Guidelines for Human Settlement Planning and Design

Compiled under the patronage of the Department of Housing
by CSIR Building and Construction Technology

Volume 2
Stabilised earth streets

The use of lime- or cement-stabilised earth streets is common in certain parts of Europe (Kézdi 1979) and could possibly be considered for local application. No research has as yet been carried out on these materials locally, but the problem of carbonation (Netterberg and Paige-Green 1983) and the potential loss of strength resulting from this process may be significant. However, it is considered that, even with carbonation, the ravelling and abrasion will probably be less than with a natural gravel although maintenance may be a problem as the loose material is likely to be non-plastic (and very dusty). Further research into this possible solution is necessary but, for the present, its use should be based on sound engineering judgement.

Dust palliatives

It is often difficult to obtain materials which will provide a dust-free surface. Dust palliatives are chemical or bituminous agents which are mixed into the upper parts or sprayed on the surface of a gravel wearing course and bind the finer portions of the gravel, thus reducing dust. A wide variety of dust palliatives is available and economic analyses need to be carried out for each product in each situation to determine their viability. The social impact of dust is, however, difficult to quantify in economic terms but should not be neglected from any analyses. Recent research has shown that the deliquescent products (usually calcium chloride), the ligno sulphonates, certain polymers and some liquid chemical stabilisers (LCS) can provide good dust palliation, cost-effectively. Dust palliatives have been fully discussed earlier in this chapter.

Most dust palliatives have so far been tested on rural and inter-urban roads. The environment in a residential area is completely different in terms of drainage, traffic volumes and speed, intersections, etc. One aspect which needs to be considered is the ease of maintenance of treated roads. Road surfaces which are treated with products that do not penetrate into the layer cannot easily be maintained once potholes and ravelling initiates. Similarly, materials which strengthen the road considerably (e.g. liquid chemical stabilisers) do not allow grader maintenance should large stones protrude from the surface, as they are not easily plucked out and lead to unacceptable roughness. The optimum solution is to mix appropriate products through the layer, ensuring that all large stones (greater than 37,5 mm) are removed from the wearing course material.

No general guideline for dust palliatives is currently available but a research project involving a performance-related study of a limited number of generic dust palliatives is in progress.
RECOMMENDED READING


CSRA (1990). The structural design, construction and maintenance of unpaved roads. Draft TRH 20, CSRA.


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SCOPE

These guidelines cover aspects that need to be considered when planning and implementing water supply projects for existing residential areas and developing communities. The guidelines will also be of assistance where a Water Services Authority compiles a Water Services Development Plan (the latter forms part of a municipality’s Integrated Development Plan).

The guidelines assist in determining and setting objectives, developing a strategy and identifying the required planning activities for implementing water services. Technical guidelines are given for use in feasibility studies and the detailed design of water supply elements.

The guidelines form part of a planned series of management guidelines intended for use by decision-makers. The series of guidelines is shown in Table 9.1.

INTRODUCTION

Water services (i.e. water supply and sanitation) in South Africa are controlled by the Water Services Act (Act 108 of 1997) and the National Water Act (Act 36 of 1998). The Water Services Act deals with water services provision to consumers, while the National Water Act deals with water in its natural state.

Central to the supply of water to a community is the Water Services Development Plan of the relevant Water Services Authority, which is required in terms of the Water Services Act. The Water Services Development Plan defines the minimum as well as the desired level of water service for communities, which must be adhered to by a Water Services Provider in its area of jurisdiction. It describes the arrangements for water service provision in an area, both present and future. Water services are also to be provided in accordance with by-laws made in terms of the Water Services Act.

Engineers and other decision-makers within a Water Services Authority, and those working for and on behalf of the Water Services Authority, should be aware of the social and organisational constraints in the provision of potable water. The issues relating to these constraints must be addressed in the objectives of any water supply project, keeping in mind that the sanitation arrangements for a community are inextricably bound to the process (see Chapter 10).

The principles of sustainability, affordability, effectiveness, efficiency and appropriateness should be kept uppermost in supplying water to a community. These and other important issues are dealt with under the relevant headings in this chapter.

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THE IMPORTANCE OF HYGIENE PROMOTION IN WATER SUPPLY AND SANITATION

Introduction

The principal purpose of programmes to improve water supply and sanitation is to improve health. On the other hand, the mere provision of water and sanitation infrastructure will not, in itself, improve health. To get the maximum benefit out of an improved water supply and sanitation infrastructure, people need to be supported with information that will enhance these benefits. This form of information, and the imparting of skills, is called hygiene education. Hygiene promotion and education provides people with information that they can use to change their behavioural patterns in order to improve their health. Changes in behaviour do not come automatically, but also have a motivational component. In many instances incentives are necessary to induce a change in behaviour, the major incentive being the benefit derived from changed behaviour.

An important lesson learnt during the International Drinking Water Supply and Sanitation Decade is that good coverage – providing a large number of people with access to facilities – does not equal success or sustainability. Because water supply and sanitation facilities are subject to misuse, non-use, or breakdown, international donors and national governments alike have come to recognise that the sustainability of systems is of critical importance. Apart from a sense of ownership of the facilities, it also means that communities should adopt hygiene practices that will help them realise the health benefits of water supply and sanitation improvements. Hygiene promotion and education is a key component of the effort to achieve these health benefits.

To achieve sustainable water supply and sanitation development requires effective complementary inputs such as community participation, community capacity-building and community training. International trends and research have indicated that hygiene promotion and education plays a major role in breaking down the transmission of diseases that are affecting many rural communities in the developing world.

In South Africa it is essential to understand the attitudes and behaviours of developing communities towards water, sanitation and hygiene. Most developing communities rely on the government to make sure that their water supply and sanitation projects are sustainable, but it is necessary for the community itself to contribute to the sustainability of its projects, as well as to the development of an appropriate hygiene-promotion and education programme. It is at community level that real decisions on hygiene promotion and education should be made, but these communities need information to be able to make decisions reflecting their aspirations, desires and needs.

For guidelines on implementing a project with the above elements, see Appendix A of Chapter 10.

What is hygiene promotion and education?

Hygiene promotion and education is not about coercion, but about bringing change in the behaviour patterns of people, to make them aware of the diseases related to unhygienic practices, poor water supply and improper sanitation. It forms an integral part of any water and sanitation development programme.

Hygiene promotion and education comprises a broad range of activities aimed at changing attitudes and behaviours, to break the chain of disease transmission associated with inadequate water supply and sanitation. It is the process of imparting knowledge regarding the links between health, water and sanitation, and seeking to provide people with information that they can use to change their behavioural patterns so that they can improve their health. It is about keeping well, about a better quality of life and about recognising that the majority of illnesses that kill children can be associated with poor sanitation practices and inadequate or unsafe water supplies. It is a primary intervention that, like immunisation but much more cheaply, aims at preventing illness or minimising the risk of infection.

A definition of hygiene promotion and education that emphasises activities aimed at changing attitudes and behaviours must recognise that behavioural change cannot be effected from outside the communities. The individuals in the community must want to change, and only they can effect sustainable change. The role of the external agent can be only that of a catalyst and of providing (or broadening) awareness. Furthermore, the role of women cannot be overemphasised. Women are the latent forces for change in local communities, and their empowerment and involvement are prerequisites to the success of a community-based health or hygiene education and awareness programme or campaign.

It is now recognised worldwide that hygiene promotion and education is an important channel to link newly installed facilities to improved health. Improved water supply and sanitation systems will reduce the persistence and prevalence of diseases.
PLANNING: OVERVIEW

General

The provision of water to a community has to follow the same route as any other project, in that it has to go through a series of distinct stages between the initial conceptualisation and the time when the project is completed. These stages, shown in Figure 9.1, can be summarised as follows:

- **Identification and preparation** comprise the pre-investment planning stages.
- **Approval** is the stage at which decision-makers, including financiers, determine whether or not a project will become a reality.
- **Implementation** is the stage at which detailed designs are completed and the project facilities are built and commissioned; supporting activities such as staff training are also undertaken.
- **Operation** is the stage during which the project facilities are integrated with the existing system to provide improved services.
- **Evaluation**, the final stage, determines what lessons have been learned so that future projects can be improved accordingly.

It is important that the project be undertaken within a framework of clear objectives, aimed at ensuring maximum operational effectiveness, as well as sustainability on completion.

Technical guidelines should be assessed in the context of the operational goals set for the water supply, and adjustments made to take into account factors such as levels of income, availability of funds and the ability of the community to operate and maintain the service. Sustainability of the service is the most important criterion that must be addressed in the planning phase.

The planning process should produce reports that define the purpose and objectives of the water supply and set the broad strategy for reaching the objectives. These reports act as overall guidelines and assist in the generation and selection of the alternative technologies that could be used in the provision of the water supply. The community to be served should be involved in the planning process.

Where the upgrading or rehabilitation of an existing water supply scheme is contemplated, a thorough investigation of existing supply arrangements is required. Eliminating water theft, reducing unaccounted-for water and improving recovery mechanisms could render capital works unnecessary, or postpone them.

**Figure 9.1: Development stages for water supply and sanitation projects**
Purpose of the water supply

Establish the purpose of the water supply. Why is the water supply needed? Who will use the water and for what activities? What is the problem with the current situation and how will the proposed water supply project alleviate the problem?

Objectives

Set broad objectives, or goals, first for the operational phase and then for the project phase. It is important to look at operational objectives first, and use these to establish the objectives for the project phase, otherwise there is a risk that the water supply system will operate inefficiently, even if the project phase was completed successfully.

The objectives of a water supply project should include the following:

- the provision of water for domestic consumption and personal hygiene in terms of the Water Services Authority’s by-laws (government policy requires that a minimum of 25 litres per person per day be provided);
- the improvement of the quality of the existing supplies (protection of the sources being the first consideration);
- the improvement of the availability of water to the community (both reliability and accessibility);
- community involvement (acceptability) and commitment;
- the improvement of public health;
- the improvement of the living standards of the community;
- the development of local technical, financial and administrative skills; and
- the improvement of the economic potential of the community (e.g. small-scale agriculture and industries).

Strategies

An overall strategy is needed to guide the project through various stages into the operational phase.

By-laws

Note should be taken of the by-laws of the Water Services Authority. The following aspects are of particular importance where Water Services Development Plans are incomplete or unclear:

Administration

The community should be involved in the planning, implementation and maintenance phases of the project (preferably through an independent committee of community representatives).

Finance

Subsidisation of the scheme by bodies outside the community is restricted to the provision of the basic level of service prescribed in government policy documents. The community must also be able to bear the operational costs involved. There are, however, exceptions to the rule, which can be found in the policy documents.

No water supply system should be planned in the absence of a tariff structure and expense-recovery mechanism, agreed to by the client community. The client community must be able to pay for its basic operation and maintenance, with due regard to the free basic water policy of the National Government.

Development impact

Maximum use should be made of local manpower and materials, with training given where appropriate. Where possible, local contractors and entrepreneurs should be employed. However, the technologies employed – including labour-based construction methods – should be cost-effective.

Health

The improvement of the quality of services should be driven by increased community awareness of health-related problems and their causes. For example, improvements in living standards and public health in a community may be impossible to achieve unless hygiene education is provided and sanitation improvements are made concurrently with an improvement in water supply.

Planning activities

The objectives, strategy and policies must provide sound guidelines for formulating and executing the activities, tasks and sub-tasks required to reach the given set of objectives.

The completion of an activity should result in an objective being met. For example, an objective could be the commissioning of a single element of the water supply that is needed to achieve the overall purpose of the whole scheme.
PLANNING: REPORTS

Project reports

In the absence of other guidelines on a project report, the format and contents of the reports should follow the following format.

Feasibility reports

Feasibility reports should cover any factors that could be relevant to the detailed planning and design of a new water supply scheme, or the upgrading of an existing one. Some analyses that should be considered in the feasibility study are given in the documents referred to in Table 9.1.

Water demand

Future water demand is one of the key issues in water supply planning. The following important points regarding the demographic and economic situations determining future water demand should correspond with the contents of the Water Services Development Plan.

The demographic and service information required includes:

- the current population;
- the number of households;
- the number of residential consumer units;
- the incomes related to these consumer units;
- the number and type of non-residential consumer units;
- current levels of water service;
- current consumption; and
- the demand for services, in terms of willingness to pay for the services desired.

The information required to make proper projections of future requirements includes:

- population growth;
- economic growth;
- growth in number of consumer units;
- level of service provided to residential consumer units;
- changes in income levels of residential consumer units;
- changes in consumption per consumer unit;
- effects of water-metering programmes; and
- weather patterns and climate.

Water conservation and demand management (DWAF 2002)

One of major impediments to the implementation of water conservation and demand management at a local level is the lack of social awareness and understanding about these topics among both consumers and water service institutions/authorities. If not implemented in an integrated, targeted and strategic manner, social awareness campaigns will have limited success in achieving the desired behaviour change in water use patterns. Social awareness campaigns need time, energy and resources, and those promoting water demand awareness need to adopt a single, consistent message.

Attempts to implement water conservation and demand management have generally focused on narrow, technical solutions. However, successful implementation is as much about raising awareness as it is about technical interventions. As social awareness is often implemented in conjunction with other measures, gauging its impact on consumer demand is not easy, making it a less attractive option compared to those that provide quick, clear and good results. Awareness-raising is also perceived either as difficult to implement, or simply about making posters or pamphlets. Those involved in raising awareness about water issues do not approach it from the type of marketing perspective needed to sell a product or a concept.

Raising awareness about water conservation and water demand management issues facilitates changes in behaviour, as knowledge about the subject increases through the education of stakeholders. The effectiveness of any awareness campaign is ultimately measured by the results of the implemented water conservation and water demand measures.
To be successful, any awareness/education campaign has to be integrated, ongoing, relevant and targeted. Preliminary research is therefore necessary to develop an understanding of the characteristics, conditions and dynamics of the context/community in which awareness raising needs to be conducted. The Knowledge, Attitudes and Practices (KAP) survey tool provides a model for facilitating change on an individual basis, to incorporate new practices that are being introduced.

**General**

Several methods may be used to predict the future population. It is important to note that conditions in this country differ to a great extent from those in other countries, and population growth is influenced by a host of demographic factors, which include migration and urbanisation. It is therefore considered important to consult demographers and town planners, as they are best equipped to deal with the issues of socio-economic planning and hence the future population of a given area. Designers should take note of the consequences of accepting an excessive growth rate, but cognisance should also be taken of the characteristics of the study area. Factors like employment opportunities, available residential area, infrastructural services and HIV/AIDS can have a significant effect on growth rates.

Water demand figures adopted for design purposes should be based on a projected value for, say, 20 years hence.

Design periods for the integral components (i.e. purification works, reservoirs, pumps and mechanical components, electrical components and main pipelines – outside reticulation) should not exceed 10 years.

Design water demand values for communities are given under the section “Design Criteria for Water Distribution and Storage Systems” in this chapter. These are average daily figures and the design demand should be based on the peak daily demand at the end of the economic design life of the project (i.e. the point where more capital will be required to expand the facilities).

Designers should note that, in adopting water demand figures for a specific design, cognisance should be taken of local factors such as income level, climate and water charges, when interpolating between the upper and lower limits given in this chapter.

**Wastewater disposal**

It should be borne in mind that increasing the quantity of water supplied to an area also increases the quantity of wastewater for disposal. It is therefore imperative, in the planning stage, that present wastewater disposal practices be evaluated to assess whether these methods can cope with an increased load arising from increased water usage. This aspect is dealt with in Chapter 10 (Sanitation). The recycling of wastewater can reduce the demand on water significantly and could be implemented where feasible and where human health will not be compromised.

A broad approach to the contents of project reports is given in Table 9.2.

**Project business plans**

The business plan of a project describes a strategic programme-based approach to water service delivery by:

- giving details of the project;
- demonstrating how it will conform to national policy;
- describing how it will be implemented and managed;
- showing how progress will be measured against goals specified; and
- discussing a funding strategy and sustainability.

Business plans normally have the following components:

- an introduction, describing the purpose of the business plan;
- a description of the management structure;
- a project description, which should include the technical details;
- the details of conformity with national policy and other guidelines of funders;
- a table of cost estimates; and
- time plans.

The format and content of business plans is usually prescribed by funding agencies and government departments.

**WATER QUALITY**

**General**

Water quality refers to the presence of living organisms or substances suspended or dissolved in water. Water used for domestic purposes needs to be of an acceptable quality and should have a certain amount of dissolved salts present, both for taste and
### Table 9.2: Broad approach to contents of planning reports

<table>
<thead>
<tr>
<th>TOPIC</th>
<th>PRESENT SITUATION</th>
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</thead>
<tbody>
<tr>
<td>Climate</td>
<td>Rainfall, evaporation, seasonal changes.</td>
</tr>
<tr>
<td>Prevalent diseases</td>
<td>Water-related (typhoid, cholera, gastro-enteritis, scabies, bilharzia, malaria). Nutrition-related (malnutrition, kwashiorkor).</td>
</tr>
<tr>
<td>Financial resources</td>
<td>Average expenditure per household. Savings.</td>
</tr>
<tr>
<td>Existing water supply and distribution</td>
<td>Springs, pumps, water vendors, tanks, boreholes. Reliability and demand. Costs. Type and age of piping. Present consumption.</td>
</tr>
<tr>
<td>TOPIC</td>
<td>FUTURE DEVELOPMENTS</td>
</tr>
<tr>
<td>Public facilities</td>
<td>Schools; clinics, hospitals; transport; recreation centres.</td>
</tr>
<tr>
<td>Commercial and Industrial</td>
<td>Factories, shops, offices, restaurants.</td>
</tr>
<tr>
<td>Financial prospects</td>
<td>Improved per capita income. Savings.</td>
</tr>
</tbody>
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### COMMUNITY VALUES, ATTITUDES, NEEDS AND SKILLS IN RESPECT OF:

| Water supply | Quality; distance; quantity (expected consumption after upgrading). |
| Sanitation facilities | Toilets, disposal systems; washing hands; disease transmission. |
| Expertise and skills | Administrative; technical; financial; leadership. |
| Need priorities | Domestic water; sanitation; public facilities; commercial enterprises; industrialisation. |
| Education and training needs | Health; water supply schemes; maintenance. |
to minimise the corrosive potential of the water. Furthermore, it has been estimated that only one out of every 20,000 strains of bacteria is pathogenic, and the mere presence of bacteria in drinking water is not necessarily a cause for concern. The approach to water quality control in water supply projects should therefore include the following steps:

- the protection of all components (including the source, storage units and pipelines) against possible contamination by pathogenic organisms;
- the improvement of the existing water quality to ensure aesthetic acceptability (removal of turbidity and unpleasant taste); and
- the education of consumers regarding basic precautions for the collection, storage and use of water.

Aspects of water quality that have a bearing on these requirements are discussed in the following sections.

**Diseases associated with water**

Water development projects are intended to improve the quality of the human environment. However, unless well planned, designed and implemented, a water project may bring about a decrease in one type of disease but cause an increase in a more severe type. This may be especially true of projects designed to improve local agriculture.

Hence, one of the chief concerns of water quality control is the spread of diseases where water acts as a vehicle. The World Health Organisation (WHO) estimates that 80% of illnesses in developing countries are related to waterborne diseases.

Information on water related diseases is available in various textbooks.

In order to minimise water related diseases the following should be observed:

- the disinfection of domestic water supplies;
- the provision of well-designed and -constructed toilets;
- an increased quantity of water for domestic use;
- the provision of laundry facilities, thereby reducing contact with open water bodies; and
- the provision of adequate drainage and the disposal of wastewater.

**Water quality**

Water for human consumption must comply with the requirements of SABS 241. This standard provides for a Class 0 or Class 1 water – the two classes intended for lifetime consumption – and a Class 2 water, intended for short-term consumption, in relation to the physical, organic and chemical requirements as specified. All classes of water must comply with the specified microbiological requirements.

**Stability of water supplies**

Water that is put into distribution pipelines should be neither corrosive nor scale-forming in nature. Corrosive water may lead to corrosion of the pipelines, fittings and storage tanks, resulting in costly maintenance, and/or the presence of anti-corrosion products in the final water being delivered to the consumer.

**WATER SOURCES**

When planning a water supply scheme for an area, the potential sources of water should first be assessed. Consideration should be given to the quantity of water available to meet present and future needs in the supply area, as well as to the quality of the water. Water that is unfit for human consumption will need to be treated before being distributed.

Water for human settlements can be obtained from one or more of the following sources:

- springs;
- wells and boreholes;
- rainwater;
- surface water – rivers and dams;
- bulk-supply pipelines; and
- a combination of the above.

**Springs**

A spring is a visible outlet from a natural underground water system. Management and protection of the whole system, including the unseen underground part, is essential if the spring is to be used for water supply. The seepage area can be identified by visual inspection of the topography, and the identification of plant species associated with saturated ground conditions. The area can be fenced off, surrounded by a hedge, or just left under natural bush and marsh vegetation. Gardens and trees can be safely planted some distance downstream of the spring, but not within the seepage area above the eye of the spring. The conservation of wetlands or spring seepage areas is an extremely important and integral part of spring water development and management.
Generally, springs fall into three broad categories. These are:

- **Open springs**: occurring as pools in open country. Some form of sump or central collection point from which an outlet pipe can be led is all that is required. It may sometimes be necessary to protect the eye of the spring.

- **Closed springs**: the more common form of spring found in rolling or steep topography. In this case a “spring chamber” is constructed around the eye of the spring, completely enclosing it. Some form of manhole should be provided so that desilting, routine maintenance, and inspection of the pipe intake can be undertaken. It should not be the function of the spring chamber (cut-off wall, spring box or V-box) to store water, since a rise in the chamber’s water level above the eye of the spring can result in the underground flow of water finding additional outlets or eyes.

The spring chamber in Figure 9.2 should be designed according to the principles of underground filters. Provide a graded filter or filter cloth between the in-situ material and the outlet pipe.

- **Seepage field**: where the spring has several eyes or seeps out over a large area. In this case, infiltration trenches are dug and subsoil drains constructed. The drains feed the spring water to a central collector pipe. Subsoil drains can be made of stone, gravel, brushwood, tiles, river sand, slotted pipes, filter material or a combination of the above.

The outlet pipe from a protected spring is usually fed to a storage tank, which keeps the water available for use. The storage tank should have an overflow pipe that is below the level of the spring outlet in the case of gravity feed.

The area immediately above and around the spring outlet or protection works (see Figure 9.3) should be fenced, to prevent faecal contamination by humans and animals. A furrow and berm should be dug on the upstream side of the outlet, to prevent the direct ingress of surface water into the spring after rains.

The reliable yield from a spring is estimated by measuring the outlet flow rate during the driest months of the year (August/September in summer rainfall areas, February/March in winter rainfall areas). The reliable yield is then calculated by multiplying this flow rate by a factor. This factor (see Table 9.3)
Water supply depends on a number of variables, including geology, soil types, land use, and hydrological characteristics. As a first approximation the following factors may be used, but it is advisable to try to obtain additional information where possible.

Usually, the local populace can provide information on whether the spring ever dries up, or how many containers can be filled in an hour for the worst drought years.

It is also reasonable to assume some level of risk, especially since during at least 90% of the year better flow conditions than the reliable yield can be expected.

**Wells**

Where the underground water does not emerge above the natural surface of the ground, this water can be accessed by digging a well in the case of shallow depths, or drilling a borehole when the water level is deep (i.e. greater than 15 m).

**Hand-dug wells**

A well is a shaft that is excavated vertically to a suitable depth below the free-standing surface of the underground water. It is usually dug with hand tools, and consists of a well head (the part visible above ground), a shaft section and the intake (the area where water infiltrates).

The well head’s construction will depend on local conditions but must be built in a way that contributes to hygiene and cleanliness. The well lining should extend above the ground surface, to prevent contaminated surface water from running down into the well. For this reason, and to prevent subsidence, the space between the lining and the side of the shaft should be backfilled and compacted. A concrete apron, sloping away from the well, should preferably be cast around the well.

It is necessary to provide some form of lining to prevent the walls of the shaft collapsing, both during and after construction. Types of linings used include:

- reinforced concrete rings (caissons);
- curved concrete blocks;
- masonry (bricks, blocks or stone);
- cast-in-situ ferrocement;
- curved galvanised iron sections; and
- wicker work (saplings, reeds, bamboo, etc).

The well must be sunk sufficiently deep below the free-standing surface of the groundwater to form a sump in order to provide adequate water storage, to increase the infiltration capacity into the well, and to accommodate seasonal fluctuations in the depth of the water table. The larger the diameter of the hole, the faster it will recharge, depending on the characteristics of the aquifer. Joints between the linings can be sealed with mortar or bitumen above the water table, but left open below it.

The intake section is that part of the shaft in contact with the aquifer. Joints in this section must be left open. It is advisable to cover the bottom of the well with a gravel or stone layer to prevent silt from being stirred up as the water percolates upwards, or as the water is disturbed by the bucket or pump used for abstraction.

The well should be covered with a slab and equipped with a suitable pump or bucket and a lifting mechanism.

| Table 9.3: Factors for obtaining reliable yield estimates of spring water |
|-------------------------------|---------------|
| **RAINFALL DURING PREVIOUS WET SEASON** | **FACTOR** |
| Above average, extending into normally dry season | 0.25 |
| Above average | 0.35 |
| Average | 0.50 |
| Below average | 0.65 |
| Below average, longer than usual dry period | 0.80 |

Figure 9.4: Hand-dug well (IRC 1980 & 1983)
**Tube wells (also called bored wells)**

In sandy soils, the hand-digging of wells is problematic and expensive since loose sands tend to collapse. Therefore, hand-digging in sandy soils is not recommended as cheaper, more efficient methods are available. These methods include jetting, hand-drilling and augering of small-diameter holes (50 to 500 mm). The holes are lined using uPVC or mild steel casings to prevent collapse. The section below the water table is fitted with some form of well screen to allow for filtration of the groundwater while preventing the ingress of silt.

As with hand-dug wells, the tube well should be covered with a slab and equipped with a suitable pump and concrete apron. Specially designed buckets that can fit into the tubes and be winched down to the water table are still commonly used in tube wells. Certain designs of bucket eliminate the need for handling and, hence, the possibility of polluting the well water with germs, etc., from unwashed hands.

**Boreholes**

Generally, underground water is of a better quality, in terms of bacteria and suspended solids, than surface sources, and its supply is often more reliable. For these reasons, human settlements throughout history have shown a preference for underground water, when available, for domestic water supplies. In all cases, groundwater should be analysed to determine its fitness for human consumption as well as its possible effect on pipe systems.

When the water table occurs at a great depth and/or in rock formations that do not facilitate the construction of hand-dug wells, a relatively small hole can be drilled using mechanical equipment. With the proper equipment, such boreholes can be sunk to depths of 100 m or more, if required.

The borehole should be drilled by a reputable drilling contractor registered with the Borehole Water Association of South Africa. The drilling should also be executed in terms of accepted procedures and standards, e.g. the Association's publication *Minimum Code of Practice for Borehole Construction and Pump Installation*.

The diameter of the hole should suit the size of the casing to be installed, plus any temporary casing required to keep the hole open during drilling and gravel-packing. For most hand-pump installations a casing diameter of 100 to 110 mm is adequate, while submersible pumps normally require a minimum diameter of 120 mm, and preferably at least 150 mm.

As with hand-dug wells and tube wells, it is important to prevent surface water entering the borehole, and to drain any excess water from the borehole site. If necessary, a concrete apron or collar should be provided. The installation of a sanitary seal provides effective protection against aquifer pollution via the borehole annulus. Wherever possible, a local resident should be trained to maintain the borehole and borehole pump and to alert the appropriate authorities when major breakdowns occur. Water level measurements should be taken regularly and recorded, to ensure the pump is submerged at all times and provide early warning of source depletion.

**Siting of wells and boreholes**

The presence, amount and depth of deep underground water cannot normally be predicted beforehand with a high degree of accuracy. Boreholes and wells previously sunk in the area could give valuable information as to the depth and amount of water available. Trained geoscientists (e.g. hydrogeologists or geophysicists) are able to establish the most favourable sites by using techniques such as aerial photograph interpretation and geophysical exploration – e.g. electrical resistivity, magnetic, seismic and gravimetric measurements. National and regional groundwater maps providing synoptic and visual information on South Africa’s groundwater resources are available from the Water Research Commission and the Department of Water Affairs & Forestry. These maps are not site-specific and cannot be used for borehole siting or any site-specific groundwater conditions, but are an aid in determining borehole prospects and other groundwater related information such as quality.

Groundwater is vulnerable to pollution. All boreholes not correctly equipped should be properly closed. As a minimum guideline, boreholes for domestic use should be at least 30-50 m away from potential pollution sources such as on-site toilets, cattle kraals or cemeteries; however, this general rule must be considered against site-specific conditions and circumstances.

**Determination of yield**

Once a successful borehole has been established, it is important to carry out tests to estimate the yield likely from that borehole. The type of test and its duration must be chosen to suit the level of reliability required. Recommendations in this regard are given in Table 9.4. These recommendations represent the minimum requirements, and can be altered to suit the situation (extract from *Test pumping standards for South Africa* published by the Ground Water Division of the Geological Society of South Africa).

All the aspects addressed above are covered in a document *Minimum standards and guidelines for groundwater resource development for the community water supply and sanitation programme* published by the Department of

**Rainwater**

Rainwater can be collected and stored. The harvesting of rainwater from roof runoff can supplement domestic supplies, even in semi-arid areas. In particular, rainwater can be harvested not only for domestic use, but also to provide water at remote public institutions like schools and clinics, as well as resorts. Usually the limit is not the amount of rainfall that can be collected, but the size of the storage tank that will provide a sustained supply during periods of little or no rainfall. It should, however, be considered a supplementary supply for non-potable use since it could pose a health risk.

Rainwater collection from roofs constructed from corrugated iron, asbestos sheeting or tiles is simple. Guttering is available in asbestos cement, galvanised iron, uPVC, plastic or aluminium. The guttering and downpipes can be attached directly to the ends of rafters or trusses, and to fascia boards.

Because the first water to run off a roof can contain a significant amount of debris and dirt that has accumulated on the roof or in the gutter, some mechanism (such as that in Figure 9.5) to discard the first flush is desirable. In addition, the inlet to the storage tank should be protected with a gauze screen to keep out debris, as well as mosquitoes and other insects or rodents.

Materials commonly used for rainwater tanks include corrugated iron, glass fibre, asbestos cement, high-density polyethylene (all prefabricated types) or ferrocement, concrete blocks, masonry, reinforced concrete, and precast concrete rings (tank constructed in-situ). Subject to the availability of a suitable mould, ferrocement construction is one of the most economical options at present. Ferrocement construction without the use of a mould is also possible, however.

Larger quantities of rainwater may be collected from specially prepared ground surfaces. Surface preparations to make the ground less permeable include compaction and chemical treatment, or covering with impermeable materials such as plastic, rubber, corrugated iron, bitumen or concrete. In the case of ground-level rainwater harvesting, the storage tank will normally need to be located underground. The catchment area should also be protected (fenced off) to minimise the risk of possible faecal contamination.

The average quantity of water available from a rainwater catchment area is found by multiplying the area (in plan) with the mean annual rainfall in that area, and adjusting by an efficiency factor (average rainwater (litres) = catchment area (m²) x mean rainfall (mm) x efficiency, where efficiency, has a value between 0 and 1.0). For roofs an efficiency of 0.8 is usual.

<table>
<thead>
<tr>
<th>USE OF WATER</th>
<th>TEST</th>
<th>DURATION</th>
<th>RECOVERY TEST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stock or domestic</td>
<td>Extended step</td>
<td>Total 6 hours</td>
<td>Up to 3 hours</td>
</tr>
<tr>
<td>Hand pump</td>
<td>Extended step</td>
<td>Total 6 hours</td>
<td>Up to 3 hours</td>
</tr>
<tr>
<td>Town water supply</td>
<td>Step</td>
<td>4 x 1 hour</td>
<td>-</td>
</tr>
<tr>
<td>Low-yield borehole</td>
<td>Constant discharge</td>
<td>24 hours</td>
<td>Complete</td>
</tr>
<tr>
<td>Town water supply</td>
<td>Step</td>
<td>4 x 1 hour</td>
<td>-</td>
</tr>
<tr>
<td>High-yield or main borehole</td>
<td>Constant discharge</td>
<td>72 hours or more</td>
<td>Complete</td>
</tr>
</tbody>
</table>

**Table 9.4: Recommended test and duration to estimate subsurface water yield**

![Figure 9.5: Arrangement for diverting the “first foul flush” (IRC 1980)](image-url)
Fog harvesting

Fog harvesting is limited in application and confined to particular geographical areas. A number of pilot projects are currently being undertaken at Cape Columbine, Pampoenvlei, Lamberts Bay, Brand se Baai, Kalkbaken se Kop and Kleinsee. The publication *Fog harvesting along the west coast of South Africa: a feasibility study* by J. Olivier (Water SA, vol 28 no 4, October 2000) can be referred to in this regard.

The technique is fairly simple – nets spanned between poles. Fog condenses on the nets and runs down into an open chute for collection in a storage facility.

The findings of a number of test sites are currently awaited.

Surface water

The Catchment Management Agency or the Department of Water Affairs and Forestry’s Regional Office should be consulted where surface water is used as source. Surface water sources, such as streams, rivers, lakes, pans and dams, will always contain suspended solids (turbidity) and microbiological pollutants. In addition, the quantity of water that can be abstracted from these sources is dependent upon droughts and floods, unless sufficient storage is available or can be provided. The following aspects should therefore be taken into account when relying on surface water to supply a community:

- The water should be treated for the removal or destruction of pathogenic organisms (e.g. bacteria, viruses, protozoa), as well as for turbidity.
- Where deemed necessary, a back-up source (e.g. a borehole) should be provided for times of shortage and drought, to ensure a minimum supply for domestic use.
- A pump station or other water extraction facility should be protected from possible damage by floods or vandalism.

The water supply intake may be sited at any point where the surface water can be withdrawn in sufficient quantities. In some situations where the gradient is steep enough, the water to be used may be diverted directly into a canal or pipeline, without the need for pumps.

In the case of a small stream or river it may be necessary to construct a weir across the river bed to provide enough depth for intake and to maintain the water level within a fairly narrow range. A weir may be constructed with concrete, cement blocks, or rocks covered with impermeable plastic sheeting. The type of construction selected will depend on economics and on the flood conditions expected.

The river or dam's intake point should be selected to abstract the best quality of water from the source. For example, a float intake (see Figure 9.6b) may be selected to withdraw water just below the surface. This may be desirable as the surface water may be clearer than the water at deeper levels. Alternatively, an intake placed below the bed of a river (see Figure 9.6d) would result in the water being partially filtered as it passes through the sand of the bed. While this may appear to be the most desirable, it is important to ensure that any such filtered-intake system is firmly fixed in place because, when the river floods, the river bed tends to become unstable.

In a stationary body of water like a dam or lake, it may be desirable to withdraw water well below the surface to minimise the amount of algae in the water extracted. However, if the water is extracted from too deep a level, the quality of this water may show a marked difference from the surface water. This is because of the possible thermal stratification of the lake in the warm summer months, when the oxygen levels in the deeper waters could be depleted, causing deterioration in quality.

Bulk-supply pipelines

The storage and distribution system, often comprising the major expense, must be appropriate for the area in terms of cost, complexity and operational requirements.

When a developing area is located alongside an already developed area, it may be possible to purchase water directly from the authority supplying water to the developed area. In many cases, the existing water pipelines will be able to support the additional requirement of the developing area. If the pipeline is situated close to the developing area, this position could be highly cost-effective. A storage reservoir may be required to ensure a continuous supply where excess water is only available during off-peak periods. If the water in the pipeline is untreated, some treatment will be required to ensure that the water is safe for domestic use. The authority responsible for the pipeline will require payment for the water withdrawn from the pipeline, and hence it will be necessary to meter the connection.

WATER TREATMENT

General

Water treatment is considered a specialised subject. This section therefore gives a broad background only and does not attempt to give guidance to the design engineer. Specialists should be consulted where water purification is considered.
In many cases, water obtained from a particular source will require some treatment before being distributed for domestic use. Water obtained from boreholes, protected wells, protected springs and harvested rainfall often requires little or no treatment. However, as a precautionary measure and to minimise biological activity in the storage reservoirs and pipelines, even such waters should be chlorinated before distribution.

Most surface waters will require treatment, both to remove turbidity and for disinfection.

Certain surface waters and groundwaters will require additional treatment for the removal of organic and/or inorganic contaminants. Many groundwaters in southern Africa are highly saline, and unless a suitable alternative source of water can economically be located, they will require partial desalination to make them suitable for domestic use.

Unfortunately, there is no such thing as a universal, simple and reliable water treatment process suitable for small community water supplies. Treatment should be affordable and reliably operated. Okun and Schultz (1983) suggest that under all circumstances groundwater is the preferred choice for community supplies, as it generally does not require treatment. When treatment is required, this will be determined by the extent of contamination and by the characteristics of the raw water.

A simple approach for the selection of a treatment system is given by Thanh and Hettiaratchi (1982) (see Table 9.5). The emphasis on slow sand filtration is valid for areas where skilled personnel may not be permanently available to operate the plant, where chemical shortages may occur, where space is available at low cost, and where supervision may be irregular. Marx and Johannes (1988) found slow sand filtration to be an economical and successful option for water treatment plants in developing areas of South Africa.

Where sufficient money and skilled operators are available, standard water treatment plants (e.g. chemical flocculation, radial settler, rapid sand filtration and chlorination) have worked well under most circumstances.

**Package water treatment plants**

Package water treatment plants (see glossary) for smaller communities in rural areas have potential and could fulfil the need for potable water. Attention should, however, be given to operation and maintenance requirements as well as to backup from suppliers.

More information can be obtained from a Water Research Commission (1997) publication entitled *Package water treatment plant selection.*
Table 9.5: Treatment selection criteria (Thanh and Hettiaratchi 1982)

<table>
<thead>
<tr>
<th>RAW WATER QUALITY</th>
<th>TREATMENT SUGGESTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbidity 0-5 NTU</td>
<td>No treatment</td>
</tr>
<tr>
<td>Faecal coliform</td>
<td></td>
</tr>
<tr>
<td>0/100 mℓ</td>
<td></td>
</tr>
<tr>
<td>Guinea worm or</td>
<td></td>
</tr>
<tr>
<td>schistosomiasis</td>
<td></td>
</tr>
<tr>
<td>endemic</td>
<td></td>
</tr>
<tr>
<td>Turbidity 0-20 NTU</td>
<td>Slow sand filtration</td>
</tr>
<tr>
<td>Faecal coliform</td>
<td></td>
</tr>
<tr>
<td>1-500/100 mℓ</td>
<td>Chlorination if possible</td>
</tr>
<tr>
<td>Turbidity 20-30 NTU</td>
<td>Pre-treatment advantageous</td>
</tr>
<tr>
<td>Up to 30 NTU for a few days only</td>
<td>Slow sand filtration</td>
</tr>
<tr>
<td>Faecal coliform 1-500/100 mℓ</td>
<td>Chlorination if possible</td>
</tr>
<tr>
<td>Turbidity 20-30 NTU</td>
<td>Pre-treatment advisable</td>
</tr>
<tr>
<td>Up to 30 NTU for several weeks</td>
<td>Slow sand filtration</td>
</tr>
<tr>
<td>Faecal coliform 1-500/100 mℓ</td>
<td>Chlorination if possible</td>
</tr>
<tr>
<td>Turbidity 20-150 NTU</td>
<td>Pre-treatment</td>
</tr>
<tr>
<td>Faecal coliform 500-5 000/100 mℓ</td>
<td>Slow sand filtration</td>
</tr>
<tr>
<td>Chlorination if possible</td>
<td></td>
</tr>
<tr>
<td>Turbidity 30-150 NTU</td>
<td>Pre-treatment</td>
</tr>
<tr>
<td>Faecal coliform &gt;5 000/100 mℓ</td>
<td>Slow sand filtration</td>
</tr>
<tr>
<td>Chlorination</td>
<td></td>
</tr>
<tr>
<td>Turbidity &gt;150 NTU</td>
<td>Detailed investigation (and possible pilot-plant study)</td>
</tr>
</tbody>
</table>

WATER SUPPLY OPTIONS

Selection of water supply terminals

Water supply terminals are divided into public (or communal) and private installations. Public or communal installations are those installations to which the public and the community have access. Private installations are those that render water to individual households.

The selection of terminals for a community depends on a number of factors, the most important being:

- affordability of the system (by agency/users);
- selected method of cost recovery;
- unit cost to end-user; and
- long-term maintenance requirements.

With regard to water for domestic use, the relative importance of these factors for each terminal is given in Table 9.6. The value judgements in this table are subjective and a number of other factors may influence the final selection, or the validity of the judgement for a particular situation.

If possible, individual connections should be provided to schools, clinics and possibly some businesses, no matter which option is selected.

Public or communal water supply terminals

Rudimentary systems fall within the category of public or communal water supply terminals. These systems normally comprise a source or consumer terminal where water is collected in containers or buckets. Walking distance is usually between 200 and 500 metres. A minimum of water is provided – between 5
and 15 l/c/d, mainly for drinking and cooking.

The most basic systems are run-of-river abstraction, rainwater harvesting, unprotected springs and open wells. The systems are often augmented by hand pumps, spring protection, a windmill, solar pump or some storage tanks. All systems require home treatment.

**Communal street tap: Ordinary type**

The system comprises a water reticulation system with standpipes in open areas or in road reserves. The Department of Water Affairs and Forestry’s White Paper of 1994 defined basic water as access to 25 litres of potable water per person (capita) per day at a communal street tap which is within 200 metres of the dwelling, with 98% reliability and a 10 l/min flow rate. Provision is usually made in the design for upgrading.

The design of the standpipe installation requires careful planning, and special attention should be given to drainage of excess water and avoiding wastage, in order to minimise health risks. A typical example is shown in Figure 9.7.

In the case of communal standpipes serving dwelling houses, the following criteria should be satisfied (payment arrangements may influence these considerations):

- one tap required per 25-50 dwellings;
- maximum number of people served per water point: 300;
- maximum number of people served per tap: 150;
- maximum walking distance from a dwelling to a standpipe: 200 m.

An acceptable discharge capacity from a standpipe is about 10 l/min per tap. For commonly used taps the calculated discharge range, at an assumed efficiency of 80%, is given in Table 9.7.

These flow rates should be considered only as a guide; the actual flow rate depends on the type of tap used. The high discharge rates indicated for a 60 m head will normally be reduced by the limitations of the pipework. In practice, measured flow rates to single dwelling houses seldom exceed 40 l/min.

In order to reduce water wastage, and to prolong the life of the tap washers, pressures should be limited.
Access for physically disabled persons:
Barriers that prevent access to water and sanitation facilities for disabled people tend to fall into the following categories (WEDC, 2002):

- Environmental: barriers in the physical environment and infrastructure;
- Individual: functional limitations of the individual disabled person;
- Social: negative attitudes and behaviour of the community and society; and
- Institutional: discriminatory legislation, policies, and organisational practices.

Involvement of disabled people at all stages of project planning and implementation will improve both effectiveness and sustainability.

The provision of communal street taps should take cognisance of the requirements of physically disabled persons. Taps should be situated on smooth, even pathways, and ramps should be provided in lieu of steps. Ramps should be not less than 1100 mm wide with a slope not exceeding 1:12.

Communal street tap: Prepaid type

The basic (RDP) standard (25 l/c/d within 200m at 98% reliability and 10 l/min flow), with the addition of prepaid meters at street taps.

Water kiosks

Water kiosks are being used in developing areas where urbanisation has caused the rapid growth of settlements. The sale of water at kiosks provides an effective means of recovering costs, which is especially relevant in places where community management structures are not yet in place.

Due to their higher cost and the relatively large number of users required to make individual units commercially viable, kiosks are usually spaced further apart than standpipes would normally be. For the system to be viable, individual kiosks should supply at least 100 dwellings.

Facilities for accurately measuring and dispensing the standard purchase volume (usually 20 to 25 litres) should be provided. The structures should be sturdy, and have lockable facilities.

### Table 9.7: Typical discharge rates for taps (assumed efficiency rate 80%)

<table>
<thead>
<tr>
<th>TAP DIAMETER</th>
<th>DISCHARGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 m head</td>
</tr>
<tr>
<td>15 mm</td>
<td>16 l/min</td>
</tr>
<tr>
<td>20 mm</td>
<td>22 l/min</td>
</tr>
</tbody>
</table>

**Figure 9.7: Typical standpipe detail**

**Table 9.7: Typical discharge rates for taps (assumed efficiency rate 80%)**

**Water supply**

**Chapter 9**
**Water tanks with taps**

Water tanks with taps may be the first level of supply improvement before any distribution piping is installed. Water may be supplied by gravity flow from a spring, from a borehole equipped with an engine-driven pump, by rainwater, or from a small treatment plant. People may need to walk long distances to the tanks to collect this water. However, its quality is usually good, and it may often be the only source of water available to a community.

The size and design of the tanks should be in accordance with the design principles given elsewhere in this chapter.

**Handpump installations**

The following criteria are considered important for effective water supply to areas using handpumps:

- The handpump chosen should take into account corrosiveness of the environment, together with suitable riser pipe material for the pumping head.
- The community should be consulted in the choice of the handpump; this selection should be made from a well-informed position.
- The pump should be installed professionally.
- The site should also be free from contamination by animals and humans, and generally be distant from sources of possible pollution.
- The pump should be taken care of by selected, motivated community members in order to facilitate maintenance tasks.
- It should not be expected of communities to be completely self-sufficient; adequate spares and maintenance should be available.

**Private water supply terminals**

Yard connections and house connections fall within the category of private water supply terminals.

**Yard connections**

*Ordinary type*

Water is provided, at pressure, at a tap on the boundary just within the stand. No storage facilities are provided on site and there is no supply to the house. However, an outside toilet may be supplied with a hand-washing facility or washtub.

*Yard tank (or ground tank): low-pressure, trickle feed*

Water is provided at full pressure up to specially manufactured yard tanks. The tank inlet has a flow regulator (trickle feed), which is sized to give a predetermined volume (mostly 25 l/c/d) to the household. A ball valve inside the tank prevents it from overflowing. Supply can be shut off if required.

*Yard tank (or ground tank): low-pressure, manually operated*

This is similar to the Durban tank (Figure 9.8). Water is provided at full pressure into yard tanks. The volume of supply is either manually controlled by a bailiff who, on a daily basis, opens the supply at a control node, or electronically controlled to fill each tank where the monthly flat rate has been paid. The supply volume can be adjusted by changing the tank size and increasing the monthly flat rate. A ball valve inside the tank prevents it from overflowing. Supply can be shut off if required.

*Yard tank (or ground tank): low-pressure, regulated*

Water is provided at regulated pressure and flow rate into yard tanks. Volume and pressure of supply is regulated by “equity” valves at control nodes located on the RDP pipe network. A ball valve inside the tank prevents it from overflowing. Bailiffs can shut off supply if required. Volume of supply can easily be adjusted by changing the size of the equity valve.

*Roof tank: medium-pressure, manually operated*

Water is provided at full pressure into a roof tank either in or on top of the roof of the house. The water supply is sometimes throttled to discourage excessive use. Water use in the house is at roof-height pressure. A ball valve inside the tank prevents it from overflowing. The volume of supply is unlimited and metered conventionally.
Customers are regularly invoiced for water consumed.

**Roof tank: medium-pressured, regulated**
Water is provided at high pressure to reticulation nodes, and at reduced pressure into a roof tank either in or on top of the house. The water supply is sometimes throttled to discourage excessive use. Water used in the house is at roof-height pressure.

The volume of supply is regulated by the “equity” valve at the node, and can be changed to upgrade or downgrade the level of water use. The volume of supply is unlimited and metered conventionally. Customers are regularly invoiced for water consumed.

**House connections**

**Full-pressure conventional house connection**
Water is provided at high pressure into the house, and all water use is at full pressure and unregulated flow. Water use is metered conventionally. Customers are regularly invoiced for water consumed.

The communication pipes for erf connections for dwelling houses (Residential zone 1) should be sized according to Tables 9.8 and 9.9.

For developments other than dwelling units metered individually, the communication pipe should be sized according to the specific demand.

**House connection: full-pressure, prepaid**
Water is provided at high pressure into the house, and all water use is at full pressure, and available with prior payment (prepayment tokens) activating the prepayment meter. These tokens can be bought at central vending offices. No monthly meter reading and billing is required.

**DESIGN CRITERIA FOR WATER DISTRIBUTION AND STORAGE SYSTEMS**

**General**

Water distribution and storage are, in most instances, the most costly parts of a water supply scheme. Hence savings in these areas through good design can often result in significant savings for a whole project.

The elements of a water distribution and storage system include some or all of the following:

- bulk water transmission systems;
- bulk-storage reservoirs;
- intermediate-storage reservoirs;
- distribution networks; and
- terminal consumer installations.

This section deals with water demand and is presented in two parts. The first part deals with water demand in developing areas and the second part deals with developed areas. It does not therefore mean that the guidelines given are applicable only to a particular area – the designer should always be aware of the dynamics within a community that could influence the development of an area.

### Table 9.8: Communication pipes across roads for house connections

<table>
<thead>
<tr>
<th>INCOME LEVEL</th>
<th>MINIMUM ACTUAL INTERNAL DIAMETER (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SERVING TWO ERVEN</td>
</tr>
<tr>
<td>Higher</td>
<td>40, branching to 2 x 20</td>
</tr>
<tr>
<td>Middle</td>
<td>40, branching to 2 x 20</td>
</tr>
<tr>
<td>Lower</td>
<td>20, branching to 2 x 15</td>
</tr>
</tbody>
</table>

### Table 9.9: Communication pipes on near side of road for house connections

<table>
<thead>
<tr>
<th>INCOME LEVEL</th>
<th>MINIMUM ACTUAL INTERNAL DIAMETER (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SERVING TWO ERVEN</td>
</tr>
<tr>
<td>Higher</td>
<td>40, branching to 2 x 20</td>
</tr>
<tr>
<td>Middle</td>
<td>40, branching to 2 x 20</td>
</tr>
<tr>
<td>Lower</td>
<td>20, branching to 2 x 15*</td>
</tr>
</tbody>
</table>

* The communication pipe may be reduced to 15 mm nominal diameter, provided the minimum head in the reticulation main at the take-off point for the erf connection under instantaneous peak demand is not less than 30 m.
Developing areas are considered to be those areas where the level of services to be installed may be subject to future upgrading to a higher level.

Developed areas are considered to be those areas where the services installed are already at their highest level and will therefore not require future upgrading.

**Water demand**

Water demand is usually based on historical consumption. Where water consumption records are not available, present consumption per capita can be estimated by consulting the residents. However, once the supply system has been upgraded, consumption is likely to change and Tables 9.10 and 9.11 may be used to estimate typical consumption. An improved estimate could be obtained by studying existing water supply systems in the same area. It has also been shown that extensive education programmes could have a positive influence on water demand.

### Table 9.10: Water demand for developing areas (IRC 1980)

<table>
<thead>
<tr>
<th>TYPE OF WATER SUPPLY</th>
<th>TYPICAL CONSUMPTION (l/c/d)</th>
<th>RANGE l/c/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communal water point</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• well or standpipe at considerable distance (&gt;1000 m)</td>
<td>7</td>
<td>5-10</td>
</tr>
<tr>
<td>• well or standpipe at medium distance (250-1000 m)</td>
<td>12</td>
<td>10-15</td>
</tr>
<tr>
<td>• well nearby (&lt;250 m)</td>
<td>20</td>
<td>15-25</td>
</tr>
</tbody>
</table>

### Table 9.11: Water consumption in areas equipped with standpipes, yard connections and house connections (adapted from Department of Water Affairs & Forestry, 1992: Guidelines for the selection of design criteria)

#### DOMESTIC WATER CONSUMPTION

<table>
<thead>
<tr>
<th>TYPE OF WATER SUPPLY</th>
<th>TYPICAL CONSUMPTION (l/c/d)</th>
<th>RANGE l/c/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standpipe (200 m walking distance)</td>
<td>25*</td>
<td>10 - 50</td>
</tr>
<tr>
<td>Yard connection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>With dry sanitation</td>
<td>55</td>
<td>30 - 60</td>
</tr>
<tr>
<td>With LOFLOs</td>
<td></td>
<td>45 - 75</td>
</tr>
<tr>
<td>With full-flush sanitation</td>
<td></td>
<td>60 - 100</td>
</tr>
<tr>
<td>House connection (developed areas) #</td>
<td></td>
<td>60 - 475</td>
</tr>
<tr>
<td>Development level:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>80</td>
<td>48 - 98</td>
</tr>
<tr>
<td>Moderate to high</td>
<td>130</td>
<td>80 - 145</td>
</tr>
<tr>
<td>High</td>
<td>250</td>
<td>130 - 280</td>
</tr>
<tr>
<td>Very high</td>
<td>450</td>
<td>260 - 480</td>
</tr>
</tbody>
</table>

* This consumption of 25 l/c/d is the minimum to be made available per person in terms of government policy.

# The water demand in this category, based on a different approach, is also given in Table 9.14 and Figure 9.9.
Notes:
- A handpump should be considered as being similar to a well, since additional effort is required to obtain the water.
- A spring should be considered as being similar to a standpipe, especially when it has been protected.
- A climb of more than 60 m over a short distance should be considered as being similar to walking a distance of about 1 000 m.

Factors influencing water demand
- The type of sanitation system and the development level affect the water consumption, particularly in the category “House connection”.

The development levels are as follows:
- **Moderate**: medium-sized formal housing with limited finishing, moderate gardens.
- **Moderate to high**: limited formal suburban housing, moderate finishing, extensive gardens.
- **High**: extensive formal suburban housing, small stands, extensive gardens, moderate-flush toilets.
- **Very high**: formal suburban housing, large stands, extensive gardens, fully reticulated.

- Inhibiting factors like topography, water quality and water tariff.
- Metering and cost-recovery mechanisms.

Non-domestic water demand in developing areas

Water requirements for non-domestic purposes are difficult to estimate and, where possible, field measurements should be taken. Provision must also be made for the water demand at public open spaces. See Table 9.12 and 9.14 category 13.

Water demand for stock

The water demand for stock is given in Table 9.13. It must be pointed out that the provision of potable water for stock is highly undesirable and has serious cost-recovery implications.

Water demand in developed areas

The water demand figures in Table 9.14 should be used for detail design where applicable. Studies on water demand show there is usually a large degree of variance about the mean demand, and several factors can cause short-term variations. Therefore, the

---

### Table 9.12: Non-domestic water demand

<table>
<thead>
<tr>
<th>NON-DOMESTIC USERS</th>
<th>WATER DEMAND</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Schools:</strong> day boarding</td>
<td>15-20 litres/pupil/day</td>
</tr>
<tr>
<td></td>
<td>90-140 litres/pupil/day</td>
</tr>
<tr>
<td><strong>Hospitals</strong></td>
<td>220-300 litres/bed/day</td>
</tr>
<tr>
<td><strong>Clinics</strong></td>
<td>5 - outpatients 40-60 - in-patients litres/bed/day</td>
</tr>
<tr>
<td><strong>Bus stations</strong></td>
<td>15 - for those persons outside the community litres/user/day</td>
</tr>
<tr>
<td><strong>Community halls/ restaurants</strong></td>
<td>65-90 litres/seat/day</td>
</tr>
</tbody>
</table>

### Table 9.13: Water demand for stock

<table>
<thead>
<tr>
<th>STOCK</th>
<th>WATER DEMAND litres/head/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensive: meat: LS</td>
<td>50</td>
</tr>
<tr>
<td>SS</td>
<td>12</td>
</tr>
<tr>
<td>Dairy: LS</td>
<td>120</td>
</tr>
<tr>
<td>Extensive: LS</td>
<td>50</td>
</tr>
<tr>
<td>SS</td>
<td>10</td>
</tr>
</tbody>
</table>

LS refers to large stock.
SS refers to small stock.
Intensive: the business of the land owner is farming.
Extensive: keeping a few animals for domestic purposes.

Differences between Tables 9.11 and 9.14 should not be seen as significant and adjustments can be made to these demand figures to take local conditions into account. Attempts to base water demand on other erf-related data have not yet been validated.
Table 9.14: Water demand for developed areas

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>TYPE OF DEVELOPMENT</th>
<th>UNIT</th>
<th>ANNUAL AVERAGE WATER DEMAND (l/day) UNLESS OTHERWISE STATED</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dwelling houses <em>(Residential zone I)</em></td>
<td>Erf area for dwelling house</td>
<td>See Figure 9.9 for erven not exceeding 2 000 m². For erven &gt;2 000 m², base demand on local conditions</td>
</tr>
<tr>
<td>2</td>
<td>Low-rise multiple-dwelling unit buildings <em>(Residential zones II and III)</em></td>
<td>Dwelling</td>
<td>Upper limit 1 000(a) Lower limit 600(a)</td>
</tr>
<tr>
<td>3</td>
<td>High-rise multiple-dwelling unit buildings <em>(Residential zone IV)</em></td>
<td>Dwelling</td>
<td>Upper limit 700(a) Lower limit 450(a)</td>
</tr>
<tr>
<td>4</td>
<td>Offices and shops</td>
<td>100 m² of gross floor area(b)</td>
<td>400</td>
</tr>
<tr>
<td>5</td>
<td>Government and municipal</td>
<td>100 m² of gross floor area(b)</td>
<td>400</td>
</tr>
<tr>
<td>6</td>
<td>Clinic</td>
<td>100 m² of gross floor area(b)</td>
<td>500</td>
</tr>
<tr>
<td>7</td>
<td>Church</td>
<td>Erf</td>
<td>2 000</td>
</tr>
<tr>
<td>8</td>
<td>Hostels</td>
<td>Occupant</td>
<td>150</td>
</tr>
<tr>
<td>9</td>
<td>Developed parks</td>
<td>Hectare of erf area</td>
<td>≤2 ha: 15 k(l)(d) &gt;2 ha ≤10 ha: 12,5 k(l)(d) &gt;10 ha: 10 k(l)(d)</td>
</tr>
<tr>
<td>10</td>
<td>Day school / crèche</td>
<td>Hectare of erf area</td>
<td>As per developed parks(d)</td>
</tr>
<tr>
<td>11</td>
<td>Boarding school</td>
<td>Hectare of erf area plus boarders</td>
<td>As per developed parks plus 150 l/boarder</td>
</tr>
<tr>
<td>12</td>
<td>Sportground</td>
<td>Hectare of erf area</td>
<td>As per developed parks</td>
</tr>
<tr>
<td>13</td>
<td>Public open spaces(e)</td>
<td>Hectare of erf area</td>
<td>See note (e) below</td>
</tr>
</tbody>
</table>

(a) Water demand includes garden watering of all common areas outside the limits of the buildings.

(b) Gross floor area obtained using applicable floor space ratio from the town planning scheme.

(c) Demand for developed parks to be considered as drawn over six hours on any particular day in order to obtain the peak demand.

(d) Where the designer anticipates the development of parks and sportsgounds to be of a high standard, e.g. 25 mm of water applied per week, the annual average water demand should be taken as follows:

≤2 ha: 50 k(l)(d); >2 ha ≤10 ha: 40 k(l)(d); >10 ha: 30 k(l)(d).

(e) Refer to Chapter 5 and distinguish between “soft open space” and “semi-public open space”.
Figure 9.10 could be used as a guide where yard tanks are supplied and a single 15 mm tap is fitted on the service pipe between the consumer connection and the storage tank (usually a 200 litre capacity).

The peak factors mentioned in Table 9.15 are intended as a guide only. The actual choice of the peak factor requires considerable thought from the designer, and depends on several factors that must be taken into account. Recent studies have indicated that the peak factors currently in use are conservative; however, a comprehensive review is still outstanding.

The following are some of the factors that may significantly influence the choice of a specific peak factor:

- employment trends and practices in the community;
- gardening activities;
- number of persons per tap;
- agricultural activities;
- number of dwellings (where supply to less than 200 dwellings is being considered, consideration should be given to a higher peak factor; Figure 9.10 could be used as a guideline in this case);
- economic status;
- extent of unauthorised connections;

| TYPE OF DOMESTIC SUPPLY       | SUMMER PEAK FACTOR | DAILY PEAK FACTOR | INSTANTANEOUS PEAK #
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Low density**</td>
</tr>
<tr>
<td>House connection</td>
<td>1.5</td>
<td>2.4</td>
<td>3.6 - 4.0</td>
</tr>
<tr>
<td>Yard connection</td>
<td>1.35</td>
<td>2.6</td>
<td>3.5 - 4.0</td>
</tr>
<tr>
<td>Street tap / standpipe</td>
<td>1.2</td>
<td>3.0</td>
<td>3 - 3.6</td>
</tr>
<tr>
<td>Yard tanks</td>
<td>-</td>
<td>-</td>
<td>see note</td>
</tr>
</tbody>
</table>

Table 9.15: Peak factors for developing areas

Unrestricted systems are those systems where no specific arrangements restrict the flow at all. The instantaneous peak factor for restricted flow systems (yard tanks) is 1.5 at all times.

Low-density areas are typically found in rural localities. High-density areas are those areas typically found in urban localities.

* Increases with diminishing number of consumers. Figure 9.10 could be used as a guide.
• “skeletonising” (see Glossary) of reticulation networks; in the case of low-level serviced communities, due consideration should be given to the design of the network for the ultimate scenario and the reticulation network being skeletonised to the requirements of the immediate level of service; and

• system constraints (e.g. maximum possible flow from a tap, or limited supply by a water bailiff). Reticulations in the developing areas may be significantly affected by the discharge rate from standpipes. Table 9.7 gives guidelines on tap discharges.

It is not advisable to reduce peak factors to effect cost savings. Cognisance must be taken of the fact that the water supply to developing areas could be upgraded at a later stage, and the long-term development of the water supply to the community must be taken into account.

**Peak factors for developed areas**

In order to determine the instantaneous peak factor for developed areas from the graph, the type of development should first be converted to “equivalent erven” (ee) according to the design annual average daily demand, accepting as a basis for design that one ee has an annual average daily demand of 1 000 litres.

Using the ee thus obtained, the instantaneous peak factor pertaining to any point in the network should be obtained from Figure 9.11.

The annual average daily demand multiplied by the peak factor gives the instantaneous peak flow.

**Storage**

The peak factor will be reduced in the case of the provision of terminal storage (in which case only the terminal storage volume is designed to cater for peak demands).

The provision of intermediate storage will also result in a reduction in the peak flows in the elements prior to the intermediate storage facility.

Where the installed capacity is unable to cater for the peak demand, the demand curve will flatten out, resulting in the actual peak demand being limited to the supply capacity of the system, extended over a longer period of time. This may be of some inconvenience to residents, but will not lead to a water shortage.

**Residual pressures in developing and developed areas**

To obtain the residual head at any point in the reticulation, the network should be balanced using instantaneous peak flows and fire flows.

**Hydraulic formulae for sizing components**

Any of the recognised hydraulic formulae may be used to size pipeline components.

**WATER TRANSMISSION**

**General**

Pipelines are the most common means of transmitting water, but canals, aqueducts and tunnels may also be used. Water transmission conduits usually require considerable capital investment and therefore all technical options with their associated costs should be carefully evaluated when selecting the best solution in each particular case.

![Figure 9.11: Factor for obtaining the peak flow in mains in developed areas](image-url)
Pipelines will usually mean minimum water losses, and also imply the shortest transmission distance. However, pipeline costs may be considerable and the option of canals for the transportation of non-potable water could be considered. Canals will result in higher losses, longer transmission distances, and the possibility of deterioration in water quality due to algal growth. However, the lower costs and the option of labour-intensive construction may make this option more attractive. Designers should also take into account the habits and lifestyle (keeping of livestock) of those communities where canal systems for water supply are considered.

Water can be transported either by gravity or pumping, or a combination of these. Clearly, the preferred choice will always be a gravity supply. Aqueducts and tunnels should only be used in special circumstances. However, physical or economic constraints may limit the options and necessitate a pumping component.

**Canals**

Canals may be used to transport large volumes of water over long distances. They should be lined (usually with concrete) and inspected regularly for cracks and leaks in the joints. The growth of algae may need to be addressed by shock chlorination from time to time. Canals should only be used for transporting non-potable water.

**Water tankers**

The operational costs of supplying water by tanker are usually extremely high, but may serve as a temporary measure in an emergency situation, or for a new settlement. However, alternative tank size and delivery vehicle combinations should be considered when undertaking a feasibility study. The use of multi-purpose vehicles (e.g. tractors with different trailer combinations) could also be considered as a means of reducing the capital costs.

**PIPELINE DESIGN**

**Basic requirements**

- The static pressure should be kept as low as possible by reducing the pressure in a balancing or separate break-pressure tank, or by means of a pressure-reducing valve.
- To avoid air pockets, the number of high and low points should be kept to a minimum by trying to follow the contour lines, rather than roads or tracks.
- To minimise the number of air-release valves, the pipeline trench depths may be varied to avoid local high and low points.
- The cost of a water transmission system is more sensitive to the total length of pipe installed than the diameter of the pipes. Therefore, it is generally advantageous to design a transmission system (at least the major components) to meet the ultimate capacity.
- Velocities in pipes should be approximately 0,6 m/s and should not exceed 1,2 m/s.
- Velocities in special fittings (fittings specifically manufactured) should not exceed 6 m/s.
- Air valves should be installed at summits, and scour valves at low points between summits.
- Thin-walled pipes susceptible to buckling must have valves that automatically allow air to enter when the pipeline is emptied, so as to prevent a vacuum that will cause the pipe to collapse.
- To facilitate the location of a buried pipe during maintenance, curved pipe routes should be avoided. All bends should be marked with a post or a suitable beacon, and the pipeline laid in a straight line between bends.
- To avoid air pockets in pipelines, the slope should be greater than 0,3% (0,3 m per 100 m length), or 0,2% for large-diameter pipes (>200 mm).
- To avoid damage to pipelines during backfilling of a trench, a proper pipe-laying specification should be provided by the designer. Recommended minimum trench depths are as follows:
  - road crossings: pipe diameter + bedding + 0,80 m;
  - otherwise: pipe diameter + bedding + 0,60 m.
- Bedding thickness should normally be a minimum of 0,10 m or one-sixth of the pipe diameter, whichever is greater.
- The likely effect of water hammer/surge pressure should be considered in the design of a pressure pipeline system, as this may be the crucial factor in the selection of pipe class, or may indicate the need to provide surge or accumulator tanks.

The suitability of any pipe for a particular application is influenced by:

- its availability on the market, both in respect of dimensions and pressure classes;
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- its purchase price and associated costs of valves and fittings;
- its susceptibility to corrosion, mechanical damage and material ageing, as well as any other cause of material deterioration in the particular application;
- its storage costs; and
- the diameter of pipeline (internal and external).

Pipes laid above ground

It may happen that pipes have to be laid above ground due to adverse conditions, such as rock. When considering laying pipes above ground, the following factors need to be taken into account:

- Provision should be made for expansion joints (the effects of thermal changes must be considered).
- Each pipe section should be properly supported. The supports should be designed to carry the load of the pipe as well as the water it conveys. Sufficient supports should be included in order to prevent sagging of the pipeline. The pipe should be strapped to the support, leaving room for movement.
- Adequate thrust blocks should be designed to cater for hydraulic forces at bends.
- Adequate anchoring should be provided, especially in steep slopes, and directional and elevation changes.
- The consequences of pipe failure should be evaluated.
- Heavy equipment like valves should be supported independently.
- Adequate protection should be provided to cope with external abrasion.
- Vulnerability to damage from veld fires, animals and rodents should be assessed.

VALVES AND OTHER FITTINGS

General

Valves and fittings should be carefully located and designed to facilitate the operation of the system. Careful routing of the pipeline will minimise the number of costly fittings required.

Isolating valves

Isolating valves should be installed at one- or two-kilometre intervals on transmission mains. Where possible, these should be combined with air-release valves. Pressure-relief valves should be installed on pumping mains to avoid damage caused by pumping against closed valves.

In reticulation networks, isolating valves should be provided so that not more than four valves need to be closed to isolate a section of main. Valves should be spaced so that the total length of main included in an isolated section does not exceed a nominal 800 m. This will obviously depend on circumstances.

In order to facilitate identification, valves should be located at street corners opposite erf corner boundary (splay) pegs, and intermediate valves opposite the common boundary peg for two erven.

Where pipes intersect, isolating valves should generally be installed in the smaller-diameter branches.

Isolating valves should be installed to facilitate maintenance of the main, and generally located to suit the topography.

To reduce cost, isolating valves in larger mains may be of lesser size than the pipeline. The design should ensure that the cost of the smaller valve, together with reducers, is less than the cost of a full-size valve. In addition, care should be taken to ensure that velocities through the valve are not excessive.

Depending on the size of the valve and the unbalanced pressure across the valve, devices such as thrust bearings, spur gearing and a separate bypass valve may be required.

When flanged isolating valves are used, a flange adaptor coupling should be installed to facilitate removal of the valve.

Air valves

Air valves are required to release air from the pipeline during the filling process and during normal operation. Whereas automatic small-orifice air-release valves are desirable, these may be replaced with public standpipes or other suitable distribution points. As air-release valves require servicing from time to time, it is recommended that a gate valve be installed with the air-release valve for easy removal and repair.

Where possible, pipelines should be laid such that the need for air valves is avoided. Fire hydrants can also be used to vent the main during charging.

Air valves are a possible source of contamination, and the air-valve installation arrangements should be such that contamination of the system cannot occur, while an adequate air flow for the valve is always maintained.
Air valves should be provided to suit the longitudinal section of the pipeline in relation to the hydraulic gradient.

Air valves should be sized according to the air flow rate generated by the rate of inflow or outflow of the water in the pipeline.

Air valves should be installed with an isolating valve on the air valve branch to facilitate maintenance, and should preferably be fitted with a cock tapped into the bottom of the valve body, to enable the effective operation of the valve to be checked.

**Scour valves and outlets**

Scour valves should be installed at low points in pipelines with a diameter of 80 mm or more. A scour valve comprises a hand-operated valve on a drainpipe of a diameter 0.4 to 0.6 times the diameter of the pipe being drained. There should be an open drain to lead the washout water to a suitable watercourse.

Scour outlets not connected to a stormwater drain system should be designed to limit the erosion caused by the escaping water.

In reticulation networks, a fire hydrant should, if possible, be positioned so that it can be used as a scour valve. Dead-end mains should terminate in a scour point.

Scour outlets should be sized to permit complete draining of a section of main between isolating valves within two hours.

**Anti-vacuum valves**

Anti-vacuum (or air-admission) valves should be provided downstream of each section valve in a transmission pipeline, to prevent the build-up of a vacuum when the section valve is being closed. Most air-release valves also act as air-admission valves.

**Break-pressure devices**

Break-pressure devices may be either break-pressure tanks or pressure-reducing valves.

Where possible, break-pressure tanks should be combined with balancing tanks.

When used, pressure-reducing valves should be provided with a pressure-relief valve on the outlet side, to prevent the possible build-up of pressure resulting from failure of the pressure-reducing valve to operate correctly. The discharge from the relief valve should be conspicuous when it occurs.

The installation should also be provided with a dirt box upstream of, and a bypass pipe around, the pressure-reducing valve, complete with an isolating valve protected against accidental opening. A pressure gauge should be provided on both the upstream and downstream sides of the dirt box.

**Marker posts**

Marker posts should be placed along the pipelines at intervals sufficient to facilitate location of the route. Marker posts should also be placed at all pipe bends, junctions, and other features.

**Anchorage and thrust blocks**

Anchorage and thrust blocks should be used whenever the pipeline changes vertical or horizontal direction by more than 10°. Thrust blocks should also be used where the size of the pipeline changes, at blank ends, and on steep slopes (more than 1:6).

**Surge control**

The likelihood of pressure surges should be investigated and, where necessary, provision made for surge control.

**Valve chambers**

Sufficient working space to allow a spanner to be used on all bolts should be provided in chambers for isolating, air and other valves.

Venting of air-valve chambers should allow for adequate air flow.

Roof slabs should be designed to allow for removal and replacement of the valve.

Valve chambers should, where possible, be finished proud of the final ground level.

Where necessary, the design should make provision for the possibility of differential settlement between the valve chamber and the pipeline.

**WATER STORAGE**

**General**

The purpose of storing water is to meet balancing requirements and cater for emergencies (e.g. fire-fighting) or planned shut-downs.

The balancing volume is required to cater for peak outflows while a constant (or variable) inlet flow is being received.

**Reservoir storage**

Where water is obtained from a bulk water supply
authority, the storage capacity provided should comply with the requirements of the authority. A storage capacity of 48 hours of annual average daily demand is suggested, although there may be situations where 24 hours will suffice.

The nominal capacity for elevated storage, based on the typical period involved in power failures, is given in Table 9.16.

The nominal capacity of the duty pump should be equivalent to the sum of the instantaneous peak demand and the fire demand (obtained from the section on provision of water for fire-fighting), or the instantaneous peak demand plus an allowance of 20%, whichever is the greater.

All pumps should be rated for similar duties so that they are interchangeable.

The standby power source should operate automatically in the event of an electricity supply failure.

Under certain limited circumstances, as an alternative to providing elevated storage and pumps, a scheme comprising booster pumps (variable speed can also be considered) delivering directly into the reticulation can be considered. The total cost, including running and maintenance, should be taken into account. This type of scheme is, however, not a preferred option.

The capacity of the supply main to the reservoir should be designed to provide an inflow rate to the reservoir of not less than 1.5 x annual average daily demand for the area served by the reservoir.

Note should be taken of existing water consumption patterns that can be applied to the area to be served by the planned service reservoir. Demand patterns should lead the design engineer at all times.

It will be to the advantage of the local authority to make use of optimal design techniques for determining reservoir storage, like the time-simulation and the critical-period techniques. Both these methods were developed in the mid-1980s and make full use of the interrelationship between the feeder-main capacity and the reservoir capacity. The time-simulation technique is based on analysing river reservoir behaviour. The critical-period technique is based on the relationship between the total storage required and the feeder-main capacity. If use is made of the techniques mentioned, 48 hours’ storage capacity need not be provided.

Caution should be exercised when determining the capacity of reservoirs – too large a reservoir may cause problems associated with stagnant water.

Other storage reservoirs

Storage reservoirs may also be required for the following primary purposes:

• water collection from various sources;
• to provide contact time for a certain water treatment operation, such as chlorination; and
• to provide water to a pump station (booster reservoir).

A reservoir may be either at ground level or elevated.

Location of service reservoirs

Where the main storage reservoir also serves as the service reservoir (i.e. it supplies water at the required pressure to the farthest point in the area), the reservoir should be located near the centre of the area. In flat areas this may be achieved by constructing an elevated tank at the centre. In undulating areas it will usually be more advantageous to select the highest point for its construction. By locating the tank as close to the centre as possible, distribution pipe costs can be minimised, and a more even distribution of pressure achieved.

Alternatively, the reservoir could be situated between

<table>
<thead>
<tr>
<th>Table 9.16: Elevated storage capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PUMPING PLANT SERVING THE ELEVATED STORAGE FACILITY</strong></td>
</tr>
<tr>
<td>One electrically driven duty pump, plus one identical electrically driven standby pump, plus standby power generation independent of the electricity supply.</td>
</tr>
<tr>
<td>One electrically driven duty pump, plus one identical electrically driven standby pump</td>
</tr>
</tbody>
</table>

* derived as described in the section above on peak factors.
the distribution area and the source of supply, or at the highest point surrounding the distribution area to obviate the need for elevated storage.

It is also advisable that, if possible, the difference in elevation of the highest water level in the storage reservoir and the lowest laid pipeline should not be more than 60-70 m. If this difference is greater it may be necessary to provide break-pressure devices in the distribution system.

**Intermediate storage**

The provision of intermediate storage can have a number of objectives, the most important of which are:

- a reduction in the sizes of the main distribution pipes, by reducing the peak-flow demand of these mains;
- a reduction in pipeline pressures;
- a reduction of the impact of supply breakdowns;
- a division of the supply into smaller subsections which can be more easily managed by community organisations; and
- a reduction in the size of the main storage reservoir, in terms of both balancing storage and emergency storage.

The provision of intermediate storage will usually be economically feasible only in areas where the topography is steep enough to obviate the need for elevated storage, or where undulating topography dictates the need for different pressure systems for different sections of the community.

The selection and design of intermediate storage will be based on criteria similar to that for bulk-storage reservoirs.

On-site storage is discussed in the section on “Terminal consumer installations” elsewhere in this chapter.

**DISTRIBUTION NETWORKS**

**General**

One of the most important requirements for an economic distribution system is the location of the service reservoir as near to the distribution network as possible. Among other advantages, peaks are evened out and fire protection can be more easily achieved.

**General requirements for distribution network design**

- The maximum head during the reticulation (under static conditions) should not exceed 90 m.
- The minimum head during the design peak flow should be according to Table 9.17.
- Minimum pipe sizes should not be less than 50 mm (internal diameter).
- Major reticulation pipes should be sized to suit the design period.
- It is advantageous to use the minimum number of different pipe sizes to reduce the holding stock required for maintenance and repair.
- Wherever possible, pipelines should be laid in road reserves and preferably not pass through residential or privately owned property.
- Pipelines on private land should be protected by servitudes in favour of the service owner.
- Where pipelines need to cross roads, care should be taken to ensure that the pipe is well bedded and at a sufficient depth (min 0,8 m cover). It is advisable to maintain a larger-diameter pipe for road crossings than may be required from design considerations.
- Comments in the section on valves and other fittings are also valid for distribution networks.

**Table 9.17: Residual pressures**

<table>
<thead>
<tr>
<th>TYPES OF DEVELOPMENT</th>
<th>MINIMUM HEAD UNDER INSTANTANEOUS PEAK DEMAND (m)</th>
<th>MAXIMUM HEAD UNDER ZERO FLOW CONDITIONS (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dwelling houses: house connections</td>
<td>24*</td>
<td>90</td>
</tr>
<tr>
<td>Dwelling houses: yard taps + yard tanks</td>
<td>10*</td>
<td>90</td>
</tr>
</tbody>
</table>

* Plus the height difference between the main and the highest ground level at any point on the erf not exceeding 50 m from the boundary adjacent to the main. A minimum head of 5 m for site-specific cases (e.g. developing on top of a hill) may be considered.
• Where air valves and scour valves are required, taps on standpipes or at other terminals should be sited to fulfil this function wherever possible.

• Isolating valves should be located at street corners, or opposite erf corner boundary pegs.

• Where pipes intersect, isolating valves should be installed in the smaller-diameter branches.

• Pipes should not rise above the hydraulic grade line.

• Flushing points (or fire hydrants) should be provided where dead-end mains cannot be avoided.

• A developing practice, “skeletonising” of the network, should be considered where developing areas’ services are subject to future upgrading.

Residual pressures

The reticulation system should be designed so that the residual pressure in the reticulation main at any point is within the limits given in Table 9.17 (the desirable residual pressures applicable during fire-flow conditions are given in Table 9.20).

MATERIALS

Considerations in the selection of materials

Most of the materials referred to in these guidelines are listed and described in the relevant sections of the SABS 1200 series and SABS product specifications. Refer to product specifications for details of working pressures and dimensions of pipes made from the alternative materials. Specifications other than SABS should also be consulted where no applicable SABS specifications exist (e.g. ISO).

The materials suitable for use on a particular project and the internal and external corrosion-protection systems for the pipes, joints, fittings and specials may be specified by the controlling authority. If not, the following factors should be considered when selecting suitable materials:

• the life-cycle cost (initial capital plus maintenance costs);

• the chemical composition of the water to be distributed or stored (for example, certain types of pipes may not be advisable for conveying water with a Langelier Saturation Index of less than -0.5, and a detailed assessment of the circumstances will be necessary in such cases); brass fittings, couplings, valves, etc, particularly if soft water is conveyed, should be especially resistant to de-zincification;

• the corrosive nature of the soil and ground water, and the possible existence of stray electric currents; and

• the structural strength of the pipes and reservoirs.

Circumstances requiring particular attention are heaving clay soils, dolomitic areas and high external loading.

In the case of rigid pipes of small diameter, the designer should check for the possibility of beam-type failure. SABS Code of Practice 0102:1987 – Part 2 gives guidelines on the external loadings that can be applied to buried pipelines. The minimum class of pipe, from a structural consideration, should be Class 9.

Materials for pipelines

• Cast iron, steel and galvanised steel are the strongest pipe materials and should be used where high operating pressures are expected. The cost of fittings, especially at high pressures, and the susceptibility of these pipes to corrosion, should, however, be kept in mind. Joint types include threaded, Viking Johnson-type flexible couplings, continuously welded, flanged or spigot and socket types with rubber rings.

• Fibre-cement (asbestos-cement, FC) pipes cost less than iron and steel pipes. FC pipes should preferably be bitumen-dipped. Care must be exercised to ensure good bedding of the pipes when they are installed, as they are susceptible to fracturing as a result of ground movements. Couplings include asbestos-cement sleeves with rubber rings, cast-iron flexible couplings, or Viking Johnson-type flexible couplings. FC bends are not recommended.

• Unplasticised polyvinyl chloride (uPVC) and modified polyvinyl chloride (mPVC) provide easy-jointing pipes and good corrosion resistance. However, PVC pipes suffer a loss in strength when exposed to sunlight, and should therefore not be stored in the open. Pipes may be damaged by careless handling and, as with FC pipes, must be carefully bedded, avoiding stones and hard edges. The preferred type of coupling is spigot and socket rubber ring joint.

• Polyethylene (PE) pipes are supplied in rolls and are relatively flexible. Thus the number of joints and bends is greatly reduced. PE does not deteriorate significantly when exposed to sunlight. There are two types of polyethylene: low-density polyethylene and high-density polyethylene. Low density PE is mainly used for irrigation purposes. High-density PE is suitable for small-diameter mains, secondary pipelines and service pipes. Joints on larger diameter HDPE pipes are typically made
by butt-welding. On smaller pipe sizes, compression-type joints are used.

- Reinforced and pre-stressed concrete are suitable for long, large-diameter transmission lines. Both types have considerable strength and are resistant to corrosion. Spigot and socket joints are used for most reinforced concrete pipes. Pre-stressed pipe-jointing systems can vary, and depend to some extent on the pre-stressing design.

- Glass-reinforced polyester pipes have been made available on the market recently. Various projects have been completed successfully using these pipes. The pipes are also suitable for long and large transmission lines. No corrosion control is required and the pipe compares favourably with the PE pipe.

**Materials for communication pipes**

Materials generally suitable for communication pipes are:

- galvanised steel with screwed and socketed joints or Viking Johnson-type flexible couplings; and

- polypropylene (PP), high-density polyethylene (HDPE) and low-density polyethylene (LDPE) with external compression-type joints.

Where pipes are laid in aggressive soils, especially where moisture is retained in the soil under a paved surface, metallic pipes must be well protected against corrosion. Plastic pipes are more suitable under these conditions.

**Materials for reservoirs**

Large reservoirs (>200 m$^3$) are usually constructed of steel or reinforced concrete. Elevated tanks of steel panels have proved reasonably successful in areas away from the aggressive coastal environment. Lined earth reservoirs with floating covers, or concrete reservoirs with floating covers, are an economical choice for ground reservoirs in South Africa.

For smaller (<50 m$^3$) reservoirs, ferrocement, masonry, galvanised iron, asbestos-cement and certain plastic and rubber tanks may also be used. Polyethylene and fibreglass tanks, if used for potable water, should be constructed so as to prevent light penetration, which may encourage algal growth.

Traditional structures employed for water storage in the rural areas are not always durable or hygienic. It is often not possible or desirable to erect reinforced-concrete water-retaining structures in these remote areas because the cost may be prohibitive.

**Ferrocement**

The use of ferrocement tanks in rural areas may be considered, since their construction can be undertaken without sophisticated equipment or highly trained manpower.

Ferrocement simply consists of one part cement mixed with two parts sand and just sufficient water to form a paste-like consistency. This is forced onto layers of closely and evenly distributed wire mesh reinforcement (chicken netting) by hand or by trowel. This technique allows for complex structures with a thin shell thickness.

It has a high strength-to-mass ratio when compared to reinforced concrete. It also requires little or no maintenance when compared to metal tanks, and is more durable than fibre cement. Readers are referred to the following publications, which are noteworthy:


- *Ferrocement water tanks*: International Ferrocement Information Centre. (Available from the Cement and Concrete Institute, Midrand.)

**Masonry**

Masonry tanks have been constructed successfully and have been in use for many years. Standard plans are available from the Department of Public Works. This type of construction can also be executed with lesser skilled manpower.

**Galvanised tanks**

Galvanised tanks are also suitable for use in rural areas. Although these tanks can be erected in a short space of time, designers should consider their cost. Specialist contractors are usually employed and opportunities for training and the use of local manpower are therefore limited. Galvanised tanks are also notorious for poor thermal insulation and their service life, even with regular maintenance, is not comparable with, for instance, concrete reservoirs.

**Asbestos cement, plastic, fibreglass, polyethylene and rubber tanks**

The main advantage of these products is the speed involved in making available storage capacity. Once again, limited opportunities exist for use of local manpower. Transporting these prefabricated tanks is usually difficult. Polyethylene tanks should be considered as only a temporary measure.
CONSTRUCTION

General

Designers ought to be aware of the need for job creation in the provision of services and facilities, and should take this into account. It is also important to consider the requirements of government departments, municipalities and other service authorities in this regard. The decision as to whether specifications are to be modified in order to promote job creation lies with the employer and is not discussed in these guidelines.

National Standardised Specifications for Engineering Construction

The sections of SABS 1200 listed below are recommended for general use:

- SABS 1200 A: General
- SABS 1200 AA: General (Small works)
- SABS 1200 D: Earthworks
- SABS 1200 DA: Earthworks (Small works)
- SABS 1200 DB: Earthworks (Pipe trenches)
- SABS 1200 G: Concrete (Structural)
- SABS 1200 GA: Concrete (Small works)
- SABS 1200 L: Medium pressure pipelines
- SABS 1200 LB: Bedding (pipes)
- SABS 1200 LF: Erf connections
- SABS 1200 LK: Valves
- SABS 1200 LN: Steel pipe and linings

Watertightness test

For the requirements and tests for watertightness of reinforced concrete reservoirs and elevated storage facilities, refer to Clause 3.3.38 of SABS 0120:1980 – Part 2, Section G.

Disinfection of reservoirs and elevated storage facilities

Following completion of construction, the structure should be cleared of debris and the floor swept clean using damp sawdust, to prevent dust from rising. The walls and floors should be hosed down and the water drained away. Water should be admitted into the structure to a depth of approximately 300 mm and uniformly chlorinated so as to attain a minimum chlorine residual of 10 mg/l.

All internal surfaces of the structure, including pipework, should be thoroughly hosed down with the chlorine solution. After all personnel have vacated the structure, a quantity of the chlorinated solution should be poured over the internal access ladder.

The chlorinated solution should be drained prior to filling the structure with potable water. Should it be necessary for the structure to be emptied after the initial filling so that personnel can gain access to the water retaining portion of the structure, then the disinfection process described above should be repeated.

Markers for valves and hydrants

The positions of isolating valves and hydrants should be clearly indicated by means of permanent marker posts located on the verge opposite the fitting, or painted symbols on road or kerb surfaces.

Symbols on markers should be durable. Where services pass underneath national or provincial roads, markers should be placed on both sides of the road reserve. Similarly, markers should be placed on both sides of servitudes of other service providers.

MANAGEMENT OF WATER DISTRIBUTION SYSTEMS

General

It is not the purpose of this section to discuss all the functions of management as far as water supply systems are concerned. This section is primarily aimed at informing the engineer of the importance of the control of unaccounted-for water in supply systems, and other aspects relating to regulations in this regard. The Water Services Act requires that a Water Services Authority should have full control of water supply in its area of jurisdiction, and therefore unaccounted-for water will be an integral part of management reports.

Unaccounted-for water

The SABS 0306 Code of Practice should be followed in accounting for potable water within distribution systems and in the corrective action to reduce and control unaccounted-for water.

The code also gives guidance on the design of water reticulation systems with water management in mind, and gives guidance on leak detection and pipeline monitoring.

Metering

The information required for accounting and management is generated by proper metering. The importance of metering cannot be overemphasised. The Regulations relating to Compulsory National Standards and Measures to Conserve Water (Government Notice R 22355 dated 8 June 2001), published in terms of the Water Services Act, is a very important document that governs the relationship between the local authority and the consumer.
The regulations stipulate that water to any consumer must be measured by means of a water-volume-measuring device, and that all water be supplied in terms of an agreement between the local authority and the consumer. Metering water districts within water distribution schemes is also a requirement.

Those involved in water supply to communities should take note of these regulations.

Guidelines for metering can be found in the catalogues of meter suppliers.

It is important to note the following requirements:

- All mechanical meters must comply with SABS specifications;
- All meters must be installed according to the manufacturer’s instructions;
- Meters must be correctly sized;
- Meters are to be tested (and replaced if necessary) at regular intervals;
- Unmetered connections should not be allowed;
- Regular inspection of actual flow is required to confirm meter sizes, where larger meters are installed;
- Meter installations should at all times correspond with financial records;
- Prepaid water meters should be considered if the community is in favour of this option;
- Meters must comply with the Trade Metrology Act (Act 77 of 1973); and
- Consumer installations must comply with SABS 0252: Water supply and Drainage for Buildings.

PROVISION OF WATER FOR FIRE-FIGHTING

General

The provision of water for fire-fighting should comply with the requirements as described in SABS Code of Practice 090:1972 – Community Protection against Fire, but with deviations from and additions to the code as described below.

Scope of the SABS Code of Practice 090:1972

The code covers recommendations for the organisation of fire services, water supplies for fire-fighting, and by-laws relative to fire protection. It includes a fire-rating schedule.

It is also intended for use by designers of water supply systems for normal industrial areas, central business districts and residential settlements. Specifically excluded from this document are special types of development, such as bulk oil and fuel storage facilities and airports. For these types of development, reference must be made to specific standards or regulations governing the fire-service requirements.

Fire-risk categories

Areas to be protected by a fire service should be classified according to the following fire-risk categories.

High-risk areas

These areas in which the risk of fire and of the spread of fire is high, such as congested industrial areas, congested commercial areas, warehouse districts, central business districts, and general residential areas with floor space ratio of 1,0 and greater where buildings are four storeys and more in height (residential zone IV).

Moderate-risk areas

These are areas in which the risk of fire and of spread of fire is moderate, such as industrial areas, areas zoned “general residential” with a floor space ratio of less than 1,0 (residential zones II and III) where buildings are not more than three storeys in height, and commercial areas normally occurring in residential districts where buildings are not more than three storeys in height.

Low-risk areas

These are areas in which the risk of fire and the spread of fire is low. This category is subdivided into four groups as follows.

- Low-risk – group 1: Residential areas (residential zone 1) where the gross floor area of the dwelling house, including outbuildings, is generally likely to be more than 200 m².
- Low-risk – group 2: Residential areas (residential zone 1) where the gross floor area of the dwelling house, including outbuildings, is likely to vary between 100 m² and 200 m².
- Low-risk – group 3: Residential areas (residential zone 1) where the gross floor area of the dwelling house, including outbuildings, is generally likely to be less than 100 m² but more than 55 m². This group includes low-cost housing schemes where the gross floor area of the dwelling house, including
outbuildings and allowing for extensions by the owner, would generally not exceed 100 m². Restrictions in force control the height and area of buildings, materials used in their construction and the distances from common erf boundaries. Attached dwelling units are separated by a fire wall with a minimum fire-resistance rating of one hour.

- **Low-risk – group 4**: Residential areas (residential zone 1) where the gross floor area of the dwelling house, including outbuildings, is generally not more than 55 m². This group includes low-cost housing schemes. Restrictions in force control the height and area of buildings, materials used in their construction and the distances from common erf boundaries. Attached dwelling units are separated by a fire wall with a minimum fire-resistance rating of one hour.

**Fire protection in general**

In the case of areas not yet developed, a subdivision of the planned layout into areas or zones according to the relevant fire-risk category should be made, taking into account possible planning parameters such as floor space ratios, height restrictions and building-material restrictions.

When water reticulation systems are being designed for industrial areas, these areas should generally be classified as moderate-risk.

Where the reticulation in an industrial area has been designed on the basis of a moderate-risk classification, a limited number of high fire-risk types of industry can subsequently be permitted to be established in the area without warranting a re-classification of the area to the high-risk category. In this case, the approval conditions for the establishment of the industry should specify the provision of the extra water for firefighting (as deemed necessary by the fire department) which is over and above that allowed for in the design of the reticulation. Such provision could take the form of an additional supply to the site, or storage of water on the premises, and would be provided at the cost of the applicant.

Examples of high-risk types of development are:

- timber-storage yards;
- timber-clad buildings;
- institutional buildings and buildings in which hazardous processes are carried out; and
- areas where combustible materials are stored which, because of the quantity of such materials, the extent of the area covered by the materials and the risk of fire spread, may be deemed high-risk.

In the case of existing developed areas, a survey of the fire hazards of the area should be made at intervals of not more than three years. Such a survey should take account of the height, the type of construction, the occupancy of the buildings, the means of approach to buildings, the water supply available and any other feature affecting the fire risk.

Should such a survey indicate the need for re-classification of an area into a higher risk category, then the area should be re-classified accordingly, and the chief fire officer, in conjunction with the local authority engineer, must prepare a report for submission to the controlling authority, requesting that the fire service be upgraded according to the new classification.

**Water supply for fire-fighting**

The elements in a water reticulation system for the supply of water for fire-fighting are:

- **trunk main**: the pipeline used for bulk water supply;
- **water storage**: reservoir and elevated storage;
- **reticulation mains**: the pipelines in the reticulation to which hydrants are connected; and
- **hydrants**: these may be of the screw-down or sluice-valve type.

The capacity of the above elements is determined according to the category of fire risk applicable.

The fire flow and hydrant flow for which the water reticulation is designed should be available to the firefighting team at all times. Close liaison between the water department of the local authority and the fire service should be maintained at all times, so that the water department can be of assistance in times of emergency – for example, isolating sections of the reticulation in order to increase the quantity of water available from the hydrants at the scene of the fire.

**Note: Low-risk – Group 4 category**

No specific provision for fire-fighting water is made in trunk mains, water storage, or reticulation mains in these areas. Hydrants should, however, be located at convenient points in the area on all mains of 75 mm nominal internal diameter and larger, and in the vicinity of all schools, commercial areas and public buildings.

Fire-fighting in areas zoned Low-risk – Group 4 should generally be carried out using trailer-mounted water tanks or fire appliances that carry water, which can if necessary be replenished from the hydrants provided in the reticulation.
Development within areas falling into the Low-risk – Group 4 category, and which qualify for inclusion in higher risk categories, should be protected according to the relevant category as outlined in the Code of Practice and these Guidelines.

**Design of trunk mains**

The mains supplying fire-risk areas should be designed so that the supply is assured at all times.

Trunk mains serving fire-risk areas should be sized for a design flow equivalent to the sum of the design instantaneous peak domestic demand for the area served by it, and the fire flow given in Table 9.18.

Where an area served by the trunk main incorporates more than one risk category, then the fire flow adopted should be for the highest risk category pertaining to the area.

**Water storage**

**Ground reservoirs**

The storage capacity of reservoirs serving fire areas should, over and above the allowance for domestic demand, include for the design fire flow obtained from Table 9.18 for a duration at least equal to that given in Table 9.19.

Where an area served incorporates more than one risk category, then the design fire flow and duration used should be for the highest risk category pertaining to the area served by the reservoir.

**Elevated storage**

There need be no provision for storage of water for fire-fighting when the pumping plant serving the elevated storage facility is sized to deliver the sum of the instantaneous peak demand and the fire flow obtained from Table 9.18, or the instantaneous peak demand plus an allowance of 20%, whichever is the greater. A standby pumping plant should also be provided.

**Reticulation mains**

Reticulation mains in fire areas should be designed according to the design domestic demand required. The mains should, however, have sufficient capacity to satisfy the criteria given in Table 9.20.

The minimum residual head should be obtained with the hydrant discharging at the minimum hydrant flow rate, assuming the reticulation is operating under a condition of instantaneous peak domestic demand at the time.

The water reticulation design for each reservoir supply zone should be checked for compliance with this paragraph on the minimum basis of the following:

**High-risk and moderate-risk areas**

The group of hydrants (see Table 9.18) included in each critical area in the reticulation are in use simultaneously. Critical areas should be checked individually.

**Low-risk areas**

- **Areas of less than 2 000 dwelling units:**
  assume one hydrant in use at a time; each critical area should be checked individually;

- **Areas of 2 000 and more dwelling units:**
  assume a hydrant in each critical area in use simultaneously on the basis of one hydrant per 2 000 dwelling units or part thereof.

<table>
<thead>
<tr>
<th>Table 9.18: Design fire flow</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FIRE-RISK CATEGORY</strong></td>
</tr>
<tr>
<td>--------------------------</td>
</tr>
<tr>
<td>High-risk</td>
</tr>
<tr>
<td>Moderate-risk</td>
</tr>
<tr>
<td>Low-risk – Group 1</td>
</tr>
<tr>
<td>Low-risk – Group 2</td>
</tr>
<tr>
<td>Low-risk – Group 3</td>
</tr>
<tr>
<td>Low-risk – Group 4</td>
</tr>
</tbody>
</table>
Hydrants

Hydrants should not be provided off mains smaller than 75 mm diameter.

Hydrants should be located in vehicular thoroughfares and opposite erf boundary pegs, and according to Table 9.21.

The hydrants for the high-risk and moderate-risk categories should be the 75 mm diameter sluice-valve type. For the low-risk category, the hydrant may be the screw-down type.

In the case of new developments, hydrant types should be similar to those used by an adjacent metropolitan area, if relevant.

The location of hydrants should be clearly indicated.

Hydrants should be serviced and the flow rate checked for conformity with Table 9.20 at intervals not exceeding one year.

Isolating valves

In reticulation networks, isolating valves should be provided so that not more than four valves need to be closed to isolate a section of main, and so that the total length of main included in an isolated section does not exceed a nominal 600 m.

Valves should be located at street corners opposite erf corner boundary (splay) pegs, and intermediate valves opposite the common boundary peg between two erven.

Fire protection in developing and rural areas

Fire protection in developing and rural areas needs special attention. Designers of water-reticulation systems should accept that the local unavailability of fire-fighting resources at the time of design will most certainly change during the lifetime of the scheme. It is not suggested that the design of systems be according to the guidelines given for developed areas, but designers should consider the following:

- Whatever fire-fighting equipment is provided should be compatible with that of the surrounding area; close liaison with the responsible emergency services agency is considered essential.

- The provision of permanent equipment – like fire hydrants at business sites and institutional erven – should be considered and the type and location should be chosen to minimise vandalism or illegal use.

- The accessibility of the area and the space required for vehicles used by fire-fighting services should be taken into account.

Table 9.20: Fire-flow design criteria for reticulation mains

<table>
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<tr>
<th>FIRE-RISK CATEGORY</th>
<th>MINIMUM HYDRANT FLOW RATE FOR EACH HYDRANT (l/min)</th>
<th>MINIMUM RESIDUAL HEAD (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-risk</td>
<td>1 500*</td>
<td>15</td>
</tr>
<tr>
<td>Moderate-risk</td>
<td>1 500*</td>
<td>15</td>
</tr>
<tr>
<td>Low-risk – Group 1</td>
<td>900</td>
<td>7</td>
</tr>
<tr>
<td>Low-risk – Group 2</td>
<td>500</td>
<td>6</td>
</tr>
<tr>
<td>Low-risk – Group 3</td>
<td>350</td>
<td>6</td>
</tr>
<tr>
<td>Low-risk – Group 4</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

*With a design maximum of 1 600 l/min per hydrant

Table 9.21: Location of hydrants

<table>
<thead>
<tr>
<th>FIRE-RISK CATEGORY</th>
<th>LOCATION OF HYDRANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-risk</td>
<td>distance apart: 120 m maximum</td>
</tr>
<tr>
<td>Moderate-risk</td>
<td>distance apart: 180 m maximum</td>
</tr>
<tr>
<td>Low-risk – Group 1</td>
<td>distance apart: 240 m maximum</td>
</tr>
<tr>
<td>Low-risk – Group 2</td>
<td>distance apart: 240 m maximum</td>
</tr>
<tr>
<td>Low-risk – Group 3</td>
<td>distance apart: 240 m maximum</td>
</tr>
<tr>
<td>Low-risk – Group 4</td>
<td>Convenient points on mains 75 mm diameter and larger</td>
</tr>
</tbody>
</table>
• Dams and rivers could be utilised by placing hydrants close by for the purpose of pumping water from them.

• Close liaison with the community is required to determine what fire-protection arrangements exist and whether these should be revised.

• Where water-reticulation networks are designed, consideration should be given to their possible future upgrading, and allowance should be made for fire flow in pipelines, taking into consideration the other factors mentioned above. Reference should also be made to “skeletonising” (see Glossary).
GLOSSARY

Balancing storage refers to the volume required in a storage reservoir to cater for peak flows while receiving a constant inlet flow.

Developing areas are considered to be those areas where the services to be installed are subject to future upgrading.

Developed areas are considered to be those areas where the services installed are not subject to future upgrading (i.e. the services are already at the highest intended level).

Fire hose: flexible pipe used for fire-fighting purposes, suitable for connection to a hydrant.

Fire flow: the rate of flow of water required by the fire-fighting service for the extinguishing of fires.

Hydrant: a valve-controlled outlet on the water reticulation system to which a fire hose can be attached, either directly or with an adaptor or standpipe.

Hydrant flow: the discharge rate of water from a hydrant.

Package water treatment plant: a prefabricated purification plant that is assembled on site. It may or may not require small civil construction works and piping for complete functioning.

Peak factor: a dimensionless value, indicating the relationship between peak consumption and average consumption.

Residual head: the pressure in the water main at the hydrant take-off point while the hydrant is discharging.

Skeletonising: is the practice of designing and installing major reticulation pipes for a future higher level of service (which implies that the system will have spare capacity under present conditions.)

Turbidity: a measure of the resistance of water to the passage of light through it; it is caused by suspended or colloidal matter in the water.

Water transmission: means the transport of water from the source to the treatment plant (if there is one) and onward to the distribution area.

BIBLIOGRAPHY AND RECOMMENDED READING


DWAF (2000a). Proposed regulations dealing with contracts between water services authorities and water service providers. Department of Water Affairs and Forestry.


GUIDELINES FOR HUMAN SETTLEMENT PLANNING AND DESIGN

Water supply

Chapter 9


McDonald, D and Pape, J (2002). Cost recovery is not sustainable: Mail & Guardian. Online, September.


Weaver, J M C (Ed) (undated). Test pumping standards for South Africa. Groundwater Division, Geological Society of South Africa.


# GUIDELINES FOR HUMAN SETTLEMENT PLANNING AND DESIGN

## Chapter 10: Sanitation

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SCOPE

The guidelines for sanitation provision cover aspects that need to be considered when planning and implementing sanitation projects for existing residential areas and developing communities. The guidelines will also be of assistance where the Water Services Authority compiles a Water Services Development Plan (the latter forms part of the municipality’s Integrated Development Plan).

The guidelines will also assist in determining and setting objectives, developing a strategy and identifying the required planning activities for implementing sanitation projects. Technical guidelines are given for use in feasibility studies and the detailed design of sanitation provision.

The guidelines form part of a planned series of management guidelines intended for use by decision makers. The series of guidelines is shown in Table 9.1 of Chapter 9: Water Supply.

INTRODUCTION

Water services (i.e. water supply and sanitation) in South Africa are controlled by the Water Services Act (Act 108 of 1997) and the National Water Act (Act 36 of 1998). The Water Services Act deals with water services provision to consumers, while the National Water Act deals with water in its natural state.

As in the case of water supply, the provision of sanitation to a community should take place in terms of the relevant Water Services Development Plan, which is required in terms of the Water Services Act. The Water Services Development Plan (which should, of course, be compiled taking cognisance of the National Sanitation Policy) defines the minimum level of sanitation as well as the desired level of sanitation for communities that must be adhered to by a Water Services Provider in its area of jurisdiction. It describes the arrangements for water services provision in an area, both present and future. Water services are also to be provided in accordance with regulations published in terms of the Water Services Act.

The provision of appropriate sanitation to a community should take place in accordance with national policy. Among the major aims set out in the National Sanitation Policy are the following:

• to improve the health and quality of life of the whole population;

• to integrate the development of a community in the provision of sanitation;

• to protect the environment; and

• to place the responsibility for household sanitation provision with the family or household.

The minimum acceptable basic level of sanitation is (Department of Water Affairs & Forestry, 2001):

• appropriate health and hygiene awareness and behaviour;

• a system for disposing of human excreta, household wastewater and refuse, which is acceptable and affordable to the users, safe, hygienic and easily accessible, and which does not have an unacceptable impact on the environment; and

• a toilet facility for each household.

The safe disposal of human excreta alone does not necessarily mean the creation of a healthy environment. Sanitation goes hand in hand with an effective health-care programme. The importance of education programmes should not be overlooked, and the Department of Health is able to assist in this (refer to the following section “Hygiene in sanitation projects”).

Sanitation education is part of the National Sanitation Policy and should embrace proper health practices, such as personal hygiene, the need for all family members (including the children) to use the toilet and the necessity of keeping the toilet building clean. Education should also include the proper operation of the system, such as what may and may not be disposed of in the toilet, the amount of water to add if necessary, and what chemicals should or should not be added to the system. The user must also be made aware of what needs to be done if the system fails or what options are available when the pit or vault fills up with sludge.

Current policy is that the basic minimum facility should be a ventilated improved pit (VIP) toilet, or its equivalent. In this chapter, therefore, levels of service lower than this will not be discussed.

The use of ponds is frequently considered for dealing with wastewater in rural areas, and hence their inclusion in this document.

The five main criteria to be considered when providing a sanitation system for a community are:

• reliability;

• acceptability;

• appropriateness;

• affordability; and

• sustainability.

With these criteria in mind, designers should note the following principles from the White Paper on Basic
Household Sanitation, September 2001:

Sanitation improvement must be demand-responsive, and supported by an intensive health and hygiene programme

Household sanitation is first and foremost a household responsibility and must be demand-responsive. Households must recognise the need for adequate toilet facilities for them to make informed decisions about their sanitation options. For users to benefit maximally, they must also understand the link between their own health, good hygiene and toilet facilities.

Community participation

Communities must be fully involved in projects that relate to their health and well-being, and also in decisions relating to community facilities, such as schools and clinics. Communities must participate in decision-making about what should be done and how, contribute to the implementation of the decisions, and share in the benefits of the project or programme. In particular, they need to understand the cost implications of each particular sanitation option.

Integrated planning and development

The health, social, and environmental benefits of improved sanitation are maximised when sanitation is planned for and provided in an integrated way with water supply and other municipal services.

The focal mechanism of achieving integrated planning and development is the municipality-driven Integrated Development Planning (IDP) process (of which the Water Services Development Plan is a component).

Sanitation is about environment and health

Sanitation improvement is more than just the provision of toilets; it is a process of sustained environment and health improvement. Sanitation improvement must be accompanied by environmental, health and hygiene promotional activities.

Basic sanitation is a human right

Government has an obligation to create an enabling environment through which all South Africans can gain access to basic sanitation services.

The provision of access to sanitation services is a local government responsibility

Local government has the constitutional responsibility to provide sanitation services.

Provincial and national government bodies have a constitutional responsibility to support local government in a spirit of co-operative governance.

“Health for all” rather than “all for some”

The use of scarce public funds must be prioritised, in order to assist those who are faced with the greatest risk to health due to inadequate sanitation services.

Equitable regional allocation of development resources

The limited national resources available to support the incremental improvement of sanitation services should be equitably distributed throughout the country, according to population, level of development, and the risk to health of not supporting sanitation improvement.

Water has an economic value

The way in which sanitation services are provided must take into account the growing scarcity of good quality water in South Africa.

The “polluter pays” principle

Polluters must pay the cost of cleaning up the impact of their pollution on the environment.

Sanitation services must be financially sustainable

Sanitation services must be sustainable, in terms of both capital and recurrent costs.

Environmental integrity

The environment must be protected from the potentially negative impacts of sanitation systems.

PLANNING

The various planning stages and other information related to the planning of projects are fully described in Chapter 9 (Water supply). The planning steps and approach with respect to sanitation do not differ from those described in that chapter, and are not repeated here. The reader is thus referred to Chapter 9 for planning information.

HYGIENE IN SANITATION PROJECTS

An introductory discussion on hygiene in water and sanitation projects can be found in Chapter 9.
For people to change their cultural practices and behaviours – some of which are developed around deeply seated values – a lot of motivation is required, accompanied by marketing of the new or modified practices. For instance, when people are accustomed to defecating in the open (free of charge) it will take a lot of effort to motivate them to install toilets (at a cost), and to use those toilets, which come in as a new practice. Furthermore, the motivation for installing toilets or practising a higher level of hygiene must clearly emphasise the benefits to the individual and to the community.

The main components of a hygiene-promotion and -education strategy in a project should include the following:

- motivation and community mobilisation;
- communication and community participation;
- user education (operation and maintenance);
- skills training and knowledge transfer;
- development of messages;
- presentation of messages; and
- maintenance of good practice.

Many of these components overlap, or cut across the whole programme of implementation. For instance, motivation and community mobilisation would need to be maintained throughout the programme and after. The same goes for communication, which is required at all stages of a hygiene-promotion and -education programme. In practice there is no particular cut-off point between one component and another.

The following should be implemented during the projects’ stages (see Appendix A) to ensure that water supply and sanitation projects have a positive impact on the quality of life and level of hygiene in communities:

- Development and structuring of a strategic plan for the implementation of hygiene promotion and education in water and sanitation projects: This strategic plan should fit in and dovetail with national and provincial strategies for health and hygiene in South Africa, and should include advocacy, training and capacity-building, implementation, monitoring and evaluation.

- Liaison with other programmes/projects active in the health and hygiene field: Other initiatives regarding hygiene (PHAST, etc) should be identified and coordinated to prevent duplication, and to optimally address the needs of government and the communities. A number of other activities and programmes in schools, clinics, hospitals and the media (TV, radio, newspapers, magazines), should be identified and coordinated for a broader impact of hygiene promotion and education.

- Informing and training local government structures, environmental health officers (EHOs), non-governmental organisations (NGOs), community-based organisations and consultants: A programme should be developed to inform and train all local, regional and national institutions and structures involved in water supply and sanitation, health and hygiene promotion and education.

- Monitoring and evaluating the implementation of hygiene in water and sanitation projects: A body or organisation should be established and tasked to monitor the quality and standard of hygiene promotion and education. The results of hygiene promotion and education should be evaluated against key health indicators set up at the start of a project.

- Disseminating information regarding hygiene in water and sanitation projects: The process and results of hygiene promotion and education in a project should be disseminated in articles, conference papers, reports, seminars and workshops with other researchers in the field of health and hygiene.

**TECHNICAL INFORMATION**

Before a sanitation system is selected, the available options should be examined. This section describes the various systems and factors that could influence the selection. Detailed design information is not included in this chapter. Instead, reference is made to various publications in which all the required information may be found. Some general background information on the different sanitation technologies is, however, included.

Only sanitation systems commonly used or accepted in South Africa are described.

**Categories of sanitation systems**

There are two ways to handle human waste. It can either be treated on site before disposal, or removed from the site and treated elsewhere. In either case, the waste may be mixed with water or it may not. On this basis the following four groups may be distinguished:

- **Group 1**: No water added – requiring conveyance.
- **Group 2**: No water added – no conveyance.
- **Group 3**: Water added – requiring conveyance.
- **Group 4**: Water added – no conveyance.
Table 10.1: Categories of sanitation systems

<table>
<thead>
<tr>
<th>NO WATER ADDED</th>
<th>REQUIRING CONVEYANCE (off-site treatment)</th>
<th>NO CONVEYANCE REQUIRED (treatment, or partial treatment, on site; accumulated sludge also requires periodic removal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER ADDED</td>
<td>GROUP 3: Full waterborne sanitation.</td>
<td>GROUP 4: Flushing toilet with septic tank and subsurface soil absorption field. Low-flow on-site sanitation systems (LOFLOs): Aqua-privy toilet.</td>
</tr>
<tr>
<td></td>
<td>Flushing toilet with conservancy tank. Shallow sewers.</td>
<td></td>
</tr>
</tbody>
</table>

Table 10.1 illustrates the sanitation systems associated with each of the above groups. Note that some of the systems fall somewhere between the four categories as, for example, where solids are retained on each property and liquids are conveyed from site, or where water may be added, but only in small quantities. Since increasing the number of categories would complicate the table unnecessarily, these systems have been included in the categories that best describe the treatment of the waste. The operating costs of systems in which waste is conveyed and treated elsewhere can be so high that these systems may in the long term be the most expensive of all. The capital and installation costs of any conveyance network using large quantities of clean water to convey small quantities of waste are very high, and a possibly inappropriately high level of training and expertise is also required to construct and maintain such systems.

Developers should consider all the sanitation alternatives available before deciding on the most appropriate solution for the community in question. A solution that may be appropriate in one community may be a total failure in another because of cost, customs and religious beliefs, or other factors. A solution must also not be seen as correct purely because developers and authorities have traditionally implemented it.

Description of sanitation systems

The main types of sanitation systems are described below. The list is not complete and many commercial manufacturers provide systems that may be a variant of one or more.

The advantages and disadvantages of each system will depend on its particular application. What may be a disadvantage in one situation may in fact be an advantage in another. Thus the advantages and disadvantages listed after each description should be seen not as absolutes, but merely as aids to selecting the right sanitation system for a particular application.

Group 1: No water added — requiring conveyance (for treatment at a central treatment works)

Chemical toilets (not a preferred option)

A chemical toilet stores excreta in a holding tank that contains a chemical mixture to prevent odours caused by bacterial action. The contents of the holding tank must be emptied periodically and conveyed to a sewage works for treatment and disposal. Some units have a flushing mechanism using some of the liquid in the holding tank to rinse the bowl after use. The chemical mixture usually contains a powerful perfume as well as a blue dye. Chemical toilets can range in size from the very small portable units used by campers to the larger units supplied with a hut. The system can also be used where emergency sanitation for refugees is required, in which case it can give the planners the necessary breathing space to decide on the best permanent solution. It should not be considered as a permanent sanitation option.

Factors to consider before choosing this option are the following:

- Chemical toilets have relatively high capital and maintenance costs.
- It is necessary to add the correct quantity of chemicals to the holding tank.
• Periodic emptying of the holding tank is essential; this requires vacuum tankers, so access should be possible at all times.

• The system only disposes of human excreta and cannot be used to dispose of other liquid waste.

• The units can be installed very quickly and easily.

• They can be moved from site to site.

• They require no water connection and require very little water for operation.

• They are hygienic and free from flies and odour, provided that they are operated and maintained correctly.

• The chemicals could have a negative effect on the performance of wastewater treatment works.

It is possible to construct the entire toilet from local materials, although it is more usual to use commercial products for the vent pipe and the pedestal. Several toilet superstructures are also commercially available. When the pit is full, the superstructure, pedestal, vent pipe and slab are normally moved to a freshly dug pit and the old pit is covered with soil. The VIP toilet can be made more permanent by lining the pit with open-jointed brickwork or other porous lining. The pit can then be emptied when required, using a suitable vacuum tanker, without the danger of the sides of the pit collapsing. Water (sullage) poured into the pit may increase the fill-up rate (depending on soil conditions) and should be avoided; this sanitation technology is therefore not recommended where a water supply is available on the site itself.

Factors to consider before choosing this option:

• If the stand is small there may be insufficient space to allow continual relocation of the toilet; therefore arrangements should exist for emptying the toilet.

• Unlined pit walls may collapse.

• The excreta are visible to the user.

• The system may be unable to drain all the liquid waste if large quantities of wastewater are poured into the pit.

• The cost of the toilet is relatively low; it provides one of the cheapest forms of sanitation while maintaining acceptable health standards.

• The toilet can be constructed by the recipients, even if they are unskilled, as very little training is required.

• Locally available materials can be used.

• If required, the components can be manufactured commercially and erected on a large number of plots within a short space of time.

• The system is hygienic, provided that it is used and maintained correctly.

• The system can be used in high-density areas only if a pit-emptying service exists.

**Figure 10.1: Chemical toilet unit**

**Group 2: No water added – no conveyance**

*(treatment or partial treatment on site before disposal)*

**Ventilated improved pit (VIP) toilet**

The VIP toilet is a pit toilet with an external ventilation pipe. It is both hygienic and relatively inexpensive, provided that it is properly designed, constructed, used and maintained. Detailed information on VIP design is available in the publication *Building VIPs* by Bester and Austin (1997), which is obtainable from the Department of Water Affairs & Forestry, Pretoria. Information on different soil conditions, as they affect the building of VIP toilets, is also included. A SABS Code of Practice for the construction of VIPs is currently under preparation by the SABS. There are also variations of VIP toilets available – the Archloo, Phugalutho, Sanplat, etc. Those mentioned have been used with success and are firmly established in the industry.

Sanitation
The system can be upgraded at a later stage to increase user convenience (e.g. to a urine-diversion toilet).

The system cannot ordinarily be installed inside a house.

The quantity of water supplied to the site should be limited.

If a pit-emptying service exists, proper access to the pit should be provided.

Detailed information on VIDP design is also available in the publication Building VIPs by Bester and Austin (1997), obtainable from the Department of Water Affairs & Forestry, Pretoria.

Factors to consider before choosing this option are similar to those for the VIP, but include the following:

- Some training is required to ensure that the pit lining is properly constructed.
- The contents of the used pit may be safely used as compost after a period of about two years in the closed pit.
- The user may not be prepared to empty the pit, even though the contents have composted.
- The superstructure can be a permanent installation.
- The system can be regarded as a permanent sanitation solution.
- The system can be used in high-density areas.
- The system can be used in areas with hard ground, where digging a deep pit is impractical.

Ventilated improved double-pit (VIDP) toilet
The VIDP toilet, also known as the twin-pit composting toilet, was developed mainly for use in urban areas where, because of limited space on the smaller plots, it may be impossible to relocate the toilet every time the pit becomes full. The VIDP is a relatively low-cost and simple but permanent sanitation solution for high-density areas. Two lined shallow pits, designed to be emptied, are excavated side by side and are straddled by a single permanent superstructure. The pits are used alternately: when the first pit is full it is closed and the prefabricated pedestal is placed over the second pit. After a period of at least one year the closed pit can be emptied, either manually (if this is culturally acceptable) or mechanically, and then it becomes available for re-use when the other pit is full. Each pit should be sized to last a family two to three years before filling up. It is important that the dividing wall between the pits be sealed, to prevent liquids seeping from the pit currently in use into the closed pit, thus contaminating it. The VIDP toilet can be built partially above the ground in areas where there is a high water table, but the distance between the pit floor and the highest water table should be at least 1 m.

Ventilated vault (VV) toilets
The VV toilet is basically a VIP toilet with a watertight pit that prevents seepage. It can be regarded as a low-cost, permanent sanitation solution, especially in areas with a high groundwater table or a poor capacity for soil infiltration, or where the consequences of possible groundwater pollution are unacceptable.
The amount of wastewater disposed of into the vault should be limited to avoid the need for frequent emptying, so it is advisable not to use this type of sanitation technology where a water supply is available on site. Should an individual water connection be provided to each stand at a later date, as part of an upgrading scheme for the residential area, then the vault can be utilised as a solids-retention tank (digester) and liquids can be drained from the site using a settled-sewage system, also called a solids-free sewer system (see the section on “settled-sewage systems” under Group 3). Ventilation, odour and insect control operate on the same basis as the VIP toilet.

Factors to consider before choosing this option are similar to those of the VIP, but include the following:

- It is necessary to make use of a vacuum-tanker service for periodic emptying of the vaults.
- Builder training and special materials are required if a completely waterproof vault is required.
- The system can be used in areas with a high water table if the vault is properly constructed.
- The system can be used in areas where pollution of the groundwater is likely if a VIP toilet system is used.
- The system can be used in high-density areas.
- This system provides very good opportunities for upgrading since the vault can be used as a solids-retention tank when upgrading to solids-free sewers.
- The cost of emptying equipment and the operation of a vacuum-tanker service could be excessive (see also the section on vacuum tankers).

Urine-diversion (UD) toilet

The urine-diversion toilet, also known as the “dry-box”, is a superior type of dry toilet that circumvents the problems sometimes encountered with the implementation of VIP toilets, namely unfavourable geotechnical or hydrological conditions, high-density settlements with small erven, etc. The main advantage is that a pit is not required, so the toilet may be installed inside the house, if desired by the owner. Urine is diverted at source by a specially designed pedestal and, owing to the relatively small volumes involved, may simply be led into a shallow soakpit. Alternatively, urine can be easily collected in a container and re-used for agricultural fertiliser, as it is rich in plant nutrients such as nitrogen, phosphorus and potassium. Faeces are deposited in a shallow vault and covered with a sprinkling of ash or dry soil, which absorbs most of the moisture. They are further subjected to a dehydration process inside the vault, which hastens pathogen die-off. Depending on the temperature and degree of desiccation attained in the vault, the faeces may be safe to handle after a period of six to eighteen months, and can then be easily removed from the vault and either disposed of or re-used as soil conditioner, depending on individual preferences.

Other favourable aspects of this type of toilet are an absence of odours or flies (if it is properly used), a relatively low capital cost that may, depending on the specific circumstances, be even less than a VIP toilet, and a negligible operating cost. There are also environmental advantages, due to the fact that no pit is required.

Detailed guidelines on the implementation of this technology are contained in the publication Urine-diversion ecological sanitation systems in South Africa by Austin and Duncker (CSIR, 2002).

Factors to consider before choosing this option:

- The technology is well suited to dense urban settlements and places where environmental conditions do not favour other types of sanitation.
- Use of the toilet requires an adherence to certain operational requirements, and a proper commitment from owners is required. Good user education is therefore especially important.
- Building materials similar to those for a VIP toilet may be used, and the toilets can be
constructed by relatively unskilled persons. Components can also be manufactured commercially.

- The system is hygienic, provided that it is used and maintained correctly. Safe re-use of the urine and faeces is also facilitated.
- The system can be installed inside a house, if desired.
- There may be reluctance on the part of the user to empty the vault, even though the contents are innocuous.
- The system can be regarded as a permanent sanitation solution that will never need upgrading.

Factors to consider before choosing this option are the following:

- The system is expensive to install, operate and maintain.
- The system can be designed and installed only by trained professionals.
- The treatment works must be operated and maintained properly if pollution of waterways is to be avoided.
- The system requires large amounts of water to operate effectively and reliably.
- The system is hygienic and free of flies and odours, provided that it is properly operated and maintained.
- A high level of user convenience is obtained.
- The system should be regarded as a permanent sanitation system.
- The toilet can be placed indoors.
- This system can be used in high-density areas.
- An adequate, uninterrupted supply of water must be available.

**Group 3: Water added – requiring conveyance**

*(treatment at a central works)*

**Full waterborne sanitation**

This is an expensive option and requires ongoing maintenance of the toilet installation, the sewer reticulation and the treatment works, and the recipient community should be informed accordingly. The system requires a water supply connection to each property. The water is used to flush the excreta from the toilet pan and into the sewer, as well as to maintain a water seal in the pan. The excreta are conveyed by the water, in underground pipes, to a treatment works that may be a considerable distance from the source. The treatment works must be able to handle the high volume of liquid required to convey the excreta. The quantity of water required (usually 6-10 litres per flush) can be reduced by using low-flush pans designed to flush efficiently with as little as three litres. Research has indicated that the operation of the sewer system is not adversely affected by low-volume flush toilets. Flush volumes of 8-9 litres are normally used, however. In an area where water is costly or scarce, it may be counter-productive to purify water only to pollute it by conveying excreta to a treatment and disposal facility.
Shallow sewers
The shallow sewer system is basically a conventional system where a more simple approach with respect to design and construction is followed. Basically it entails a system where gradients are flatter, pipes are smaller and laid shallower, manholes are smaller and constructed of brickwork, and house connections are simpler. Where such systems are installed, community involvement in management and maintenance issues is preferred.

Design of sewer networks:

The professional responsibility in design remains with the engineer, and guidelines should never be regarded as prescriptive. Most local authorities have their own requirements and preferences on technical detail, such as pipe slopes, manhole details, materials, and so on. These are based on their own particular experiences and new designs should therefore be discussed with the relevant controlling authority.

Designers should not assume that sewer systems will always be properly maintained, and allowance should be made for this.

The hydraulic design of the sewers should be done according to acceptable minimum and maximum velocities in the pipeline. A number of pipe manufacturers have design charts available in their product manuals and these can be used in the absence of other guidelines.

The construction of a system should be in accordance with the relevant sections of SABS 1200:1996. The depth of the sewer is normally determined by its position on site. Sewers in mid-block positions and on sidewalks can normally be laid at shallower depths. Should laying of sewer and water pipes in the same trench be considered, workmanship should be of a high standard. Appendix C gives design guidelines that should be useful.

Flushing toilet with conservancy tank
This system consists of a standard flushing toilet that drains into a storage or conservancy tank on the property; alternatively, several properties’ toilets can drain into one large tank. A vacuum tanker regularly conveys the excrement to a central sewage treatment works for purification before the treated effluent is discharged into a watercourse. The appropriate volume of the conservancy tank should be calculated on the basis of the planned emptying cycle and the estimated quantity of wastes generated. Tank volumes are sometimes prescribed by the service provider.

Factors to consider before choosing this option are the following:

- The system is expensive to install, operate and maintain, although the capital cost is lower than the fully reticulated system.
- The system can be designed and installed only by trained professionals.
- A treatment works must be operated and maintained properly to avoid the pollution of waterways.
- A fleet of vacuum tankers must be maintained by the local authority.
- Regular collection is essential.
- The system is hygienic and free of odours, provided that it is properly operated and maintained.
- A high level of user convenience is obtained.
- The toilet can be placed indoors.
- The system can be used in high-density areas.

Figure 10.7: Shallow sewer system
Figure 10.8: Flushing toilet with conservancy tank
This system has good potential for upgrading since the conservancy tank can be used as a digester when upgrading to a settled-sewage system.

An adequate, uninterrupted supply of water must be available.

Settled sewage system
In settled sewage systems, also known as solids-free systems or Septic Tank Effluent Drainage (STED), the solid portion of excreta (grit, grease and organic solids) is retained on site in an interceptor tank (septic tank), while the liquid portion of the waste is drained from the site in a small-diameter sewer. Such sewers do not carry solids, and have very few manholes. Tolerances for excavation and pipe laying may be greater than for conventional sewers, allowing lesser skilled labour to be used. Although the liquid portion of the waste must be treated in a sewage works, the biological design capacity of the works can be greatly reduced because partial treatment of the sewage will take place in the retention tank on the site. The tank will also result in a much lower peak factor in the design of both the reticulation and the treatment works. The retention tank should be inspected regularly and emptied periodically, to prevent sludge overflowing from the tank and entering the sewer. This system is an easy upgrading route from septic tanks with soakaways, conservancy tanks, and other on-site systems, as they can be connected to a settled-sewage system with very little modification. Tipping-tray pedestals and water-saving devices can also be used in settled-sewage schemes without fear of causing blockage resulting from the reduced quantity of water flowing in the sewers.

Factors to consider before choosing this option are the following:

- The system requires a fairly large capital outlay if new interceptor tanks have to be constructed (i.e. if there are no existing septic tanks which can be used).
- Care must be taken to ensure that only liquid waste enters the sewers; this may mean regular inspection of the on-site retention tanks.
- Vacuum tankers must be maintained by the local authority.
- The system is hygienic and free of flies and odours, provided that it is properly operated and maintained.
- A high level of user convenience is obtained.

The system can be regarded as a permanent sanitation system.

The toilet can be placed indoors.

All household liquid waste can be disposed of via this sanitation system.

The sewers can be installed at flatter gradients and can even be designed to flow under pressure.

The system provides an easy and reasonably priced option when areas with on-site sanitation need to be upgraded, because of increased water consumption and higher living standards.

The system can be used in high-density areas.

An adequate uninterrupted supply of water must be available.

Regular inspection of the septic tank/digester is required to prevent an overflow of sludge.

Technical information on the design of these systems may be found in the CSIR, Division of Building and Construction Technology publication *Septic tank effluent drainage systems* (1997).

Group 4: Water added – no conveyance
(treatment or partial treatment on site before disposal)

These systems generally dispose of all or part of the effluent on site. Some systems retain only the solid portion of the waste on site and the liquids are conveyed to a suitable treatment and disposal facility.
Systems that dispose of the liquid fraction on site require a soil percolation system, and the amount of liquid that can be disposed of will depend on the system’s design and the permeability of the soil.

**Flushing toilet with septic tank and soakaway**

Water is used to flush the waste from a conventional toilet pan into an underground septic tank, which can be placed a considerable distance from the toilet. The septic tank receives the sewage (toilet water and sullage (greywater)) and the solids digest and settle to the bottom of the tank in the same manner as in the settled-sewage system. The septic tank therefore provides for storage of sludge. The effluent from the tank can contain pathogenic organisms and must therefore be drained on the site in a subsoil drainage system. The scum and the sludge must be prevented from leaving the septic tank as they could cause permanent damage to the percolation system. It is therefore advisable to inspect the tank at intervals to ascertain the scum and sludge levels. Most tanks can be emptied by a conventional vacuum tanker. Liquid waste from the kitchen and bathroom can also be drained to the septic tank. Septic tanks should be regarded as providing a high level of service.

Factors to consider before choosing this option are the following:

- It is relatively expensive and requires a water connection on each stand.
- It requires regular inspection, and sludge removal every few years, depending on the design capacity of the septic tank.
- Percolation systems may not be suitable in areas of low soil permeability or high residential density.
- It provides a level of service virtually equivalent to waterborne sanitation.
- The system is hygienic and free of flies.
- The toilet can be inside the dwelling.
- This system has excellent potential for upgrading, since the septic tank outlet can easily be connected to a settled-sewage system at a future date.
- An adequate, uninterrupted supply of water must be available.

Designers are referred to the publication *Septic tank systems* (BOU/R9603), available from the CSIR, Division of Building and Construction Technology, for information on the design of septic tanks.

Reference to the percolation capacity of soils is made later in this chapter under the section “Evaluation of sites”.

**Low-flow on-site sanitation systems (LOFLOs)**

The term LOFLOs refers to the group of on-site sanitation systems that use low volumes of water for flushing (less than 2.5 litres per flush). These systems include a pedestal, digestion capacity and soakaway component. They are:

- aqua-privies;
- pour-flush toilets* and low-flush systems*; and
- low-flow septic tanks*.

*These types are not generally found in South Africa.

**Aqua-privies:**

An aqua-privy is a small, single-compartment septic tank directly under or slightly offset from the pedestal. The excreta drops directly into the tank through a chute, which extends 100 mm to 150 mm below the surface of the water in the tank. This provides a water seal, which must be maintained at all times to prevent odour and keep insects away. The tank must be completely watertight; it may therefore be practical to use a prefabricated tank. The tank must be topped up from time to time with water to compensate for evaporation losses if flushing water is not available. This can be done by mounting a wash trough on the outside wall of the superstructure and draining the used water into the tank. The overflow from the tank may contain pathogenic organisms and should therefore run into a soil percolation system (it can also be connected to a settled-sewage system at a later stage).
Factors to consider before choosing this option are the following:

- The excreta are visible to the user.
- The tanks must be completely watertight.
- The user must top up the water level in the aqua-privy to compensate for evaporation losses.
- The system is hygienic, provided that it is used and maintained correctly.
- It is relatively inexpensive.
- The system can be regarded as a permanent sanitation solution.
- This system has excellent potential for upgrading, since the tanks work in the same way as a septic tank and can thus be connected directly to a settled-sewage system.
- The tanks need regular inspection, and sludge removal is required from time to time.
- An adequate, uninterrupted supply of water must be available.

**FACTORs AFFECTING THE CHOICE OF A SANITATION SYSTEM**

**General considerations**

The primary reason for installing a sanitation system in a community is to assist in the maintenance of health and should be seen as only one aspect of a total health programme. The choice of a sanitation system by a community will be influenced by several factors, such as the following:

- The system should not be beyond the technological ability of the community insofar as operation and maintenance are concerned.
- The system should not be beyond the community’s ability to meet the capital as well as the maintenance costs.
- The system should take into account the level of water supply provided, and possible problems with sullage (greywater) management.
- The likelihood of future upgrading should be considered, particularly the level of service of the water-supply system.
- The system should operate well despite misuse by inexperienced users.
- In a developing area the system should require as little maintenance as possible.
- The system chosen should take into account the training that can be given to the community, from an operating and maintenance point of view.
- The system should be appropriate for the soil conditions.
- The community should be involved to the fullest extent possible in the choice of an appropriate system.
- To foster a spirit of real involvement and ownership, the community should be trained to do as much as possible of the development work themselves.
- Local customs should be carefully considered.
- The local authority should have the institutional structure necessary for the operation and maintenance of the system.
- The existing housing layout, if there is one, should not make the chosen system difficult to construct, maintain or operate.
Environmental factors should be considered: surface pollution, possible groundwater contamination, etc.

The cost of the system

Many people in developing areas are not only unable to afford sophisticated sanitation systems, but these systems may also be technically inappropriate for them. At the same time, the sanitation alternative with the lowest overall cost may also be inappropriate because of the community's cultural background or because of its unwillingness or inability to operate the system correctly.

When the costs of different systems are compared, all relevant factors should be taken into account. Examples of costs often ignored are the following:

- A pit toilet may require relocation on the site or emptying every 4-10 years, depending on its capacity.
- Sludge from septic tanks and other on-site sanitation systems may require treatment before disposal.
- Training may be required for operators and maintenance staff.
- The community may have to be trained in the use of the system for it to operate effectively.
- Regional installations such as treatment works may be required.
- Special vehicles and equipment may be required for operation or maintenance.

To keep costs to a minimum, several issues are relevant:

- Who pays what? For example, if a government institution or development agency is paying all of the capital costs, then the community will generally demand the most expensive, highest level of sanitation. If, on the other hand, the capital costs are to be recovered from the community, then its choice of sanitation system may be quite different. The lack of income to pay for maintenance could have serious financial implications as well as health risks.
- Would the community prefer lower capital costs and higher maintenance costs, or vice versa?
- Will the cost comparison between options change if all the potential benefits and costs are included?
- Are any of the costs incorrectly or dishonestly represented? For example, have capital grants or soft loans been ignored? Do certain services have hidden subsidies that produce misleading comparisons (for example, where treatment costs are paid by regional authorities)?

Where finance is limited, developers should consult the community, determine its priorities, and seek ways to achieve the improvements desired. This may take extra time but a motivated community will contribute more to successful project implementation and, perhaps more importantly, to the long-term operation and maintenance of the system selected.

Sanitation at public facilities

Sanitation facilities are required at public buildings such as schools and clinics. The large number of people using a concentrated facility can cause problems if there is inadequate on-site drainage and a lack of general maintenance, such as cleaning of the toilet and replacement of toilet paper. Most types of on-site sanitation systems can be used, provided that developers take note of the special requirements for public facilities.

Generally speaking, the system should use as little water and require as little routine maintenance as possible. Before choosing a system that requires daily maintenance for effective operation, one must ensure that maintenance tasks will in fact be performed. A rural school may not be able to afford the services of a janitor to look after routine maintenance.

The number of sanitation units required at schools is covered in the National Building Regulations (SABS 0400:1990). Because of the number of users, care should be taken to prevent pollution of the groundwater, particularly if there is a borehole supplying the school with water.

Urinals that do not require water for flushing are available from commercial sources. These can be used effectively in sanitation facilities. However, they require the weekly addition of a special oil to the trap and the application of a special deodorised cleanser to the bowl or slab. They perform satisfactorily as long as the weekly maintenance is carried out and should therefore be used only where the necessary training can be given to the cleaners and where the supply of oil and cleanser can be assured.

DISPOSAL OF SLUDGE FROM ON-SITE SANITATION SYSTEMS

All forms of on-site sanitation will result in an accumulation of sludge that, at intervals, must be removed from the pit or tank and conveyed to some treatment or disposal facility. If the pit or tank contains fresh sewage, the sludge must be treated or disposed of in a way that will not be harmful to the
The most suitable method of emptying a pit mechanically involves the use of a vacuum tanker, where a partial vacuum is created inside a tank and atmospheric pressure is used to force the pit contents along a hose and into the tank. The use of a vacuum is preferred to other pumping methods, because the contents do not come into contact with the moving parts of the pump, where they can cause damage or blockages. Various techniques can be used to convey this sludge along the pipe to the tank. Thin sludge with a low viscosity can be conveyed by immersing the nozzle below the surface of the sludge, drawing a constant flow into the tank.

Thicker, more viscous sludge requires a pneumatic conveying technique, where the particles of waste matter are entrained in an air stream. This can be achieved by holding the end of the nozzle a few centimetres above the surface of the waste and relying on the high velocity of the air to entrain particles and convey them along the pipe to the holding tank. This technique requires very high-capacity air pumps to operate effectively. Devices such as an air-bleed nozzle can be used to obtain the same effect with less operator skill and smaller air pumps. Pneumatic conveyance can also be achieved with a low-capacity air pump by using the plug-drag (or suck-and-gulp) technique. This method relies on submerging the hose inlet, allowing a vacuum pump to create a vacuum inside the tank, then drawing the hose out to allow a high-velocity air stream to convey a plug of waste into the tank. The plug-drag technique works best with a vehicle with a fairly high-capacity pump (say 10 m³/min) and a relatively small holding tank (1.5-2 m³).

**Sludge flow properties**

Sludge generally exhibits a yield stress, shear thinning behaviour and thixotropy. In effect, this means that the hardest part of the operation is to get the sludge moving. The addition of small quantities of water to the sludge can assist greatly in getting it to move by causing shearing to take place. Being thixotropic, the sludge “remembers” this and exhibits a lower shearing stress next time.

**Vacuum tankers**

Most vacuum tankers available today are designed for use in developed countries, where roads are good and maintenance is properly done. However, some manufacturers are realising the special conditions that exist in developing countries and are now adapting their designs or, even better, are developing completely new vehicles designed to cope with the actual conditions under which these vehicles will have to work.

The size of conventional vacuum tanker vehicles prevents their gaining easy access to toilets. They are
high off the ground, which may limit the depth of pit that can be emptied, and they are so heavy when loaded that travelling over bad or non-existent roads is extremely difficult. The equipment on the vehicle is often complex and requires regular maintenance, which is seldom carried out by the unskilled people who, in most cases, will operate the vehicles. Watery sludge from conservancy tanks and septic tanks may not be a problem, but the tankers often cannot cope with the more viscous sludge found in pit toilets.

A purpose-designed pit-toilet-emptying vehicle should have the following attributes:

- a low mass;
- a low overall height;
- high manoeuvrability;
- ability to travel on extremely poor roads;
- a small-capacity holding tank with a relatively high-capacity pump, to facilitate the use of plug-drag techniques;
- the ability to transfer its load to another vehicle or trailer if there are long haul distances to the disposal site;
- both vehicle and equipment must be robust;
- little skill should be required to operate the vehicle and the equipment;
- capital and operating costs must be as low as possible, to facilitate operation by emerging contractors or entrepreneurs;
- a small pressure pump and water for washing down must be provided; and
- storage compartments must be provided for the crew’s personal effects.

Disposal of sludge

Pit-toilet sludge can be disposed of by burial in trenches.

Dehydrated faecal matter from urine-diversion toilets may be safely re-used as soil conditioner, or, alternatively, disposed of by burial, if preferred. It may also be co-composted with other organic waste.

Sludge from septic tanks, aqua-privies, etc, can be disposed of only in accordance with the prescribed methods. See Water Research Commission (1997) Permissible utilisation and disposal of sewage sludge.

Unless the sludge has been allowed to decompose until no more pathogens are present, it may pose a threat to the environment, particularly where the emptying of pits is practised on a large scale. The design of facilities for the disposal of sludge needs careful consideration, as the area is subject to continuous wet conditions and heavy vehicle loads. The type of equipment employed in the disposal effort should be known to the designer, as discharge speed and sludge volume need to be taken into account. Cognisance should be taken of the immediate environment, as accidental discharge errors may cause serious pollution and health hazards.

Emptying facilities at treatment works need not be elaborate, and could consist of an apron on which to discharge the contents of the vehicle and a wash-down facility. The nature of the sludge can vary widely and this should be taken into account when designing the sewage works. Depending on the habits of the pit owners and the effectiveness of refuse removal in the area, there may also be a high proportion of rags, bottles and other garbage in the sludge. Generally a higher grit load will also come from developing communities. Pond systems can be very effective in treating sludge from on-site sanitation systems. If the ponds treat only sludge from pit latrines it may be necessary to add water to prevent the ponds from drying out before digestion has taken place. Sludge from on-site sanitation systems can also be treated by composting at a central works, using forced aeration.

Although it is usually still necessary to treat sludge from on-site sanitation systems, the cost of treatment is lower than for fully waterborne sanitation. This is because partial treatment has already taken place on the site through the biological decomposition of the waste in the pit or tank. In addition, the treatment works do not have to be designed to handle the large quantities of water which must be added to the waste for the sole purpose of conveying solids along a network of sewer pipes to the treatment and disposal works.

EVALUATION OF SITES

It is not possible to lay down rigid criteria for the suitability of a site for on-site sanitation, because soil and site conditions vary widely. Two basic criteria should, however, be considered – namely, whether the soil can effectively drain the liquids brought to the site and whether there is any danger of pollution of the groundwater or surface water.

Topographical evaluation

All features that can affect the functioning of the sanitation system should be noted and marked on the site plans during a visual survey of the site. The position of depressions, gullies, rock outcrops and
other features should be noted and an assessment made of how they are likely to affect the functioning of the system. The type and gradient of slopes should also be noted as steep slopes can result in the surfacing of improperly treated effluent, especially during periods of high rainfall. Surface and subsurface drainage patterns, as well as obvious flood hazards, should be reported. The vegetation on the site will often reflect soil-drainage characteristics.

**Soil profiles**

Sampling holes should be excavated to a depth of at least one metre below the bottom of proposed pit toilets or soakaways. Soil properties (such as texture, structure and type) should be determined. The presence of bedrock, gravel, groundwater or a layer with poor permeability should be noted. Soil mottling indicates the presence of a high seasonal groundwater table, which can affect soil percolation.

**Percolation capacity of the site**

If the soil is unable to drain liquid waste effectively, swamplike unsanitary conditions can result. This can occur in areas with very shallow water tables or with poor permeability, or where a shallow, restrictive layer such as bedrock occurs. On-site sanitation can be used in low-permeability soils, but the system must be carefully selected in relation to the quantity of water supplied to the site. If the efficient functioning of a soil-percolation system is in doubt, it is advisable to create an inspection point where the level of the water in the subsoil drain can be monitored, so that adequate warning of failure is obtained to allow the local authority to plan for an alternative solution to liquid drainage problems before a crisis develops. This will be effective only if the recipient community fully understands the need for regular inspection of the drain, as well as the consequences of failure. On-site sanitation can be used in areas with poor percolation, but it may be necessary to retain all the liquids on the site in a sealed vault and provide a regular emptying service, or to drain the site with settled sewage systems.

The percolation test is designed to quantify the movement of liquids in the soil at a specific time of the year. Percolation rates usually change as the soil's moisture content changes, and it is best to conduct the test in the rainy season. The percolation test should be regarded only as an indication of the suitability of the soil for a specific sanitation system. The following procedures should be complied with:

**Calculation of number of test holes**

The number of test holes needed is determined by the size of the settlement and the variability of the soil conditions. Usually test holes should be spaced uniformly throughout the area, at the rate of five to ten holes per hectare, if soil conditions are fairly homogeneous.

**Percolation test**

The test procedure to be followed is described in SABS 0400.

**POLLUTION CAUSED BY SANITATION**

When there is a high density of people living in an area, both the surface water and groundwater can be expected to become polluted to some degree, irrespective of the type of sanitation system used in the area. Some basic precautions will minimise the risk of serious pollution.

**Surface pollution**

The surfacing of partially treated effluent can create a direct health risk, and can cause pollution of surface waters. This type of pollution should and can usually be avoided. It is most likely to occur in areas where the groundwater table is very high or in areas with steep slopes where a shallow, permeable layer of topsoil covers an impermeable subsoil. In areas where cut-and-fill techniques are used to provide platforms for house construction, sanitation units and soakaways should be carefully sited to minimise the possibility of surface pollution. Sanitation units and soakaways should also be sited in such a way that rainwater ingress cannot occur, as this could cause flooding, with resultant surface pollution.

Poor maintenance of reticulation systems, pumping stations and sewage-purification works can cause serious pollution with associated health risks, especially in remote areas close to streams and rivers.

**Groundwater pollution**

Groundwater can be contaminated by a sanitation system; therefore the risk should be assessed or the groundwater periodically monitored, particularly where this water is intended for human consumption. The guidelines made available in the publication *A protocol to manage the potential of groundwater contamination from on-site sanitation* by the Directorate of Geohydrology of the Department of Water Affairs & Forestry (1997), should be observed. The soil around the pit toilet or subsurface drain provides a natural purification zone, and tests carried out both in South Africa and other parts of Africa indicate that on-site sanitation does not pose a serious threat, provided the water is not intended for human consumption. Generally, the susceptibility of a water source to pollution decreases quite sharply with increasing distance and depth from the source of pollution, except in areas with fissured rock, limestone, very coarse soil or other highly permeable soils.
Soakaways attached to on-site sanitation systems should, wherever possible, be located downstream of drinking water supplies. The following could be used as a guide for the location of a soakaway:

- 7.5 m from the drinking-water source if the highest seasonal water table is more than 5 m below the bottom surface of the pit or soakaway;
- 15 m from the water source if the highest seasonal water table is 1-5 m below the bottom surface of the pit or soakaway; and
- 30 m from the water source if the highest seasonal water table is less than 1 m below the bottom of the pit or soakaway; and
- there is no safe distance from a source of drinking water in areas that have fissured rock, limestone or very coarse soil.

These distances are given as a guide only. Permeability of the soil is not the only factor. Geology, topography, the presence of trees, groundwater flow direction, etc, also influence the position of the borehole (Xu and Braune 1995).

**SULLAGE (GREYWATER) DISPOSAL**

**General**

On-site excreta-disposal technologies require that separate provision be made for the disposal of sullage. Sullage, also referred to as greywater, is defined as all domestic wastewater other than toilet water. This refers to wastewater from baths, sinks, laundry and kitchen waste. Although this “greywater” is supposed not to contain harmful excreted pathogens, it often does: washing babies’ nappies, for example, automatically contaminates the water. Sullage, however, contains considerably fewer pathogenic micro-organisms and has a lower nitrate content than raw sewage. It also has a more soluble and biodegradable organic content.

Sullage is produced not only on private residential stands but also at communal washing places and taxi stands, and provision should therefore be made for its disposal.

**Volumes**

The per capita volume of sullage generated depends on the water consumption. The water consumption is to a large extent dependent on the level of water supply and the type of on-site sanitation the contributor enjoys. It is not difficult to find local figures of generation and one should try to obtain these, even if it requires actual measurement in the field. Typical figures are given in Table 10.2.

**Health aspects**

Mosquito breeding can take place where ponds are created by casual tipping of sullage, and conditions favourable for the development of parasitic worms could also be created in this way. Infection can also occur in constant muddy conditions. In order to reduce potential health hazards, it is of the utmost importance to choose the right option for sullage disposal. See also Figure 6.31, Chapter 6.

**Disposal**

The type of disposal system chosen by the designer will depend on various factors such as the availability of land, the volume of sullage generated per day, the risk of groundwater pollution, the availability of open drains, the possibilities of ponding and the permeability of the soil. Where water is available on the site, a disposal facility should definitely be considered.

**Disposal systems**

Sullage can be used to effect flushing of certain systems.

**Casual tipping**

Casual tipping in the yard can be tolerated, provided the soil has good permeability and is not continually moist. Where casual tipping takes place under other conditions it may result in ponding and/or muddy conditions, with adverse health effects as mentioned above. Good soil drainage and a low population density can accommodate this practice.

**Garden watering**

This practice can also be tolerated, provided plants and vegetables that are watered in this manner are not eaten raw, for disease transmission may occur.
Soakaways

A soakaway is probably the safest and most convenient way of disposing of sullage, as long as soil conditions permit this. The design of the soakaway can be done according to the guidelines given in SABS 0400. Designers should be aware that groundwater pollution is still a possibility, though to a much lesser extent. Where simple maintenance tasks are able to be carried out, the use of grease traps should be considered.

Piped systems

The disposal of sullage in piped systems is hardly ever an economical solution, although it may be a viable option when dealing with communal washing points generating large amounts of sullage. Solids-free sewer systems are ideal for this purpose.

Sullage treatment

The fairly high BOD₅ value of sullage (typically 100 mg/l) makes it unsuitable for discharging into rivers and streams. If treatment is required, single facultative ponds could be used.

TOILET PEDESTALS AND SQUATTING PLATES

Various types of toilet pedestals and squatting plates can be used with on-site sanitation systems. Members of some cultures are used to squatting for defecation, and cases of constipation have been recorded when they change to a sitting position. Some cultures also require water for anal cleansing.

The simplest form of appliance is a plain seat or pedestal, or a squatting plate. The hole should be approximately 250 mm in diameter for adults, and have a cover to restrict the access of flies and other insects to the pit. It is good practice to provide a second seat with a hole size of approximately 150 mm for young children, so that they need not fear falling into the pit. The plain seat found in a VIP toilet normally has similar dimensions.

Pedestals with water seals can be used in conjunction with most sanitation systems. Various methods can be employed to effect a water seal in a toilet system. They significantly increase user convenience by eliminating odour and screening the contents of the pit. Some water seal appliances require a piped water supply. These are not recommended for on-site sanitation systems, unless the extra water can be disposed of on the site (see the section on sullage disposal). Most water seal appliances can operate efficiently on a tank filled by a bucket of household wastewater.

A conventional toilet bowl is an example of a water seal pedestal, but it can require between 6 and 12 litres per flush. Special pans or bowls, so-called low-volume flush pans, have been developed that require only three litres per flush. These low-volume flush toilets do not have any negative effects on the self-cleaning capacity of waterborne sewerage systems. Various tipping-tray designs are also available, with flush requirements varying from 0,75 to 2 litres, depending on the design. These appliances have a shallow pan or tray that holds the water necessary for the seal. After use the tray is cleared by tipping it, allowing the waste matter to fall into the pit below. Thus the water is used solely for maintaining the seal, not for clearing the pan.

Pour-flush bowls can also be used to maintain a water seal. These pans are flushed by hand, using a bucket, and generally require about two litres per flush. The biggest disadvantage of this appliance is that the effectiveness of the flush depends on the human element – which varies greatly – and there is no control over the amount of water used per flush. The pedal of an aqua-privy does not have its own water seal. The water seal is effected by directing the pipe straight into the digester. No water is needed for flushing, but the level of liquid in the tank must be maintained.

DESIGN OF VIP TOILETS

Detailed design information can be obtained from the publication Building VIPs by Bester and Austin. A VIP Code of Practice is currently also under preparation by the SABS.

TOILET FACILITIES FOR PHYSICALLY DISABLED PERSONS

Some introductory remarks on water and sanitation facilities for disabled persons can be found under the section “Public or communal water-supply terminals” in Chapter 9. Toilet aids help to preserve the dignity and independence of disabled persons. Outdoor toilets should be situated on smooth, even pathways, and ramps should be provided in lieu of steps. Ramps should be not less than 1100 mm wide, with a slope not exceeding 1:12. The appropriate layout and dimensions of a toilet room suitable for wheelchair users are shown in Figure 10.12. If there is enough space for a person using a wheelchair, then there should be enough space for ambulant people using crutches or technical aids. Taps or washbasins, if fitted, should also be in an accessible position and at an appropriate height for use from a wheelchair. Reference should be made to Part S of SABS 0400-1990 for further design information.
TRAINING OF MAINTENANCE WORKERS

The training of local people as maintenance workers should be seen as an integral part of capacity-building within the community. Training should not take place merely because it is a fundamental principle or policy of the day.

Members of the community should be trained to install and operate a system, or to act as advisers to others who would like to install their own system. This can be achieved by establishing a “sanitation centre” where the community can purchase a variety of appliances and other necessary materials. The manager of this centre can be trained to become the local sanitation expert and can advise the population on maintenance requirements when necessary.

When assessing training needs, one must expect that some of the people trained will move to other areas where greater employment opportunities are available.

The degree of training and the amount of institutional support required will increase with the level of complexity of the sanitation system. On-site sanitation has the advantage that the greater part of the system belongs to the users. Sewer systems, on the other hand, have long lengths of underground piping and manholes, as well as pumping installations, which are the property of the local authority and must be regularly maintained by properly trained people in order for the system to work properly.

UPGRADING OF SANITATION FACILITIES

Possible upgrading routes should be considered when the initial choice of a system is made, particularly if an appreciable increase in the water supply is expected at some time in the future. However, it is unlikely that all the residents of a township will be able to afford upgraded services at the same time, which will be necessary if one is upgrading to full waterborne sanitation.
Most forms of pit toilet can be greatly improved by providing a water seal between the user and the excreta. This effectively stops odours and flies from exiting the pit via the toilet pedestal, and removes children’s fears of falling into the pit. A water seal can be provided by a tipping-tray, a pour-flush or a low-flush toilet bowl. Designers should ensure that the quantity of water used with every cleaning operation does not increase the water content of the pit to a point where it can no longer be drained by the soil.

When the water supply is increased to the point at which the soil can no longer absorb it naturally (usually when an individual water connection is provided to each stand), it will be necessary to make special arrangements to remove the wastewater from each site in order to maintain healthy living conditions.

This is a major step in the upgrading process and will require additional financial input from the residents. The most economical solution may be a settled-sewage system, as this would be far easier to install in an existing settlement than a conventional sewer system.

If the developer is reasonably confident that the area’s water supply will be upgraded within a few years, it may be advantageous to install septic tanks at the time of the original development. If this is done, then the settled-sewage system can be connected directly to the outlet from these systems and the soakaway can be bypassed and left inactive on the site.

Some possible upgrading routes are described in Appendix B.

**OFF-SITE WASTEWATER TREATMENT**

Off-site wastewater treatment is considered a specialised subject and, except for some general comments on pond systems and package purification units, falls outside the scope of this document. Where the introduction of a treatment works is considered, specialist consultants should be involved. The quality of effluent emanating from a wastewater treatment works is prescribed by legislation and has to meet licensing requirements. Water Services Providers should be licensed in terms of the National Water Act.

**Pond systems**

Although pond systems are regarded as treatment plants, the effluent does not normally meet acceptable effluent standards. Pond effluents have therefore to be irrigated. A pond system is regarded as a wastewater treatment works and its owner should also obtain a licence from the Department of Water Affairs & Forestry.

Pond systems are usually used in remote or developing areas, normally where land is available and relatively cheap. Skilled operators are not required and, depending on the circumstances, electricity need not be a requirement. Stabilisation (or oxidation) ponds are cheaper to build than conventional sewage purification works.

Although pond systems are regarded as being comparatively less sophisticated than other purification systems, they nevertheless require proper planning, application, design, construction and maintenance. Ponds do not need daily attendance, but should never be allowed to fall into disrepair.

The Water Institute of South Africa (WISA) has made available a design manual based on South African experience. This manual can be used as a guide to the design of pond systems.

Stabilisation or oxidation ponds are classified according to the nature of the biological activity taking place, as follows:

- facultative-aerobic ponds (where aerobic and facultative conditions exist) – facultative organisms use dissolved oxygen when it is available, but convert to anaerobic processes in its absence; and
- anaerobic-aerobic ponds (where the primary ponds are completely anaerobic and the secondary ponds are mainly aerobic).

The following important aspects should be considered regarding siting and land requirements:

- the cost of the land;
- the minimum distance between pond systems and the nearest habitation;
- the direction of the prevailing winds – ponds should, as far as possible, be downwind of town limits;
- possible groundwater pollution;
- geotechnical conditions that will influence costs;
- the land required for irrigation purposes, which is an integral part of the pond system; and
- the topography of the site, which can influence costs.

Irrigation of crops may take place only as prescribed in the publication *Permissible utilisation and disposal of sewage sludge* by the Water Research Commission 1997.
Package purification units

The use of package purification units is dependent on factors similar to those mentioned above, but the operational costs involved when opting for package purification plants should be carefully considered. It is not a preferred option.
APPENDIX A

INFORMATION REQUIRED FOR THE PLANNING AND DESIGN OF SANITATION PROJECTS

This appendix gives information regarding data that should be collected for the proper planning, design and implementation of a sanitation project. Note that the definition of sanitation in the White Paper on Basic Household Sanitation of 2001 is the following:

“Sanitation refers to the principles and practices relating to the collection, removal or disposal of human excreta, household wastewater and refuse as they impact upon people and the environment. Good sanitation includes appropriate health and hygiene awareness and behaviour, and acceptable, affordable and sustainable sanitation services.

The minimum acceptable basic level of sanitation is:

(a) appropriate health and hygiene awareness and behaviour;

(b) a system for disposing of human excreta, household wastewater and refuse, which is acceptable and affordable to the users, safe, hygienic and easily accessible and which does not have an unacceptable impact on the environment; and

(c) a toilet facility for each household.”

COMMUNITY MANAGEMENT APPROACH

Research done and projects launched in culturally different communities require an openness and adaptability to the issues that are important to the community. A growing awareness of the failures of conventional development approaches in meeting the needs of people with few resources has led to the exploration of alternative methodologies for investigating resource-management issues, and planning, implementing and evaluating development initiatives. There is a wide range of approaches with strong conceptual and methodological similarities. These include:

- Participatory rural appraisal (PRA);
- Participatory learning methods (PALM);
- Rapid rural appraisal (RRA);
- Rapid assessment procedures (RAP);
- Participatory action research (PAR);
- Rapid rural systems analysis (RRSA);
- The demand responsive approach (DRA);
- The SARAR approach;

and many others. The themes common to all of these approaches are:

- the full participation of people in the processes;
- the concept of learning about their needs and opportunities; and
- the action required to address them.

The experience gained in the past decade in particular has pointed to the need for three key elements to be successful both in water-supply and in sanitation projects, namely:

- involvement of the community in all aspects of the projects;
- the use of appropriate technology; and
- the need for institution-building and training activities in conjunction with the project.

Community development, however, does not take place in a vacuum; it is always situated in a concrete social, economic and political context. Therefore, it is of the utmost importance that a multi-disciplinary team be involved in community development. Because development is development for the people, the people should remain central to the process. To ensure this, it is inevitable that social engineering should precede any development project, and run parallel with it until completion of the project.

Over the past few years, holistic development has become a vital aspect of sustainable development. It is recognised worldwide that projects that take human factors into consideration are more likely to be successful than those that do not. It is therefore of the utmost importance for development agencies to collaborate closely with communities at inception and through all stages of infrastructural development.

As distinct from community participation, community management means that beneficiaries of infrastructural services have the responsibility for, and authority and control over the development of such services.

Although the spin-offs of this approach are obvious, they are not easy to achieve within a short space of time. It should also be noted that the mere participation of communities in the project is not a solution, but a necessary forerunner of successful
community projects. It is imperative that participation should be coupled with capacity-building efforts through training.

The application of scientific research methods (such as fact-finding and community surveys) is recommended in the initial stages of community development. These methods can be adapted in research forums that promote community participation, and which will create opportunities for interaction between the developer and the identification of needs by community members themselves. Examples include community surveys, social reconnaissance and action research. This emphasises a systems approach and inter-disciplinary teamwork, continued involvement of the community members in all decisions and activities, development as a learning process (including the need for training), and continued monitoring and evaluation activities.

Seven phases have been identified in the participatory strategy for integrated rural development.

**Phase 1**

This phase consists of an initial reconnaissance of the community among which the project is going to be implemented by the social scientist or community worker. Existing documentary sources about the community are studied and field visits, mini-surveys and interviews with key people, etc, are undertaken. The main aim is to identify initial goals and to commit the development committee, which must include representatives (male and female) from the community, to these goals.

**Phase 2**

The second phase is the identification of priorities by means of field studies and research. The planner/developer performs specific investigations in order to identify areas of priority or problems. Community members and other agents are trained in problem identification and analysis. Insight is also gained in the functioning of the system and its problems.

**Phase 3**

The third phase consists of the formulation of possible solutions for the identified problems. The social scientist or community worker gives direction, but community members are involved fully in exercises of discovering solutions. Continued involvement and participation of the community members should be ensured.

**Phase 4**

In the fourth phase feasibility studies are performed. It is important that objectives be compatible with each other.

**Phase 5**

This phase is the implementation of the project. The implementation implies various political and planning activities, such as official approval of the project, planning and design, formal project descriptions, communication with the authorities, liaison and linkage with other institutional agencies, financial support, physical input and specific services.

**Phase 6**

This phase consists of planning the completion, termination, or continuation of the project. Community members should be trained in the operation and maintenance of the system, and supported in their efforts for a period of time to ensure sustainability.

**Phase 7**

The seventh phase refers to project evaluation. Formal project evaluation, preferably by an external agent, is supported by internal evaluation procedures as an ongoing activity in the development process. Monitoring and auditing form part of the evaluation activities. The main function of evaluation is to identify weaknesses in a project, in order to avoid similar problems and facilitate sound planning in future projects.

**HUMAN-RELATED DATA**

The following data are necessary to ensure sustainability.

**Socio-cultural data**

Religious and tribal customs, as well as cultural factors affecting the choice of technology (for example, traditional materials and practices for cleansing and ablution), include:

- the general level of literacy and education, especially hygiene education;
- important watersource-related activities (such as laundry, bathing and animal watering); and
- community attitudes to the recycling and handling of decomposed human waste.

**Community preferences**

After considering costs, note preferences of the community regarding the following:

- the type of sanitation service;
the position of the toilet (for example, should it be inside or outside the house? If outside, should the toilet door face the house? How far should the toilet be from the house?);

the appearance of the toilet building and pedestal (colour, form, etc);

the size of the toilet;

the seats or squatting plates; and

the permanency of the superstructure.

**Economic and social conditions**

These include:

- present living conditions, types of housing (including condition, layout and building materials used) and occupancy rates;

- population numbers according to income levels (present and projected), and the age and sex distribution of the community ethnic groups, and settlement patterns in the project area;

- land-use and land-tenure patterns;

- locally available skills (managerial and technical); and

- major occupations, approximate distribution, unemployment and under-employment.

**Health and hygiene conditions**

These include:

- location of toilet/defecation sites;

- toilet maintenance (structure and cleanliness);

- disposal of children’s faeces;

- hand-washing and use of cleansing materials;

- sweeping of floors and yard;

- household refuse disposal;

- drainage of surrounding area;

- incidence and prevalence of water- and faeces-related diseases;

- treatment of diseases; and

- access to doctors/clinics/hospitals.

**Institutional framework**

These include:

- The identification and description (responsibility, effectiveness and weaknesses) of all institutions and organisations, both governmental and non-governmental, that are providing the following services in the project area:

  - water and sanitation;
  - education and training;
  - health and hygiene;
  - housing;
  - building material supplies; and
  - transport.

- Identification of all other major local organisations (social and political), the type and number of members they have and the influence they could have on the project.

**Environmental and technical aspects**

Important factors to consider are:

- the position of the site in relation to existing settlements;

- existing supplementary services (type, availability, reliability, accessibility, cost, etc) such as water supply, roads, energy sources and sanitation schemes;

- environmental problems such as sullage removal, stormwater drainage, refuse removal, transport routes;

- site conditions such as topography, geology (soil stability, rockiness, permeability, etc);

- groundwater data, such as availability, quality and use;

- prevailing climatic conditions such as rainfall, temperature and wind;

- type and quantity of local building materials that may be suitable;

- existing building centres supplying building materials and equipment (type of materials and equipment, availability, quality and cost); and

- the need for, and existence of, appropriate building regulations and by-laws.

**INFORMATION REQUIRED FOR POST-PROJECT EVALUATION**

To evaluate the success and sustainability of a sanitation project, it is necessary to correlate environmental conditions in the project area with the health profile of the community concerned after the scheme has been in operation for some time (especially projects where the upgrading of existing services is planned). To be able to do this, additional information should be collected – for example the following:
• A concise description of the community's living conditions in general, and their existing sanitation and water supply facilities in particular.

• How long have the people been living in the area and for what period have the existing sanitation facilities been in use?

• With regard to the community's perception of the present situation and sanitary practices, and their interest in or susceptibility to change:
  - Do they regard the present water supply as satisfactory, in quantity and quality?
  - What arrangements are there for refuse removal – do they regard them as satisfactory?
  - What facilities exist for personal hygiene – where do they bathe or wash themselves?
  - Are they aware of any advisory service on health and hygiene, and do they make use of it?

• Identify all major health problems in the community:
  - List all diseases recorded in the area that can be related to water supply and sanitation.
  - Obtain figures on present morbidity and mortality rates.
  - Identify possible disease-contributing factors, such as possible contamination of drinking water.
  - What was the actual total cost of the project?

• What amount of money do they spend on doctors, clinics, medicines and other health-related aspects?

• Do they regard the present sanitation facilities as adequate?
APPENDIX B

UPGRADING OF EXISTING SANITATION SYSTEMS

BASIC UPGRADING ALTERNATIVES

Alternative 1 – Aesthetic upgrading
The options in this category can be implemented by individual stand-owners, as the necessary financial resources become available. These are limited to the superstructure and the pedestal. An example would be where a functional superstructure is replaced with a more permanent or more aesthetic structure, such as one built from bricks and mortar. The property owner can decide on factors such as the size of the superstructure and whether the door should open inward or outward. The door and roof materials of the original superstructure could be re-used.

Alternative 2 – Introduction of a water seal
This will effectively remove odours emanating from the pit and will ensure that the user cannot see the excreta. This will also reduce the fear, particularly among children, of falling into the pit. A water seal can be introduced by installing a tipping tray, a pour-flush pan or a low-flush pan. The difference between the three types of water seal lies mainly in the quantity of water required, and thus their suitability would also depend on the ability of the soil to drain the additional quantity of water supplied to the site. This type of upgrading can be undertaken by the individual owner whenever funds are available. Depending on what type of water-seal appliance is used, it may or may not be necessary to provide an individual water connection to each stand.

Alternative 3 – Removal of liquids from the site
When individual water connections are provided to each stand, the situation will often arise where the soil can no longer adequately drain the additional water. This makes the removal of water necessary to maintain health standards. Liquids can be removed from the site by means of sewers (either a full waterborne sanitation system or a settled sewage system), or they may be retained on site in a conservancy tank and then removed periodically by a vacuum-tanker service. The installation of a sewer system will be a costly step in the upgrading process, and will require each resident to contribute to the construction costs, or some form of outside subsidy will need to be found. The ability of the local authority to manage and maintain these sanitation systems must be assessed when considering the introduction of the system. Generally, the sewers would need to be laid in the entire township at the same time. Upgrading should be undertaken only when the community can afford to pay for the higher level of service. Practically, this means that upgrading in Group 1 and 2 can be implemented at any time by individual property owners, independently of neighbours. On the other hand, upgrading in Group 3 will require both the greatest financial outlay from the property owners and implementation of the entire development at the same time. Note that, in the case of a settled sewage system, the sewers will need to be laid to neighbourhoods at the same time, but individual owners need not all connect to the system simultaneously, since it is not necessary to maintain cleansing velocities in sewers that convey only the liquid portion of the wastes. Thus, property owners could connect to the system when they have the financial means to construct the necessary solids-retention tank. Note that some on-site sanitation systems, for example septic tanks, can be used as solids-retention tanks and therefore can be connected to the settled-sewage system with only minor alterations.

UPGRADING ROUTES FOR THE VARIOUS SANITATION SYSTEMS

There are many possible upgrading routes that could be taken and the following should be seen as an indication of the various possibilities for the systems as defined in Table 10.1, which categorises sanitation systems.

Group 1
Upgrading chemical toilets
The use of chemical toilets would probably be a temporary solution in a developing community. Upgrading to a more permanent system would therefore take the form of total replacement with any one of the other sanitation systems. The chemical toilet would be removed from the site as a unit; thus there would not be any re-use of materials.

Group 2
Upgrading unventilated pit toilets
The first and most important step in upgrading would be to install a vent pipe to convert the toilet into a ventilated improved pit (VIP) toilet. This upgrading should be undertaken at the earliest possible
upgrading would follow the same route as a VIP toilet.

**Upgrading ventilated improved pit (VIP) toilets**

The VIP toilet provides several opportunities for upgrading. A major improvement can be obtained by introducing a water seal between the user and the excreta, thus providing a level of convenience that is more acceptable to users.

It may thus be necessary to consider Alternative 3 upgrading (removal of liquids from the site) only if problems arise with the drainage of excessive quantities of water, which situation can be expected when individual water connections are provided to each site. Since the pit of a VIP toilet is not watertight, it will probably be necessary to construct a new tank on the site for solids retention if upgrading to a settled-sewage system is required. The pit of the VIP toilet will then become redundant. Thus, if at the outset the final stage of the upgrading route is known to be a conservancy-tank or settled-sewage system, it is preferable to begin with a sealed-tank system (such as a vault toilet, aqua-privy or on-site digester), to avoid constructing a new tank when the upgrading takes place.

The installation of a urine-diversion pedestal will make a significant difference to a VIP toilet. The contents of the existing pit should be covered with a layer of earth, and the structure may thereafter be operated as a normal urine-diversion toilet, where urine is diverted to a soakpit or collection container and faeces are covered with ash or dry soil.

**Upgrading ventilated vault (VV) toilets**

This system is a variation of the VIP toilet, with the important distinction that it has a waterproof pit or vault. The comments on upgrading in Alternatives 1 and 2, for VIP toilets, also apply to this system. Upgrading to Alternative 3 will be different from that of the VIP toilet because the VV toilet has a lined, waterproof vault that can be used. The option of upgrading to a conservancy tank is not mentioned because the ventilated vault toilet is a type of conservancy tank. Because the VV toilet already has a waterproof tank, this system is ideal for upgrading to a settled sewage system and it is therefore highly unlikely that this system would be upgraded to a fully waterborne sewer system.

**Upgrading ventilated improved double pit (VIDP) toilets**

This system is basically a variation of the VIP toilet, so the comments for the VIP also apply to the VIDP toilet.

**Group 3**

**Upgrading full waterborne sanitation**

No upgrading of this system is necessary, but the stand owner can implement aesthetic improvements to the pedestal and superstructure.

**Upgrading conservancy tank systems**

A conservancy tank provides an ideal opportunity for upgrading to a settled sewage system, since the tank can be used to retain solids on the site.

**Upgrading the settled sewage system**

No upgrading of this system is necessary, but the stand owner can implement aesthetic improvements to the superstructure.

**Group 4**

**Upgrading septic tank systems**

A septic tank also provides an ideal opportunity for upgrading to a reticulated system, since the outlet from the septic tank can be connected to a settled sewage system without any further alterations being necessary. Solids would be retained on the site and digested in the septic tank.

**Upgrading aqua-privies**

The aqua-privy has a rough water seal, but this can be greatly improved by removing the pedestal and chute and replacing them with a device such as a tipping-tray, pour-flush or low-flush pan. An aqua-privy also provides an ideal opportunity for upgrading to a settled sewage system, since the outlet from the aqua-privy can be connected into the reticulation system without any further alterations. Solids would then be retained on the site and digested in the aqua-privy tank.
APPENDIX C

DESIGN GUIDELINES FOR WATERBORNE SANITATION SYSTEMS

SCOPE

These guidelines are applicable to the design and construction of sewerage reticulation for undeveloped residential areas, where the future houses are to be provided with full waterborne sanitation. They do not apply to on-site drainage, and do not cover any form of on-site disposal such as septic tanks and soil-percolation systems. They also do not apply to settled sewage systems.

Certain basic guidelines applicable to non-gravity systems (i.e. pump stations and rising mains) are included, but detailed design criteria for these systems are not included, as they are regarded as bulk services.

Except in cases where illustrations are provided, the reader is referred to various figures in the relevant sections of SABS 1200.

DESIGN CRITERIA

Design flows

Flow-rate units

The unit of flow rate used in these guidelines is litres per second (l/s).

Depth of flow and infiltration

Sewers should be designed to flow full at the peak design flow. An allowance of 15 per cent for stormwater infiltration and other contingencies should be incorporated in the design figures used for single-family dwelling units.

Average daily flow (A)

The average daily flow per single-family dwelling unit is given in Table C.1.

Table C.1: Average daily flows per single-family dwelling unit (du)

<table>
<thead>
<tr>
<th>INCOME GROUP</th>
<th>LOWER</th>
<th>MIDDLE</th>
<th>HIGHER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Litres per dwelling unit per day</td>
<td>500</td>
<td>750</td>
<td>1 000</td>
</tr>
<tr>
<td>Based on average total persons per dwelling unit</td>
<td>7</td>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>

Notes:

(i) The above figure is based on a dwelling unit with a floor area of 100 m² and a floor space ratio (FSR) of 0.6. If a FSR other than 0.6 is prescribed, the flow figure above should be adjusted accordingly.

(ii) Maximum density allowable under the scheme is the overriding factor.

Church sites

A church site should be treated as a "special residential" erf.

Schools and business sites

The discharge from day schools and business sites need not be taken into account, since these are relatively minor flows that do not peak at the same time as the main residential flow.

Peak design flows

In these guidelines the following factors apply to single-family dwelling units:

Peak Factor (PF) = 2.5

Percentage allowed for extraneous flow = 15 %

To calculate the unit design flow rate:

Average daily flow (l/du/d) = A

Average daily flow rate (l/s) = \( \frac{A}{24 \times 60 \times 60} \)

= \( \frac{A}{86 400} \)
Peak flow rate = Average daily flow rate x peak factor

$$\frac{A \times 2.5}{86400} = B$$

Design flow rate = Peak flow rate + % of peak flow rate for extraneous flows

$$B \times 1.15 = \frac{A \times 2.5 \times 1.15}{86400} = 0,000\,033\,A = C$$

Thus, for a population up to 1,500,

$$C = \frac{A \, (l/s/du)}{30,000}$$

Thus, from Table C.1:

- For lower income group: $0.0167 \, l/s/du$
- For middle income group: $0.0250 \, l/s/du$
- For higher income group: $0.0333 \, l/s/du$

If unit design flows are, instead, obtained from actual flow-gauging of adjacent settlements of similar nature, these unit design flows should not exceed those given above.

**Attenuation**

To take advantage of the attenuation of peak flows in gravity sewer systems as the contributor area and population increases, design peak factors may be reduced in accordance with the graph in Figure C.1 for sizing any sewer receiving the flow from a population greater than 1,500. If actual local attenuation factors are available, however, these should be used instead.

**Hydraulic design**

**Flow formulae**

The following flow formulae are acceptable for the calculation of velocity and discharge in sewers:

- Manning: $n = 0.012$
- Crimp and Bruges: $n = 0.012$
- Colebrook-White: $K_s = 0.600$
- Kutter: $n = 0.012$

Any formula can be used as long as it produces values approximately the same as the equivalent Colebrook-White formula using $K_s = 0.6$.

**Minimum size of sewers**

The minimum diameter of pipe in sewer reticulation should be 100 mm.

**Limiting gradients**

Sewers may follow the general slope of the ground, provided that a minimum full-bore velocity of 0.7 m/s is maintained.

Table C.2 shows the minimum grades required to achieve this minimum full-bore velocity for various pipe sizes up to 300 mm in diameter.

If flatter grades and lower velocities than those in the table are acceptable, the designer may choose a setting of grade that provides a velocity that is lower than 0.7 m/s, provided the time of travel is not excessive.
Table C.2: Minimum sewer gradients

<table>
<thead>
<tr>
<th>SEWER DIAMETER (MM)</th>
<th>MINIMUM GRADIENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>1 : 120</td>
</tr>
<tr>
<td>150</td>
<td>1 : 200</td>
</tr>
<tr>
<td>200</td>
<td>1 : 300</td>
</tr>
<tr>
<td>225</td>
<td>1 : 350</td>
</tr>
<tr>
<td>250</td>
<td>1 : 400</td>
</tr>
<tr>
<td>300</td>
<td>1 : 500</td>
</tr>
</tbody>
</table>

Table C.2 are contemplated, it is essential that a detailed cost-benefit study be carried out. This should take into account the cost of the regular systematic maintenance and silt/sand removal that will be required when flatter grades and lower velocities are used, instead of the additional first cost required to maintain the above minimum grades and full-bore velocity of 0.7 m/s.

Non-gravity systems

Rising mains
Velocities:
The minimum velocity of flow in a rising main should be 0.7 m/s.

The maximum velocity of flow in a rising main should be 2.5 m/s.

Minimum diameter:
The minimum diameter of a rising main should be 100 mm, except where a macerator system is used, in which case the diameter can be reduced to 75 mm.

Gradient:
Wherever practicable, rising mains should be graded so as to avoid the use of air and scour valves.

Stilling chambers:
Stilling chambers should be provided at the heads of all rising mains, and should be so designed that the liquid level always remains above the soffit level of the rising main where it enters the chamber. Stilling chambers should preferably be ventilated.

Sumps for pump stations
Emergency storage:
A minimum emergency storage capacity representing a capacity equivalent to four hours flow at the average flow rate should be provided, over and above the capacity available in the sump at normal top-water level (i.e. the level at which the duty pump cuts in). This provision applies only to pump stations serving not more than 250 dwelling units. For pump stations serving larger numbers of dwelling units, the sump capacity should be subject to special consideration in consultation with the local authority concerned. Emergency storage may be provided inside or outside the pump station.

Sizing:
In all pump stations, sumps should be sized and pump operating controls placed so as to restrict pump starts to a maximum of six per hour.

Flooding:
Care should be taken in the design of pump stations in order to avoid flooding of the dry well and/or electrical installations by stormwater or infiltration.

Screens:
Adequate protection, where necessary, in the form of screens or metal baskets, should be provided at the inlets to pump stations for the protection of the pumping equipment.

Pumps
Standby:
All pump stations should be provided with at least one standby pump of a capacity at least equal to the capacity of the largest duty pump. The standby pump should come into operation automatically if a duty pump or its driving motor fails due to mechanical failure.

Safety precautions
Safety precautions in accordance with the relevant legislation should be incorporated into the design of all pump stations and, in particular:

- all sumps and dry wells should be adequately ventilated;
- handrails should be provided to all landings and staircases and to the sides of open sumps and dry wells;
- skid-proof surfaces should be provided to all floors and steps; and
- the layout of the pumps, pipework and equipment should allow easy access to individual items of equipment without obstruction by pipework.

Physical design

Minimum depth and cover

Except under circumstances discussed in the following paragraph, the following are the recommended minimum values of cover to the outside of the pipe barrel for sewers other than connecting sewers:
• in servitudes 600 mm
• in sidewalks 1,4 m below final kerb level
• in road carriageways 1,4 m below final constructed road level

Lesser depths of cover may be permitted, subject to integrated design of all services including trunk services allowed for in development plans, provided that, where the depth of cover in roads or sidewalks is less than 600 mm, or in servitudes less than 300 mm, the pipe should be protected from damage by:

• The placement of cast-in-situ or precast concrete slab(s) over the pipe, isolated from the pipe crown by a soil cushion of 100 mm minimum thickness. The protecting slab(s) should be wide enough and designed so as to prevent excessive superimposed loads being transferred directly to the pipes (see Figure C.2); or

• The use of structurally stronger pipes able to withstand superimposed loads at the depth concerned; or

• The placement of additional earth filling over the existing ground level in isolated cases where this is possible.

Except in very special circumstances, the encasement of pipes in concrete is not recommended. Where encasement is unavoidable, it should be made discontinuous at pipe joints, so as to maintain joint flexibility (see Figure LD-6 of SABS 1200 LD).

Trenching, bedding and backfilling

The trenching, bedding and backfilling for all sewers should be in accordance with the requirements of SABS 1200 LB and the supporting Specifications.

Under normal ground conditions, structural design considerations for pipe strength and increased bedding factors do not come into play for sewers up to 225 mm diameter. Standard rigid pipes are laid on either Class D or Class C beds, as depicted in Drawing LB-1 of SABS 1200 LB, while flexible pipes (plastic or pitch fibre) are laid according to Drawing LB-2 of SABS 1200 LB.

Structural design of the pipe/bedding should be checked where trenches are:

• located under roads;
• deeper than 3 metres; and
• other than those classified as “narrow” (i.e. where overall trench width is greater than nominal pipe diameter d + 450 mm for pipes up to 300 mm diameter).

Where grades steeper than 1 in 10 are required, 15 MPa concrete anchor blocks should be provided that are at least 300 mm wide and embedded into the sides and bottom of the trench for at least 150 mm, as shown on Drawing LD-1 of SABS 1200 LD.

Curved alignment

A straight alignment between manholes should normally be used, but curvilinear, horizontal or vertical alignment may be used where the economic circumstances warrant it, subject to the following limitations:

• the minimum radius of curvature is 30 m;
• curvilinear alignment may be used only when approved flexible joints or pipes are used;
• in the construction of a steep drop, bend fittings may be used at the top and bottom of the steep short length of pipe, thus providing a curved alignment between the flat and steep gradients.
Siting
Sewers should be sited so that they provide the most economical design, taking the topography into account (i.e. in road reserves, servitudes, parks, open spaces, etc). When the sewer is to be located in a trench by itself, the minimum clear width to be allocated to it in the road reserve should be 1.5 m.

Manholes

Location and spacing
Manholes should be placed at all junctions and, except in the case of curved alignment and at the top of shallow drops, at all changes of grade and/or direction.

The maximum distance between manholes on either straight or curved alignment should be:

- 150 m where the local authority concerned has power rodding machines and other equipment capable of cleaning the longer lengths between manholes;
- 100 m where the local authority concerned has only hand-operated rodding equipment.

Note:
The economics of acquiring power cleaning equipment in order to permit a greater manhole spacing should be demonstrated to local authorities.

Where manholes have to be constructed within any area that would be inundated by a flood of 50-years recurrence interval, they should, wherever practicable, be raised so that the covers are above this flood level.

Sizes
The minimum internal dimensions of manhole chambers and shafts should be as shown in Table C.3. The minimum height from the soffit of the main through pipe to the soffit of the manhole chamber roof slab, before any reduction in size is permitted, should be 2 m.

Benching
An area of benching should be provided in each manhole so that a man can stand easily, comfortably, and without danger to himself, on such benching while working in the manhole.

<p>| Table C.3: Minimum internal dimensions of manhole chambers and shafts |</p>
<table>
<thead>
<tr>
<th>SHAPE</th>
<th>CHAMBER</th>
<th>SHAFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circular</td>
<td>1 000 mm</td>
<td>750 mm</td>
</tr>
<tr>
<td>Rectangular</td>
<td>910 mm</td>
<td>610 mm</td>
</tr>
</tbody>
</table>

Manhole benching should have a grade not steeper than 1 in 5 nor flatter than 1 in 25, and should be battered back equally from each side of the manhole channels such that the opening at the level of the pipe soffits has a width of 1.2 d, where d is the nominal pipe diameter.

Design
All manholes, including the connection between manhole and sewer, should be designed in accordance with the requirements of SABS 1200 LD and, where manholes are of cast-in-situ concrete, chambers, slabs and shafts should be structurally designed to have a strength equivalent to a brick or precast concrete manhole.

For manholes located in road reserves, spacer rings or a few courses of brickwork should be allowed for between the manhole roof slab and the cover frame, in order to facilitate minor adjustments in the level of the manhole cover. Adjustable manhole frames may also be used.

Steep drops
Steep drops should be avoided wherever possible, but where this is unavoidable (e.g. to connect two sewers at different levels), use should be made of a steep, short length of pipe connected to the higher sewer by one or more 1/16 bends and to a manhole on the lower sewer also by one or more 1/16 bends, as shown in Figure C.3.

Sewer connections

Size and siting
Each erf, excepting those listed below, should be provided with a 100 mm (minimum) diameter connecting sewer, terminating with a suitable watertight stopper on the boundary of the erf or the boundary of the sewer servitude, whichever is applicable. The connecting sewer should be located deep enough to drain the full area of the erf portion on which building construction is permitted.
Exceptions

- In special residential areas, where an erf extends for a distance of more than 50 m from the boundary to which the connecting sewer is laid, provision need only be made to drain the area of the erf within 50 m of this boundary.

- School sites should be given special consideration with regard to the position, diameter and depth of the connection(s) provided.

- Where detailed development proposals are submitted for subdivided erven as group schemes, one connecting sewer may be provided to serve such group of erven.

Note:
Where erven have to be connected to a sewer on the opposite side of a street, consideration should be given to the economics of providing 100 mm diameter sewer branches across the road to serve the connecting sewers from two or more erven.

The sewer connection should be provided at the lowest suitable point on the erf. On street boundaries the connection should be located either at a distance of 1,15 m or at a distance of 5 m or more from a common boundary with an adjacent erf, unless a local authority has already an accepted standard location.

Depth and cover
Except under the circumstances described in the following paragraph, recommended minimum values of cover to the outside of the pipe barrel for connecting sewers are:

- in servitudes 600 mm
- in road reserves 1 000 mm

Where lesser depths of cover are permitted, this should be subject to the same conditions discussed previously in this appendix, and the same protection should be provided.

When designing the invert depth of the main sewer in order to ensure that all the erven can drain to it, the fall required from ground level at the head of the house drain to the invert of the main sewer at the point where the connecting sewer joins the main sewer should be taken as the sum of the following components:

- 450 mm to allow for a minimum cover, at the head of the house drain, of 300 mm, plus 150 mm for the diameter and thickness of the house drain;

- the fall required to accommodate the length of the house drain and the connecting sewer, assuming a minimum grade of 1 in 60 and taking into account the configuration of the erf and the probable route and location of the house drains; and

- the diameter of the main sewer (see Figure LD-7 of SABS 1200LD).

Note:
In the case of very flat terrain, and where the house drains may be laid as an integral part of the engineering services, flatter minimum grades than 1 in 60 for the house drains may be considered. This relaxation could also be applied to isolated erven difficult to connect, or the ground in such erven could be filled to provide minimum cover to the drains.

Junction with main sewer
A plain 45º junction should be used at the point where the connecting sewer joins the main sewer. Saddles should not be permitted during initial construction.

Type details
Details of the connecting sewer should be in accordance with one of the types shown in Figures LD-7 and LD-8 of SABS 1200LD.

Invert levels
The invert levels indicated at a manhole location should be the levels projected at the theoretical centre of the manhole by the invert grade lines of the pipes entering and leaving such manhole. In cases where branch lines with smaller diameters enter a manhole, the soffit levels of these branch lines should match those of the main branch line. However, in areas where pipes are laid to minimum grades, this practice may need to be relaxed.

The slope of the manhole channel should be as required to join the invert levels of the pipes entering and leaving the manhole, without allowing any additional fall through the manhole chamber.

MATERIALS

Pipes and joints
Pipes suitable for the conveyance of sewage, under the particular working and installation conditions to which they will be subjected, should be in accordance with Sections 3.1 and 3.2 of SABS 1200 LD.

All joints for rigid pipes should be of a flexible type, and rigid joints should only be used where the pipes themselves are flexible.
Manholes
All materials used for manholes should be in accordance with Section 3.5 of SABS 1200 LD.

Pumping installations
In general, all materials should be durable and suitable for use under the conditions of varying degrees of corrosion to which they will be exposed.

Pipework
The relevant requirements for materials given in SABS 1200 L and 1200 LK should apply if a rising main forms part of the sewerage system.

Concrete
Structural reinforced concrete and plain concrete below ground level and/or in contact with sewage should be designed and constructed in accordance with SABS 1200 G or 1200 GA, whichever is applicable.

Structural steelwork
All exposed steelwork should be adequately protected against corrosion with a suitable approved paint system, and should otherwise be designed and constructed in accordance with SABS 1200 H or 1200 HA, whichever is applicable.

Electrical installations
All electrical installations should comply with the Factories Act and with the relevant local authority electricity supply by-laws/regulations.

Other materials
Other materials used should comply with the requirements of SABS 1200 LD where relevant.
GLOSSARY

**BOD₅**: The oxygen used for bacterial oxidation of organic pollutants or ammonia, determined under standard conditions of incubation at 20°C over 5 days.

**Sullage**: Wastewater emanating from baths, kitchen sinks, laundries and showers (toilet water is excluded).

**Thermophilic bacteria**: A kind of bacteria functioning best at a certain temperature range.

**Thixotropic**: Refers to the property of becoming temporarily liquid when disturbed and returning to its original state when stationary.

BIBLIOGRAPHY AND RECOMMENDED READING


Bester, J W and Austin, L M (1997). Building VIPs: *Guidelines for the design and construction of domestic Ventilated Improved Pit Toilets*. Division of Building Technology, CSIR. Issued by the Department of Water Affairs & Forestry.


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INTRODUCTION

Aim of the guidelines

This chapter discusses waste management for developing urban areas. The aim of the guidelines is to assist such areas in implementing a waste-management plan that will enable them to deal with waste as economically and safely as possible. Waste produced by any urban community may, if left uncontrolled, not only be an aesthetic problem, but also pose serious health risks. This can be aggravated if hazardous material is present in the waste. It is therefore important that waste is collected from all sources as efficiently as possible, and disposed of in controlled disposal facilities. In the context of urban development, waste management at landfill sites is considered a bulk service and will not be discussed in any detail. As there are a number of existing disposal facilities in operation, it is necessary to understand the importance of proper disposal and the influence of landfill sites on the service provided and the community as a whole. The level of service is dependent on financial inputs and can therefore vary. There is, however, a basic level of waste management that needs to be provided to all communities. These guidelines should assist authorities to achieve this basic level and also provide some information to enable standards to be upgraded.

The waste cycle

As waste management comprises many variable and interrelated components, it is important to understand the waste cycle and that when one component of the system changes, it invariably affects other parts of the system.
• recycling agencies;
• entrepreneurial development;
• education of the community;
• secure markets; and
• economic viability.

Disposal

With landfilling being the final step in the waste management cycle, consideration should be given the method used (i.e. baling) which would

• reduce cover material requirements;
• reduce both wind-blown litter and vermin;
• reduce leachate production; and
• influence the type of landfill equipment needed on the site.

It is therefore important to consider the implications prior to implementation, if sustainability of the service is to be achieved.

SOUTH AFRICAN SCENARIO

History

A formal waste collection service was first implemented in the Cape Colony in 1786, and by the 1820s a regular waste collection service on specific days of the week, using animal-drawn carts, was established.

It was only in the 1920s, with the advent of motor vehicles in South Africa, that the advantages of mechanical transport could be tested. The first trucks used for refuse collection were able to replace a number of carts with a significant cost saving and the advantage of easier supervision.

Social revolution

The rapidly changing socio-political situation has meant that traditional mechanised methods of collection have had to be rethought to adapt to the changing times. Rapid urbanisation, population growth and the ability of people to pay for the service are major influencing factors. Improvements in community health and demands for a better service, coupled with environmental concerns, are factors that significantly impact on waste management.

Mix of well-developed and poorly-developed areas

Population influx has created many informal and congested pedestrian-only settlements in open spaces and on the peripheries of towns and cities. This has provided the authorities responsible for waste management in South Africa with new challenges.

To integrate well-developed and poorly-developed areas, engineers and town planners need to provide innovative and cost-effective methods of waste collection, while maintaining a standard acceptable to both the community and the environment. This integration has created a new platform where the involvement of the communities in planning waste management systems is crucial, if sustainability and acceptance of the system are to be achieved.

Demand for land

Influx and rapid urbanisation, plus social and political pressures, have put land at a premium in the city and town areas. A city landfill once thought of as being an acceptable distance from suburban housing now sits cheek by jowl with generally low-income - but politically vocal and influential - communities. The search for acceptable disposal sites within an economically viable radius of collection operations, becomes more and more problematic. Public participation and consultation is therefore of the utmost importance.

Social upliftment and empowerment in underprivileged areas

With about half the potentially economically active population unemployed, there is increased pressure on authorities to couple the delivery of social services with increasing elements of job creation. Labour-intensive - rather than mechanised - methods are positively encouraged by central government and this form of collection is rapidly becoming the norm rather than the exception, as it provides entrepreneurial opportunities and job creation in an activity where there are no serious technical or financial barriers to entry. The government’s privatisation policy further encourages this pattern, but the demand for higher wages and career opportunities must mean that “old technology” must incorporate modern methods of cost control, efficiency and planning in order to provide a cost-effective service.
Public perceptions

The concept of waste management is generally understood by most citizens of South Africa. Discussions with residents in both formal and informal settlements from Slovoville west of Johannesburg to Mandela Village east of Pretoria, and as far afield as Emondlo in northern KwaZulu-Natal and Phuthaditjhaba in the Free State, highlighted the need for a regular collection service and adequate on-site storage facilities. There is also a huge plea for help from most communities to educate and assist them in understanding the fundamental principles of waste management.

Legislation

It is vital that the local authority, including its representatives and community leaders as well as the service provider or contractor, be familiar with all legislation regarding waste management. This is necessary to ensure that, regardless of the level of service implemented, an affordable and environmentally acceptable standard is achieved.

<table>
<thead>
<tr>
<th>Table 11.1: Current South African legislation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ACT</strong></td>
</tr>
<tr>
<td><strong>Environment Conservation Act 73 of 1989</strong></td>
</tr>
<tr>
<td><strong>Water Act 54 of 1956 (certain sections still in effect at time of writing)</strong></td>
</tr>
<tr>
<td><strong>Health Act 63 of 1977</strong></td>
</tr>
<tr>
<td><strong>Atmospheric Pollution Prevention Act of 1965</strong></td>
</tr>
<tr>
<td><strong>Occupational Health and Safety Act 85 of 1993</strong></td>
</tr>
</tbody>
</table>
WASTE CATEGORIES

Waste by definition can be described as any matter - whether gaseous, liquid or solid - originating from any residential, commercial or industrial area, which is superfluous to requirements and has no further intrinsic or commercial value.

Domestic and household waste

Domestic and household waste comes mainly from residential areas and may include foodstuffs, garden waste, old clothing, packaging materials such as glass, paper and cardboard, plastics, and, in certain cases, ash.

Business and commercial waste

Business and commercial waste from offices, stores, and schools consists mainly of packaging materials such as glass, paper and plastics, cans, etc, with a limited quantity of foodstuffs emanating from hotels and restaurants. Where smaller industries are dispersed among normal commercial operations, regular monitoring is necessary to identify the need for special collection and disposal procedures.

Sanitary waste

Although not considered part of the general waste stream, if no proper sanitation system exists arrangements for the controlled removal and disposal of sanitary waste must be provided for (see Chapter 10 on Sanitation).

Non-hazardous industrial waste

Non-hazardous industrial waste (excluding mining waste) generally consists of a combination of commercial waste and discarded metal, timber, plastic and textile offcuts. With the majority of industries placed within municipal boundaries, careful identification of these wastes to ensure that proper disposal procedures are followed is important, particularly where chemical processing is apparent.

Construction waste

Construction waste generally consists of inert materials such as rubble and bulky construction debris. If mixed with household waste it attracts rodents, which can constitute a health risk, but it is generally considered more of an aesthetic problem. Removal of this material can in some instances require specialised equipment.

Hospital and medical waste

Waste from hospitals is generally separated at source. The general component is collected with normal domestic refuse. The medical component, consisting of body tissue, discarded syringes, swabs and contaminated material, is normally incinerated on site or collected by specialist private concerns. With smaller clinics and doctors’ rooms, where the risk of accidents is no less, special arrangements for the collection and disposal of contaminated waste is essential. Mini-incinerators are also commercially available.

Hazardous and toxic waste

Due to the complexity of identifying the proper handling and disposal procedures, hazardous and toxic waste is generally the domain of specialist operators. It is, however, important that industries producing hazardous and toxic substances are identified and monitored to ensure that proper procedures are followed.

ON-SITE STORAGE

Inadequate on-site storage and collection systems account for the bulk of illegally dumped refuse in a large percentage of developing communities. The method of on-site storage thus has a significant effect on the collection system to be implemented (see Figure 11.3). It is important to plan and decide on the appropriate means of on-site storage in conjunction with transport options before implementing any system.
### Description

<table>
<thead>
<tr>
<th>Description</th>
<th>Common Usage</th>
<th>Collection Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>85 litre plastic bin liners</td>
<td>Domestic/household, Small business &amp; industry, General public amenities</td>
<td>By hand on-site or on sidewalk. Liners deposited directly into collection vehicle.</td>
</tr>
<tr>
<td>85 litre rubber/galvanised steel bins</td>
<td>Domestic/household, Small business &amp; industry, General public amenities</td>
<td>By hand on-site or on sidewalk. Bins emptied directly into collection vehicle.</td>
</tr>
<tr>
<td>120/240 litre mobile refuse bins</td>
<td>Domestic/household, Small business &amp; industry, General public amenities</td>
<td>Rear-end loading compactors with special lifting equipment.</td>
</tr>
<tr>
<td>1,0 and 1,2 m³ mobile refuse containers</td>
<td>Small business and industry</td>
<td>Rear-end loading compactors with special lifting equipment.</td>
</tr>
<tr>
<td>4.5, 5,5, 6, 9 &amp; 11.0 m³ bulk containers</td>
<td>Large business &amp; industry, garden refuse, building rubble, general public amenities &amp; bulk wastes and communal collection systems</td>
<td>Load luggers. Rear-end loading compactors with special lifting equipment.</td>
</tr>
<tr>
<td>15 to 30 m³ open bulk containers</td>
<td>Large business &amp; industry, garden refuse, building rubble &amp; bulk wastes and communal collection systems</td>
<td>Roll-on roll-off vehicles.</td>
</tr>
<tr>
<td>11, 15 &amp; 35 m³ closed containers</td>
<td>Large shopping centres, transfer stations &amp; selected industries</td>
<td>Roll-on roll-off vehicles.</td>
</tr>
</tbody>
</table>

*Figure 11.3: On-site storage options*
WASTE COLLECTION

Local authorities are responsible for ensuring that a service is provided to the communities they serve. Collection can be done by the local authority, a conventional contractor, or an emerging entrepreneur. Several factors therefore need to be considered when selecting the appropriate waste management approach for a particular community, all of which will influence the waste handling and disposal options. These factors include:

1. Affordability
   - capital and operational costs;
   - level of income within the community; and
   - grants or subsidies available.

2. Accessibility
   - road infrastructure and conditions.

3. Level of education
   - literacy and awareness of the community to understand the principles of waste management.

4. On-site storage facilities
   - availability and suitability; and
   - composition and volume of the waste.

5. Potential benefits
   - clean and healthy environment; and
   - job creation and upliftment.

6. Available facilities and infrastructure
   - appropriate vehicles; and
   - available expertise.

7. Distance to disposal site
   - transfer facility requirements.

8. Pollution potential
   - blocked sewers and stormwater canals; and
   - illegal dumping and littering.

Collection systems

Many innovative or alternative collection systems have been attempted in South Africa, where collected waste is exchanged for food, or financial reward is made for bags collected. These have, in the main, been financed through grants or sponsored by various agencies and can therefore not be regarded as sustainable services, but rather as a process of education which should be supplemented by an effective collection system.

Communal collection

Communal collection is generally considered an option in poorly developed areas where the householders or entrepreneurial contractors are required to place the waste in strategically positioned containers for collection and disposal by large motorised refuse vehicles.

Door-to-door collection

Door-to-door collection can be carried out in two ways:

(a) the collection crew removes the waste container from the premises and returns it after it is emptied into the collection vehicle; and

(b) the householder places his or her refuse containers on the sidewalk, ready for collection by the collection crew, and retrieves them after collection.

It is important to understand that flexibility of refuse collection is an important factor in today’s urban development. Although it is understandable and logical that an efficient mechanical system of collection can evolve in a conventional suburban environment, this method may be totally inappropriate for highly dense, congested settlements that have mushroomed on the fringes of local authority areas. Now, more than ever, administrators and engineers are faced with a dilemma: capital-intensive solutions that were well justified a few short years ago, are becoming obsolete and inappropriate less than halfway through their amortisation period. The norm, for the next decade at least, will be to have a mix of old and new technology and the ability to integrate both systems to maximise economic advantage.

Collection vehicles

There are several options available for transporting collected waste for disposal, ranging from the basic hand cart to the technically sophisticated and motorised front- and rear-loading compaction vehicles. All options have a place in providing an effective collection service in the varied and mixed development areas currently faced by engineers and administrators. Careful consideration of the local road conditions, accessibility and topography - in conjunction with town planners - of the area to be serviced is needed before selecting any one of the options (see Chapters 5 and 7).
GUIDELINES FOR HUMAN SETTLEMENT PLANNING AND DESIGN

Chapter 11

Solid waste management

Figure 11.4: Refuse collection and transport options

Push cart
Tip truck
Animal-drawn cart
Load lugger (skip loader)
Tractor-trailer
Rear-end loader
Flat-bed truck
Roll-on roll-off
The graphs below give an indication of vehicle requirements based on the relationship between distance to landfill / transfer station and number of households.

1. 0.12 m³ of waste per household per week
2. Average speed 40 km/h

Figure 11.5: Graphs of vehicle requirements
Should more than one option be considered, it is equally important to identify how they will complement each other to eliminate the need for radical changes as the development progresses. The type of vehicle selected will also depend on the waste composition, as high-density waste (high ash content) will not require compaction. The relationship between payload and distance to the landfill or transfer station must also be considered. Table 11.2 gives some indication of the capital cost of the various options.

The options for transport are the following:

**Hand cart**

Hand carts, although not commonly used in South Africa, can be designed for specific applications. These may include small informal communities with no planned or designed road infrastructure, and even planned developments during the early stages where occupancy does not warrant sophisticated equipment, particularly in what can be considered the lower income groups. Although limited in carrying capacity, hand carts can be effectively employed where job creation and limited capital expenditure are the main considerations.

The use of hand carts has the advantage of not only providing more employment opportunities within the community due to the relatively small areas of responsibility of the operator, but also of combining street cleaning with normal refuse collection. The main disadvantage is that they would need to be supplemented with a communal bin system and the appropriate vehicle for final disposal.

**Animal-drawn cart**

Animal-drawn carts are also not commonly used in South Africa, yet have similar applications to the hand cart. The only significant difference is that the area of responsibility can be increased due to a relatively larger carrying capacity. A disadvantage is that animal-drawn carts can only be used if a community-based waste collection system is implemented and the “contractor” has his own choice of transport. Should the disposal facility be within a practically attainable distance, the need for support facilities could also be eliminated, provided access via freeways is not required.

**Tractor and trailer**

The tractor and trailer, although not the first, was probably the most common means of mechanical transport for waste collection prior to the introduction of compaction units, and can still be effectively utilised in most developed and undeveloped areas. The variations and combinations available are numerous and must be carefully assessed prior to implementation. The tractor-trailer combination can be operated where road conditions are not suitable for trucks, but is limited to a maximum 10 kilometre distance to the disposal facility, provided access via freeways is not required.

**Flat-bed truck**

The flat- or open-bed truck is not commonly used in South Africa. It has the disadvantage of a high loading height, particularly for use in developing areas where the high ash content of the collected waste results in increased mass of the container.

---

**Table 11.2: Capital cost of transport and collection options (1996)**

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>UNIT</th>
<th>TRACTOR</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 m³ half pack fel</td>
<td>348 500</td>
<td>400 000</td>
<td>748 500</td>
</tr>
<tr>
<td>19 m³ F5000 rel</td>
<td>207 000</td>
<td>400 000</td>
<td>607 000</td>
</tr>
<tr>
<td>20,6 m³ HC250 rel</td>
<td>175 600</td>
<td>400 000</td>
<td>575 600</td>
</tr>
<tr>
<td>12 ton roll-on roll-off</td>
<td>111 000</td>
<td>400 000</td>
<td>511 000</td>
</tr>
<tr>
<td>8 ton roll-on roll-off</td>
<td>85 000</td>
<td>400 000</td>
<td>485 000</td>
</tr>
<tr>
<td>12 ton skip</td>
<td>66 700</td>
<td>400 000</td>
<td>466 700</td>
</tr>
<tr>
<td>8 ton skip</td>
<td>64 700</td>
<td>340 000</td>
<td>404 700</td>
</tr>
<tr>
<td>10,5 m³ M160 rel</td>
<td>110 000</td>
<td>250 000</td>
<td>360 000</td>
</tr>
<tr>
<td>20 m³ gravity pack</td>
<td>68 200</td>
<td>250 000</td>
<td>318 200</td>
</tr>
<tr>
<td>13 m³ gravity pack</td>
<td>33 400</td>
<td>250 000</td>
<td>283 400</td>
</tr>
<tr>
<td>aim refutip 20 m³</td>
<td>145 000</td>
<td>100 000</td>
<td>245 000</td>
</tr>
<tr>
<td>dome trailer 12 - 15 m³</td>
<td>60 000</td>
<td>100 000</td>
<td>160 000</td>
</tr>
<tr>
<td>power system</td>
<td>40 000</td>
<td>100 000</td>
<td>140 000</td>
</tr>
<tr>
<td>motorised tricycle</td>
<td></td>
<td></td>
<td>40 000</td>
</tr>
<tr>
<td>hand cart max 1,2 m³</td>
<td></td>
<td></td>
<td>750</td>
</tr>
</tbody>
</table>
Waste must also be covered during transport to prevent further environmental nuisance.

**Tip-pack**

The tip-pack is the forerunner of the rear-end loader. With the tip-pack, the weight of the refuse is used for compaction and normally has a capacity not exceeding 10 m$^3$. Trailers with similar applications have since been developed for use with tractors.

**Rear-end loaders**

Rear-end loaders are available in sizes varying from 10 m$^3$ to 21 m$^3$, and have a relatively advanced compaction system allowing a compaction ratio of up to 4:1. This high compaction ratio and carrying capacity, with the versatility of being capable of handling containers up to 6 m$^3$, has made the rear-end loader the most popular and commonly used collection vehicle in developed areas. This is particularly so where volumes are high and distances to disposal facilities are in excess of 10 km. The main disadvantages of using the rear-end loader are relatively high maintenance costs, and that they can only be effectively used where good road infrastructures are in place. Legal payloads need to be monitored in the event of high-density wastes, to prevent a negative impact on the road infrastructure.

**Load luggers**

The load lugger is a special application vehicle and limited to container applications. The most common application is the handling of bulk containers from industries and large businesses, communal collection systems and the removal of builders rubble from construction sites.

**Roll-on roll-off**

Roll-on roll-off vehicles are specially designed vehicles with very specific applications. They are mainly used for the transportation of large-capacity open or closed compacted containers ranging from 18 m$^3$ to 30 m$^3$.

**Rail**

Rail has only recently become an option in waste management, particularly where the pressures of urban development have dictated that landfills need to be positioned further from the source of waste generation.

**STREET CLEANING**

Wind-blown litter and illegal dumping of uncollected waste are probably the most visible aspects of poor waste management within any community and one that unfortunately receives the least attention, particularly in newly developed communities. If not controlled, these become major contributors to blocked stormwater drains and sewers, often the main cause of complaints within communities. Street cleaning is unfortunately an unrecoverable cost but a necessary component of the waste collection service that needs to be provided, and should be budgeted and planned for in any collection system (see also the section on street cleaning in Chapter 6: Stormwater Management).

**TRANSFER STATIONS/SYSTEMS**

A transfer station is a facility for transferring waste from the collection vehicle to a more appropriate vehicle where longer haul distances are necessary for final disposal. The purpose is to reduce not only the transport unit cost of collection vehicles, and obtain more cost-effective payloads, but also to allow quicker turnaround times and therefore increased productivity.

The need for a transfer station and the degree of sophistication required will be determined by the volume of waste generated, the collection system implemented, and the distance to the disposal site.

A transfer station can be designed to operate at various levels of sophistication:

- depositing the waste into containers of various capacities for specially designed vehicles, commonly used in communal waste-collection systems and garden-refuse sites;
- depositing the waste onto a suitably designed platform for either mechanical or manual loading into the long-haul vehicle;
- depositing directly into the long-haul vehicle; and
- depositing the waste into large compacting units for transporting by specially designed vehicles.

Transfer stations can be considered the final disposal point by the community, particularly where communal collection services are in operation. Communal disposal facilities, where open bulk containers are utilised, therefore need to be managed and controlled with the same care and responsibility as that required for a landfill site.
Location

The location of communal disposal points must be selected with sensitivity and careful planning to ensure accessibility and acceptance by the community, and not to interfere with pedestrian movement, or create an eyesore, or a public nuisance of dust and odour. Refer also to Chapter 5.

The larger or more sophisticated transfer station systems should be located with equally careful planning. Easy access to trunk routes and minimal conflict with future development are some of the more important considerations.

Other aspects often not considered in locating transfer stations and landfill sites, particularly in large operations, are traffic densities and road design. It is important that the requirements of both the local and provincial authorities are complied with, particularly in respect of paving design as well as visibility and traffic flow at intersections and access roads. Refer also to Chapters 7 and 8.

RECYCLING

Recycling means the remanufacturing of recovered materials, as opposed to re-use where the recovered product is simply re-used for similar purposes, e.g. beverage bottles.

The increasing pace of life in South Africa’s developed commercial and industrial areas, particularly in the larger cities, reflects an increasing demand on the individual’s time - both in work and leisure activities. These demands have changed consumption needs, which in turn have led to an increase in discarded goods and packaging.

Aim

The ultimate aim of recycling is the protection of the environment and public health by reducing the ever-increasing volumes of waste being generated by developing societies, as well as reducing the amount of natural resources necessary for the manufacture of any product.

History

Despite several million rands having been spent on sophisticated recycling plants, the history of recycling on a large scale in South Africa has not been particularly successful. There has been reasonable success in certain regions, with organisations such as Collect-a-Can, Nampac, Sappi, Mondi and Consol Glass concentrating mainly on beverage cans, paper, plastics and glass. Voluntary recycling and small buy-back centres have met with some success, which is generally dependent on the user-friendliness of the scheme.

Markets

The success of recycling is largely dependent on the market availability of both the raw product and the remanufactured product, and unfortunately they have a direct effect on each other. As waste cannot be considered recycled until it is reprocessed, these markets have achieved little more than providing subsistence levels for the individual entrepreneurs.

Education

Education in the principles and effect of waste minimisation and recycling is a critical part of the waste management process. The process of education will no doubt be slower in developed communities, where new attitudes need to be cultivated. The opportunities for success are far greater in newly developed communities if proper planning and educational programmes are an integral part of the collection system.

DISPOSAL

All communities, regardless of size and location, will need to make provision for the final disposal of collected refuse. To ensure environmental acceptability the Department of Water Affairs & Forestry (1994) has produced the document Minimum Requirements for Waste Disposal by Landfill. It is important to understand that, should no registered landfill site be available, a permit for disposal based on the “minimum requirements” will be enforced as required under Section 21 of the Environment and Conservation Act (Act 73 of 1989).

### Table 11.3: Landfill classification

<table>
<thead>
<tr>
<th>LANDFILL SIZE</th>
<th>MAX. RATE OF DEPOSITION (tons per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communal</td>
<td>Less than 1</td>
</tr>
<tr>
<td>Small</td>
<td>Greater than 1; less than 25</td>
</tr>
<tr>
<td>Medium</td>
<td>Greater than 25; less than 500</td>
</tr>
<tr>
<td>Large</td>
<td>Greater than 500</td>
</tr>
</tbody>
</table>

Landfill site classification

The volume and content of the waste to be disposed of will dictate the size and classification of the landfill, and necessary requirements for licensing purposes. There are generally only two distinct types of landfill:

- general waste landfills (G) for waste normally produced within residential and business communities, with the exception of hazardous or toxic wastes; and
• hazardous waste landfills (H) for waste which has the potential to have adverse effects on both public health and the environment, even in small quantities, due to its inherent chemical and physical qualities.

The process of developing any landfill site requires the local authority or private concern to conduct an investigation as to whether it complies with the minimum requirements under Section 4 (Site selection) of the above document provided by the Department of Water Affairs & Forestry. Should the results of these investigations meet with the Department’s approval, it will be necessary for the developer to obtain a permit to develop and operate the landfill facility, based on further requirements outlined in Section 5 (Permitting) of the same document.

**INCINERATION**

With large open tracts of land still available and the high capital cost of this option, waste incineration on a large scale has not yet been considered a viable alternative in South Africa. The demand for land, however, and the need to protect our limited groundwater resources, suggests that alternative solutions to landfilling need to be investigated.

As a possible alternative energy resource, with job-creating potential for developing communities, the option of incineration as an alternative to landfilling must be given consideration in any future waste management planning strategies, with due regard to prevailing air-quality standards.
### Table 11.4: Minimum requirements for landfill sites

<table>
<thead>
<tr>
<th>LEGEND</th>
<th>C</th>
<th>S</th>
<th>M</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>B⁻ No significant leachate produced</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>B⁺ Significant leachate produced</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>N Non-requirement</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>F Special consideration to be given by departmental representative</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MINIMUM REQUIREMENTS / CATEGORY</th>
<th>B⁻</th>
<th>B⁺</th>
<th>B⁻</th>
<th>B⁺</th>
<th>B⁻</th>
<th>B⁺</th>
<th>B⁻</th>
<th>B⁺</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appoint responsible person</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Classify proposed landfill site</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Eliminate areas with fatal flaws</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Identify candidate landfill sites</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Buffer zone</td>
<td>200m</td>
<td>200m</td>
<td>500m</td>
<td>500m</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>Minimum unsaturated zone</td>
<td>2m</td>
<td>2m</td>
<td>2m</td>
<td>2m</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>Rank sites as indicated</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Site feasibility study</td>
<td>N</td>
<td>N</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Site description</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Complete permit application form</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Preliminary geohydrological investigation</td>
<td>N</td>
<td>N</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Preliminary environmental impact assessment</td>
<td>N</td>
<td>N</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Identify critical factors</td>
<td>N</td>
<td>N</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Assess critical factors</td>
<td>N</td>
<td>N</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Confirm no fatal flaws</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Consult interested and affected parties</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Confirm best site</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Compile and submit feasibility report (including maps)</td>
<td>N</td>
<td>N</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Department of Water Affairs &amp; Forestry confirmation of feasibility</td>
<td>N</td>
<td>N</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
</tbody>
</table>
### Table 11.5: Minimum requirements for permitting a landfill site

<table>
<thead>
<tr>
<th>LEGEND</th>
<th>( C )</th>
<th>( S )</th>
<th>( M )</th>
<th>( L )</th>
</tr>
</thead>
<tbody>
<tr>
<td>B⁻ No significant leachate produced</td>
<td>B⁻</td>
<td>B⁻</td>
<td>B⁻</td>
<td>B⁻</td>
</tr>
<tr>
<td>B⁺ Significant leachate produced</td>
<td>B⁺</td>
<td>B⁺</td>
<td>B⁺</td>
<td>B⁺</td>
</tr>
<tr>
<td>R Requirement</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>N Non-requirement</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>F Special consideration to be given by departmental representative</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
</tr>
</tbody>
</table>

#### MINIMUM REQUIREMENTS / CATEGORY

- Appoint responsible person: R R R R R R R R
- Confirm site classification: R R R R R R R R
- Landfill permit: R R R R R R R R
- Deal with department's regional office: R R R R R R R R
- Deal with department's head office: N N N N N N N N
- Permit application form: R R R R R R R R
- Site demarcated on a map: R R R R R R R R
- Site visit by state departments: F F F F R R R R
- Full permit application report: N N N F R R R R
- Feasibility study report: N N N R R R R
- Geohydrological investigation report: N N R R R R R R
- Geological investigation report: N N R R R R R R
- Environmental impact assessment: N N N R R R R R R
- Environmental impact control report: N N N R R R R R R
- Landfill conceptual design: R R R R R R R R
- Landfill technical design: N N N R R R R
- Approval of technical design by department: N N N R R R R
- Development plan: R R R R R R R R
- Operation and maintenance plan: R R R R R R R R
- Closure/rehabilitation plan: R R R R R R R R
- End-use plan: N N R R R R R R
- Water quality monitoring plan: N N R R R R R R
- Amend title deed to prevent building development on closed landfill: N N R R R R R R
- Report change of ownership: R R R R R R R R
- Site inspection prior to commissioning: N N N N R R R R

**Legend**

- B⁻: No significant leachate produced
- B⁺: Significant leachate produced
- R: Requirement
- N: Non-requirement
- F: Special consideration to be given by departmental representative
- C: Communal landfill
- S: Small landfill
- M: Medium landfill
- L: Large landfill
- B⁺: Significant leachate produced
LEVELS OF SERVICE

For any collection service to be truly effective all waste must be removed completely from all storage and collection points. This, however, has many practical and cost implications. It is therefore important to establish a minimum standard that is acceptable and affordable by the community, based on the on-site storage facilities provided, the frequency of collection and the effectiveness of the service provided. All levels of service are therefore based on the premise that the local authority provides the necessary guidance and a minimum collection/removal service at least once a week rendering an acceptable level of cleanliness within the community.

There are many permutations in providing a waste collection service within the current South African scenario. Particular thought and attention should be given to the mix of levels of service and cost-effective options of servicing the Phase 1 disposal points (see Figure 11.6).

**Level 1**

This first level of service can be considered the minimum, where the residents are required to deliver their waste to specifically allocated communal disposal points (Phase 1 disposal). These disposal points could be specially designed masonry structures with embankments, or ready-made containers strategically placed. Should the option of fixed structures be selected, these would need to be cleared either by manual labour or mechanical means and the waste transferred to suitable vehicles for transport to the disposal site. The container option allows the use of either rear-end loader or special application vehicles that have the capability of lifting and transporting the containers in use.

**Level 2**

This level of service requires the local authority to provide for the collection of refuse from each household by the cheapest possible means (i.e.
wheelbarrow or handcart). Refuse is collected from site or from the kerbside and transported to the nearest or designated communal disposal point.

**Level 3**

This level of service can be considered a natural progression from Level 2. The collection agent has the option of making use of animal-drawn carts or motorised tricycles, allowing for a larger area of responsibility. Where the landfill is considered to be an economically viable distance from the collection area, the need for Phase 1 disposal points may be eliminated, provided access via freeways is not required.

**Level 4**

This level of service can be considered a progression from Level 3, where the collection agent has the option of using mechanical means for transporting the collected refuse; depending on the terrain, this could be in the form of tractor-trailer or suitable light delivery vehicle. Again, should the landfill be considered an economically viable distance from the collection area, the need for Phase 1 disposal can be eliminated.

**Level 5**

This level of service can be considered the optimum means of collection in the majority of developed communities. The waste is collected from site or the kerbside by means of specially designed collection compactor vehicles and transported directly or via transfer station to point of final disposal.

**GUIDELINES FOR IMPLEMENTATION OF LEVELS OF SERVICE**

Levels of service 1 through 4 would as a rule only be implemented in conjunction with community-based programmes, or entrepreneurial development programmes in relatively small and developing communities. This, however, does not preclude their application in developed communities and elsewhere, or in combination with Level 5.

Table 11.6 provides some indication of the application, responsibility and conditions that need to be identified prior to implementation.

**Quantity and composition**

Proper and accurate estimation of the quantities and composition of the waste stream is an important aspect of the waste management system, as over- or under-estimation can result in either incorrect vehicle selection, shortened landfill life or increased costs.

The standard method of reporting waste generation is in terms of mass - this is necessary for proper vehicle selection. However, weight data are of limited value in designing landfills and selecting storage containers, which are identified by volumetric measurement. Volumetric measurement of the waste does, however, depend on how much the waste has been compacted and its density.

There are two methods for determining waste-generation rates:

*Load count analysis or weight volume analysis*

- A specific area of collection is selected and the number of individual loads, corresponding vehicle volumes and characteristics, and the weight of each load are recorded over a specified period of time.

*Materials balance analysis*

- Identify a system boundary.
- Record all activities that cross and occur within the boundary, which affect the waste generation rate.
- Identify and record the rate of generation associated with these activities.
- Identify and record the composition of the waste generated within the boundary.

**Collection-route balancing and planning**

Once the quantity of waste needing collection is determined, it is important to plan collection routes to ensure a productive and economical service. This can be done by obtaining a map or plan of the area in order to identify the following:

- all service points;
- all one way streets;
- any culs-de-sac; and
- areas that do not require a service.

Areas of daily collection should be compact and not fragmented and, where possible, natural boundaries should be used. Collection routes should be planned to maximise vehicle capacities. For the convenience of householders it is preferable to maintain a regular routine, to ensure their waste is ready for collection.
### Table 11.6: Guide to responsibilities and conditions

<table>
<thead>
<tr>
<th>LEVEL OF SERVICE</th>
<th>COMMUNITY</th>
<th>LOCAL AUTHORITY (and/or appointed agent)</th>
<th>CONDITIONS</th>
<th>DESCRIPTION</th>
<th>REQUIREMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 1</strong></td>
<td>Residents</td>
<td>Community liaison</td>
<td>No formal road infrastructure Maximum distance to disposal point ±200 m</td>
<td>Containers (minimum 1 per ±50 households)</td>
<td>Dependent on waste volumes Dependent on frequency of service (Phase 1 disposal)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Collect waste from disposal point Maintenance of disposal point Environmental awareness programmes</td>
<td>Transport vehicles</td>
<td></td>
<td>Dependent on distance to landfill (see graphs)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Litter prevention</td>
<td></td>
<td>Hand carts</td>
<td>Dependent on community-based programme</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Delivery of waste to disposal point</td>
<td></td>
<td>Containers (minimum 1 per ±50 households)</td>
<td>Dependent on waste volumes Dependent on frequency of service (Phase 1 disposal)</td>
</tr>
<tr>
<td></td>
<td>Hand carts</td>
<td></td>
<td></td>
<td>Transport vehicles</td>
<td>Dependent on distance to landfill (see graphs) Dependent on frequency of service</td>
</tr>
<tr>
<td></td>
<td>Animal-drawn carts/motorised tricycles</td>
<td>Place waste for collection on kerbside</td>
<td>No formal road infrastructure Maximum distance to disposal point ±1 000 m</td>
<td>Animal-drawn carts/Motorised tricycles</td>
<td>Dependent on community-based programme</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Community liaison</td>
<td>Limited road infrastructure Maximum distance to disposal point ±3 000 m Allowable road ordinance conditions</td>
<td>Containers (minimum 1 per ±50 households)</td>
<td>Dependent on waste volumes Dependent on frequency of service (Phase 1 disposal)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Collect waste from kerbside Collect waste from site (where necessary) Collect waste from disposal point Maintenance of disposal point Litter collection Environmental awareness programmes</td>
<td>Transport vehicles</td>
<td></td>
<td>Dependent on distance to landfill (see graphs)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Litter prevention</td>
<td></td>
<td>Tractor-trailer combinations/LDV's</td>
<td>Dependent on community-based programme</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Community liaison</td>
<td>Limited road infrastructure Maximum distance to disposal point ±10 km Allowable road ordinance conditions</td>
<td>Containers (minimum 1 per ±50 households)</td>
<td>Dependent on waste volumes Dependent on frequency of service (Phase 1 disposal)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Collect waste from kerbside Collect waste from site (where necessary) Collect waste from disposal point Maintenance of disposal point Litter collection Environmental awareness programmes</td>
<td>Transport vehicles</td>
<td></td>
<td>Dependent on distance to landfill (see graphs)</td>
</tr>
<tr>
<td><strong>Level 5</strong></td>
<td>Rear-end loaders</td>
<td>Place waste for collection on kerbside</td>
<td>Allowable road ordinance conditions Proper road infrastructure</td>
<td>Transport vehicles</td>
<td>Dependent on waste volumes Dependent on frequency of service Dependent on distance to landfill (see graphs)</td>
</tr>
</tbody>
</table>
Detailed routing of collection vehicles can be planned for collection from both sides of the street or from one side only. Collection from one side only is preferable in business areas and areas with high traffic densities, to avoid conflict with traffic patterns and the safety of the workers. Figure 11.7 provides examples of collection-route alternatives.

**CONCLUSION**

Waste management in the changing societies in South Africa is a dynamic process, in terms of both collection and disposal. It is the responsibility of the local authority to ensure the service is provided to its communities. Town and city engineers therefore need to be vigilant in identifying changes, and be innovative in making the service affordable, while meeting the standards expected by these communities.

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SCOPE
These guidelines cover aspects that need to be considered for the optimum planning and designing of electricity supply systems for residential townships, including developing communities.

INTRODUCTION
This section provides electricity layout planners with the required background to effectively follow the correct steps to achieve optimal design. It describes the approach to “greenfield” projects with reference to the information, resources and documentation available to assist the planner/designer. Original content is kept to a minimum and there is effective referencing to established documents with explanatory notes where necessary. The guidelines are written with low technical content to maximise ease of reading and practical application.

NOTE: Reference materials are continually being updated to match developments in technology. The use of typical analytical software tools is described and substantiated with practical examples.

Special attention is given to the methods that can be used to estimate After Diversity Maximum Demand (ADMD) figures and the ADMD vs consumer classification relationships.

Details regarding the method that should be followed when optimising an electrical layout and technology selection are given. Practical tips on service connection strategies and recommendations on the voltage drop calculation method are given.

(See Appendix A for lists of reference documents).

PLANNING OVERVIEW
Role of planning
Planning is vitally important to ensure the optimal application of technology and to achieve the required quality of supply. Planners have to consolidate and validate the information received from marketing surveys. Using the information at hand, a selection of technology (voltages and ratings) and its application (layout and configuration of network) must be decided upon. A strong feedback system is required to ensure that the as-built status of the network is in accordance with the plan. The planner is responsible for ensuring that future upgrades are properly planned and optimised.

Experience has shown that it is best to plan the development of an area in phases. The area will have an initial plan and a future envisaged masterplan. The implementation of the masterplan in phases is known as a “phased implementation plan”. The terms “master plan”, “initial plan” and “phased implementation plan” are used in the text.

Initial plan
It is unlikely to be economically feasible to implement the master plan immediately, and an initial plan that caters for expected network loading after five to seven years must be implemented first. The objective is to delay capital expenditure for as long as possible to reduce life cycle costs, while maintaining an acceptable quality of supply.

Master plan
The master plan layout refers to the long-range plan for the area (based on the expected loading after 20 years), using the optimised technology. The objective of master planning is to ensure upgradability and optimised long-term infrastructure development.

TERMS AND DEFINITIONS
A glossary of terms used in the planning and design of electrical distribution systems is given in the National Rationalised Specifications NRS 034-Part 0. A few terms have been extracted and adapted for ease of reading in the context of this chapter. Definitions are listed below in alphabetical order.

After diversity maximum demand (ADMD)
The simultaneous maximum demand of a group of homogeneous consumers, divided by the number of consumers, normally expressed in kVA.

Thus the ADMD of N consumers is:

$$ADMD(N) = \frac{MD(N)}{N}$$

This value generally decreases to an approximately constant value for 1 000 or more consumers and has therefore been chosen as a convenient reference value. (Practically no difference in ADMD exists between 100 and 1 000 consumers.)

ADMD with no mention of the number of consumers (N) is defined as that representing the ADMD of 1 000 consumers, i.e.

$$ADMD = ADMD(1 000)$$

For customers who have the potential to have a high or very high demand, an individual customer's maximum demand is generally approximately two to three times the ADMD for a group of similar customers. For customers with a limited potential demand, in the very

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low, low, or moderate consumption range, an individual customer’s consumption is typically four to five times the ADMD for a group of similar customers.

**DSP**

A domestic supply point (consumer metering point).

**Intermediate voltage (IV)**

An AC medium voltage in the range 1 000 V to 3 300 V phase-to-phase.

**Intermediate voltage distribution**

Typically a distribution system operating at a nominal AC voltage of 1,9 kV phase-to-neutral, or 3,3 kV phase-to-phase.

**Load factor (LF)**

A ratio of the actual energy supplied (in kWh) over a period divided by the maximum demand in kW over that period, multiplied by the time period selected (i.e. actual energy supplied divided by potential energy supplied). It is always less or equal to unity.

\[
LF = \frac{\text{Actual Energy}}{\text{MD (kVA)} \times PF \times t} \leq 1.0
\]

\[
\text{MD (kW)} = \frac{\text{MD (kVA)}}{PF}
\]

where PF is the power factor.

(See Figure 12.1.1.)

**Low voltage (LV)**

The range of AC voltages up to and including 1 000 V r.m.s. (see SABS 1019:1985 for a full definition).

**Maximum demand (MD)**

The highest averaged electrical demand for a specified period. Typically, 5 to 60 min and 30 min are normally used as these are close to the thermal constant of transformers and lines. (See Figure 12.1.1.)

**Medium voltage (MV)**

The range of AC voltages exceeding low voltage, up to and including 44 kV. (See SABS 1019:1985 for a full definition.)

---

**STATUTORY VOLTAGE LIMITS**

The South African statutory voltage limits for the supply voltage to residential consumers have been summarised from Government Notice No R103 of 26 January 1996, which amended Regulation 9 of the Electricity Act (No 41 of 1987).

This notice stipulates that:

a) for nominal system voltages lower than 500 V, the supply voltage shall be the standard voltage;

b) in the case of a distribution system with a nominal system voltage lower than 500 V, the supply voltage shall not deviate from the standard voltage by more than 10%; and

c) the Board (i.e. The National Electricity Regulator) may on application permit other deviations from the stipulated supply voltage and frequency.

The statutory voltage limits imply that all new networks must conform to the standard voltage of 230 V ± 10% or 253 V maximum and 207 V minimum at the point of supply.

Typically, economic studies indicate the economic apportionment of voltage drop, to meet the statutory limits of 230 V ± 10%, is to aim for an approximately 8% voltage drop on the LV distributor, including service connections. This figure can be increased to 9% or even a bit higher, provided that the regulated busbar is electrically close to the electrification area and steps can be taken to make the LDC (load density classification) of the transformer respond only to the electrification area feeder’s loading.
NOTES

- A further 5% voltage drop is permissible within the customer’s premises (see SABS 0142).
- The assessment method for calculating the voltage from sample measurements is described in NRS 048-part 2.
- The regulated MV busbar must be controlled via LDC setting and electrification area distribution transformer tap positions (if fitted), to maintain at least 230 V during heavy load periods and not exceed 230 V + 10% during light load periods at the MV transformer's LV output.
- Care should be taken to limit the voltage drop in LV service cables near the end of LV distributors to less than 2% (using the appropriate undiversified ADMD), especially where long looped services supply a number of consumers.

ANALYSIS SOFTWARE

The availability of personal computers has led to the development of programs to assist with the analysis of networks. These packages are in some cases available from the market, but also from consultants and the network planning departments of electricity suppliers.

Three types of systems are available: ADMD modelling, low voltage simulation and electricity loss modelling.

ADMD modelling

An After Diversity Maximum Demand modelling approach is based on appliance usage information to calculate the ADMD, maximum demand, energy consumption and monthly electricity costs for any domestic community.

NOTE: This method should be used with extreme caution, because to obtain valid data on appliance availability and usage requires specialist market research.

Low voltage simulation packages

These are low voltage network simulation packages that integrate MV/LV transformer, LV distributor and service cables using per-phase analysis techniques. ADMD figures obtained from other systems are used as input.

Electricity loss modelling

This involves electrification loss-management systems that may be used to monitor system losses for implemented projects, or as design tools during the planning stage to help with network optimisation.

LOAD FORECASTING

Load forecasting impacts on the whole network plan, as well as capital expenditure. Residential township load forecasts focus on ADMD forecasting over a 15- to 20-year period, which reflects the economic life of the plant. ADMD is used for MV/LV transformer sizing and to calculate voltage drop over the LV feeders, service cables and MV/LV transformers.

Final vs initial ADMD

Two ADMD figures should be determined prior to any other analysis work or technology decisions:

- a seven-year (initial) ADMD figure is required to determine the first phase of the future master plan; and
- a master plan ADMD (final) for loads in 15 to 20 years’ time is the major influencing parameter that determines the masterplan settlement layout.

Essential to the viability of the project is the use of a phased upgraded plan that progresses from the initial plan towards the master plan, using the respective ADMD values.

How to estimate ADMD

Three acceptable methods of determining the ADMD figures can be used:

Appliance model

This has an approach or design basis that models domestic appliance behaviour over the peak hour to estimate the appliance’s contribution to the ADMD and the expected energy consumption per appliance per month.

This technique gives the planner the information required to forecast individual energy and demand requirement forecasting for the electrification area, and is the preferred method for ADMD determination.

NOTE: Recent experience with this method indicates that, for customers in the high and very high consumption classes, the consumption can be severely underestimated using this method.

Direct measurement

The ADMD may be determined by measuring the maximum demand of a representative existing suburb over the peak month (typically winter for Johannesburg). The suburb in question must ideally have been electrified for many years to yield the correct ADMD figure. If that suburb was provided with electricity only five years previously then a
five-year ADMD figure will be determined, whereas the aim should be to establish a 20-year ADMD figure.

This method may therefore prove inappropriate for recently electrified suburbs.

Non-residential loads (such as for schools, hospitals and small industries) must be excluded from this measurement exercise to ensure homogeneity (only the peak time contribution of these loads must be subtracted from the overall measured ADMD, to take non-residential diversity into account).

Therefore,

\[ \text{MD}_{\text{residential}} = \text{MD}_{\text{total}} - \text{MD}_{\text{non-residential}} \]

**Energy load factor method**

A further approach is that used where energy sales forecasts are available. The ADMD can be determined by estimating a load factor at suburb level, which is typically between 25% and 45% (if the individual DSP-level load factor is used then the ADMD will be undiversified, i.e. the demand for one DSP would be determined).

Example:

For a suburb the expected 20-year horizon for energy sales is estimated to be 2 400 units per annum, with expected sales of 1 440 units per annum after seven years.

The annual load factor for the township is estimated to be 26% for both time horizons.

Therefore,

\[ \text{ADMD}_{\text{final}} = \frac{\text{kWh}}{\text{LF x h}} = \frac{2 400}{0.26 \times 8 760} = 1.1 \text{ kVA} \]

\[ \text{ADMD}_{\text{seven}} = \frac{\text{kWh}}{\text{LF x h}} = \frac{1 400}{0.26 \times 8 760} = 0.6 \text{ kVA} \]

NOTE: The calculations are more appropriately done over annual periods than monthly periods, because there are significant differences in both consumption and load factor in different months.

**CONSUMER CLASSIFICATION**

**Consumption classification**

Consumers can be divided into classes according to annual consumption and appliance utilisation. NRS 034-1, Table 2, provides guidance for ADMD figures according to broad categories of consumption class. This table is given in Table 12.1.1 below, with annual load factors at suburb level (full diversity) added. These load factors have been derived from the NRS Load Research Project.

The results of investigations to correlate the annual energy consumption of consumers, the major classification characteristics of the consumers and the expected ADMD have been recorded in a report on the NRS Load Research Project, which is continuing. The results have been used to derive the planning parameters set out in the second edition of NRS 034-1.

Consumption classification can be derived from appropriate market research programmes and economic studies for each area to be electrified. This type of work is usually undertaken by consultants with the necessary marketing and engineering background.

\[ \text{ADMD} (N) = \frac{\text{MD}_{\text{residential}}}{\text{DSPs}} \]

provided that DSPs > 100, to allow for full diversity. If DSPs < 100 then adjust the ADMD as shown in Table 12.1.1.

**Load density classification**

Load density (kW/ km²), which is a function of ADMD and stand size, is a very useful aid when selecting technology and calculating voltage drop. Table 12.1.2

<table>
<thead>
<tr>
<th>CONSUMPTION CLASS (SEE 4.3.3.2 OF NRS 034-1)</th>
<th>APPROX. FINAL LOADING AND DESIGN ADMD (kVA)</th>
<th>APPROX. ANNUAL LOAD FACTOR (%)</th>
<th>APPROX. kWh PER ANNUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very high</td>
<td>&gt; 6</td>
<td>&gt; 42*</td>
<td>&gt; 22 000</td>
</tr>
<tr>
<td>High</td>
<td>3 to 6</td>
<td>35 to 42</td>
<td>9 200 to 22 000</td>
</tr>
<tr>
<td>Medium</td>
<td>1.5 to 3</td>
<td>31 to 35</td>
<td>4 100 to 9 200</td>
</tr>
<tr>
<td>Low</td>
<td>0.5 to 1.5</td>
<td>29 to 31</td>
<td>1 200 to 4 100</td>
</tr>
<tr>
<td>Very low</td>
<td>≤ 0.5</td>
<td>28 to 29</td>
<td>&lt; 1 300</td>
</tr>
</tbody>
</table>

* In the very high consumption class, there might be demand-side management techniques, such as the application of ripple control that would influence the load factor.
can be used to select a settlement’s domestic density classification.

PLANNING PROCEDURE

A planning procedure based on an approach agreed upon between municipal engineers and Eskom is set out in NRS 034-1.

The recommended method for calculating voltage drops on LV distributors is to use the Herman beta algorithm described in NRS 034-1. The basis is statistical, and it can be conveniently implemented using spreadsheet software.

Available technologies

Currently available technologies for South African residential areas are:

- Conventional three-phase system with transformation from three-phase medium voltage to three-phase low voltage (e.g. 22/0.4 kV).

- Conventional single-phase system with transformation from medium voltage using two phases to single-phase low voltage (e.g. 22/0.4 kV).

- Intermediate voltage system using three-phase medium voltage source, stepping through two voltage transformations, first to an intermediate voltage and then to low voltage using either single- or three-phase alternatives (e.g. 22/3 kV, 3/0 kV, 4 kV for the three-phase option or 22/1 kV, 9/0 kV, 23 kV for the single-phase option).

- MV/LV maypole system for rural areas. This system usually employs smaller transformer sizes and the low voltage network consists only of service cables (e.g. 220/0.23 kV).

- Single wire earth return (SWER) system for very low loads and remote areas where the earth is used as a return load current path. The SWER line could, for example, be designed to be 22 kV between the ground and the single overhead wire (e.g. 22/0 kV, 23 kV).

Table 12.1.3 indicates the applications of these technologies for various domestic density classifications. For high-density urban applications the conventional three-phase system is the only appropriate one to use. For rural networks any system may be appropriate depending on the local conditions - even conventional three-phase systems may be used on a small scale where high-density pocket load areas are present. Economics will govern the decision-making process.

Planning steps

The following are the recommended steps for each of the selected technologies and their alternatives (test against a single representative sub-area to minimise optimisation time):

1. Select the domestic load density classification from Table 12.1.2.

2. The expected ADMD of the community can be determined for the five- to seven-year initial investment period and the final ADMD for the master plan using appropriate software and the information obtained from marketing surveys.

3. Do a high-level preliminary technology selection from Table 12.1.3. Various technologies would generally apply at this point.
4. Each selected technology constitutes a range of alternatives that must be tested to obtain the optimum arrangement of that specific technology. Therefore, choose the various conductors and transformer sizes to be evaluated to establish alternatives for each technology.

5. Determine the maximum feeder distance (intermediate voltage feeder, LV feeder or service connection, depending on the technology).

6. Determine the maximum number of feeders for each transformer size (intermediate voltage feeders, LV feeders or service connections, depending on the service cables - e.g. 22/0.23 kV).

7. Determine the total loss (kW) per configuration.

8. Determine the maximum number of DSPs per configuration.

9. Determine the cost for each configuration, including the cost of losses, plot these costs for each technology and choose a few of the lowest-cost options, keeping flexibility in mind for the masterplan.

The various arrangements for each technology will produce an economic comparison or trade-off between transformer sizes and cable size. A typical result using this method is illustrated in Figure 12.1.2, which in this case produced an optimum LV feeder length of approximately 6.5X m. The graph is non-linear because, in general, larger cable sizes will be used for longer distances. The transformer and cable sizes that satisfy this minimum point should be used as the selected alternative for the technology.

10. With the above information, identify the transformer supply areas from the layout for the chosen options, while maintaining flexibility for phased implementation.

11. Route the maximum number of LV feeders from the transformer positions, considering the information obtained from Step 6 for each option.

12. Calculate the voltage drop in a few typical and worst-case transformer supply areas. Change the feeder routes or lengths, if necessary, to meet voltage drop and conductor thermal constraints.

13. Complete the various design layouts to generate a bill of structures.

14. Use standard material costs to determine the masterplan cost and add the cost of losses using the guidelines in NRS 034-1.

15. Select the phased upgrade plan that defers the largest amount of the five- to seven-year capital cost, but will enable easy and inexpensive upgrading when the load materialises.

16. Life-cycle loss modelling forms an essential part of optimisation. It is therefore important that a simplified electrical layout model be subjected to loss calculations, to ensure optimal system loading. Do an energy-loss calculation, using appropriate software, and ensure close to equal load vs no-load transformer losses.

Area load densities

It is necessary to determine the load densities in kW/km² for the area under consideration. This value can be used to help with the preliminary selection of technology and sizing of transformers.

The first step is to determine the total load for the area by multiplying the final ADMD by the total number of DSPs.

\[ \text{Area load} = \text{ADMD} \times \text{DSPs} \text{ (kW)} \]

Second, determine the total area to be supplied, excluding open spaces such as parks etc. (in km²).

Example:

\[ \text{ADMD} = 1,2 \text{ kVA}, \text{DSPs} = 1,500, \text{Area} = 1 \text{ km}^2 \]

\[ \text{Total load} = 1,2 \times 1,500 = 1,800 \text{ kW} \]

\[ \text{Load density} = 1,800 \text{ kW/km}^2 \]

Transformer supply areas

A maximum LV distributor length can be calculated using the stand size and ADMD. The area to be served by a single transformer is roughly described by a circle with radius equal to the distributor length.

\[ \text{Transformer supply area} = \pi R^2 \]

If \( R = 300 \text{ m} \) then trfr. sup. area = 0.28 km²

For a load density of 1 800 kW/km²
Transformer load = 0.28 \times 1800 = 500 \text{ kW}

A suitably rated transformer, taking account of its overload capability and the cyclic nature of the load, can be selected from the preferred sizes in the relevant specification (SABS 780:1979). For this example a transformer rated at 315 kVA would typically be suitable.

**Master plan layout**

The planner may start by drawing transformer supply circles on a site plan of the area. These circles have radii equal to the maximum LV distance that is allowed. Some overlap in the circles will naturally occur. Transformers may be positioned approximately in the centre of the circles. The entire LV layout can be established by working systematically from one end of the site to the other, making use of appropriate software to simulate voltage drop in the conductors. MV conductors may be modelled using load-flow software.

**Practical considerations**

After selecting the best technology option and arrangement for a particular settlement, the planner needs to do a complete electrical layout design and the following practical considerations are useful:

**Initial layout**

As discussed earlier, the initial phase is usually determined using the expected ADMD after seven years.

Installing only every second transformer planned for the master plan can reduce the number of transformers installed. The worst-case LV layout should be modelled to ensure acceptable voltage criteria, using the longer LV distributors (to the positions of those transformers removed). An alternative approach is to have reduced cable dimensions or single-phase arrangements for the initial layout, but then upgrading will be more costly.

**MV operating criteria**

The planner can determine the best MV system operation by specifying the location of normally open points, etc. MV voltage drop calculations are usually straightforward since, for the most part, only balanced three-phase alternatives are considered, with diversity allowed for as a scaling factor in repeated calculations.

It is important not to under-design the MV network, since this could be costly to replace at a future date. Use the maximum MV/LV transformer loads as point loads and do not diversify further. This will ensure sufficient MV line capacity to cater for future masterplan loading conditions.

**Optimisation for urban application**

Optimisation studies carried out in the electricity supply industry (ESI) used models that calculate, for high-density urban electrification application, the following information for various technologies:

- maximum distance per feeder;
- number of feeders to be supplied from a transformer;
- maximum transformer load;
- maximum number of consumers in transformer zone; and
- system losses.

From these results the total costs of all the configurations were determined and compared.

It was found that a three-phase LV design is optimal for high-density urban environments.

For stand sizes below 400 m², the use of three-phase LV 315 kVA transformers and a 35 mm² aerial bundled conductor (ABC) was in general the most cost-effective. For stand sizes between 400 m² and 1 000 m² the use of three-phase LV 200 kVA transformers and 70 mm² ABC was the most cost-effective alternative. In a medium density urban environment the best three-phase LV alternative was also found to be a 200 kVA transformer and 70 mm² ABC combination.

Single-phase LV and centre-tap LV designs were not only more expensive for this application, but exhibited the following disadvantages:

- limited reach;
- low efficiency;
- the centre-tap LV system will have imbalances in the primary system, although the secondary system is balanced; and
- the centre-tap LV transformer can only be loaded to 86% of its capacity.

Nevertheless, single-phase, dual-phase and SWER systems may often be more cost-effective alternatives for rural/low density applications.
**Areas of cost saving**

Although every system might potentially benefit from being uniquely designed, there is often a penalty in both design cost and time, and the cost of using non-standard items. Given resource constraints, the use of a limited selection of preferred sizes of standardised items should lead to overall cost savings. Most of the items that are used in electrification projects are the subject of NRS specifications that specify preferred sizes/types/ratings as agreed by electricity suppliers, through the Electricity Suppliers Liaison Committee (see Appendix A).

**Practical examples:**

- Depending on the ADMD, a first-time capital cost saving of between 5% and 25% can be achieved using 315 kVA transformers and 35 mm² ABC compared to designs using 100 kVA transformers and 35 mm² ABC.
- In low and very low consumption areas the use of 4 mm² service conductor rather than 10 mm² can result in further incremental savings.

**Pre-payment systems**

It was evident from the studies that the electricity dispenser (ED) and ready board (RB) are the two components that have a significant influence on electrification costs.

A clear strategic direction for domestic metering needs to be developed to optimise business functionality requirements, technology standardisation, and cost, especially for rural areas.

It is also clear that a phased-implementation approach will result in considerable savings due to the initial cost reduction and delay in capital expenditure.

For low and very low consumption areas, an alternative is the use of an “electricity control unit” (ECU) that combines the functions of a prepayment meter and a ready board into one housing. Typically this option will be suitable for consumers with a maximum supply requirement of 8 A.

**LV VOLTAGE DROP CALCULATIONS**

Voltage drop calculations seem straightforward and easy until phenomena such as diversity between consumer currents and unbalanced network loading become important facts to consider.

Recent research in South Africa has shown that the deterministic method used to calculate voltage drop, which was derived empirically and adapted from methods used in the UK, frequently overestimated the consumption and did not take account of all influencing factors. It also assumed a Gaussian distribution of customer loads, and the research has shown that the distributions are skewed, being better modelled as beta distributions.

**Recommended method for voltage drop calculation**

*Herman beta methodology*

The technique described in the second edition (1997) of NRS 034-1 takes account of important research that gave rise to the Herman beta methodology, which takes account of the statistical nature of residential loads and is sensitive to all influencing parameters. This is the recommended method for voltage drop calculations. It is intended that the factors applied will be reviewed and - if necessary - amended, as additional information is derived using data from the NRS load research project (see the section on “consumption classification” above).

**Alternative method for voltage drop calculation**

*Monte Carlo simulation*

A full Monte Carlo simulation implementation procedure can be used to simulate the actual network behaviour during peak periods. It is necessary to model the consumer load characteristics around domestic peak consumption periods to provide a load model for the simulation software.

However, the method is generally impractical for use in electrification project design, as it is time-consuming owing to the large number of simulations required. Its use is normally confined to applications in research.

Two methods of allocating consumer loads may be used: direct measurement of consumer currents and the use of statistical distribution functions.

**Measurement of consumer currents**

Metering equipment can be installed at randomly selected customer installations within a homogeneous group of customers. It is essential that the total group has the same classification to ensure similar energy-usage behaviour patterns. Current measurements at each installation, averaged over five-minute intervals, provide adequate resolution to capture the dynamic behaviour of individual customer currents.

Summation of all the customers’ currents will produce a diversified profile over the selected measurement period. The peak day and peak five-minute period can
then be selected. This summated current, divided by
the number of DSPs gives a diversified maximum
current per DSP. A kW value for ADMD is used, which is simply:

\[
\text{ADMD} = I \times V_{\text{nom}}
\]

with \(I\) the ADMD current value at time of peak, and
\(V_{\text{nom}}\) the nominal LV phase voltage = 230 V.

**SERVICE CABLE CONNECTION STRATEGIES**

Service cable phase connections may have various
configurations, and decisions regarding how many
phases to take from each node or pole and how to
arrange subsequent connections to minimise voltage
drop must be made. One of the largest contributing
factors to voltage drop in LV networks is the presence
of neutral currents due to unbalanced loading
conditions. Not much can be done about the
behaviour of consumers and technical imbalance
minimisation techniques must be provided.

**Oscillating vs non-oscillating connections**

It can be shown that an oscillating phase connection
strategy is the best solution. The following explains
the application of oscillating and non-oscillating phase
connections. All examples use four service connections
per node (pole or kiosk).

**One phase per node**

Planners often design electrification projects to
cater for single-phase service cable take-off points
via pole-top boxes or the equivalent. This is the
simplest method of servicing individual households.

One phase per node, non-oscillating (RWB-RWB):

<table>
<thead>
<tr>
<th>NODE</th>
<th>RED</th>
<th>WHITE</th>
<th>BLUE</th>
</tr>
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<tr>
<td>1</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

One phase per node, oscillating (RWB-BWR):

<table>
<thead>
<tr>
<th>NODE</th>
<th>RED</th>
<th>WHITE</th>
<th>BLUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

This connection strategy results in much improved
balanced loading conditions and a significant
reduction in neutral voltage drop.

**Two phases per node**

Oscillating phase connection taking two phases out
per node produces the following connection
arrangement:

RR-WW
BB-BB
WW-RR
RR-WW
BB-BB
WW-RR, etc.

**Three phases per node**

Oscillating phase connection taking three phases
out per node produces the following connection
arrangement:

RWBB
WRRW
BBWR
RWBB
WRRW
BBWR, etc.

Using three phases per node decreases the voltage
dropped as a result of the unbalanced condition by 10-
20% over the two-phase per node case. Owing to this
relatively small difference it is recommended that two
phases be taken out per node and, in addition, that
the oscillating phase connection strategy be used.
AREA LOSS MODEL
Planning proposals should include a full technical loss model with analysis results using forecasted energy-usage patterns and associated expected demands. Loss management should be incorporated as a basic requirement for all implemented electrification projects.

DOCUMENTATION REQUIREMENTS
Electrification projects should have a minimum set of documents, which include a planning proposal with the following:

• Maps of the area.

• List of evaluated technology options with technology cost comparisons as described in this document.

• Master plan layout and assumptions.

• Phased-implementation plan.

• MV loadflow calculation results showing system loading, losses and high/low voltages.

• MV/LV transformer and LV distributor plus service connection voltage-drop calculation results, using voltage profiles, LV distributor and MV/LV transformer loading. Results must include the master plan and the phased-implementation plan results.

• Loss evaluation of the system.

• Complete consultants brief if applicable.

See also Table 12.1.4.
**Table 12.1.4: Summary of documentation required and examples**

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<th>MINIMUM INFORMATION</th>
<th>EXAMPLE</th>
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</thead>
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<tr>
<td><strong>1. MASTER PLANNING</strong></td>
<td></td>
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<tr>
<td>1.1 Geographical load forecast</td>
<td></td>
</tr>
<tr>
<td>1.1.1 Domestic final energy consumption (kWh/month)</td>
<td>480 kWh/month per consumer</td>
</tr>
<tr>
<td>1.1.2 Domestic final ADMD (kVA)</td>
<td>2.7 kVA</td>
</tr>
<tr>
<td>1.1.3 Domestic load factor (% for 1 000 consumers)</td>
<td>25%</td>
</tr>
<tr>
<td>1.1.4 Final number of households</td>
<td>7 000</td>
</tr>
<tr>
<td>1.1.5 Bulk loads and notified max demand (no and kW)</td>
<td>2 x 130 kVA and 6 x 70 kVA and 13 x 18 kVA</td>
</tr>
<tr>
<td>1.1.6 Bulk loads contributions to peak (no and kW)</td>
<td>2 x 70 kVA and 6 x 20 kVA and 13 x 6 kVA</td>
</tr>
<tr>
<td>1.1.7 Electrification area bulk supply demand (kW)</td>
<td>20 600 kW (assumed 7% peak demand losses)</td>
</tr>
<tr>
<td>1.1.8 Electrification area supply energy (kWh)</td>
<td>3 700 000 kWh/month (estimated)</td>
</tr>
<tr>
<td>1.1.9 Electrification size (km²)</td>
<td>4.7 km²</td>
</tr>
<tr>
<td>1.1.10 Average domestic sand size (m²)</td>
<td>400 m²</td>
</tr>
<tr>
<td>1.1.11 Load density of total area (kVA/km²)</td>
<td>4 100</td>
</tr>
<tr>
<td>1.1.12 Load density of pocketed areas (kVA/km²)</td>
<td>4 100 (no pocket loads in urban areas)</td>
</tr>
<tr>
<td><strong>1.2 Optimised technology selection</strong></td>
<td></td>
</tr>
<tr>
<td>Technology type</td>
<td>Conventional MV/LV</td>
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<tr>
<td>General LV conductor choice (ABC 35 etc.)</td>
<td>35 mm² ABC</td>
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<tr>
<td>Average LV conductor length</td>
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<tr>
<td>Max LV conductor length (m)</td>
<td>100/160 kVA ANSI CSP</td>
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<tr>
<td>Generally used transformer (kVA)</td>
<td>Most economical for high density urban application</td>
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<tr>
<td>Reason for choice</td>
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<td><strong>1.3 Optimised voltage drop allocation</strong></td>
<td></td>
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<tr>
<td>Regulated % MV voltage during peak</td>
<td>103.5%</td>
</tr>
<tr>
<td>% MV voltage at MV/LV transformer at peak</td>
<td>101% (lowest MV voltage)</td>
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<tr>
<td><strong>2. PHASED-IMPLEMENTATION PLAN</strong></td>
<td></td>
</tr>
<tr>
<td>(in 5 to 7 years’ time)</td>
<td></td>
</tr>
<tr>
<td>2.1 Domestic energy consumption (kWh/month)</td>
<td>260 kWh/month per consumer</td>
</tr>
<tr>
<td>2.2 Domestic ADMD (kVA)</td>
<td>1.8 kVA</td>
</tr>
<tr>
<td>2.3 Domestic load factor (% for 1 000 consumers)</td>
<td>20%</td>
</tr>
<tr>
<td>2.4 Number of households connected</td>
<td>4 000</td>
</tr>
<tr>
<td>2.5 Bulk loads and notified max demand (no and kW)</td>
<td>1 x 130 kVA and 2 x 70 kVA and 9 x 18 kVA</td>
</tr>
<tr>
<td>2.6 Bulk loads contributions to peak (no and kW)</td>
<td>1 x 40 kVA and 2 x 10 kVA and 9 x 4 kVA</td>
</tr>
<tr>
<td>2.7 Electrification area bulk supply demand (kW)</td>
<td>7 700 kW (assumed 5% peak demand losses)</td>
</tr>
<tr>
<td>2.8 Electrification area supply energy (kWh)</td>
<td>1 100 000 kWh/month (estimated)</td>
</tr>
<tr>
<td>2.9 Electrification size (km²)</td>
<td>3.3 km²</td>
</tr>
<tr>
<td>2.10 Load density of total area (kVA/km²)</td>
<td>2 200</td>
</tr>
<tr>
<td>2.11 Load density of pocketed areas (kVA/km²)</td>
<td>2 200 (no pocket loads)</td>
</tr>
</tbody>
</table>

**FINANCIAL CALCULATIONS**

Refer to NRS 034 part 1 for details on financial calculation methods.
APPENDIX A
REFERENCE STANDARDS, SPECIFICATIONS AND GUIDELINES

A.1 The NRS rationalised user specifications

The NRS specifications for application in the electricity supply industry are approved for use by the Electricity Suppliers Liaison Committee which comprises, inter alia, representation from the Association of Municipal Electricity Undertakings (AMEU) and Eskom. The committee provides considered choices of planning techniques, codes of practice, recommended practices and preferred equipment, as well as material types, sizes, and ratings, the widespread use of which should lead to overall cost benefits in the electrification drive.

<table>
<thead>
<tr>
<th>NRS</th>
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<td>002:1990</td>
<td>Graphical symbols for electrical diagrams&lt;br&gt;Amendment 1 - Index, architectural and reticulation symbols</td>
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<tr>
<td>003-1:1994</td>
<td>Metal-clad switchgear, Part 1: 1 kV to 24 kV - Requirements for application in the ESI</td>
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<td>003-2:1993</td>
<td>Part 2: Standardised panels</td>
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<tr>
<td>004:1991</td>
<td>Mini-substations, Part 1: up to 12 kV - Requirements for application in the ESI</td>
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<tr>
<td>005:1990</td>
<td>Distribution transformers: Preferred requirements for application in the ESI</td>
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<tr>
<td>006:1991</td>
<td>Switchgear - Metal-encl. ring main units, 1 kV to 24 kV</td>
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<td>008:1991</td>
<td>Enclosures - Metal-encl. ring main units, 1 kV to 24 kV</td>
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<td>009 Series</td>
<td>Electricity sales systems</td>
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<tr>
<td>009-2-2:1995</td>
<td>Part 2: Functional and performance requirements; Section 2: Credit dispensing units</td>
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<td>009-4-1:1995</td>
<td>Section 1: National electricity meter cards</td>
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<td>009-4-2:1993</td>
<td>Section 2: National electricity meter numbers</td>
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<tr>
<td>009-6-1:1996</td>
<td>Part 6: Interface standards; Section 1: Interface Credit Distribution Unit (CDU) to Standard Token Translator (STT)</td>
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<td>013:1991</td>
<td>Electric power cables form 1 kV to 36 kV</td>
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<td>016:1995</td>
<td>Code of Practice for earthing of low-voltage distribution systems</td>
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<tr>
<td>017 Series</td>
<td>Single-phase cable for aerial service connections</td>
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<td>Part 1:1997</td>
<td>Split concentric cable</td>
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<td>Part 2:1997</td>
<td>Concentric cable</td>
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<td>018 Series</td>
<td>Fittings and connectors for LV overhead powerlines using aerial bundled conductors</td>
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<td>018-1:1995</td>
<td>Part 1: Strain and suspension fittings for self-supporting conductors</td>
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<tr>
<td>018-2:1995</td>
<td>Part 2: Strain and suspension fittings for insulated supporting conductors</td>
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<td>018-3:1995</td>
<td>Part 3: Strain and suspension fittings for bare supporting conductors</td>
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<td>018-4:1996</td>
<td>Part 4: Strain and suspension fittings for service cables</td>
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<td>Part 5: Current-carrying connectors and joints</td>
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<td>020:1991</td>
<td>Aerial bundled conductor - Cable ties</td>
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<td>022:1996</td>
<td>Stays and associated components (second edition)</td>
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<tr>
<td>025:1991</td>
<td>Photo-electric control units (PECUs) for lighting</td>
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<td>027:1994</td>
<td>Electricity distribution - Distribution transformers - Completely self-protecting type</td>
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<td>028:1993</td>
<td>Cable lugs and ferrules</td>
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<td>029:1993</td>
<td>Outdoor-type current transformer</td>
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<td>030:1993</td>
<td>Electromagnetic voltage transformers</td>
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<tr>
<td>031:1993</td>
<td>Alternating current disconnectors and earthing switches (above 1 000 V)</td>
</tr>
<tr>
<td>032:1993</td>
<td>Electricity distribution - Service distribution boxes - Pole-mounted (at 230 V)</td>
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<td>033:1996</td>
<td>Guidelines for the application design, planning and construction of MV wooden pole overhead power lines above 1 kV and up to and including 22 kV</td>
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<td>034 series</td>
<td>Guidelines for the provision of electrical distribution networks in residential areas</td>
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<tr>
<td>034-0:1998</td>
<td>Part 0:1998: Glossary of terms (in course of publication)</td>
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<td>034-1:1997</td>
<td>Part 1: Planning and design of distribution systems</td>
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<tr>
<td>034-2-3:1997</td>
<td>Part 2-3: Preferred methods and materials for overhead lines</td>
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<td>034-3:1995</td>
<td>Part 3: O/h distribution in low and moderate consumption areas</td>
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<td>035:1994</td>
<td>Outdoor distribution cut-outs (drop-out fuses) - Pole-mounted type up to 22 kV</td>
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<td>036 series</td>
<td>Auto-reclosers and sectionalisers - Pole-mounted types</td>
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<tr>
<td>936-1:1994</td>
<td>Part 1: Programmable protection and remote control</td>
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<td>036-2:1997</td>
<td>Part 2: Auto-reclosers with programmable protection</td>
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<td>036-3:1997</td>
<td>Part 3: Sectionalisers</td>
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<td>038-1:1997</td>
<td>Concrete poles, Part 1: Concrete poles for o/h distribution and reticulation systems</td>
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<tr>
<td>039:1995</td>
<td>Surge arresters - Application guide for distribution systems</td>
</tr>
<tr>
<td>040-1:1995</td>
<td>HV operating regulations, Part 1: Definitions of terms</td>
</tr>
<tr>
<td>040-2:1994</td>
<td>Part 2: Voltage colour coding</td>
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<td>040-3:1995</td>
<td>Part 3: Model regulations</td>
</tr>
<tr>
<td>041:1995</td>
<td>Code of practice for overhead power lines for RSA</td>
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<tr>
<td>042:1996</td>
<td>Guide for the protection of electronic equipment against damaging transients</td>
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</table>
A.2 SABS standards

The following South African Bureau of Standards documents may assist in the planning, design and construction of electrical networks in residential areas.

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<th>SABS STANDARD</th>
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<tbody>
<tr>
<td>97:1991</td>
<td>Electric cables - impregnated-paper-insulated metal-sheathed cables for rated voltages from 3,3/3,3 kV up to 19/33 kV</td>
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<tr>
<td>152:1997</td>
<td>Low-voltage air-break switches, air-break disconnectors, air-break switch-disconnectors, and fuse-combination units</td>
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<tr>
<td>156:1977</td>
<td>Moulded-case circuit-breakers</td>
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<tr>
<td>171:1986</td>
<td>Surge arresters for low-voltage distribution systems</td>
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<tr>
<td>172:1994</td>
<td>Low-voltage fuses</td>
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<tr>
<td>177 (in 3 parts)</td>
<td>Insulators for overhead lines of nominal voltage exceeding 1 000 V</td>
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<tr>
<td>178:1970</td>
<td>Non-current-carrying line fittings for overhead power lines</td>
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<tr>
<td>753:1994</td>
<td>Pine poles, cross-arms and spacers for power distribution and telephone systems</td>
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<td>754:1994</td>
<td>Eucalyptus poles, cross-arms and spacers for power distribution and telephone systems</td>
</tr>
<tr>
<td>780:1998</td>
<td>Distribution transformers</td>
</tr>
<tr>
<td>1029:1975</td>
<td>Miniature substations</td>
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<tr>
<td>1030:1975</td>
<td>Standard longitudinal miniature substations of ratings not exceeding 315 kVA</td>
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<tr>
<td>1180 (in 3 parts)</td>
<td>Electrical distribution boards</td>
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<td>1268:1979</td>
<td>Polymeric or rubber-insulated, combined neutral/earth (CNE) cables with solid aluminium phase conductors and a concentric copper wire waveform combined neutral/earth conductor</td>
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<td>1339:1992</td>
<td>Electric cables - Cross-linked polyethylene (XLPE)-insulated cables for voltages from 3,8/6,6 kV to 19/33 kV</td>
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<td>1411</td>
<td>Materials of insulated electric cables and flexible cords</td>
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<td>1418 (in 2 parts)</td>
<td>Aerial bundled conductor systems</td>
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<td>1473</td>
<td>Low-voltage switchgear and controlgear assemblies</td>
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<tr>
<td>1507:1990</td>
<td>Electric cables with extruded solid dielectric insulation for fixed installations (300/500 V to 1 900/3 300 V)</td>
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<tr>
<td>1608:1994</td>
<td>Portable earthing gear for busbar systems and overhead lines</td>
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<tr>
<td>1619:1995</td>
<td>Small power distribution units (ready boards) for single-phase 230 V service connections</td>
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<tr>
<td>IEC 60076 (in 5 parts)</td>
<td>Power transformers</td>
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<tr>
<td>IEC 60099-4:1991</td>
<td>Surge arresters Part 4: Metal-oxide surge arresters without gaps for AC systems</td>
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<tr>
<td>IEC 60129:1984</td>
<td>Alternating current disconnectors and earthing switches</td>
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<tr>
<td>IEC 60265-1</td>
<td>High-voltage switches Part 1: High-voltage switches for rated voltages above 1 kV and less than 52 kV</td>
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<tr>
<td>IEC 60269-1 (in 6 parts and sections)</td>
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Chapter 12.2

Other forms of energy
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<td>ENERGY-EFFICIENT BUILDING DESIGN</td>
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<td>Benefits of energy-efficient buildings</td>
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Other forms of energy

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SCOPE

This section is intended to provide engineers, settlement planners and developers with information about energy sources and applications other than grid electricity. The scope of application includes both urban and rural settlements.

Important energy sources and applications in this context include

- energy efficient building design;
- the supply and use of hydrocarbon fuels (paraffin, LPG, coal, wood); and
- solar energy applications (in particular, solar water heating and the use of solar photovoltaic systems for off-grid electricity supply).

Guidelines are provided on the costs, applications, environmental and safety aspects, and relevant planning considerations associated with these energy sources and technologies.

Background information and references are also provided for other renewable energy technologies which are less widely used in South Africa, but which might be considered by planners in specific circumstances: wind turbines for electricity generation, small-scale hydropower, biogas digesters, extraction of landfill gas and solar-thermal electricity generation.

Some of the practices addressed in this section are still under development in South Africa and not yet well standardised. These topics are therefore addressed in a more descriptive and lengthy way. Improved concise guidelines should be possible in future revisions, as the practices become more widely established.

INTRODUCTION

The supply of grid electricity is the foremost energy infrastructure concern for planners, engineers and developers in South African urban settlements.

However, in lower-income urban communities - which include the majority of South Africa’s urban population - grid electricity is only one part of energy supply and use. In practice, low-income households continue to use a variety of other energy sources, even when grid electricity is available. It is therefore useful for planners to consider these wider energy needs.

A second reason for considering energy alternatives to grid electricity is that, in dispersed or remote settlements (generally rural), grid electrification can be highly uneconomical. In this situation, decentralised “off-grid” sources of electricity may be preferable. These are nearly always more costly than a normal urban electricity supply, but nonetheless may be cheaper than grid extension and reticulation over long distances with low load densities. Again, electricity is only a part of the energy supply/use equation in such areas, and other fuel use must also be taken into account.

A third reason for examining energy alternatives arises from environmental concerns. Global environmental concerns about reducing pollution and greenhouse gas emissions have led to a greater awareness of the benefits of energy conservation and energy efficiency, as well as to a preference for using renewable energy sources where possible rather than fossil fuels which pollute the environment. Local environmental issues include serious concerns about

- the impact of smoky local indoor/outdoor environments on health;
- fires;
- contamination and poisoning; and
- land degradation caused by pollution from power stations and the over-exploitation of natural vegetation for energy purposes.

PLANNING CONSIDERATIONS

Most of the energy sources and applications treated in this section do not involve the provision of extensive physical infrastructure within settlements. Many of them involve economic and behavioural choices by individual consumers or households. Physical planning issues do arise, but other important consumer-oriented considerations include

- mechanisms to encourage the integration of thermally efficient design in low-cost housing developments;
- suitable distribution channels for commercial fuels, energy-related equipment, and appliances;
- finance and repayment mechanisms;
- social planning, consultation, education and awareness-building; and
- the application of technical, safety and environmental standards.

Relevant planning issues will be noted in each of the sub-sections below. In general, the following broad recommendations could be considered by planners:
• Understand local energy needs, consumption patterns and supply options.

• Recognise that electricity does not address all the energy needs of lower-income communities, and make provision for the optimal use of other energy sources.

• Ensure consumers are able to make well-informed choices about their energy options, through awareness and education campaigns. Include information about costs, health and safety.

• In physical planning, take account of the orientation and spacing of buildings for good use of passive solar design principles (alongside other factors affecting layout choices, such as security, variety, etc).

• Promote the energy-efficient and cost-saving design of buildings.

• Take account of the environmental impacts of different energy options.

ENERGY CONDITIONS IN SOUTH AFRICA

This section provides a brief overview of household energy consumption patterns in South Africa, the costs and availability of non-electric fuels and renewable energy options, and the distribution of renewable energy resources in South Africa.

Energy consumption patterns in South Africa

Overall, the residential sector accounts for approximately 20% of the energy consumption in SA. The percentage of households with access to grid electricity stood at about 66% in 1997-98 and is steadily increasing. However, in lower-income newly electrified settlements the average levels of electricity consumption per household are quite low - typically 50 to 150 kWh/month in the first few years after electrification (Davis 1995).

There are several reasons for this. Income constraints can make it difficult to afford higher electricity bills, and also difficult to acquire the more expensive energy-intensive electric appliances, such as stoves. Such households may therefore continue using existing cheaper appliances (such as primus stoves), cheaper fuels (such as coal for heating in winter) and non-commercial fuels like fuelwood and dung. Households without any electricity have, of course, to rely on such non-electric fuels and appliances.

“Fuel-switching” is a common phenomenon. It used to be thought that households in Southern Africa and similar developing countries would progressively switch from traditional fuels (e.g. wood) through transitional fuels (e.g. paraffin), then towards the partial use of electricity and finally to almost complete reliance on electricity. This may turn out to be a valid long-term trend, but in the medium term fuel-switching occurs in both directions, depending largely on economic circumstances and changes in prices. Multiple fuel use is likely to continue to be the norm for lower-income households in South Africa, both urban and rural, electrified and non-electrified.

The proportions of different fuels used tends to vary in different parts of the country, reflecting climatic differences (e.g. cold winters in the interior highveld) and local differences in prices (e.g. cheap coal in proximity to coalfields). Figure 12.2.1 illustrates this variation for households in four metropolitan centres.

Figure 12.2.1: Percentage of households using different energy carriers, in four metropolitan areas
Note: Percentages total more than 100%, indicating multiple fuel use by households.
Source: Williams 1993

Rural households make extensive use of wood and other biomass (crop residues, dung, etc) for cooking and heating. However, the use of wood also occurs in urban and peri-urban settlements. When wood can be collected “free” - although often involving considerable labour - it may be the most economically attractive or indeed the only energy option for low-income households. However, wood is also increasingly a commercial fuel, especially in areas of fuelwood scarcity.

Comparative energy costs

It is difficult to give accurate costs for the “useful” energy obtained from different fuel-appliance combinations, because the efficiency of the energy utilisation can vary. Table 12.2.1 provides estimated comparative costs for (a) the energy content and (b)
the useful energy derived from different fuels, assuming the efficiencies shown, and based on typical 1997 prices for Gauteng and Cape Town.

Thermal energy services (cooking, heating, cooling) consume the largest amounts of household energy and are therefore a major concern for household choices about which fuels and appliances to use. As mentioned, the cost of the appliances themselves can be a deciding factor as well.

In general, poorer households spend a larger proportion of their income on energy services than more affluent households. They may also use less efficient appliances and pay more for the fuels they use, for example, by buying fuels like paraffin in small quantities. The use of candles for lighting is widespread in non-electrified households, but also in low-income electrified households. Households without an electricity supply often spend a large portion (e.g. one-third) of their overall energy budgets on dry-cell batteries for radios, etc (Hofmeyr 1994).

For lighting and media appliances (radio, TV, etc) small solar photovoltaic systems can provide a cost-effective alternative to paraffin lamps, candles and dry-cell or rechargeable batteries. The capital cost is higher, but life-cycle costs are lower for equivalent services. Table 12.2.2 gives examples of comparative lighting costs (using 1992 relative prices) for equivalent lighting levels.

### Table 12.2.1: Comparative consumer costs of different fuels for domestic cooking and heating (1997 prices)

<table>
<thead>
<tr>
<th></th>
<th>Unit Cost of Fuel (Units as Shown)</th>
<th>Cost of Energy Content (Cents/kWh)</th>
<th>Assumed Efficiency of Utilisation</th>
<th>Cost of Useful Energy (Cents/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gauteng</td>
<td>Cape Town</td>
<td>Gauteng</td>
<td>Cape Town</td>
</tr>
<tr>
<td><strong>Cooking</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grid electricity</td>
<td>20 c/kWh</td>
<td>25 c/kWh</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>Coal</td>
<td>26 c/kg</td>
<td>55 c/kg</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Paraffin</td>
<td>220 c/litre</td>
<td>168 c/litre</td>
<td>21</td>
<td>16</td>
</tr>
<tr>
<td>LP gas</td>
<td>395 c/kg</td>
<td>321 c/kg</td>
<td>29</td>
<td>24</td>
</tr>
<tr>
<td>Wood (commercial)</td>
<td>21 c/kg</td>
<td>45 c/kg</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td><strong>Combined Cooking and Space-Heating</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grid electricity</td>
<td>20 c/kWh</td>
<td>25 c/kWh</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>Coal</td>
<td>26 c/kg</td>
<td>55 c/kg</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td><strong>Water Heating</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grid electricity</td>
<td>20 c/kWh</td>
<td>25 c/kWh</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>LP gas</td>
<td>395 c/kg</td>
<td>321 c/kg</td>
<td>29</td>
<td>24</td>
</tr>
</tbody>
</table>


### Table 12.2.2: Comparative energy costs for 1 000 lumen-hours of lighting

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Candles</td>
<td>R2,50</td>
</tr>
<tr>
<td>Paraffin lamp (wick)</td>
<td>R0,40</td>
</tr>
<tr>
<td>Pressurised paraffin lamp</td>
<td>R0,10</td>
</tr>
<tr>
<td>LP gas</td>
<td>R0,20</td>
</tr>
<tr>
<td>Solar home system</td>
<td>R0,05</td>
</tr>
<tr>
<td>Grid electricity</td>
<td>R0,002</td>
</tr>
</tbody>
</table>

Source: Cowan et al (1992)

The Distribution of Renewable Energy Resources in South Africa

Solar energy resources

Solar energy is generally abundant in South Africa, with a daily average of between 4 500 Wh (Durban) and 6 400 Wh (Upington) per square metre per day. These are values for solar irradiation measured on a horizontal surface (see Figure 12.2.2). For purposes of collecting solar energy, the solar collector is usually tilted to receive more energy throughout the year. Table 12.2.3 includes solar irradiation values for tilted surfaces. For many solar energy applications, a fixed-tilt angle is chosen which maximises the solar irradiation received during the “worst” solar month of the year, as shown in Table 12.2.3.

Solar radiation data for approximately 100 weather stations, and detailed data for the ten major South African measuring sites shown in Table 12.2.3, can be obtained in Eberhard (1990) and Cowan et al (1992); the latter source also includes software for calculating solar irradiation on north-facing tilted surfaces at different times of year, hour by hour.

For some purposes (e.g. in building design) it is useful to know the solar irradiation on vertical surfaces. Examples are provided in Table 12.2.4. Monthly values for all major weather stations are obtainable in Cowan et al (1992) and Eberhard (1990).

Table 12.2.4: Solar irradiation on vertical north-facing surfaces

<table>
<thead>
<tr>
<th>Location</th>
<th>Maximum month</th>
<th>Minimum month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bloemfontein</td>
<td>6 115 (Jul)</td>
<td>2 045 (Dec)</td>
</tr>
<tr>
<td>Cape Town</td>
<td>4 929 (Apr)</td>
<td>2 387 (Dec)</td>
</tr>
<tr>
<td>Durban</td>
<td>4 972 (Jun)</td>
<td>1 837 (Dec)</td>
</tr>
<tr>
<td>Pretoria</td>
<td>5 696 (Jun)</td>
<td>1 697 (Dec)</td>
</tr>
</tbody>
</table>

Source: Cowan et al (1992)

Figure 12.2.2: Annual mean solar irradiation on a horizontal surface (in Wh per square metre per day)

Source: Eberhard (1990)

Table 12.2.3: Solar irradiation values, from long-term measurements

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>MONTHLY MEAN SOLAR IRRADIATION, IN WH PER SQUARE METRE PER DAY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ON A HORIZONTAL SURFACE</td>
</tr>
<tr>
<td></td>
<td>BEST MONTH</td>
</tr>
<tr>
<td>Alexander Bay</td>
<td>8 364</td>
</tr>
<tr>
<td>Bloemfontein</td>
<td>8 096</td>
</tr>
<tr>
<td>Cape Town</td>
<td>7 956</td>
</tr>
<tr>
<td>Durban</td>
<td>5 740</td>
</tr>
<tr>
<td>Grootfontein</td>
<td>8 238</td>
</tr>
<tr>
<td>Nelspruit</td>
<td>6 045</td>
</tr>
<tr>
<td>Port Elizabeth</td>
<td>7 216</td>
</tr>
<tr>
<td>Pretoria</td>
<td>6 908</td>
</tr>
<tr>
<td>Roodeplaat</td>
<td>6 963</td>
</tr>
<tr>
<td>Upington</td>
<td>8 390</td>
</tr>
</tbody>
</table>

Source: Cowan et al (1992)

Note: A fixed north-facing tilt, in degrees from horizontal, which maximises solar irradiation for the worst month of the year.
Wind energy resources

Wind-speed measurements for South Africa are available from a large number of measuring stations across the country. However, the majority are agricultural stations and these wind measurements (usually at a height of 2 m and often in sheltered locations) are not always useful for judging wind-energy resources. Wind speeds can vary greatly over short distances in complex terrain. Wind-energy potential is highly sensitive to wind speeds, since doubling the wind speed increases the available power by a factor of eight. Average wind speeds of 6 ms\(^{-1}\) or more are favourable for electricity generation from wind, and wind speeds below 4.5 ms\(^{-1}\) are usually not viable, except for water pumping. Figure 12.2.3 provides an indication of wind-energy potential in different parts of South Africa. However, accurate site-specific wind assessments are essential to establish the viability of wind generation in a particular location. The most comprehensive source of analysed wind data, including frequency distributions and monthly variations, is Diab (1995).

Diab (1995) presents wind distribution statistics for 79 stations with hourly wind data. Of these, the following have wind data for at least two years, measured at a height greater than 2 m, and show annual mean wind speeds greater than 4 ms\(^{-1}\) (normalised to 10 m above ground level):

- > 4.0 to 4.5 ms\(^{-1}\) Alexander Bay, Beaufort West, Cape Town Airport, East London, Hermanus, Port Elizabeth, Stilbaai, Struisbaai, Vrede
- > 4.5 to 5.0 ms\(^{-1}\) Berg River, Wingfield
- > 5.0 to 5.5 ms\(^{-1}\) Gordons Bay
- > 5.5 to 6.0 ms\(^{-1}\) Buffeljagsbaai, Danger Point, Die Gruis, Gansbaai
- > 6.0 to 6.5 ms\(^{-1}\) —
- > 6.5 to 7.0 ms\(^{-1}\) Waenhuiskraans

Other measurements of promising wind speeds, which either come from shorter periods of data or come from stations which were excluded from Diab's wind distribution statistics (and may not be fully reliable), are:

- > 6.0 to 6.5 ms\(^{-1}\) Bird Island, Klippepunt, Saldanha, Thyspunt
- > 6.5 to 7.0 ms\(^{-1}\) Cape Infanta, Hluhluwe
- > 7.0 to 7.5 ms\(^{-1}\) Cape Recife, Hangklip
- > 7.5 to 8.0 ms\(^{-1}\) Seal Island

Hydropower resources

Hydro-power resources in South Africa are even more site-specific than wind. In general, the eastern slopes of the country from the Drakensberg down to the coast are more likely to offer the combination of sufficient water flow and gradient usually needed for viable small-scale hydro-electric installations (see later section on Small Hydropower).

Energy-efficient building design can help to reduce:

- excessive consumption of electricity or other fuels to maintain comfortable working, leisure or sleeping spaces;
- indoor/outdoor pollution; and
- health risks from a polluted or thermally uncomfortable environment.

This section discusses principles of building design, layout and user behaviour which can save energy, reduce costs and contribute to improved living environments. The focus is on information of interest to planners, designers, builders and building owners/occupants in residential areas.

Benefits of energy-efficient buildings

The energy consumption and expenditure required to maintain a comfortable (or in some cases simply bearable) indoor environment can be very significant, across all classes of housing and commercial building.
types. The potential for energy savings through improved energy-conscious building design can be as much as 70% in some cases. The “passive design” or “solar passive design” of buildings refers to construction/design techniques which

- make better use of natural energy flows (e.g. solar heating in the day, cooling at night);
- use building elements to insulate, capture, store or otherwise control energy flows; and
- reduce the need for “active” energy consumption/management.

Such techniques can be low-cost, long-lasting and offer the following potential benefits:

- lower energy bills for owners/occupants (especially in winter, when the energy bills of poorer households can rise significantly);
- reduced total electricity consumption - winter consumption levels are about 1 600 GWh/month higher than summer (Eskom, 1996);
- reduced electricity peak demand, associated with “cold snaps” (with resultant economic benefits both for electricity generation and the peak national/local distribution capacity required);
- less pollution (and lower health costs); and
- generally, a more pleasant and healthy environment in the home or workplace.

A particular South African health problem is respiratory disease caused by use of coal and wood for indoor cooking and space-heating (Terblanche et al 1993; Van Horen et al 1996). This could be partially alleviated by thermally efficient building design in low-income communities reliant on these fuels for heating.

Both the national electrification programme and the national housing programme present important drivers for improved thermal efficiency in housing:

- As the number of electrified houses increases, electric space-heating has an increasing impact on electricity consumption and winter peak demand (which will lead to more peaked and expensive generation, transmission and distribution).
- The national housing programme represents a unique opportunity to include low-cost thermal improvements which will reduce energy consumption for space-heating; if this opportunity is missed, it could result in long-term cost increases for residents, service providers and society at large (Simmonds 1997).

Guidelines for energy-conscious design

For specific climate zones and building types, it is possible to state relatively concise guidelines. However, the field is complex, and as Holm (1996) warns, over-simplification can lead to inappropriate application.

The approach adopted here is to discuss the principal elements of energy-conscious building design, and to give some indication of possible strategies. For more detailed information, Holm and Viljoen (1996) and Holm (1996) are useful resources. There are also numerous international texts in this field.

The Directorate: Settlement Policy of the Department of Housing (in association with other government departments) is in the process of drafting a set of guidelines for “environmentally sound low-cost housing”.

Principal elements in managing indoor environments

Occupational comfort is related to temperature, air flow, lighting, humidity, the level of activity and clothing. The last two parameters are primarily under the control of occupants, and thus not discussed here. The other parameters are often actively managed in large commercial buildings, and to a lesser or greater extent in other buildings such as houses.

Energy-efficient or “passive” building design aims to reduce the active use of energy, and to achieve moderate variations around comfortable mean temperature (and other) conditions, using more economical means.

Figure 12.2.4 illustrates a cross-section through two rooms in a house, to show the main energy flows and parameters that influence the indoor environment.
Figure 12.2.4: Principal energy flows in a home

Important elements of the energy flow diagram are:

- **energy source elements** - the sun shining through windows or heating external surfaces, human activity, appliances, heaters etc. in the home;

- **elements that remove energy from a home** - cooler air either flowing through a house or cooling external walls and roof, dark sky acting as a radiation sink at night, an air conditioner; and

- **energy stores within a home** - walls, floors, bodies of water within the home which can either absorb heat energy (helping to keep space temperatures lower) or give energy out (helping to warm a space).

Heat transfer is always from regions of higher temperature to regions of lower temperature. Three heat-transfer mechanisms are important:

- **conduction** through solid structures such as walls and roofing materials, which is highly dependent on the composition and thickness of the material (e.g. the conductivity of steel is a thousand times the conductivity of insulators like glass-fibre quilt);

- **convective** heat transfer, strongly related to air movement (which is enhanced by ventilation, or reduced through the use of multiple barriers or sealed cavities, as in a cavity wall); and

- **radiation**, proportional to the fourth power of the absolute temperature (Kelvin), and thus highly significant at elevated temperatures. Absorption of radiant energy also depends on the reflectivity of surfaces (highly polished surfaces and those painted with light colour paints are able to reflect most solar radiation while dark, rougher surfaces may absorb 95% or more).

Most heat transfer processes (e.g. from the air inside a room, through the wall to the outside) involve all three mechanisms. Tables listing heat transfer and thermal properties of common building materials are readily available (Wentzel et al 1981; Everett 1970; Burberry 1983; Quick II 1998).

Each of the principal building elements is discussed below, with attention given to opportunities for improvement.

**Roof**

Fifty to seventy percent of the heat loss from a home in winter can be through an uninsulated roof (Simmonds 1997). Furthermore an uninsulated roof will allow excessive heat gain during the day in summer. The addition of a ceiling can reduce space-heating energy bills by more than half and, even for homes with ceilings, the proper use of ceiling insulation can be a further cost-effective intervention in most climatic regions of South Africa (Temm International 1997; Van Wyk and Mathews 1996).

The following points need to be considered:

- Ceiling and insulation materials should be chosen with due consideration of other aspects of the building. There is little sense in adding thick, high-quality insulation to the ceiling of a draughty, thin-walled home. Cardboard or other low-cost insulators will achieve most of the benefits, at a fraction of the cost.

- Where buildings are otherwise thermally efficient, proper installation of thicker insulation with greater resistance to heat transfer is to be preferred.

- A gap of at least a few centimetres should be allowed between the top of the ceiling and the roof, as this will increase the insulation of the entire structure significantly, and allow ventilation.

- Materials of high reflectance and low emissivity (e.g. reflective aluminium-foil products) can also act as useful insulators, where radiation causes significant heat loss or unwanted gain (as in roof spaces).

- Where high thermal gradients occur across relatively thin insulation (e.g. cardboard ceilings) it is important to place a vapour barrier on the warm side of the insulation, to prevent condensation as warm, moist air comes into contact with cold exterior surfaces. Plastic sheeting or reflective aluminium foil is effective, if properly applied and sealed.

- Light colours tend to reflect more light. Heat gain from a roof is difficult to control in summer, so it is sensible to paint roofs a light colour.
Windows

Windows can be significant sources of both heat gain and loss in a home. Thermal performance will depend on size, orientation, shading, air tightness, material used for glazing, the use or absence of moveable insulation such as shutters or curtains, and on whether or not double glazing is used. Heat loss is primarily the result of convection, conduction and longwave radiation, all of which are significantly reduced by glass. Thus, provided the sun is shining, a window can cause heat gain even on a cold day.

- Windows that face east or west are more difficult to shade in summer (with greater potential for overheating). They should thus be kept relatively small, unless the user regulates the shading using moveable shades or other means discussed below.
- South-facing windows will tend to lose more energy than they gain; they are useful if the intention is to cool a space in summer, but will make it cold during winter. They can also be useful to collect diffuse light for work spaces.

CSIR (1997) provides an excellent paper-based method for calculating shadow angles at different orientations and times of the year, and provides helpful hints for controlling sunlight entry into buildings.

Building occupants should manage windows, either opening or closing them to allow ventilation, or drawing curtains at night or in cold weather to minimise heat loss. To retain heat, curtains should be heavy, and/or windows should have close-fitting shutters. On the other hand, interior drapes will tend to absorb heat energy and release much of it into the building. Heat gain can most effectively be reduced using external shutters, louvres or highly reflective interior blinds. More expensive control measures, which are worthwhile in extreme climatic conditions, include double-glazing, adhesive films (which can be retrofitted) and low-emissivity glass.

Walls

Conductivity/Insulation: Exterior walls should generally have good thermal insulation properties, to help keep heat out in summer and in during winter. Standard brick or block walls have reasonable thermal properties, especially if a cavity construction is used. Thin (single) brick, fibreboard and especially corrugated iron external walls are inefficient and cold in winter (or hot in summer) and should be insulated (but avoid using dangerously flammable materials).

Even low-cost insulation can reduce winter heat loss in corrugated iron dwellings by 50% (Weggelaar and Mathews 1998). If applied to 700 000 such dwellings in Gauteng, these authors estimate potential energy savings valued at R275-R450 million per year.

Thermal mass: High thermal mass (the specific heat capacity x mass of an element) can have a moderating effect on the temperature inside a building. High thermal mass walls exposed to the sun or warm air during the day will warm up slowly (without overheating) and then re-radiate heat into the house overnight, helping to keep the home warm. This is particularly relevant in climates where day-night temperature variations are high (e.g. the highveld and interior regions of the country).

As with windows, north-facing massive uninsulated walls under eaves can be shaded in summer, but exposed to the sun in winter, providing a naturally moderated energy input to the home.

Wall Colour: Light colours help to reflect heat. This can reduce overheating of thin, poorly insulated walls exposed to the summer sun.

The Trombe wall is a well-known specialised passive design technology which can be effectively used to warm a house in winter. An external glass pane shields the wall from wind, and significantly reduces convective and long-wave radiation losses,
while allowing short-wave radiation from the sun to enter and warm the wall. These walls can also be used to enhance ventilation and facilitate cooling during hot weather, by placing vents that open to the outside near the top of the wall, and fitting temporary insulation on the inner surface. Air heated by the sun rises in the gap between wall and glass and leaves the house, drawing fresh, cooler air into the dwelling.

Other elements with high thermal mass

Floors, massive roof structures (earth or concrete) and specially designed elements such as water-filled structures all have high thermal capacity, and can be used to moderate indoor temperatures. In summer, a house can be fully opened at night, to lose as much heat as possible to the dark sky, and then closed during the day in an effort to keep the heat out and derive the benefit of the pre-cooled walls and floors.

On the other hand, if a building or room is used only for short periods, it may be appropriate to carpet the floors and use insulated walls of a low thermal mass, so that air-conditioning or heating will quickly get the room to the desired temperature without undue energy transfer to walls or floor.

In well-designed buildings, attention should be given to the balance of floor area, effective (exposed) thermal mass and north-facing window area. If window areas are too great for the house’s thermal mass, then overheating can occur - even during winter days - and the house will cool down too rapidly at night. Windows that are too small will provide insufficient heat gain. Basic design guidelines are not given here, as appropriate ratios can vary significantly, depending on the thermal properties of different construction materials. Suffice it to say that optimum north-facing window areas are of the order of 10% or more of building floor area (Holm et al. nd).

Ventilation

Adequate ventilation is essential to avoid overheating in summer, to avoid damp interiors and, perhaps most importantly, to remove pollutants released by indoor fires and coal stoves, where these are used. It is, however, important that such ventilation be controlled, and to a certain extent directed.

In hot weather, good cross-ventilation can be facilitated by windows or vents on both the leeward and the windward side of buildings. Exit windows should be high, to avoid warmer (lighter) air being trapped above them. Ceiling fans, and especially smaller fans directed as required, can significantly enhance user comfort in hot weather, at a much lower cost than air-conditioning.

Many South African households, however, are over-ventilated in winter, with poorly fitted doors, windows and ceilings. Again, potential savings are significant - in the order of 25% in some simulations performed by Van Wyk and Mathews (1996) on shack-type dwellings. “Weatherisation” - using caulking, weather strips, or even old cloths and cardboard - is a useful strategy.

Where smoky stoves or braziers are used, a direct chimney is better than extensive general ventilation to remove asphyxiating smoke and carbon monoxide. Space-heating efficiency is improved if there is also a specific air-supply vent for the stove/fire - otherwise the combustion draws cold air into the building.

Lighting

Daylight is cheap, provides good colour definition, and tends to have positive effects on people (compared to artificial lighting). Windows and skylights are well known, and work well. Where glare or direct sunlight is not welcome, diffusers or external shading devices can be advantageous. The success of shading devices is strongly dependent on orientation (see above). Excessive summer-heat gain from skylights can be a problem, as external shading is difficult to arrange. More specialised technologies such as solar tubes, and white or translucent reflectors/diffusers placed inside north-facing vertical glazed openings are sometimes useful and should be more widely used.

Humidity

The most important heat loss mechanism for humans is through the evaporation of sweat from the skin. If humidity levels are high, this evaporation is severely impaired, leading to discomfort at high ambient temperatures. Very low humidity leads to excessive dryness and is also undesirable. Reduced humidity levels are difficult to achieve using low-cost passive design features. Mechanical air-conditioning systems are generally used. However, in hot dry climates, air flow over ponds or through screens of wet porous material can be a highly effective method to increase humidity and cool the air.

The external environment

The texture and composition of surface material used around a building can have an important impact:

- Deciduous trees and vines on the sunny sides of a building will naturally adjust to the seasons,
GUIDELINES FOR HUMAN SETTLEMENT PLANNING AND DESIGN

Chapter 12.2

Other forms of energy

providing needed shade in summer, and allowing sunshine to reach the walls and windows in winter.

- Evergreen shrubs and bushes around the south-western to south-eastern borders can help to shelter houses from high winds (e.g. Western Cape) and provide a measure of insulation from cold winter skies in the highveld or interior.

- Low shrubs could be a disadvantage in humid, mild to hot climates, such as in coastal KwaZulu-Natal, where they will tend to obstruct the welcome movement of air. Trees with a high canopy are more desirable.

- Paving, especially on a northern or western aspect will reflect heat against walls and windows, and can add to heat build-up. If the paving is shaded by deciduous plants on a pergola in summer, however, the potential for enhanced heating can be turned to advantage in winter. Grassed areas will tend to be cooler.

- Pergolas and verandas can provide an important buffer zone around a building, especially with potted plants (their high thermal mass and active transpiration tend to cool the environment).

**Site and building orientation**

Buildings with a longer axis should preferably be orientated within 15˚of an east-west line. This will tend to allow more windows, other openings such as doors, and increased wall area on the northern side to gain maximum benefit from the winter sun, while avoiding overheating in summer (see comments above regarding shade angles). Designers should locate living spaces on this northern side. Westerly orientations, in particular, should be avoided in hotter regions, as a baking afternoon sun can be very difficult to keep out. Northerly orientation can also facilitate the installation of solar water heaters (depending on roof design).

However, the effect of orientation is marginal for small, square structures that have small window areas. It should be stressed that other factors - such as access, security, variety, privacy/conviviality, slope and prevailing wind - should play a role in site layout and planning. Careful planning can still harness the benefits of passive solar design for a range of building orientations.

**Solar access**

Options for passive solar design can be severely restricted by adjacent buildings, especially on the northern side of a property. Site planners and designers should take careful cognisance of existing buildings, and future building possibilities, from the point of view of the current project as well as the needs of future developers on the southern side. In some countries solar rights are legislated, with shading of sites by adjacent buildings between 9 am and 3 pm prohibited (Holm and Viljoen 1996). Shared walls on the eastern and western sides can be an advantage, as they provide excellent insulation.

Site layout and development planning should be carried out with the above concerns regarding shading borne in mind. Road and stand plans should maximise the northern aspects, and avoid dense packing on south-facing slopes (where shading by adjacent buildings will be more severe).

**Different climatic conditions**

Most of the suggestions discussed above can be used to good effect to reduce the cost of energy services and enhance the built environment in all parts of South Africa. However, cost-effectiveness and appropriateness of different interventions is highly dependent on climate. The interior of the country generally has colder night-time and winter temperatures, and in some parts higher daytime summer temperatures. Thus insulation, winter solar gain and thermal mass are important. The Western Cape coastal regions tend to have a more temperate climate, and savings from passive design investments will not be as significant. In hot, humid areas such as coastal KwaZulu-Natal, summer ventilation and avoidance of heat gain (shaded walls, reflective insulation in roofs) are more important. Holm (1996) provides a detailed description of 13 climatic zones in Southern Africa, and provides design guidelines for each.

**Economics and implementation**

Changes to standard designs that bear relatively little cost - such as orientation of buildings towards the north, proper placement of windows for ventilation and summer shading - should be implemented wherever possible. Poor airtightness is frequently a result of poor quality control in construction, and can be improved by better training and quality control. Post-construction weatherisation can also be done low cost.

Cost-benefit estimates for more expensive options (installation of ceilings, insulation, etc) should consider three perspectives, namely those of:

- the householder;
- society at large; and
- the energy utility (especially the electricity-supply authorities).

Sometimes, the savings accruing to building owners...
may be insufficient to justify extra expense but, if the potential savings to the electricity-supply agency or society at large are also considered, a stronger motivation for an intervention can be made.

In general, ceilings and ceiling insulation will be cost-effective for all three parties in most parts of the country. The addition of low-cost insulation to single-skin corrugated-iron structures can also yield positive net benefits to householders. However, especially in coastal regions where ambient temperatures tend to be more stable, it may not be worthwhile from the householder’s perspective to invest in ceiling insulation, or even a ceiling.

Estimates of the energy savings that can result from specific changes in design in specific climate zones can be derived from simulations or manual calculations - for example the CR method (Wentzel et al 1981). Computer programs are useful, some of which have been validated in South Africa (e.g. QUICK II 1998). Internationally developed and marketed programs such as DOE-2E, BLAST, and TRNSYS are also useful, provided that appropriate weather data are used. Such software can be sourced through enquiries addressed to the USA National Renewable Energy Laboratory, or similar institutions.

The viability of different interventions is also affected by the unit energy cost of the fuel being saved. Households using lower-cost heating fuels such as coal or wood will realise smaller financial savings than those using electricity. On the other hand, their health benefits may be greater.

Depending on a household’s ability to set aside money for longer-term benefits (the effective “household discount rate” which balances capital investment against current demands on income), fuel savings from improved building design may not pay back the cost of the investment sufficiently quickly to be attractive. Poor people, in particular, can generally ill-afford capital expenditure, even if payback times are short.

Nevertheless, from the perspective of an electricity-supply utility (seeking to reduce peak demand), or the perspective of local or international society at large (seeking to reduce the impact of excessive energy consumption for space heating on health and the environment), it may be worthwhile to support such investments. This support can be in the form of

- direct subsidies;
- incentives offered for residential demand-side energy management; and
- careful structuring of finance packages (especially for new homes) to encourage people to choose better building designs which will save them money in the longer term.

A particular opportunity to support such investments, which is becoming more readily available, is access to international sources of finance, motivated by global environmental concerns.

Frequently, the pressure on housing developers is to deliver the maximum number of units possible, with minimum capital cost. In the absence of prescriptive legislation in South Africa to enforce construction methods that are more thermally efficient, this tends to result in householders and energy utilities being left with the long-term burden of high energy costs, and uncomfortable living environments. The development of social compacts between prospective homeowners, NGOs, planners and developers (and possibly with international funders) is an important element of building community-wide strategies to rationalise longer-term energy consumption.

HYDROCARBON FUELS

Paraffin

Paraffin is a liquid hydrocarbon fuel, which is produced by refining crude oil. It is very widely used in South Africa as a household fuel in non-electrified or recently electrified settlements.

Paraffin has a calorific value of 37.5 MJ/litre or 46 MJ/kg.

Utilisation and availability

Paraffin is mainly used in domestic applications for

- space heating;
- cooking;
- water heating;
- lighting; and
- refrigeration (less common).

Unlike liquified petroleum gas (LPG), paraffin is not suited to piped reticulation in buildings and is consequently not used in institutions or commercial enterprises.

Approximately 850 million litres of paraffin are used annually in South Africa (DME 1996).

Paraffin is widely available from small traders, garages and supermarkets in quantities determined by the customer’s container size. The standard form of distribution is in 220 litre drums or 20-25 litre tins.

Appliances

A wide range of paraffin appliances is available. These may be pressurised (as in the case of a Primus stove or hurricane lamp) or non-pressurised, as in
the case of a wick lamp. Pressurised appliances are more efficient and provide higher levels of output than non-pressurised units. Paraffin appliances tend to be portable and operate from a dedicated (or integral) fuel tank, which requires periodic refilling from a storage container.

Typical appliances include

- stoves - usually single-pot stoves;
- heaters - wick or pressurised;
- lamps - wick or pressurised hurricane-type; and
- fridges and freezers - usually wick-type units.

Appliances are widely available from general dealers, supermarkets and hardware stores.

Comparative costs

The retail price of paraffin is highly variable, due to the diversity in the distribution chain. Consequently, the retail price ranges from R2.50/litre upwards (October 1997 prices).

Hazards

The hazards associated with the use of paraffin include household fires, burns, asphyxiation and, most significantly, poisoning. Paraffin is poisonous in both liquid form and as a vapour. Up to 10% of children in lower-income households suffer accidental poisoning (PASASA 1997). Children in the age group 1-4 years are most at risk.

Asphyxiation may occur as a result of the inhalation of poisonous paraffin fumes or due to the production of carbon dioxide and monoxide in confined or sealed rooms.

Safety measures

The high social costs of healthcare for paraffin-related injuries or poisoning have resulted in a concerted effort to provide practical measures and greater public awareness of safety in the use of paraffin.

The basic concerns include

- safe packaging and storage - dedicated containers with labels, safety caps, and a locked and ventilated storage area;
- safe utilisation - care of and correct use of appliances, safe handling by using a funnel, avoiding and cleaning spills, adequate ventilation of rooms; and
- health and safety awareness - information pamphlets, poison treatment cards, poison information centres.

The Paraffin Safety Association of South Africa, PASASA (tel: 0800 22 44 22) has developed a child-proof paraffin safety cap for commonly used containers. In addition, PASASA has developed paraffin safety labels for containers, safety posters and training packs for free distribution.

Planning considerations

As in the case of LPG (see below), the planning considerations for paraffin relate to the distribution of paraffin through a network of depots (or wholesalers) and small traders, and to general household fire and safety concerns.

Liquid petroleum gas (LPG)

Liquified petroleum gas (LPG) is a mixture of butane and propane gas stored under pressure, usually in steel cylinders. It is heavier than air, non-toxic and odourless. A smelling agent is added to aid users to detect leaks.

LPG is convenient as it has a high calorific value (energy content per kg) and is hence very portable, provides instantaneous heat, and is easy to ignite and clean-burning.

It is the most environmentally friendly of the commonly used fossil fuels because it is usually efficiently used and has low levels of harmful combustion products.

LPG has a calorific value of 49.7 MJ/kg or 13.8 kWh/kg, which is equivalent to 13.8 units of electricity.

Utilisation and availability

Approximately 280 million kilograms of LPG are consumed annually in South Africa (DME 1996).

Typical uses include

- space heating;
- cooking;
- water heating;
- refrigeration;
- lighting;
- workshop uses: brazing, soldering, welding; and
- school/technical laboratories for use in

- domestic households;
- restaurants;
- hospitals;
- schools;
- small businesses; and
- recreation/leisure.
Appliances

LPG appliances include most of the commonly used electrical appliances other than electronic and/or motorised equipment. These include

- stoves/ovens;
- grills/braais;
- heaters (portable and fixed);
- instantaneous water heaters;
- lamps (portable and fixed);
- irons;
- refrigeration;
- welding plant; and
- bunsen burners.

The most commonly used LPG appliances are cooking, space heating and lighting appliances.

Appliances are designed to operate at an unregulated high pressure, such as in the CADAC (or similar) type of camping appliances, or at a lower pressure controlled by a regulator mounted on - or adjacent to - the gas storage cylinder. High-pressure and low-pressure appliances are not interchangeable.

Most households use gas appliances which operate off a small dedicated gas cylinder, rather than off a reticulated system of gas piping and fixed storage cylinders. Commonly used cylinder sizes are No 3 to No 10, and 9 kg cylinders (see Table 12.2.5).

Gas appliances must comply with SABS 1539:1991.

Comparative costs

The 1998 retail cost of LPG was R4.20 per kg (i.e. a unit energy cost of 8 c/MJ or 30 c/kWh).

The comparative effective costs per energy service are presented in Table 12.2.1.

Hazards

Typical hazards with LPG include:

- burns - common;
- explosions - quite uncommon; and
- asphyxiation due to displacement of air (by unburnt LPG in basements or on tanked floors or, more often, by carbon monoxide build-up in closed rooms).

Installation practices

LPG storage cylinders are supplied in a range of standard sizes in two categories: camping/hobby-type and household/industrial type.

The larger (9-48 kg) cylinders are designed to operate at 7 bar and are tested to 30 bar.

SABS 087:1975, Part 1, Code of practice for consumer LPG cylinder installation, is applicable to the storage of cylinders and gas piping in all cases when more than one cylinder, or a cylinder greater than 19 kg, is used on household premises.

In practice, it is recommended to use two cylinders, a duty and a standby cylinder, to ensure continuous service when the duty cylinder runs empty. It is also more convenient for households to manage two No 10 cylinders (4.5 kg) rather than one 9 kg cylinder.

Fixed gas installations must be installed by a registered gas installer (accredited installers can be checked with the LP Gas Association - refer to contact details below).

Guidelines for installation

The most important installation consideration is

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the provision of good ventilation, preferably natural ventilation, in the storage area and the appliance area. Two airbricks or 150 x 150 mm weather louvres at ground level and high up on an exterior wall are recommended.

Storage of cylinders: outdoors, in a lockable and protected area, in an upright position.

Pipework: 10 mm Class 2 copper with brass compression fittings.

Regulators should comply with SABS 1237:1990.

Safety measures

The LP Gas Association (tel 011 886 9702 or 021 531 5785, PO Box 456, Pinegowrie, 2123) has developed a range of safety-information material and provides training courses for gas suppliers.

The basic safety issues include:

- Safe storage - safe handling and storage of cylinders.
- Safe utilisation - care of and correct use of appliances.
- Health and safety awareness - information pamphlets and training courses for suppliers.

Planning considerations

LPG distribution is provided via depots, which supply small traders or dealers such as general dealers or hardware stores.

Small traders typically supply approximately 2 000 kg/month which corresponds to settlements of between 500-1 000 households or 2 000-10 000 people, depending on the average monthly consumption and household sizes.

An average coverage per small trader could be 3 000 people.

An LPG depot is capable of distributing cylinders to 10-15 small traders.

Coal

Household use of coal

Coal (bituminous or ordinary coal) is one of the lowest-cost fuels available to households for space heating, and ranks on a par with most other fuels when used for cooking and water-heating (see Table 12.2.1). As a result it is widely used in Gauteng, parts of KwaZulu-Natal and in rural and urban settlements close to coal mining districts (refer to Figure 12.2.1). About one million households use coal in these areas (5 to 6 million people). Coal use is less common in other areas, partly because of higher prices due to transportation costs.

Typical appliances include

- cast iron “coal stoves” with closed combustion chambers exiting to a chimney (such as the Dover stove); and
- open and closed braziers, with the Mbaula being a common example; these do not have a chimney and are normally ignited outside, before being brought into the home.

Environmental and health issues

The coal generally used by householders is of relatively low quality (C or D grade), as this is significantly cheaper than higher grade coals. It has an energy content greater than 21 MJ/kg, an ash content of 15% to 50%, and releases noxious volatiles on combustion. The sulphur content is relatively low (1-2%). When burnt relatively inefficiently (as in a stove or Mbaula), the dangerous pollutants include particulates and noxious gases such as sulphur dioxide. Aside from general concerns regarding unpleasant smog and grime on buildings, the indoor and outdoor pollution levels in communities that use coal are high enough to markedly increase the risks of respiratory tract illnesses, with the use of coal in the home increasing risk by a factor of nine in one study (Van Horen et al 1996). If homes are under-ventilated, there is also a risk of asphyxiation from carbon monoxide poisoning. The direct health risks attached to household coal combustion thus have high personal and societal costs.

Efforts to reduce pollution

Strategies to reduce indoor and outdoor pollution from residential coal consumption include

- encouraging the substitution of coal use by other fuels which are cleaner, but require different appliances (LPG, paraffin, electricity);
- the provision of other fuels which can replace coal in existing coal-burning appliances (low-smoke coal, wood, briquettes);
- legislation to reduce allowable smoke emissions and/or prohibit coal use;
- improvement of stove combustion efficiency;
- education on the need to ignite Mbaulas outside the home, only bringing them inside
Once smoke production has reduced:

- Education regarding proper lighting methods (starting a fire on top of a pile of coal rather than underneath can reduce the amount of smoke produced);
- Education regarding proper ventilation;
- Substitution of open braziers and Mbaulas by stoves with chimneys (to remove smoke from indoor environment); and
- Improving the thermal performance of houses to reduce the requirement for space heating (refer to the energy-efficient building design section above).

Although many of the interventions listed above fall primarily within the responsibility of coal users themselves, the effects of pollution affect society as a whole, and it is therefore important for planners, local authorities and national agencies to be directly involved. Some of the above strategies are discussed briefly below.

**Substitution of coal with different “clean” fuels (e.g. electricity, gas).** Both electrification and the provision of gas have the potential to reduce coal combustion in homes, reducing local pollution effects to a minimum. Experience to date, however, indicates that coal stoves continue to be used even after settlement electrification (Van Horen et al 1996). Costs to the householder remain an important barrier to fuel substitution. Coal can be the cheapest fuel for thermal applications (especially space heating - Table 12.2.1). Furthermore, replacement of the multi-purpose coal stove can require the purchase of three appliances: a stove, a water heater and one or more space heaters. Strategies to increase the rate of transition to electricity include

- the subsidisation of new-appliance costs (or improving access to credit for appliance purchase); and
- the subsidisation of electricity tariffs for low-income households (currently being mooted by the National Electricity Regulator).

Similar strategies can be used to promote gas use.

**Substitution of coal with low-smoke coal or other similar solid fuels.** A number of “low-smoke coal” fuels have been developed. These offer the potential of easier substitution in the market place: householders would not have to purchase new appliances or change their cooking and space-heating social/behavioural practices. These fuels can also be marketed through existing coal dealer networks, reducing disruptive effects on employment, etc.

However, low-smoke coals are more expensive than ordinary coal, with production costs three or more times the pithead price of bituminous (ordinary) coal. Even if one assumes savings in distribution costs for locally produced fuels, low-smoke fuels retail prices are from 1.7 to 10 times the retail price of coal (on a per-unit energy basis). Since they have relatively few advantages to the customer (apart from low smoke emission), it is clear that some form of market intervention would be necessary to achieve more widespread use. For a discussion of fuel types and market intervention options see Van Horen et al (1995).

Three products have recently been tested in a large-scale experiment:

- Two brands of devolatilised discard coal (produced by heating discard coal under controlled conditions).
- Compressed paper with a binder. User and merchant reaction was mixed. The devolatilised coal fuels, in particular, were difficult to light, initially blocked grates because they had too high a percentage of fines, and did not have good heat retention. The paper-based fuel was much easier to use, although it also did not have good heat-retention properties. There are thus a number of problems still to be overcome, before it will be possible to actively market a product that can compete directly with coal (Asamoah et al 1998).

**Legislation of smoke-control zones**

Part III of the Atmospheric Pollution Prevention Act (No 45 of 1965) makes provision for smoke control zones in which the sale or combustion of coal for domestic use can be controlled. Enforcement is usually through an education process, with warnings or “abatement” notices being served prior to prosecution for an offence in terms of the Act. Although effective in wealthier communities, where alternatives to coal are affordable, the Act cannot be expected to be observed in poorer communities where there is little economic alternative to coal. It is thus necessary to develop and implement other viable strategies before considering enforcing the observance of a legislated smoke-control zone.

**Education and awareness**

National or regional strategies can be effective only in as much as they are taken on board by communities and individuals. It is therefore important to engage in debate and education...
Biomass

Biomass is extensively used for cooking in South Africa, with an estimated 16 million people relying predominantly on wood for space heating and cooking needs (Van Horen et al 1996). People tend to use open or sheltered fires, usually with a few stones or bricks to support pots or a grid. Varieties of “improved wood stoves” are available, but have not been extensively used or marketed in South Africa. Mean annual per capita consumption of biomass varies depending on the availability of wood, and the degree of substitution with other fuels such as paraffin, gas or even electricity. Typical values are from 350-700 kg per capita per year. Wood is usually collected at low or zero direct financial cost to the household. However, collection times are long (often three or more hours per trip), with multiple trips required per week. Commercialisation of the fuelwood market in rural areas is increasing. Prices are of the order of 20c to 50c per kg (1997-98), depending on availability and quantities purchased.

Concerns regarding fuelwood use

Wood is in many ways an attractive fuel for residential energy supply, as it is low cost (see Table 12.2.1), popular, familiar to people, and the resource is generally well distributed. If harvested on a sustainable basis the net greenhouse gas emissions are zero, and the resource is renewable. However, there are health and broader environmental concerns which should be addressed.

Health related concerns include the following:

• Burning wood brings increased risk of respiratory tract infection and eye diseases as a result of exposure to smoke in poorly ventilated houses. Studies have recorded exposures to total suspended particles from two to eight times recognised international standards (Van Horen et al 1996).

• Even if ventilation is provided, cooks may be so close to the fire that smoke exposure is still high.

• In denser settlements, outdoor air pollution from woodsmoke may also be a problem.

• The risk of burns, especially to children around open fires, is increased.

• Spinal injury and other personal-safety risks are associated with wood-collection trips.

Supply sustainability concerns include the decreasing availability of wood fuel as a result of

• unsustainable harvesting pressure and practices (environmental denudation); and

• competing land use claims for agriculture and housing development.

Biomass strategies

Key strategies for improvement of health and safety in the household environment include the following:

• Substitution of fuelwood with cleaner fuels (electricity, gas, paraffin). However, where wood remains significantly cheaper than alternative fuels, such strategies are expected to have limited impact.

• Greater use of improved stoves with chimneys. Such stoves should remove all smoke from the immediate cooking environment and also have good combustion efficiency to reduce total emissions. “Cooking efficiency”, which is related to combustion efficiency, heat transfer efficiency, and the ability to control the rate of combustion are also important. A key difficulty is the establishment of a sustainable market that can deliver products of adequate standard.

Concerns regarding sustainability of supply can be partly addressed by reducing consumption. However, what is more important is the achievement of an integrated development and resource utilisation framework which takes into account land-use priorities, institutional and private ownership constraints, and biomass energy requirements. Measures directly related to biomass supply include the following:

• Redistribution of wood from areas of surplus to areas of need, preferably using commercially sustainable mechanisms. Sources of potential surplus include commercial farms, commercial forests, water-catchment areas infested with alien vegetation, and farm and game management areas suffering from bush encroachment.

• Encouragement of sustainable harvesting practices. These are often already practised by communities and include collection of dead wood only, cutting of selected branches to allow coppicing to occur, and careful selection of trees to be felled on the basis of size, position and species. Where coppicing does occur it is often useful to prune new shoots selectively to achieve more rapid re-growth of the remaining shoots.

• Development of tree planting and management strategies can enhance the supply
of wood for fuel and other purposes (construction, fencing, carving, etc). Options include woodlots, agroforestry and social forestry.

Woodlots require the establishment and management of small- to medium-sized plantations to produce fuel and other forest products. They have met with mixed success, as management and ownership structures are difficult to establish and maintain in the long term. However, where suitable local authority management structures are in place, they can be effective.

Agroforestry involves the planting of trees in association with crops. This can have benefits for crop production (shade, windbreaks, nitrogen enrichment).

Social forestry is a broad term, referring to community-based resource management involving the planting and management of trees in woodlots, as part of agroforestry, as part of land-reclamation processes, or in greening projects. Greening projects are perhaps most important in terms of settlement development and planning, as they can result in more pleasing and comfortable living spaces and greater access to fruit, wood and other products, depending on species and planting practice (Gandar 1994).

The Directorate of Forestry (Department of Water Affairs & Forestry) is the national entity responsible for overseeing many of the above strategies.

Town gas

Town gas, also called "producer gas", is the term used to describe reticulated gas, which is supplied in older parts of South African cities, such as Woodstock and Observatory in Cape Town, Melville in Johannesburg and parts of Durban and Port Elizabeth.

The gas is usually produced from coal, using a coal gasifier, or as a by-product of the chemical industry. Its calorific value varies, depending on the source, method of manufacture and supply pressure, ranging from 13.3 to 34.0 MJ/m³.

The gas is reticulated in pipes (or gas mains) in the streets and supplied onto each erf via a gas meter, as for water or electricity.

Town gas is currently not considered for any new settlements, although this may change if the Pande natural gas reserves in Mozambique are developed and marketed in Mpumalanga and Gauteng.

Appliances

Built-in appliances such as instantaneous water heaters, cooking stoves and "gas fires" (space heaters) are commonly supplied by town gas.

In general, town-gas appliances operate at a lower pressure than bottled LPG appliances. Consequently, although most gas appliances can operate off either type of supply, they would require modifications to the jets or burners to adapt to the difference in pressure.

Safety

The safety considerations for LPG appliances apply equally to town gas appliances. However, the protection and marking of underground gas pipes also requires attention, to avoid accidental damage and leaks.

Planning considerations

No planning for town gas is required until town gas becomes an available option for new settlements.

Solar energy applications in South Africa

Provision of energy to sites and buildings usually requires the development of infrastructure to deliver the energy carrier (electricity, town gas, LPG, paraffin, etc) to properties. Solar energy is, however, generally available to householders. The following sections discuss the methods and mechanisms to facilitate the use of freely available solar energy for services such as water heating and electricity provision.

The Solar Energy Society of Southern Africa (SESSA) may be contacted for information at PO Box 152, La Montagne 0184, tel (012) 804 3435, fax (012) 804 5691.

Solar photovoltaic electricity supply

Photovoltaic (PV) modules are semiconductor devices that convert the radiant energy of the sun into a direct current (DC) electrical source. These can be coupled with energy storage devices such as batteries and power management equipment, to form an integrated system capable of delivering electricity for wide range of application. Simple systems usually have DC outputs to DC appliances such as lights, television, radio or hi-fi. Larger systems often incorporate a DC-AC inverter to power AC loads. PV systems are modular, have low enviromental impact, are quiet and have a long life (15 year warranties on the PV modules are common). Unit costs of energy are relatively high (R3,60 to R5,00 per kWh, in 1997 rands). However, PV systems can be installed at the point of
need, thus significantly reducing the capital expenditure required for grid extension and even local distribution.

Typical applications of PV systems

Typical applications are listed below, with some indication of the number of installations in South Africa as at September 1998.1

- power for telecommunications (between 60 000 and 100 000 systems, or more than 2 MWp installed);
- rural health-centre service provision (communications, vaccine refrigeration, lighting), with more than 180 such systems installed;
- school lighting and educational equipment power supply (more than 1 200 systems installed);
- domestic lighting, media and other high-quality energy supply needs:
  - individual household systems, often called Solar Home Systems (SHS), with an estimated 50 000 to 60 000 systems installed
  - battery-charging systems (shared by a number of users), a few pilot projects in operation
  - mini-grid reticulation systems (very little SA experience to date);
- water pumping (thousands of systems have been installed - see solar water pumping section below); and
- galvanic protection of structures against corrosion.

Potentially important applications of PV systems which have not yet been implemented on a significant scale in South Africa include

- street lighting in unelectrified communities or along roads not served by nearby sub-stations;
- grid-connected distributed generation systems - for example to provide reinforcement for daytime peak loads at the end of a long line which has insufficient capacity, or for back-up power; and
- building-integrated systems in which the PV modules also serve as facade or roof covering (these offer considerable potential in the future, as the dual purpose renders the products more economically viable).

The use of large PV power plants to generate electricity for the grid is not yet cost-effective.

Hybrid energy supply systems

Sometimes the reliability and cost-effectiveness of a renewable energy system can be improved by connecting two or more energy sources to the system, creating a hybrid energy system. A diesel generator in combination with PV modules will increase the ability of the system to cope with an uneven load demand profile or periods of adverse

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1 The power of PV modules and system is rated in peak watts, or Wp, corresponding to the instantaneous output under standard irradiation conditions, similar to clear sun at midday.

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Figure 12.2.6: Principal components of a stand-alone photovoltaic system
weather conditions. Wind turbines can also complement PV systems effectively, especially in regions where periods of cloudy weather tend to be accompanied by windy weather. Hybrid systems are by nature more complex, and are thus usually justified only for larger systems (5 kWh per day and above). Design guidelines and general reference material on hybrid potential in South Africa may be found in Seeling-Hochmuth (1998). An application receiving considerable attention at present is that of remote-settlement household electrification using mini-grid reticulation systems powered by hybrid energy systems.

Costs

The modular nature of PV systems tends to make their costs per unit of energy available (kWh/day) relatively independent of system size. Most other energy systems show significant economies of scale, with diesel systems tending to be more economical where the daily power demand is greater than 2 kWh/day. PV thus tends to be most economical for smaller-scale applications. Figure 12.2.7 shows generic life-cycle cost estimates (including battery replacement, but excluding a technician’s travelling time), while Table 12.2.6 indicates the range of capital costs for some common applications (including the cost of system-specific appliances).

Selection of the most appropriate technology

Independent isolated applications

Capital and running costs are among the most important factors in deciding whether PV, hybrid systems, diesel, extension of the grid or other technologies are most suitable for a particular application. Costs of energy supply technologies can often be estimated reasonably accurately, and discounted life-cycle cost analyses provide an important tool to aid investment decisions. Figure 12.2.7 gives the approximate unit energy costs for PV, diesel and grid for individual applications (e.g. provision of power to a remote household or

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**Table 12.2.6: Typical PV applications and associated capital costs**

<table>
<thead>
<tr>
<th>SYSTEM DESCRIPTION</th>
<th>SYSTEM SIZE (PEAK WATTS PV ARRAY POWER) AND APPROXIMATE DESIGN LOAD (Wh/DAY)</th>
<th>CAPITAL COST (INCLUDING INSTALLATION)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar home system (medium):</td>
<td>50 Wp</td>
<td>R2 500 to R4 000 depending on supplier and quantity (1997)</td>
</tr>
<tr>
<td>3 DC lights, socket for B&amp;W TV.</td>
<td>110 - 150 Wh/day</td>
<td></td>
</tr>
<tr>
<td>School system (as installed during 1996 Eskom programme):</td>
<td>500 Wp</td>
<td>R55 000</td>
</tr>
<tr>
<td>Lighting for a few classrooms, inverter to provide power for audio-visual equipment, etc.</td>
<td>1 100 - 1 500 Wh/day</td>
<td>R61 000 (Borchers and Hofmeyr 1997)</td>
</tr>
<tr>
<td>900 Wp</td>
<td>2 000 - 2 600 Wh/day</td>
<td></td>
</tr>
<tr>
<td>Health Centre:</td>
<td>450 Wp</td>
<td>R62 000</td>
</tr>
<tr>
<td>Lighting, vaccine refrigeration (high availability required), examination lighting, communications; staff quarters lighting and entertainment.</td>
<td>900 - 1 200 Wh/day</td>
<td>R76 000 (Borchers and Hofmeyr 1997)</td>
</tr>
<tr>
<td>600 Wp</td>
<td>1 200 - 1 600 Wh/day</td>
<td></td>
</tr>
</tbody>
</table>
health centre). From this figure it is clear that PV systems tend to be the most cost-effective for relatively small loads, remote from the grid. Additional factors which may increase the desirability of PV systems - even for higher load applications - include

- concerns regarding maintenance costs, reliability and security of fuel supply of diesel systems (particularly for systems where high reliability is important, such as telecommunications); and
- a requirement for low noise and/or pollution levels (particularly in environmentally sensitive areas, such as nature reserves or tourist areas).

When comparing costs of systems, it is important to consider the load devices that will be used. As will be discussed in more detail below, it is frequently worthwhile to use different appliances (and a broader range of energy carriers) than would be the case if grid electricity were available.

Settlement electrification - when to extend the grid or use off-grid technology

Where technology selection may affect an entire community, the decision is more complex. The South African electricity-supply industry is currently engaged in a large, heavily subsidised programme to extend grid access to millions of households. The rapid pace of development, and the changeable nature of planning structures, means that there is little long-term certainty regarding the future reach of the grid. Furthermore, even remote communities usually have high expectations of gaining access to the grid in the near future. As a result there is considerable reluctance on the part of communities and many institutions to invest in PV, as subsidised grid access is a far more preferable power supply option, if it can be obtained. The arrival of grid to a settlement will significantly reduce the value of any prior investment in PV or other off-grid technology. Every effort should therefore be made to determine the probability of grid electrification. Grid-planning uncertainty remains one of the most important barriers to wider-scale use of PV technology for rural electrification.

From a financial (and economic) point of view, the principal factors affecting technology choice for community electrification are listed in Table 12.2.7. However, electrification planning decisions are fraught with political, economic and social ramifications. It is thus essential that decision-makers consult appropriately, both with authorities and proposed target communities.

**PV system design:**

The principal components of a typical stand-alone PV system are the PV array (comprising one or more PV modules), charge controller and a lead-acid battery (see Figure 12.2.6). In some cases an inverter will be used to deliver AC power. Larger systems may incorporate a maximum power-point tracker. Both the wiring used and the specific appliances used are crucial to successful operation of a PV system. It is therefore advisable to consider the entire system from module to load appliances when conceiving and implementing a PV system application. The following aspects are important considerations for PV system design. For more detailed information on technical design elements refer to Cowan et al (1992) or Hankins (1995).

Polycrystalline, monocrystalline and amorphous (thin film) modules are available. While the latter have lower costs, they tend to suffer gradual degradation of output power over time, and should thus be used with caution in situations where long life is important.

Physical tracking of the sun can lead to gains of 25 to 35% in PV array output. However, the added complexity and reduced reliability means that this is usually not economical.

Given the high capital cost of PV systems, it is important to specify load accurately, and to avoid overdesign of capacity.

Appliance efficiency is more important for PV systems than for grid or diesel systems, due to the high marginal costs of energy.

An energy-service approach should be adopted in preference to an electricity-service approach. This requires consideration of the most appropriate energy source for each appliance/service required. For most applications involving heating PV will not be the most appropriate, as gas or other clean fuels provide a convenient and cheaper service. Refrigeration is also cheaper using gas, provided that supply availability can be assured.

The cost increases significantly if the system is required to store enough energy in the battery to deliver the full load, even under prolonged adverse weather conditions. Prioritisation of loads can be considered. Very high availability levels (requiring over-sizing) are normally only specified where essential (e.g. for vaccine refrigeration or telecommunications).

Careful matching of PV array size, storage capacity and load for local solar radiation conditions is important to reduce overall costs. Paper-based methods and a computer program (POWACOST)
are included in Cowan et al (1992).

The charge controller (or regulator) is the heart of a PV system. It is very important to match its control characteristics to those required by the particular type of battery used.

Battery technology selection is important, as incorrect matching of battery to charge controller and system load profile can lead to high battery-replacement costs. For larger systems, the use of specialist deep-cycle batteries is advised. Cowan et al (1992) provide a detailed description of battery technologies and implications for PV systems. IEC 61427-1 is a draft standard for secondary cells and batteries for PV systems.

Current flows in DC systems tend to be quite high (a 100 W load will draw 8.3 A at 12 V). Voltage drop in cables should be kept below 8%.

Both DC and AC output systems can be used. Selection of appropriate voltage will depend on the requirements of available appliances and load duty profiles. For simple systems DC is usually satisfactory. DC refrigerators are also usually more efficient. For larger systems, some appliances require AC (audio-visual equipment, workshop tools). However, the choice of DC or AC lighting on large systems is not simple. Careful analysis of the cost, efficiency and reliability implications of different options is required.

Installation of PV systems with a system voltage less than 50 V currently does not fall under the SABS 0142:1993 code of practice on the wiring of premises. However, there are indications that this will become a requirement. Cowan (1996) provides a detailed code of practice for installations.

<table>
<thead>
<tr>
<th>Table 12.2.7: Criteria for grid versus off-grid electrification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SETTLEMENT CHARACTERISTIC VIABILITY</strong></td>
</tr>
<tr>
<td>Proximity to existing or planned grid infrastructure of suitable capacity and voltage rating.</td>
</tr>
<tr>
<td>Settlement size (number of households).</td>
</tr>
<tr>
<td>Proximity of households to each other (hh/km²).</td>
</tr>
<tr>
<td>Proximity of settlement to other similar settlements.</td>
</tr>
<tr>
<td>Expected load, especially for businesses, institutions and water supply.</td>
</tr>
<tr>
<td>Presence or otherwise of exceptional renewable energy resources.</td>
</tr>
<tr>
<td>Existence in settlements of community services such as schools, health centre, community centre, police, water pumps, etc.</td>
</tr>
</tbody>
</table>
Important applications of PV in rural settlements

Four major programmes using PV technology to deliver services in rural settlements have been initiated in South Africa. Considerable technical expertise has been built up, and although national standards are not yet available, potential users are encouraged to contact the organisations below to obtain information on standards and specifications:

- Health centre electrification: principally through the Independent Development Trust (Cape Town), with technical support primarily through the Energy & Development Group (Noordhoek).
- School electrification: Eskom (Megawatt Park and Non-Grid Electrification), with international and government support through the Department of Minerals and Energy.
- Solar Home System projects: a variety of role-players including government, Eskom and the private sector. Detailed specifications are being drafted by Eskom NRS (NRS 052, draft 1998).
- Rural telecommunications service delivery: primarily managed by Telkom.

Maintenance and user training

PV systems are generally regarded as being low-maintenance items. However, the remote location of most installations means that scheduled or unscheduled maintenance costs can be very high. Unfortunately, experience in rural community household-electrification programmes (in South Africa and internationally), and in many institutional settings such as schools and water-supply projects, indicates that provision for maintenance (financial, institutional, training, user education) is frequently insufficient. Three areas are critical:

- **Cost of components**
  
  Battery replacements, in particular, represent an ongoing cost, particularly in low-cost household applications, where average lifetimes are about 3,5 years. Lights also have a finite life (1 000 to 10 000 hours) and will need to be replaced.

- **Availability of technical resources**
  
  Although most small systems are not complex, the average user will not be able to carry out all the maintenance. Given the high cost of travelling and specialised staff, it is important to establish and support local technicians, equipped to service the systems in a given area.

End-user/customer training

PV systems serving loads that are under user control (households, schools, clinics, etc) need to be properly operated to obtain maximum benefit, and to reduce the probability of premature battery failure. It is thus important to provide informative user education, and to ensure that systems are equipped with indicators to inform the user regarding battery status.

Quality assurance and specifications

Although the PV industry has been active in South Africa for close on twenty years, the market size has been inadequate to develop recognised quality-assurance standards, training certification, and standard specifications for PV systems and components (other than the modules). As a result, it is sometimes difficult for the purchaser to ensure that components used are efficient and of good quality, and to ensure that design and installation are properly carried out. Changes are, however, taking place rapidly, both within the country and internationally. Standard specifications for particular system configurations and for specific balance of system components are being developed. A number of codes of practice for installation have also been developed, and may be incorporated into national standards documents. Although there has been some development of training courses, certified PV training courses are not yet well established. The following documents (or the latest drafts) are useful:

- NRS 052:1998 (draft), Technical specification for PV systems for use in individual homes.

Finance and dissemination models

PV systems require large capital investments up front (as does grid electrification). However, the dispersed location of customers and the autonomy of installations mean that they are not normally considered part of utility business. As a result, consumers do not gain access to the low-interest - and often subsidised - long-term finance so essential to grid development, or to the project management and consumer support programmes that are crucial to normal grid-electrification project development and long-term operation.
For institutional clients such as schools, health centres and water authorities, access to finance for capital expenditure and project management can usually be resolved. Longer-term maintenance is often more difficult, as discussed above.

For households, the problems are far more intractable. Finance services geared to remote rural areas are expensive to administer, particularly for the small- to medium-scale loans required for PV systems. Incomes are often uncertain and security may be a problem. Customers require assurance that systems will work for extended periods, and there are also concerns regarding the sustained provision of maintenance services. Despite these barriers, numerous householders (numbered in the tens of thousands) have already purchased PV systems. Various strategies have been proposed or tested to enhance dissemination potential.

Hire purchase or loan schemes involve the establishment of specialised credit facilities that can be used either by individuals or, in some cases, by groups or co-operatives, to purchase PV systems. In parallel with the credit facility, NGOs, government, industry or perhaps the grid utility provide project-management services to facilitate bulk purchasing, customer education, local technician training, and efficient installation of PV systems within a community. A variation of this system is to establish a local service point near the targeted communities. This owner/franchisee/agent can then act as a liaison for loan applications, system supply and technical support. Although customers will need to make provision in the long term for ongoing maintenance costs, purchase costs are for a finite period (typically three or four years) and, once the system is paid off, monthly costs will be significantly reduced.

An alternative is to maintain more of a utility approach to PV electrification. In this case financial, technical and administrative infrastructure is established in a region to enable long-term leasing of PV systems by customers for a monthly fee. Essentially, the customer pays for an energy service, not a product. The approach is potentially more attractive to customers, as the risks involved are far lower, and monthly payments should be lower than for a loan-based system. Maintenance will remain the responsibility of the service provider (except for lights and possibly house wiring). Should the grid arrive at some future date, customers can simply stop their lease and return the systems to the service provider, with relatively little loss of investment.

An important technical development which makes both “service-based” and loan-based dissemination strategies simpler to administer, is the introduction of pre-payment meter technology to PV systems. This allows the user to have greater control over monthly expenditure, and provides a reasonably efficient way to eliminate bad debts. The addition of active security chips to controller, array and battery makes it possible to reduce the potential for tampering and theft.

**Solar water pumping**

Solar water-pumping systems use the sun’s energy to produce electricity which, in turn, drives a submersible or line-shaft pump.

Solar water pumping is increasingly attractive as a replacement for hand pumps, wind pumps and diesel pumps. Between 10 000 and 20 000 systems are already in operation internationally, roughly 3 000 of which have been installed in southern Africa. Some solar pumps have been in operation for more than 10 years in South Africa.

**Comparison of different pumping options**

**Grid electricity pumps**

These are the cheapest option if grid electricity is available at the water source. However, extensions of MV powerlines typically cost from R40 000 to R60 000 per km and consequently non-grid options are often cheaper if grid supply is not available.

**Diesel water pumps**

This option is widely used for off-grid applications. Although the initial costs are low there are significant disadvantages to diesel systems. These include very high operating costs, high levels of maintenance and supervision, noise and dirt, and a dependence on a reliable fuel supply.

**Solar water pumps**

This option is applicable for off-grid applications and is more widely used now that farmers and authorities are becoming more familiar with the benefits of minimal maintenance, low operating costs and quiet and reliable operation. Disadvantages include the high initial costs (two or three times the costs of diesel) and the risk of theft of solar panels.

**Wind pumps**

This option has been widely used on farms and in rural areas. Approximately 300 000 wind pumps have been supplied in South Africa. Disadvantages include the relatively high levels of maintenance required and the unreliability of the wind.
Hand pumps

This option is suitable for very small water demands (<50 people). It is not suited to reticulated water-supply schemes.

Table 12.2.8 shows the comparative characteristics of these different pumping options.

When is solar pumping appropriate?

Solar pumping is appropriate in any application where grid electricity is unlikely to be available for five years (or more) and the average pumping requirement is less than 2 000 m³/day - that is, volumetric demand (m³/day) multiplied by the total head (m). The criterion of 2 000 m³/day is illustrated in Figure 12.2.8.

![Figure 12.2.8: Volume and head relationship for the pumping criterion of 2 000 m³ per day](image)

<p>| Table 12.2.8: Comparative characteristics of different community water pumping options |
|---------------------------------------------------------------|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>NO OF PEOPLE</th>
<th>INITIAL COST</th>
<th>O&amp;M COSTS</th>
<th>OPERATOR INPUT</th>
<th>RISK OF THEFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid</td>
<td>Any</td>
<td>Depends on access</td>
<td>Very low</td>
<td>None</td>
</tr>
<tr>
<td>Diesel</td>
<td>&gt;1500*</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Solar</td>
<td>&lt;1500*</td>
<td>High</td>
<td>Low</td>
<td>Minimal</td>
</tr>
<tr>
<td>Wind</td>
<td>&lt;200</td>
<td>Medium</td>
<td>Low</td>
<td>Minimal</td>
</tr>
<tr>
<td>Hand</td>
<td>&lt;50</td>
<td>Low</td>
<td>Very low</td>
<td>Minimal</td>
</tr>
</tbody>
</table>

* Assumes a 50 m total head.

Source: Borchers (1998)

| Table 12.2.9: Typical initial costs and associated operating costs for different pumping systems (in 1997 rands) |
|---------------------------------------------------------------|-----------------|-----------------|-----------------|-----------------|
| NUMBER OF PEOPLE | 100 | 500 | 2 000 | 6 000 |
| PUMPING REQUIREMENT | 125 m³/DAY | 625 m³/DAY | 2 500 m³/DAY | 7 500 m³/DAY |
| Grid | Initial cost | 7 500 | 8 500 | 11 500 | 16 500 |
| | Annual cost | 500 | 1 000 | 2 300 | 5 400 |
| Diesel | Initial cost | 36 000 | 39 500 | 46 800 | 63 000 |
| | Annual cost | 9 000 | 16 000 | 2 300 | 34 000 |
| Solar | Initial cost | 14 000 | 43 300 | 240 000 | - |
| | Annual cost | 100 | 200 | 350 | - |
| Wind | Initial cost | 15 500 | - | - | - |
| | Annual cost | 2 000 | - | - | - |
| Hand | Initial cost | 8 500 | - | - | - |
| | Annual cost | nil | - | - | - |

Source: Borchers (1998)
Costs

Typical comparative initial costs and operating costs for the different pumping options are shown in Table 12.2.9.

Principles of operation

Solar (photovoltaic) panels convert solar light energy directly into direct current (DC) electricity, which is conditioned in a controller, to an electrical output suitable for a DC or AC pump motor. Water is generally pumped into a storage reservoir and reticulated to households or community standpipes. Figure 12.2.9 illustrates the principles of operation.

Three of these are illustrated in Figure 12.2.10.

Life-cycle costs of different pump types

Typical unit water-pumping costs (1998) for different solar pump options based on 15-year life-cycle costs are shown in Table 12.2.10.

Table 12.2.10: Typical pumping costs for solar pumps, based on 15-year life-cycle costs

<table>
<thead>
<tr>
<th>PUMP TYPE</th>
<th>TYPICAL PUMPING CAPACITY</th>
<th>UNIT COST FOR WATER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Submersible diaphragm / piston pumps</td>
<td>0 - 400 m³</td>
<td>&gt;1,2 c/m³</td>
</tr>
<tr>
<td>Surface-mounted line shaft pumps</td>
<td>0 - 1 200 m³</td>
<td>1,5 - 5 c/m³</td>
</tr>
<tr>
<td>Submersible multi-stage pumps</td>
<td>0 - 4 500 m³</td>
<td>&gt; 20 c/m³</td>
</tr>
</tbody>
</table>

Source: Borchers (1998)

Planning and installation considerations

The planning and installation considerations for solar water pumps are generally similar to other water-pumping systems, except that special care needs to be taken to minimise the risk of theft of the PV modules.

The risk of theft of the modules may be reduced through community participation and ownership, and the location of solar pumps out of sight of opportunistic thieves (i.e. not near main roads).

Solar water heating

Water heating accounts for up to 40% of household energy consumption. Solar water heating (SWH) systems can provide water at temperatures of up to 85°C on sunny days, independently of other energy sources, for a wide range of uses in urban and rural areas. SWH systems generally have some form of auxiliary (or backup) heating for periods of overcast weather and for short-term peak demands which exceed the average daily output of solar-heated water.

SWH systems are an attractive alternative to more conventional water-heating systems because they have fewer negative effects on the environment and can be more cost-effective within comparatively short payback periods - as little as 3-5 years (depending on the exact application).
Typical applications include

- domestic water heating;
- hot water for public bath houses;
- underfloor heating;
- old age homes;
- swimming pools;
- horticulture / aquaculture;
- small businesses: laundries; hairdressers; undertakers; caterers/restaurants;
- hospitals;
- clinics; and
- school hostels.

**Advantages**

- the ability to provide 40-100% of hot water needs;
- the use of renewable energy (avoidance of environmental costs of electricity generation and transmission);
- the reliability of the energy source;
- the fact that it is financially cheaper (after a period of between 3-5 years); and
- the reduction of uncertainty of monthly cash flows.
Disadvantages

- the high initial cost (twice as much as a conventional electrical “geyser”);
- the need for some form of backup heating for overcast weather; and
- the lack of confidence in quality assurance.

This section focuses on domestic and institutional (i.e. hostels, public bath houses, hospitals and clinics’) hot-water systems.

Current use of SWH systems in SA

SWH systems have been available commercially for many years. The supply and installation of SWH systems experienced a significant peak in the mid-1970s as a result of the energy crisis and subsequent focus on alternatives to fossil-fuel-based energy systems.

SWH systems are relatively simple devices which are well suited to local manufacture. Consequently, SWH systems offer opportunities for job creation, in addition to electricity and energy savings. However, the relative ease of production requires careful consideration of quality assurance measures, to prevent poor performance and premature failure.

Current estimates suggest that, by 1994, over 70 000 domestic SWH systems had been installed in South Africa (Energy and Development Group 1997a). See Table 12.2.11.

When is SWH appropriate?

SWH systems produce hot water whenever the sun shines, regardless of whether the hot water is used. SWH systems are therefore most suited to applications which require consistent quantities of hot water on a daily basis throughout the year. Solar water heating is generally not suited to applications which require variable and unpredictable hot water demands.

In the case of households, SWH should immediately be considered if grid electricity is not available (i.e. for use in conjunction with non-grid electricity systems such as PV, wind or diesel units).

In cases where grid electricity is available, SWH systems may become cost-effective in 18 months to a few years (depending on the circumstances) for new houses and new institutional applications.

Although SWH systems operate well anywhere in South Africa, they are more appropriate in the sunny inland regions of the country.

Comparative costs

The comparative (1998) costs of SWH, electrical storage heating systems and instantaneous water heating for a typical family of four to five persons are presented in Table 12.2.12 in terms of overall life-cycle costs over 10 years.

The cumulative costs and payback characteristics are shown in Figure 12.2.11.

| Table 12.2.11: Estimated solar water-heater capacity installed in South Africa |
|-----------------|-----------------|-----------------|
| APPLICATION      | INSTALLED COLLECTOR AREA (m²) | COMMENTS |
| Domestic         | 220 000          | Approx 70 000 systems |
| Commercial and industrial | 34 000          | e.g. Milnerton Girls’ School |
| Agriculture/horticulture | 2 600          |  |
| Swimming pools   | 227 000          | Approx 8 000 systems |
| Public bathhouses | -              | e.g. Durban Metro, Langa |


| Table 12.2.12: Comparative water-heating costs |
|-----------------|-----------------|-----------------|
| APPLICATION      | SWH SYSTEM | ELECTRICAL GEYSER | ELECTRICAL INSTANTANEOUS HEATER |
| Initial cost     | R3 750      | R2 000            | R2 400            |
| Annual operating cost | R375        | R950             | R750             |
| Life-cycle costs | R5 800      | R7 100            | R6 600            |

Note: The life-cycle costs are highly sensitive to the particular application and should be established for each specific case. The key sensitivities are initial cost, real discount rate, operating lifetime, and utilisation of the solar heated water (or solar fraction).
Typical considerations in planning for SWH systems

Water supply

Reticulated water supply, for a continuous/pressurised supply, or standpipe in the yard, for a batch-heating type of supply.

Water pressure

Generally best at <200 kPa to reduce water consumption, minimise the mixing of hot and cold water in the storage tank, and reduce stress and wear and tear on the valves and connections.

Water quality implications

Generally, water which is safe for potable use is safe for use in SWH systems. Corrosion of SWH systems may be a problem with untreated (farm) water, but is generally avoided through appropriate choice of materials, such as copper and plastics.

System durability and expected lifetimes

SWH systems generally last as long as - or longer than - standard electrical storage heaters. Unless abnormal hail or freezing damages the SWH systems, the storage tank is likely to fail first.

Criteria for selecting SWH for water heating

Access to grid electricity

If the need for hot water cannot be met with grid electricity, SWH systems (with LPG or wood-fired auxiliary backup heating) are highly recommended. If grid electricity is available, the comparative costs and benefits of electrical and solar water heating need to be assessed in detail.

Hot water draw-off patterns

The water consumption patterns of the users (volume, time of draws, consistency of draw-off patterns) can influence the utilisation of solar heated water. For example, use of hot water in the afternoon and early evening is ideal (high levels of solar utilisation) while early morning consumption is less satisfactory due to overnight heat loss and the need for auxiliary backup (non-solar) heating.

Solar access

The effectiveness of SWH systems is dependent on solar access, that is, geographical location, orientation of the collectors (facing north in the range 15°E – 45°W) and angle of tilt of the collectors (ideally latitude +10°), and shading by adjacent buildings or trees. Clearly, if the collectors are not oriented correctly or if they are shaded, they will need to be oversized to compensate, thereby increasing the cost.

Freezing conditions

SWH systems are very exposed and vulnerable to freezing if they are not specifically designed for such areas (e.g. indirect heating systems). In general, all inland parts of South Africa (except the Lowveld in Mpumalanga and the Northern Province) are freezing areas. The immediate coastal zones are generally non-freezing areas.

System types

The two essential basic components of all SWH systems are the solar collector (or absorber) and the solar water-storage tank (with safety valves). Other optional components, depending on the system type, are insulated interconnecting pipework, a circulating pump, non-return valves, auxiliary backup heating systems, support structures, and instrumentation.

SWH systems may use direct heating or indirect heating systems depending on the type (see below) and the need for protection of the solar collector and interconnecting pipework against damage due to freezing. In direct-heating systems the hot water is heated directly in the solar collector, whereas in indirectly heated systems it is heated in the storage tank, using an anti-freeze primary heating fluid and a heat exchanger.

Domestic SWH systems are generally supplied in four types:
Direct batch heater

A small (10-50 litre) directly heated, portable SWH system which is filled and drawn off by hand and manually placed in the sun.

Application: Suitable for households which do not have piped water (i.e. non-pressurised) and which may not be able to afford bigger or more complex systems.

Auxiliary backup heating: None.
Typical cost: R100-R800 (1998).
Typical output: 30-120 litres/day at 55°C for multiple draw-offs.
Suitable for freezing and non-freezing areas.

Integral SWH system

Figure 12.2.12 - a small (100-litre, typically) directly heated SWH system in which the solar water-storage tank is painted black and enclosed in a glazed and insulated casing to act as the solar collector. Integral systems are usually roof-mounted and can be pressurised. Integral SWH systems are not suitable for early morning water draw-offs, due to high overnight heat loss.

Auxiliary backup heating: Integral systems generally do not have backup heating, although electrical backup is possible.

Application: Suitable for households which have piped water but which may not be able to afford more sophisticated systems.
Typical cost: R1 200-R1 800 (1998).
Typical output: 100-150 litres/day at 55°C for multiple draw-offs.
Suitable for freezing and non-freezing areas.

Close-coupled SWH system

Figure 12.2.13 - a small to large (100 litre/1.6 m² - 300 litre/4.2 m²) direct or indirect heating, roof-mounted SWH system in which the horizontal solar storage tank and solar collector are mounted adjacent to one another as a packaged, close-coupled unit. It may be pressurised <400 kPa and equipped with an optional single electrical backup heating element (1.5-3 kW) mounted halfway up the tank height.

Application: Retrofit to existing houses or install in new houses which have flat or low-pitched roofs and will not allow a tank to be mounted in the roof space.

Typical cost: R4 000-R10 000 (1998).
Typical output: 150-400 litres/day at 55°C for multiple draw-offs.
Suitable for freezing areas (indirect heating) or non-freezing areas (direct heating).

Split collector/storage system

Thermosiphon or pumped - Figure 12.2.14 - the most elegant and sophisticated of SWH system configurations, in which the solar storage tank is mounted in the roof space and the solar collector is mounted externally on the roof. These are usually larger systems (200 litre/2.8 m² - 300 litre/4.2 m²) and pressurised <400 kPa. The heating fluid may circulate automatically by thermosiphon if the storage tank is physically higher than the top of the solar collector, otherwise it will require the additional complexity of a circulation pump. Electrical backup with single or dual (bottom and halfway up) elements (1.5-3 kW) forms part of the system.

Application: Aesthetic appearance most suitable for new houses with sufficient pitch in the roof to accommodate the storage tank.
Typical cost: R4 500-R12 000.
Typical output: 150-400 litres/day at 55°C for multiple draw-offs.
Suitable for freezing areas (indirect heating) or non-freezing areas (direct heating).
Large commercial or institutional systems

These are all-purpose designed split collector/storage-type systems. They are generally forced-circulation systems, although thermosiphon systems are possible if the storage tanks can be located sufficiently high above the collector bank. As in the case of domestic SWH systems, indirect heating is required in freezing areas.

Typical examples of larger systems are those at the Milnerton Girls School (Maclean 1982) and an old age home in Durban (Forbes and Dobson 1982).

Design for upgradability

In cases where the user/client is reluctant to spend the full initial cost of the SWH system, it is recommended that the (electrical) water-heating system be designed so that it can be upgraded for solar heating at a later stage.

Upgradability requires minimal extra expense (a solar-adaptable storage tank), consideration of solar access (for the future collectors), and the location of the storage tank in a position which allows short and inclining collector loop piping.

System sizing

Tables 12.2.13 and 12.2.14 provide guideline information for sizing SWH systems in typical South African conditions.

System design

System design should focus on functionality and reliability. Although thermal efficiency is important, the utilisation of SWH systems is directly dependent on reliable operation over the full design life of the system.

In the case of domestic hot water systems, there are two applicable SABS standards:


### Table 12.2.13: Typical hot water requirements for domestic and institutional purposes

<table>
<thead>
<tr>
<th>HOT WATER SERVICE</th>
<th>HOT WATER SUPPLY TEMPERATURE (DEG C)</th>
<th>WATER TEMPERATURE REQUIRED (DEG C)</th>
<th>VOLUME PER DAY (LITRES/PERSON)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic</td>
<td>55</td>
<td>43</td>
<td>50 - 75</td>
</tr>
<tr>
<td>Hospitals</td>
<td>65</td>
<td>43</td>
<td>120</td>
</tr>
<tr>
<td>Old age homes</td>
<td>65</td>
<td>43</td>
<td>100</td>
</tr>
<tr>
<td>Per shower</td>
<td>55</td>
<td>43</td>
<td>25 - 35</td>
</tr>
<tr>
<td>Per bath</td>
<td>55</td>
<td>43</td>
<td>80 - 120</td>
</tr>
</tbody>
</table>

### Table 12.2.14: Guidelines for sizing domestic SWH systems

<table>
<thead>
<tr>
<th>NUMBER OF PEOPLE PER HOUSEHOLD</th>
<th>LITRES OF HOT WATER REQUIRED AT 43°C</th>
<th>SOLAR STORAGE TANK SIZE (LITRES)</th>
<th>COLLECTOR AREA (m²) DUE NORTH AT LATITUDE +10°</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 - 3</td>
<td>100</td>
<td>100</td>
<td>1,4 - 1,6</td>
</tr>
<tr>
<td>4 - 6</td>
<td>200</td>
<td>200</td>
<td>2,8 - 3,2</td>
</tr>
<tr>
<td>6 - 8</td>
<td>300</td>
<td>300</td>
<td>3,8 - 4,2</td>
</tr>
</tbody>
</table>
Other solar energy applications in South Africa

Solar water heaters, solar photovoltaic units and the passive solar design of buildings remain the most significant solar energy applications in South Africa at present.

Solar energy can also be used for process heat in industry and agriculture, but this is generally not of relevance to settlement-planning.

In the future it is possible that other means of generating electricity from solar energy will become more widespread. Brief details on solar thermal electricity generation are provided in the section “Other renewable energy sources” below.

Solar cookers

Solar stoves and solar ovens would have great relevance in South Africa if they were popularly adopted on a wide scale. They are mostly considered as a supplementary cooking option in areas of fuel scarcity, in addition to LPG, paraffin, fuelwood and crop residues. In particular, they could benefit households struggling to collect fuelwood, crop residues or dung for their cooking needs, and might help to conserve the environment.

Solar cookers generally use reflectors to concentrate radiant solar energy either directly onto a pot or into a glazed and insulated box (called a “box cooker” or “solar oven”). They are capable of cooking the typical meals of rural and low-income households. A variety of designs are available locally and internationally, including simple solar ovens, reflector-type cookers and heat pipe cookers.

Experience with the promotion of solar cookers in Southern Africa in the 1980s was disappointing. Cooking customs are deeply rooted and slow to change (except in extreme conditions - for example in refugee camps). However, a recent one-year, field testing project (Palmer Development Group 1998) undertaken on behalf of GTZ and the Department of Minerals & Energy has shown high levels of satisfaction (93%) and good utilisation (38% of all meals cooked) of a range of solar cookers.

Typical costs of the cookers in this study ranged from R180 (Sunstove) to R4 600 (SCHW1). The study found clear user preference for certain cooker types, based on utility and cost, and many of the participating households opted to buy a solar cooker.

Solar cookers are safer than fuelstoves or fires, due to the absence of a flame and greater stability.

OTHER RENEWABLE ENERGY SOURCES

This section provides a brief description of other renewable energy sources which are not widely used in South Africa at present (with the exception of wind pumps), but which may be considered in specific circumstances. The topics covered in this section are

• wind power;
• small hydropower;
• biogas and exploitation of landfill gas; and
• solar-thermal electricity generation.

Wind power

Wind power is usually employed either directly (mechanically) for water pumping, or for electricity generation.

Wind pumps

Water-pumping by windmill is a well-established technology that has long been widely used in South Africa, mainly in rural areas but also in small towns. The familiar “American farm windpump” design (with a large number of blades) is well proven, efficient for water pumping, and locally available from a number of manufacturers. More than 300 000 windpumps of this type have been installed in the country (Cowan 1992) although not all would still be in operation. These types of windpump are particularly suited to pumping relatively small quantities of water from deep boreholes, using positive-displacement pump mechanisms (e.g. for livestock watering) and can be used in areas with quite low average wind speeds (e.g. 3 ms\(^{-1}\)) but are more likely to be a cost-competitive option if wind-speeds average 4 ms\(^{-1}\) or more. Regular basic maintenance is required for trouble-free operation, and partly for this reason there has been a trend in countries such as South Africa and the United States to move towards solar PV pumps for typical ranch and game park applications (in areas without grid electricity).

The use of wind pumps for community water supplies in rural areas has so far not had a very good record in South Africa. The main problems appear to have been unreliable maintenance, lack of community involvement and ownership (Wiseman 1992), and sometimes unreliable supply/storage of water due to variations in wind energy at different times of the year, and from year to year. Any decision to use wind pumps for a community’s water supply, and the design of suitable installations, should take account of

• community water needs (quantities, quality, reliability);
• the nature and reliability of the water-supply source;
• the availability of reliable wind-speed data;
• the adequacy of the local wind resource, especially in the calmest months;
• linked to this, the amount of windmill oversizing and water storage required to provide a reliable supply (or else the availability of back-up water supplies);
• water-treatment facilities;
• reliable provisions for routine maintenance and speedy repair; and
• the comparative costs and advantages/disadvantages of alternative water-pumping options.

A good guide to wind pump sizing, design and economics is Van Meel and Smulders (1989). South African wind pump suppliers have considerable experience and can provide practical recommendations, sizings, costings, etc.

Wind-powered electricity generation

The use of wind energy for electricity generation is one of the fastest-growing developments in the world energy industry at present. Electric wind turbine generators have been used for decades for off-grid electricity (e.g. on farms) but large-scale wind farms feeding power into national grids are more recent. In areas of the world where there are favourable wind resources for electricity generation (greater than 6.5 ms\(^{-1}\) mean wind-speeds, preferably higher) and where other sources for electricity generation are expensive or inadequate, grid-connected wind farms are financially viable.

Grid-connected wind generation

Large, efficient and reliable wind turbines involve high-technology design and manufacture. The most cost-efficient machines used to be in the range of a few hundred kilowatts (rated power) but, through technical advances, now generate 1-1.5 MW. In the competitive world market for such wind turbines, there are a number of international market leaders. This leading-edge technology is considered mature and reliable, but still advancing.

Typical costs

Typical international capital costs and electricity generation costs for large-scale wind farms in 1997 were in the region of 4.5 US cents per kWh generated, in locations with very good wind resources.

The costs per kWh are highly dependent on wind speeds, because available wind power is proportional to the cube of the wind velocity. Locations for viable wind farms typically have annual wind speeds in the range 6.5-10 ms\(^{-1}\).

Dependence on wind speeds

The total power of a wind, moving through an area of \( A \) m\(^2\) with velocity \( V \) ms\(^{-1}\), is given by \( 0.5 \rho A V^3 \), where \( \rho \) is the density of the air in kg.m\(^{-3}\) (typically 1.2 kg.m\(^{-3}\) at sea-level, 1.0 kg.m\(^{-3}\) at 1 500 m altitude). Not all this kinetic energy can be captured by a wind turbine. There is a theoretical maximum which can be captured - about 59% of the total power, known as the Betz maximum; the actual power captured is always less than this. Table 12.2.15 shows the dependence of maximum power on wind velocities.

### Table 12.2.15: Maximum wind-power flux (Wm\(^{-2}\)) for different wind speeds

<table>
<thead>
<tr>
<th>WIND SPEED (ms(^{-1}))</th>
<th>TOTAL WIND POWER (Wm(^{-2}))</th>
<th>MAXIMUM USABLE WIND POWER (BETZ MAXIMUM, Wm(^{-2}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>35</td>
<td>21</td>
</tr>
<tr>
<td>6</td>
<td>119</td>
<td>70</td>
</tr>
<tr>
<td>8</td>
<td>282</td>
<td>166</td>
</tr>
<tr>
<td>10</td>
<td>550</td>
<td>325</td>
</tr>
<tr>
<td>12</td>
<td>950</td>
<td>561</td>
</tr>
<tr>
<td>14</td>
<td>1 509</td>
<td>890</td>
</tr>
</tbody>
</table>

Note: For air density 1.1 kg.m\(^{-3}\).

Wind turbines can be designed to obtain their peak efficiency at lower or higher wind speeds. However, this does not alter the fact that much less usable power is available from lower-speed winds.

The rated power of a wind turbine is specified for a particular wind speed (often 10 ms\(^{-1}\) or more). If a 1 MW machine is rated for a windspeed of 10 ms\(^{-1}\) it may deliver only 200 kW at a windspeed of 6 ms\(^{-1}\), or 600 W at 4 ms\(^{-1}\).

This strong dependence on wind speeds illustrates the vital importance of having (a) sufficiently good...
wind resources, and (b) reliable wind data when assessing and approving the feasibility of wind-generation schemes. A 10% error in estimating the wind resource could lead to a 30% error in estimating the costs of generating electricity.

**Energy “storage” through grid connection**

Available wind power at a particular site varies from hour to hour, day to day and year to year. Connection to the national grid can provide a “storage” buffer. For example, a wind farm can provide for a local municipality’s needs when sufficient wind power is available, and export to the national grid when there is a surplus. When there is a deficit, power from the national grid is imported. South African wind regimes tend to be highly variable, particularly in higher-wind areas affected by cyclic weather patterns.

Financial and regulatory issues include the tariffs at which surplus wind-generated electricity will be purchased by the grid utility, the obligation on the utility to purchase surplus generation (if applicable) and the licensing conditions for the independent power producer (IPP), if applicable. None of these has yet been fully established in South Africa, but policies are on the table to pave the way for fair access to the national transmission network by IPPs.

**Applicability of grid-connected wind generation in South Africa**

It seems unlikely that the South African national grid, or the Southern African Power Pool, will incorporate significant wind-generation sources in the next ten years. The main reason is that electricity-generation costs from South African coal-fired power stations and from regional hydropower are less than half the best-case costs for wind generation. In the longer term, increases in the cost of coal-fired electricity generation, and pressures to rely increasingly on renewable forms of energy, may encourage more extensive use of wind energy. Pilot wind farms could be justified partly on the grounds of establishing experience for such longer-term developments.

In the short term, such pilot projects would usually require an element of subsidisation or concessionary loan finance in order to be economically sustainable. In specific situations the required subsidy element may be small - for example where:

- a municipality cannot obtain an adequate national-grid supply for less than say 25-30 cents/kWh, and/or is willing to pay a comparable amount for wind-generated electricity;
- existing transmission lines are adequate for maximum imports(exports);
- local wind-speeds average more than 7 ms\(^{-1}\) (at the hub-height of the wind turbines); and
- there is sufficient local demand for wind-generated electricity to allow for wind projects large enough to achieve economies of scale, to justify the maintenance infrastructure, etc (e.g. several MW).

In such a situation, a detailed feasibility assessment for localised wind-farm electricity generation would be warranted. To date, no wind farms have been established in South Africa, although a promising scheme in Darling (Western Cape) is at an advanced feasibility stage.

International interests in promoting environmentally sustainable energy are favourable for obtaining “green” concessionary finance for such wind schemes. In many parts of the world where wind generation is already financially viable without any subsidy, commercial and development banks are widely engaged in wind finance.

**Preliminary steps for feasibility assessments**

There are two primary questions in any South African feasibility assessment for a potential grid-connected wind generation scheme:

- Are the wind resources in the identified locality sufficiently good for cost-effective wind generation?
- If so, can wind generation be cost-competitive with other electricity-supply options in this locality (taking into account any environmental subsidies for wind generation, if applicable)?

In South African conditions, it is very unlikely that grid-connected wind schemes could deliver electricity for less than the international best costs of 4-5 US cents/kWh. Therefore, if this cost is out of range for consideration, a detailed feasibility assessment is probably not warranted.

Assessing wind resources accurately is expensive and a detailed assessment for wind-farm costing and siting should preferably be undertaken by experts. Before one proceeds to this stage, however, an initial rough assessment of wind energy potential in the proposed locality can be undertaken:

- Check published wind data (e.g. Diab 1995). Is there evidence to suggest promising wind speeds in the region (e.g. an annual mean around 6 ms\(^{-1}\) or more)? Is there insufficient...
evidence to judge? Or is there evidence that annual mean wind speeds are generally too low?

• Check available sources of wind data for the area. How close are the nearest measuring stations? Are the measuring instruments accurate, well maintained and well exposed? Is the data sufficiently long-term to be reliable?

• Consider topography. Are there localities where wind enhancement is expected (e.g. long smooth slopes, “necks”, etc)? Is the terrain too complex to make valid use of existing available data? Is turbulence a potential problem (e.g. in mountainous terrain)?

• Consider environmental acceptability (distance from dwellings, visibility impacts) and land-use.

Suitable wind data for initial cost estimates should consist at least of frequency distributions of hourly wind speeds, per month, covering a period of two years or more. These can be multiplied by the “power curves” of suitably sized wind-turbine generators, to estimate the expected electricity generation per year, leading to an initial cost estimate, and a decision whether to proceed to more detailed site-specific wind monitoring. Wind turbine manufacturers/suppliers would normally be pleased to assist.

If available wind data is not adequate for an initial assessment, preliminary site-specific monitoring can be considered, for example by installing a suitably located mast with accurate anemometers at two heights (to measure wind shear) and reliable data-logging. However, given the time implications (at least a year of data collection for preliminary assessment and more than this for detailed assessment) it is advisable to have a strategy for combining these, and expert advice would be useful. The basic techniques for initial assessment are covered well in Lysen (1982).

The broader steps in planning and implementing a wind-energy plant are covered well in the “European best practice guidelines for wind energy development”, which is produced by and obtainable from The European Wind Energy Association, e-mail address 10175.1101@compuserve.com.

Off-grid wind generation

Wind power can be used for electricity supply in off-grid areas, either in the form of wind-charger/battery systems or more complex hybrid power systems (where several types of electricity-generating sources are combined - e.g. wind, diesel, solar).

In localities with average annual windspeeds above 4 m/s, even small wind turbines can generate electricity at a lower R/kWh cost than solar PV systems (Cowan et al 1992), but the problem is that the electricity supply from a wind turbine can be very variable in South African climatic conditions. In periods of high wind, much more energy is generated than in periods of low wind. Therefore, if the high-wind periods are interspersed with low-wind periods, a large amount of energy storage is needed to cover the lulls and profit from the peaks in electricity generation, in an optimal way.

In a stand-alone wind/battery system, battery storage/cycling of energy is expensive, adding at least R1-2/kWh to the electricity-generating cost. It is not cost-effective to install sufficient battery capacity to store the full amounts of electricity generated during high-wind periods, and this pushes up the average generating costs of usable energy. As a result, the net costs of off-grid electricity from wind/battery systems are expected to be higher than for PV/battery systems, according to computer modelling for the wind regimes in Cape Town, Port Elizabeth, Alexander Bay and all other major weather data stations in South Africa (Cowan et al 1992).

There is a different situation, however, if wind generators are used in a “hybrid system” configuration for off-grid power supply. By combining different sources of electricity it is possible to level out the electricity supply. To some extent, the combination of wind and solar PV generators can be complementary (especially in areas where higher winds occur during “bad” weather) but the strongest advantages occur when a controllable electricity source such as a diesel (or other engine) generator forms part of the hybrid system. This can reduce the amount of energy storage required, thus reducing costs, and provide a versatile power system for covering peaky and variable loads.

Such hybrid systems are worth considering

• for medium-load demands (e.g. 5-100 kWh/day, although there is no fixed upper limit - that will depend on the cost-competitiveness of other options, in the local circumstances);

• where the load profile is too irregular to permit the use of diesel generators at consistently high capacity factors (this pushes up the operating and maintenance costs of a simple genset power supply); and

• where skilled maintenance and diesel fuel can be provided on a regular basis.
Before including a wind generator in such a system, reasonably accurate wind-speed data should be to hand. It is likely that a partial contribution from wind generation could be technically economical if mean wind speeds are above 4-4.5 m/s. However, the extra complexity of a hybrid system (including the maintenance tasks, and the more complex system control gear required for optimal performance) should be taken into account. For more detailed information on hybrid-system design and applications, a manual and software design tool is available from the Department of Minerals and Energy in Pretoria (Seeling-Hochmuth 1998).

**Applications in South Africa**

Stand-alone wind-battery systems have been used in applications such as off-grid coastal holiday homes (usually less than 1 kW), and occasionally in larger applications, such as at remote schools. For larger applications, however, it is more common to combine wind generators with diesel or some other form of power back-up.

Hybrid wind-PV systems are being employed at a small number of rural clinics. Hybrid wind-diesel and wind-diesel-PV systems have been used quite extensively on off-grid commercial farms, for example in the Northern Cape.

There is considerable interest in exploring the potential of such hybrid systems to supply power for local mini-grids, in communities far from the grid. This would provide a higher level of electricity service than individual solar home systems, and may therefore be more attractive to consumers. However, the comparative costs have not yet been fully investigated. The viability is likely to depend on government policy decisions about rural electrification subsidies as well as local conditions (load density, energy resources, capacity for maintenance, etc). Hybrid systems for remote-area power supply have been particularly well developed in Australia, but are not yet common for community electricity supply in South Africa.

**Small hydropower**

Worldwide, hydropower is the largest application of renewable energy, producing more than 20% of the world’s electricity. Within South Africa’s borders the potential for large-scale hydropower is limited, due to water shortage, but the broader Southern/Central African region has great potential. It is likely that electricity from hydropower will play an increasingly important role in the Southern African Power Pool. This section, however, is concerned with small-scale applications of hydropower as an alternative to electricity from the national grid. Under suitable conditions, small hydropower plants can supply electricity at a lower cost than other off-grid electricity-supply options such as PV, wind or diesel generators.

Definitions of “small”, “mini” and “micro” hydropower vary. Typical definitions (Fraenkel 1996) are:

- small-scale hydropower: < 10 MW;
- mini-hydropower: < 500 kW; and
- microhydropower: < 100 kW.

Off-grid hydro plants in South African conditions are most likely to occur in the “micro” range. Eskom, for example, has focused on the development and testing of < 15 kW turbines for off-grid remote applications (Beggs 1996).

**Applications in South Africa**

Off-grid hydropower plants have been used for farm power and water pumping, for institutional use (e.g. electricity for boarding schools) and, to a limited extent, for local-area grids providing community electricity supply. It is estimated that several hundred micro-hydropower systems have been installed in the country. The main limiting factors are:

- the availability of suitable hydrological conditions (see below);
- the ability to match the hydropower supply to local electricity demand; and
- the comparative costs of grid electricity.

**Typical configurations**

Micro-hydropower configurations are usually “run of river”, that is, they make use of the flow of a river and natural gradients, rather than the head of dams.

Figure 12.2.15 shows typical elements of a micro-hydropower installation. A penstock delivers water at pressure to a turbine. The penstock is often a significant cost element, requiring piping of sufficient strength and diameter to handle the water pressure, flow and shock forces. For this reason, depending on the physical characteristics of the site, it is common to construct a gradually sloping canal (gradient 1:500 to 1:1 000) from the water intake to the penstock forebay, in order to reduce the length and cost of the penstock piping. However, in some site conditions, a canal may be unnecessary or impractical.
Chapter 12.2

Other forms of energy

The design of micro-hydropower installations is covered well in many texts (e.g. Harvey 1993; Inversin 1986).

Requirements for cost-effective applications

The cost-effectiveness of off-grid hydropower is highly site-specific. It depends mainly on the hydraulic power available (water flow rate and head), the civil construction required, the size and load profile of electricity demand in the locality, and (where applicable) the cost of distributing the electricity.

Hydraulic power

The gross hydraulic power \( P_{\text{gross}} \) (kW) available from a vertical head of \( h_{\text{gross}} \) (m) and volume flow rate \( Q \) (m\(^3\)s\(^{-1}\)), is given by

\[
P_{\text{gross}} = 9.8 \times Q \times h_{\text{gross}}
\]

After frictional losses, transmission losses, etc, the net electrical power \( P_{\text{net}} \) (kW) which can be delivered is usually about 40-60% of the gross hydraulic power (Harvey 1993), leading to the approximation

\[
P_{\text{net}} \approx 5 \times Q \times h_{\text{gross}} \text{ (kW)}.
\]

Figure 12.2.16 shows approximate net electrical power for a range of flow rates and heads.

Flow rates can be measured by a variety of techniques, including

- installing a notched weir across the river - the water level above the notch indicates flow rate; and

- the “salt gulp” method - where salt water is poured into the river upstream and a conductivity meter is employed downstream to record the rate at which the salt cloud passes (Harvey 1993).

Account must be taken of variations in flow rate, requiring measurements at different times of year. Estimates of year-to-year variations can be made by looking for correlations between such measurements and longer-term records (e.g. records of water flow for gauged rivers in the same/nearby catchment area) or more detailed hydrological assessments.

Civil construction

This can include a weir for intake protection/regulation, the intake itself, a flood spillway, silt basin, canal, forebay tank with silt basin and spillway, penstock (and anchors), powerhouse and tailrace. Costs (and optimum design choices) are affected by labour costs, accessibility and cost of materials.

The proportion of total capital costs attributable to civil works will therefore vary (averaging perhaps 40% in Nepal and Sri Lanka - see Table 12.2.16) and will strongly affect viability.

Electricity demand characteristics

Total demand

Micro-hydropower schemes can show economies of scale. Assuming that sufficient hydraulic power is available throughout the year, the cost-effectiveness is increased for higher load demands. Conversely, if the available hydraulic power is insufficient/unreliable, more expensive back-ups may be required to meet energy needs, raising the overall cost.

Load factor and capacity factor

Hydropower plants have relatively high capital costs and low operating and maintenance costs. Run-off-river hydropower plants do not have significant energy storage, and are therefore most economical when the electricity generated can be fully utilised. If the combined loads are very peaky (e.g. electricity consumption mainly for domestic cooking and...
lighting) the load factor will be low (average kW consumed ÷ maximum kW consumed) and the hydropower plant is likely to operate at a low annual capacity factor (kWh/year useful output ÷ maximum kWh/year that could be generated). Oversizing the hydropower plant will also result in low capacity factors. Low capacity factors mean higher unit energy costs, because less benefit is derived from the initial investment. Micro-hydropower viability is therefore improved if

- combined load demand is not too peaky (preferably with peaky loads smoothed out by steadier base loads);
- load demand can adjust to any seasonal variations in hydropower generation capacity; and
- plant capacity factors are high.

Electricity distribution

In cases where hydropower is used for a local grid, supplying many consumers, the electricity distribution costs are likely to be similar to conventional grid distribution. Average electricity costs per consumer, including distribution costs, will be affected by

- distance from the hydropower station and spatial density of consumers; and
- consumption levels and load factor per connection.

Large distances between consumers, with low consumption levels and low load factors, will adversely affect the economics of a hydropowered mini-grid.

In situations where a number of isolated load centres are to be connected (e.g. a number of scattered schools in a district) the use of lower-cost transmission by SWER (single wire earth return) may be indicated. Such a scheme, undertaken by Eskom Non-Grid Electrification, is reported in Dooge (1996).

Typical costs

It is difficult to give general cost guidelines for micro-hydropower electricity supply, because the costs are site-specific. Capital costs for the turbine/generator can be in the region of R3 000/kW (1998 estimate). An indication of the breakdown of the total capital costs (based on figures from Nepal and Sri Lanka) is given in Table 12.2.16.

In 1992, typical South African micro-hydropower unit electricity costs, levelised over a 20-year system life, were estimated as given in Table 12.2.17.

These figures should be inflated by 60-100% to give comparable 1998 estimates. They still show that micro-hydropower can be the cheapest off-grid electricity source, in suitable conditions.

### Table 12.2.16: Examples of micro-hydropower capital cost proportions

<table>
<thead>
<tr>
<th></th>
<th>NEPAL</th>
<th>SRI LANKA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penstock</td>
<td>12 %</td>
<td>21 %</td>
</tr>
<tr>
<td>Other civil works</td>
<td>19 %</td>
<td>13 %</td>
</tr>
<tr>
<td>Electro-mechanical</td>
<td>27 %</td>
<td>48 %</td>
</tr>
<tr>
<td>Engineering cost</td>
<td>14 %</td>
<td>12 %</td>
</tr>
<tr>
<td>Distribution</td>
<td>28 %</td>
<td>6 %</td>
</tr>
<tr>
<td>Total</td>
<td>100 %</td>
<td>100 %</td>
</tr>
</tbody>
</table>

Source: Harvey (1993)

### Table 12.2.17: Typical supply costs of micro-hydroelectric power (1992 estimates, excluding reticulation)

<table>
<thead>
<tr>
<th>HEAD/SLOPE</th>
<th>DAILY DEMAND</th>
<th>CAPACITY FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0,25</td>
</tr>
<tr>
<td>Head 10 m</td>
<td>5 kWh</td>
<td>74 c/kWh</td>
</tr>
<tr>
<td>Slope 1:10</td>
<td>25 kWh</td>
<td>30 c/kWh</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0,25</td>
</tr>
<tr>
<td>Head 10 m</td>
<td>5 kWh</td>
<td>95 c/kWh</td>
</tr>
<tr>
<td>Slope 1:50</td>
<td>25 kWh</td>
<td>39 c/kWh</td>
</tr>
</tbody>
</table>

Source: Cowan et al (1992)

Other forms of energy
BIOGAS AND LANDFILLS

Biogas and landfill gas are both potential sources of energy for heating and lighting applications in South Africa. In both cases, methane gas (also known as marsh gas) is produced from a process of digestion of organic waste material. This methane gas can be collected, stored and reticulated for use in households and small businesses. The gas may be used directly in suitably adjusted appliances or indirectly in gensets for electricity generation.

Biogas is highly dependent on a reliable and suitable supply of organic waste (animal manure and plant material) and water. Landfill gas is available only from landfill sites.

Consequently, neither option is generally applicable but there are a number of successful applications which could be replicated. Many municipal sewage works produce biogas as a by-product of the treatment process. This biogas is usually used on site, and not supplied to the surrounding communities. Interestingly, communal household biogas digesters have been widely used in China to handle the digestion of human waste (primarily) and to produce biogas for heating and cooking.

In the case of landfill gas, there are at least two South African applications of note. These include the Grahamstown landfill project, which supplies an adjacent brick kiln, and one of the Johannesburg landfills which provides methane to the chemical industry.

**Biogas production**

Biogas is produced in a purpose-built biogas digester. The digester comprises an airtight container into which raw waste can be poured, together with water, as a slurry and from which methane gas can be collected under some pressure. There are many configurations of digester, including the underground “Chinese”, or fixed-dome, digester, and the “Indian” or floating-dome, digester.

The methane is produced by anaerobic digestion of organic matter. The production of methane is highly sensitive to temperature and increases dramatically at higher than ambient air temperatures. The added complexity of auxiliary heating of the digester cannot always be justified by the extra production obtained.

**Landfill gas production**

Landfill gas is automatically produced in landfills as a result of decomposition of the organic content of municipal refuse collections. This gas is a potential explosion hazard if it is not managed properly and can be utilised productively by creating sealed landfill compartments and extraction wells (similar to boreholes).

**Solar-thermal electricity generation**

Photovoltaic panels provide a simple, low-maintenance option for generation of electricity from the sun. However, as discussed in the section on solar photovoltaic electricity supply, the per-unit energy costs are relatively high, and there is little size-related reduction in cost as plant size increases. A potentially lower-cost alternative for both small- and large-scale grid-connected plants is to use concentrators to focus sunlight to heat a working fluid, which is then used to drive a conventional thermodynamic power cycle. Thermal-energy storage and/or supplementation with gas-fired burners can be used to deliver power over extended periods. Given the high levels of solar radiation available in parts of South Africa, there has been considerable interest in the possible development of such large-scale grid-connected plants. At present, however, the generation costs would be higher than for South African coal-fired power stations.

Four main technology options are potentially suitable for grid connection. Parabolic dish systems also have the potential to be used in smaller-scale applications (5 kW or larger), either as part of a grid-connected distributed generation system, or for mini-grid or stand-alone applications.

**Parabolic trough-based systems**

These systems focus sunlight energy onto heater pipes contained within evacuated tubes located along the focal axes of parabolic troughs. Insulated piping connects a field of troughs to a steam generator (with natural gas backup), used to drive a conventional Rankine Cycle turbine-generator. This technology is well established, with a number of plants having been installed. A series of eight plants with a total output of 354 MW has been operating since the late 1980s in California. Demonstrated peak efficiencies of 20% have been achieved.

**Power-tower systems**

These systems use an array of heliostats (large, individually tracking mirrors) to focus sunlight onto a receiver located at the top of a tower. Here the energy can be used either to generate steam to drive a Rankine Cycle, or to heat air to drive a...
Brayton Cycle machine. Several power-tower plants have been established, with the recently commissioned (1996) “Solar Two” project demonstrating integration of molten-salt thermal storage technology.

**Dish-Stirling or Dish-Brayton cycle machines**

These systems are generally much smaller (of the order of 5-50 kW) per machine. A Stirling or Brayton (gas turbine) machine is mounted at the focal point of a parabolic dish. A large power plant would require a field of such engines to be installed. They are, however, potentially well suited to distributed generation or even stand-alone applications, such as for a mini-grid or for specific higher load applications in rural areas. Dish-Stirling systems currently hold the record for system solar-to-electricity conversion efficiency at 29.4% and can generate AC power directly. The Stirling-engine generator unit also has the potential to be powered by gas or biomass. This allows greater productivity of the capital invested and the potential for night-time or weather-independent power, without relying on expensive battery storage.

**Solar chimney**

This somewhat unusual approach involves construction of an enormous glass-covered expanse, with the exterior perimeter open and surrounding a tall chimney (perhaps 750 to 1500 m high in current conceptual designs being considered in South Africa). Solar radiation would heat the air trapped under the glass, lowering its density. As a result it would then rise up in the chimney, generating wind speeds in the chimney of the order of 15 m s\(^{-1}\). Wind turbine technology can then be used to generate power. Unlike the technologies described above, solar chimney plants are expected to have low efficiencies (of the order of 1%).

None of the above technologies is currently at a stage where commercial utilisation in South Africa could be justified on financial or economic grounds. However, given the excellent solar resource in parts of the country, the potential reductions in cost that are expected for some of these technologies, and increasing environmental concerns regarding fossil-fuel utilisation, the future prospects for solar thermal power generation may be good. Particular niche markets include regions remote from the grid, or sites where transmission costs result in added cost for conventionally generated power. EPRI & DOE (1997) provide an excellent review of the technical and economic status of solar thermal technologies, from which much of the above material has been drawn.
BIBLIOGRAPHY


GUIDELINES FOR HUMAN SETTLEMENT PLANNING AND DESIGN

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