens, and the whole structure surrounded by a ditch to divert surface water (Fig. 6.4). A full sanitary inspection checklist is given in Annex 2.

Springs usually become contaminated when barnyards, sewers, septic tanks, cesspools, or other sources of pollution are located on higher adjacent land. In limestone formations, however, contaminated material frequently enters the water-bearing channels through sink holes or other large openings and may be carried along with groundwater for long distances. Similarly, if material from such sources of contamination enters the tubular channels in glacial drift, water may remain contaminated even after travelling for long distances.

The following precautionary measures will help to ensure that spring water is of a consistently high quality:

- Providing for removal of surface drainage from the site. A surface drainage ditch should be located uphill from the source so as to intercept surface-water runoff and carry it away from the source. The location of the ditch and the points at which the water should be discharged are a matter of judgement, based on factors such as topography, subsurface geology, land ownership, and land use.

- Constructing a fence to prevent the entry of livestock. The location of the fence should be selected in the light of the considerations mentioned above. The fence should exclude livestock from the surface-water drainage system at all points uphill of the source.
- Providing for access to the tank for maintenance; unauthorized removal of the cover should be prevented by fitting a suitable locking device.
- Designing the cover in such a way as to prevent contamination from entering the storage tank.
- Monitoring the quality of the spring water by means of periodic checks for contamination. A marked increase in turbidity or flow immediately after a rainstorm is a good indication that surface runoff is reaching the spring.

Water from a protected spring may be supplied to small communities either directly or via a distribution system. Such systems may not be disinfected because the water is bacteriologically safe and chlorination is expensive. Where spring-fed water supplies do require disinfection, either because it is mandatory under local legislation or because of inadequate quality, this is generally done on a continuous basis: chlorine is added either as the water enters the conduction pipe from the spring box, or as it leaves a storage tank to enter the distribution network.

Artesian springs should be protected by a box with walls extending above the maximum static head; a strong sanitary cover should also be provided. To conserve water and increase the productivity of an artesian well, the casing must be sealed into the confining stratum, otherwise water may be lost through leakage into lower-pressure permeable strata at higher elevations. A flowing artesian well should be designed so that the movement of water from the aquifer can be controlled; water can be conserved if the well is equipped with a valve or shut-off device. When the recharge area and aquifer are large, and only a small number of wells penetrate the aquifer, the flowing artesian well produces a fairly steady flow of water throughout the year.

6.5 Rainwater catchment

Rainwater collected from clean house roofs can be of better microbiological quality than water collected from untreated household wells. When rain falls after a long dry period, however, any rainwater collected may carry with it significant amounts of contamination and debris which have accumulated on the roof and in the gutters. It is therefore recommended that the water running off the roof after the first storms of the season, and preferably for the first 5–10 minutes afterwards or until it runs clear, should be discarded or used for purposes other than drinking. Various devices are available for diverting this initial flow to waste or secondary uses.

The quality of the collected rainwater can also be improved by proper maintenance of the roof and gutters, and careful cleaning at the beginning of every wet season. Some form of mesh should be placed between the guttering and the downpipe to prevent the entry of coarse debris; it then becomes important to clean the screen regularly to prevent blockage. The worst fouling of roofs occurs when they are situated under trees in which birds roost. In areas where malaria is endemic, care should be taken to avoid creating pools of water that could become breeding sites for mosquitos.

A rainwater storage tank should be completely covered and well maintained. If the cover is inadequate, lizards and geckos will enter and produce elevated thermotolerant (faecal) coliform counts. A fine mesh fitted to all openings to the tank will prevent the entry of organic debris. Water should be drawn off by a tap located a little above the base of the tank. A sanitary inspection checklist for rainwater tanks is given in Annex 2.

6.6 Water treatment

For small communities, it is generally preferable to protect a groundwater source that requires little or no treatment than to treat surface water that has been exposed to faecal contamination and is usually of poor quality. In many circumstances, however, surface water is the only practicable source of supply and requires affordable treatment and disinfection. The range of treatments available for small-community supplies is necessarily limited by technical and financial considerations; the most appropriate and commonly used treatments are summarized below. Installation of packaged treatment plants is not a suitable means of dealing with the typical water-quality problems that prevail in rural areas.

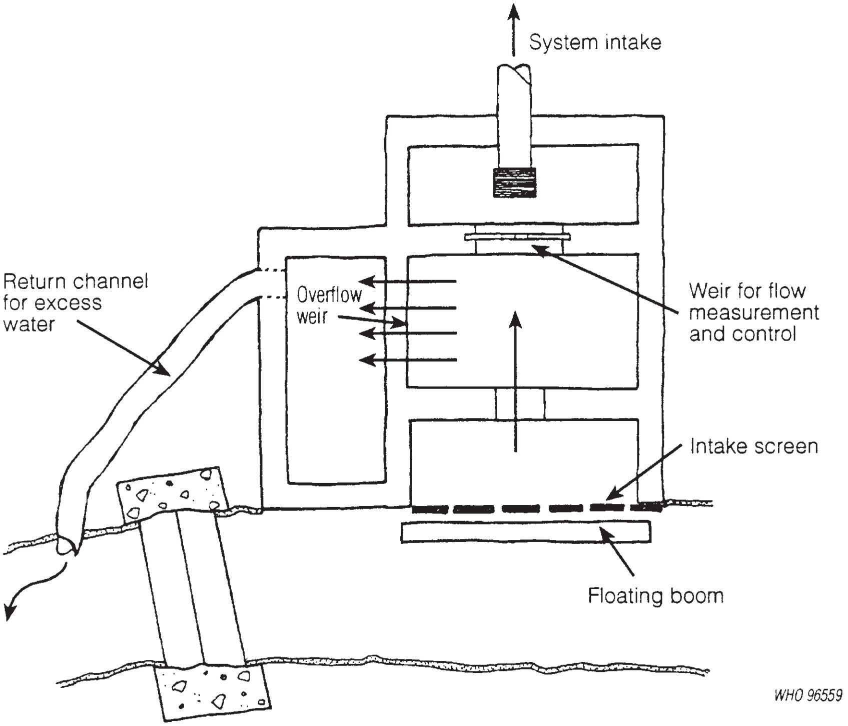
6.6.1 Abstraction

The control measures required at the point of abstraction are determined to a large extent by the characteristics of the source water and the particular water-treatment method adopted. Screens are necessary where floating or large suspended solids are present in the source water; these will require periodic cleaning. Properly constructed intake channels or side weirs can be used to provide regular lateral intake flows from a surface-water source. Sluice-gates and valves offer a means of controlling flow but require regular maintenance and adjustment.

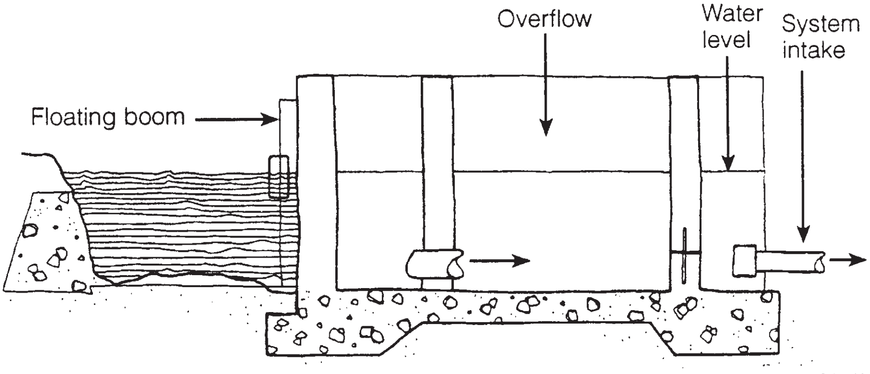
When upstream flow depths are controlled by properly constructed overflows, use of weirs will provide relatively fine flow control with a minimum of attention. For community supplies, the “V” notch angle required may be 45°, instead of the more common 90°, to enable a reasonable upstream depth to be achieved.

Many of the major problems of community surface-water supply begin at the point of abstraction; the following are the most common (see also Fig. 6.8 and Annex 2).

Fig. 6.8 Surface water intake



A. Plan view



B. Cross-section

- There is no weir across the stream or river, and at times of low flow there is insufficient water to supply the community.
- There is no intake screen and consequently the intake is often blocked; this either causes interruptions in supply or allows large debris to pass on to the treatment plant.
- There is no floating boom at the intake, and floating substances (oils, fats) therefore pass on to the treatment plant.
- There is no flow control or the flow control is inappropriate or lacks an overflow.

6.6.2 Preliminary treatment by storage

Preliminary storage in a reservoir helps to guarantee a continuous supply of water despite variations in demand and in source-water availability. It can also provide an economical means of settling out some of the suspended solids.

In areas affected by schistosomiasis, protected storage for a minimum of 48 hours provides a degree of safety: the cercariae are unable to infect a host and will die. The numbers of other organisms can also be reduced in this way. If longer retention times can be achieved, the numbers of microorganisms can be significantly reduced, although this often requires storage for more than a week. However, prolonged storage in uncovered reservoirs can encourage algal growth and mosquito breeding. If the required storage volume is such that it is not practicable to construct a covered reservoir, efforts must be made to avoid the creation of habitats suitable for mosquitos, snails, or other organisms associated with disease in the surrounding communities.

6.6.3 Plain sedimentation

Surface waters may contain sand, grit, silt, and other suspended solids which can damage pumps, block filters, clog pipes and reduce the effectiveness of disinfection. Sedimentation helps to reduce suspended solids before treatment by filtration and can remove significant numbers of harmful organisms from polluted water. Fine silt or clay particles, however, are unlikely to be removed to any significant extent in a sedimentation tank without the use of chemical coagulation (see section 6.6.6).

Grit or coarse suspended solids can be removed in a grit tank or channel (coarse sedimentation tank) with a throughput velocity of less than 0.75 m/s and a retention time of a few minutes. The amount of finer suspended matter can be reduced by passing the water slowly through a settler or sedimenter (sedimentation tank), allowing time for it to settle out. Inlet, outlet, and internal baffle arrangements should be designed to maximize the retention time in the tank. The baffles should also assist in creating a regular flow pattern, without turbulence, throughout the tank. Construction of the sedimentation tank must be such as to permit routine desludging and cleaning operations to be carried out. The retention time in a sedimentation tank is usually significantly shorter than that for a storage reservoir, typically a few hours.

The principal problems of plain sedimenters, which can lead to poor water quality, are:

- Short-circuiting of the flow because of the absence or poor design of baffles.
- Poor maintenance, leading to the accumulation of excessive amounts of sludge and consequent carry-over. A suitable design is shown in Fig. 6.9, which also indicates the key points to be checked during sanitary inspection.

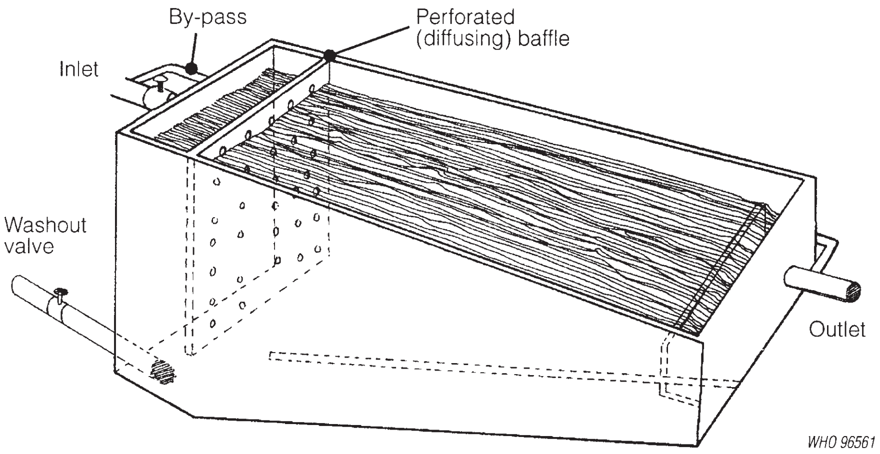
To ensure effective operation:

- The inlet baffle wall of the sedimentation tank should be perforated so that water is introduced uniformly across the entire cross-section of the tank and rapid transit across the surface of the tank is avoided.
- The floor of the sedimenter should slope towards a sludge channel, which should in turn slope towards the washout valve. It is important to ensure that:
  - — the washout valve is of large diameter so that drainage is rapid;
  - — the valve is functional and greased;
  - — the floor of the tank is relatively clean after washout.

The effectiveness of the sedimenter should be assessed by the following means:

- Checking the turbidity at the inlet and outlet. As a guideline, an ineffective sedimenter may reduce turbidity by less than 50% but an efficient one can achieve up to 90% reduction.
- Checking the retention time. This is done by introducing sufficient salt at the inlet to increase the conductivity of a "plug" of water. The time taken for the

Fig. 6.9 Plain sedimentation tank



> increased conductivity to be measurable at the outlet is measured, and a curve is plotted of conductivity at the outlet against time. In a well designed sedimenter, the increase in conductivity at the outlet should occur at least 2 hours after the salt was introduced at the inlet. A minimum retention time of 2 hours is essential for most types of water if removal efficiencies of greater than 50% are to be achieved.

A by-pass pipe around the sedimenter is essential to ensure continuity of flow during maintenance.

6.6.4 Prefiltration

In small treatment plants where the suspended solids content and turbidity of the source water are continuously or periodically high, prefiltration with gravel or other coarse material before sand filtration is an effective means of preventing the rapid blocking of the sand filters. A typical prefilter consists of a tank divided into several compartments filled sequentially with material of sizes ranging from very coarse, e.g. 50-mm pebbles, in the upstream compartment to fine, e.g. gravel 6–10 mm in diameter, in the downstream compartment. Raw water is passed vertically or horizontally through the different compartments and is then collected in an outlet chamber. If vertical flow is chosen, either upflow or downflow is possible, but upflow filters are easier to clean and thus more likely to operate effectively.

Typical filtration rates for three-stage gravel prefilters are in the range 0.5–1 m^3/m^2 per hour. The lower loading is appropriate for raw waters of periodically high turbidity (in excess of 80 NTU). In well operated prefilters, suspended solids, turbidity, and microbiological contamination can be significantly reduced. Prefilters require a "running-in" or ripening period, which may be of several months' duration for raw waters with low nutrient levels, before they reach peak operating efficiency. Care should be taken to cover the chambers or to keep water levels below the top of the gravel fill; this not only prevents birds and other animals from being attracted to the installation and fouling the prefilter, but also prevents algal growth.

In vertical upflow or downflow prefilters, periodic cleaning can be carried out by means of a high-capacity drain assembly that can be opened to allow a full filter to discharge rapidly to a waste channel. Horizontal-flow prefilters may also be cleaned in the same manner but this is less effective and the filters must periodically be emptied of gravel for cleaning; such prefilters are less cost-effective.

Prefilters will produce significant improvements in water quality when correctly designed and operated. They are particularly useful for small surface supplies when slow sand filters are overloaded with silt, and they can be managed by community caretakers if adequate support is provided by the water-supply agency. During a sanitary inspection of a prefilter the following are the principal points that should be checked:

- Is the turbidity of the water leaving the prefilter less than 60 NTU?
- Is the flow rate of water through the filter medium controlled and appropriate for local conditions (e.g. in the range 0.5–1 m^3/m^2 per hour)?
- Is the effectiveness of turbidity removal by the prefilter in the range 70–90% when turbidity is greater than 100 NTU?
- Is the prefilter routinely cleaned?
- Is the cleaning effective? (This may be checked by taking a sample of gravel and estimating the amount of silt present by sieve analysis.)
- Are the filter and filtrate protected from recontamination by animals and birds?

A vertical upflow gravel prefilter is shown in Fig. 6.10.

6.6.5 Slow sand filtration

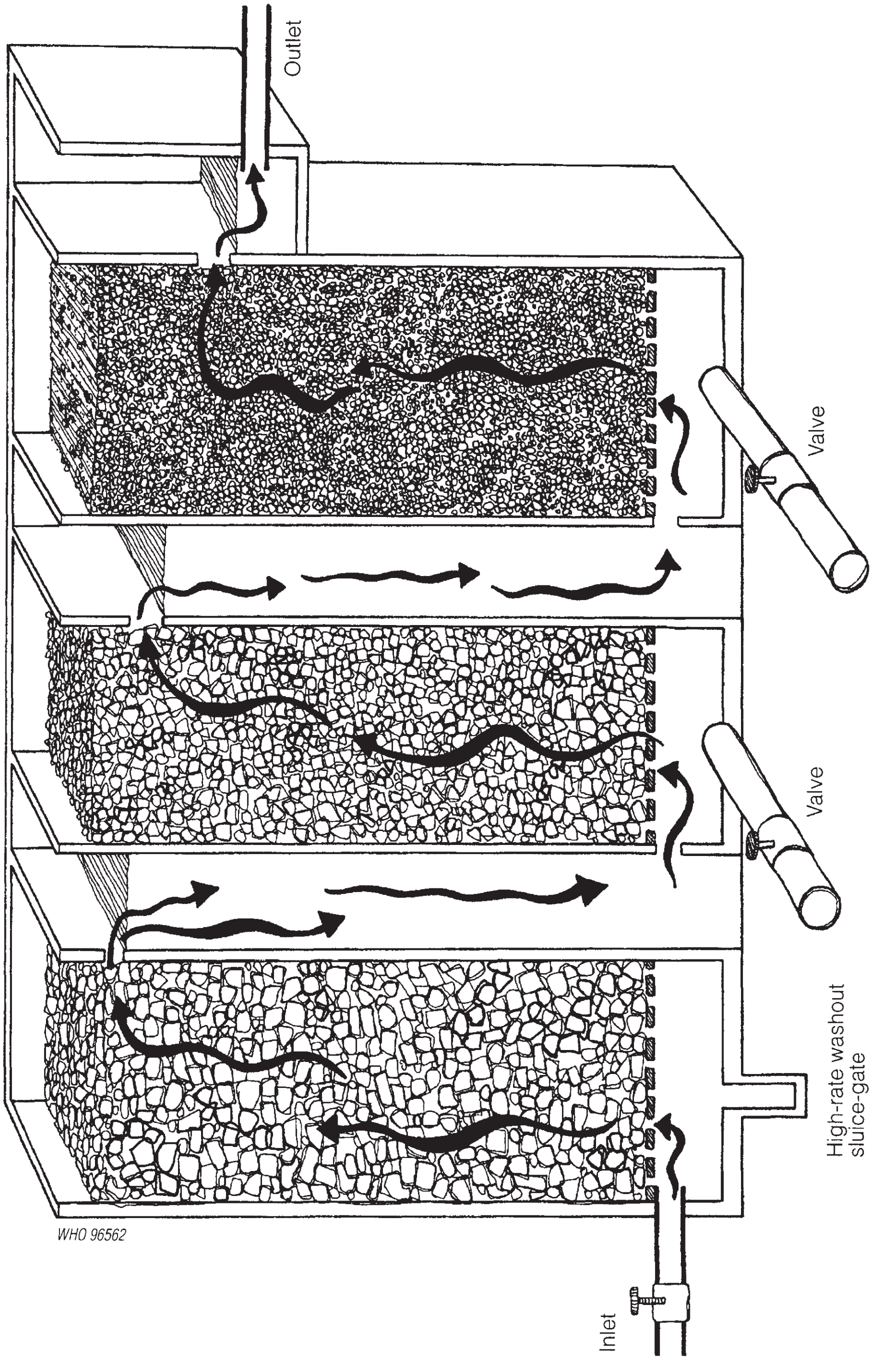
Slow sand filtration improves the physical, chemical, and microbiological quality of water; it is reliable and inexpensive, and is therefore particularly useful in small-community water supplies.

Slow sand filters consist of a bed of sand overlying a gravel support layer and an underdrainage system. The depth of the sand filter bed is typically in the range 0.5–1.2 m, varying as the sand is skimmed off from time to time to prevent blocking on the upper surface. A sand bed depth of 0.5 m should be considered the absolute minimum to ensure adequate treatment. When a bed has been skimmed down to this depth it should be reconstructed using clean sand. The sand skimmed from the top of the bed is generally used again after it has been washed. The sand filter bed is submerged beneath supernatant (influent water) to a depth of approximately 0.6–1.5 m. Where possible, slow sand filters should be covered for protection from sunlight, which can promote the growth of algae. Covers can also reduce the risk of fouling by birds and animals and (in cold climates) of freezing.

Slow sand filters are generally operated with filtration rates in the range 0.1–0.3 m^3/m^2 per hour and require a much larger area than a rapid gravity filter of similar capacity. Filter sand should have a medium to coarse grading; sands containing appreciable amounts of fine particles will be quickly blocked by suspended solids in the influent flow. It is generally necessary to wash sand before using it in a slow sand filter.

The most significant feature of slow sand filtration is that the purification of the influent is effected by microbiological means. A thin, slimy mat, known as the *schmutzdecke* or filter skin, forms on the upper surface of the filter bed; this is largely organic in character and biologically extremely active. Microorganisms in the influent water are trapped and digested in the *schmutzdecke*, and are thus significantly reduced in number. Water percolating downwards passes through a biologically active zone of depth approximately 0.3–0.4 m. Fine particles are trapped on the sand grains, where microorganisms consume organic material,

Fig. 6.10 Vertical upflow gravel prefilter



including pathogens in the influent and one another (predation). The overall effect is a substantial reduction in the number of indicator bacteria and pathogenic microorganisms in the water. In a well operated filter, the efficiency of pathogen removal may exceed 99%. The efficiency of slow sand filtration may be appreciably reduced at water temperatures below 6 °C.

After a slow sand filter is cleaned, it takes some time before the *schmutzdecke* is reestablished; with high-nutrient influent it may be a few days, but this may extend to a few weeks if the nutrient content is low. During this time, water should be allowed to flow through the filter, but it should not—ideally—be supplied to consumers. Where possible, two slow sand filters should be constructed, so that one can continue to operate while the other is being cleaned.

Slow sand filters should be operated at a constant flow rate and must never be allowed to dry out during a filtration run. Raw-water turbidity should not exceed 60 NTU for more than a few hours, since this leads to rapid blockage and consequent inefficiency in operation. Thus the efficient functioning of slow sand filters often depends on the filters being protected from high raw-water turbidities, e.g. by means of prefilters.

A typical slow sand filter design is shown in Fig. 6.11. The level of the water outlet from the filter is higher than that of the sand bed in order to avoid accidental drying of the bed due, for example, to an interruption in the source flow. Drying of the bed will rapidly kill the organisms responsible for purification.

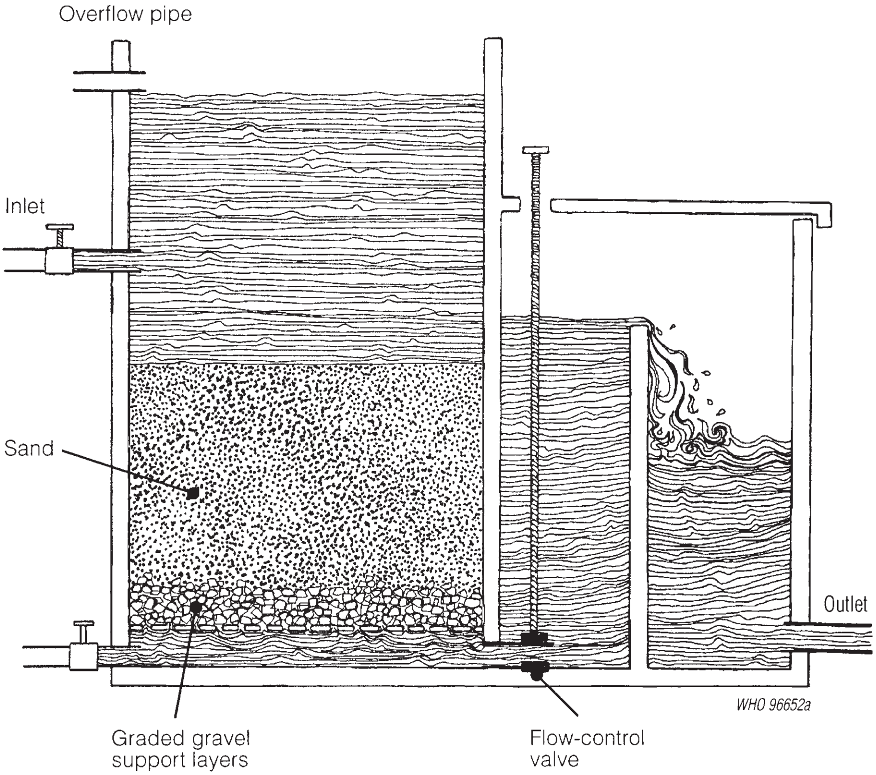
Sanitary inspection of slow sand filters should check the following principal points:

- Is the turbidity of the filtered water less than 5 NTU?
- Is the flow rate of the water through the sand filter in the range 0.1–0.3 m^3/m^2 per hour and is it constant?
- Is the turbidity of the water entering the slow sand filter consistently less than 60 NTU?
- Is the slow sand filter skimmed when necessary?
- Is the depth of the sand in the filter bed greater than 0.5 m?
- Is the skimmed sand washed and stored in a sand store?
- Is a minimum head device installed and does it prevent drying of the bed if the source flow is interrupted?

6.6.6 Coagulation, flocculation, and sedimentation

Fine suspended particles may be removed from water by dosing with chemicals that cause formation of an absorbent, bulky precipitate. These chemicals are known as coagulants and react with suspended particles to produce settleable flocs. Most coagulants are salts of iron or aluminium, e.g. aluminium sulfate (alum) and ferric chloride. The nature of the floc depends mainly on the characteristics of the raw water, the type of coagulant employed, and the dosing rate. Rapid mixing is essential as soon as the coagulants are added to the water. After

Fig. 6.11 Slow sand filter

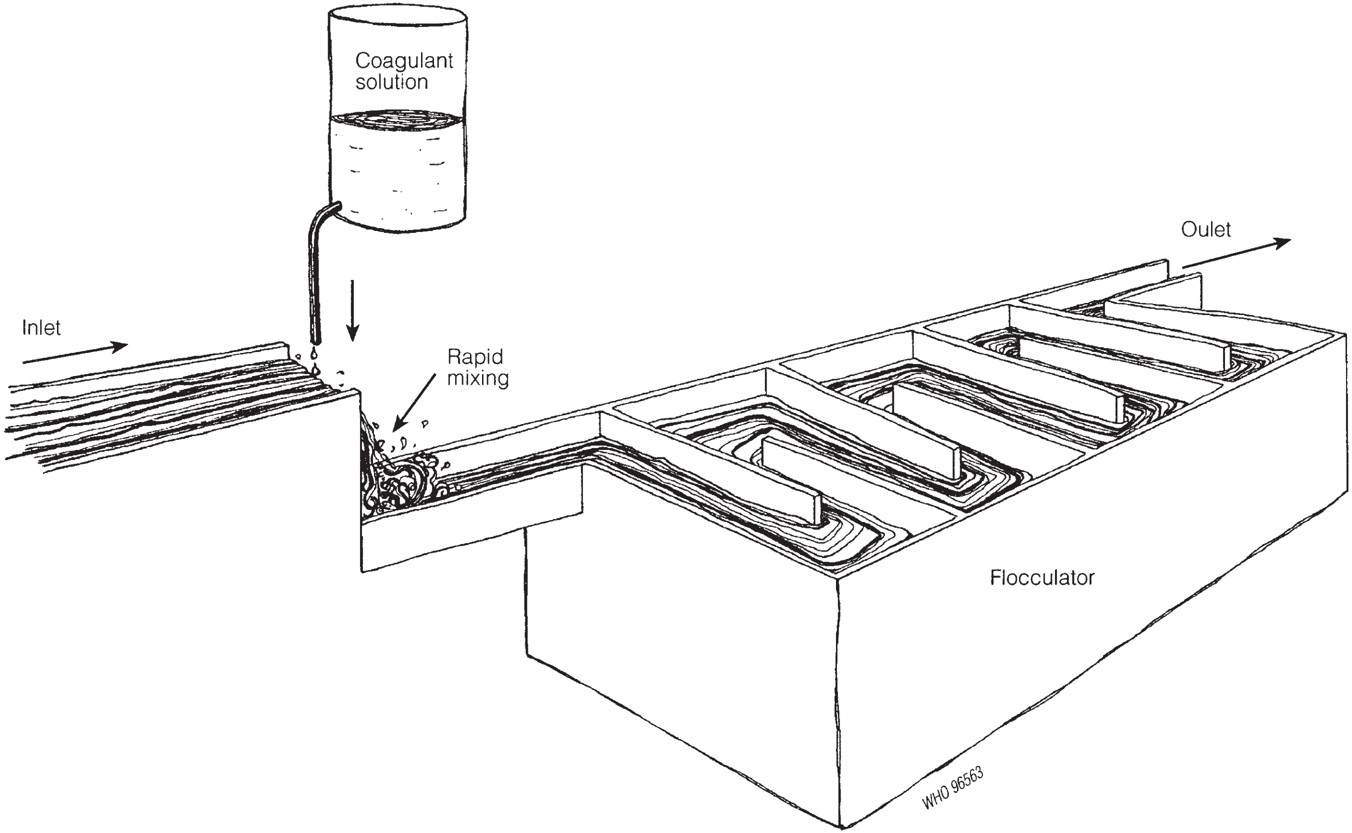


mixing, microflocs start to form which, following a suitable period in a flocculator, aggregate into settleable and filterable macroflocs. These are removed by secondary sedimentation in a clarifier, by filtration or by a combination of both processes in series. The heavier the precipitate or floc, the quicker will be its rate of settlement.

Coagulants are generally added downstream of any pretreatment such as screening or prefiltration that is designed to remove larger particles from the source water. This then allows the coagulant to act more efficiently on the finer particles.

The coagulation, mixing, and flocculation tank generally takes the form of a rectangular basin, the water flowing horizontally from one end of the tank to the other. Floc settles in the lower levels of the tank, and a high-level outlet or weir takes off the clear water (Fig. 6.12). Removal of the floc from the lower levels of the tank may be effected by means of drains. Some clarifiers are constructed in the form of an inverted pyramid, the water entering at the base and flowing upwards

Fig. 6.12 **Coagulation, mixing, and flocculation tank**



through the ever-widening tank with steadily decreasing velocity. A “sludge blanket” forms at a position where the upward force of the flow balances the downward force exerted on the floc by gravity. Clear water continues upwards, to be taken off by high-level outlets; the accumulating sludge must be “bled off” continuously to maintain the sludge blanket.

The physicochemical characteristics of the raw water determine the choice and quantity of coagulant required. These characteristics may vary with the season so that periodic adjustment of coagulant dose may be required. The problem most commonly encountered in coagulant treatment is incorrect choice of dosing rate. It is therefore essential to carry out regular jar tests to determine the optimum dose, taking into account fluctuations in turbidity or suspended solids loadings, and any other relevant factors. Quality-control procedures should also include the routine monitoring of turbidity and pH. The type and dose of coagulant can usually be determined only by experimentation in the laboratory.

During sanitary inspection, stocks of chemicals should be checked to ensure that they are safely and correctly stored, properly dispensed, used in rotation, and recorded in an inventory.

Coagulation and flocculation require relatively large financial outlay on plant, tanks, chemical dosing, and maintenance. Inevitably, therefore, the cost of any water treated in this way is high. The technique may be of some value to certain small communities, such as periurban fringe settlements, which can be easily reached by maintenance personnel from the water supplier. Coagulation may also be useful in helping to remove some chemical contaminants such as fluoride. Generally, however, the technique is too difficult to apply and control satisfactorily in most isolated rural communities.

A sanitary inspection check list is included in Annex 2.

6.6.7 Rapid sand filtration

In large treatment works, rapid sand filtration is frequently used after coagulation–flocculation–sedimentation and before disinfection. It may also be used as a prefiltration step before large-scale slow sand filtration. Rapid filtration can be carried out in open tanks (rapid gravity sand filters) or closed metal tanks through which the water passes under pressure (pressure filters). Rapid gravity filters usually operate at filtration rates considerably higher than those typical of slow sand filtration (about 4.0–5.0 m^3/m^2 filter area per hour). As a consequence, the filters are considerably smaller in area for a similar throughput capacity. Coarse sand is generally used in rapid gravity filters; multimedia filters (containing e.g. very coarse anthracite particles above coarse sand) have been employed where it has been necessary to protect against blocking of the surface of the filter by straining. Rapid gravity filter beds are generally 0.6–1.0 m in depth with typical particle diameters in the range 0.4–1.0 mm.

Microbial removal rates in rapid gravity filters are low, but suspended solids are removed quite efficiently. Filters are quickly blocked by surface straining or excessive sedimentation in their upper layers. Cleaning must therefore be carried out regularly (typically daily), and involves vigorous backwashing with water, sometimes in combination with compressed air scour. When rapid gravity filters are overloaded, breakthrough can occur within a very short time because of the coarse nature of the media employed. If overloading is a problem, an increase in backwashing frequency or plant capacity will be required. Mudballing and cracking can occur in the filter bed if routine cleaning is not carried out in a proper and effective manner.

6.6.8 Aeration

Aeration can be used in water treatment to reduce tastes and odours (e.g. by oxidation of hydrogen sulfide), lower the levels of volatile organics, and alter the concentrations of dissolved gases, although it has little appreciable effect on those associated with algal growth. The aerators best suited for use in community supplies are the cascade, multiple-tray, and packed-bed types, in which a thin film of water flows over surfaces to maximize oxygen transfer into the water from the surrounding air.

Cascade aerator

A cascade aerator consists of a stairway over which water flows in a very thin film. Typically, the width and depth of each step is 10–15 cm and the height 1–4 m; the head requirement for larger cascades can be a major design problem if pumping is to be avoided.

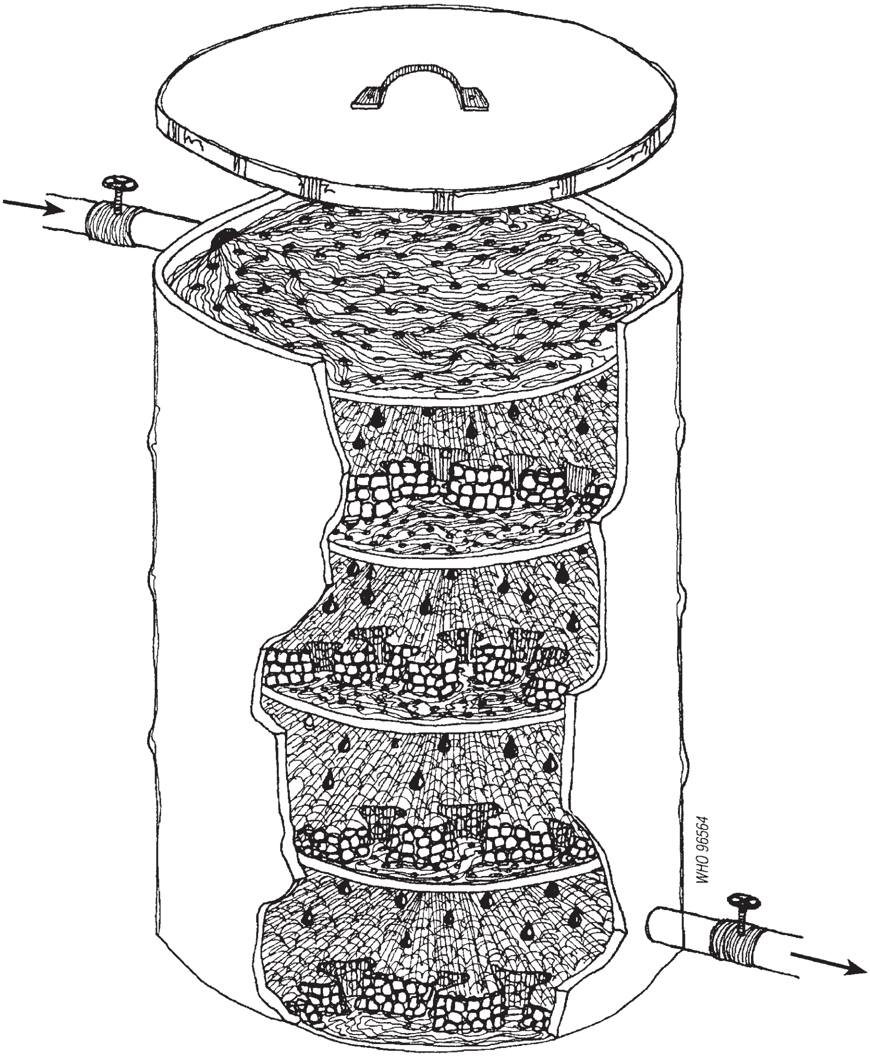
Multiple-tray aerator

A multiple-tray aerator (see Fig. 6.13) comprises a series of trays formed by perforated metal plates, metal screens, or wooden slats, arranged vertically above one another in the form of a small tower. The individual trays contain a layer 15–30 cm deep of stone, coke, or fired-clay material 5–15 cm in size. Water is delivered to the top of the multiple-tray assembly where it is either sprayed or sprinkled from a perforated tank onto the top tray. Appropriate loading rates should be determined by pilot plant trials, as the characteristics of water can vary from one site to another and may also be subject to seasonal changes. Typical loading rates are in the range 0.25–10 m^3/m^2 of total effective tray area per hour.

Air passes through the media, and open louvres are often inserted between the trays to maximize the flow. In some extreme circumstances, mechanical forced-draught ventilation may be employed to maintain the highest possible rate of aeration in a particular installation. Performance can be badly affected by ice formation during periods of freezing weather.

Apart from aeration, multiple-tray aerators can also be used to remove the iron present in some waters.

Fig. 6.13 Multiple-tray aerator



Packed-bed aerators

A packed-bed aerator consists of a tower containing fired-clay, ceramic, plastic, stone, or coke media of particle size 5–15 cm and is generally used to strip volatile organics from the water stream. Specialized media are available, including ceramic cylinders or plastic in various shapes. Forced ventilation is required, and the performance must be determined in a pilot plant before a full-scale installation is constructed.

If the source water is rich in metals (some groundwaters contain iron, for example), concentrations above 0.3 mg/litre may produce detectable taste and odour. Furthermore, water containing iron may cause stains when used for laundry, accumulations of iron precipitates in the pipework of the distribution system, and the growth of *Crenothrix* bacteria. Packed-bed aerators can be used to remove iron, which is deposited on the media. Manganese removal is more difficult to accomplish and must be carried out at a pH greater than 9, and combinations of metals can also be difficult to remove. The addition of strong oxidizing agents, such as chlorine, ozone, or potassium permanganate, can assist in the deposition process.

As with multiple-tray aerators, the performance of packed-bed aerators can be badly affected by ice formation if periods of freezing weather are experienced.

6.6.9 Fluoride removal

Fluoride can occur naturally or may be added to drinking-water during treatment. A fluoride concentration of around 1 mg/litre can help to reduce the incidence of tooth decay, but concentrations above 1.5 mg/litre may cause browning of teeth; very high concentrations may cause skeletal fluorosis.

High fluoride levels, for example in groundwaters, are locally common in some areas of the world, and in most such circumstances it may be more practical and cost-effective to use alternative water sources. However, fluoride can be removed from water by filtering through bone char, which can subsequently be regenerated, and this approach has been adopted for some small-community water supplies.

Addition of fluoride to drinking-water supplies to reduce the incidence of dental caries should be closely monitored to ensure that safe levels are not exceeded. The fluoride is generally added in the form of a solution, both for convenience and because powders are toxic and require special handling arrangements. Hydrofluosilicic acid provides a suitable solution for this purpose, although the normal precautions required in the handling of acids must then be taken and appropriate equipment is required.

6.6.10 Control of nitrites and nitrates

The presence of either nitrites or nitrates in drinking-water is a matter of concern from the point of view of human health, since there is evidence that they may cause methaemoglobinaemia in infants. Nitrites and nitrates are present in surface waters mainly as a result of the oxidation of ammonia in sewage effluents and the excessive use of nitrate fertilizers in farming. Nitrite can occur as an intermediate stage in the oxidation of nitrogen to nitrate. Nitrates in groundwaters are often reduced to nitrites.

Algal assimilation can significantly reduce nitrate levels in surface waters. Seasonal variations in nitrate levels in rivers and streams are likely to occur for reasons associated with changes in the overall levels of biological activity in the water.

There is no water treatment method for reducing nitrite and nitrate levels that is both convenient and generally appropriate for small-community water supplies. Consideration should therefore be given to the protection of water sources, particularly where the principal sources of contamination are the agricultural use of fertilizers or wastewater and sewage discharges. If seasonally high levels are experienced in a river source, it may be possible to blend water from lake or groundwater sources with the surface water to achieve the required quality. Bankside reservoir storage can provide an opportunity to close intakes when high peaks in river nitrate levels are expected. Algal activity in reservoirs can reduce nitrate levels significantly, aided by the denitrifying activities of bacteria in the bottom silt layer.

6.6.11 Disinfection

The microbiological quality of drinking-water can be substantially enhanced by protecting the source and by treating the raw water, especially if slow sand filtration is employed. However, where raw waters are not of a consistently high quality, some form of disinfection is essential to ensure that the supply is microbiologically safe. Provided that the physical and chemical quality of the water is acceptable, disinfection provides the most effective means of reducing the numbers of microorganisms in drinking-water.

Disinfection methods may be either physical or chemical. Physical methods include boiling and ultraviolet (UV) irradiation; chemical methods include the addition of ozone, or, most commonly, chlorine and its derivatives. Only chlorination has been widely applied in treating community water supplies, although UV irradiation is also sometimes appropriate, as is on-site generation of disinfectant gases.

Chlorine is an oxidizing agent that reacts rapidly with organic and inorganic matter present in water. If adequate disinfection is to be achieved, due allowance must be made for the chlorine consumed in these reactions in addition to that needed for disinfection. The amount of chlorine required to react with other compounds (mainly ammonia, some metal ions, and organic compounds) is termed the chlorine demand of the water. Thus, the chlorine dose must be sufficient both to satisfy the chlorine demand and to produce an unreacted excess known as the free residual. A minimum free residual of 0.5 mg/litre is recommended, together with a minimum contact time of 30 minutes and a water turbidity of less than 5 NTU (ideally less than 1 NTU). The chlorine demand of some waters (particularly river waters) can increase dramatically at times of heavy pollution, particularly after rain. It may therefore be necessary to increase the dose to allow for this. The residual chlorine level should be determined (see Annex 9) in samples taken from various points throughout the distribution system, to ensure that a free residual exists in the water supplied to the public.

Chlorination usually requires the addition of one of the following three substances to the water:

- Chlorine gas, Cl_2, liquefied under a pressure of 505 kPa (5 atm). This requires careful handling because it is highly toxic: the gas supplier should provide clear operational guidelines and the surveillance officer should check that these are being strictly observed.
- Sodium hypochlorite solution for water disinfection, containing up to 14% available chlorine, or liquid bleach (about 1% available chlorine). Solutions are unstable at warm temperatures and should be stored in brown or green glass bottles or opaque plastic bottles in a cool, dark place. They should be checked regularly to ensure that the chlorine content is adequate since the concentration may fall if the container has been opened or stored for a long time.
- Solid calcium hypochlorite, commonly available as bleaching powder or chlorinated lime, containing about 30% available chlorine when fresh. The compound is unstable at warm temperatures and should be carefully stored. High-test hypochlorite (HTH) can also be used; it normally contains 50–70% available chlorine.

Simple devices for use in chlorination include the constant-head drip and double-pot chlorinators; typical examples are shown in Figs 6.14 and 6.15, respectively.

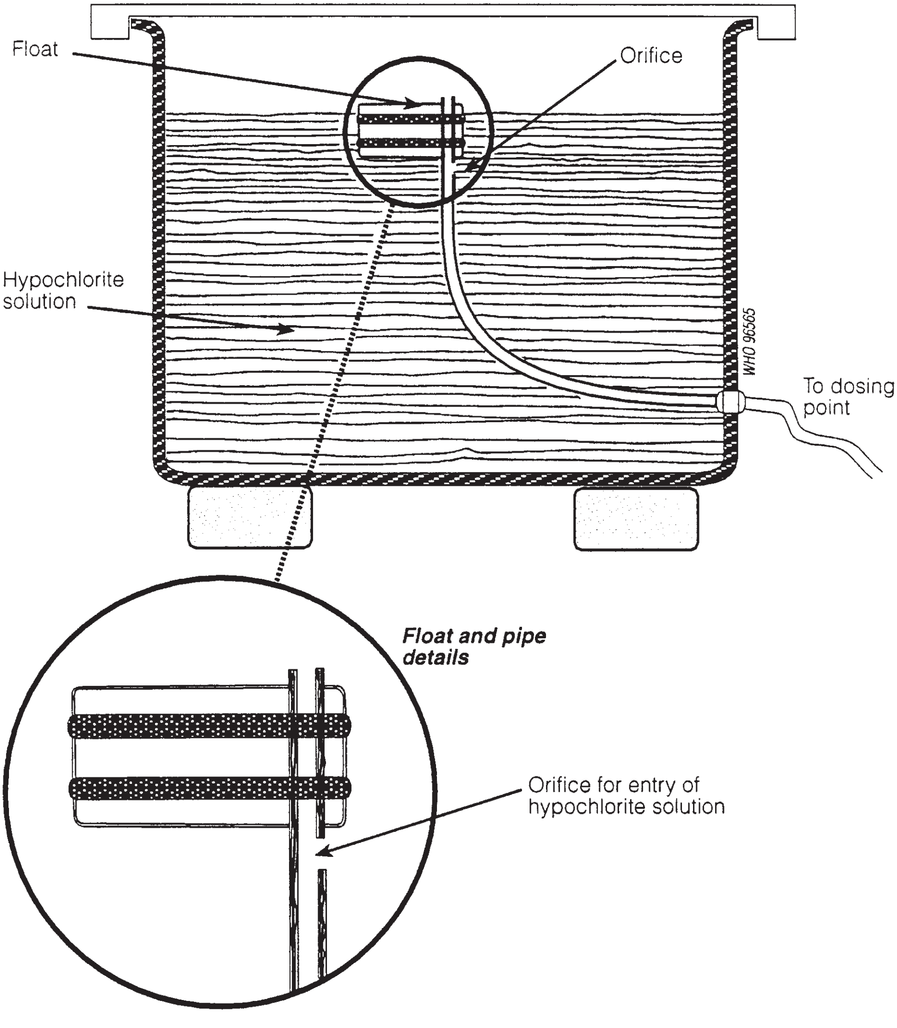
6.6.12 Water-treatment plants

The only proven method of treating polluted surface water by means of simple equipment is based on the multiple-barrier principle, i.e. on the use of at least three unit treatment processes in series which progressively remove pathogens and other contaminants (notably turbidity). The technology is robust and has the advantage that failure of any one barrier should not significantly increase the risk of transmission of infectious waterborne disease. A typical multiple-barrier series of unit processes is shown schematically in Fig. 6.16, and includes:

— plain sedimentation
— triple-stage gravel prefiltration
— slow sand filtration
— disinfection.

The two main parameters determining the selection and performance of treatment plants are the thermotolerant (faecal) coliform count per 100 ml and the turbidity. These should be reduced so that, however many unit processes are employed, the water leaving the plant always has a zero thermotolerant (faecal) coliform count and turbidity below 5 NTU. These treatment objectives have been incorporated into Table 6.2 to show the required performance of the unit processes considered appropriate for community water supply.

Fig. 6.14 Constant-head drip chlorinator



6.7 Household water treatment and storage

Where the source of water used by a community is unprotected and/or untreated, or when the water supply is contaminated, household water may require treatment in the home to ensure that it is safe for consumption. Household treatment and hygienic storage can improve the aesthetic quality of water (turbidity, temperature, etc.) and reduce faecal contamination, but its use to improve chemical

Fig. 6.15 Double-pot chlorinator

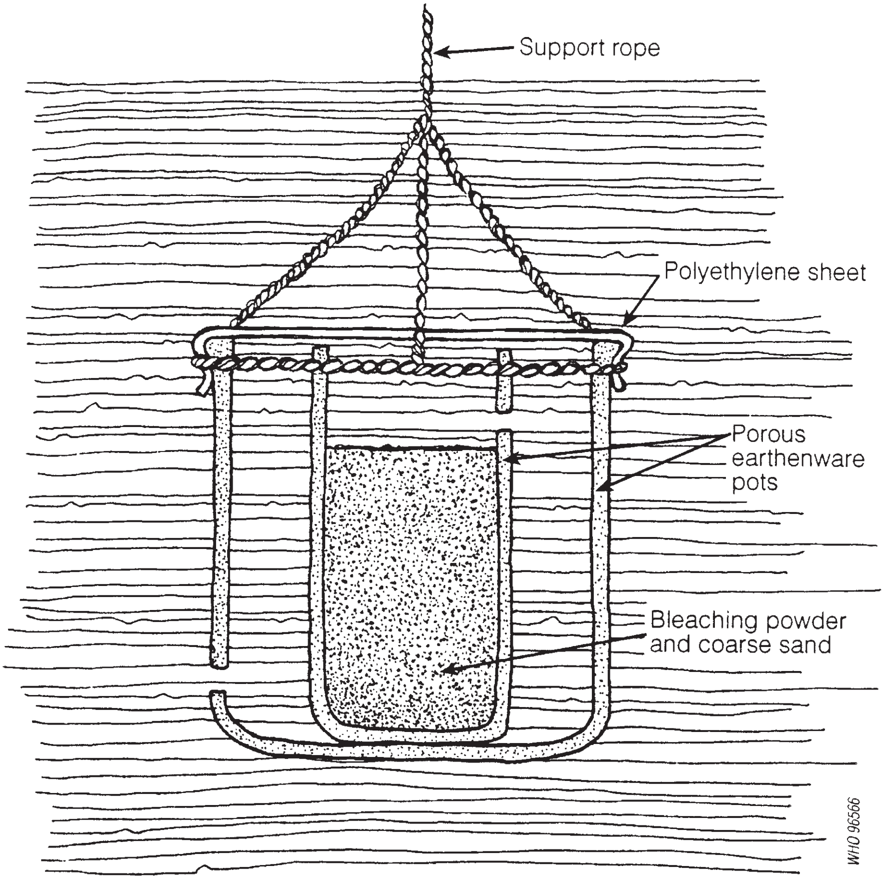
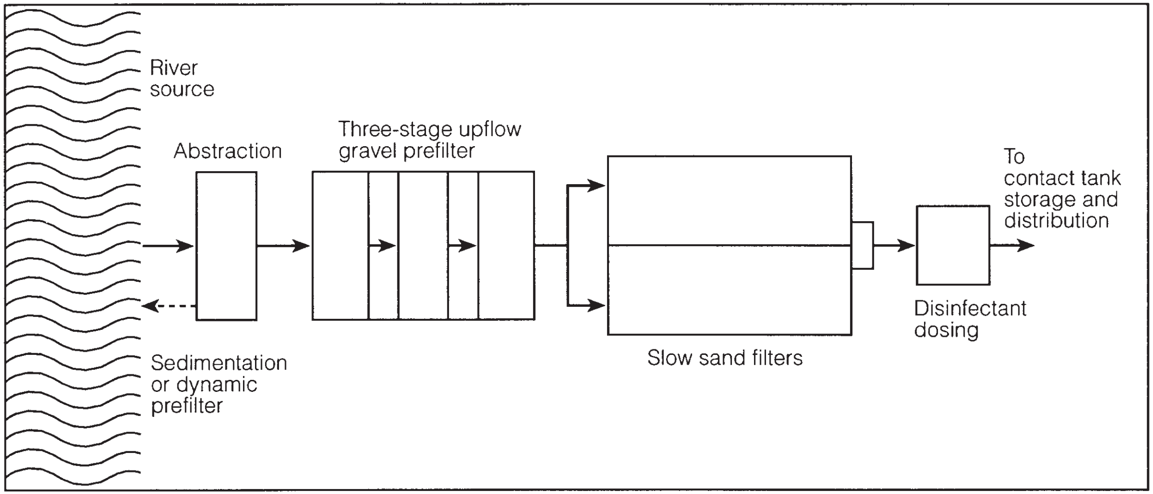


Table 6.2 An example of performance objectives for removal of turbidity and thermotolerant coliform bacteria in small-scale water treatment

Stage and process	Turbidity			Thermotolerant coliform bacteria		
	Removal (%)	Average loading (NTU)	Maximum loading (NTU)	Removal (%)	Average loading (per 100 ml)	Maximum loading (per 100 ml)
Plain sedimentation	50	60	600	50	1000	10 000
Gravel prefilters (3-stage)	80	30	300	90	500	5 000
Slow sand filter	>90	6	60	95	50	500
Disinfection	NA[a]	<1	<5	>99.9	<3	25
Distributed water	NA[a]	<1	<5	NA[a]	<1	<1

[a] NA, not applicable.

Fig. 6.16 Typical multistage treatment system for small-community supplies



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quality is uncommon; this section therefore deals only with reducing the faecal contamination of drinking-water to prevent the transmission of infectious waterborne diseases.

In many situations water must be transported, often carried, from a well, spring, or standpost to households. In these circumstances and where the water supply to the household is intermittent, water must be stored in the home to ensure that enough is available when it is needed. Water that is transported or stored unhygienically may be recontaminated, which represents a public health risk; water supplied at the well or standpost may be microbiologically safe but become grossly contaminated with faecal material before consumption because of poor handling. A surveillance programme should therefore include the testing of water stored in the household to establish whether recontamination is occurring.

If drinking-water regularly becomes recontaminated, the best remedial action is a hygiene education programme. This should involve all the community but focus particularly on those members with most responsibility for water collection, storage, and treatment (usually women and children). Most recontamination is the result of behavioural patterns; if these can be changed, the health risk can be reduced or eliminated. Technical interventions (like those described below) may also be used, but are unlikely to result in any significant reduction in recontamination without a complementary hygiene education programme. Hygiene education is dealt with in Chapter 7.

6.7.1 Household water treatment

Where local water supplies are known to be contaminated or have not been tested, household treatment should generally be recommended. Faecally contaminated water can be treated by:

- — boiling
- — filtration
- — chemical disinfection
- — cloth filtration (to prevent dracunculiasis).

Boiling

Boiling is a simple way of killing any ova, cysts, bacteria, and viruses present in contaminated water. Water should be heated until it comes to a "rolling boil" (large bubbles continuously coming to the surface of the water) which is maintained for 1 minute. Water boils at a lower temperature as altitude increases, and 1 minute of extra boiling time should therefore be added for every 1000 metres above sea level. Boiling has the following disadvantages:

- Large amounts of fuel are required, so that cost may prevent people from boiling water in many areas.
- It may give an unpleasant taste to the water which may be unacceptable.

- Very hot water can cause accidents in the home.
- Boiled water can become recontaminated once it has cooled.

Simple household filters

There are many different types of household filter, some produced commercially and others that can be manufactured locally. Most will remove a high proportion of solids and silt. Many will also remove parasites including cysts, ova, and guinea worm larvae, but some simple filters may not remove all microorganisms from water. The various types of simple household filter are candle, stone, and sand filters.

Candle filters are often commercially produced. In this type of filter, contaminated water is allowed to filter slowly through a porous ceramic material (see Fig. 6.17). Larger microorganisms—ova, cysts, and most bacteria—are left in the outer layer of the filter material, which is periodically cleaned by gently scrubbing the filter under clean, running water. Smaller microorganisms, such as the virus that causes hepatitis A, may not be removed by candle filters.

Candle filters should be designed to minimize the risk of recontamination of water after filtering. Most commercial filters consist of two interlocking containers. The upper container for the candle(s), into which the raw water is poured, is usually fitted with a lid. The base of this container fits securely onto the top of the lower container; an overlapping lid prevents recontamination of the filtered water. The lower container, which collects the filtered water, is fitted with a tap near the base to allow hygienic withdrawal of the water.

It is important that the manufacturer's instructions for cleaning and the safe life span of the filter should be carefully followed.

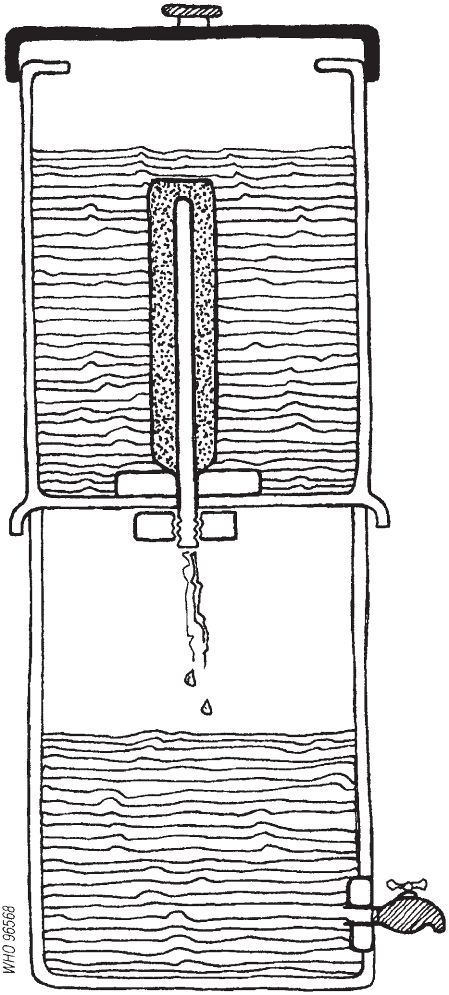
Stone filters are similar to candle filters but are carved from porous local stone (see Fig. 6.18). They are generally difficult to clean and heavy to lift, but have the advantage of being relatively inexpensive if they can be produced locally. If these filters are commonly used in a particular area, it would be worthwhile to test water from a representative sample to determine the efficiency of removal of faecal contamination. Filtered water is generally collected in an open vessel, often close to the ground, so that there is a significant risk of recontamination.

Sand filters should not be confused with the slow sand filters discussed earlier in this chapter, which are very efficient at removing microorganisms from contaminated water. A slow sand filter would be difficult to operate in a household as it requires a continuous and constant flow of water if it is to function effectively. Household sand filters (see Fig. 6.19) will remove solid material from water and often ova, larvae, cysts, and *Cyclops* spp. Because bacteria and viruses are not removed, additional treatment, such as disinfection (usually with chlorine), may be desirable after filtration.

Removal of turbidity. When water is extremely turbid, it may be necessary to remove some of the particulate matter before the water is passed through a filter in order to avoid blockage. Pretreatment, either by settling or coagulation, will often also help to reduce faecal contamination to some extent.

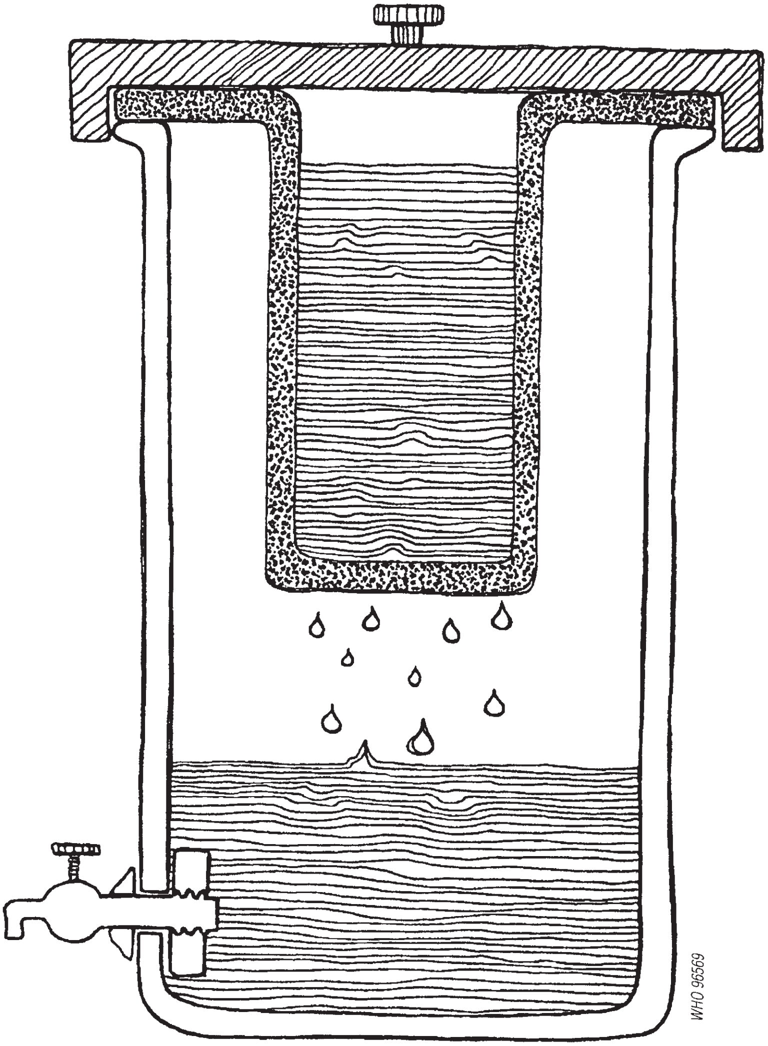
- Settling. If turbid water is left in a closed container for several hours, e.g. overnight, a proportion of the suspended matter will settle to the bottom. The clearer water can then be decanted from the top and poured into a filter.
- Coagulation. Turbid water can be settled more rapidly and effectively if a chemical coagulant is used to make the suspended particles stick together.

Fig. 6.17 Candle filter



The dose of alum required will depend on the turbidity of the water and should be selected on the basis of local experience whenever possible. Certain indigenous plants can also be used to make suspended particles stick together, and in some areas such natural coagulants are widely and successfully used. So many different plants are used for this purpose in different parts of the world that no general recommendations can be made. Local experience and practice should be investigated and used as a guide.

Fig. 6.18 Stone filter



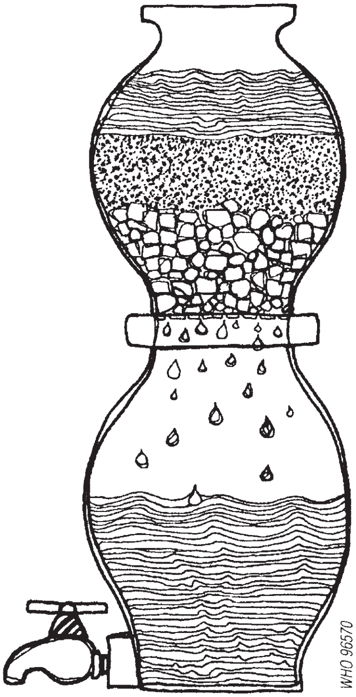
Disinfection

If water is contaminated but clear, disinfection can be used to kill the microorganisms it contains. Using chlorine for this purpose will provide a disinfecting residual that will help to prevent recontamination.

Of the various ways of disinfecting household drinking-water, the commonest is to use chlorine. A 1% solution of chlorine is often used, in the form of sodium hypochlorite (liquid bleach), calcium hypochlorite (generally as a powder), or HTH (high-test hypochlorite in powdered form); see also p. 115.

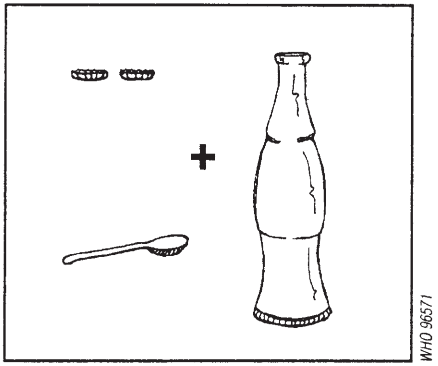
Chlorine is a hazardous substance. It is highly corrosive in concentrated solution and splashes can cause burns and damage the eyes. Appropriate precautions should be taken when concentrated chlorine solutions or powders are handled. If the eyes or skin are splashed, they should immediately be rinsed thoroughly with water. Solid forms are less hazardous to handle during transport than solutions. It is good practice to wash the hands after handling concentrated chlorine in any form. All containers in which chlorine is stored should carry a label clearly identifying the contents and including a hazard warning in a form that is readily understandable locally. Storage sites for chlorine in any form should be secure, and special precautions should be taken to prevent access by children.

Fig. 6.19 Household sand filter

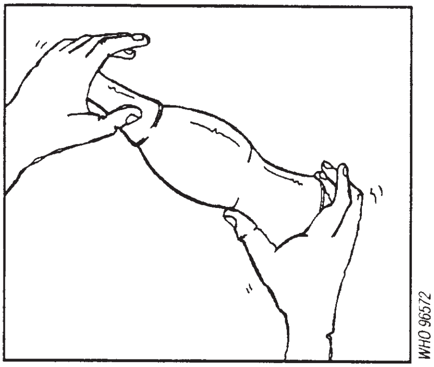


Where drinking-water is to be both disinfected and filtered, disinfection should follow filtration; otherwise the disinfectant may be neutralized by the filter. Disinfection is less effective in turbid or cloudy water as the chlorine can be consumed by the suspended particles in the water; particulate matter may also protect bacteria from the disinfectant action of chlorine.

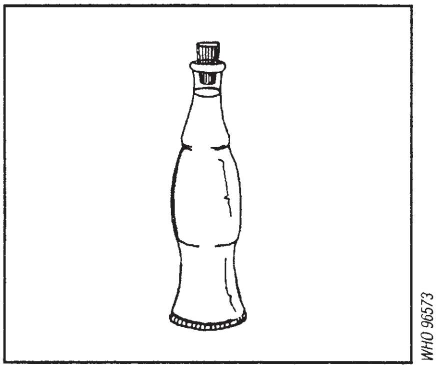
Fig. 6.20 Method of preparing chlorine solutions using local materials



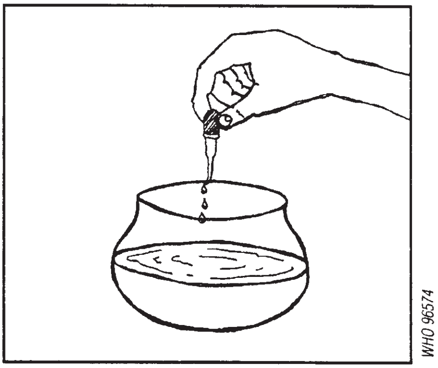
1. Fill two bottle tops, or one level teaspoon with chlorine powder (HTH), put into a small drink bottle (about 300 ml) and add clean water to the top.



2. Cork the bottle and mix well for 2 minutes. Leave to stand for 1 hour.



3. Now you have the same chlorine as household bleach. Put it in a dark place away from children.



4. Add 3 drops of the chlorine solution for every litre of water. Leave for 1 hour, then taste. You should just be able to taste the chlorine. If you cannot taste it, add 1 drop per litre until you can. The water will only be safe to drink for 24 hours.

Sodium hypochlorite solution can be used directly to disinfect household drinking-water as its chlorine concentration is already 1%; calcium hypochlorite and HTH need to be diluted to this concentration before use. The quantity of powder used will depend on the concentration of chlorine present. Community members should employ locally available and familiar containers and units of measurement. An example of a method of preparing chlorine solutions which has been used successfully is shown in Fig. 6.20.

Cloth filtration to prevent guinea-worm disease

Guinea-worm disease (dracunculiasis) is transmitted via contaminated drinking-water (e.g. from stagnant ponds, cisterns, or step wells). The disease occurs in a number of countries in Africa and Asia and causes severe suffering and disability among the world's most deprived people. Infected individuals do not develop immunity. There is no known animal reservoir, and people can disseminate the parasite 1 year after infection and during 1–3 weeks after emergence of the worm. For these reasons and because control of transmission, including treatment of drinking-water, is simple, global eradication of this disease is feasible.

Dramatic reductions in the prevalence of dracunculiasis have been achieved through improvement of water supplies and by promoting proper hygiene in areas where the disease is endemic. In such areas, guinea worm (*Dracunculus medinensis*) can be effectively eliminated by filtering all drinking-water through fine cloth (see Fig. 6.21). Filtration of drinking-water is thus a primary strategy for the control of guinea-worm disease.

Filters should be of mesh size less than 130 μm; this should remove all infected intermediate hosts. Monofilament synthetic cloth (nylon) is most suitable because it clogs less rapidly and is easily cleaned; it has a mesh size of 100–130 μm. Cotton cloth can be used but tends to clog rapidly. Boiling is also effective as a means of controlling the disease.

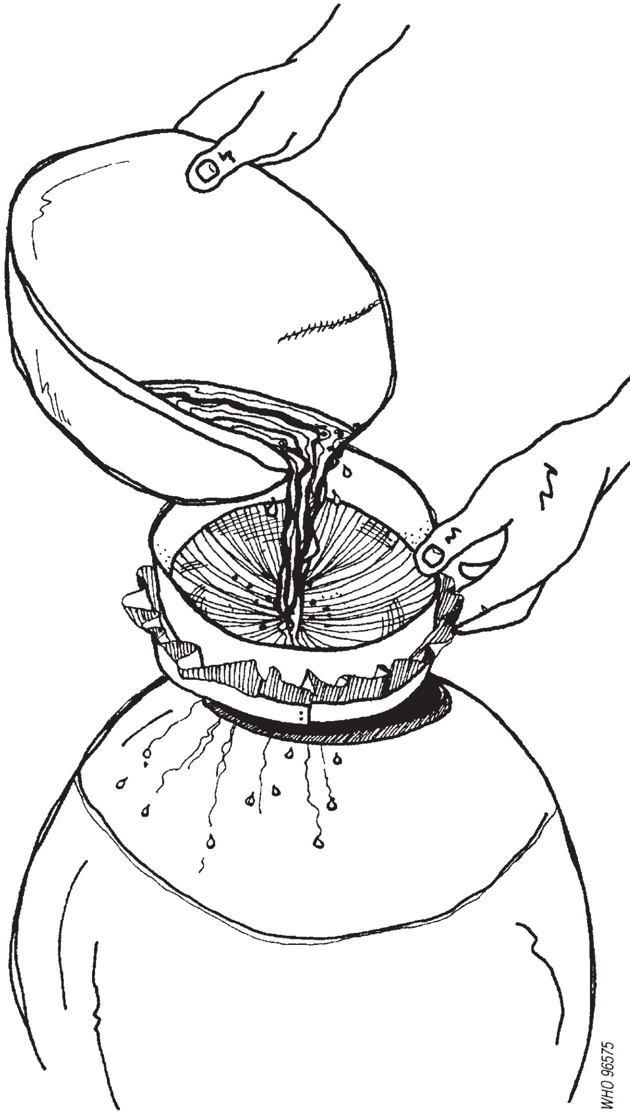
6.7.2 Household water storage

The principal health risk associated with household water storage is the ease of recontamination during transport and storage, particularly where the members of a family or community do not all follow good hygiene practice. Good hygienic measures include the following:

- careful storage of household water and regular cleaning of all household water-storage facilities;
- construction, proper use, and maintenance of latrines;
- regular hand-washing, especially after defecation and before eating or preparing food;
- careful storage and preparation of food.

Water that is clean from the supply or has been treated in the household needs to be protected from recontamination. The following precautions and considerations are important:

Fig. 6.21 Pouring water through a monofilament filter to control transmission of guinea worm



- *Location of storage vessel.* The storage vessel should be placed above ground level to restrict access by children and animals. It should preferably be placed in a shaded position to keep the water cool, and should be accessible to users and for refilling.

- *Design of storage vessel.* The storage vessel should be designed to reduce the risk of contamination: it should have a secure, tight-fitting lid, be robust enough to withstand rough handling without cracking, and be easy to lift from the ground and carry back to the storage point after filling. Stored water may be kept cool by using earthenware jars or pots; these allow some water to evaporate, which has a cooling effect. Containers should be easy to fill and clean, so that contact with hands is minimized.
- *Removal of water.* It should be possible to remove water from the container hygienically, with no contact between hands and the water. Water is commonly withdrawn by means of a cup. This may be acceptable where the cup is not used for any other purpose, is cleaned regularly, and is stored where contamination cannot occur. However, as it is difficult to dip the cup into the water without also putting in the hands, the risk of contamination is still high. It is better to use a ladle that is stored permanently inside the container; this reduces the risk of contamination while the ladle is not in use. However, the ladle should be used *only* to transfer water to a cup or other vessel. Drinking from it directly may cause contamination of the water. The ladle should be held only by the top of the handle and not by the scoop or any part that is immersed in the water during storage. Fitting a tap to the container minimizes contact with the water and is the most hygienic method of withdrawal. However, users must not wipe the tap with dirty hands or hang cups, etc. from the tap as this increases the risk of contamination before consumption. Taps are expensive, may be difficult to fit on traditional containers, and may also weaken the container.

Substances such as petrol, diesel fuel, pesticides, and solvents should not be stored or used near water facilities (sources, catchments, storage tanks, etc.). Containers that have been used for the storage, transport, or handling of these substances should not subsequently be used to store water intended for human consumption, even after thorough cleaning.

The most important elements of water storage can be summarized as follows:

- Use a clean water source or treat the water, either at home or in a storage tank.
- Store water in an earthenware or plastic container with a lid.
- Store the water container at a height that puts it beyond the reach of children and animals.
- Fit a tap to the container for drawing clean water in order to prevent contamination by dirty cups, ladles, or hands.

6.7.3 Storage tanks

Where a piped water supply to the household operates intermittently, a storage tank is commonly used to ensure that there is sufficient water for the family needs throughout the day. The tank should be covered to prevent contamination of the water and to restrict access by children and animals. It may be located inside or outside the house, but a secure cover should be fitted to an outdoor tank.

If the water running into the tank is clean (i.e. comes from a protected source or a treatment plant), the tank should be inspected, cleaned, and disinfected at least once a year. Where the water supplied is not clean, the tank will require more frequent cleaning, the frequency depending on the water quality. Water of poor quality should be treated by the most appropriate means.

The pipes running from a household storage tank to the taps must *not* be made of lead, which is toxic; pipes made of galvanized iron, copper, or plastic (such as potable grade PVC) should be used instead. Galvanized iron pipes should not be used where the water supplied is highly acidic or alkaline because they will corrode. A non-lead solder should be used, where possible, to join metal pipes, and a nontoxic solvent cement for plastic pipes. The system should be thoroughly flushed before use to remove any traces of solvent or metal solder from the pipes.

When a household storage tank and pipes for drinking-water are installed, they should ideally be filled with water containing 50 mg/litre of chlorine and left to stand overnight so that the system is disinfected before use.