

## 7. Water supply

### 7.1 Water-supply preparedness and protection

Water-supply problems arise in all phases of the disaster-management cycle. As with all other elements of emergency management, water supplies can be designed and maintained in ways that help to reduce the health impacts of disasters.

It is useful to distinguish between large-scale, formal water-supply systems (e.g. urban water-supply systems) and small-scale, scattered supplies. The distinction is not so much between urban and rural areas, as one based on the level of technology and the institutional arrangements for management, maintenance, and protection. Whether the affected systems are rural or urban, sanitation surveys may be necessary to identify the main health hazards (World Health Organization, 1997a).

Water sources are exposed to a variety of hazards that may damage or contaminate them, but they can be protected against disasters to some extent. This section is concerned mainly with ways in which improvements to existing water supplies can make them more resistant to damage.

#### 7.1.1 Establishing and protecting small-scale decentralized supplies

##### Kinds of damage to small-scale water supplies

Roof catchment systems are often damaged by wind in tropical storms. People who depend on canals are vulnerable to chronic and acute pesticide poisoning or, where the canal drains an industrial zone, poisoning from the release of toxic chemicals. Unlined canals may also be easily washed away or broken during floods, so cutting water supplies. Shallow wells in areas with a high water-table are more prone to contamination from flooding than are deep boreholes. They may also dry up sooner in a drought. Hillside springs may be destroyed in a landslide. Wells near rivers can be contaminated and filled with sand during unusual flash flooding. All piped systems are subject to breaks and disruption during earthquakes, landslides or civil strife. Dug wells and boreholes are particularly vulnerable during wars, since bodies or toxic materials can be dumped in wells, and borehole pumps sabotaged.

##### Routine forms of protection

In all activities to provide or improve water supplies during “normal” times, it is important that those responsible are aware of the specific hazards to which water sources might be subject. This hazard mapping should be as much a part of the planning of water-supply systems as other factors, such as water quality and taste, distance to users, and capital and recurrent costs.

Simple modifications in design can sometimes help to protect the water source from an extreme natural event or industrial accident. For instance, flexible plastic pipe is more resistant than rigid pipe to earth tremors.

Some basic improvements, such as raising the head wall of a dug well, and providing a cover and outward-sloping concrete apron around it, simultaneously provide additional

protection from contamination due to floods and run-off into the open hole, and short-circuit seepage from nearby puddles; they also prevent contamination by debris and animals falling into the well.

If the surface or groundwater could be affected by toxic hazards, it is probably better to avoid the water source. Providing an alternative water source should then be a high priority.

#### Need for consultation with water users

Many people use multiple sources of water. Some will prefer certain sources for drinking-water and others for laundry, bathing, watering animals and irrigation.

Wherever a hazard, or the potential for disruption of the water supply, exists, the primary health-care workers or other development personnel should discuss alternative drinking-water sources with the people concerned. These discussions should take place before an emergency arises. A delegation from the local health committee or safety committee should visit the alternative sources regularly to check on their status. Where recent improvements in water supply have resulted in former sources being abandoned, the committee may want to discuss the desirability of providing some minimal maintenance at the old site to preserve it for use in an emergency.

There should also be local contingency plans for rapidly ensuring the safety of such reserve sources of drinking-water. These will usually involve stockpiling a limited amount of chemicals to disinfect the source (taking into consideration the shelf-life of these chemicals), plus fencing to exclude animals. Depending on the economic base of the community or neighbourhood concerned, the discussion may go on to consider the provision of alternative or reserve water for livestock, small-scale industry, or irrigation; however, the first priority should always be water for drinking, cooking and personal hygiene.

### 7.1.2 Establishing and protecting large-scale, centralized supplies

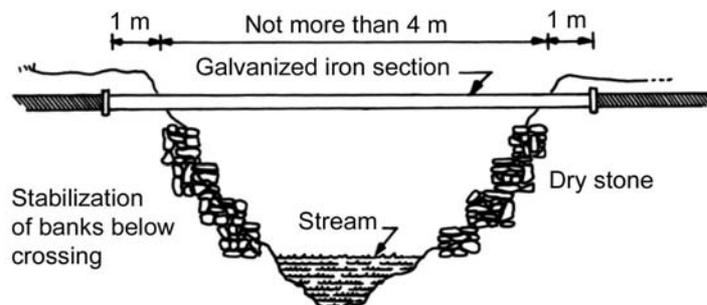
#### Types of hazard

The location of sources and the design of water-supply systems are critical in emergency and disaster preparedness. Hazards to catchments (e.g. forest fires or chemical contamination), reservoirs (drought, earthquake, contamination, landslides), pumping and treatment plants (flood, earthquake, fire, explosion, chlorine gas leaks), as well as to the distribution system (earthquake, flooding), need to be taken into account in siting, design and contingency planning. Sabotage may pose a hazard to all stages of a water-supply system.

#### Strengthening existing systems

Weak points in distribution systems, such as river crossings, open canals, landslide scars, etc., or places where pipes cross earthquake faults, should be strengthened (see Figure 7.1). Low-lying, flood-prone facilities can be raised or protected with levees or bunds. Reserve electrical generators can be provided if necessary, as well as a stock of pre-positioned replacement pumps and pipes for emergency repairs. Standardization of pumps, pipes and fittings, etc. is important, so that spares and equipment can be sent as temporary replacements from an unaffected town.

Systems based on rapid sand filtration can be made less vulnerable to disasters by appropriate staff training and by including emergency provisions at the planning stage that will help cope with prolonged high turbidity, power failures and shortages of chemicals. Emergency provisions include extra stocks of chemicals, stand-by power generators and emergency prefiltration storage/sedimentation capacity.

Figure 7.1 Reinforcement of water pipes crossing streams or gullies<sup>1</sup>

<sup>1</sup> Sources: American Water Works Association (1984), Jordan (1984).

Staff should be rigorously trained in the action to be taken in an emergency to assess the state of the water-supply system and to restore and ensure its integrity from the standpoint of health and the environment.

#### Long-term investment decisions

Long-term design and investment decisions should also take into account the possibility of disaster. For instance, slow sand filters, which can be adequate even for large cities (e.g. London and Amsterdam), are less vulnerable than other treatment systems to hazards, such as interruption of chemical supplies and power supplies (Pickford, 1977). Decisions on routing water-transmission mains and distribution networks should also take into account the possibility of damage due to natural causes, such as earthquakes and landslides, and to sabotage.

### 7.1.3 Preparation for displacement emergencies

When a risk of population displacement is identified in the vulnerability assessment (see Section 3.3), steps should be taken to prepare for such an event, taking into account the likelihood of displacement, the likely numbers of displaced people, displacement routes, and likely destinations. Preparedness measures may include: identifying water sources along displacement routes and at potential temporary settlements; pre-positioning stocks of lightweight water equipment (pumps, flexible reservoirs, pipes and taps) and supplies (fuel and water treatment chemicals); identifying and training staff; and holding discussions with local communities along displacement routes about access to water sources. During a large population movement, it may be very difficult to move staff and equipment along the congested roads, so it is important to establish a local response capacity.

## 7.2 Emergency water-supply strategy

### 7.2.1 Situations demanding an emergency water-supply response

Short-term water-supply needs and emergency measures may differ in the following types of situations:

- short-term emergencies affecting rural or unserved periurban communities;
- short-term emergencies in urban situations where a central water service is available;
- short-term emergencies involving population displacement and temporary shelters;

- long-term displacement emergencies that result in semipermanent emergency settlements.

These situations are considered in turn in sections 7.2.3–7.2.7.

## 7.2.2 Emergency response strategy

### Priorities

The first priority is to provide an adequate quantity of water, even if its quality is poor, and to protect water sources from contamination. A minimum of 15 litres per person per day should be provided as soon as possible (Sphere Project, 2000), though in the immediate post-impact period, it may be necessary to limit treated water to a minimum of 7 litres per day per person (United Nations High Commissioner for Refugees, 1992a). If this is the case, then people may use an untreated water source for laundry, bathing, etc. Water-quality improvements can be made over succeeding days or weeks.

The main public health priority is usually to provide a basic water supply to the affected population. It is often better to organize separate human and material resources for providing water supplies for hospitals, nutrition centers, etc., so that work on the general water supply is not delayed. Hospitals will soon be swamped with cases of water-related disease if the general water supply is not sufficient. However, priorities should be defined for each situation, on the basis of an assessment (see Section 7.3).

### Gradual improvement of water supplies

In all situations, a successful emergency response in the water-supply sector depends on improvisation and gradual improvement of water supplies, progressing from basic services during the emergency and recovery phases, to more sustainable services in the long term, when installations should be more robust and less vulnerable to disasters. These improvements should be incremental, wherever possible. In other words, emergency measures should be designed and implemented in such a way that they can be built upon later. However, this may not be possible, and temporary measures that require complete replacement after weeks or months may be required, such as the use of lightweight petrol pumps and flexible tanks.

### Assessment, monitoring and review

The most effective emergency water supply measures are ensured through a process of assessment, monitoring and review. Assessment is required to identify needs, damage and resources, so as to be able to respond appropriately and with maximum impact; monitoring of activities and the context is essential to ensure that the water supply activities are carried out as planned, with timely indications of problems and unmet needs; and periodic reviews of the situation and the response are essential to ensure that the response remains relevant to the needs and resources of the communities affected by the disaster. Assessment of damage, resources and needs in the water-supply sector is discussed in Section 7.3.

### Hygiene promotion and participation

The emergency water-supply response should be carried out with, or as part of, a hygiene promotion programme that works with the affected population to respond to disasters to reduce risk, increase resilience and mitigate the impact of disasters on health. This should ensure the design and maintenance of water systems that meet the needs of all

the groups involved, including women, the elderly, children and the disabled. Opportunities for participation should be sought in assessment, monitoring and review, as well as in programme design and implementation. See Chapter 15 for more information on hygiene promotion and participation.

### 7.2.3 Rural emergencies

Rural communities are usually less vulnerable than urban communities to disruption of water supplies in disasters, as their supplies are generally decentralized and based on simple technology, and there are frequently alternative sources available. However, certain hazards, such as floods and droughts, may have a greater impact in rural areas than urban areas. This section is concerned principally with floods and droughts, although other hazards, such as earthquakes, landslides and conflict, may produce the same type of damage.

#### Floods

If the usual water source is not damaged or contaminated and is still safely accessible to the population, it is necessary only to monitor the source and react quickly to increased numbers of cases of diarrhoea. However, if the accustomed source is contaminated, commonly the case after floods, an alternative source should be sought or water should be chlorinated before consumption until the source can be disinfected and protected (see Section 7.4.3). In any case, preventive disinfection will help reduce the health risks associated with contaminated water.

Emergency repairs to damaged supplies may include repair or replacement of pumps; repair of spring catchments; repair of gravity supply pipes and distribution systems; and providing steel or plastic tanks to replace broken concrete reservoirs. It is common to find in rural areas that a significant proportion of water supply installations are out of order, owing to long-term problems with maintenance and repair. These installations may be brought back into service as part of the emergency response.

#### Droughts

Even if populations do not migrate in search of food during a prolonged drought, they will seek new or alternative sources of water. Diseases caused by water shortages, such as trachoma and scabies, increase during droughts. The incidence of diarrhoea and water-borne diseases such as cholera may also increase because of lack of water for washing, and intensive use of a small number of water supplies vulnerable to contamination. Drought itself can therefore constitute an emergency, even if reserves of cash, food and livestock are sufficient to avoid food shortages.

In droughts, water quantity is an absolute priority and health staff should cooperate with the government public works or water-supply departments, and with nongovernmental organizations and others involved, to ensure that attempts are made to increase the yield of existing water sources or to find additional ones.

During droughts, there is also often a problem of water quality, because of increased pressure on water sources that remain, many of which may be unprotected. Measures for protecting sources used for multiple purposes are described in Section 7.4.1.

Water trucking may be needed following disasters that affect rural water supplies, though this is more expensive and difficult to organize than in urban situations. See Section 7.4.4.

## 7.2.4 Emergency water-supply measures in urban areas

### Damage likely

When urban water-supply systems are damaged, it is useful to distinguish between damage to water-distribution networks, damage to the source, and damage to the treatment and pumping facilities. Different components are susceptible to different hazards. In most earthquakes, for example, the following components of urban water-supply systems are usually damaged:

- house service connections;
- power supplies;
- control systems;
- trunk mains;
- service reservoirs;
- pumps and treatment plants.

Priority should be given to identifying areas of the city in which water supplies have been disrupted or contaminated, but which do not have alternative local sources, as well as periurban populations that are not normally served by central distribution, but are nevertheless in need of water because of the disaster. Special measures may need to be taken to ensure continued water supply to prisons and hospitals.

Damage to chlorine gas storage facilities may pose an extreme danger and require the evacuation of the surrounding area. Well-trained staff with specialist equipment are needed to deal with this.

### Meeting immediate needs

Such areas and populations will need emergency supplies trucked to distribution points or piped in from unaffected areas. An alternative to trucking water into these areas or to providing emergency piped connections is to use mobile purification units connected to the nearest untreated source (see Section 7.4.4).

Alternative temporary water sources and treatment plants may sometimes be available from dairies, soft-drink bottling plants, breweries, or even large swimming pools (see Box 7.1).

In urban areas, it may be necessary to ration or restrict water use while repairs are being made, to ensure that the available water is being used according to agreed priorities. These priorities should be decided on the basis of an assessment, and should be discussed and agreed with agencies working in related sectors, such as health, water supply, sanitation and public works. Where water rationing is required, it is essential that water users are informed of the reasons for this, and the way in which the rationing system is to work.

Where sanitation relies on water-borne systems, relatively large quantities of water may need to be provided quickly, to ensure that those systems function, otherwise a sanitation crisis is likely.

### Rapid repairs to urban water systems

If the water-treatment plant or pumping stations are flooded, the flood water should be pumped out and equipment cleaned and disinfected. Damaged mains and feeders should be repaired as quickly as possible. The quick coupling and plastic patching of pipes, and the use of accelerators in concrete and cement can speed repairs, but technicians in the water company need to have practised these techniques (hence the necessity of training exercises). It is also sometimes possible to bypass damaged sections. Good records, maps of the system, and a good stock of spare parts and tools are also essential.

**Box 7.1 Water emergency in Puerto Limón, Costa Rica**

In 1991, an earthquake affected the Atlantic coast and hinterland of Costa Rica. Water mains were broken in the coastal town of Puerto Limón, and landslides increased the sediment and turbidity of the Banano river which supplied water to the town's water-treatment plant. Within 8 hours of the earthquake a team of water engineers from the national water company (AYA) decided on twin approaches to the urgent problem of providing the town of 40 000 people with water. Contact was made with a major soft-drinks bottling company in San José, the capital. The management agreed to convert its entire plant to filling 2-litre bottles with clean water. Within 18 hours of the earthquake, the first planeload of bottled water arrived, and the local plant requested additional plastic bottles from Miami. In all, some 130 000 litres were provided during the first three days.

Simultaneously, work began damming a small creek, about 3 km from the water company's pumping station. This source was not affected by landslides and sediment. Although there was no road, access was gained by four-wheel drive vehicles up the stream bed. Temporary pipe was laid above ground to bring this new water supply to the pumping station. From there, water could be pumped to the treatment plant which had not been seriously damaged by the earthquake. Treated water was then distributed by tanker truck to the town until water mains were excavated and repaired. People reused the bottles that had been provided. During the critical first few weeks, 20% of water requirements came from springs that had been unaffected and 80% from the Banano River.

Within 60 days, additional water was added from wells drilled along the course of the main pipe from the treatment plant to the town and fed directly into the system; 120 breaks in the main pipelines had been repaired; and service was available for 6 hours a day. Within 90 days, another 200 breaks in the distribution network had been repaired, and deeper wells had been dug to supplement supplies from the new diversion works on the Banano River.

After repairs, the new sections of pipe should be disinfected by filling them with a strong chlorine solution (100 mg/l) for one hour, or a weaker solution for a longer period (e.g. 50 mg/l for 24 hours), and then flushed through with treated water before being put back into service.

The review of water-system status should include catchments and reservoirs. Where a dam or reservoir wall has been badly damaged and is dangerous, the reservoir should be partly or completely drained.

Following floods and damage to sewerage systems, it is wise to ensure a continuous water supply with adequate pressure and to increase the free residual chlorine level to as high as 1 mg/l to prevent contamination through the entry of polluted water into the distribution system. This high level of free residual chlorine should be a short-term measure that is discontinued as soon as flood-waters have receded and the risk is reduced.

In general, emergency repairs should aim to restore conditions as nearly as possible to those that existed before the disaster, rather than attempt any substantial upgrading of the service. However, the real risks of a cessation of funding after the initial repairs have been made should also be taken into account. In addition, any opportunity should be taken to incorporate into the system some basic protection against similar disasters and other local hazards.

**7.2.5 Supplies for affected periurban areas**

There may also be a large demand for water in areas of a town or city that have not previously been served by the water company. The short-term methods adopted to meet these needs may be similar to those described above for rural areas (i.e. existing sources

should be repaired and disinfected; and water should be trucked in if nothing else can be done, etc.). However, the emergency can be an opportunity to develop new water sources for an unserved urban population. This is an incremental improvement that contributes to longer-term vulnerability reduction. See Section 7.4.1 for a description of water sources.

Failing all other means of providing safe water, residents should be advised on how to treat water in the home when this is realistic, using one of the methods described in Section 7.4.3.

### **7.2.6 Short-term displacement and temporary shelters**

Providing emergency water supplies to people during their displacement and while they are in temporary shelters, such as transit camps, is made easier if prior preparedness measures have been taken (see Section 7.1.3). However, it is often impossible to prepare for displacements, and staff are obliged to respond without prior preparation. Where possible, existing and known water sources should be used to supply people on the move and in transit shelters. Temporary solutions, involving water trucking and lightweight, mobile equipment, are more appropriate than solutions designed for gradual improvement. The situation should be reviewed frequently to estimate likely numbers of people to be catered for, their health status, and the length of time they are likely to be in need of emergency water supplies.

### **7.2.7 Long-term emergency settlements**

Long-term emergency settlements, such as refugee camps that may exist for several years, present specific challenges and opportunities. The potential for epidemics of enteric disease is higher in a weakened population living in crowded conditions for a considerable time, particularly in settlements that form spontaneously, without adequate site selection and planning (see Chapter 6). On the other hand, more time is available for gradual improvements in the water supply, as well as for intensive health promotion and training of water-supply staff and other health and environmental workers.

Early in the life of emergency settlements, when displaced people continue to arrive, often in large numbers and in a poor state of health, water supplies may be totally inadequate, and emergency systems need to be set up rapidly to reduce the risk of epidemics. As in other situations, priority should be given to providing the minimum quantity of water needed for drinking, cooking, and personal and domestic hygiene. In large settlements, while the distribution system is being constructed, people may need to travel to the water-treatment installation to collect water. As the distribution system is extended, water is brought gradually closer to peoples' shelters, so encouraging increased water consumption. Priorities for developing the system should be set according to unmet needs and the pattern of water-related disease in the settlement.

The techniques and equipment used for water-supply systems in emergency settlements are described in section 7.4. The emergency water equipment developed by a number of agencies, described in section 7.4.5, is particularly suitable for population displacements and emergency settlements.

## **7.3 Assessment**

Following a disaster, an assessment of damage, available water resources and unmet needs enables staff to direct resources where they are most needed.

### 7.3.1 Assessment of damage and available water resources

In urban areas, a thorough assessment of the post-impact status of the entire water-supply system should be undertaken, while taking steps to meet the immediate, emergency water needs of the population. This assessment should consider the following types of damage:

- contamination of the water source and damage of the raw-water intake;
- damage to the water-treatment works, including structural damage, mechanical damage, loss of power supply and contamination due to flooding;
- damage to pumping stations;
- pressure failure in all or part of a water distribution network, allowing backflow;
- damage to both sewerage and water mains in the same locality, with local seepage into water pipes where the pressure is reduced;
- badly repaired plumbing in domestic or public buildings, resulting in back-siphonage;
- failure to disinfect a contaminated source correctly, or to maintain an adequate chlorine residual throughout the system.

In rural areas, the damage and resources assessment should be simpler, as installations are less complex. The following information on water resources is required:

- the current availability of supplies from all sources, the causes of supply problems (e.g. dry streams and wells, pipe breaks, dams empty, tanks damaged or silted up, roof catchments destroyed, etc.), and alternative sources and their status;
- the causes or indicators of contamination (e.g. human or animal bodies in the water, discoloration of the water, high turbidity, unusual smell, saltiness, diarrhoea or other possible water-related illnesses in the population).

Although simpler than urban assessments, rural damage and resources assessments usually take longer to carry out because of the distances involved. Information may be gathered by local health and community workers, using standardized procedures and reporting formats, to enable priorities to be set.

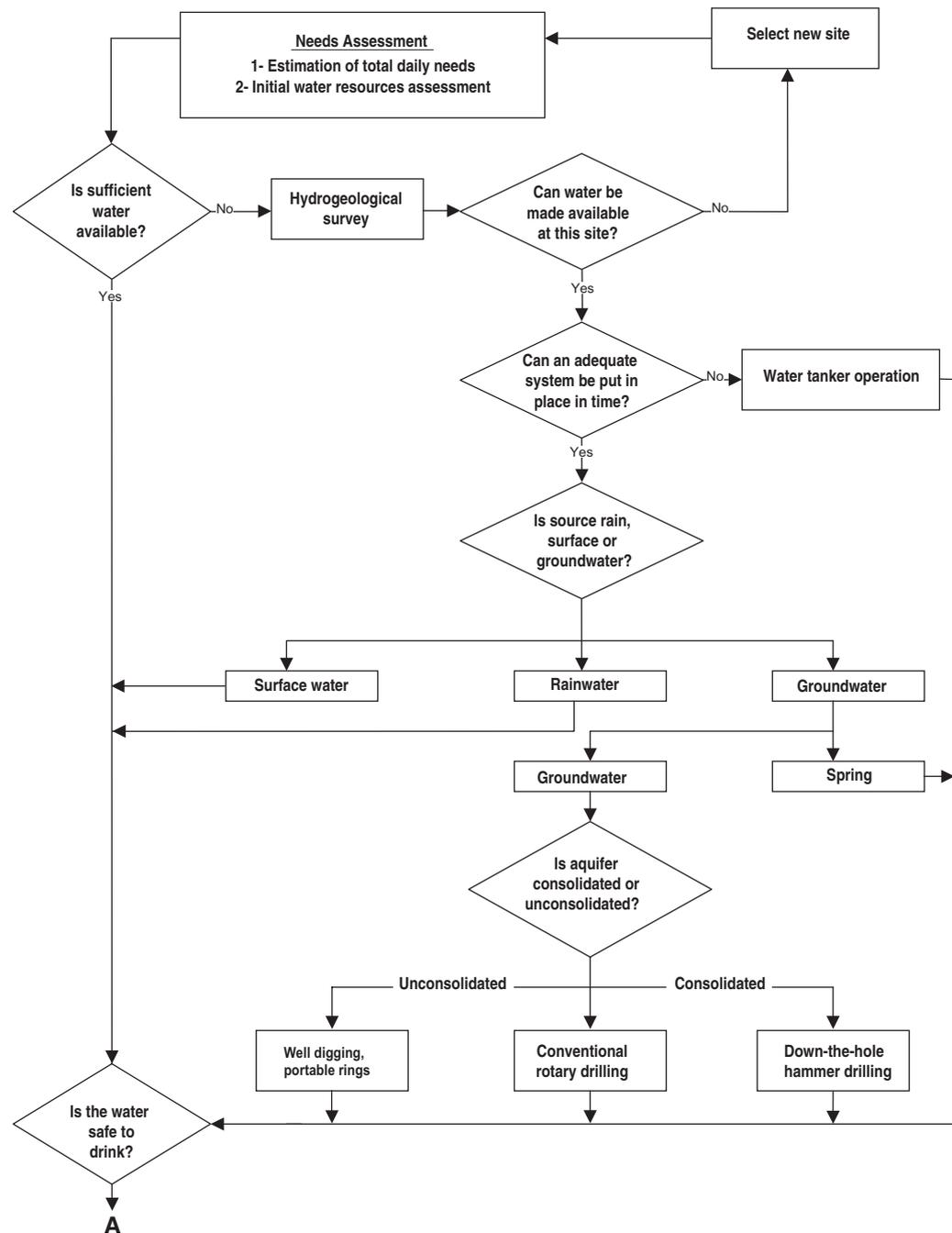
### 7.3.2 Needs assessment

An assessment of unmet needs is usually carried out at the same time as the assessment of damage and water resources, and by the same people. However, in urban situations, engineering staff may focus on assessing damage to infrastructure, while environmental health staff assess the degree of unmet need. In such cases, it is important that the two areas of assessment are well coordinated so that the information they provide can be usefully combined.

The unmet-needs assessment should identify the population affected by insufficient or contaminated water supplies; the quantity of water needed for various purposes (e.g. for drinking, other household uses, agriculture, livestock, industrial uses); how often it will be needed; and any additional treatment, storage and distribution facilities needed.

Figure 7.2 shows a needs and resources assessment that covers all the general issues in planning an emergency water-supply system. The particular assessment in Figure 7.2 was developed for refugee emergencies, but something similar can be adapted for use in each country or region, and can provide a helpful guide for environmental health field teams.

Figure 7.2 Needs and resources assessment: general considerations for planning an emergency water-supply system

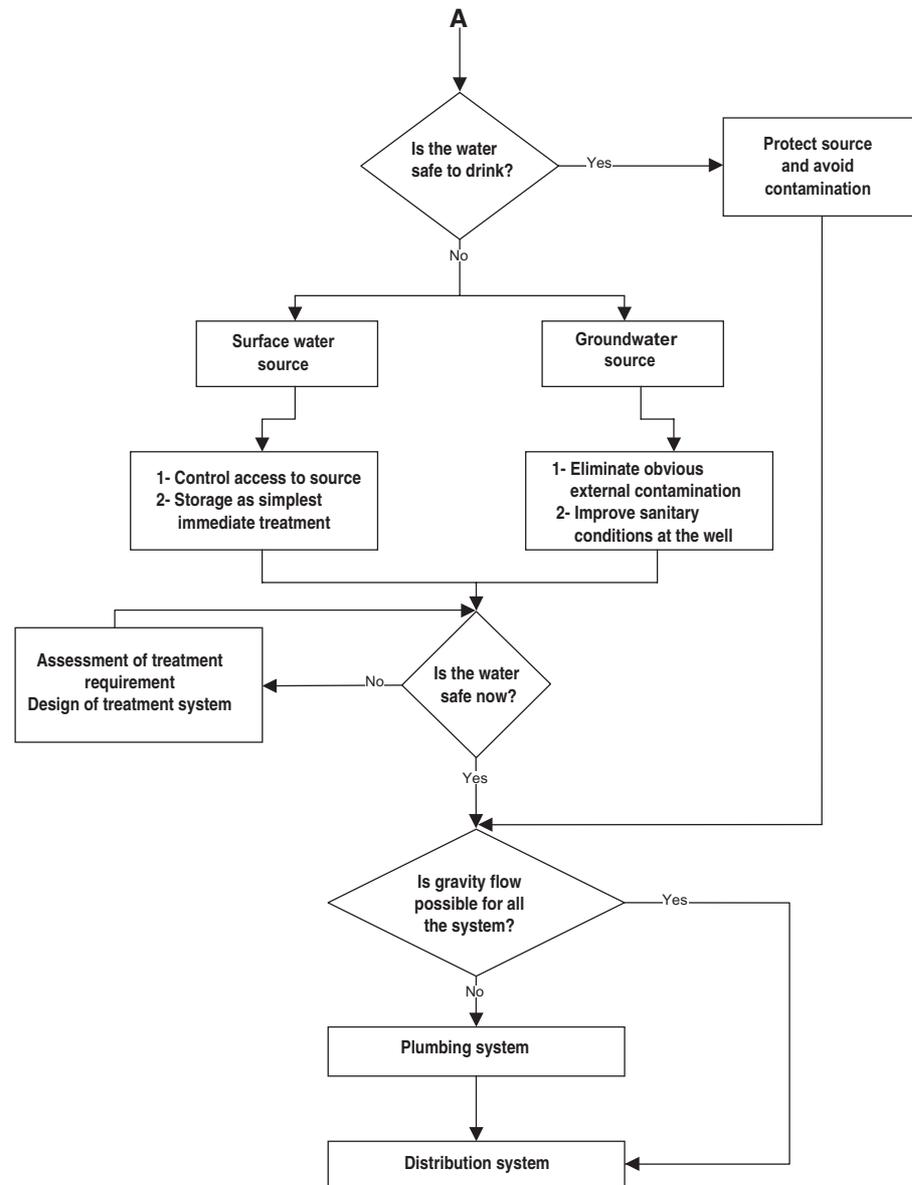


### 7.3.3 Needs and standards

When designing an emergency response, it is important to set objectives that are based on both general and specific agreements about needs. A number of agencies have been using standards for general guidance in setting targets for emergency water-supply interventions for many years.

For example, the minimum personal allowance of water for drinking, cooking and hygiene is set by the United Nations High Commissioner for Refugees (1992a) at 7 litres per day per person over a short emergency period. In most situations, however, water needs are much higher, as follows:

Figure 7.2 (Continued)



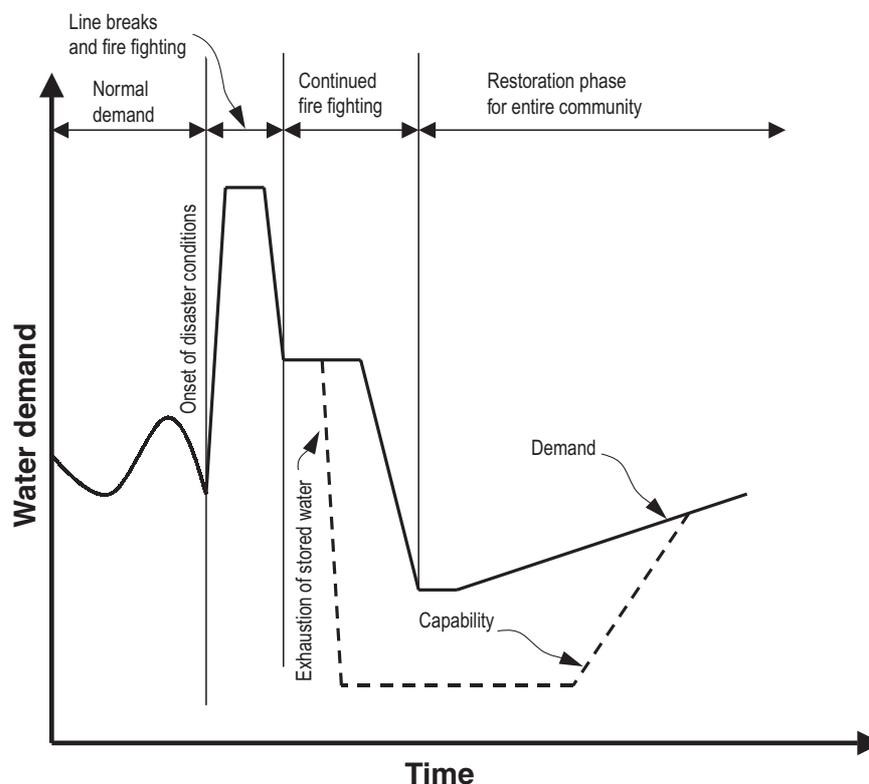
Reproduced, with permission, from: United Nations High Commissioner for Refugees (1999).

- for the general population: 15–20 litres per day per person;
- for operating water-borne sewerage systems: 20–40 litres per day per person;
- in mass feeding centres: 20–30 litres per day per person;
- in field hospitals and first-aid stations: 40–60 litres per day per person;
- in mosques: 5 litres per visitor;
- for livestock accompanying displaced persons and refugees: 30 litres per day per cow or camel, and 15 litres per day per goat or other small animal.

More recently, the Sphere Project has identified broadly agreed standards for emergency water supply (Sphere Project, 2000).

In addition to the 3–5 litres per person per day required for drinking and cooking, an ample supply of water is essential for controlling the spread of water-washed diseases

Figure 7.3 Water demand under normal and emergency conditions



(diseases transmitted through lack of hygiene), even if the water supply does not meet WHO drinking-water quality guidelines or national standards.

The quantity of water needed by a community changes with time after the disaster. After a typical urban disaster, for example, there is a massive increase in water demand for fire fighting, and a gap between demand and supply capacity may occur when supplies of water stored in the treatment and supply system are exhausted (Figure 7.3).

## 7.4 Emergency water-supply techniques

### 7.4.1 Water sources

#### Site selection and water sources

A major factor in the choice of site for an emergency settlement should be the existence of reliable, good-quality water sources nearby. An inventory of the existing water sources should be made as part of the site-selection process. Permanent water-supply arrangements will depend on the length of time that the settlement is to be in use and the size of the population to be served. When existing water sources have been destroyed, new sources may also need to be selected.

Table 7.1 summarizes the characteristics of the principal water sources and options for extraction, treatment and distribution of water. Figure 7.4 shows a decision tree for choosing an appropriate water source for short-term emergency supplies.

#### Improving existing water sources

Steps should be taken to progress rapidly from the initial emergency supply of water by whatever means possible, to gradual improvement. In the longer term, it should be possible to improve and protect existing sources and to develop new ones, such as springs

Table 7.1 Typology of water sources<sup>1</sup>

Source	Treatment	Extraction	Distribution	Remarks
Rain	Unnecessary if catchment and receptacles clean	Channelling off suitable roofs and/or hard ground	Collection directly at household or institutional level	Useful as supplementary source of safe water in certain seasons
<i>Groundwater:</i>				
Natural spring	Unnecessary if properly protected	Simple gravity flow: preferably piped from a protective spring box	Individual collection directly, via storage tanks or gravity-fed distribution system	Source must be protected; yield may vary seasonally
Deep well (low water-table)	Unnecessary if properly located, constructed and maintained	Handpump possible if water-table less than 60m deep and output required is low, otherwise motor pumps necessary	Individually pumped by hand, or motor pumped to storage tanks, possibly linked to distribution systems	Yield unlikely to vary much with seasons unless prolonged drought. Special construction equipment and expertise required. High yields often possible
Shallow well (high water-table)	Unnecessary if properly located, constructed and maintained	Hand pump or rope and bucket	Pumped or drawn directly from wells by individuals	Yield may vary seasonally; can be dug/drilled by local skilled labour. Care needed to avoid contamination
<i>Surface water:</i>				
Flowing (stream, river)	Always necessary: sedimentation, filtration and/or chlorination	Preferably pumped to storage and treatment tanks	Individual collection, preferably from storage/treatment tanks	Yield may vary seasonally; access to source should be controlled
Standing (lake, pond)	Always necessary, as above	As above	As above	As above

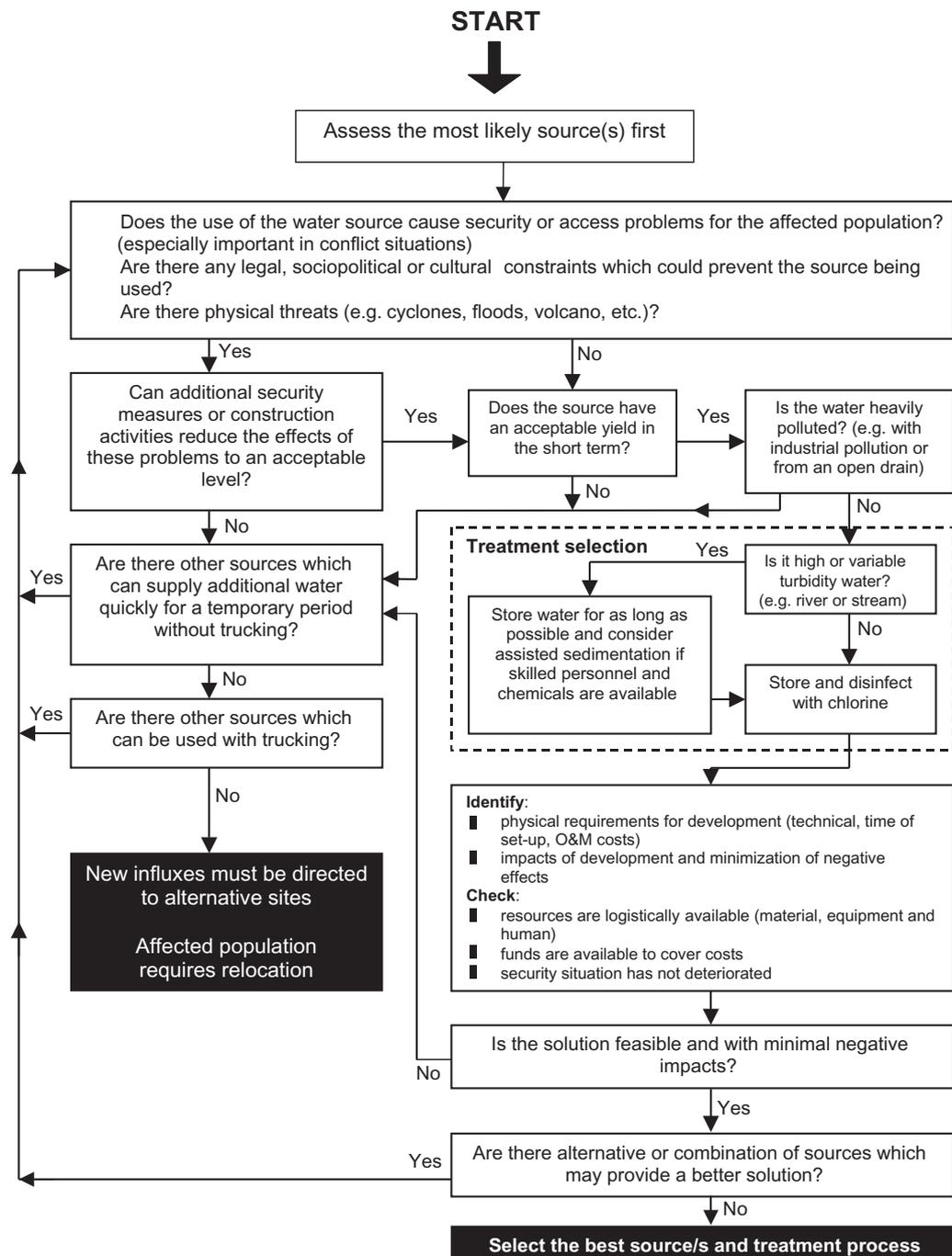
<sup>1</sup> Adapted from United Nations High Commissioner for Refugees (1992a).

and boreholes. The host population may give permission for their sources to be improved and shared. Figure 7.4 facilitates the selection of a water source and the identification of treatment options.

### Water source protection

A minimum number of essential measures to protect water supplies should be taken immediately after a disaster, as follows:

- Consult and involve the people concerned in solving (and thus understanding) the problems associated with water supplies.
- Segregate water uses (drinking, bathing, livestock watering).
- Protect water sources from faecal contamination by fencing them in, and by arranging for the use of a defecation field or shallow trench latrines at a suitable distance from the source.
- Store water in large covered tanks or containers for a day or two, if possible, allowing sediment to settle out, as subsequent chlorination is more effective if the water

Figure 7.4 Choosing a water source and treatment options for a short-term emergency water supply<sup>1</sup>

<sup>1</sup> Source: House & Reed (1997)

is clear. After a few days, a better choice of locally-available water sources and more elaborate treatment may be possible.

- Give preference to groundwater rather than to surface water. Initially, it should be assumed that all surface water is contaminated.
- Use chlorine to protect water from contamination in the course of distribution and use, such that a free chlorine residual of 0.4–0.5 mg/l is achieved immediately after treatment (or 0.2–0.5 mg/l at the point of distribution).

### Controlling direct use of sources

When people take water for a variety of uses directly from a source, the most rapid intervention to protect health is to segregate uses in time or space, to reduce the risk of contaminating drinking-water. Livestock should not be allowed to trample and defecate near human water sources, and water for livestock should be piped to watering troughs some way away from the source. Fencing maintained by local volunteers should be used to demarcate the human and animal watering places (Figure 7.5).

Environmental health staff should consult the people concerned, the village/community health or safety committee, and the primary health-care workers so that culturally acceptable methods of coordinating and segregating different types of use are adopted. There are usually socially established rules governing access, in terms of both time and space, to local water supplies, although in an emergency these may break down. They can, however, provide a basis for a constructive discussion of the problem with local people.

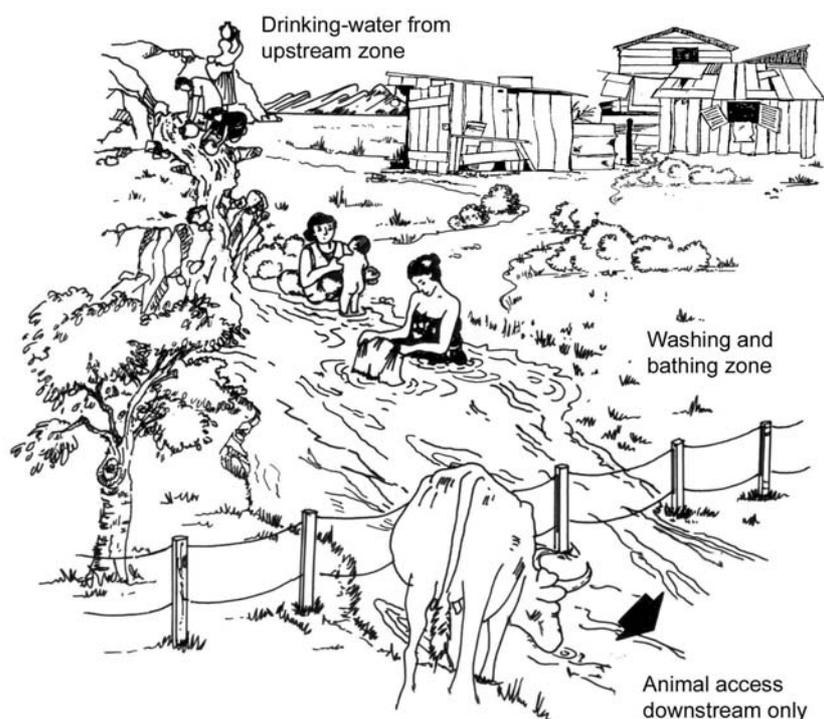
### Roof-catchment systems

Depending on climate and weather conditions, roof-catchment systems can be used to supplement water supplies. Corrugated metal and tile roofs are best for this purpose, but even thatched roofs can provide good water, if debris is filtered out (Hall, 1990). Properly filtered and chlorinated, roof-catchment water can make a good independent or supplementary/reserve source for the camp kitchen or health centre.

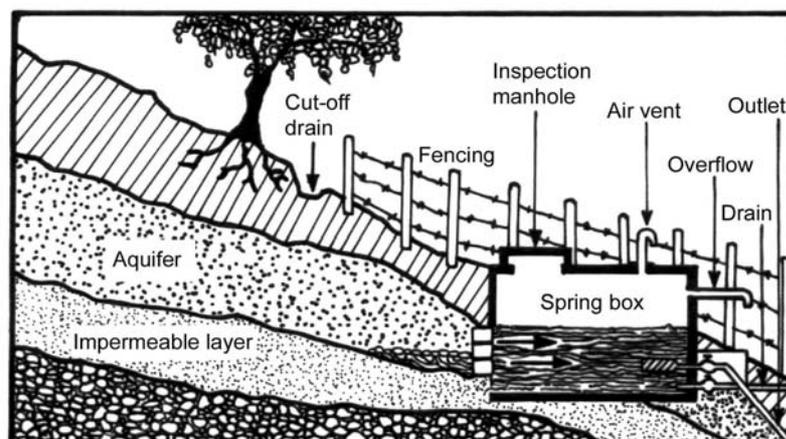
### Springs

Unprotected springs can be capped to prevent inflow of polluted surface waters (see Figure 7.6). The water can be piped into a covered reservoir, or to collection points convenient to both the host population and the camp.

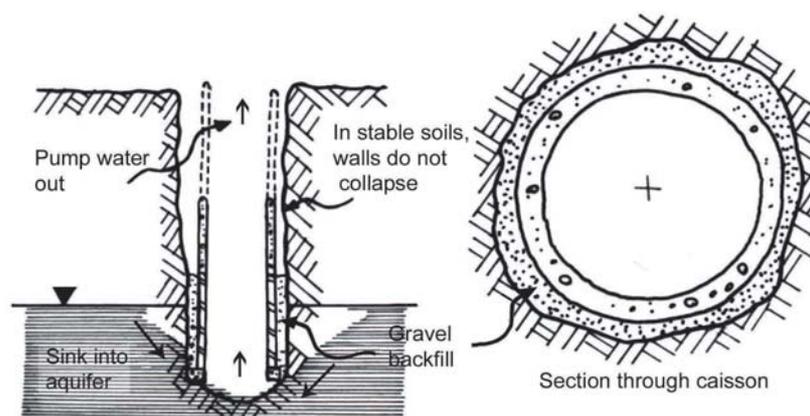
Figure 7.5 Use of fencing to demarcate human and animal watering places<sup>1</sup>



<sup>1</sup> Source: Chartier et al. (1991).

Figure 7.6 A protected spring<sup>1</sup>

<sup>1</sup>Source: adapted from World Health Organization (1997a)

Figure 7.7 Improvement of water hole with concrete caisson<sup>1</sup>

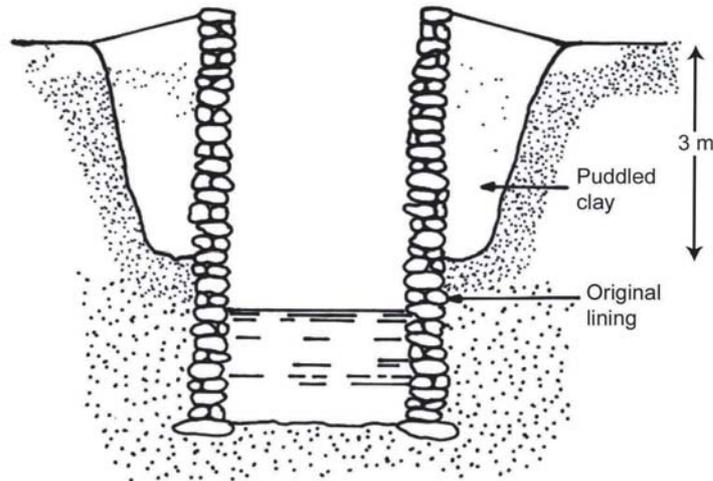
<sup>1</sup>Source: Watt & Wood (1979).

### Crude water holes and shallow wells

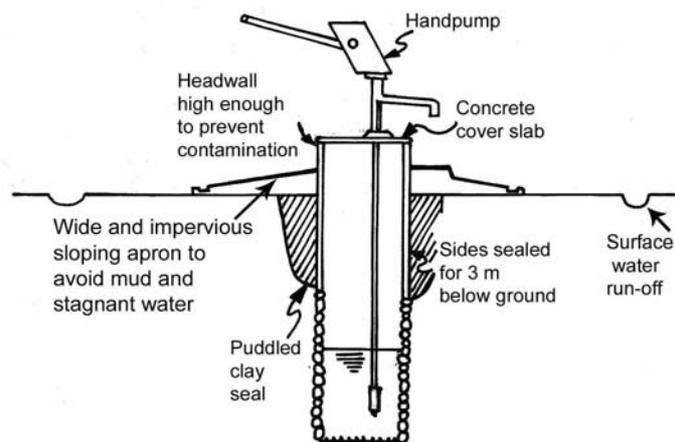
Where there is an open water hole dug into the groundwater table (i.e. not simply a depression that accumulates run-off), concrete rings or caissons can be inserted into the well once it has been deepened (see Figure 7.7). Whether it is a well or an infiltration gallery, a crude water hole still needs further improvement to prevent contamination of the aquifer by surface water. The outside of the well may need to be sealed.

Where the existing source is an open, unprotected well, it can be improved by sealing the upper 3 metres of the walls and providing a cover, surface drainage and an improved low-maintenance pump (see Figure 7.8).

To seal the well, earth is excavated all round the existing well lining (as depicted) and refilled with “puddled clay”, i.e. clay that has been thoroughly mixed with a little water and sand to the consistency of a thick paste, which is then compacted into position. The well should then be disinfected with 50–100 mg/l chlorine for 24 hours and flushed out. Water should be monitored for subsequent contamination. If contamination is detected (or if users are complaining of diarrhoea), water can be drawn from the well and chlorinated at the well, or at the household level (leaving a free residual chlorine of 0.4–0.5 mg/l after 30 minutes), until the source of contamination is found and removed.

Figure 7.8 Improving an existing well with puddled clay<sup>1</sup>

<sup>1</sup> Sources: adapted from United Nations Children's Fund (1986), Cairncross & Feachem (1978).

Figure 7.9 A typical protected dug well installation<sup>1</sup>

<sup>1</sup> Source: adapted from United Nations High Commissioner for Refugees (1992a).

These simple improvements are the first stages in the protection of a well. The most important improvements that can be made are providing a sloping surface around the well for drainage and raising the head wall high enough to block surface run-off. Other important features of a protected dug well are shown in Figure 7.9. Where possible, cover slabs and handpumps should be used, rather than buckets and windlasses, particularly when there is great demand from each well.

For information on safety precautions for digging wells, see Box 7.2.

### Improving the yield of wells

Dug wells can be deepened and protected at the same time. They can also be extended laterally into the water-bearing stratum, which is especially useful if they cannot be deepened because of impenetrable rock. Figure 7.10 shows several possibilities: tunnels or adits constructed at the bottom of the well, porous pipes driven through the well lining, porous pipe driven or bored into the base of the well, etc. Care must always be taken to protect the well and the aquifer against the inflow of contaminated surface water. *Extreme caution must always be exercised to ensure that workers are not endangered* (see Box 7.2).

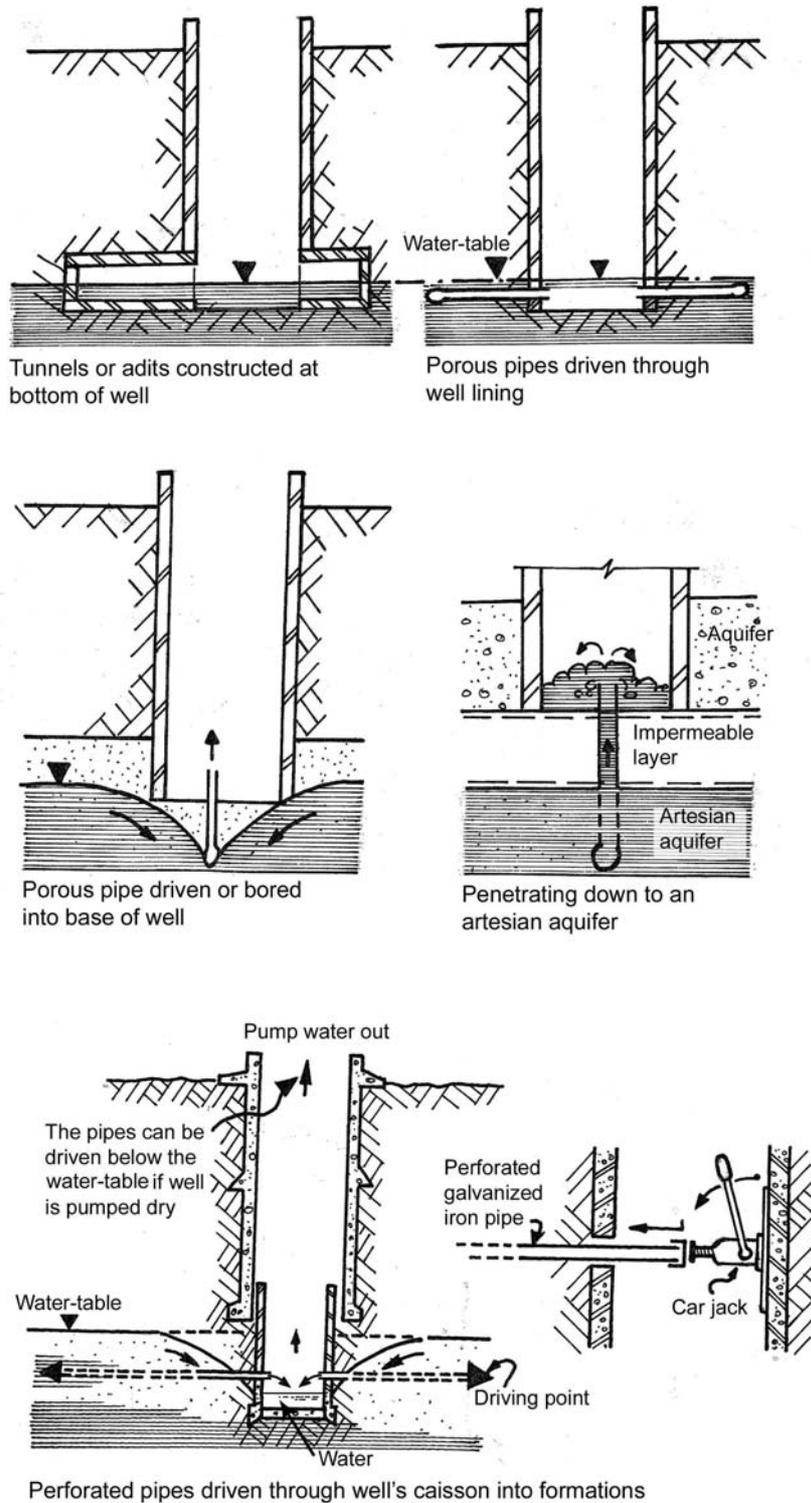
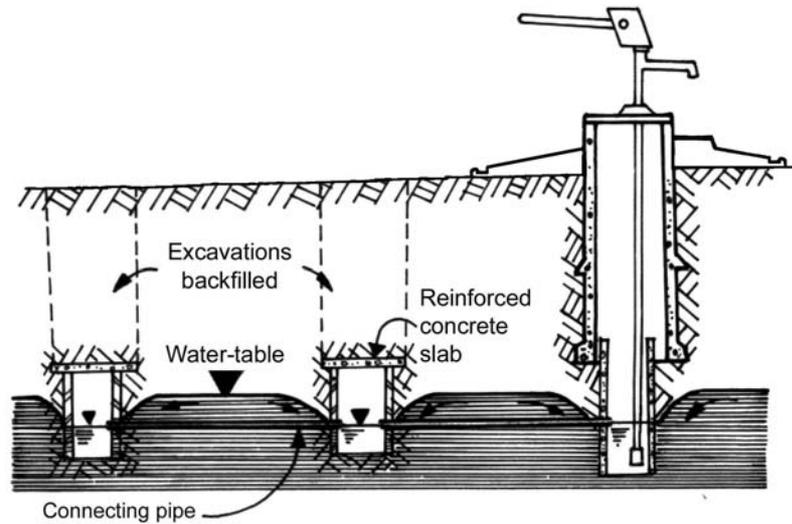
Figure 7.10 Methods of improving the output of wells<sup>1</sup><sup>1</sup>Source: Watt & Wood (1979).

Figure 7.11 Connected wells<sup>1</sup>

<sup>1</sup> Source: Watt & Wood (1979).

#### Box 7.2 Safety precautions for digging wells

Well-diggers should:

- not work in sections more than 1 m deep when deepening wells, without temporary shuttering or well lining to prevent a collapse, unless the soil is known to be very stable (for instance from previous experience with unlined wells in the same locality);
- be aware of the risk of dangerous gases in deep wells;
- not allow building materials to fall into the well;
- exercise care while removing buckets of excavated earth and when entering or leaving the well (preferably using a harness or simple bosun's chair and never descending with one foot in a bucket);
- be provided with and wear hard hats and protective boots;
- ensure that electrical cables for dewatering pumps are properly protected and checked regularly for damage;
- never lower diesel- or petrol-driven dewatering pumps into the well while deepening, as **exhaust fumes are fatal**.

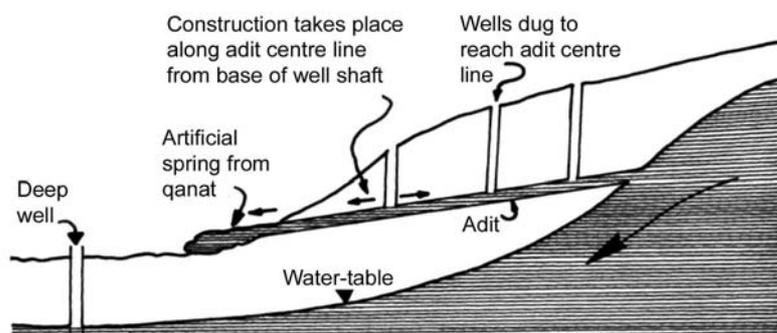
For further information, see: Watt & Wood (1979), Oxfam (1990).

In some shallow aquifers, wells are constructed close together in a row and connected with a tunnel or bored pipe. Only one is left open, and the remainder are backfilled, thus saving lining material and time (see Figure 7.11).

In a variation on the well-established Iranian *qanat* (or *falaj*), a borehole can be drilled horizontally into the hillside until the water-table is hit, providing an artificial spring or, in the traditional way, a horizontal adit can be dug between a series of vertical wells until the water-table is encountered (Figure 7.12).

#### Boreholes

Over the past 40 years, a variety of well-drilling rigs have been developed, with different designs now available for drilling through a range of geological formations, from unconsolidated alluvium to very hard crystalline formations. Some of this equipment is rela-

Figure 7.12 Construction of a *qanat* or *falaj*<sup>1</sup>

<sup>1</sup> Source: Watt & Wood (1979).

### Box 7.3 Contracting out borehole drilling

Drilling will often be carried out by a specialized contractor hired by an NGO, health authority or municipality. The following should be considered when selecting a contractor:

- Has the company a local or national reputation for good work? Can it provide details of similar drilling work that it has completed recently? Does it belong to a professional organization? Is it on a list of approved contractors for an organization employing drilling contractors?
- Is there evidence that the company has the equipment to do the work? Is the equipment in good repair and well maintained? Does the company have maintenance and back-up facilities in case of plant breakdown? Is its depot close to the proposed drilling site, so that backup can be efficient? Is the depot kept in a clean and workmanlike state?

When contracting out for a more than 10 boreholes, it may be useful to hire two contractors, each with a clause in the drilling contract that specifies that if they do not meet time and quality requirements, the other contractor may be awarded the outstanding work.

Contracting out borehole drilling is a difficult exercise that requires considerable knowledge and experience. Having recognized this problem, UNHCR has published a suggested format for technical specifications for borehole drilling (United Nations High Commissioner for Refugees, 1992a).

tively cheap, portable, and simple to use. For instance, in an area with a high water-table, a well can be drilled with a hand auger, with a filter tube and filter pack of sand and gravel placed at the bottom; the entire well is sealed, protecting it from surface contamination. Other types of drilling equipment are expensive, large, and complex, requiring specialist teams of technicians to operate them. For a summary of drilling techniques, see United Nations High Commissioner for Refugees (1992a) and Davis and Lambert (2002).

Drilling boreholes is a skilled activity requiring specialist equipment and it is often contracted out (see Box 7.3).

Boreholes, deep wells and protected springs consistently yield the safest water from a bacteriological point of view. With deep boreholes in unfamiliar geology however, care should be taken to identify the chemical characteristics of the water by means of the appropriate tests in accordance with the *WHO Guidelines for drinking-water quality* (see also: United Nations High Commissioner for Refugees, 1992a).

Environmental health staff should provide information on water needs to help in the choice of drilling locations. They may be involved in sampling and testing water to ensure it is potable (see Section 7.4.3), and disinfecting boreholes before they are put into use.

### Water harvesting

Various water-harvesting techniques are possible, ranging from roof catchments to more elaborate harvesting of rare, but heavy, rainfall. For example, Figure 7.13 shows the design of a Somali *hafir* routing run-off from rain into a ground reservoir and then to an outlet well.

Dust, animal manure, human excreta and other contaminants should be considered in all methods of water harvesting and, in an emergency, harvested water should be treated in the same way as surface water because of the likelihood of contamination during harvesting.

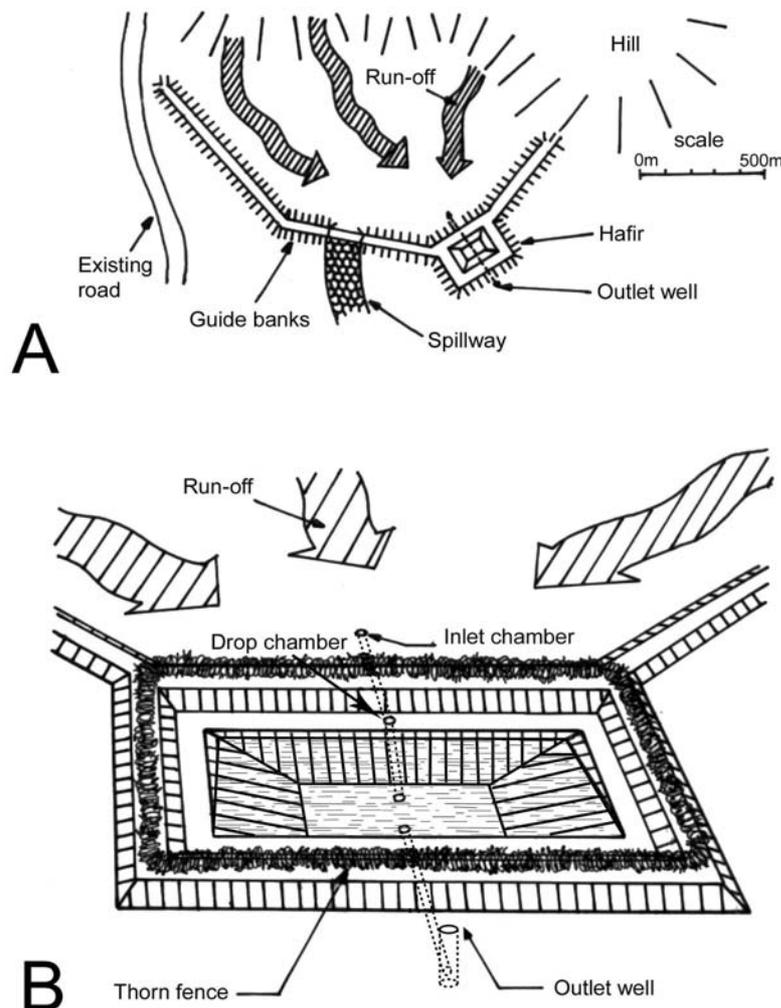
### Rivers and lakes

It should be assumed that all surface water is contaminated and should be treated before consumption. It should only be used as a primary source if groundwater is unavailable or insufficient.

A wooden crib, anchored on the river bed with gravel or rocks, will protect the intake from physical damage (see Fig. 7.14A).

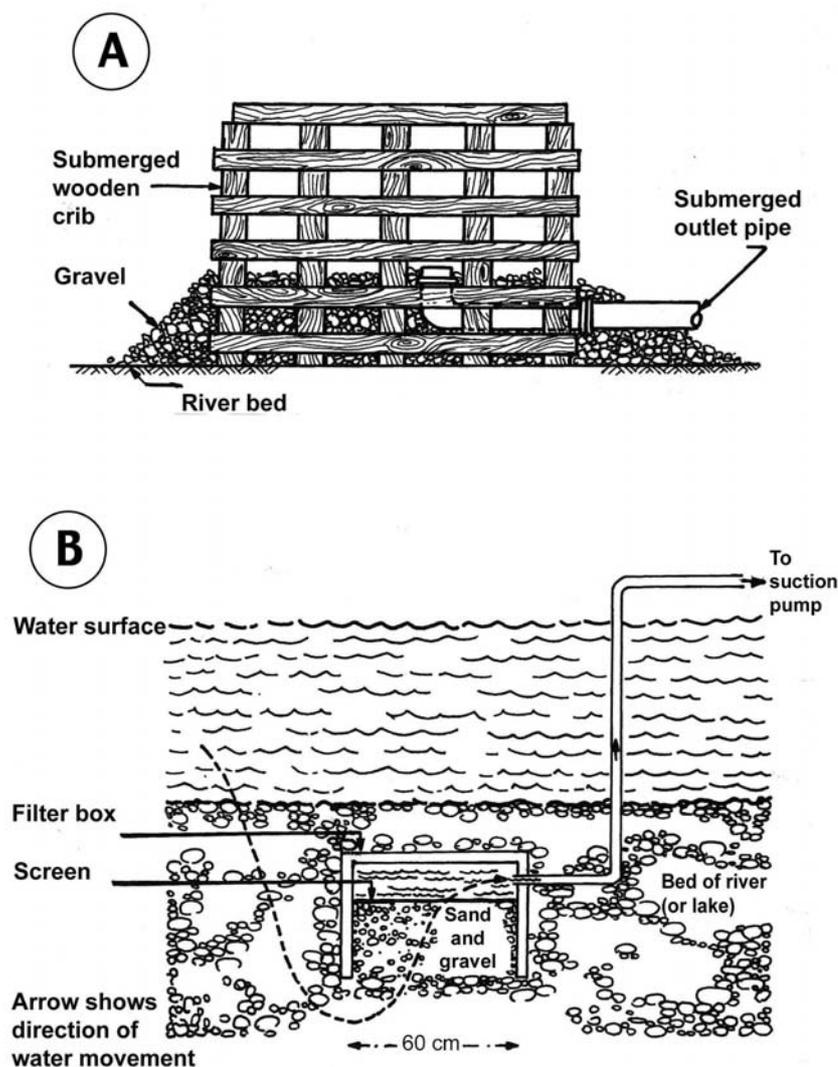
Surface water often needs some form of pretreatment to reduce turbidity before filtration and/or disinfection. Various methods are described in Section 7.4.3. The water

Figure 7.13 Design of Somali *hafir*. A: overall plan; B: detail in perspective<sup>1</sup>



<sup>1</sup> Source: Pacey & Cullis (1986).

Figure 7.14 Water intake systems for lakes or rivers: (A) Wooden crib at intake; (B) Lake or river-bed filter<sup>1</sup>



<sup>1</sup> Sources: A: Pickford (1977). B: United Nations Children's Fund (1986).

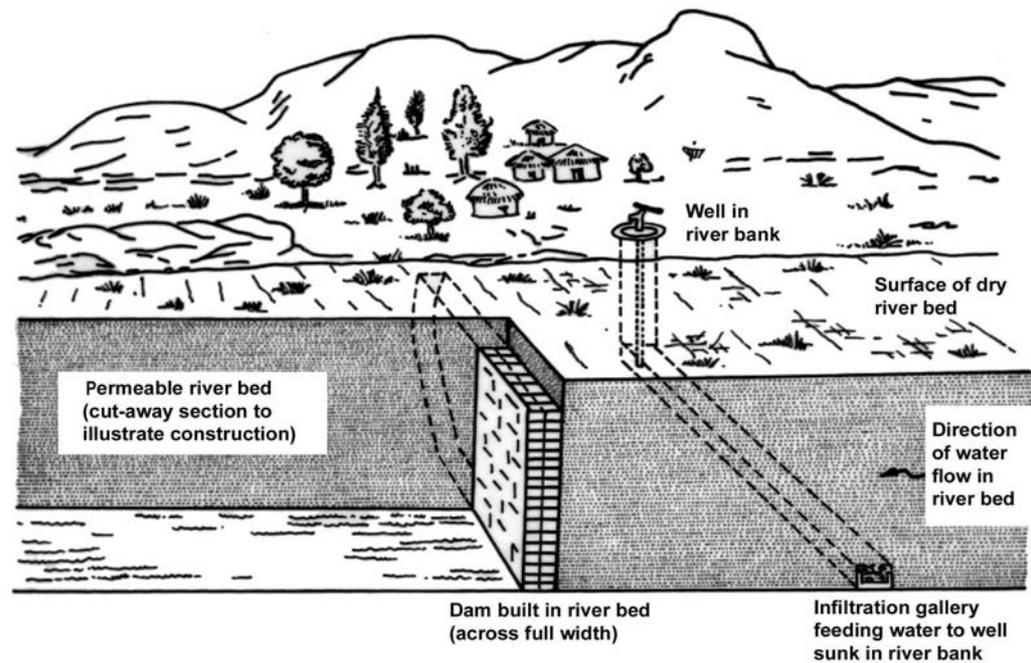
abstraction structure may incorporate a river-bed or lake-bed filter, as shown in Figure 7.14B. Water abstracted through such a sand and gravel filter (or even a crude screen) can then be stored and treated onshore.

Another method of pretreatment at source is the installation of an infiltration gallery leading to a protected well dug in the river or lake bank (see Figure 7.15). In low-flow rivers or streams that dry up seasonally, an underground dam may be constructed to impound underground water behind it.

#### 7.4.2 Water quality and water testing in emergencies

##### Important quality criteria

The greatest water-borne risk to health in most emergencies is the transmission of faecal pathogens, due to inadequate sanitation, hygiene and protection of water sources. Water-borne infectious diseases include diarrhoea, typhoid, cholera, dysentery and infectious hepatitis. However, some disasters, including those involving damage to chemical and nuclear industrial installations, or involving volcanic activity, may create acute problems from chemical or radiological water pollution.

Figure 7.15 Subsurface dam and infiltration gallery<sup>1</sup>

<sup>1</sup> Source: United Nations Children's Fund (1986).

Whatever the source and type of contamination, decisions on acceptable water quality in emergencies involve balancing short- and long-term risks and benefits to health. At the same time, ensuring access to sufficient quantities of water is vital for health protection.

Many chemicals in drinking-water are of concern only after extended periods of exposure. Thus, it is advisable to supply water in an emergency, even if it significantly exceeds WHO guidelines for some chemical parameters, if the water can be treated to kill pathogens and then supplied rapidly to the affected population. This will reduce the risk of outbreaks of water-borne and water-washed disease. When water sources are likely to be used for long periods, chemical and radiological contaminants of more chronic health importance should be given greater attention. In some situations, this may entail adding treatment processes, or seeking alternative sources.

### Bacteriological testing

The principle of bacteriological testing is to identify a "faecal indicator" organism that is always excreted by warm-blooded animals, both healthy and unhealthy, and to take the degree of its presence as an indication of the degree of faecal contamination. Bacteria from the thermotolerant (faecal) coliform group are nearly always present in faeces, so their presence in water is a strong indication of faecal contamination. Typically, most thermotolerant coliforms are of the species *Escherichia coli*, which is always derived from faeces. The presence of any bacteria from the total coliform group is sometimes tested for, particularly as an indication of the effectiveness of a water-treatment system. Many members of the total coliform group are free-living and their presence does not depend on the presence of faecal contamination, but it can indicate that a treatment process has not removed or killed all bacteria. Other faecal indicator bacteria include faecal streptococci/intestinal enterococci.

Field kits for bacteriological testing usually employ the membrane-filtration technique, where a measured volume of water is filtered through a membrane, which retains

the bacteria on its surface. The membrane is then incubated on a suitable medium, using a battery-powered incubator, for 18 hours. During this time, the thermotolerant coliform bacteria reproduce and form colonies. The number of colonies formed provides an index of the degree of faecal contamination in the original sample. This test is generally easy to perform. However, high turbidity caused by clay, algae, etc. (which may be suspended in large quantities after storms and floods) can interfere with the test, but as small volumes are often analysed in these circumstances, this may not be a significant problem.

The multiple-tube method is an alternative to membrane-filtration. Quantities of the water to be tested are added to tubes containing a suitable liquid culture medium and incubated, typically for at least 24 hours. The bacteria present in the water reproduce, and the most probable number of bacteria present is determined statistically from the number of tubes giving a positive reaction (colour change and/or gas production). This test can accommodate even turbid samples, containing sewage, sewage sludge, or mud and soil particles.

### Bacteriological guidelines

Conventional bacteriological standards may be difficult to achieve in the immediate post-disaster period. The WHO guideline of zero *E. coli* per 100 ml of water should be the goal (World Health Organization, 1993a) and should be achievable even in emergencies, provided that chemical disinfection is employed.

Recognizing that achieving the guideline standards may be difficult in some emergency situations, it is practical to classify water quality results according to the degree of health concern (Lloyd & Helmer, 1991; Delmas & Courvallet, 1994). For example:

- zero *E. coli*/100 ml: guideline compliant;
- 1–10 *E. coli*/100 ml: tolerable;
- 10–100 *E. coli*/100 ml: requires treatment;
- greater than 100 *E. coli*/100 ml: unsuitable for consumption without proper treatment.

An indication of a certain level of a faecal indicator bacteria *alone* is not a reliable guide to biological water quality. Some faecal pathogens, including many viruses and protozoa, may be more resistant to treatment (such as by chlorine) than the indicator bacteria. More generally, if a sanitary survey suggests the likelihood of faecal contamination, then even a very low level of contamination measured by bacteriological analysis may be considered to be a risk, especially during an outbreak of a disease like cholera that may be water-borne.

The parameters most commonly measured to assess microbial safety are: *E. coli* (thermotolerant coliforms); residual chlorine; pH; and turbidity.

### Residual chlorine

Chlorine content should be tested in the field with a colour comparator, generally used in the range of 0.2–1 mg/l of water. Taste does not give a reliable indication of chlorine concentration.

### pH

It is necessary to know the pH of water because more alkaline water requires a longer contact time or a higher free residual chlorine level at the end of the contact time for adequate disinfection (0.4–0.5 mg/l at pH 6–8, rising to 0.6 mg/litre at pH 8–9, and may be ineffective above pH 9).

### Turbidity

Turbidity, or cloudiness, is measured to determine what type and level of treatment is needed. It can be carried out with a simple turbidity tube that allows a direct reading in turbidity units (NTUs). Turbidity adversely affects the efficiency of disinfection (see Section 7.4.3.)

### Sanitary surveys and catchment mapping

It is possible to assess the likelihood of faecal contamination of water sources by a sanitary survey. This is often more valuable than bacteriological testing alone, because a sanitary survey makes it possible to see what needs to be done to protect the water source, and because faecal contamination may vary, so a water sample only represents the quality of the water at the time it was collected. This process can be combined with bacteriological, physical and chemical testing to enable field teams to assess contamination and—more importantly—provide the basis for monitoring water supplies in the post-disaster period.

Even when it is possible to carry out bacteriological quality testing, results are not instantly available. Thus, the immediate assessment of contamination risk should be based on gross indicators, such as proximity to sources of faecal contamination (human or animal); colour and smell; the presence of dead fish or animals; the presence of foreign matter, such as ash or debris; and the presence of a chemical or radiation hazard, or a wastewater discharge point upstream. Catchment mapping that involves identifying sources and pathways of pollution can be an important tool for assessing the likelihood of contamination of a water source.

It is important to use a standard reporting format for sanitary surveys and catchment mapping, to ensure that information gathered by different staff is reliable and that information on different water sources may be compared. For an example sanitary survey format, see: World Health Organization (1997a), Davis & Lambert (2002). For more information on catchment mapping, see: House & Reed (1997).

### Chemical and radiological guidelines

Water from sources that are considered to have a significant risk of chemical or radiological contamination should be avoided, even as a temporary measure. In the long term, achieving WHO guidelines should be the aim of emergency water-supply programmes based on the progressive improvement of water quality (Sphere Project 2000).

### Testing kits and laboratories

Portable testing kits allow the determination in the field of water pH (acidity/alkalinity), free residual chlorine, faecal coliform bacteria count, turbidity and filterability. The use of such a kit in Nicaragua is described in Box 7.4.

When large numbers of water samples need testing, or a broad range of parameters is of interest, laboratory analysis is usually most appropriate. If laboratories at water-treatment works, environmental health offices and universities no longer function because of the disaster then a temporary laboratory may need to be set up. When samples are transported to laboratories, handling is important. Poor handling may lead to meaningless or misleading results.

Workers should be trained in the correct procedures for collecting, labeling, packing and transporting samples, and for supplying supporting information from the sanitary survey to help interpret laboratory results. For standard methods of water sampling and testing, see: World Health Organization (1997a), Bartram & Ballance (1996).

**Box 7.4 Use of portable water-testing kits after hurricane Joan in Nicaragua<sup>1</sup>**

Portable water-testing kits have been effectively used under disaster conditions, such as in Nicaragua after hurricane Joan blew away all the roof water-catchment systems in the town of Bluefields in 1988. People were forced to resort to old open, shallow wells that were normally used only for washing and cleaning, and that were located near latrines. The hurricane had also flooded these wells with filth. The least turbid and obviously contaminated ones were selected as emergency water sources and continuous chlorination was begun. Residents in each of the town's neighbourhoods were responsible for checking on free residual chlorine levels daily and adding daily doses of chlorine.

<sup>1</sup> Catholic Institute for International Relations (1989).

**7.4.3 Treatment of emergency water supplies**

The processes required to render raw water potable depend on its physicochemical and biological quality. Surface water that is highly turbid and heavily contaminated usually needs some form of pretreatment to prepare it for disinfection or, in some cases, slow sand filtration. The pretreatment processes described below are storage and plain sedimentation, coagulation and flocculation, and roughing filtration.

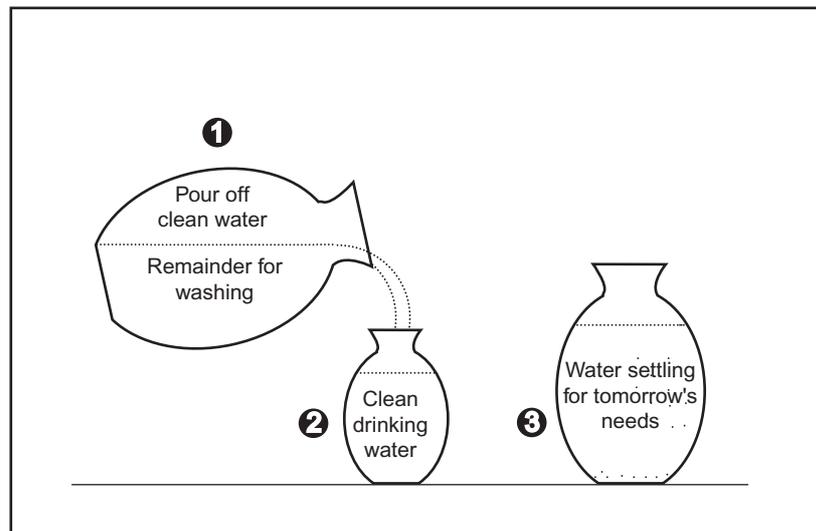
**Storage and plain sedimentation**

Simply storing water for a number of hours improves water quality. Solid particles settle to the bottom of the storage tank, taking a proportion of the pathogens with them and reducing turbidity; there is a degree of improvement through natural bacterial die-off; and storing river water provides a buffer stock, allowing operators to avoid using raw water during peaks in turbidity after rains (Davis & Lambert, 2002). Water storage and plain sedimentation may be arranged at central level, as pretreatment for a piped supply. In such cases, samples of raw water should be taken and jar tests carried out to see how fast the solids settle, and to choose an appropriate storage time, storage capacity and dimensions of the storage tanks. In an emergency it is rarely possible to design and build tanks for specific situations, but an effective system may be improvised using a series of available water tanks in a configuration that takes account of the raw water quality, the degree of pretreatment required, and the quantity to be pretreated.

Plain sedimentation can also be organized at household level where centralized treatment is not possible. Water is allowed to settle in whatever large, clean, covered storage vessels are available. After 24 hours (or more if possible), the clear water is drawn or poured off the top. The sediment is discarded, or used for laundry if water is scarce. The resulting clear water should be chlorinated. Figure 7.16 shows a simple household storage system that allows settling to take place.

**Coagulation and flocculation**

Another method of reducing the turbidity of water uses coagulation and flocculation. In this process, colloidal particles such as clays, that do not readily settle in plain sedimentation, are encouraged to combine to form heavier particles that will settle by adding a chemical coagulant, such as aluminium sulphate (alum), ferric chloride, ferric sulphate, or natural coagulants. The dose of coagulant required depends on the nature of the raw water and the chemical used and has to be determined by carrying out jar tests with different doses of the coagulant. The effectiveness of coagulation and flocculation is strongly influenced by the pH of the water.

Figure 7.16 Simple household storage system for removal of sediment<sup>1</sup>

<sup>1</sup> Source: Chartier, Diskett & UNHCR (1991).

Once the dosage rate has been determined, a simple dosing system can be set up in an emergency, where the coagulant is rapidly mixed with the raw water as it is fed into a treatment tank. In a second stage, the mixture is gently stirred for 30 minutes, to facilitate flocculation. After this time, clear water may be drawn from the upper level of the tank, but in a batch treatment process (as opposed to a continuous flow process) it may take up to 8 hours for the particles to settle to the bottom of the tank and for the water to be ready for distribution. The rapidity of settling is greatest when initial mixing is done thoroughly. After a period, which depends on the turbidity of the raw water and the quantity being treated, the sludge at the bottom of the tank needs drawing off and disposing of. Care should be taken to ensure that sludge disposal does not contaminate water sources or agricultural land.

### Roughing filtration

Roughing filtration is a process that combines filtration and sedimentation, that can be used to reduce the turbidity of water carrying large amounts of suspended solids. The clarified water may then be further treated by rapid sand filtration or slow sand filtration, or disinfected directly, if the turbidity is sufficiently reduced (to below 5 NTU preferably, but up to 20 NTU may be permitted). Roughing filters use relatively coarse media (5–25 mm diameter), and may be constructed to operate with horizontal flow or vertical flow. They have several advantages, including their simplicity, but they can take some time to install. Vertical-flow roughing filters may be made rapidly using Oxfam-type rigid tanks.

### Rapid sand filtration and slow sand filtration

Rapid sand filters are commonly used in urban water-treatment systems, and they may need attention in an emergency because of changes in raw water quality or mechanical and electrical breakdowns. However, they are not recommended as an emergency water-treatment option because of a number of drawbacks, including the fact that they provide only partial treatment through a simple filtration process. Disinfection is required after rapid filtration.

Slow sand filtration, on the other hand, removes microorganisms and, if properly operated, produces water which is safe to drink. Slow sand filters may be designed and built following relatively simple procedures, on a large scale and on a small scale. A filter adequate for processing 60 litres per hour may be made in a few hours with only a metal drum and simple tools and fittings, though the need for careful operation makes this generally unsuitable for household level in an emergency. The method works best in warm climates at low levels of turbidity. Two major disadvantages of slow sand filtration is the relatively low yield for the size of the installation required, and the need for careful operation to ensure the top layer of sand with the trapped disease-causing organisms does not dry out. In addition, when there is a significant risk of water contamination in the distribution system or in the household, the treated water should still be chlorinated.

### Disinfection

WHO endorses disinfection of drinking-water and in emergency situations drinking-water should be disinfected in all cases where population size and concentration, lack of sanitary facilities, or health information suggest a significant risk of water-borne disease. Disinfection should not be used as a substitute for protecting water sources from contamination. Water sources should always be protected to reduce the contamination of raw water and reduce the health risks associated with incomplete or unreliable disinfection procedures.

There are a number of different water disinfection methods used in stable situations, but the most common method in emergencies is chlorination. Important advantages of chlorine disinfection are that it is simple to dose and to measure, and that it leaves a residual disinfection capacity in the treated water, safeguarding against contamination in the home. This is particularly important when sanitation is inadequate. Chlorine gas is most commonly used in urban water-treatment works, but this requires careful storage and handling by well-trained staff, as well as dosing equipment. For emergency water-treatment installations, chlorine compounds in solid or liquid form are most often used, as these are simple to store and handle, and may be dosed using simple equipment, such as a spoon or bucket.

The chlorine compound most commonly used for water disinfection in emergencies is calcium hypochlorite, in powder or granular form. One form of calcium hypochlorite that is frequently used is high-test hypochlorite (HTH). Calcium hypochlorite should be stored in dry, sealed corrosion-resistant containers in a cool, well-ventilated place to ensure that it retains its strength. All concentrated chlorine compounds, such as HTH and concentrated chlorine solutions, give off chlorine gas. This gas is poisonous and may burn the eyes and skin, and can start fires or explosions. All concentrated chlorine compounds should be handled with care by trained staff wearing protective clothing.

Free residual chlorine levels of more than 0.3mg/l for more than 30 minutes are required to kill bacteria and most viruses. Chlorination of stored water for direct consumption is best achieved using a 1% stock solution of chlorine made up according to the instructions given in Table 7.2. With this stock solution as base, water can be treated as described in Table 7.3. Minimum target concentrations for chlorine to point of delivery are 0.2mg/l in normal circumstances and 0.5mg/l in high-risk circumstances.

Chlorination is less effective in turbid water. If the raw water has a turbidity over 20 NTUs, then some form of pretreatment should be carried out. Ideally the turbidity should be less than 5 NTUs.

Contact time or free chlorine residual should be increased in water with a high pH (see Section 7.4.2).

Table 7.2 Preparation of 1% chlorine stock solution<sup>1</sup>

**To make 1 litre of the stock solution, mix the quantity shown of one of the following chemical sources with water and make up to 1 litre in a glass, plastic or wooden container:**

<b>Chemical source</b>	<b>Percentage available chlorine</b>	<b>Quantity required</b>	<b>Approximate measures</b>
Bleaching powder	35	30 g	2 heaped tablespoons
Stabilized/tropical	25	40 g	3 heaped tablespoons bleach
High-test hypochlorite	70	14 ml	1 tablespoon solution
Liquid laundry bleach	5	200 ml	1 teacup or 6-oz milk tin
Liquid laundry bleach	7	145 ml	10 tablespoons
Javelle water	1	Is itself a 1% stock solution	

A 1% solution contains 10 g of chlorine per litre = 10 000 mg/l or 10 000 ppm (parts per million).

1 tablespoon = 4 teaspoons

Avoid skin contact with any of the chemical sources or the stock solution, and avoid inhaling chlorine fumes.

This stock solution should be *fresh*, i.e. made every day, and protected from heat and light.

<sup>1</sup> Source: United Nations Children's Fund (1986).

Table 7.3 Disinfecting water using a 1% stock solution<sup>1</sup>

**To produce an initial chlorine concentration sufficient to leave a free residual chlorine concentration of 0.4–0.5 mg/l after 30 minutes:**

1. Prepare a 1% chlorine solution (see Table 7.2).
2. Take 4 nonmetallic water containers (e.g. 20-litre plastic buckets) and put 10 litres of the water to be chlorinated in each one.
3. Using a syringe, add progressively greater doses of 1% chlorine solution to the containers:
  - 1<sup>st</sup> container: 1 ml
  - 2<sup>nd</sup> container: 1.5 ml
  - 3<sup>rd</sup> container: 2 ml
  - 4<sup>th</sup> container: 5 ml
4. Wait for 30 minutes and then measure the residual free chlorine concentration, using a comparator or test strip.
5. Choose the sample with between 0.4–0.5 mg/l of free residual chlorine.
6. Calculate the amount of 1% chlorine solution needed for the quantity of water to be treated.

<sup>1</sup> Source: Delmas & Courvallet, 1994.

Designated individuals should be responsible for monitoring daily the free residual chlorine level in all distributed and stored supplies, including water in household containers. They can be recruited from the affected population and trained.

Chlorine-based tablets (containing trichloroisocyanuric acid) may be used for short-term emergency chlorination in floating plastic containers. These tablets are normally used for swimming pool chlorination, but may also be used in emergency situations for

the continuous chlorination of water in wells or storage tanks, though the chlorine dosage is hard to control.

As indicated in Tables 7.2 and 7.3, a more reliable technique is to add the correct dose of chlorine to the water once it is drawn, at the collection point or at the household level, using a stock solution of a known active chlorine concentration (normally 1%). In an emergency, this may be organized by placing workers with a supply of chlorine stock solution at untreated-water collection areas, to add the correct dose of chlorine to water in buckets just after collection.

#### Disinfecting contaminated wells and tanks

A free residual chlorine level of 1–5 mg/l in a well or tank for 24 hours is sufficient to kill most pathogens once the well or tank has been cleaned of debris and protected. The well or tank should be pumped out, or flushed after disinfection, until the free residual chlorine concentration is below 0.5 mg/l. If there is an ongoing risk of contamination, then the source of contamination should be removed and/or the water should be disinfected continuously.

#### Other disinfection methods

Bringing water to a vigorous or rolling boil will kill most pathogens. Turbid water should be filtered through a clean cloth before boiling, to remove larger particles. The problem for most people in emergencies or disasters is the lack of facilities and fuel to do this. The boiling-point of water decreases with increasing altitude, so one minute of boiling time should be added for every 500 metres above sea level (United Nations High Commissioner for Refugees, 1992a).

In an emergency, individual households can treat a limited amount of water by storing it in clear glass containers and allowing it to remain in direct sunlight for a day to kill the pathogens. This method is more effective when the water has been oxygenated by leaving some space at the top of the bottle and then shaking it well (Reed, 1997).

Emergency decontamination processes may not always accomplish the optimal level of disinfection recommended by WHO, particularly with resistant pathogens such as viruses, and protozoan cysts or oocysts. However, implementation of emergency procedures may reduce the numbers of pathogens to levels where the risk of water-borne disease is largely restricted or even eliminated.

### 7.4.4 Water movement, storage and distribution

#### Water tankers

In the short term, water can be transported by purpose-built water-tank trucks (capacity typically 12 000 litres), water-tank trailers, or ordinary trucks carrying tanks, although this is an expensive option. Where purpose-built water tankers are not available, they may be improvised by securing rigid water tanks or flexible rubber/plastic tanks (also called pillow tanks or bladder tanks) onto the back of flatbed trucks. Flexible rubber or plastic tanks provide convenient storage on the ground for tankers to discharge into. However, they can be difficult to transport when filled with water, especially on poor-quality roads. Water delivered by tankers should be drawn from the safest possible sources and should be disinfected.

An element of contingency planning should be an inventory of tank trucks available locally, for instance in dairies, breweries and bottling plants, and those not being used by the fire service. Borrowed tankers must be thoroughly cleaned and disinfected before they are used for transporting water.

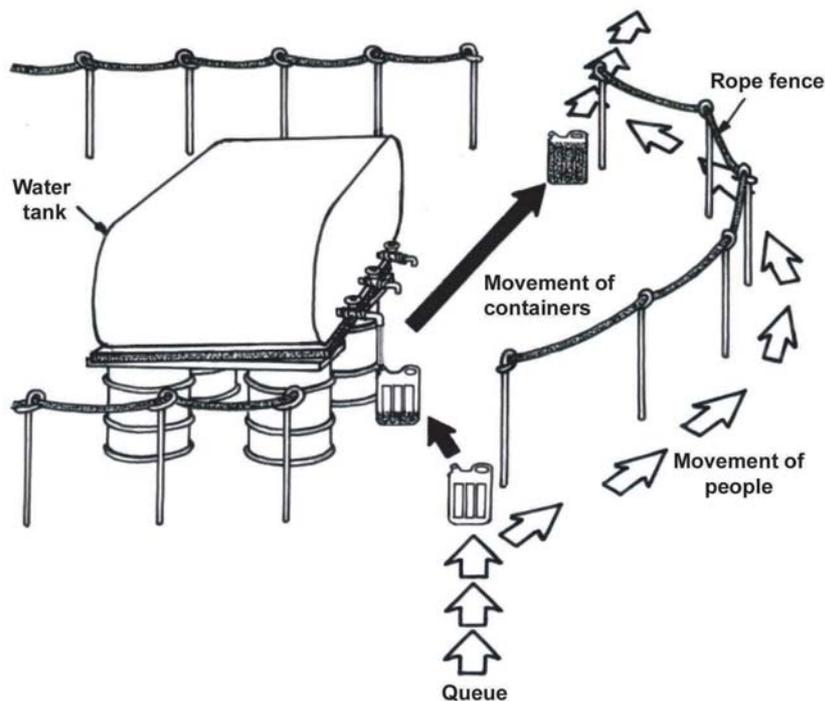
If water is carried in tankers, some arrangement should be made for filling them and for adequately storing the water at distribution points. Tankers should offload rapidly into small storage tanks at specified distribution points, rather than into individual water containers, which wastes a lot of time (see Figure 7.17). Water may be disinfected in tankers by adding the correct amount of chlorine as they are being filled, which allows time for chlorination during the delivery journey. The level of chlorine in the water at delivery should be monitored by independent staff, as well as by the drivers.

Water tankering is a costly option that requires very intensive management and monitoring. It should only be used as a temporary measure, unless there are no other suitable options.

### Storage tanks

Water should be conveyed (possibly through pumping) to a storage tank of a suitable size, depending on the population to be served, the reliability of the water source, and the treatment system. As a general rule, for groups of fewer than 2000 people, storage volume should be equal to one day's demand. For larger groups, the storage volume per person may be smaller, but never less than one-sixth of the daily water demand (United Nations High Commissioner for Refugees, 1992a). However, the appropriate storage volume will depend on a number of specific factors, such as the reliability of the water source and pumping facilities (where relevant), security considerations, cost, and peaks in demand. If the tank can be raised to provide 10–20 metres head of water, final distribution to the settlement by gravity will be possible. Ready-made plastic/rubber pillow tanks and onion tanks, or steel section tanks with rubber liners should be used if available, as they are rapidly installed. For further details, see Section 7.4.5. Otherwise, ferrocement or masonry tanks may be required. A temporary water tank can be made by building a perimeter wall out of sandbags and lining it with plastic sheeting. However,

Figure 7.17 A temporary water-distribution stand with three taps<sup>1</sup>



<sup>1</sup> Source: Davis & Lambert (2002).

skill is required to create a stable structure and to construct an effective outlet arrangement.

### Water transmission and distribution

Both gravity flow and pumps are normally used for transmitting and distributing water. Gravity flow is preferable as it avoids dependence on pumps and power supplies, so reducing costs, workload, and the risk of supply cuts as a result of breakdowns or fuel shortages. If natural slopes are not available, storage tanks can be built on raised mounds of compacted earth, an adequate margin of earth being provided around the tank to avoid collapse due to erosion. If pumps are used for distribution, a back-up pump should always be available together with a fuel reserve in case fuel supply to the settlement is cut off.

Polyethylene pipe and uPVC pipe are usually used to distribute mains water in emergency settlements. They are both commonly used in diameters of 75–150 mm. Polyethylene pipe is also available in 50-metre or 100-metre coils, which can be laid rapidly. Polyethylene pipe also has the advantage of being very robust and flexible, so it may be laid on the surface for a short space of time. It is, however, considerably more expensive than uPVC pipe, and less readily available in some countries. Both types of pipe should be buried in a trench to reduce the risk of breakages (particularly uPVC pipe, which is more brittle), and to reduce exposure to sunlight, which causes them to deteriorate. When uPVC pipes with push-fit couplings are used for rapid laying in an emergency, they must be buried to avoid water pressure pushing them apart. Care should be taken to protect plastic pipes from being crushed by vehicles before they are buried. Gullies and areas where the pipe could be washed away or broken by a landslide should be avoided if possible. If they are unavoidable, these obstacles should be crossed by sections of steel pipe, suitably supported by cables or structures to protect them (see Figure 7.1).

Polyethylene pipe of 32 mm or 50 mm diameter can be used for final distribution to the taps. Water is directed to distribution points at regular intervals in the camp so that no one has to walk further than 500 metres to reach one. One tap is required for every 140–200 people. Typical distribution stands have multiple taps (e.g. six). Smaller and more evenly distributed water points are more accessible to the population, but may be more costly and take longer to install. Taps should be 0.6–1.0 metres above the ground, to allow containers to be filled easily, and should be self-closing. Distribution networks should normally be designed to provide a residual head of between 5–10 metres at the taps. A number of 50 mm valves can be fitted on distribution networks so that fire-fighting hoses can be connected. Regular supervision of the tap stand is desirable to avoid abuse and damage.

Washing clothes and bathing should not be allowed at taps used for drinking-water, but separate bathing and laundry areas should be provided. If these areas are not close to the water points, then they should have a piped water supply, otherwise people will tend to wash at the water points. Tapstands, and laundry and bathing areas, should be well drained and arrangements should be made with users to regularly clean the facilities and report leaks and damage. See Chapter 8 for information on drainage of wastewater.

### Water containers

Families will also need containers, preferably with a narrow neck, to keep transported and stored water supplies free of mosquitoes and contamination. Rigid jerrycans are often available locally and are inexpensive. However, they are expensive to transport, which is a great disadvantage in situations where they need to be imported rapidly in large quantities. Many agencies have used collapsible models, which are smaller when

folded and hence can be transported at greatly reduced cost. These are not very robust, however. Stackable water containers, with snap-on lids that include a small opening, are also used by some agencies.

#### 7.4.5 Prepackaged water kits

Oxfam GB has designed a series of modular water kits, for use in emergencies, that are robust and easy to assemble. These have been widely used since 1982, both by Oxfam and by other organizations, mostly for supplying water to refugees and displaced people. The kits include a range of lightweight pumping, storage and distribution kits for rapid response; groundwater development kits; rubber-lined steel storage tank kits (commonly known as Oxfam tanks) in a range from 11 m<sup>3</sup> to 90 m<sup>3</sup>; water-testing and treatment kits; and distribution kits based on industry-standard transmission and distribution pipe with distribution tapstands and self-closing taps.

Médecins Sans Frontières uses a range of lightweight prepackaged water kits for emergencies, including water-storage kits (2 m<sup>3</sup> and 15 m<sup>3</sup>); a water-transportation kit (collapsible tanks of 5 m<sup>3</sup> for truck platforms where tankers are not available); a water/sedimentation-coagulation kit; a water-filtration kit; a water-pumping kit (diesel and petrol motor pumps); a water-chlorination kit; and a water-distribution kit (stand-pipes with six self-closing taps).

IFRC provides emergency response units (ERUs), which are modular kits with trained personnel to meet the medical and sanitary needs of large numbers of people in emergencies. The IFRC specialized water-supply ERU produces 120 000 litres a day of high-quality water suitable for hospitals and health institutions. Other IFRC ERUs include a mass water and sanitation ERU that can meet the needs of at least 40 000 beneficiaries. It provides chemical treatment, storage, transportation and distribution of 400 000–600 000 litres per day of clear water. IFRC has also had good experience with their basic health-care ERUs that provide basic essential, preventive and curative care in emergencies, based on WHO emergency health kits.

The kits mentioned above are light and transportable by road or air. They come complete and ready for installation, and are designed for installation within hours of arrival by a team of semiskilled workers with some supervision by an experienced engineer. They can easily be disassembled, moved and reassembled. The kits used by a number of different agencies are compatible, thanks to the inclusion of a range of types and sizes of pipe fittings.

Mobile water-treatment units, mounted on trailers or in shipping containers, usually combine coagulation, filtration and disinfection, or simply filtration and disinfection, and can provide anywhere from 4000–50 000 litres an hour. They can rapidly produce water of high quality without the need to design and construct temporary water-treatment facilities. However, they are expensive to have on-hand for emergency use, and they require a water source near the affected area, as well as specialist technical expertise to operate them and provide adequate maintenance.

#### 7.4.6 Facilities for personal hygiene

Communal facilities for maintaining personal cleanliness should be provided in shelters and camps. These may include showers, washrooms, laundries and disinfection rooms.

Proper maintenance and supervision of all these facilities is the responsibility of environmental health personnel and the users. Regular meetings are required to ensure this shared task is carried out correctly.

Soap is an essential aid to reducing disease in emergencies: regular hand-washing with soap is very important. People should have access to at least 250 g of soap per person per month, for personal and domestic hygiene (Sphere Project, 2000).

## Showers

Showers are preferable to baths, both for sanitary reasons and to conserve water. As a temporary measure before showers can be built, a specific place on a stream, lake or pond can be set aside for bathing, and screened for privacy. Different hours or separate places for men and women can be designated. Bathing areas must be separated from the drinking-water source. The number of showers to be provided should be determined through consultation with the users, as it may vary greatly, depending on climate and habits. Shallow basins should be provided for parents to bathe their small children.

Temporary bathing water should be checked to ensure that those using it will not contract water-borne diseases. If necessary, water should be filtered and allowed to settle before it is used. In some countries, mobile bathing facilities, mounted on trucks or rail cars may be available.

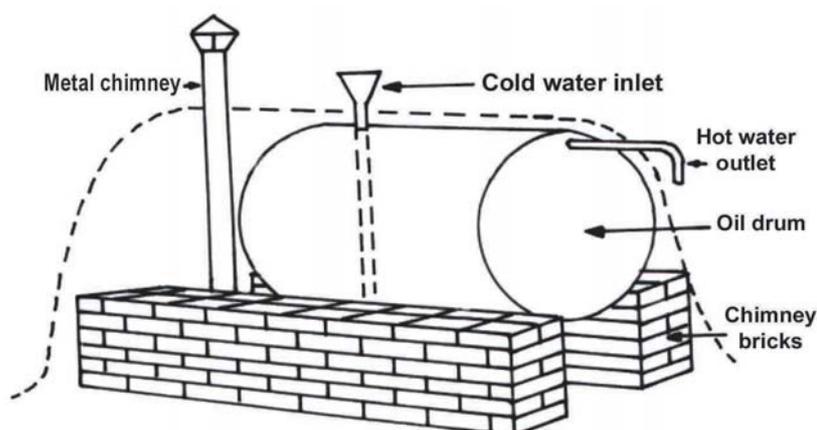
Overall water consumption for bathing is likely to be 30–35 litres per person per week at public facilities. Residents should have the opportunity to shower at least once a week and should be encouraged to bathe children frequently. If water supplies are limited, showers should be organized on an appropriate rota system, with records kept or tickets issued by the camp health committee.

While cold water can be sufficient in hot climates, hot water can be provided with the type of heater shown in Figure 7.18. This heater can be made from a 200-litre oil drum. The cold-water inlet, consisting of a pipe 4 centimetres in diameter, extends to approximately 5 centimetres from the bottom of the drum. The hot-water outlet is placed as close as possible to the rim so that no hot water is lost by overflow. The hot water in the drum is recovered by pouring in cold water. This forces the hot water upwards and through the outlet. The drum is placed on chimney bricks, approximately 6 bricks high, and a metal chimney is fitted at the rear of the drum. A gas, oil, wood or coal fire may be used, and the bricks act as a fire box to control ventilation. The entire heater can be covered by turf to insulate it.

## Laundries

In temporary shelters, people may be expected to wash their clothes in tubs provided. In longer-term camps, however, communal laundry slabs or basins should be provided. When disinfection rooms are needed, clothes should be washed in them. Whenever possible, hot water should be provided. One washing stand should be provided for every

Figure 7.18 Put-and-take water heater<sup>1</sup>



<sup>1</sup>Source: adapted from Assar (1971).

100 people, and a schedule for use established by the camp health committee. Soap should be used, rather than detergents. Proper drainage should be provided for wastewater, with traps for grease, soap and sand.

## 7.5 Operation and maintenance

When populations remain in one place for months or years after the disaster, longer-term measures can be taken. Health personnel can assist by designing a training programme for the community-based operation and maintenance of the water-supply system, or at least of the water distribution points and communal hygiene facilities of large systems (Arlosoroff, 1998; Shaw, 1998). This programme might also include sanitary inspection by local residents, especially women, and possibly gardening, which could be linked to child nutritional supplementation. On the whole, such integrated programmes for improving the health of communities are more effective than single-purpose approaches based on water supply alone.

Environmental health staff should ensure that a monitoring programme is established so that water quality and availability are maintained at agreed standards and that problems are rapidly dealt with. It is useful to carry out periodic investigations of water consumption and water quality in the home, to find out if all the affected people have adequate access to the water supplied, and if there is a problem of water contamination in the home.

All mechanical equipment, as well as storage tanks, distribution systems and communal hygiene facilities need regular inspection, with an increasing need for repairs and replacement over time. Even if the water users contribute substantially to this work, the water-supply agency will usually need to take responsibility for the purchase of spare parts and materials.

## 7.6 Further information

For further information on:

- water sources, see: Watt & Wood (1979), Simmonds, Vaughan & Gunn (1983), Jordan (1984), van Wijk-Sijbesma (1985), Clark (1988), Kerr (1989), United Nations High Commissioner for Refugees (1992b), House & Reed (1997);
- water treatment, storage and distribution, see: Jahn (1981), Schultz & Okun (1984), Dian Desa (1990), United Nations High Commissioner for Refugees (1992b), Davis & Lambert (2002);
- water quality standards and water quality monitoring, see: Lloyd & Helmer (1991), World Health Organization (1993a), World Health Organization (1997a), Sphere Project (2000);
- managing water quality in the home, see: Sobsey (2002).