

## 2.7 Technical aspects

This section examines the technical principles and practices involved in the successful implementation of WS&S projects and programmes. It accepts from the start that the associated principles covered in relation to social development (Section 2.2), health and hygiene promotion (Section 2.8), and institutional development (Section 2.6) will apply in conjunction with the technical principles outlined here. In particular, that means assuming that the consideration of technological options, design features, and operation and maintenance requirements takes place in a participatory way. Though it may not say so explicitly every time, the guidance should be read as indicating approaches and decision-making carried out with the full involvement of appropriate stakeholders. These issues are developed in Chapter 3, which also includes a list of indicators in Section 3.6.7.

### General principles

#### 2.7.1 Water, sanitation, and hygiene promotion

Household water supply, sanitation, and hygiene promotion need to be planned together, if the desired health and other benefits are to be achieved. In making the link, it is also necessary to recognize that there are significant differences in the approaches to the different elements.

All are essentially local issues, usually with wider connotations in terms of integrated water resources management and pollution prevention. At the community level water supply is primarily a communal service, whereas sanitation and hygiene behaviour are individual or family affairs (although in urban areas especially, inadequate sanitation has communal implications and solutions may well involve shared facilities such as sewer systems).

**Water supply** improvements are usually implemented by some form of co-operation between an organization or institution and representatives of the communities to be served. User involvement in construction and management is commonly through a community committee, as are payments for implementation, operation, and maintenance. The levels of technology involved are often such that there is a need for technical support at all stages of the process. The key technical issues are selection of possible solutions, detailed design, costing, supervision of construction, and management of operation. It is common for technologists to be the professionals most involved in implementation. Furthermore improved water supply is a commonly felt need of communities; hence they are usually happy to co-operate in its development.

**Sanitation** for the poor can involve shared facilities, but more often the appropriate facility is a household latrine for which the family retains responsibility. Families decide when and what to construct and are normally responsible for construction, operation, and maintenance. The role of external organizations is usually limited to sanitation promotion, aiding the selection of technical options, and

Health benefits are maximized only when improvements cover the three inter-related areas of water supply, sanitation, and hygiene behaviour.

A major shortcoming of past interventions has been a concentration on water supply alone. User demand is heavily biased in this direction, where the needs are perceived and the benefits tangible.

This does not apply to hygiene or sanitation where the education and promotion of benefits are essential components of support.

Water supply stands apart in one other important respect. It has a relatively high technological content requiring technical support that continues from the design and planning stage through construction and into operation and maintenance.

For these reasons support in water supply programmes is dominated by technicians whereas sanitation and hygiene interventions mainly need social and health workers, with inputs beginning well before facilities are installed.

support to implementation. The groups most involved in development are primarily social and healthworkers. The ability to understand and relate to ordinary people is more important than technical expertise. The main technical issues are related to selecting feasible solutions, preparing detailed designs and material lists, determining unit costs, and advising on construction or production of prefabricated components. While these look similar to the issues addressed in water supply, the level of technical skill required is usually considerably lower.

Since water supply is so different from sanitation, there is no reason why they should be implemented by the same organization. This is particularly true when the implementing agency is connected to government. All the evidence points to the fact that when a single organization is charged with implementing both water supply and sanitation in a region, one of them will receive more attention than the other and it is usually water supply. Concurrent, co-ordinated development should be the guiding principle, but the lead partners may well be different for each component, depending where the appropriate skills reside.

**Hygiene promotion** is important because it provides the link between the technologies and users. It explains why the new systems are so important and how to obtain the maximum benefits from their use. Promotion must begin before implementation as it gives users the knowledge with which to make informed decisions. It helps, too, to create the demand which is necessary for all community-based activities. Although hygiene promotion is a necessary component of both water supply and sanitation interventions, the skills required for its use are more likely to be found in organizations linked with sanitation than in those focused on water. Hygiene promotion is discussed further in Section 2.8 below.

### 2.7.2 Sustainable technology choices

Water and sanitation facilities are community services, just like electricity and roads. If they are to be of long-term use to the community and the country they must operate reliably for a considerable period. In other words, they must be sustainable. As we saw in Section 2.1, sustainability is dependent on financial, social, institutional, and environmental factors, but the choice of technology is also central to achieving sustainable systems.

- The technology must be understandable and physically within the capability of the people responsible for operation and maintenance.
- Spare parts and equipment need to be easily obtainable, preferably in-country.
- The technology must be affordable to operate and maintain for the people bearing these costs.
- The technology or level of service provided must be attractive and culturally acceptable to the users.

To be sustainable technology-based improvements must be affordable to the users and properly operated and maintained. The supporting institutions must ensure adequate training for the latter functions, and assured systems for obtaining spare parts and technical assistance for major repairs. In-country supplies should be aimed for, the more local the better.

### Appropriate technology and levels of service for the urban poor

A housing estate for council employees was constructed in a town in Uganda during the 1960s. The houses were all equipped with internal plumbing and flush toilets with water-borne sewerage. The council undertook to pay all employees' water bills.

Since Idi Amin's regime, the council has not been paying these bills; a survey in 1996 found that, as a result, 92 per cent of the inhabitants of this estate had been disconnected from the water supply system but were still using flush toilets with water-borne sewerage — clearly an unsanitary situation.

The lesson is that people should be provided with facilities and levels of service which they can fully afford to maintain without relying on external subsidies.

### Handpump production and maintenance by women

The Sarvodaya Movement in Sri Lanka trains mostly uneducated women to produce, install, and maintain a type of handpump. Among the skills the women learn are metalworking and borehole drilling. Sarvodaya staff work with the communities, showing the men how to construct the apron slab ready for installation of the pump. They train the local women in handpump maintenance and give back-up support when required. They also provide health and hygiene promotion.

*House, Smith, and Smout, 1997*

*An appropriate technology is, by definition, a sustainable one, but it does not necessarily have to be low cost.* ActionAid has recently installed windmills in Uganda to drive borehole pumps for rural communities. This is not a cheap option, but it seems appropriate in an area that is frequently windy but has poor access and a population that cannot afford to pay for the fuel to run a motor pump.

Support agencies should be alert to ongoing training needs. Skills are valuable. In many cases those initially trained in O&M duties, for example, move on and have to be replaced.

Sustainability of technology will depend on the institutional arrangements that are in place, and on the capacity building that has been undertaken to make available local spares, materials, and skilled operators (see also Section 2.6). Staff must be motivated and skilled to ensure that duties are carried out correctly.

An area of sustainability often overlooked is training. Projects frequently include training for all cadres, but it is often forgotten that people do not remain static after the end of the project. Handpump mechanics move on and engineers become managers. Sustainability requires that structures are in place to replace skilled workers as they depart.

#### 2.7.3 Design for operation and maintenance

The ease of operation and maintenance of a facility is central to its sustainability and must be given careful consideration in design. Some operation and maintenance issues are location specific, but urban and rural projects differ fundamentally in the complexity of the technologies involved.

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For rural projects the principle of designing for Village Level Operation and Maintenance (VLOM) has proved its worth. There is no reason why the enshrouded maxims of simplicity of operation and ease of maintenance, so that systems can be managed by the community, cannot be extended into urban systems. More technically advanced hardware may mean that operation and maintenance is not within the scope of users but it should be possible for suitably trained local technicians.

For all systems the objective is minimum need for external input.

In rural areas the concept of Village Level Operation and Maintenance Management (VLOM) is a philosophy which has been gaining favour over the years. The VLOM approach restricts technology choices to those that can be operated and maintained within the community for which the intervention is intended. It was coined at the beginning of the International Drinking Water Supply and Sanitation Decade, as an approach for achieving reliability, sustainability, and replicability.

VLOM was first proposed as a concept for use in handpump projects. Twenty years ago the handpumps supplied for most projects in developing countries were similar in design to those used in Europe in the last century. They were expensive and could only be maintained using specialist equipment and skills. The VLOM principle has revolutionized handpump design and manufacture. Many are now capable of being maintained by local people using very simple tools. The concept has been so successful that it has spread to many other areas of rural development.

It is rare for the VLOM principle to be taken to its ultimate conclusion. In most situations there will be a time when external materials or skills are needed. Good planning will ensure that those occasions are minimized and support is available when required. In fact, the VLOM concept allows for this. The two Ms (Maintenance and Management) imply only that the village *manages* maintenance. The fact that it may choose to do so by summoning a district mechanic from the nearest centre does not invalidate the principle, providing the service is dependable, affordable, and under village control.

In urban situations, where supply systems will generally be more complex, the design and technology chosen will shape the long-term operation and maintenance requirements. The following quote (Wagner and Lanoix, 1969), although it is thirty years old, illustrates the responsibility of the engineer in finding and designing appropriate solutions:

‘If by diligent work he can eliminate a pump, an engine, another piece of equipment or a treatment process, he is thereby removing a possible obstacle to efficient operation.’

(Of course, many water engineers are women nowadays!)

When designing a piped water supply or sewerage system, the engineer must take into account operation and maintenance factors such as the availability of chemicals for treatment, spare parts, and equipment, the reliability of power supplies, and the availability of local skills and capacity to undertake O&M.

#### 2.7.4 Standardization

At first it may seem that there is an inherent conflict between the principles of user choice and standardization. In fact, standardization is a crucial part of any strategy to achieve sustainability and replicability, and users can appreciate that point just as well as any

Standardization of designs, equipment, parts and construction methods is a valuable aid to effective, sustainable improvements. When allied to simplicity of design the benefits are pervasive. Familiar techniques lower the skills levels needed in all programme phases from design to maintenance; the benefits of training programmes are spread wider. In plant and equipment terms 'more of the same' encourages local production and stockholding, thereby aiding availability.

Some caution is needed — there must be options, for example in construction materials or elements, to ensure affordability for all. And, at a wider level, donor agencies and host country organizations must seek to address a major continuing failing of standardization planning — the lack of linkages between the practices of donor agencies that can leave a country with a host of localized 'standard systems' impossible to sustain.

### The Afridev experience: The original VLOM handpump

The Afridev handpump is the result of a design and development process which started in 1972 and has been evolving ever since. The original pump was designed to the following criteria. It:

- used appropriate technology;
- used lightweight, non-corrosive components;
- could be maintained by women;
- could be manufactured locally to an exact specification;
- needed only one or two simple tools for installation and maintenance;
- was relatively cheap; and
- was designed with preventative maintenance in mind.

Over the years some design features have been modified and improved to aid VLOM. The Afridev has been specified for standardization in many countries including Ethiopia, Cambodia, Pakistan, and Ghana.

*Wood, 1993; Skinner, 1996*

other stakeholders. The point is that standardization applies within a range of technological options and alternative management approaches. So users may choose whether they want supplies from a handpump, standpost, or house connection, accepting that if, for example, they opt for handpump supplies, the model will be a standard one for which local spares are available and which local mechanics can be trained to repair.

The standardization of equipment, parts, designs, construction methods, etc., has many benefits. Design is simpler. Choices are made from a limited range of options. In the short term this may marginally increase construction costs as the standard designs may not be perfectly suited to the situation. But it requires lower skill levels in the design process, and repetitive construction of the same item improves quality.

Operation and maintenance benefits too. Limiting the range of spare parts increases the quantity of each item that is required (i.e. more of a few items rather than less of many). This encourages local manufacture because the limited range reduces start-up costs and the increased quantity improves profitability. Local tradesmen will also be more willing to stock the parts because the increased demand for a more limited range of items will both reduce the investment required in stock and increase turnover. Standardization also reduces the number of skills required to install and maintain the piece of equipment, thus increasing the probability of local craftsmen being able to carry out the work.

In rural water supply schemes it is common to standardize the design of storage reservoirs and limit the number of pipe sizes used. Handpump schemes usually limit the number of types of pump used to two or three. In sanitation projects it is common to limit the range of latrine designs offered, and to design them so that many of the components used in each design are the same (the pit cover slab for example).





WEDC/Sarah Parry-Jones

### Handpump standardization in Cambodia

The Cambodian government recognized the need for handpump standardization in order to achieve sustainable VLOM in rural areas. The following pumps were selected for national standardization:

suction lift — No.6 Pump

medium lift — TARA Pump

deep lift — Afridev

These choices were made through a two-day standardization workshop which was attended by all the partners involved in public water supply. The selected pumps have all been proved to be reliable and easy to maintain at village level and can be locally manufactured.

*Kjellerup & Ockelford, 1993*

Standardization is very common within individual projects, particularly those related to water supply. It is less common between projects, especially if they are funded by different donors. The multiplicity of designs and equipment installed under different donor projects has left many countries with such a wide variety of facilities that none are supportable. It is important that governments develop policies and guidelines to address this problem and that donors respond with a willingness to support national standardization strategies.

In some cases, though, standardization can be detrimental, particularly where it limits user choice. Insisting that all families construct a simple pit latrine with a concrete floor slab and brick superstructure may prevent the poor complying because of the high cost, and deter the wealthy because of the perceived low level of technology being promoted. Standardization must never be so narrow that it prevents users choosing from several options to suit their income and preference.

#### 2.7.5 Replicability

Project-based development, especially when funded by external aid, will never be able to satisfy fully the demand for water and sanitation services for the poor. If full coverage is to be achieved, then populations will have to implement their own services. National and local governments must draw up policies and strategies for ensuring that best practice, as developed in individual projects, is expanded to improve coverage in other areas of the country. If we wish those facilities to be of good quality then we must set good examples that others can follow. In other words we should try to develop solutions that others want, can afford, and are able to copy. This is what is meant by replicability.

Replicability applies to process as much as to outputs. Wells, piped supplies, pit latrines, etc., should be constructed using designs, materials, and techniques that local populations appreciate and are

Project partners must confront too the fact that donor-based projects can do no more than illustrate the way ahead, building operating systems and supporting institutions that can be replicated by the indigenous populations using their available material and human resources. Only in that way can the growing WS&S needs of the poor be satisfied.

### Condominial sewerage in Brazil: A case for replication

Condominial sewerage is a low-cost system which was developed in Brazil in the 1980s. Sewers are laid through back yards at shallow depth, rather than under the street. This approach involves a high level of negotiation between agency staff and customers, who are offered the choice of three levels of service. The system has been proven to work well when there is political will and the pace is driven by customers' demands. While there are still problems with implementation, the condominium approach has been successfully scaled up and replicated in a number of cities in Brazil, where there are now extensive condominium networks.

*Watson, 1995*

### Incremental upgrading of pit latrines, Medinipur, India

An incremental improvement approach can be used to upgrade a pit latrine as the family's income increases. They can start with a simple pit and superstructure. In time, the latrine can be upgraded to a pour-flush type, a more permanent structure can be built, and ultimately a twin-pit might be added.

willing and able to copy. In addition, management and operational structures must be installed that can be understood and copied. Community motivators, like the teams in the WAMMA project described in Section 2.2, can be real powerhouses for replication, if they are empowered and equipped for the task.

#### 2.7.6 An incremental approach

The essence of a WS&S programme is offering people a choice of improvements over what they already have. All people need water to live, so there must be *some* form of water supply already or the people would not be there. Similarly, everyone needs to excrete and so there must be some existing sanitation facility or practice.

To design improved facilities, it is first necessary to look in detail at current practices, views, and the performance of the existing infrastructure. The problems, constraints, and shortcomings of the existing water and sanitation infrastructure need to be identified. In rural areas these issues may include:

- unlined pit latrines are collapsing
- people have to walk far to water sources
- handpumps have failed
- traditional sources are contaminated
- seasonal droughts affect surface water

In urban areas, with more complex infrastructure, a whole different set of problems may be encountered, including:

- sewers are blocked
- water supply is intermittent and unreliable
- water pressure is low
- illegal connections are common
- distribution system is too limited.

User demand may drive an improvement programme or, as frequently happens with sanitation or hygiene projects, the driving force may come from an outside agency with the expertise to see that improvements could bring health benefits. In either case a 'step by step' approach is to be favoured, fashioning improvements that are affordable and relevant to immediate shortcomings rather than to an ambitious long-term objective. At the same time the next step should be borne in mind, building in 'upgradability' where possible.

At the most basic level, where communities have no sanitation and no close water source, new facilities are the only answer. There are many other instances where improvement may be brought about by repairing or rehabilitating what exists, always bearing in mind that systems do not fall into disrepair without reason. Dysfunctional facilities may have been inappropriate to need or demand or suffered from inadequate support. Corrections in these areas are an essential preliminary to technology changes.

Cost is a major consideration. For affordability, least cost must be the aim.

### Rehabilitation is not always the best option

Mozambique's Limpopo Railway Line, which was constructed by the Portuguese in the 1950s, originally ran steam trains. In order to meet the high daily water demand of these trains, elaborate water supply systems were built to supply the main stations. These systems were sabotaged and ceased to function during the years of the civil war.

In 1995 a project was initiated to restore water supplies to the townships around these stations. The client was keen to rehabilitate the existing systems, some of which comprised up to 35 miles of transmission mains together with numerous pumping stations. Since the steam trains are no longer running, however, and the projected demand of the local population was found to be less than half the existing system's capacity, it was clearly inappropriate to rehabilitate. It was found to be much cheaper to develop groundwater sources at most stations.

The state of the existing system or practices will affect the decision of whether to replace, upgrade, rehabilitate, or leave it as it is. In a demand-responsive approach, however, the needs and desires of the primary stakeholders will be central to this decision-making process. (See Sections 2.1, 2.2, 2.5 for discussion of participatory approaches and willingness-to-pay surveys.)

If the facility is operating satisfactorily, not producing a significant health hazard, and all the users are happy with it, then there will probably be no effective demand for change. There may, however, be a case for promoting improved hygiene behaviour or improving the sanitation facilities, building on satisfaction with an existing water supply system. The main point about the incremental approach is to seek feasible and affordable improvements to the current situation, rather than insisting on major change to achieve an ultimate solution.

Small improvements are likely to be more sustainable and replicable. An emphasis on upgradable technology also provides scope for further improvement to meet growing demand, as shown in Figure 2.7.1.

If a facility is functioning satisfactorily and is sustainable but does not meet the demand from the community, then upgrading or extending what is already there may turn out to be the best option. The old adage 'If it ain't broke don't fix it!' is very appropriate.

If the current facilities are beyond repair or improvement, then the provision of new infrastructure has to be considered. The main reason for their failure must be investigated, however, to ensure that the new facilities do not suffer the same fate.

#### 2.7.7 Least-cost solutions

All WS&S interventions should be designed to provide the best value for money to all stakeholders. This is particularly important when targeting the most vulnerable users in both rural and urban areas. Engineers have a responsibility to find the most appropriate, least-cost solution to match the needs and desires of a community. Initially this



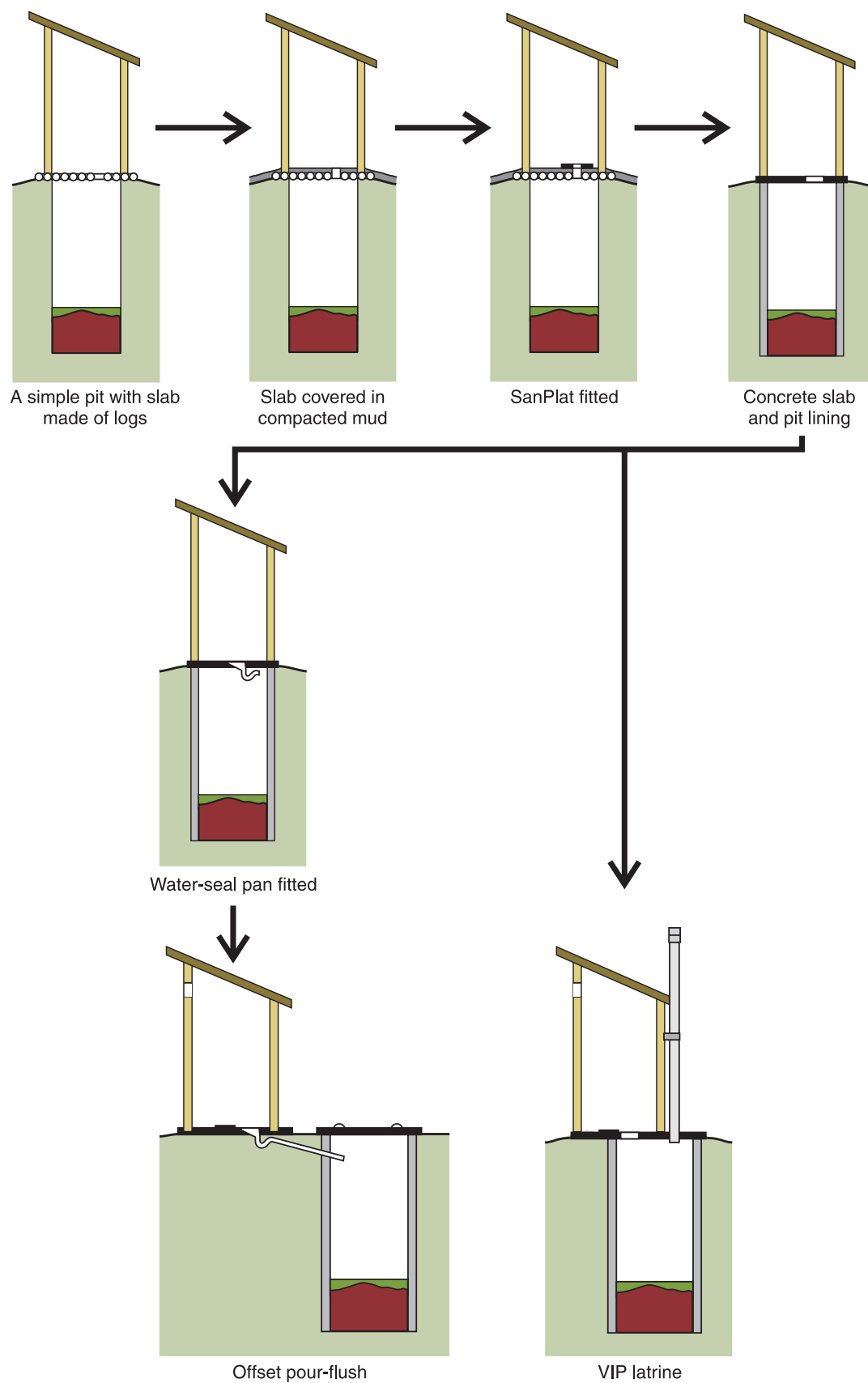


Figure 2.7.1. Incremental improvements to sanitation facilities

Technical options must be assessed on their whole life costs with main equipment items and structures given an annual depreciation value based on assessed design life, and all costs converted to Net Present Value.

In choosing equipment an obvious consideration is the longer design life and lower maintenance costs that might be expected from an item with higher initial cost. Less obvious, but equally important, are the repercussions of breakdowns on such items — typically a need for more skilled maintenance labour and more sophisticated parts and tools than might be locally available; long periods off line are the usual result.

Cheaper equipment may fail more often but be easily and quickly repaired with local resources. It has one other distinct but not immediately obvious advantage in that the long design life of an expensive item may never be fully used in the volatile environments of the poverty-ravaged areas where WS&S interventions are made. Situations and demand on equipment can change very quickly.

will involve developing a range of options and building up a cost estimate for each option. This estimate should include all the capital costs of the infrastructure (e.g. the handpump, pipeline, valves, standposts, etc.), the construction costs, and the long-term operating costs (electricity or diesel, replacement of spare parts, maintenance). The operating costs need to be considered for the entire design life of the system, so in order to compare different options on an equal basis, the long-term costs for each option should be discounted to the present so that all the options are compared by their Net Present Value (NPV).

The design life is the length of time that a system or piece of equipment is expected to be in use before it either wears out or can no longer meet the demand. It can be an important criterion in identifying the standardized technologies which will be most appropriate for a country or region. The choice of design life is always a compromise between cost and durability. Facilities with a long design life will tend to be more robust and require less major maintenance. On the other hand, they will tend to be more expensive than equipment designed to last a shorter period.

It is necessary to consider changes which are expected to occur during the design life of the facility, for example new demand due to increases in the population served, or growth in demand due to increased consumption (e.g. from consumers changing to higher levels of service). This is particularly important for the water supply distribution system.

Long design lives assume a stable environment where the future can be predicted with some certainty. In unstable societies or those undergoing rapid social or political change, such as urban slums, designing facilities to last a long time is probably inappropriate, as no

### Example of incremental design approach

A simple spring catchment and transmission main for a rural community can be upgraded. As demand increases a header tank can be added to provide the storage capacity. The dendritic distribution system can then be upgraded to a loop main, with additional tapstands or yardtaps, etc.

### Convenience of water sources is important

Gravity systems were built in rural areas of Rwanda to provide water of good microbiological quality. Two years after construction, water fee payment had dropped from over 90 per cent to under 20 per cent and many people went back to their traditional sources. On carrying out a participatory analysis with the community, it was discovered that a major reason for this was that the waterpoints were often no nearer than the old polluted sources. To the community, distance was more important than quality. They saw little improvement in the new system and therefore were unwilling to pay for it.

*Bailey, 1996*

one can predict what is likely to happen even in the short term. There is also a trade-off between durability and repairability. Heavy pumps and valves need special equipment for repair and may be out of action for a long time when they do eventually break down. The origin of the VLOM concept was the long downtime of old-style handpumps waiting for trucks and mechanics to make long journeys to repair them. Lighter pumps, it was argued, may break down more frequently, but if they could be repaired in a few minutes by a village caretaker, the 'reliability' was much improved.

There is no need for all parts of the same facility to have the same design life. The water pumps in a simple water treatment plant will probably have a shorter design life than the buildings or the pipework in the distribution system, simply because mechanical equipment wears out more quickly than buildings and pipes. Similarly the floor slab of a pit latrine may be designed to last longer than the superstructure if the slab is to be used on a succession of pits as the previous ones fill up.

### 2.7.8 Convenience

As Section 2.3 makes clear, the health focus of government and donor investments in WS&S improvements is not the benefit most understood by users. Convenience of both water supply and sanitation facilities is given a high priority, particularly by women and children. Facilities need to be easily accessible and easy to use: if they are not, users will look for alternatives. It is important therefore that new facilities are at least as convenient to use as existing ones. This concept is particularly relevant to selection of levels of service for water supply programmes (see Section 2.7.14). In the case of sanitation facilities, the level of service considerations are more subjective. They often relate to feelings of pride, prestige, and local custom rather than any measurable indicators. A flush latrine with a soakaway pit will provide the same measurable benefits as a latrine connected to a sewer, but most families would consider the latter a higher level of service.

### 2.7.9 Gender in technology

Sanitation and water supply facilities are used by women and children more than by men. It is therefore imperative that all sections of the community are fully consulted at all stages of the project and that the facilities are designed for all to use. Most water and sanitation technologies are designed by men and they are frequently unaware of the impact that the differences between the sexes can make on the convenience of using a piece of equipment. Simple things such as the height of taps and handles or the spacing of footrests on a latrine slab can make all the difference to the ease with which a facility can be used.

Gender has other impacts on technology besides simple design. The location and the way the technology interacts with the community are important and can affect their usage. For example, women may not

Improvement means more convenience (in terms of use) than what was previously available, but there is more to convenience than siting the water source nearer the house. In sanitation matters, for example, women and children especially may have good but less overt reasons for wishing to take more than the first step up the improvement ladder. Support agencies must be alive to the underlying personal and family values and community social norms that may influence demand.



WEDC/Sohrab Baghri



A key consideration in the construction of WS&S improvements is the need for effective supervision both to ensure worker safety and the quality of the end product. Neither may be of the standard expected on UK sites but the same principles should be applied, with the desired standards instilled by appropriate training and communication.

Community labour and supervisory input is desirable if local conditions, such as viable money-earning activities elsewhere, do not preclude it. Local input almost always produces the least-cost solution.

use a handpump placed near a mosque. While men see a tapstand purely as a place for collecting water, women may see it as a place to meet others and discuss points of common interest. Designing facilities to promote such interactions may make them far more desirable to the users. Similarly, designing a latrine superstructure so that it can be used for bathing or laundry may considerably increase its value to women but have little impact on men. There are many other socio-cultural issues involved in the design and use of WS&S facilities which make it crucial for women to have an influential role in their selection.

### 2.7.10 Construction

The quality of construction will impact on the sustainability of the scheme: for example, a concrete mix made with a low cement content will be weak and could ultimately result in the failure of pit latrine slabs. It is therefore important to have an adequate level of skilled supervision in order to ensure that the desired quality is achieved. If the work is not properly supervised then incompetence, corruption, or corner-cutting may affect the end product.

While it is often considered appropriate to involve the community in construction and supervision, this may not always be possible. In urban or peri-urban areas many people already earn a living and would not be prepared to contribute labour to a water supply or sanitation scheme but would rather contribute cash. This situation needs to be assessed at the early stages of a project. It is generally more cost-effective to use labour from within the community as much as possible. Using community labour does have training implications, however, since most residents will not be skilled in construction. It would clearly be inappropriate to use small local contractors and community supervision for the construction of a large pumping main or a complex treatment works.

Construction is a notoriously dangerous occupation and it is important that local safety standards are maintained at all times. These may be well below the accepted UK standards, but it is not realistic to expect all labourers to possess hard hats and steel toe-caps! The key to good safety and also to quality construction is good communication, so

**Table 2.7.1** Comparison of construction and supervision costs of collector sewers in Orangi, Pakistan

Construction and supervision	Length of sewer (m)	Cost per metre (Rs)
Built by small contractors, supervised by community group	89,536	52
Built by small contractors, supervised by individual user groups	189,926	50
Built by large contractors, supervised by local government agency	34,267	295



WaterAid/Jim Holmes

## Design for the needs of the users — normally women

In 1992 DFID evaluated the Eastern Region Water Supply Project in Nepal. The project had been primarily engineering-led, and local and expatriate technical staff had liaised with communities mainly through the leaders of the Panchayats, the local political structures. Links with the communities were therefore only through a small group of local leaders who might not have been broadly representative of the various interests and views of all sections of the communities. Where users developed views on scheme design, there were no channels for these views to be fed back to the engineers. The distribution of water supplies was generally equitable, but in some cases tapstand locations were considered to be unduly public, especially for women. Tap stands are used for bathing purposes, and some tapstands were close to roads, where there was little or no privacy. The design of the tapstands was also considered unsatisfactory, as users and especially women wanted larger concrete aprons around the tapstands for washing clothes and to reduce crowding.

In the town of Letang, some hand-dug wells were in use, and these had head walls built above ground level. The head-walls were tall and wide, so it was difficult and exhausting (even for one of the assessors, a tall man), to lift water from the wells because the headwalls came up almost to his armpits, and he had to lift the water with his arms straight. The difficulty must have been much greater for Nepali women, who were significantly shorter.

*House, Smith, and Smout, 1997*

channels of communications between all parties on site should be simple and well-defined (Coburn, 1995).

### Perceptions of project completion

The decision on when a project is complete often causes friction between implementers and the community. Completion for the implementer is quite straightforward. It is defined by contracts, drawings, and statutes. Communities have a more practical approach to completion. Once the project produces the benefits for which they agreed to undertake it they see no reason to spend further time and money on it. A common example of this is in shallow well construction. When communities participate in their construction they will frequently cease to participate once the hole is dug. The implementing agency may wish to build some form of structure on top of the well to improve both durability and the quality of the water produced. To a community suffering from water shortage this is often seen as unnecessary. Once the hole is dug and the water reached they have access to water and the implementer's desire to spend additional time and money on the well-head may not be supported, even though it is necessary to maximize health benefits.

The answer is to reach some form of compromise. The main reason for improving WS&S provision is to improve the health and well-being of the community. If this has largely been achieved then trying to force people to do things that they do not want to, especially when they are paying for it, is counter-productive. If there are any items that the implementer considers essential but the community does not (e.g. a building to put a water pump in), then the reasons for it should be

Construction planning should take account of and aim to circumvent the common tendency for community commitment to wane when users believe their main demand objective has been achieved. If less obvious health benefits are to be realised, support agency staff may need to devise means to maintain user interest until all the works are completed as planned. Sometimes there must be acceptance that substantial completion gives most of the benefits; the users may raise their sights at a later date.





In most instances affordable sanitation for the poor means on-plot latrines of varying degrees of sophistication. Restricted space or unsuitable ground conditions may force people to resort to other techniques in urban slums; usually piped sewerage is the only safe alternative. This expensive solution generally brings with it an obligation of long-term subsidy as cost recovery for construction and probably operation will be beyond the means of users.

Adherence to western design and construction standards has contributed to an in-built acceptance of high costs. More appropriate standards are beginning to be used to

explained to the community to try to persuade them to build it before the main works reach a point where work is likely to cease, or to build the project into some form of contract between the implementer and the community. The principle of incremental improvement is worth bearing in mind here. The project may not be finished to the implementer's perception of completeness, but it is the users who count. It is possible that at a later date they will upgrade the facility to something similar to what was wanted originally.

## Sanitation principles

In rural areas, the most appropriate and affordable technology for excreta disposal is generally provided by on-plot pit latrines, such as simple pits (Figure 2.7.2) with pre-cast slabs which may be re-inforced or domed (Figure 2.7.3), ventilated improved pit latrines (VIPs) (Figure 2.7.4), and pour-flush latrines (Figure 2.7.5). A particularly low-cost solution is to upgrade an existing pit with a SanPlat — a pre-cast concrete slab placed on top of the existing pit cover. This is also usually the case for poor people in small towns and peri-urban areas. In urban slums on-plot sanitation is often the most cost-effective solution, but it may not be appropriate in some circumstances, for example:

- if there is no room available to construct a latrine with an on-site disposal system (see Section 2.7.20 for more detail on this);
- if ground conditions are unsuitable for on-site disposal systems; or
- where water usage is greater than the disposal capacity of the existing facilities.

There is commonly pressure from urban communities to provide a higher level of service for waste disposal, in which case pour-flush or cistern-flush latrines may be used with on-site disposal. These can also be used on upper floors in multi-occupancy buildings, which pose problems for other types of on-plot sanitation.

When on-plot sanitation cannot provide a solution, alternative forms of sanitation must be considered. In nearly every case that will be sewerage. Unfortunately sewerage is very expensive and usually unaffordable by the urban poor. It must be accepted that if sewerage is to be implemented then subsidies will be required during both construction and operation, and the local government or other body will need to accept the recurrent subsidy as a justifiable long-term commitment (see Section 2.5 on subsidies).

### 2.7.11 Reducing the cost of sewerage

Work carried out in a number of countries has shown that the cost of sewerage can be considerably reduced. Past design and operation of sewerage has been based almost entirely on methods developed in North America and Europe. Many of the standards used are inappropriate for either developing countries or the needs of their communities. Costs can be significantly reduced by:

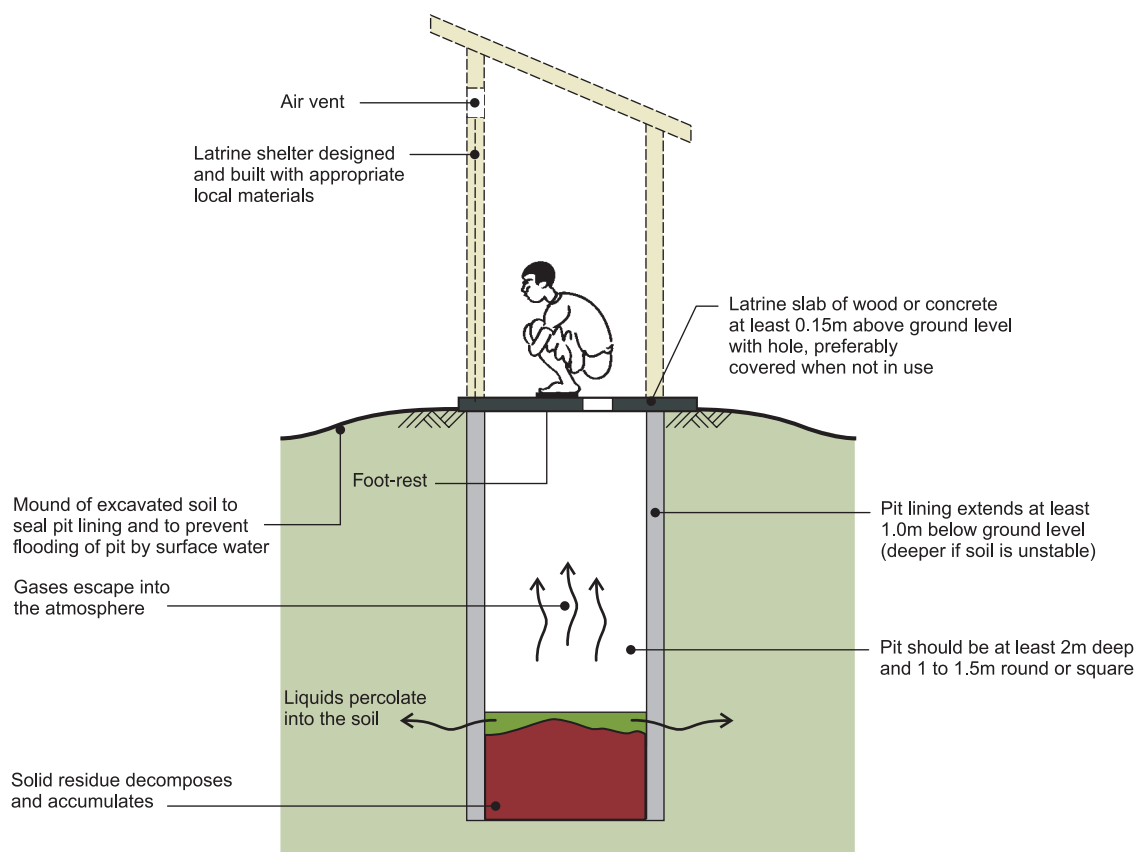


Figure 2.7.2. A simple pit latrine

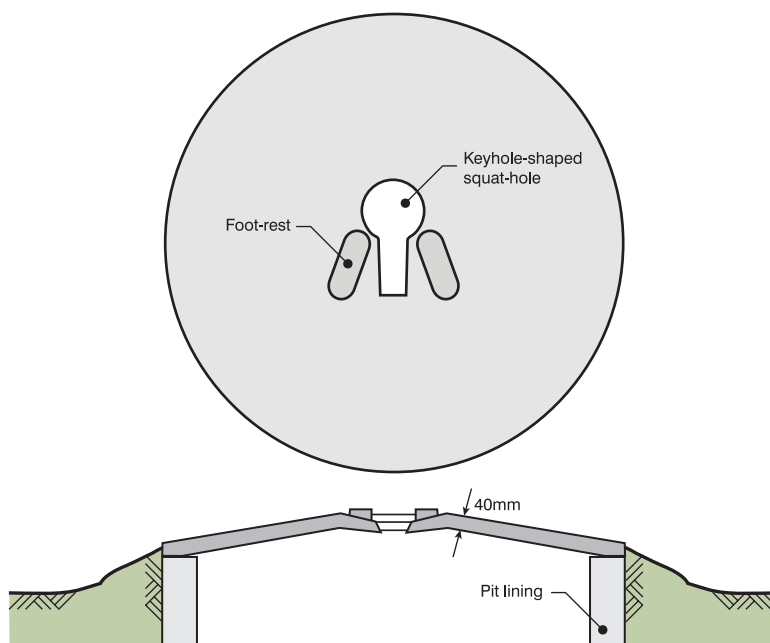


Figure 2.7.3. A domed slab

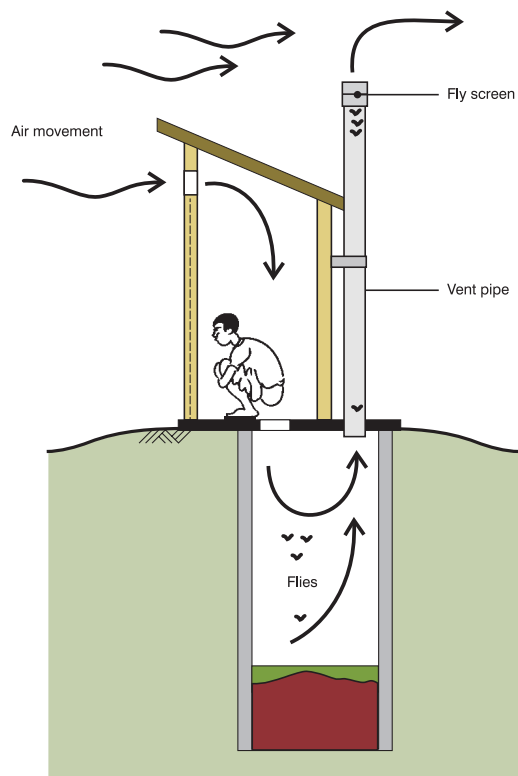


Figure 2.7.4. A VIP latrine

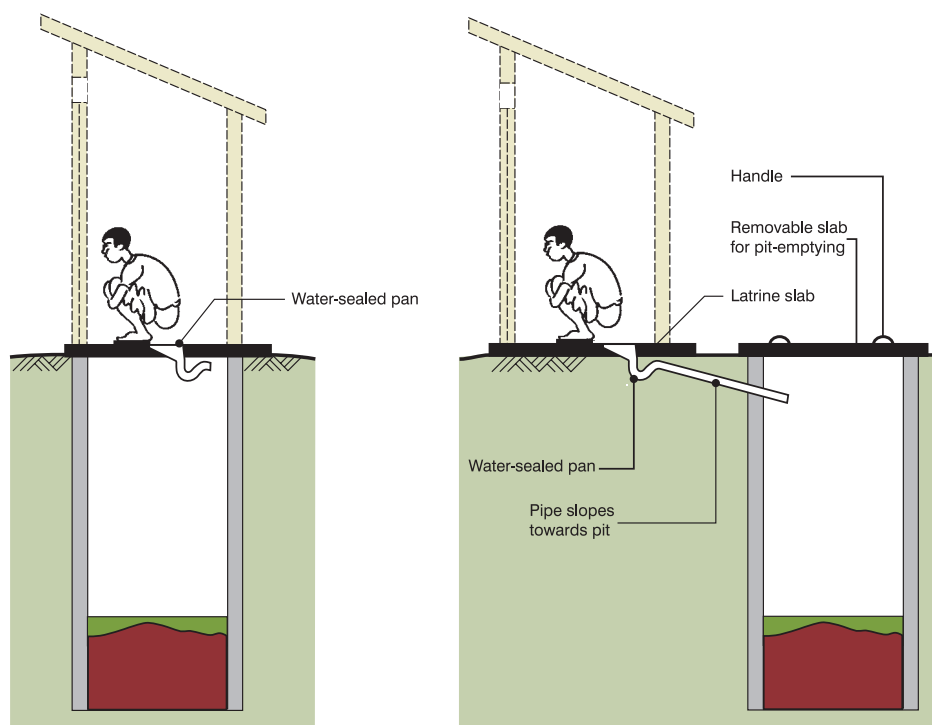


Figure 2.7.5. Pour-flush latrines

good effect and costs can also be reduced by revised approaches to operation and maintenance and charging.

Western thinking is biased towards off-site disposal of faecal material with piped sewers leading to high-tech sewage treatment works where wastes are processed to separate the liquid and solid components, remove nutrients from the liquid, and make the solid residues (sludge) fit for disposal. Public health remains a priority objective but others, ranging from clean rivers to avoiding public nuisance, are added to dictate the need for these hugely expensive systems.

Properly maintained on-site sanitation is equally effective as a barrier to the spread of pathogenic organisms — the over-riding priority in the developing world — and has the added advantage of dispersing rather than concentrating wastes, an important consideration if facilities are not well maintained. As the affordable, least-cost option it should therefore be the first choice in WS&S interventions unless user demand or local physical conditions force a move to piped sewerage.

One other serious disadvantage of piped

- reducing construction costs by revising design criteria, and eliminating redundant features (see Section 2.7.21);
- improving the quality and methodology of operation and maintenance; and
- strengthening institutions to improve the efficiency of tariff setting and collection.

In addition, a marginal costing approach can be used to encourage families to connect to the sewer network after it has been constructed.

### 2.7.12 Sewage treatment

On-site sanitation is often (and should be) the first option when considering a sanitation intervention. Such systems have very distinct advantages, not least that they are individual systems, which means that the disposal of faecal material is dispersed over a wide area and not centralized, as with a conventional sewage treatment works. One problem with centralized facilities is that when they go wrong, the resulting problems are much more acute.

It should be remembered that from a *health* point of view, there is not much difference between any of the different options for sanitation (both on- and off-site) — as long as they are all functioning properly. It is largely a question of *convenience* — an off-site system where wastes are flushed off the owner's property is more convenient as it gets rid of the problem from the owner's property. Off-site sanitation is usually much more expensive than on-site.

There are instances where off-site sanitation is deemed necessary — because of unsuitable ground or housing conditions for on-site systems, or because of a community's desire to have a 'better' system. There is a certain amount of prestige in having an off-site connection — such 'peer pressure' is often a significant motivating force.

Once the decision has been made to implement an off-site system, then sewers become a necessity. Water has a large dispersion, dilution, and carriage capacity, and it is therefore used as the carriage medium in most sewer systems. Usually, potable water is supplied to the house and used for flushing toilets — and as much as 40 per cent of household water use may be for this purpose. Some countries do use dual-supply systems where non-potable water (often seawater) is used for toilet flushing, but such a system requires more infrastructure and has obvious capital cost implications. Therefore, most sewer systems are a heavy user of precious potable water supplies, which should be a factor when considering their implementation, especially in water-short areas.

Sewerage is a mechanical system for removing wastes (sewage) from the place where it is generated. It does not clean the wastes. At some point the wastes must leave the network to be either treated or discharged into the environment. The decision as to whether or not to treat the wastes is an important one, as installing a sewage treatment

sewerage systems should be borne in mind — they need a lot of carrier water, and may require increased water supply.

Going a stage further, to sewage treatment, raises more questions. It can double construction costs without adding any health benefit to the community it serves. Unless adverse impacts on other communities are clearly indicated, the money spent on sewage treatment is usually better allocated to extending piped sewerage or more basic sanitation to other deprived communities.

Where treatment facilities are planned the selection of appropriate technology is fundamental, as is a shift from the design thinking of the West. Domestic sewage uncontaminated with dangerous industrial constituents need not be viewed as a problem to be disposed of after removing as many undesirables as possible. It can be a resource.

plant may almost double the cost of construction. There can be no doubt that sewage treatment is preferable. It reduces the environmental damage done by polluted waters and removes a potential source of disease.

Unfortunately, in a developing country these benefits have to be weighed against the benefits that could be obtained from using that money in other ways, such as constructing more sewers. The biggest benefits of sewerage are gained by the communities using the system. Sewerage improves the local environment and reduces exposure to disease. In most societies these benefits will far outweigh the potential damage being done to the environment downstream of the outfall by untreated sewage, and the economic justification for sewage treatment may be weak (see Section 2.5.12). It should be remembered that in Europe and the USA sewage treatment only became common practice many decades after the sewers were constructed.

The discussion in Section 2.4 on water quality objectives for water courses is highly relevant to decisions on whether or not sewage treatment should be considered.

Traditionally, sewage has been seen as a *problem* requiring treatment and disposal. Most conventional sewage treatment options are based on protecting the aquatic environment in Northern countries — which has usually meant a reduction in biodegradable organic material and suspended solids and, perhaps, some nutrients (nitrogen and phosphorous). Treatment involves ‘removing’ these pollutants — but removal is usually conversion to another product, usually sludge. The disposal of sewage sludge is a major consideration in many locations — it is often seen as an offensive product which is either dumped or burned.

The priorities in developing countries are often different from those in developed countries. Often the main issue is protecting people by controlling pathogenic material — and any form of sanitation (on- or off-site) should have this as the main objective. There are treatment options which can remove pathogenic material — notably waste stabilization ponds (see Section 2.7.20).

Increasingly, sewage is being seen as a *resource*, and it is often re-used legally or clandestinely. The water and nutrient content, in particular, can be very useful for agricultural purposes — for example, through irrigation — particularly in relatively arid environments. This can involve substantial health risks, for both those who consume the crops and those who grow them. There are various ways in which the practice can be made safer, including:

- treating the waste;
- restricting its use;
- using it only on industrial or fodder crops; and
- applying the waste in specific ways or only at certain times.



Whenever sewage is put to use in this way the practices must be adequately regulated to prevent health risks.

Experience has shown that regulation of the practice to make it safer is more effective than attempting to ban it. For further details see Mara and Cairncross (1991).

There are treatment options which seek to use this resource potential (see Section 2.7.20). As another example of re-use, traditional sewage treatment practices in South-East Asia pass wastes through pond systems which are used to cultivate fish and generate feed for animals. Some community-based approaches (in Latin America in particular) separate ‘grey’ wastewater (non-faecally contaminated wastewater) from ‘black’ water (that which is faecally contaminated) so that they can both be recycled and re-used as appropriate. In principle, the grey water can be re-used as irrigation water and the black water/waste treated and re-used as fertilizer.

Traditionally, sewage is treated through large centralized schemes. Many of these do not work — and when they do not work, the resultant pollution and health problems are often severe. The reason for failure is frequently that inappropriate, unsustainable, options have been chosen in the first place. Often, sewage treatment is a low priority compared to water supply, and municipal councils simply do not have the resources to keep the facilities operational. In such circumstances, there is a growing body of opinion that advocates moves towards *decentralized*, local systems, which, it is argued, could be supported by community-based organizations. Such approaches have been implemented in locations in South America.

## Water supply principles

### 2.7.13 Quantity and quality

As we saw in Section 2.3, research into the relationship between water quantity and quality and health impact shows that the benefits of additional water quantity far outweigh those of improved quality. From a technical standpoint the aim should be to deliver the quantity and quality of water that the user demands. However these aspects of demand are not always clear. Users may know how much they use now, but may be unaware of how a change in supply will affect their future use. To that extent the professionals must use their knowledge of similar situations to advise users on what is likely to happen in the future. This applies particularly to the use of water for productive uses such as watering livestock and gardens.

Water consumption will depend on the convenience of the supply, as shown in Table 2.7.2, but as a general rule, water supply systems for a minimum level of service should be designed to deliver at least 20 litres per person per day (plus wastage) without excessive queuing. For the design of standposts, including flow rates, number of taps, etc., see IRC Technical Paper No.14 (1979).

Particularly in urban areas, a major component of total supply from the source may be unaccounted - for water due to leakage, illegal connections, and deficiencies in metering and billing. It is also



SCF/Alan Nicol

For water supply interventions the starting point for facilities design is to establish the quantity and quality of water needed. It has already been said that health benefits depend more on quantity than quality of

supply, and here two key points should be borne in mind; consumption increases with convenience of supply (current consumption is therefore not a good guide to the future), and system input must be greater than supply at the tap to account for intermediate losses by, for example, leakage and illegal connections.

Convenience of supply, use of facilities, and affordability are three of the closely linked issues that make decisions on levels of service a complex matter. A single level of service may have to be accepted in some instances, but is not usually the best choice or what users want. Willingness and ability to pay vary within communities; service levels should be varied accordingly.

Convenience is accorded a high priority; tap supplies in some houses may provide the impetus for wider moves from yardtaps and standpipes at a later date. Conversely unreliable but clean standpipe supplies will do little to advance community health if dirty but free pond water is close by.

necessary to consider water consumption by institutions such as schools, hospitals, markets/shops, and offices.

Water quality demand is even more difficult to quantify. Few users are aware of all the factors that affect quality. They are more likely to be interested in aspects such as taste and colour than in bacteriological quality. Again the professionals must advise the users on what is feasible and acceptable. The World Health Organization's *Guidelines on Water Quality* (1993) permit countries to adapt standards to suit local circumstances, and are a good source of information on the parameters to be taken into account. It is recommended that countries adopt national or regional standards for drinking water quality, and that sources and treatment options be assessed in accordance with the agreed standards.

#### 2.7.14 Levels of service

In general, the more water a community uses, the better the prospects for health and the higher the community's status and well-being. However, the amount of water used is related to the level of service — the convenience of the water-supply facility in terms of distance to source, time to collect, quality, quantity, and timeliness. Thus, for a given system, a private house connection provides a higher level of service than a yardtap outside the house, which in turn gives a higher level of service than a public standpost at some distance from the household (see also Section 2.1.4). This convenience factor is a high priority for users, particularly where a range of sources or supply options is available. People will choose the level of service which is perceived to suit their needs best at an affordable price, and may use different sources of water for different uses.

Therefore it is desirable to design for a mixed level of service within a community, in order to provide each customer with the service they are willing to pay for. This is more complex than designing and implementing a uniform level of service, and in some circumstances the simpler uniform approach may be preferred as a pragmatic solution.

A rural example would be the installation of new handpumps in a village. If the original water source, say a pond, was easier to use and required less effort, then it is likely that users would continue to use the pond rather than change to the handpump. This would be

#### Planning for demand

If the progressive development of service levels is not planned ahead, piped water supply schemes can quickly meet capacity problems. A public standpost scheme for 400 villages in Latin America ran into financing problems because the demand for private taps was higher than anticipated. Conversion to house connections brought operational problems which resulted in non-payment. The whole scheme was eventually abandoned.

IRC, 1991

**Table 2.7.2** Example of average water supply consumption figures

Type of supply	Distance from home	Range of consumption (litres/capita/day)
Communal water-point (well or standpost)	> 1000m*	5 - 15
Communal water-point (well or standpost)	250m-1000m*	10 - 30
Village well or Communal standpost	<250m	15 - 50
Yardtap	in compound	20 - 80
House connection — single tap	in house	30 - 80
House connection — multiple taps	in house	70 - 250

\* Note these supply systems are below the minimum level of service standard (see Section 2.1.4)

**Table 2.7.3** Example of levels of service versus household incomes from Jinja, Uganda

Level of service (water supply)	Sanitation facilities	Typical weekly household income (US\$)	Average water consumption l/c/d	Cost of water per 20 litres	Weekly expenditure on water supply (US\$)
traditional sources, springs or handpumps	simple pit latrine	<10	15.8	free	0
standpost	simple/improved pit latrine	<30	15.5	US\$ 36	1.2
yardtap	pit latrine or pour-flush connected to septic tank	>30	50	US\$ 14.4	1.6
house connection	flush toilet connected to septic tank	>50	155	US\$ 14.4	4.9
house connection	flush toilet connected to sewer	>50	155	US\$ 25.4*	8.7*

*\*includes charge of 75% of water bill for sewerage  
Exchange rate: \$1 = US\$ 1000*

The table illustrates the range of payments that people make for different levels of service, and also shows the relationship between household income and level of service for water supply and sanitation. It is interesting to note that the people using standpipes are paying 2½ times more per 20 litres than people with yardtap and house connections. The actual water company's tariff for water from standpipes is only US\$9 for 20 litres but the standposts are mainly operated as private enterprises and thus water is sold at a significant profit. Many poor people could actually receive a much higher level of service at the same monthly cost if they upgraded from a standpost to a yardtap connection. However they are normally constrained by the high initial capital cost of obtaining a private connection.

particularly true if the users were asked to pay for maintenance of the handpump. In circumstances with insufficient demand (or tariffs that are higher than people are willing to pay), it is unrealistic to rely on hygiene promotion to create demand for improved water supply.

In urban and peri-urban areas, poorer people may be served by public standposts. The level of service from these standposts may be affected by low pressure or intermittent supply. Thus a programme could seek

Meters are a popular aid to cost recovery and water conservation in the West but there are many valid reasons for not including them in WS&S programmes. In certain situations some of the problems may be overcome by using a pre-payment meter, in effect an in-house control valve that can be actuated with a previously purchased token or card, to pass a known volume of water. A more effective route to revenue collection in low-income settlements is for the utility to use a community-based organization as intermediary, responsible for bulk purchase of water and then for equitable distribution and cost recovery from users.



WEDC/Sarah Parry-Jones

to improve levels of service by improving the reliability of supply to standposts. However, many people would like to improve their level of service by obtaining their own yardtap to save time on collection and increase consumption. A demand-responsive approach to programme development should aim to meet people's desired levels of service, and provide flexibility to allow them to upgrade over time. Generally, the more convenient the facilities are the more people will be willing to pay for the service.

### 2.7.15 Metering policy

Many water utilities are keen to install domestic meters in order to improve cost recovery and minimize consumer wastage. However, even if the concept of metering is acceptable to the consumer, there are still constraints to achieving effective coverage with domestic meters. The cost of installing a meter is relatively high and the utility must decide whether to bear this cost or pass it on to the consumer. This may affect new connection take-up. The utility must then allocate substantial resources to read the meters on a monthly or quarterly basis. There is also a risk of sabotage to the meters and under-reading due to corruption. On the other hand, intermittent supplies can cause false high readings and damage to meters.

There is also the problem of replacement. Cairncross and Feachem (1993) refer to a World Bank study in Lahore, Pakistan which found that the average meter lasted only five years. It concluded that metering was not an economic proposition unless it reduced consumption by at least 60 per cent. The situation may have improved since. Kent Meters (1998) expect a life of at least ten years where the water is of average cleanliness. Meters are now made in developing countries, but if they need to be imported the foreign exchange cost for replacement meters may be substantial.

If a water supply is going to be managed by a community, then there is a good case for a community-based organization (CBO) bulk-buying water at a metered connection off a transmission main. The community can then organize itself to take responsibility for distributing water, maintaining the tertiary pipework, and collecting revenue to pay the utility. This concept of bulk delivery has another big benefit in urban fringe areas: it helps to overcome the dilemma posed by squatter settlements with no land tenure. If a utility delivers bulk supplies to a legitimate CBO, it avoids the implication of 'legitimizing' otherwise illegal settlements, while still providing the means to satisfy basic needs.

Token or card-operated pre-payment water metering has been tried in some countries, for example South Africa and Uganda. This system has the advantage of ensuring cost recovery and reducing the operating costs associated with meter reading, invoicing, and debt collection. It also enables customers to link consumption directly with expenditure on a daily basis so that large, unaffordable bills are avoided. However, prepayment systems require relatively complex

Demand management has become the watchword for water conservation. Enforced restrictions on abstractors and end users can help, but worthwhile curbs on demand come only by a composite of actions on a wide front, using appropriate tariffs to discourage waste in conjunction with a range of 'hardware-based' interventions.

technology, and require a high initial capital investment. In trials in South Africa, the system has also been faced with political and public opposition.

### 2.7.16 Demand management

Traditionally, engineers and planners have sought to provide for ever-increasing demands in water supply. There is now a realization that there is a limit to water resources, and supplies have to be carefully managed in all circumstances.

In the face of ever-increasing demands, attention should be shifted away from trying to *manage the supply* of water by providing for these increasing demands. Instead, the *management of the demand* should be the priority, i.e. attempts should be made to reduce the need for increasing the water supplied. *Demand management* must be a fundamental aspect of any water supply scheme, including mandatory practices where appropriate.

Methods of demand management can be grouped into two categories: financial or physical. Financial control includes the setting of appropriate water tariffs to penalize waste. Physical methods includes techniques such as:

- control of unaccounted for water and leakage (illegal connections are a particular problem in many urban areas);
- adoption of water-using devices with lower consumptive use (e.g. low-flush toilets);
- use of fittings that give lower flow (e.g. spray or self-closing taps);
- use of non-potable water for non-potable uses (e.g. salt water is supplied in a dual supply systems for use in toilet flushing in Hong Kong and in several small island states, e.g. Marshall Islands, Kiribati, and Cayman Islands); and
- re-use of suitably treated wastewater for irrigation purposes. This is quite common practice in many locations worldwide. In extreme

### Freshwater resources in short supply

There are many areas of the world where freshwater resources are in short supply. Many major cities are in severe danger of water becoming so short as to present a severe constraint on any future development. The location of some new cities in developing countries has not taken account of available water resources — these are located where they are because of other reasons (e.g. mining/mineral resources). Cities like Bulawayo in Zimbabwe regularly face water shortages. In the drought of 1992-3, Bulawayo was days away from having no water at all. It has been estimated that Beijing will have a daily water shortfall of 500,000m<sup>3</sup> by the year 2000.

Faced with such problems, many city authorities have turned towards grand water transfer schemes. The Lesotho Highlands Water Project is an example of this — water is transferred from one river basin to a neighboring one to supply Johannesburg and the cities in the Transvaal area of South Africa. The financial costs of such schemes are huge, and the environmental implications of such inter-basin transfers are largely unknown.



One example, offering potential for significant savings, is leakage control. Leakage losses are typically 40 per cent or more, aggravated in developing countries by the high incidence of leak-forming illegal connections. High-tech methods of leak detection are not essential; effective investigation can be made by locally trained operators using simple, locally manufactured 'listening sticks'.

For real effectiveness leakage monitoring and control must be a regular activity, and not based on incident response as is often the case in developing countries. Leaks waste a scarce resource: the money invested in treatment and distribution and the revenues from lost sales.



Mott MacDonald Ltd

cases, treated wastewater can be recycled back into the supply network (e.g. in Windhoek, Namibia). Bulawayo (Zimbabwe) uses wastewater for irrigation of park land, after treatment both by sewage treatment and water treatment processes.

### 2.7.17 Leakage control

Not all the water that leaves a water treatment works reaches the consumer. A significant amount — as much as 50 per cent, or even more — is lost through leakages. All pipe materials deteriorate with age, and all connections are potential sources of leaks. A common feature of water distribution networks in developing countries is the high number of unauthorized connections to the network. These cause many problems, including loss of pressure and contamination of the supply, and contribute significantly to leakage.

It is impossible to get zero leakage from a system. There comes a point where the cost of leakage detection and control outweighs the benefits of locating and repairing the leaks. This is sometimes referred to as the economic level of leakage. Recent experience in the UK where great efforts have gone into leakage control show that it is difficult to get under a figure of about 12 per cent of water lost through leakage. Typical figures for leakage in an average developing country are around 30 to 40 per cent.

There are many electronic methods of leakage control used in developed countries. Most of these are expensive and inappropriate for developing countries. A common feature of water supply networks in low- and middle-income areas is that they do not supply water 24 hours a day. Sometimes, the rationale is that by limiting the hours of supply, then the consumption can be limited, but the reverse is often true. When supply is limited, many people store water as a safeguard, and when supply is resumed they waste the stored water. Also, as the supply is limited and there are many illegal connections, the pressure of the water is often very low. In such circumstances, people tend to connect their own small booster pump to their connection to the main, and draw out what water they can. This reduces the pressure in the main further and sucks out all the available water — and adds to the possibility of further leakage.

Water in a pipeline is under pressure, so when there is a hole it will escape. As it does so, there is a noise — a 'hissing' sound. Most leakage detection methods are based on listening for this sound. There are many types of sophisticated instruments used to listen for the sound electronically, but the most traditional way is through the use of a listening stick used by a trained operator. As labour is usually cheap and listening sticks can be made by local craftsmen, this is often the most appropriate way of detecting leaks. When there is an intermittent supply at low pressure, however, leakage detection is very difficult because if there is no flow in the pipe, there will be no sound to detect. Under such conditions, leakage detection has to be carried out by isolating sections of the network and testing under

pressure when it is there (and it will often have to be artificially induced).

Leakage detection and control in many developing countries is usually done as a response — when a leak is reported it is repaired. However, leakage detection should be a routine preventative function of a water utility as the water lost is a waste — of a valuable commodity which is limited in its availability, and of money (in the effort spent in treating and distributing the water which is wasted, and in the loss of the potential revenue associated with the lost water).

### 2.7.18 Source selection and treatment

Source selection determines treatment needs and, in turn, construction costs for abstraction and treatment and the ongoing operating and maintenance costs of the treatment process. Groundwater is generally preferred, often requiring only minimal treatment, but it can be difficult to locate and to assess yield.

In most areas, there will be more than one source to choose from when developing a new supply system. The different types of source are detailed in Table 2.7.3 and the range of treatment processes is shown in Table 2.7.4. Broadly, water sources are classified either as surface (e.g. rivers, streams, and lakes) or sub-surface groundwater (which can be deep, shallow, or a spring). The choice of water source and the level of treatment are interdependent: in general groundwater is preferred, particularly in rural areas, because the water is relatively pure and requires minimum treatment. However, groundwater can be difficult to locate and yields (the amounts of water which can be abstracted) are often hard to assess.

The choice of source and treatment will affect the design of the system, the cost of construction, and the long-term operating requirements. It must therefore be a well-informed decision based on available data, local knowledge, and field surveys.

### 2.7.19 Wastewater drainage

At water delivery points, whether communal or in households, designers must make adequate arrangements for the collection and safe disposal of spillages and wastewater. Standing water breeds disease.

Whenever water is delivered to a community some provision must be made for its removal after use. In rural areas the problem is most significant at the supply point. All water points waste water and its removal is important for health and environmental reasons. Standing water around a water point promotes mosquito breeding. If animals are present the ground will become smelly and muddy. All water points need to have an impervious surface around them with facilities for collecting and disposing of the spilt water. This usually takes the form of a concrete apron discharging into a nearby surface-water drain or soakaway. Sometimes, users will want to have dishwashing or clothes washing facilities adjacent to the water point, in which case disposal of the sullage water has to be part of the design too.

Programmes should institute systems for maintaining sullage drains from households and from standpoints where clothes washing and other activities occur.

In urban areas the problem can be much greater. Not only is there a larger quantity of water entering an area but there is less space for its disposal. It is common to provide surface drains along the side of roads to collect waste from both water points and domestic properties.

Drainage systems need a lot of maintenance to keep them operating properly. They frequently block up with silt and refuse and can become a favourite place for defecation. A structured maintenance programme is therefore required to keep them running.

Technical staff supporting WS&S programmes have clearly defined duties that begin with the selection of appropriate technical solutions and go on to cover all stages of design and construction. They can, and should, contribute to technical training on current projects and, by using the experience gained, to the improvement of future designs.

## Practice

The descriptions of technical principles outlined above generally have clear implications for the actions to be taken by DFID staff and other members of the stakeholder team who are designing and implementing a WS&S project or programme. The main responsibilities of the technical staff in a water and sanitation project are:

- determine which technical solutions would operate successfully in the particular environment;
- prepare outline costings and lists of parameters that would make each of the options successful and sustainable;
- *in association with others* produce a short list of options acceptable to all stakeholders;
- *in association with stakeholders* prepare outline designs and both capital and recurrent costs for each option, followed by detailed designs, costings, and materials lists for selected options;
- provide supervision and advice during the implementation of the project;
- support long-term sustainability and replicability by arranging training for local technical personnel and organizing the management of operation and maintenance;
- monitor project implementation and evaluate on completion; and
- disseminate lessons learned to improve future projects.

See Chapter 3 for further details.

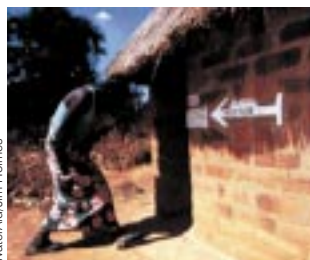
## Sanitation practice

### 2.7.20 On-site sanitation

(Recommended reading for information on the design and construction of on-site sanitation are Franceys, Pickford and Reed (1992) and Cotton and Saywell (1998b).)

#### Plot size and building design for pit latrines

In urban areas, small plot size is frequently given as a reason for discounting the use of pit latrines. The evidence shows, however, that



WaterAid/Jim Holmes

### Cultural considerations for location of toilets and design of plots, India

A slum area in Vijayawada, Andhra Pradesh, India, had been upgraded but the community were not using the new toilets provided on their house plot. This was not immediately apparent to outsiders, but when a local woman resident was asked by a speaker of the local language (Telugu) if there were any problems with the recent developments, she explained that most of the residents had not been using the toilets provided. The reason she gave was that the toilets are located on the north-east — corner of the house plots, and according to Hindu astrology this is a bad place to locate the toilet. The north-east — corner is preferential for items such as the water source, the prayer room or the main door. Toilets should be located at the south of the plot. As a result, many residents do not use the toilets provided, and go to the edge of the upgraded area to defecate in the open areas.

*House, Smith and Smout, 1997*

Some misconceptions surround the design and applicability of pit latrines, the most common solution to the sanitation problems of the poor. Lack of space, for example, is rarely a governing factor. If there is space for a toilet room there is space for a pit latrine; pour-flush types are suitable for use inside buildings, including multi-storey buildings. Nor, with correct but minimal horizontal separation, do they pose threats to groundwater sources and, where risk is identified, another source is generally a cheaper option than a piped sewerage system.

Designs exist too that overcome the often-quoted problems of smells and flies, provided the facilities are respected and maintained.



WEDC/Darren Saywell

in most low-income housing areas this is not a valid reason. A pit latrine requires little more than one square metre of land and even the most densely populated areas usually have that much land available on the plot outside the house. If the property has sufficient land to construct a toilet room then it has enough room for a pit latrine, as the pit can be constructed beneath the toilet.

In many parts of Asia, pour-flush latrines are constructed with the pit immediately outside the property. The toilet building is constructed adjacent to the boundary wall and connected to a pit or pits built under the footpath immediately outside. There are very few situations in urban Africa where housing density is so great that a pit latrine could not be built. Constructing a pit latrine inside the house is not always recommended, but there are examples of indoor pit latrines which work well, and in Lamu (Kenya) they have been used for hundreds of years. Pour-flush latrines are a particularly suitable way of meeting demand for low-cost indoor latrines, including in multi-storey buildings.

### Groundwater pollution

Potential pollution of the groundwater is another common argument against pit latrines. Again, it can easily be overstated. In general, provided a pit latrine is located more than ten metres horizontally from a groundwater source such as a spring or well, there is little chance of source pollution (Lewis, Foster and Drasar, 1980).

Even if technical advisers identify a possibility of cross pollution, it will often be more economic to find an alternative water source than to opt for a more expensive sewered alternative to a pit latrine.

### Control of smell and flies

Another common reason given for not promoting pit latrines is that they smell or are filled with flies. User surveys, however, show that these do not have a serious effect on satisfaction with improved latrines such as SanPlats and VIPs (Cotton and Saywell, 1998b), and the problems are less than in unimproved latrines. Flies are attracted to pit latrines because of the presence of a food supply and a suitable breeding site, and flies born in latrines are covered in faecal organisms.

All latrines give off some odour. Whether that odour is objectionable or not depends on the experience and background of the user. If the contents are more than a metre below the latrine floor, there will normally be no objectionable smell.

Where flies and odour are a problem they can be controlled relatively simply; a simple stopper in the latrine hole will often be sufficient. In more difficult cases the installation of a ventilation pipe will usually eliminate the problem. Pour-flush latrines should not have fly or odour problems. It is important to keep all types of latrines clean to prevent the slab or pan and surrounds becoming the sources of fly and odour problems.



Latrine emptying is a practice best avoided unless absolutely enforced by local conditions, usually as a result of space restrictions in urban slums. Rural areas do not often suffer in that respect; pits may then be cheaply constructed, used once, and abandoned. A higher standard of construction is needed when pits have to be emptied. There are no convenient or hygienic solutions although twin pits alternately used may slightly reduce the health risks and obnoxious nature of the task. Risks continue at the disposal stage — the safest option is a sewage treatment works, otherwise burial.

### Emptying latrines

The golden rule when it comes to pit-latrine emptying is: *if possible, don't*. Unless properly managed, using the correct equipment, pit-latrine emptying is a highly hazardous procedure. It requires the handling and movement of fresh excreta, exposing the operators and general public to unhealthy and unsightly conditions.

In rural areas there should be no need to empty a pit latrine. Sufficient land is usually available that when a pit is full (the contents are within half a metre of the surface) a new one can be constructed. It is only in urban areas where land for new pits is unavailable or specific ground conditions occur that it is necessary to consider emptying pit latrines.

The need to empty latrines impacts on their design. Pits that are abandoned when full can be constructed of poorer quality materials since they will only have to last a limited time. Pits that are to be emptied must be made of more durable materials and the pit itself must be fully lined to withstand the suction forces. One approach is to construct twin-pit latrines. Because there are two pits that are used alternately, the contents of one pit do not have to be emptied until the other pit is also full. This allows time for the disease-causing organisms in the excreta to die off, making it harmless to handle. However, it is rare to find twin-pit latrines used correctly, and they are much more expensive than simple pits.

The option of emptying by mechanical means (a slurry tanker) is favoured by many local authorities because it reduces contact with excreta and appears quicker than other options, but there are problems. Tankers are very expensive to purchase and maintain and they are frequently unable to negotiate the narrow roads and alleys of urban slums. They also cannot remove large solid objects such as stones, sticks, tin cans, and plastic bags. If they are to be used then a strong promotion campaign is required to persuade the community not to throw such articles into their pits.

Manual emptying is common in many parts of the world, though it has little to recommend it. Workers, usually unprotected, dig or bucket out the pit contents into a nearby hole or a small tanker that takes the sludge away for disposal. Fresh excreta are invariably spilled on the

### Latrine emptying technology

The two common techniques for emptying pit latrines are to manually excavate with a bucket or to use a large vacuum tanker. The former is unhygienic and the latter is costly and sometimes impractical. Alternative technologies have been devised; for example the MAPET (Manual Pit Latrine Emptying Technology) which has been used in Dar es Salaam. This technology builds on the traditional method of hand emptying, but uses a piston pump with a flywheel and a 200-litre vacuum tank, both of which are mounted on a handcart. The equipment provides a low-cost solution in areas where latrines are inaccessible to latrines.

*Muller & Rijnsburger, 1994 and Waterlines Technical Brief No.54, 1997*



surrounding ground and the workers are exposed to serious health hazards. While the method cannot be condoned it has to be accepted that it will continue to be used in some places. Making the practice illegal is unlikely to work if a demand still exists. It is better to remove the need for handling fresh excreta by installing twin-pit latrines or, in the last resort, improve the conditions of the workers and the tools they use, to minimize health risks.

Ultimate disposal of the sludge must also be considered. In the case of twin-pit latrines this should not be a problem since the sludge is harmless if the twin-pits are used as intended, and it can be deposited anywhere. While not a good fertilizer, it has some beneficial qualities and can be used as a soil conditioner. Fresh excreta must be disposed of safely. Options include adding the sludge to the inlet of a local sewage treatment plant, burying it, or mixing it with domestic garbage (when this is disposed of hygienically!). Composting sludge with other organic matter has been tried in a number of countries but is rarely a success because of the level of management required to operate the system successfully.

There are a number of designs for recycling human waste at the household level (Winblad and Kilama, 1985). These have generally been developed in North America and Europe and are not recommended for developing countries because of their cost, difficulties with operation, and maintenance and health hazards.

### 2.7.21 Sewerage options

(For further information on low-cost sewerage options, recommended reading includes Reed (1995) and Mara (1996).)

For areas where on-site sanitation is no longer a satisfactory option, the only realistic alternative is sewerage. While traditional sewerage schemes have relatively high capital and running costs, lower cost solutions have been adopted in some communities. The main sewerage options are:

- conventional sewerage;
- simplified sewerage;
- condominial sewerage; and
- an interceptor tank system.

A sewerage system is a series of underground pipes collecting and transporting excreta and household sullage to a point of discharge (a septic tank, natural watercourse, or treatment plant). The fixtures and fittings required include: sewer pipes, household connections, grease traps, interceptor tanks, and access chambers.

The cost of a system can be significantly reduced by limiting the number of fittings: for example, access chambers which are rarely used can account for 25 per cent of the capital cost of a system (Reed, 1995). Simplified sewerage systems are modified versions of conventional sewerage design and are built to reflect the local environment and customer affordability. This may involve reducing

If on-site sanitation is not feasible the alternative of piped sewerage need not attract the high costs inherent in systems designed to the standards and specifications of the developed world.

Professional advice and some caution should govern deviations from standards that are known to protect infrastructure and ensure trouble-free operation but, with that proviso, several cost-cutting techniques can be used. They include increased spacing of access structures and system designs that allow reductions in pipe sizes and in the depths at which they are laid.

**Table 2.7.4** Options for excreta disposal

Excreta system	Water required for operation (litres per person per day)	Technical skills for construction	Skills needed for O&M	Relative construction (cost per person)	Relative O&M (cost per person)	Institutional dependency
Simple pit	nil	similar to local house-building	cleaning only	1	1	promotion only
Pour-flush	5-25	ditto	ditto	1.1	1.1	promotion and minor education, pit emptying service
Twin-pit pour-flush	20-30	ditto	Changing and emptying pit every 2 yrs	1	1.2	promotion, education and minor ongoing technical support
VIP pit	nil	some additional skills required	cleaning only	2	1	promotion, education, and technical support, pit emptying service
Twin-pit VIP	nil	ditto	Changing and emptying pit every two years	2	1	promotion, education, and ongoing technical support
On-site septic tank*	5-40	some additional skills required	periodic tank emptying	15-25	2-3	Design, construction, emptying
Conventional sewerage*	>100	considerable additional skills required	regular maintenance of sewers and operation of treatment plant	20-70	10	Very high
Simplified sewerage*	>100	ditto	ditto	10-60	10	Very high
Sewered interceptor tanks*	2-20	ditto	ditto plus emptying interceptor tanks	5-70 depending if interceptors already existing	10	Very high
Condominial sewerage*	> 75	ditto	regular maintenance of sewers and operation of treatment plant	10-50	10	Very high

Note: \* These options require a reliable water supply. Costs are indicative and need to be related to local unit costs.

minimum pipe diameter to 100mm and minimum collector gradient to 1 in 220, increasing spacing between access points, and postponing construction of treatment works.

Condominial sewerage, which has been used extensively in Brazil, involves the laying of collector sewers at the rear of properties close to the point of waste generation. This unconventional layout reduces the length and depth of house sewers and also minimizes the amount of pumping required. The maintenance of condominial sewers is the responsibility of the community, and the housing block will generally be required to pay all the construction costs. The total cost of condominial sewerage is about half the cost of a conventional system, and it may be cheaper than on-site systems at high population densities (Mara, 1996).

An interceptor tank system relies on the settlement of solids near the point of generation. This allows the sewer network to be designed for a much reduced peak capacity: the minimum sewer diameter can be as little as 40mm. This type of system evolved from the need to sewer communities with individual septic tanks, but some systems have been specifically designed to function in this way. It is estimated that costs can be up to 75 per cent cheaper than conventional sewerage where interceptor tanks already exist.

The choice of sanitation system should take full account of its technical complexity and operation and maintenance needs in relation to the available skills and local institutional capacity.

Caution in this respect takes on added significance if sewage treatment is contemplated. There are too many non-functioning treatment plants in the developing world, memorials to wasted investment and inappropriate technology transfer. The lesson is that the large-scale, high-tech facilities of the West are not sustainable in regions where human and financial resources are severely limited.

Table 2.7.4 summarizes the range of options available for excreta disposal as discussed above. The column headings attempt to combine the principles in a way that is easy to use and non-technical.

The columns on capital and operating costs are used to bring in considerations of affordability, sustainability, and replicability.

Institutional dependency data can be compared with the strength of local institutions. A technology with a high institutional dependency in an area with weak institutions is unlikely to be sustainable.

Information on skill levels will help in deciding the level of community or family involvement in construction and operation. Technologies with high skill requirements will tend to require external inputs which will have to be paid for. This too will impact on sustainability and replicability. Water for operation links excreta disposal to water supply. Disposal systems that use a lot of water will require a high level of water supply service. Note too that though some latrines are described as requiring no water for operation, hygiene considerations mean that water for cleansing after defecation should be conveniently available.

### 2.7.22 Sewage treatment

In Section 2.7.12, the factors to consider when thinking about the implementation of a sewage treatment scheme were discussed. It is not a straight-forward decision. Most sewage treatment facilities in most developing countries do not work. This is often because most technologies for sewage treatment are big, centralized schemes which have been developed in Northern temperate climates, where adequate financial, material, and human resources are available. Transferring these technologies to tropical low- and middle-income communities is

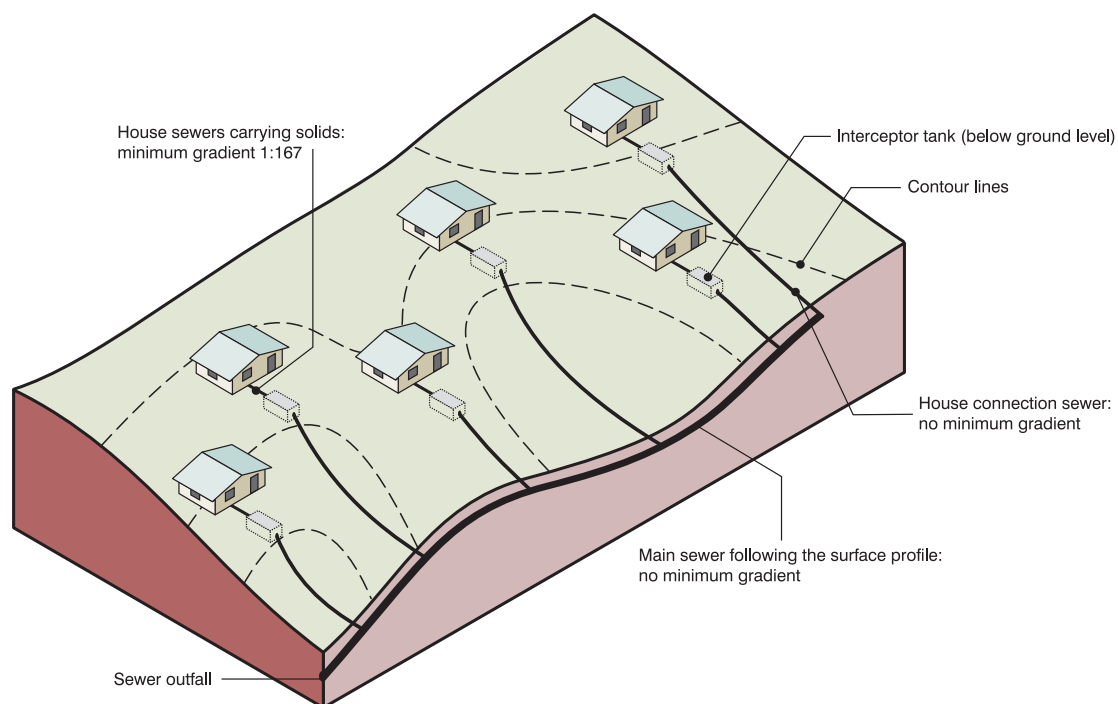


Figure 2.7.6. A schematic cut-away view of a sewerage interceptor system

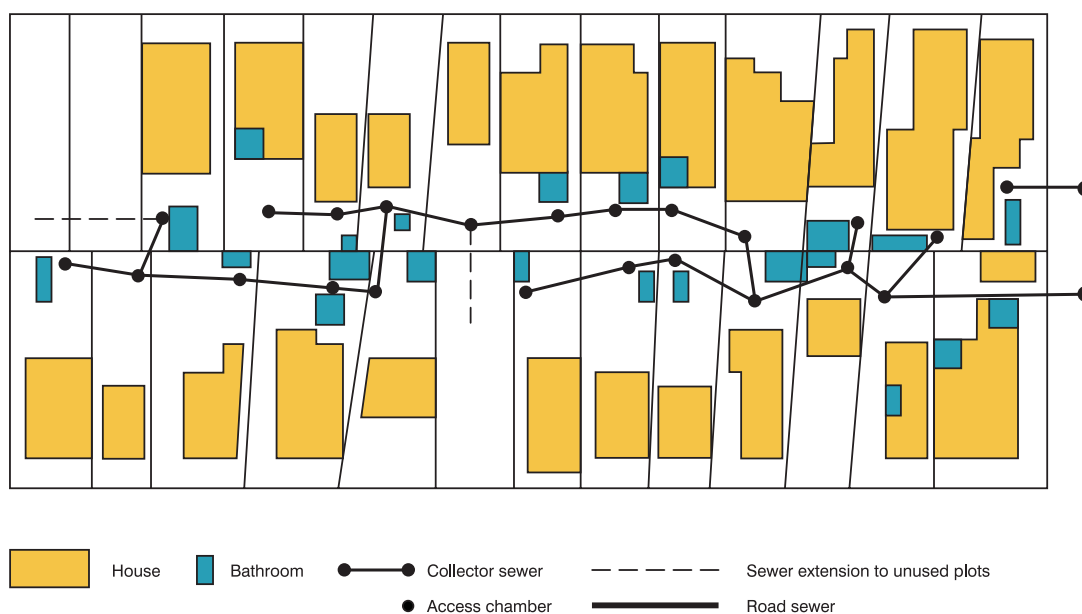


Figure 2.7.7. Condominal sewer layout in Petrolina, Brazil

fraught with potential difficulties. However, there are some sewage treatment options which are more appropriate to developing country scenarios. Such systems should generally be low cost, have low operation and maintenance requirements, and maximize the use of the potential resources (principally, irrigation water and nutrients).

Sewage treatment options may be classified into groups of processes according to the function they perform and their complexity:

- *Preliminary* includes simple processes such as screening (usually by bar screens) and grit removal (through constant velocity channels) to remove the gross solid pollution.
- *Primary* is usually plain sedimentation — simple settlement of the solid material in sewage can reduce the polluting load by significant amounts.
- *Secondary* applies to further treatment and removal of common pollutants, usually by a biological process.
- *Tertiary* is usually for the removal of specific pollutants, e.g. nitrogen or phosphorous, or specific industrial pollutants.

Preliminary and primary treatment are common to most sewage treatment works, and are effective in removing much of the gross pollution. There are many different types of secondary processes, and the most common are described in Table 2.7.5, with brief comments on their suitability for low- and middle-income countries. Tertiary treatment processes are generally specialized processes which are beyond the scope of this manual.

For further information on sewage treatment options, the reader is guided to standard texts such as Metcalf and Eddy (1994) and Mara (1976).

The majority of secondary treatment processes are biological in their nature — that is, they use the activity of bacteria to break down polluting material. Much of the polluting material is organic waste (such as faeces). Biological treatment processes can themselves be divided into two general sub-divisions — aerobic and anaerobic processes. With *aerobic* processes, bacteria use oxygen to feed on the organic material (which is a food source) to produce carbon dioxide and water, with the production of large quantities of extra bacterial mass (sludge). Most aerobic processes require the mechanical addition of oxygen to the process, which is expensive. In addition the sludge material requires disposal itself, which is often a very significant problem. *Anaerobic* processes take place in the absence of oxygen, and the bacteria break down the organic wastes to produce carbon dioxide and methane. This mixture of gases is often called *biogas* and can potentially be harnessed as an energy source. An additional advantage of anaerobic processes is that they produce much less excess sludge than aerobic processes. The major disadvantage is that the treatment efficiency is not as high as it is for aerobic processes. Some processes are a mixture of aerobic and anaerobic.



**Table 2.7.5** Options for secondary sewage treatment (\*indicates processes more suitable for developing countries)

Treatment process	Description	Key features
*Land treatment (soil aquifer treatment — SAT)	Sewage is applied in controlled conditions to the soil	Soil matrix has quite a high capacity for treatment of normal domestic sewage, as long as capacity is not exceeded. Some pollutants, such as phosphorus, are not very well removed. Can be used as a method of recharge of aquifers.
*Reed beds (or 'constructed wetlands')	Sewage flows through an area of reeds	Treatment is by action of soil matrix and particularly the soil/root interface of the plants. Requires significant land area, but no oxygenation requirement.
*Waste stabilization ponds (WSP) ('lagoons' or 'oxidation ponds')	Large surface area ponds	Treatment is essentially by action of sunlight, encouraging algal growth which provides the oxygen requirement for bacteria to oxidize the organic waste. Requires significant land area, but one of the few processes which is effective at treating pathogenic material. Natural process with no power/oxygen requirement. Often used to provide water of sufficient quality for irrigation, and very suited to hot, sunny climates.
Aerated lagoons	Like WSPs but with mechanical aeration	Not very common — oxygen requirement mostly from aeration and hence more complicated and higher O&M cost.
Oxidation ditch	Oval-shaped channel with aeration provided	Has more power requirement than WSPs, but has much reduced land requirement, and not as difficult to control as processes such as ASP (see below)
Rotating biological contactor (or biodisk)	Series of thin vertical plates which provide surface area for bacteria to grow.	Plates are exposed to air and then the sewage by rotating with about 30% immersion in sewage. Treatment is by conventional aerobic process. Used in small-scale applications in Europe.
Trickling (or 'percolating') filters	Sewage passes down through a loose aggregate bed — bacteria on aggregate treat sewage	An aerobic process in which bacteria take oxygen from the atmosphere (no external mechanical aeration). Has moving parts, which often break down in developing-country locations.
Activated sludge process (ASP)	Oxygen is mechanically supplied to bacteria which feed on organic material and provide treatment	Sophisticated process with many mechanical and electrical parts, which also needs careful operator control. Produces large quantities of sludge for disposal, but provides high degree of treatment (when working well).
*Upflow Anaerobic Sludge Blanket (UASB)	Anaerobic process using blanket of bacteria to absorb polluting load	Suited to hot climates. Produces little sludge, and no oxygen requirement (no power requirement) — but does not produce as high a quality effluent as processes such as ASP.

Note: Other anaerobic processes exist, but UASB is the most common at present.

**Table 2.7.6** Source selection for water supply

Source	Yield features	Abstraction requirements	Advantages/benefits	Risk factors	Likely treatment requirements
Rainwater harvesting	Variable and unlikely to meet demand. Useful as a household supplement	Catchment structure (e.g. roof) and storage facilities	Simple to implement and low cost	Seasonal supply only	Depending on catchment, may need Disinfection, sedimentation
Lake or pond	Depends on size — yield may diminish during dry season	Intake structure and pumping equipment	Generally easy to locate and assess	Difficult to protect source from contamination by humans and livestock, so bacteriological quality is poor. Fluctuations in level may cause abstraction problems	Sedimentation, filtration, and disinfection
Lowland river or stream	Large river flows are normally stable. Some rivers dry up in dry season	Intake structure and pumping equipment	Generally easy to locate and assess	Need to protect upstream catchment and ensure adequate downstream flow. Fluctuations in level or changes in channel profile may cause abstraction problems	Sedimentation, filtration, and disinfection
Highland river or stream	May be seasonal	Gravity flow through piped supply with diversion structure	No pumping costs, good quality for surface water	Source may be inaccessible. Protection from moving boulders required. Upstream catchment may also need protecting	Disinfection. Higher turbidities may also need sedimentation/ filtration
Spring	May be seasonal or may move location	Gravity flow through piped supply with spring box or protected spring	High-quality water, no pumping required	Spring may be inaccessible or require long pipeline to point of delivery	Disinfection only
Shallow well	Depends on aquifer, depth of well	Hand-dug well, caisson well or drilled/jetted well. Range of lifting devices from windlass and bucket to handpump to electric/diesel pumps	Better quality than surface water. Flexibility with lifting arrangements — potential for upgrading	Groundwater may be difficult to locate or access	Disinfection. Higher turbidities may also need sedimentation/ filtration
Deep borehole	Can be high depending on aquifer. Not normally affected by seasonal variations	Submersible pumps, borehole housing and transmission system	High quality water, well-protected from contamination, potentially high reliable yields	Difficult to locate water — extensive data or field tests required. Cost of drilling high and requires specialist equipment. Water may have high mineral content/ poor taste	Disinfection and possibly aeration and sedimentation or filtration

Waste stabilization ponds are the only sewage treatment process to make a significant reduction in transmission of disease-causing agents at a reasonable cost.

As stated previously, the requirement in most low-income countries is for a low-cost, low-maintenance sewage treatment system. *Waste stabilization ponds (WSPs)* provide the best option in most cases — good levels of treatment at low capital and particularly low O&M cost. In addition, it is one of the few processes which provides good treatment of pathogenic material. This has significant application potential for the re-use of the treated effluent in irrigation. The major disadvantage is that significant areas of land are needed for treatment. WSPs are used in many locations worldwide, including Africa and Asia.

Anaerobic processes, especially the *upflow anaerobic sludge blanket*, are receiving more attention as suitable treatment options for developing countries. They have the advantage of having no oxygen input requirement (unlike aerobic processes) and hence low O&M costs, and they produce low quantities of sludge for disposal — which can be a significant advantage. They are suited to hotter climates as the anaerobic bacteria like warm temperatures. The major disadvantage is that the treatment capacity is limited and their role is often as a roughing treatment to be followed by a ‘polishing’ stage to remove pathogens.

However, any sewage treatment plant needs significant investment and O&M and control, and therefore *any* decision to implement such a facility should be carefully considered.

## Water supply practice

### 2.7.23 Source selection

The Table 2.7.6 provides guidance on source selection for rural and urban water supply systems. It can serve as an initial checklist, but for detailed information the relevant texts listed at the end of this section should be referred to. Source assessment should be carried out by an experienced hydrologist or hydrogeologist.

For further guidance on source selection, see *Emergency Water Sources*, House & Reed, 1997 and *Small Community Water Supplies*, IRC Technical Paper No.18, 1983.

Using groundwater has many advantages - it is pathogen free, non turbid and drought resistant. However, there are disadvantages including non uniform distribution, extraction costs and remediation difficulties if problems occur.

There are risks associated with groundwater usage and understanding and data are required to reduce those risks. In any groundwater development project it must be accepted that some boreholes or wells will not find water.

Not all rocks contain water in useable quantities and those that do hold it in different ways. In sands, gravels and sandstones the water lies in the intergranular pore spaces throughout the rock which may be

sub-divided into near horizontal layers or aquifers. Harder, crystalline rocks such as limestones, granites and gneisses are generally not porous but are often fractured and these can contain water. Unfortunately fractures can be of variable spacing and aperture so prediction of storage capacity can be problematic.

To overcome and minimise the associated risks a hydrogeologist would map and characterise all potential aquifers in a project area. This is done by adopting a structured and logical investigation which could involve the analysis of satellite images or aerial photographs, and by carrying out geophysical surveys to record the electromagnetic, resistivity or seismic properties of the area. Interpretation of these data should help to lower the risk when physical groundwater proving is done by drilling or well digging.

For all projects but especially low budget ones a vital source of data is local knowledge of groundwater occurrences together with a vegetation survey. Because of the potential complexities groundwater development is often remote from community development but such surveys can involve recipients as would the use of Low Technology Drilling Methods which can also increase the skills base.

### Low-technology drilling methods

Low-technology drilling methods (LTDM) are simple drilling methods that can make boreholes suitable for handpumps in unconsolidated and weak rocks.

A variety of drilling techniques fall into this category including:

- percussion;
- augering;
- jetting; and
- rotary.

The key aspects of all these methods, however are as follows:

- They are simple and easy to use by local artisans after limited training.
- They are lightweight and able to be carried by hand or small vehicles to remote locations.
- They are robust and easy to maintain.
- The purchase and operating costs are low.
- They involve community members in the drilling process.

A long-term aim is that the equipment should be able to be manufactured and maintained in-country. The designs should not prevent anyone from being involved and they should be a means of skill transference.

Examples are the Vonder Rig (auger) made in Zimbabwe and the Eureka port-a-rig (mud rotary) made in the UK, but there are many others.

*Elson and Shaw, 1995*

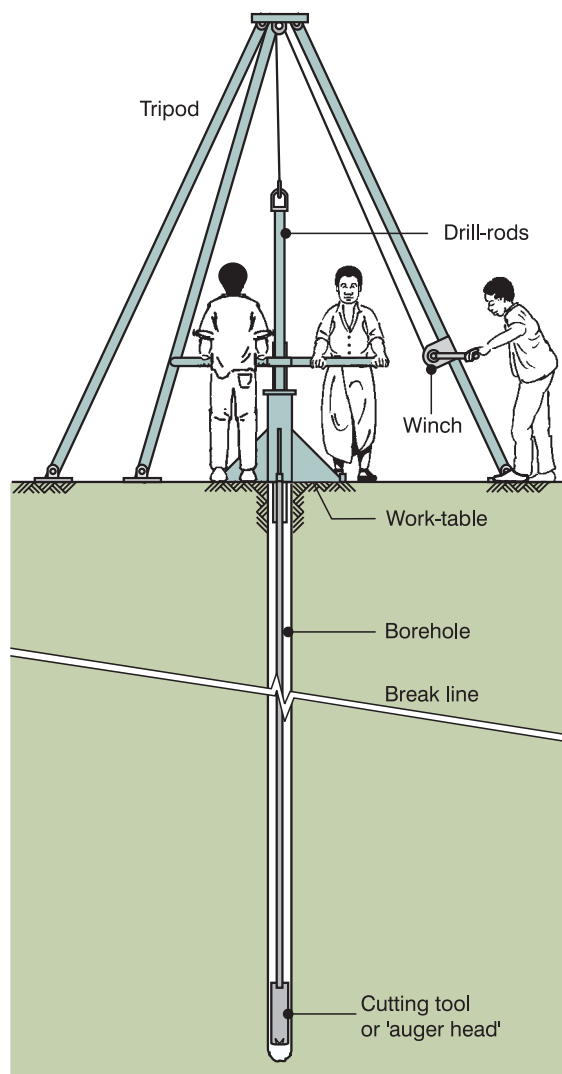


Figure 2.7.8. Hand-auger drilling

Commonly used treatments need relatively high skill levels for operation and there may be recurring costs for chemicals such as chlorine (hypochlorite) for disinfection. Professional advice is essential to determine quality objectives, treatment options, and plant design, and in the selection and assessment of the raw source.

#### 2.7.24 Choice of treatment

The water treatment process that is eventually selected will clearly depend on the quality of the water source to be used. There may be limitations due to the availability of chemicals, lack of skills or supervisory staff, cost, and so on. The desired end quality of the water should be appropriate to the situation, thus WHO or EC drinking water standards may be too arduous to attain in certain situations. The range of water treatment processes available to an engineer is summarized in Table 2.7.7, together with an indication of the O&M skills and costs associated with each process. The design of an appropriate treatment process should be done by an experienced engineer. Further information on treatment processes is available in the references at the end of this section.



**Table 2.7.7** Water treatment processes for potable water

Treatment process	Description	Action on water	O&M skills
<b>Screening</b>	Physical filtering using a metal screen	Removes large floating particles	minimal
<b>Infiltration</b>	Filtering water through natural material e.g. river bank	Removes some turbidity and has screening and anti-bacteriological effect	minimal
<b>Roughing filtration</b>	Horizontal or upflow through designed filtration bed	Reduces turbidity and removes some bacteria and pathogens	low
<b>Sedimentation</b>	Separation of smaller particles by settlement in a tank	Removes suspended particles and some bacteria and pathogens	low
<b>Sunlight</b>	Exposure to sunlight radiation	Kills most bacteria in uncovered tanks	none
<b>Assisted sedimentation</b>	Separation of smaller particles by adding chemical coagulant to form flocs	Removes turbidity, some bacteria and pathogens, and can remove some chemical contaminants	high
<b>pH adjustment</b>	Chemical adjustment of acidity/alkalinity	Modifies pH to required level	high
<b>Pre-chlorination</b>	Initial chlorine dose to assist sedimentation/rapid filtration	Kills bacteria and algae to improve sedimentation or filtration	medium
<b>Aeration</b>	Introduction of oxygen into water	Removes iron and manganese to reduce taste or colour problems	medium
<b>Slow sand filtration</b>	Water is passed down through a designed sand-bed under gravity	Removes 99% of bacteriological contaminants and turbidity	medium
<b>Rapid sand filtration</b>	Water is pushed down through designed sand-bed under pressure to speed up process	Removes some bacteriological contaminants and 50-90% of turbidity	high
<b>Disinfection</b>	Chlorine is added to water in regulated dosage	Appropriate dose of 2mg/l after 30 minutes contact time will kill bacteria and most viruses but not cysts	medium

Significant technical input is also needed in designing and costing supply infrastructure. Careful comparison of options on pipe/pump characteristics is particularly important where high pumping heads are involved.

As always designs and costs must aim to meet the various levels of service demanded by users.

Detailed information on treatment processes can be found in *Water Supply* by Twort et al., 1994 or *Water and Wastewater Technology*, Hammer and Hammer, 1996.

### 2.7.25 Water transmission and distribution systems

The complexity of the water supply transmission and distribution systems provided will depend on a range of factors, including the location and quality of the source, the levels of service demanded by the community, available capital expenditure, predicted future demand, availability of equipment, local capacity for construction, operation and maintenance, and so on. The broad range of supply options is shown in Table 2.7.8. Detailed design of water supply systems is well covered in Twort et al. (1994), *IRC Technical Papers 14* and *18* (1979, 1983), and Jordan (1984).

Table 2.7.9 outlines the wastewater drainage requirements. The drainage requirements are directly related to the water supply level of service, as outlined in Table 2.1.1.

When designing a new water supply or sanitation system and its component parts, the preferred choice is usually the least-cost option for delivering the required level of service. In order to design the optimum least-cost system it is important that both the capital and recurrent costs are taken into account for each option. In terms of a rural water supply scheme this may mean weighing up the benefit of

**Table 2.7.8** Options for rural water supply

Supply system	Skills required for construction	Skills needed for O&M	Relative per capita capital cost	Relative per capita O&M cost	Institutional dependency
Hand-dug wells	Usually locally available	minimal	1-2	1-2	promotion and construction
Borehole with handpump	medium	medium	5-10	2-3	high
Protected spring	low	low	1	1	low
Rainwater catchment (including surface)	medium	low	5-15	1	low
Pipe network to communal standposts	high	high	10-15	20-25	high
Pipe network with yardtaps	high	high	30-50	40-60	very high
Notes: 1. Costs are indicative and need to be related to local unit costs 2. Comparisons for urban supplies are more difficult because a number of source types and distribution systems may be combined 3. Surface water sources are excluded because of the range of technologies and costs possible, depending on the source.					

**Table 2.7.9** Options for wastewater drainage from waterpoints and domestic premises

Disposal system	Technical skills for construction	Skills required for O&M	Relative construction cost per person	O&M cost per person	Water disposal capacity	Institutional dependency
Surface infiltration	nil	nil	nil	nil	low — depends on land area and soil impermeability	nil
Sub-surface infiltration	similar to local house building	cleaning grease trap	1	1	low — depends on land area and soil impermeability	nil
Surface water drains	some additional skill required	routine maintenance	10-100	10-50	depends on drain size	construction and O&M
Sullage drains	some additional skill required	routine maintenance	10-20	10-20	depends on drain size	construction and O&M
Sewers	See 'sewerage' in Table 2.7.5					
Notes: Costs are indicative and need to be related to local unit costs Surface infiltration is not usually recommended because of the environmental and health risk of ponding						

**Table 2.7.10** Selection of pipe material

Pipe material	Typical range of diameters	Typical maximum working pressure (bar)	Typical usage	Disadvantages/Constraints
Cast iron	150-600mm	25	Old transmission mains. Still used for fittings for asbestos cement pipes	Very brittle. No longer widely available or popular
Ductile iron	150-1600mm	25	Transmission and distribution pressure pipelines. Expensive for diameters >1000mm	Corrosion protection required: plastic sleeve externally and bitumen or cement-mortar lining
Galvanized mild steel	15-150mm	10	Small diameter service connections	Not suitable for high pressure/ large diameter pipes. Needs corrosion protection if used underground
Steel	400-2130mm	40	Cost effective for larger diameter pressure mains	Very susceptible to corrosion if not adequately protected. High degree of skill needed for joint welds. Bedding design also important
Asbestos cement	150-900mm	12.5	Widely manufactured and used in developing countries. Used for underground transmission mains and sewers	Good bedding design required, pipes are brittle. Health hazard from dust when cutting pipes
Pre-stressed concrete	400-1500mm	12	Pumping trunk mains and sewers	Pipes are heavy. Susceptible to chloride/sulphide attack. Specially manufactured joints are required
GRP	400-1800mm	16	Good in corrosive environment — used for trunk mains and sewers. Very light for handling	Manufacture is difficult and limited experience makes construction difficult
uPVC	80-600mm	15	Service connections and distribution mains (low pressure)	Susceptible to fracture problems and degrades in sunlight
MDPE	20-600mm	12	Service connections and distribution mains (low pressure). Light and easy to transport in coils (small diameters only)	Only suitable for lower pressures. Strength of pipe decreases with time and with low temperatures.
HDPE	20-600mm	25	Pumping mains and sewers, transmission and distribution	Higher cost than MDPE but stronger and more durable. Larger diameters have lower pressure rating

Note: Other materials such as copper, lead, bamboo, vitreous clay, and wood are also sometimes used for distribution pipes.

purchasing a more expensive handpump initially, which will have lower maintenance costs than a cheaper one. Note however that this choice must be made not just on cost grounds, but also considering ease of maintenance at village level.

This issue becomes much more complex for urban piped supplies and needs a rigorous approach. If a system involves a significant amount of pumping, the capital cost of the pipe needs to be optimized against the long-term cost of pumping: that is to say, smaller diameter pipes are cheaper, but have higher associated pumping costs due to high friction losses. If the system has significant lengths of pipeline, this may be the single highest cost component and it is therefore important that the most appropriate pipe material and diameter are carefully selected. Table 2.7.10 gives an overview of the range of pipe materials available and their different properties. The actual choice of pipe material will depend largely on local conditions and preferences, availability, relative costs, etc. The information in this table has been gathered from a range of sources. Detailed information on particular materials should be obtained from manufacturers.

#### 2.7.26 Defining and costing different levels of service

The demand for different levels of service has been discussed a number of times in this manual, but it is important to be clear about the definition of each level of service and to understand the cost implications. There is often confusion over the difference between standposts (used by many households) and yardtaps (used by one household and possibly their neighbours). Detailed cost estimates should be prepared by engineers, based on local data and comparable schemes wherever possible. A useful design guide is *Public Standpost Water Supplies: A design manual* (IRC, 1979).

**Table 2.7.11** Cost data from the 'Policies and Guidelines of Uganda's Water Development Department for Rural Towns and Sanitation Program' (1992)

System	Construction Cost (US\$ '000 per capita)	O&M Cost (US\$ '000 per capita per year)
Spring catchment	2-6	0.1-0.2
Hand-dug well and handpump	8-12	0.3-0.5
Drilled borehole and handpump	20-30	0.3-0.5
Piped supply to standpost	3-6	2-5
Piped supply to yardtap	100-200	5-10
SanPlat latrine	4-8	1-2
VIP or pour-flush latrines	12-40	1-2
Septic tanks	100-150	3-5
Sewers	100-200	10-20

## Further reading

### General technical

Bailey, R.A. (ed.) (1996) *Water and Environmental Management in Developing Countries*, CIWEM, London.

This book provides an interesting overview on policies and philosophy. Also has useful chapters on practical procedures for environmental management, water supply and sanitation, and people and institutions. Unfortunately it is currently out of print.

Cairncross, S., Carruthers, I., Curtis, D., Feachem, R., Bradley, D. and Baldwin, G. (1980) *Evaluation for Village Water Supply Planning*, Wiley, Chichester.

Cairncross, S. and Feachem, R. (1993) *Environmental Health Engineering in the Tropics*, 2<sup>nd</sup> edition, Wiley, Chichester.

Excellent text providing linkages between disease and engineering. Detailed chapters on water quality, water treatment, excreta disposal, and wastewater treatment.

Davis, J. and Lambert, R. (1995) *Engineering in Emergencies: A practical guide for relief workers*, IT Publications, London.

Although intended for use in emergencies, this book has a lot of practical information for engineers in the field. Particularly good on water source development, drilling techniques, water storage, and pump selection.

Grover, B. (1983) *Water Supply and Sanitation Project Preparation Handbook, Volume 1: Guidelines*, World Bank Technical Paper No.12.

Hammer, M.J. and Hammer, M.J. Jnr (1996) *Water and Wastewater Technology*, 3<sup>rd</sup> edition, Prentice Hall, New Jersey.

WASH (1993) *Lessons Learned in Water, Sanitation and Health: Thirteen years of experience in developing countries*, Water and Sanitation for Health Project, Washington DC.

Interesting read for all water and sanitation engineers who want to do things better — it summarizes twenty lessons learned from the field which cover all project phases from programme development to operation and maintenance.

### Sanitation

Cotton, A. and Saywell, D. (1998b) *On-plot Sanitation for Low-income Urban Communities: Guidelines for selection*, WEDC, Loughborough University.

Franceys, R., Pickford, J.A. and Reed, R.A. (1992) *A Guide to the Development of On-Site Sanitation*, WHO, Geneva.

Mara, D.D. (ed.) (1996) *Low-Cost Sewerage*, Wiley, Chichester.

Pickford, J. (1995) *Low-Cost Sanitation: A survey of practical experience*, IT Publications, London.

Reed, R.A. (1995) *Sustainable Sewerage: Guidelines for community schemes*, IT Publications, London.



### Water supply

Cairncross, S. and Feachem, R. (1986) *Small Water Supplies*, Ross Bulletin 10, London School of Hygiene and Tropical Medicine, London.

House, S. and Reed, R. (1997) *Emergency Water Sources: Guidelines for selection and treatment*, WEDC, Loughborough University.

This publication has a great amount of detail on source assessment and water treatment which would be equally applicable to non-emergency projects.

IRC (1979) *Public Standpost Water Supplies: A design manual*, IRC Technical Paper No.14, IRC International Water and Sanitation Centre, The Hague.

IRC (1983) *Small Community Water Supplies*, 2<sup>nd</sup> edition, IRC Technical Paper No.18, IRC International Water and Sanitation Centre, The Hague.

Excellent handbook for engineers planning and designing relatively small-scale water supplies. Covers all aspects of water sources, treatment, transmission, and distribution.

IRC (1991) *Partners for Progress: An approach to sustainable piped water supplies*, IRC Technical Paper No.28, IRC International Water and Sanitation Centre, The Hague.

Jordan, T.D. Jnr. (1984) *A Handbook of Gravity-Flow Water Systems*, IT Publications, London.

Twort, A.C. et al, (1994) *Water Supply*, 4<sup>th</sup> edition, Arnold, London.

Classic text for water supply engineers covering the procurement, treatment, and distribution aspects of public water supply systems. Not specifically written for application in developing countries, but design data are applicable to urban or peri-urban projects.

Wagner, E. and Lanoix, J. (1969) *Water Supply for Rural Areas and Small Communities*, WHO, Geneva.

WHO (1993) *Guidelines for Drinking-Water Quality. Volume 1: Recommendations*, 2<sup>nd</sup> edition, WHO, Geneva.

### Other

Coburn, A., Hughes, R., Spence, R. and Pomonis, A. (1995) *Technical Principles of Building for Safety*, IT Publications, London.

Dudley, E. and Haaland, A. (1993) *Communicating Building for Safety*, IT Publications, London.

FINNIDA (1993) *Looking at Gender, Water Supply and Sanitation*, Finnish International Development Agency, Helsinki.

Snell, M. (1997) *Cost-Benefit Analysis for Engineers, Planners and Decision-makers*, Thomas Telford, London.

Trew, J.E., Tarbet, N.K., DeRosa, P.J., Morris, J.D., Cant, J. and Oliff, J.L. (1995) *Pipe Materials Selection Manual*, 2<sup>nd</sup> edition, WRc, Medmenham, Bucks, UK.