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**Selected technology options for sanitation provision to  
developing communities in urban South Africa**

by

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## SYNOPSIS

In 1990 the Water Research Commission initiated an evaluation of sanitation entitled "Technical, socio-economic and environmental evaluation of sanitation systems for developing urban areas in South Africa". The research project was undertaken jointly by Palmer Development Group and the University of Cape Town. The project culminated in 26 reports submitted under the collective title "Urban Sanitation Evaluation" in December 1992. This thesis is based principally on the research work that the Water Research Group, Department of Civil Engineering, University of Cape Town, contributed to the project and, in particular, the overview document entitled " Technology options for sanitation provision to developing communities" (PDG/UCT Document A5, 1992).

Since 1986, after the removal of legal restrictions on urbanisation, a high rate of population movement to the cities and towns commenced with housing of the urban poor a focal point.

The three essential aspects of housing are location in reasonable proximity to work, provision of services, in particular water supply and sanitation, and the house or shelter. Water supply and sanitation are basic health requirements. This thesis investigates selected technology options for sanitation provision to developing communities in urban South Africa.

Numerous systems of sanitation are in use throughout the developed and developing world. In South Africa the systems that have found application are:

- full waterborne sanitation - almost 18 million people of the 24.5 million people living in urban areas (65 percent) are served by this system.
- septic tank - about 440 000 people (1.8 percent) are served by septic tanks.
- bucket latrine - almost 2 million people (8 percent) are served by a bucket collection service.

- unimproved basic pit latrine - over 5 million people (21 percent) are served by the basic pit latrine.
- ventilated improved pit (VIP) latrine - about 270 000 people (1.1 percent) are served by VIPs.
- aqua-privy and conservancy toilet - over 400 000 people (1.6 percent) have access to these systems.

In addition, the PDG/UCT urban sanitation evaluation found that about half a million (2 percent) of urban South Africans lack sanitation facilities.

The septic tank and conservancy tank systems were not considered appropriate for developing communities by the PDG/UCT urban sanitation evaluation team and as such are not reviewed in this thesis. In addition to the other systems mentioned above, the basic and self-topping aqua-privy system developed in Zambia are evaluated.

Various factors affect the successful implementation, operation and sustainability of sanitation systems. These are categorised into technological, socio-cultural, economic, environmental and health factors.

Technological factors affecting sanitation provision can be both site and community specific. A site investigation to determine the subsurface soil type, a topographical investigation and a ground and surface water investigation will quantify the site specific factors. The existing or proposed water supply service level affects the options available for sanitation provision and as such enters consideration. International experience, in addition, has shown that awareness of the supporting institutional, technical and educational infrastructure (community specific) is critical for sustainable development.

Socio-cultural factors affecting successful sanitation provision are dominated by a communication support program. The increased community motivation and participation

from such a program as well as the socio-cultural data gained, can make the difference between success and failure.

Economic factors include the economic cost (that is all costs) of providing a sanitation system and the financial cost which is only the cost borne by the household. For comparing technologies the economic cost is used. The economic cost is reported as the total annual cost per household (TACH). Of the seven systems evaluated cost information was obtained for four of the systems:

- full waterborne sanitation R563
- on-site low flush aqua-privy R186
- ventilated improved pit latrine R169
- bucket collection system R310

Environmental and health factors are dominated by the concern about ground water pollution and contamination from on-site sanitation systems. In areas where the ground water is used as a source of drinking water the issue of nitrates in the water should be investigated.

Seven sanitation systems were evaluated in the thesis. The basic pit latrine because of odour and fly problems and the fact that it has been superseded by the ventilated improved pit latrine, is not considered an appropriate system for urban developing communities.

The ventilated improved pit latrine has, because of the addition of a vent pipe with a fly screen at the top, controlled the odour and fly problems experienced with the basic pit latrine. The VIP offers improved health and safety factors and has had great success nationally and internationally in both low and high density urban developments.

The basic aqua-privy has been superseded by the self-topping aqua-privy and the on-site low flush aqua-privy and as a result it is not considered appropriate for urban development. The self-topping aqua-privy and its adaptations and extensions provides a versatile system of sanitation. The aqua-privy to solids free sewer systems finding application now can learn much from this earlier version. The on-site low flush aqua-privy with new guidelines

covering basic design has a contribution to make as a technology option in providing sanitation to developing urban communities.

The bucket system is, in many situations, an extremely poor level of sanitation, often only slightly better than no sanitation at all. Taking into account the difficulties in running the system, the immediacy with which health hazards are created by any breakdown or poor operation, and the high cost, the bucket system should not be considered as a viable and acceptable option in urban areas.

Full waterborne sanitation is not only the most extensively used sanitation system in South Africa but it is also the most expensive. Provision of waterborne sanitation is the goal of many communities but an important issue is raised both by national and international experience. The system fails if the community cannot afford the operating and maintenance costs of the system. For this reason full waterborne sanitation is not recommended for any community that cannot afford to pay the full operating and maintenance costs.

Because approximately 7.5 million urban South Africans use buckets, basic pit latrines or have no access to sanitation, and the majority of whom are not able to afford a waterborne system, the ventilated improved pit latrine and the on-site low flush aqua-privy will find extensive application in developing urban areas.

In conclusion, only through continued research will new development projects be able to avoid the mistakes of the past and learn from the successful experiences. This research will guide the successful implementation, operation and sustainability of sanitation provision.

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## LIST OF ABBREVIATIONS

BOD	Biological oxygen demand
BUC	Bucket sanitation
COD	Chemical oxygen demand
DBSA	Development Bank of Southern Africa
ESKOM	Electricity Supply Commission
IDT	Independent Development Trust
NDBEPR	Nitrification-denitrification biological excess phosphorus removal
NON	No sanitation
NPV	Net present value
OSLAP	On-site low flush aqua-privy
OTH	Other sanitation, usually aqua-privies
PDG	Palmer Development Group
PIT	Basic pit latrine
RKDP	RSA/KwaZulu Development Project
ROEC	Reid's odourless earth closet
SEP	Septic tank
TACH	Total annual cost per household
TKN	Total Kjeldahl nitrogen
TPA	Transvaal Provincial Administration
UCT	University of Cape Town
VIDP	Ventilated improved double pit latrine
VIP	Ventilated improved pit latrine
WB	Full waterborne sanitation
WC	Traditional flush water closet

# **CHAPTER 1**

## **INTRODUCTION**

In the developed countries generally, flush toilets discharging to a sewer network, with the effluent being treated at a waste water treatment plant, or flush toilets discharging to a septic tank plus soakaway, are accepted as the sanitation norm, to the virtual exclusion of any other system. Until recently in South Africa this viewpoint has had wide acceptance in so far as it affected urban communities. During the early period after the Second World War when urbanisation became an increasingly significant phenomenon, the layout of townships for housing the poorer urban communities generally incorporated waterborne sewerage systems. However, during this period the rate of urbanisation was reduced to below its natural rate by legal restrictions on movement from the rural to the urban areas so that it was economically feasible to provide piped water and waterborne sanitation to every plot in new housing areas.

In 1986 legal restrictions on movement to urban areas were removed and a high rate of population movement to the cities and towns commenced, and is still taking place - squatting and informal settlements took place around the urban areas. For many of these settlements, water was supplied by stand pipes or communal tanks refilled by water tanker. Sanitation was provided by bucket or vault toilets. However, some communities lacked one or both of these facilities.

In 1990 the Water Research Commission proposed an evaluation of the sanitary state of the urban areas in South Africa under a project entitled "Technical, socio-economic and environmental evaluation of sanitation systems for developing urban areas in South Africa". The project was undertaken jointly by the Palmer Development Group and the Water Research Group, Department of Civil Engineering, University of Cape Town.

The project essentially devolved into the following tasks:

- 1) A literature survey to assess sanitary provision nationally and internationally.
- 2) A survey of the sanitary state of the urban areas in South Africa, based on a questionnaire and interviews, to determine which sanitation systems are being used, the problems encountered with them, and their capital and operating costs.
- 3) Evaluation of sanitation systems identified as being suitable or having potential for developing urban areas in South Africa in terms of:
  - life-cycle cost, capital, maintenance and operation;
  - degree of user satisfaction;
  - ease of construction, maintenance, operation and upgradability; and
  - environmental impact.
- 4) Preparation of guidelines for the selection, implementation, maintenance and operation of sanitation systems.
- 5) Development of a strategy for dealing with sanitation in these developing urban areas over the next decade.

The project was completed in December 1992 and a series of 26 reports under the collective title "Urban Sanitation Evaluation" was submitted to the Water Research Commission. For ease of reference these reports will be referred to as the PDG/UCT reports and the project as the PDG/UCT Urban Sanitation Evaluation.

Although the project tasks were undertaken jointly, the input to the tasks differed in the extent each group could bring its experience to bear on the particular task. The UCT group concentrated principally on task (3) listed above.

Based on the reports submitted in the project, in particular Document A5 entitled "Technical options for sanitation provision to developing communities" (PDG/UCT, 1992), this thesis will focus on the following aspects:

- Enquiry into the factors affecting the successful implementation, operation and sustainability of sanitation systems for low income communities.
- Evaluation of sanitation systems in developing urban communities in South Africa.

## **CHAPTER 2**

### **SANITATION AND HOUSING, TECHNOLOGY OPTIONS AND ACCESS TO SANITATION IN SOUTH AFRICA**

#### **2.1 SANITATION AND HOUSING**

A focal point in South Africa is housing of the urban poor. Housing can be defined as the environment to promote the physical, sociological and mental well-being of the household. Well-being, however, is a relative term and in countries having a high proportion of the population with low productivity and low income, with poor health education, the relative concept of well-being as a measure of success of "housing" does not provide a practical criterion for decision making. It is necessary rather to define the absolute basic requirements which "housing" must satisfy.

Housing consists essentially of three aspects:

- location in reasonable proximity (access) to work;
- provision of services, i.e. water supply and sanitation; access (not necessarily vehicular access); drainage; power; solid waste removal; and
- house or shelter.

The order of these three is not immaterial - "house or shelter" is consciously relegated to third position - in basic "housing" the "house" assumes a position of lesser importance to access and water supply and sanitation.

##### **2.1.1 Access to work**

Without access to work there appears to be no justification for constructing a house. In a rural society habitation arises naturally near the place of work. In an urban society this is equally true but the location is more flexible depending on the speed, efficiency and cost of transportation. If access to work is difficult or expensive the

journey to and from work is a constant drain on the energy, time, finances and efficiency of the low-income groups. Owing to the often dismal aspect of badly designed low-cost housing areas, there is pressure on the planner from the more affluent (and influential) urban dwellers to site low-cost housing away from the more affluent areas and often then also away from the place of work. This is a problem that presents itself sooner or later in all urbanizing communities.

### **2.1.2 Water supply and sanitation**

These two aspects of "housing" go together for they are indivisible. The provision of a drinking water supply is a priority which cannot be denied. What is sometimes not so obvious is that the provision of a satisfactory form of sanitation is equally vital. Worldwide, particularly through the WHO, there has been a strong focus on the provision of drinking water to poor communities. Where implemented, it has significantly reduced the incidence of diseases such as typhoid, dysentery and cholera. The success has to a degree obscured the fact that increasing the water supply also increases the problem of wastewater disposal. This point is well appreciated in the following quotation from the Indian Ministry of Health (1964):

" In many towns where water supply was long since installed and a sewer system held up for want of adequate 'subsidy', the delay is costing the communities dear. Insanitation and mosquito nuisance have taken root and filariasis is becoming endemic over an ever widening urban area in the entire country. This is hardly a comforting thought. Ironically enough filariasis control is fast assuming an increasing importance as a health measure with prophylactics pressed into service. This is but fighting the shadow and not the substance."

Thus the installation of water supply without adequate wastewater disposal can result in a shift from one dominant set of diseases to another. Such a shift may develop only with time; in the interim it may engender a feeling of accomplishment in the unwary so that the consequences are not appreciated.

With limited financial resources should water supply with sanitation be provided for a smaller number of people or should water supply only be provided for a larger number of people? In this form the question is unreal for it is not a simple situation of have or have not but a graduation of needs. One should rather commence by circumscribing the needs to identify the situations where the needs justify priority for assistance.

In a rural society the very dispersal of inhabitants is a powerful factor in reducing incidence of disease due to insanitation. Achieving a tolerable standard of sanitation and water supply in this situation may require provision of the most elementary nature and is often obtainable by individual or family effort. As the size and concentration of a community grows there comes a stage where individual effort no longer suffices. It becomes impossible for the individual to protect him/herself from the interaction of the insanitary practice of the neighbour on the individual. Community effort is now imperative in both water supply and sanitation - the lack of either can be equally fatal.

### **2.1.3 Shelter**

In warm temperate climates an examination of morbidity from exposure, and from lack of water supply and sanitation, will show that exposure is a relatively minor cause whereas insanitation is a major cause.

### **2.1.4 Implication**

In the provision of "housing" within the constraint of scarce resources, the responsibility for housing becomes divided between the occupier and the community (local authorities and/or State authorities being representative of the community). The community has to assume responsibility for those aspects which the individual, with the best of intentions, cannot supply for him/herself; in those aspects in which the individual can make a contribution by his/her own efforts, the responsibility passes from the community to the individual.

In urban areas the individual cannot by his/her own efforts provide road access, water supply and sanitation, and to a lesser degree, power. In water supply and sanitation the situation is particularly onerous as the interaction of the insanitary neighbour must eventually affect the individual who maintains a high standard of sanitation. The community, therefore, has a responsibility with the provision of a plot and water supply/sanitation. That is, once a plot, acceptable water supply and sanitation have been provided by the community, its prime responsibility in the provision of basic housing has been essentially satisfied.

With regard to shelter the self interest of the individual and pressure from his/her family is a spur to the individual to provide a shelter; this may range from one constructed from local materials (of whatever kind readily available) to regular building materials purchased for the construction of a house, depending on his/her personal resources. The appearance of the shelter may be unacceptable to those instilled with the concepts of what a regular house should be, but for the health protection of the community a plot and services without a house is always preferable to a plot and a house without services.

The above approach has found application in South Africa by the site-and-service scheme: The site plus services (water supply and sanitation, roads and drainage) are community responsibility, and the "house or shelter" the responsibility of the occupier of the site.

When planning site-and-service schemes the end results must be clear in the mind of the planner from inception. Planning should envisage, ultimately, the installation of individual waterborne or "water carriage" type sanitation and water supply, adequate roads, drainage and lighting. Initially it may be necessary to accept lower standards - for example unpaved roads - in order to deal with an interim situation. The term "lower standards" does not imply lower health implications. The planning, however, must be such that improvements can be made as the financial situation allows without existing services being disrupted. Pit latrines, for example, should not be sited where eventually a sewer should run. Planning on a lavish scale in terms of space or

frontage may well result in substandard services which cost as much per plot as full services in a well designed high density area. Service costs are linearly related to the frontage width of plots, hence deep plots with narrow frontages are suggested for an economical design. Often economies can also be obtained if the reticulation - electricity, water and sewerage - is located on the inner boundaries of the centre line of the blocks instead of in the street. Realistic planning of housing areas is essential in basic housing provision.

From the time the decision is made to provide housing to the time when construction of the houses commences an interval of one to four years may elapse. This period is taken up in the acquisition of capital and land, planning of the area, acquiring a source of water supply, design and installation of services, including satisfactory wastewater treatment facilities (where necessary).

The actual rate of construction of formal houses can always outstrip the rate of provision of suitable land and services. The reason for this is that in the construction of houses the units are normally replicas of a few basic designs. Consequently, the methods of construction are amenable to 'factory' type production. The comprehensive building skills needed in building (plumbers, carpenters, bricklayers) can be categorized into a number of operations (up to 200 or more). The operations are grouped and allocated to a number of teams - each team sequentially performing its function as the teams move along the "production line" of houses being built. By such methods it is possible to attain high degrees of competence and efficiency using local unskilled labour with only a few craftsmen i.e. bricklayers, carpenters and plumbers.

In contrast, the planning and installation of services are not amenable to this type of execution. Each site is unique - the soil conditions, slope, aspect and layout cannot be reproduced and codified in a number of standard solutions applicable to a variety of sites. High levels of technological competence are demanded. The bottleneck in the provision of "housing" is often centred in those functions which precede the actual building of the house.

## 2.2 TECHNOLOGY OPTIONS

Numerous systems of sanitation are in use throughout the developed and developing world.

In South Africa the systems that have found application are:

- full waterborne sanitation;
- basic pit latrine;
- ventilated improved pit latrine;
- septic tank;
- conservancy tank;
- on-site low flush aqua-privy; and
- bucket latrine.

With the exception of the septic tank and the conservancy tank systems, the others are reviewed in later chapters. The septic and conservancy tank systems were excluded from the review because they are not considered appropriate for poor communities due to their high cost. Two operational parameters - on-site/off-site and wet/dry - are often used in the classification of these systems. The first parameter refers to the location of the solid and liquid waste disposal site relative to the defecation site and this gives rise to four classes:

- on-site solid and liquid disposal (Class 1).
- on-site liquid disposal with off-site solids disposal (Class 2).
- off-site solid and liquid disposal with on-site pre-treatment (Class 3).
- off-site solid and liquid disposal (Class 4).

The second parameter refers to whether or not the system is dependent on water for its operation and this gives rise to four levels:

- dry system not requiring any water (Level 0).
- wet system requiring hand carried water (Level 1).
- wet system requiring plot connection (Level 2).
- wet system requiring house connection (Level 3).

Table 2.1 Matrix classifying sanitation systems

	Class 1	Class 2	Class 3	Class 4
Level 0	Basic pit latrine			Bucket system
Level 1		VIP/OSLAP		
Level 2			Self topping aqua-privy	
Level 3				Full waterborne sanitation

### 2.2.1 On-site solid and liquid disposal system (Class 1)

The basic pit latrine is an example of an on-site dry system. No water is required for operating this system. Faeces and urine are transported under gravity to the pit, where the waste products and anal cleansing material is collected, partially degraded biologically and finally when the pit is full and the superstructure is moved, covered and left. The liquid fraction of the waste infiltrates the surrounding soil.

### 2.2.2 On-site liquid disposal with off-site solids disposal system (Class 2)

The ventilated improved pit (VIP) latrine is an example of a Class 2 system that does not require water for its operation. Like the basic pit latrine the faeces and urine are transported under gravity to the pit, where the waste products and anal cleansing material is collected and partially degraded biologically before being desludged periodically. The liquid fraction of the waste plus any water used for cleaning the latrine infiltrates the surrounding soil.

The on-site low flush aqua-privy latrine is an example of an on-site wet system. Faeces, urine and anal cleansing material are transported to the pre-treatment tank (septic or aqua-privy) by the flush water. The pre-treatment tank stores the solid material and is desludged periodically. The liquid fraction of the waste plus flush water infiltrates the surrounding soil (soakaway). The minimum water supply level would be a communal standpipe.

### **2.2.3 Off-site solid and liquid disposal with on-site pre-treatment system (Class 3)**

On-site pre-treatment with off-site disposal is a class of sanitation system that historically was first developed in Zambia, as the self-topping aqua-privy system. In this system the faeces and sullage discharge to a simplified septic tank (aqua-privy); the tank, which is desludged periodically, retains the inorganic solids (stones etc) and unbiodegradable particulate. A relatively solids free liquid effluent is discharged from the tank to a sewer. The sewer requires no self cleansing velocity and can be laid at flat grades. The pretreated sewage from the sewers is treated and disposed of at an off-site treatment works. The minimum water supply level would be a plot connection (Level 2).

The on-site low flush aqua-privy discharging to a solids free sewer is a modification of the self topping aqua-privy. The principle difference is in the flushing unit and tank design. The operational behaviour is, however, similar to that described above. The minimum water supply level would be like the self-topping aqua-privy, a plot connection (Level 2).

### **2.2.4 Off-site solid and liquid disposal system (Class 4)**

The bucket latrine is an off-site dry system (Level 1). No water is required for its operation. In South Africa the bucket normally has a storage capacity of approximately 18 litres. In most cases the bucket is emptied twice a week and the

contents removed from the site by tanker or cart for burial or treatment at a disposal site.

Conventional flush sanitation is an off-site wet system. The flush water is required to transport the waste material and anal cleansing material to the treatment works via a sewer network. A house connection is the minimum water supply level (Level 3).

### **2.3 ACCESS TO SANITATION IN SOUTH AFRICA**

Prior to the PDG/UCT Urban Sanitation Evaluation there was no comprehensive database of the numbers of people in South Africa who had access to different sanitation systems, or to none at all. The survey carried out by the PDG/UCT Urban Sanitation Evaluation team provided the first step towards building up such a database of current access to different sanitation systems in South Africa.

A total of 826 settlements (including dense settlements) were identified using government and local authority records. Direct sanitation information was obtained by questionnaire and personal interviews for 539 of these settlements, representing 65 percent settlement coverage. In terms of the overall urban population, however, the coverage was greater - approximately 90 percent.

To obtain estimates of the numbers of urban dwellers in South Africa served by different sanitation systems the PDG/UCT Urban Sanitation Evaluation Team divided the country into the same nine development regions as the Development Bank of Southern Africa (DBSA). Figure 2.1 shows the development regions as defined by the DBSA. In Table 2.2 the number served by the different sanitation systems, full waterborne (WB), septic tank (SEP), bucket latrine (BUC), unimproved basic pit latrine (PIT), ventilated improved pit latrine (VIP), aqua-privy and conservancy toilet (OTH), and those with no sanitation (NON), are listed by development region.

Figure 2.1 Development regions of South Africa

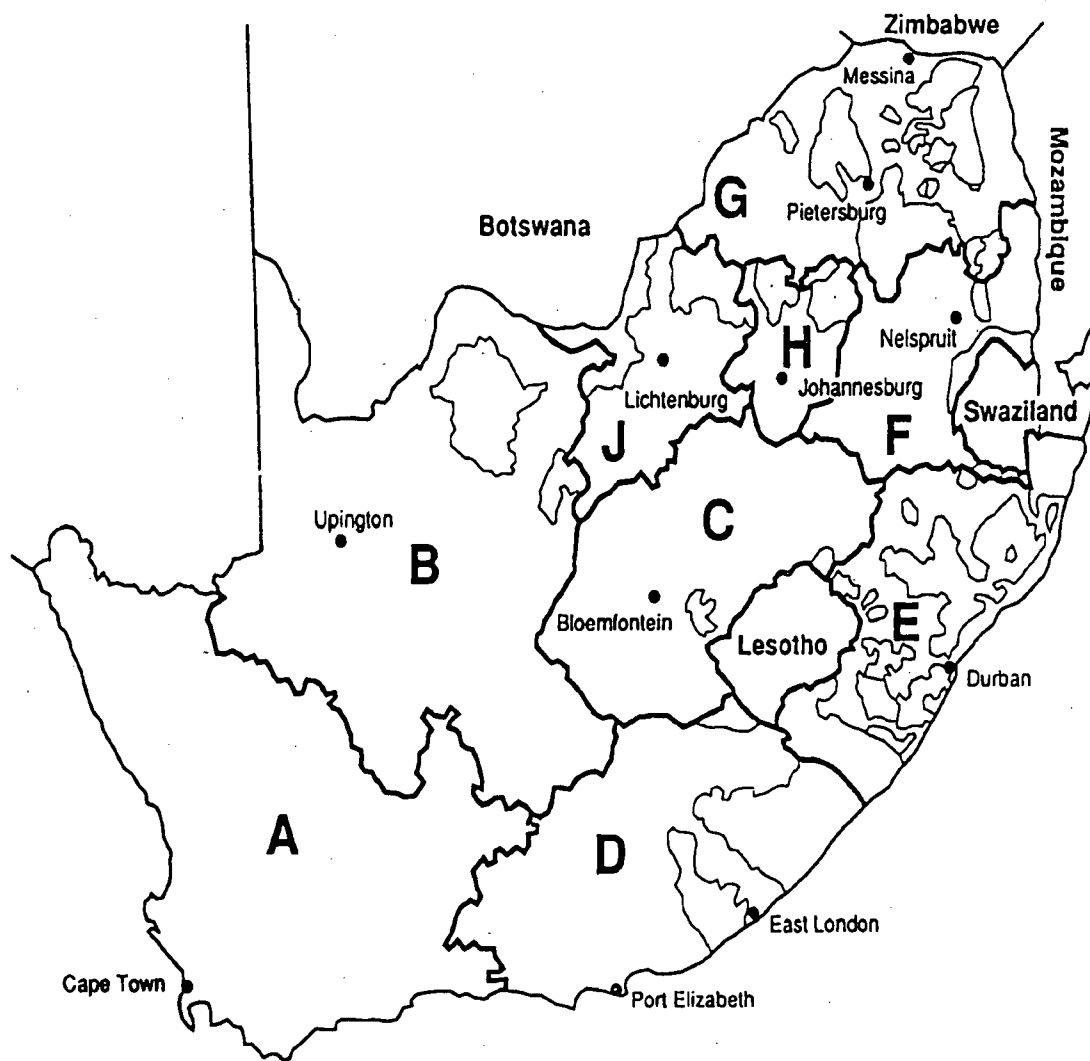


Table 2.2 National access to urban sanitation by region

REG	WB	SEP	BUC	VIP	PIT	OTH	NON	TOTAL
A	2706000	35000	280000	3200	1500	11300	119000	3156000
B	211000	42000	205000	4000	232000	4000	8000	706000
C	818000	41000	413000	138000	197000	1000	113000	1721000
D	1694000	60000	455000	4000	206000	64000	13000	2496000
E	2596000	150000	52700	111000	1479000	17500	67500	4473700
F	543000	4500	115000	500	234000	600	14000	911600
G	354500	2800	600	2500	949000	100		1309500
H	6306000	99000	260000		1627000	296000	156000	8744000
J	489000	5000	145000	3000	328000	3000		973000
TOT	15717500	439300	1926300	266200	5253500	397500	490500	24490800
%	64.18	1.79	7.87	1.09	21.45	1.62	2.00	100

The results from the survey are:

- Full waterborne (WB)  
Almost 16 million people of the 24.5 million people (65 percent) urbanised are served by full waterborne sanitation.
- Septic tank (SEP)  
About 440 000 people (1.8 percent) are served by septic tanks.
- Bucket latrine (BUC)  
Almost 2 million people (8 percent) are served by a bucket collection service.

- **Ventilated improved pit latrine (VIP)**  
About 270 000 people (1.1 percent) are served by VIP latrines. The distribution of numbers between VIPs and unimproved pit latrines is not reliable as it was difficult to obtain information on whether or not pits had been improved and were operating as VIPs - the differences between the two pit latrine versions (basic vs VIP) were not appreciated by a number of respondents indicating a lack of awareness of the characteristics of these two systems.
  
- **Unimproved basic pit latrine (PIT)**  
Over 5 million people (21 percent) are served by basic pit latrines.
  
- **Aqua-privy and conservancy toilet (OTH)**  
Over 400 000 people (1.6 percent) have access to "other systems" such as the on-site low flush aqua-privy or the conservancy tank / vault systems.
  
- **About half a million people (2 percent) do not have access to any sanitation facilities, in most instances where informal settlements have recently been established.**

## **CHAPTER 3**

# **FACTORS AFFECTING THE SUCCESSFUL IMPLEMENTATION, OPERATION AND SUSTAINABILITY OF SANITATION SYSTEMS FOR DEVELOPING URBAN COMMUNITIES**

### **3.1 TECHNOLOGICAL FACTORS**

With the provision of sanitation a number of technical constraints exist, principally concerning the type of sanitation to be provided. Some of the constraints such as the soil type, topography, surface and groundwater are site-specific. These constraints would be more clearly defined when the site investigation is undertaken. Water supply service level is a second site-specific constraint. Supporting institutional, technical and educational infrastructure involves the community structure.

#### **3.1.1 Site investigation**

The provision of any sanitation system is affected by the soil conditions at the site. Thus, it is imperative that before technologies are proposed and a system accepted and installed, a site investigation is undertaken. The site investigation should include a soils, topography and groundwater investigation.

##### **Soils investigation**

The identification of a representative proportion of the subsurface area to be developed is essential. In addition to classifying the subsurface as rock or soil, it is important to find the percent of clay, sand and silt. This will assist in identifying problem soils such as collapsing sands and heaving clays. Percolation tests must also be carried out over a representative area.

### **Topographical investigation**

The site topography may constrain the choice of technology and will always affect the cost of a system. This is particularly so with off-site water conveyed systems - in flat areas the sewers may require lifting stations to stop excessive excavation.

### **Ground and surface water investigation**

A ground and surface water investigation is particularly important if on-site sanitation is an option. For this reason the following aspects should be investigated:

- determination of water table level and likely variations in level;
- existing and proposed arrangements for the abstraction of water for drinking purposes, both within the boundaries of the site and in the vicinity of the site;
- the direction of groundwater movement;
- the identification of nearest water courses and water bodies and estimation of mean annual runoff in watercourses;
- the water quality in water bodies identified above;
- the present and proposed arrangements for abstraction of water from water bodies which could potentially be affected by the provision of on-site sanitation.

#### **3.1.2 Water supply service levels**

The amount of water available to the consumer is quickly reflected in the amount used and, hence, in the options available for its disposal. Neighbourhood standpipes ordinarily supply 20-25 litres per capita daily. This increases to 50 litres per person daily with a yard tap; when water is supplied through a tap inside the house, water use may rise to 100 litres per person daily (Kalbermatten *et al.*, 1982).

As described in Section 2.2, a number of systems can be described as water dependent. For instance, conventional sewerage or septic tank systems must have a house connection. An on-site low flow aqua-privy system should at least have a communal connection. These systems require water to transport the faeces from the

toilet bowl to its place of treatment. The VIP or bucket latrine, on the other hand, do not require water for their operation.

The selected sanitation system must have the capacity to dispose of all waste-water produced on the site. Where each site has its own water connection often an on-site sanitation system will not have the capability to dispose of the sullage and separate arrangements will have to be made, for example, construction of a sullage soakaway.

### **3.1.3 Supporting institutional, technical and educational infrastructure**

For sanitation systems to function, ongoing management of the system must be properly instituted. Where management of the system is not adequate extensive experience has indicated that sanitation systems will fail and this is particularly true of waterborne systems as these require a high level of management skill.

Management of a sanitation system cannot be divorced from the management of urban areas generally and therefore the proper structuring of local government is a prerequisite for sustainable sanitation provision.

Within a local authority the management of the sanitation system is generally part of the broader functions of the Town Engineer's Department. Here the tasks of operating and maintaining the system, including preventative maintenance, need to be defined and organised.

An adequate technological and educational infrastructure must be available for sustainable operation of any sanitation system.

Examples of technological considerations in sanitation provision in poor communities are:

- attention to the water level mechanism, springs and levers in mechanical flushing systems;

- blocked small flushing holes of S or P traps in WC toilets where toilet paper is not common; and
- competent operators and mechanics as well as a source of power for continuous satisfactory operation of mechanical pumps and treatment works.

Education considerations include health education to ensure that those people who obtain new facilities are shown how to use and maintain them. In addition, the health workers can show that personal hygiene can supplement that of the improved sanitation to provide added health benefits.

#### **3.1.4 Conclusion**

A comprehensive site investigation as well as detailed information on supporting infrastructure will enable the planners to select various systems that are technically appropriate for various service levels. It is within this framework that the socio-economic and environmental evaluation can take place.

### **3.2 SOCIO-CULTURAL FACTORS**

Nearly all studies addressing the sanitation problems of the urban poor in developing countries affirm the importance of social and cultural factors in the provision of appropriate technology. The operational recommendation generally made (Kalbermatten *et al.*, 1982) is to increase community motivation and participation in the planning and selection stages in the hope that community responsibility can be generated to use and sustain the system during the operating and maintenance stages.

#### **3.2.1 Communication support program**

According to Perrett (1984) the increase in community motivation and participation can be implemented through a communication support program. Normally, the communication activities would start some three to six months before construction, run parallel to, and continue for at least six to nine months after construction of the

sanitation system. Usually there are four principle kinds of communication activities implemented:

- participation of local men and women, particularly in making decisions;
- promotion of the project's construction or improvement activities at both community and household levels;
- information or instruction as needed by the people in the project area, for example; on how to apply for a unit; how to build the superstructure; how to clean and maintain the completed latrine; and
- health education, to ensure that those people who obtain the new facilities use them regularly and employ good hygiene habits so that the health impact is assured.

Perrett (1984) recommends that in sanitation projects, community health workers form the core of the communication strategy, although engineers, small contractors, community leaders and grass roots groups or organisations may get involved as well. The work of these people is helped and enhanced by media and materials of various kinds:

- posters
- slides
- flip charts
- models
- handouts and other aids.

According to Perrett (1984), the main steps in the implementation of communication support activities of sanitation projects normally include:

- background data collection (see section 3.2.2);
- detailed design of the communication strategy including co-ordination with the construction schedule;
- design, pre-testing and production of training materials;

- design, pre-testing and production of educational materials for use by field staff in their work;
- selection and hiring of communication staff (where a new system is being set up);
- training of field staff; and
- meetings with community leaders and organisation of public meetings to present and discuss the project including the technology options, detailed designs, and financing plans.

When the technology is understood by the population, there is no need to build demonstration models to promote it. If the technology is not understood, the use of slides or other visual media and visits to prototypes may be a rapid means of gaining the support of community leaders. Demonstration models at the project site might also be necessary. In addition Kalbermatten *et al.* (1982) suggest:

- co-ordinated distribution of media messages to support on-the-ground personal contacts with local people and community leaders;
- house-to-house visits to instruct on any self-help labour aspects of construction (ie pit and superstructure);
- house-to-house visits to encourage and instruct on good maintenance; and
- group meetings and house-to-house visits to encourage habitual good use of latrines, other improvements in personal and sometimes domestic hygiene, and good cleaning and maintenance practices.

Simpson-Herbert (1983) reports that the design of a communication support program to promote the project and bring about behavioral change will need to take into account such matters as:

- local beliefs and attitudes regarding water, sanitation and health;
- traditional water use or defecation habits and excreta handling practices; and
- current levels of knowledge in the community (especially among community leaders and other influential persons) about disease transmission.

If communications activities are to maximise their usefulness to a project, they have to be carefully monitored during implementation. Simple practical information, such as whether or not the scheduled activities are being carried out as planned, must be made available to management as needed so that managers are informed about problems that may require their immediate attention.

Evaluation of the communications activities' impact is more complex and is a longer term activity. It is the process by which results of communication activities are measured against its targets or objectives, to see whether or not they have had the desired impact.

### **3.2.2 Socio-cultural data requirements**

It is imperative that project designers know something about the diversity and prevalence of the various beliefs and the social and political structure of community power groups, political factions and lines of authority before final design and construction.

Simpson-Herbert (1983) summarises the range of socio-cultural information that may be required for low cost sanitation projects.

The range of useful socio-cultural data includes:

#### **Demography**

- population size, growth rate, mobility; and
- household size and composition (special features such as female heads of households and sharing, individual or family renters).

#### **Health**

- major health problems in the community and relative importance of water/sanitation related diseases; and
- seasonal variations.

**Occupation**

- major occupations and approximate distribution; and
- seasonality of employment.

**Organization and participation**

- major local organizations and type of membership;
- community and family level leadership in decision-making;
- major local political or social factions which might affect participation;
- extent of previous interest and participation in water/sanitation or other development activities; and
- important characteristics that would determine the acceptability and influence of outsiders working on projects in the area.

**Level of interest**

- evidence of popular interest in improving water supply and latrines, compared to other potential improvements in the community; and
- evidence of leadership commitment to improvements.

**Physical structure**

- types of dwellings, their physical condition and layout;
- types of building materials used;
- existing water supply and sanitation facilities; and
- space availability inside and outside dwellings.

**Willingness and ability to pay**

- ownership of land and house;
- income;
- expenditure patterns; and
- borrowing and savings customs.

**Water use patterns and practices**

- preferred sources of water (by purpose);

- quantity and uses;
- water-source-related activities (eg laundry, animal watering); and
- possibilities for contamination of drinking water.

#### **Defecation habits and associated practices, underlying beliefs and attitudes**

- existing practices (noting important differences between: religions, men, women and children, different age groups);
- cleansing and ablution materials and practices (eg anal cleansing materials, prevalence of bathing in latrines);
- underlying causes of above;
- important taboos, beliefs, related to locations, sharing etc;
- latrine emptying and sludge re-use practices; and
- general household cleanliness.

#### **Local technology and resource availability**

- local availability of building materials;
- availability of skilled and unskilled labour (noting seasonal variations); and
- availability of technology-related inputs (such as water for aqua-privy latrines).

#### **Education activities and potential**

- literacy level;
- mass media access in area;
- coverage by field workers, volunteers; and
- ongoing formal or non-formal health education activities.

### **3.2.3 Methods for socio-cultural data gathering**

There are four basic kinds of data-gathering methods, according to Simpson-Herbert (1983), for gathering socio-cultural data such as that listed above.

**Participant-observation**

The researcher establishes residence in the community to be studied and while participating in all the community activities, observes and records the activities and events gathering information relevant to the data needed.

**Key-informant interviewing**

The researcher interviews people in the community who are knowledgeable about certain aspects concerning the project, for example, community leaders, health workers, school teachers and local engineers and builders.

**Open-ended interviewing**

The researcher interviews men, women and children using open ended questionnaires to obtain a range of answers pertinent to the project.

**Surveys**

Surveys are used by the research team to cover a large or representative percentage of the community to obtain demographic data, for quantifying the occurrence of observable objects or characteristics and for estimating the prevalence of particular attitudes, beliefs and values.

**3.2.4 Conclusion**

There seems little doubt, according to the literature, that if a communication support program (in some form) is absent the project is bound to fail. The information gained from the data collection is imperative to design and maintain a sanitation system.

**3.3 ECONOMIC FACTORS**

The economic cost of a sanitation system, the cost of a system compared to other systems and the financial cost to be incurred by the household are the issues requiring attention in the selection of a sanitation system.

### 3.3.1 Economic costing

According to Kalbermatten *et al.* (1982), the first principle of economic costing is that all costs to the economy, regardless of who incurs them, should be included. The second principle concerns the prices that should be used to value all the identified costs. Since the objective of economic costing is to develop figures that reflect the cost to the nation in producing those goods or service, the economist is concerned that unit prices represent the actual resource endowment of the country. For example, a country with scarce water resources will have expensive water costs, in the economic sense, regardless of the regulated price charged to the customer. Because governments often have socio-political goals that may only be indirectly related to economic objectives, some market prices may bear little relation to real economic cost. For this reason it is sometimes necessary to adjust market prices in the economic costing exercise so that they represent more accurately "real" unit costs. This adjustment of market prices is sometimes known as "shadow pricing".

For most developing countries Kalbermatten *et al.* (1982) claim that where labour is abundant but capital and foreign exchange are scarce, the effect of shadow pricing is to decrease the cost of unskilled labour and to increase the cost of both capital and imported goods. Furthermore, since shadow pricing removes distortions attributable to political decisions such as minimum wage legislation, overvaluation of local currencies, and the provision of development capital at low interest rates, it is extremely valuable in the identification of the most appropriate sanitation technology for the actual resources of the country. Kalbermatten *et al.* (1982) add that, in addition to shadow pricing, economic costs differ from financial costs in that the former are based on incremental future investments rather than average historical investments. Basing costs on future investments rests on the idea that costs already incurred, ie sunken costs, should be disregarded in making decisions about future investments. Thus, in analyzing the resource cost of a given technology, it is necessary to value the components of that technology at their replacement cost rather than at their actual historical cost.

Kalbermatten *et al.* (1982) claim that the single most useful figure for comparing the cost of different technologies is the total annual cost per household (TACH), which includes both investment and recurrent costs properly adjusted to reflect real opportunity costs, ie the cost properly shadow priced. Because both investment and recurrent costs must be included for a lowest cost comparison, and because different technologies have different lifetimes, the TACH is an annualized figure.

The TACH would, however, be misleading when applied to communal facilities or cases where several households share one toilet. In those instances per person costs should be scaled up by the ratio of the number of users to the average number of persons in a household.

In general, the data necessary for the calculation of comparable economic costs should be collected fairly early in the design process, after preliminary designs have been prepared. This would allow for screening of the technologies which are not affordable even though the technologies have passed the basic tests of technical and social feasibility.

### 3.3.2 Comparison of costs of technologies

This section provides a brief overview of the typical costs of providing sanitation to the urban areas of South Africa. It is obvious that these costs are very site-specific and depend on a wide range of factors, for example: size of population, density of settlement, cane-field/in-situ development, design factors, methods of construction, cost of materials and soil conditions. No shadow pricing was included as this technique is more applicable at national policy level. The aim of this section is more to provide a point of comparison between sanitation systems and give examples of calculating TACH's. The costs in Table 3.1 reflect the range in costs that will be experienced under different circumstances. The capital costs are total **construction** costs (including 10% VAT). It should be noted that the **real** cost will be somewhat higher when design costs and indirect costs, attributed to the developer, are included.

Table 3.1 Cost ranges for sanitation systems (in 1992 Rands)

	Waterborne	OSLAP	VIP	Buckets
<b>CAPITAL COSTS</b>				
On-site	500-2000	800-2400	800-3300	500-1000
Reticulation	600-2500			
Connector Service	100-1000			
Treatment Works	300-1500			
<b>TOTAL</b>	<b>1500-7000</b>	<b>800-2400</b>	<b>800-3300</b>	<b>500-1000</b>
<b>OPERATION AND MAINTENANCE COSTS PER YEAR</b>				
On-site Maintenance	15-60	30-100	5-40	5-25
Water	80-240	3-15		
Reticulation	20-120			
Collection / Emptying		10-40	10-40	160-280
Connector Service	1-30			
Treatment	13-106	*	*	10-80
<b>TOTAL</b>	<b>129-556</b>	<b>43-155</b>	<b>15-80</b>	<b>175-385</b>

\* No treatment cost of the sludge removed from tank or pit has been included as this has been included in the collection and emptying cost estimate.

It is not possible to calculate the net present value or the total annual cost per household for a system based on a range of costs. Instead a typical capital and operating and maintenance cost must be used. The typical costs used for the comparison of technologies in this section are shown in Table 3.2. The net present value is calculated using a project life of 20 years, an interest rate of 19 percent and an inflation rate of 15 percent. The TACH is the annualized cost of the net present value over the project life.

Table 3.2 Average costs for sanitation systems (in 1992 Rands)

	Waterborne	OSLAP	VIP	Buckets
<b>CAPITAL COSTS</b>				
On-site	1100	1200	1800	600
Reticulation	1400			
Connector Service	500			
Treatment Works	700			
<b>TOTAL CAPITAL COSTS</b>	<b>3700</b>	<b>1200</b>	<b>1800</b>	<b>600</b>
<b>OPERATION AND MAINTENANCE COSTS PER YEAR</b>				
On-site Maintenance	45	63	27	15
Water	130	9		
Reticulation	80			
Collection / Emptying		20	20	228
Connector Service	15			
Treatment	33	*	*	25
<b>TOTAL OPERATION AND MAINTENANCE COSTS PER YEAR</b>	<b>303</b>	<b>92</b>	<b>47</b>	<b>268</b>
<b>NET PRESENT VALUE</b>	<b>8015</b>	<b>2510</b>	<b>2469</b>	<b>4416</b>
<b>TACH</b>	<b>563</b>	<b>176</b>	<b>173</b>	<b>310</b>

\* No treatment cost of the sludge removed from tank or pit has been included as this has been included in the collection and emptying cost estimate.

The total annual cost per household figures from Table 3.2 are converted to monthly figures and are summarized as follows:

Waterborne sanitation	R47 pm
OSLAP	R16 pm
VIP	R14 pm
Bucket	R26 pm

These amounts are the ones that a household would need to pay per month at 1992 price levels for the full cost of the sanitation system, including interest and redemption on the capital amount and assuming full cost recovery from the household.

It is clear that the TACH for waterborne sanitation is substantially more expensive than the other options ie about three times the cost of on-site systems and nearly twice the cost of a bucket system.

Bucket systems cost almost twice that of on-site liquid disposal systems.

The on-site liquid disposal systems are the most cost effective. It is indicated that there is little difference in the overall cost of the two basic types - OSLAP and VIP. VIPs generally cost more to construct but less to operate and maintain.

The way in which the costs are recovered varies considerably between the four sanitation options. The local authority plays a major role in full waterborne sanitation and bucket systems. In contrast, on-site systems can generally be operated and maintained with the input from the local authority limited to education, advice and possibly the provision of a pit/tank emptying service.

### 3.3.3 Financial implications

According to Kalbermatten *et al.* (1982) the purpose of deriving economic costs is to make a meaningful lowest-cost comparison among alternatives. Such a comparison is extremely useful to the planner and policymaker. The consumer, however, is more interested in financial costs, that is, the payment that will be asked for the system and how that payment will be spread over time. For example, in the case of most on-site systems the consumers would pay for the original facility either in full or through a loan at the interest rate that reflects the opportunity cost of capital. In addition, they would pay a periodic sum to cover the system's operational and maintenance expenses. In this case the financial cost would be identical to the economic cost except for any taxes, subsidies or shadow pricing.

In deriving financial costs in any particular case, it is necessary to talk with central and local government to determine their financial policies and non-economic objectives. If the government places a high priority on satisfying the basic needs of all its citizens, then it may be willing to subsidise part or all of the construction cost of a simple sanitation system. The general policy of international lending agencies, such as the World Bank, is that, if the cost of the minimal sanitation facility necessary to provide adequate health is more than a small part of the household income (>10 percent), then the central or local government should attempt to subsidise its construction in order to make it affordable; **however, any operation or maintenance costs should be borne by the beneficiary.** If some consumers wish to have better or more convenient facilities, they should pay the additional cost themselves (Kalbermatten *et al.*, 1982).

To calculate the base (no subsidies) financial cost of an on-site system, one adds the annualized capital cost to the annual operating and maintenance costs. This total base financial cost can then be compared with the household incomes to check affordability. If the technology is considered affordable by the community then the only financial arrangements that will be required are those necessary to aid the community in securing loans from commercial and other banks.

If the technology's base financial cost is not affordable by the households to be served, and if lower-cost solutions are not feasible or are unacceptable, then various options involving increased self help input, deferred or low interest loans and partial construction grants should be considered to compute alternative sets of financial costs. Before any of these are offered to the community, however, it is obviously necessary to obtain central or local government funding to cover the financial shortfall.

### **3.3.4 Conclusion**

Having assessed the ability of the community to pay for sanitation, it is important that the cost of the technology selected does not exceed this ability. The state or local government can subsidise the capital cost of the system, but the community must cover all operating and maintenance costs. The state and local authorities must, however, be careful not to provide a subsidy or grant to one community if a similar grant or subsidy cannot be made to all the communities under its jurisdiction, who require new or improved sanitation.

## **3.4 ENVIRONMENTAL AND HEALTH FACTORS**

One key issue in providing on-site sanitation is the environmental consequence, especially with regard to how this will affect local and other communities' health. Conventional sewage disposal technologies according to Muller (1989) aim to meet two technical objectives:

- removal of faecal pathogens from the domestic environment; and
- conversion and disposal of the resulting materials without damage to the broader environment.

The question raised by on-site sanitation technologies is whether they in fact still meet the second objective without removing the excreta from the domestic environment. A consistent concern with on-site sanitation is ground water contamination and related health risks (Macoun, 1991).

### 3.4.1 Health hazards of contaminated groundwater

Diseases related to the use of contaminated groundwater may be divided into two sections; those diseases caused by biological pathogens, and those which are caused by chemical substances. Lewis *et al.* (1980), state that in developing countries the diseases caused by chemical substances are overshadowed by those caused by biological pathogens.

#### Pathogen related diseases

There are four main groups of pathogens in human wastes (Lewis *et al.*, 1980; Macoun, 1991):

- bacteria  
Potentially pathogenic bacteria include *Campylobacter fetus* ssp. *jejuni*, *Escherichia coli*, *Salmonella*, *Shigella* ssp, *vibrio* and *Yersinia enterocolitica*.
- viruses  
Of particular importance are the adenoviruses, enteroviruses, hepatitis A virus, reoviruses, and diarrhoea-causing viruses such as rotavirus.
- protozoa  
Potentially pathogenic protozoa are *Giardia lamblia*, *Balantidium coli* and *Entamoeba histolytica*.
- helminths  
Many helminths have human hosts, some of which can cause serious illnesses.

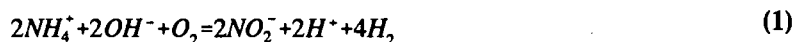
Diseases associated with the above-mentioned pathogens are numerous and include polio, diarrhoea, dysentery, hepatitis, cholera, typhoid, schistosomiasis, hookworm, ascariasis and taeniasis.

However, helminths and protozoa, because of their physical size, cannot travel through the soil with percolating waste water and can be discounted from causing diseases in all but extreme situations (Macoun, 1991). Bacteria and viruses, on the other hand, are much smaller and may be transported with percolating effluent into the groundwater causing diseases to break out where this water is used for drinking purposes. This is discussed later in Section 3.4.2.

### Nitrate related diseases

Extensive use of on-site sanitation may lead, under certain hydrogeological conditions, to elevated concentrations of nitrate in the underlying groundwater.

Nitrates and nitrites in soils and groundwater result from the microbial degradation of organic nitrogenous material such as protein to ammonium ions ( $\text{NH}_4^+$ ) which are then biologically oxidised to nitrite and nitrate, in a two step process.



These two reactions are referred to as nitrification and are mediated by two different bacteria: Reaction (1) by *Nitrosomonas* sp., and reaction (2) by *Nitrobacter* sp.; the two groups of organisms are collectively referred to as nitrifiers. Both species are aerobic chemical autotrophs, that is they obtain energy for growth from the oxidation of inorganic compounds  $\text{NH}_4^+$  and  $\text{NO}_2^-$ . These reactions can only take place with oxygen present (aerobic conditions). Because the nitrobacter readily convert  $\text{NO}_2^-$  to  $\text{NO}_3^-$  under aerobic conditions, the concentration of nitrite in surface water is usually very low (generally less than 0.3 mg  $\text{NO}_2\text{-N/l}$ ) (Lewis *et al.*, 1980).

The nitrate produced through nitrification is removed from the soil and groundwater by two means: (1) Higher plants reduce nitrate to nitrite and utilise nitrite in cell

growth (ie assimilative reduction) and (2) In the absence of oxygen, facultative aerobic bacteria can reduce nitrate to nitrite (ie nitrate reduction) or nitrate to the gaseous end products, nitrous oxide ( $N_2O$ ) or dinitrogen ( $N_2$ ) (ie denitrification). However, in well aerated waters, the rate of nitrate reduction and denitrification may be very low and under such conditions high concentrations of nitrate and nitrite (to a lesser extent) may result.

Two diseases have been associated with consumption of water containing high nitrate (and nitrite) concentrations. These, according to Lewis *et al.* (1980), are methaemoglobinaemia and carcinogenesis.

- **Methaemoglobinaemia (infantile cyanosis)**

This is a disease primarily affecting very young infants. The toxicity of nitrate occurs as a result of its reduction to nitrite, a process that can occur under specific conditions in the stomach and saliva of the infant. The nitrite ion oxidises iron in the haemoglobin molecule from ferrous ( $Fe^{2+}$ ) to ferric ( $Fe^{3+}$ ). The resultant methaemoglobin is incapable of reversibly binding oxygen, and, consequently, anoxia or death may ensue if the condition is left untreated.

In 1977 a World Health Organization European Working Group on health hazards from drinking water proposed the adoption of 11.3 mg  $NO_3-N/l$  (50 mg  $NO_3/l$ ) as the maximum acceptable concentration for infants, and of 22.6 mg  $NO_3-N/l$  (100 mg  $NO_3/l$ ) as the maximum for the population as a whole (WHO, 1977), to safeguard against this disease. These recommendations are based largely on an analysis of relatively few reported cases (Lewis *et al.*, 1980). The potential health implications for infants ingesting excessive quantities of nitrate is a topic of continuing medical attention (Lewis *et al.*, 1980).

- **Carcinogenesis**

Recently there has been increasing interest in the cancer risk associated with elevated quantities of nitrates (and nitrites) in drinking water. Nitrites (and indirectly nitrates)

can react with amines and amides to form nitrosamines and nitrosamides. Most N-nitroso compounds tested have proved to be carcinogenic in a wide range of animal species, and most were mutagenic. The epidemiological evidence suggests that high nitrate ingestion may be a contributing factor in gastric cancer. However, at present there is too little information available to draw any specific conclusions about the relationship between high nitrate ingestion and any other human cancer (Fraser *et al.*, 1980 as reported by Lewis *et al.*, 1980).

### **3.4.2 Pollutant movement and attenuation in the ground**

Improper design, construction, operation or maintenance of on-site sanitation systems can lead to failure due to the loss of infiltration capacity, with consequent surfacing of effluent. This type of failure is immediately apparent and action can be taken to eliminate it and its associated health risks. An equally important failure is that of inadequately purified effluent connecting with the water table. This can readily occur in some hydrogeological environments and result in pollution of groundwater.

#### **Hydraulic loading from on-site sanitation systems**

Estimation of the effective hydraulic loading on the unsaturated zone (in mm/d - an hydraulic loading of 1 mm/d is equivalent to 1 litre/m<sup>2</sup>/d) associated with a design of an on-site sanitation system is not straightforward (Lewis *et al.*, 1980).

Firstly, there are uncertainties about the actual daily effluent volume per capita, and the maximum and average number of people using an individual unit. Secondly, while the basal area of the pit is readily determined, the shape and cross-sectional area of the groundwater flow from any latrine will be complex. A particularly contentious issue is the scale of lateral movement of effluent out of the latrine (sidewall influence); this is a function of the ratio of horizontal to vertical hydraulic conductivity of the surrounding soil (over the appropriate range of saturation), and its prevailing natural moisture content, ie sidewall influence should be greatest in dry soils.

Lewis *et al.* (1980) in their report calculate the hydraulic loadings by dividing the probable range of daily effluent volume by the basal excavation area of the pit or soakaway.

The process of pore clogging happens when effluent enters the unsaturated zone (soil). Pore clogging eventually develops in the infiltration zone causing ponding of liquid above the clogging layers (the crust or mat) and this may lead to system failure due to surfacing of effluent.

Several phenomena contribute to the process of pore clogging and these include:

- blockage of pores by solids filtered directly from the effluent;
- accumulation of biomass from the growth of micro-organisms;
- excretion of slimes by some bacteria;
- deterioration and puddling of soil structure caused by saturation and swelling of clay minerals brought about by cation exchange; and
- precipitation of insoluble metal sulphides under anaerobic conditions.

The solid structure of the soil may also be partially destroyed by compaction and smearing during construction of the on-site sanitation system.

Because of the partial barrier to flow created by soil clogging, the soil below the organic mat becomes unsaturated. This becomes significant when effluent is applied to the soil for disposal. Liquid flow in unsaturated soil proceeds at a much slower rate than in saturated soil because flow only occurs in the finer pores. This slows the rate of infiltration through the soil, but enhances purification. The effluent is purified by filtration, biological reactions and adsorption processes which are more effective in unsaturated soils because of more intimate and prolonged contact between liquid and soil.

### **Groundwater movement in the unsaturated zone**

Groundwater flows in unsaturated soils normally do not exceed 0.3 m/d. An important exception may occur, however, in fissured rocks and coarse gravels. At moisture tensions below 0.2 m the larger fissures can conduct water, and the hydraulic conductivity increases enormously. Consequently, flow rates in excess of 5 m/d may occur, and the potential for groundwater contamination under these conditions is extremely high. Similarly, there may be rapid transport of pollutants through shrinkage cracks in desiccated clay soils with rain before swelling of the clay minerals seals cracks.

### **Factors affecting pathogen movement**

According to Lewis *et al.* (1980), the unsaturated zone is the most important line of defence against faecal pollution of aquifers. Maximization of effluent residence times in the unsaturated zone is, therefore, the key factor affecting the removal and elimination of bacteria and viruses.

Filtration has been shown by a number of authors, Ziebell *et al.* (1975), Krone *et al.* (1958), Butler *et al.* (1954), as reported by Lewis *et al.* (1980) to be the main mechanism limiting the movement of bacteria through soil. Filtration is most effective at the surface of the organic mat of the clogged zone.

However, data investigated by Lewis *et al.* (1980) suggests that filtration is unlikely to be an important mechanism for the removal of bacteria in the saturated zone except possibly in very fine-grained strata where the pore diameters of the aquifer are smaller than the actual size of the organisms (ie less than  $0.5 \times 10^{-6}$  m).

Unlike bacteria, viruses are very small and removal appears to be dependent almost entirely on adsorption. Viruses are composed of a nucleic acid core encased in a protein sheath, and thus mimic the colloidal characteristics of proteins. It has been shown by Stumm and Morgan (1981) and reported by Lewis *et al.* (1980) that adsorption of such hydrophilic colloids is strongly influenced by pH, the presence of cations and the ionizable groups present on the viruses. Viruses are strongly

negative at high and strongly positive at low pH's. In the pH range of most soils, enteroviruses have a net negative charge.

From laboratory experiments Lewis *et al.* (1980) conclude that soils with a higher clay content will be more effective at adsorption than sandy soils. In addition, the lower the soil pH, the more positively charged the virus particles become, and the easier it is for them to be adsorbed. From soil tests conducted by Green and Cliver (1975), Lewis *et al.* (1980) concluded that to enhance virus removal large hydraulic surges, or very uneven distribution, of the waste should be avoided.

Micro-organisms adsorbed onto soil particles are not necessarily permanently immobilized. Adsorption is a reversible phenomenon and micro-organisms can become desorbed and thus penetrate deeper into the soil; for instance, previously adsorbed bacteria and viruses could be desorbed by heavy rains.

In general it would appear that in soils removal of bacteria and viruses by adsorption will be enhanced by maximising effluent residence times in the unsaturated zone, ie by permitting the greatest media-liquid contact. This can be achieved by maintaining a low hydraulic loading rate, or by restricting the infiltration rate, which will occur naturally after clogging of the infiltration surface. Soil type will also affect the movement of micro-organisms, with some soils being more effective in removal than others (Bitton *et al.*, 1979). As reported by Lewis *et al.* (1980) sandy and organic soils are poor absorbers, whilst soils with a clay content are better.

#### **Groundwater movement in saturated zone**

According to Lewis *et al.* (1980), one can assume that in uniform aquifers, the lateral (horizontal) groundwater flow rate in the saturated zone is a function of the saturated horizontal hydraulic conductivity and the hydraulic gradient. In most hydrogeological conditions, the hydraulic gradient is small (less than 0.01), hence it might be expected that flow velocities, although considerably greater than in the unsaturated zone (because of much higher permeability), would invariably be relatively small (less than 2 m/d).

However, very few aquifers are uniform, and "permeability heterogeneity" will normally be present as is the case in some stratified alluvial sequences containing thin beds of well-sorted coarse gravel, and in many limestones where solution (karstification) along joints has occurred. In this case the presence of highly permeable flow paths of a small cross-sectional area results in groundwater velocities often exceeding 10 m/d, and reaching 100 m/d or more in many fissured aquifers and 1 km/d or more in some karstic limestones.

Once bacteria and viruses penetrate the water table they can be transported over considerable distances. The rate and extent of movement will be controlled by the hydrogeological factors.

### 3.4.3 Conclusion

The following conclusions relating to the unsaturated and saturated zone respectively are taken from Lewis *et al.* (1980).

#### Unsaturated zone

- Soil (and unconsolidated strata) is a very effective waste water purification system, having the ability to remove faecal micro-organisms and break down many chemical compounds. The unsaturated zone is the most important line of defence against pollution and contamination of underlying aquifers.
- Maximisation of effluent residence times in the unsaturated zone is the key factor in the removal and elimination of bacteria and viruses since the degree of purification will be determined by their retention and survival on soil particles.
- After the onset of clogging around the latrine pit, bacterial and virus removal processes (physical filtration and adsorption) will be enhanced because the rate of effluent infiltration will be restricted, and liquid movement will only occur in the smaller pores of the soil or rock with greatest media-liquid contact.

Thus it is important to avoid high hydraulic loading rates during the initial period of usage.

- Generally, the risk of faecal groundwater pollution is minimal when the thickness of relatively fine (<1 mm), continuous unsaturated soil (unconsolidated strata) beneath the base of the latrine is greater than 2 m, and provided the hydraulic loading does not exceed 50 mm/d.
- Groundwater pollution is likely in areas where the water table is shallow, or seasonally shallow, in areas where fissured bedrock is overshallow, or seasonally shallow, and in areas where fissured bedrock is overlaid by shallow soils. Standard latrine designs dictate that 1 -1.5 m of soil is removed, and this increases the chance of pollution in these high risk areas.
- Fissures in consolidated rock formations permit rapid effluent movement to underlying groundwater with little or no microbial removal. Similarly, macropores in soils can also behave like fissures. When subjected to high hydraulic loading rates, these discontinuities can cause short-circuiting with poor bacterial filtration. High intensity rainfall may intensify such short-circuiting. This conclusion has particular relevance to subsurface disposal systems in dolomitic areas. Besides the real danger of short-circuiting between the effluent and the groundwater there is the additional danger that the effluent can promote the formation of sinkholes.
- Bacteria and viruses that do penetrate the clogged interface of the latrine may be immobilized by adsorption and can survive in moist soils for long periods. Heavy rainfall may cause desorption resulting in a sudden increase in numbers of micro-organisms entering the groundwater.

#### **Saturated zone**

- Bacteria and viruses in the saturated zone have been observed to travel several hundred metres with the groundwater. The maximum extent of their travel

is governed principally by the groundwater flow velocity, and data from the literature indicates that this is the distance the groundwater flows in a period of about 10 days. The distance over which they can be traced depends on other factors such as their survival rate, initial concentration, dilution and dispersion within the groundwater, and the sensitivity of the method used to detect them.

- Decrease of bacterial numbers in the saturated zone is due primarily to die-off. The extent of micro-organism travel is limited by adsorption in slow-moving groundwaters ( $< 1$  m/d), and by physical filtration in very fine-grained formations (with pore diameters of less than  $0.5 \times 10^{-6}$  m). Mechanisms responsible for the loss of viral infectivity are not well understood; possible explanations include degradation by bacteria, or physical damage to the viral ribonucleic acid caused by environmental stress.
- It is very difficult to establish a safe minimum lateral spacing between a water supply and an on-site sanitation unit. This is because of the complexity of factors such as permeability and hydraulic gradients which control saturated flow rates.
- The extensive use of on-site sanitation schemes will almost inevitably lead to increased nitrate levels in the underlying aquifers. Nitrate concentrations in groundwater in excess of  $50 \text{ mg NO}_3\text{-N/l}$  are undesirable as they may cause methaemoglobinaemia in neonates.

## **CHAPTER 4**

### **BASIC PIT LATRINE**

#### **4.1 INTRODUCTION**

The basic pit latrine is probably the oldest form of sanitation provided in South Africa which is widely used in rural areas. In urban areas it is the second most widely used sanitation system after waterborne sanitation. The PDG/UCT Urban Sanitation Evaluation survey (Document A2, PDG/UCT, 1992) indicated that 5.2 million urban South Africans, 22 percent of the total urban population, are served by the basic pit latrine.

#### **4.2 SYSTEM DESCRIPTION**

The basic pit latrine takes many forms depending on the materials and form of construction. A typical latrine shown in Figure 4.1 (Diamant, 1978), consists of four components:

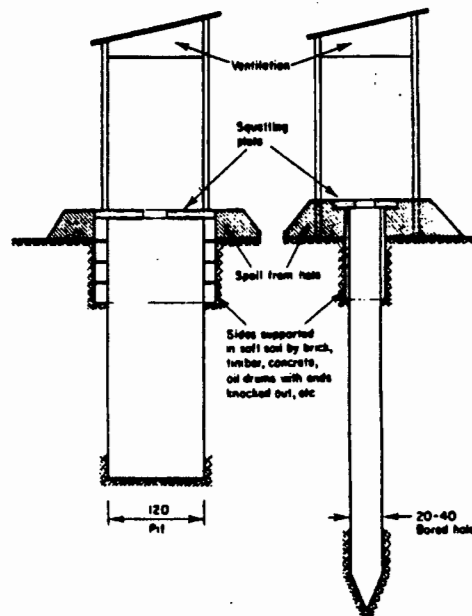
- an excavated pit;
- a floor;
- a pedestal or squat seat; and
- a superstructure.

#### **4.3 COMPONENT PARTS**

##### **4.3.1 Excavated pit**

The depth of excavation and cross section is dependent on the method of excavation and on the subsurface conditions. Pits may be excavated by a large diameter auger, some other mechanical device, or by hand. Shallow rock and high water tables might restrict the depth of excavation. Unless the ground is very hard the excavation requires a collar or shoring of at least 0.5 m at the top to stop the sides falling in and

**Figure 4.1 Basic pit latrine**



causing the superstructure to overturn or subside into the pit.

### 4.3.2 Floor

The floor covers the excavated pit and is made from either timber or concrete (pre- or insitu-cast).

### 4.3.3 Pedestal seat or squat plate

Either a pedestal (riser) seat or a squat plate is provided. The pedestal seat is a wooden or manufactured platform with a 200 to 250 mm oval hole. Some designs have a suitably designed chute below the hole to catch and direct the urine and reduce the size of the opening to the pit to make it safer for use by children. The hole is covered with a lid to stop the ingress of flies to the pit when the latrine is not being used. Where a squat seat is provided the plate ( Figure 6.2 ) has footprints cast into it to assist the user to position him/herself so as not to foul the plate. Below the plate

is a suitably shaped chute to catch and drain the urine into the pit. The squat plate is not common in urban South African pit latrines.

#### **4.3.4 Superstructure**

In urban areas the super-structure is constructed from corrugated iron, asbestos sheet, brick, timber or concrete. Wattle and dung superstructures have also found application although these are more common in rural areas.

### **4.4 SYSTEM OPERATION AND BEHAVIOUR**

#### **4.4.1 Effect of subsurface conditions**

In hard and rocky soils pits may be difficult to excavate and penetration may require blasting or the use of mechanical tools, greatly increasing the cost; seepage may be poor with the pit filling with liquid thereby reducing its useful life and creating conditions favourable for mosquito breeding. In areas with seasonally high water tables the water level may rise to near ground level causing unsanitary conditions. In sandy and soft soils the sides of the pits may collapse causing the superstructure to overturn or subside into the pit.

#### **4.4.2 Relocation of latrine**

The life of a latrine depends on the volume of the pit and the number of users. The life of the latrine may range between 2.5 to 8 years with an average of 5 years; this implies, in a housing scheme with a life of 40 years, a minimum of 5 relocations. Digging of pits, erecting or re-erecting the superstructure are recurrent expenditures.

The life of the latrine can be extended and indeed become virtually permanent if the pit can be emptied when full by vacuum tanker. In recent times desludging by vacuum tanker has become technically feasible and is now a viable option, provided the location of the latrine within the plot allows the vacuum tanker access to the pit.

Once this option is taken then provision must be made to treat the pit material off-site.

#### **4.4.3 Odour, flies and mosquitoes**

The basic pit latrines emit strong faecal odour, making the latrine and its surroundings offensive. The faecal odour attracts flies, which congregate in the latrine if the door is left open or where the ventilation openings are unscreened. The fly problem is accentuated where the cubicle is illuminated by direct light. The reason for this is that flies are attracted to light (phototropic). Fly attraction, principally from faecal odour, is considerable - Mara (1984) reported that in a 78 day monitoring period in Zimbabwe 13 953 flies were caught in the latrine cubicle of a basic pit latrine.

Where the pedestal hole is not supplied with a cover, or where the cover is not replaced after use, flies enter the pit and breed in the faecal matter, particularly when the build-up of faecal material is to within a short distance below the seat, in the region of diffused light in the pit.

Where free water is captured on the solids or a free water table surface is present, mosquito breeding can take place. Mosquitos shun areas which are well lit (photophobic) so that they are in fact attracted by the darkness in the pit. In wet pits mosquito control must be controlled by addition of paraffin, used engine oil or chemical additives. Mosquito control is a matter of public health education of the users.

#### **4.4.4 Plot size**

To reduce the problem of faecal odours permeating into the home, basic pit latrines require larger plots than other forms of sanitation to provide sufficient distance between the latrine, the house and the neighbour's house. A recognized minimum distance from the house is usually 7 m, hence there are requirements of extra land,

possibly increases in street frontages, with increased cost of attendant services such as piped water to be provided now or in the future. With high density site-and-service layouts the recommended minimum distance between latrine and the house may not be satisfied.

#### **4.4.5 Sullage water disposal**

The pit latrine system should not be used to dispose of the household waste water (sullage or greywater); where piped water is provided, waste water discharged onto the plot surface might not seep away causing unsanitary conditions and promoting mosquito breeding. Therefore, the decision to provide pit latrines must take cognisance of the level of water supply to be provided.

### **4.5 CONCLUSION**

From the discussion above, a decision on the provision of basic pit latrines in urban development must take cognisance of subsoil conditions, size of plot available, space for relocation of latrine or pit emptying, minimum distance of latrine from the house, faecal odours and fly infestation, re-usable superstructures (for relocation), life of pit (maximum expected number of users per latrine, method of excavation), level of water provision (hand carried/tap on-site) and waste water disposal.

With the high density site-and-service layouts, minimum distance requirements between house and latrine for faecal odour and fly infestation control cannot be met making the basic pit latrine a dubious choice as a sanitation system. In urban high density housing, however, recent developments in pit latrine design have produced the ventilated improved pit (VIP) latrine which provides solutions to the odour and fly infestation problems, to a degree. This development implies that in urban areas, the basic pit latrine should no longer even enter consideration as an acceptable sanitation system.

## **CHAPTER 5**

### **VENTILATED IMPROVED PIT (VIP) LATRINE**

#### **5.1 INTRODUCTION**

The ventilated improved pit (VIP) latrine constitutes a significant development of the basic pit latrine. The history of the development of the VIP latrine in Africa is not clear. Wright (1991) states that a type of VIP latrine was developed in Ghana based on the Reid Odourless Earth Closet patented in South Africa in 1944. According to Rivett-Carnac (1989), the Blair Research Institute, Zimbabwe developed and tested a VIP from 1973 to 1976 where it is called the Blair latrine.

In South Africa the VIP latrine was first used 10 years ago in rural areas but its use as a sanitation system in urban areas is very recent, since 1988. To date approximately 266 000 urban South Africans are being served by VIP latrines.

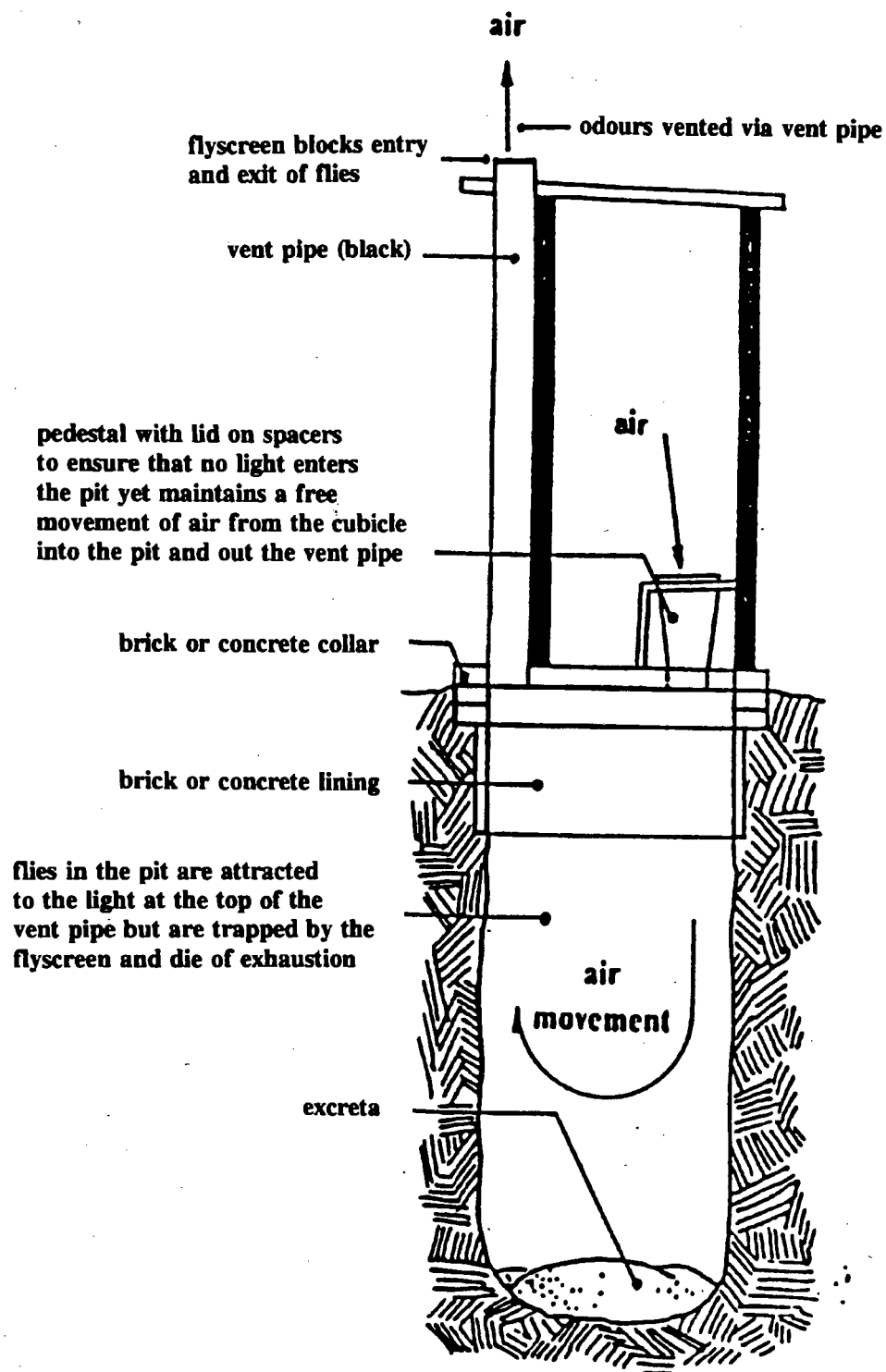
#### **5.2 SYSTEM DESCRIPTION**

The VIP latrine takes its form from the basic pit latrine and consists of:

- an excavated pit;
- a covering slab with its foundation;
- a pedestal or squat seat,;
- a superstructure; and
- a vent pipe with fly screen at the top.

A cross-section of a VIP latrine, in Figure 5.1 (Mara, 1984), illustrates its main components.

Figure 5.1 VIP latrine



## 5.3 COMPONENT PARTS

### 5.3.1 The pit

#### **Excavation**

Pits are excavated by a large diameter auger, some other mechanical device, or by hand. Subsurface ground conditions, for example, shallow rock, collapsing sand or high water table may limit the depth of excavation. Circular pits are more stable than square ones (Heap, 1984).

#### **Volume**

The volume of the pit is determined from a relationship between the number of users and the length of time between latrine relocation or pit emptying.

#### **Pit collar and lining**

The pit is provided with a collar at the surface to stabilize the foundation of the superstructure against collapse of the walls of the pit. With pits in soft soil areas the pit is lined throughout its depth by open brickwork or a geofabric supported by a grid mesh of wire or fibreglass. Where the depth of excavation is limited due to rock or high water table the pit volume is attained by building up the blockwork above ground level.

#### **Covering slab**

The covering slab is typically concrete either precast or insitu cast.

### 5.3.2 Pedestal seat or squat plate

Defecation takes place directly into the pit via a hole in either pedestal type seats or squat plates. In South Africa the pedestal seat appears to be the preferred one, but this is not necessarily general. The diameter of the hole needs consideration - a hole that is too large allows greater access to the pit for the disposal of material other than faeces and may scare children from using the latrine; conversely a small hole is easily

fouled. When not being used the toilet hole is covered by a lid designed to rest on risers. This provides a free exchange of air between the pit and the cubicle but restricts light entering the pit.

### **5.3.3 Superstructure**

A variety of designs is available for the superstructure. Walls are built of brick, blockwork or ferrocement; the roof of thin concrete slab, corrugated steel or asbestos cement sheet; the door, of timber or corrugated iron, must be lockable to prevent unwanted passersby using the latrine. The door should be designed to be self closing. The door may open either inwards or outwards. An outward swinging door, whilst allowing the superstructure cubicle to be smaller, is prone to wind damage; an inward swinging door requires a bigger cubicle, provides more security against the door being opened while the latrine is in use, and is less prone to damage from the wind. (An alternative form of entrance, a spiral doorway, is sometimes preferred in rural areas.) The design of the ventilation openings must ensure that no direct sunlight enters the cubicle when the door is closed, yet maintains the cubicle in a state of diffused light.

### **5.3.4 Ventilation pipe and flyscreen**

The vent pipe extends from the pit to a point above the roof of the latrine cubicle. The vent pipe should be sufficiently long to ensure that the roof does not interfere with the action of the wind across the top of the vent pipe. The internal diameter of the vent pipe depends on the required venting velocity necessary to achieve circulation (Rivett-Carnac, 1989).

Vent pipes are of asbestos cement, polyvinyl chloride (PVC), or built from bricks or blockwork.

A flyscreen covers the outlet at the top end of the vent pipe. The purpose of the flyscreen is to prevent the passage of flies in and out of the pit. It is important that

it is tightly fixed to the top of the vent pipe in order to prevent access by insects. The mesh aperture for the flyscreen should be no larger than 1,2 mm x 1,5 mm (Rivett-Carnac, 1989).

## 5.4 SYSTEM OPERATION AND BEHAVIOUR

### 5.4.1 Pit

Faeces and urine are deposited directly into the pit. The liquid fraction of the excreta (mainly urine), together with the small amount of water that enters the pit from cleaning the seat, infiltrates into the surrounding soil (Mara, 1984).

The faecal solids in the excreta are digested slowly by anaerobic bacterial activity - this results in the production of (1) gases such as methane, carbon dioxide and hydrogen sulphide which are exhausted from the pit via the vent pipe, and (2) soluble compounds which are either further oxidized in the pit or are carried into the surrounding soil by the infiltrating liquid fraction (Mara, 1984).

The anaerobic process acting on the faecal solids does not digest all the solids. There is a gradual accumulation of solids in the pit, although the rate of solids accumulation is much smaller than the rate of excreta addition. In "dry" pits (in which the pit does not penetrate below the water table), organic solids accumulation is at about 0.03 to 0.06 m<sup>3</sup>/yr/person; in "wet" pits, 0.02 to 0.04 m<sup>3</sup>/yr/person of solids accumulation.

When the pit fills with solids either the latrine must be relocated and the old site made good, or the solids must be removed by vacuum tanker. In high density projects, relocation of the latrine is unlikely to be a feasible option but the pit emptying option remains. Vacuum tankers for pit desludging are now on the market (eg Microvac). Pit emptying, by means of a flexible hose coupled to the vacuum tanker, takes place through the toilet seat opening. This operation has been demonstrated as "clean" with no spillage and associated health risks. Access to the VIP latrines by the vacuum tanker hose must be assured when designing the layout.

#### 5.4.2 Odour and fly control

The innovation that has given rise to the significant improvement in the pit latrine as a sanitation system is the ventilation pipe with flyscreen.

The screened vent pipe serves two functions:

- Flies are phototropic, that is, they are attracted to light. Flies in the darkness of the pit are attracted to the bright patch of light at the top of the vent pipe. They fly up the pipe but are prevented from emerging by the fly screen. The flies congregate below the flyscreen but eventually, exhausted and dehydrated, they die and fall back into the pit (Lochery and Adu Asah, 1986).
- Wind blowing over the top of the vent pipe, and to a lesser degree heating of the vent pipe by solar radiation, causes a slight vacuum in the pipe which draws air from the cubicle through the toilet hole, through the pit and venting through the screen opening at the top of the vent pipe. In this manner odours in the cubicle are "flushed" creating an odourless atmosphere. The absence of odour has the effect that the flies are not attracted to the cubicle. Flies outside the latrine may be drawn to the outlet of the vent pipe by the faecal odour from the vent but are prevented from going down the vent pipe to the pit by the fly screen over the vent opening.

Fly control is extremely effective. Mara (1984) reports that in a 78-day monitoring period in Zimbabwe, only 146 flies were caught escaping from a VIP latrine, whereas 13 953 were caught from an unvented but otherwise identical, pit latrine.

**The innovation of the screened vent pipe has changed the malodorous fly infested basic pit latrine system to one which is free of nuisance and health hazards and has promoted its status as an option in high density areas.**

Where corrugated iron is used for the superstructure, it has been noted that the retention of heat by the cubicle may in the early evening cause a reversal of air flow ie down the vent pipe through the pit and into the cubicle. In this case the cubicle will become odorous and attract flies (personal comment: G. Norris, 1992).

#### **5.4.3 Mosquitoes**

Where free water is captured on the solids or a high water table surface is present, mosquito breeding can take place. Mosquitoes shun areas which are well lit (photophobic) so they are, in fact, attracted by the darkness in the pit. In wet pits mosquito breeding must be controlled by addition of paraffin, used engine oil or chemical additives. Mosquito control is a matter of public health education of the users.

### **5.5 TECHNICAL CONSIDERATION**

#### **5.5.1 Technical design**

The literature on the technical design of VIP latrines is well developed; the following papers and reports should be consulted:

De Villiers, DC (1984) The ventilated improved double pit latrine Information Sheet BOU/ 2-68 National Building Research Institute of the CSIR, PO Box 395, Pretoria.

Heap, MA (1984) The ventilated improved pit latrine Information Sheet BOU/71, National Building Research Institute of the CSIR, PO Box 395, Pretoria.

Kalbermatten, JM, De Anne, SJ, Gunnerson, CG, and Mara, DD (1982) Appropriate sanitation alternatives - A planning and design manual, The World Bank, Washington, Johns Hopkins University Press, Baltimore.

Mara, DD (1984) The design of ventilated improved pit latrines Technology Advisory Group TAG Technical Note No 13, United Nations Development Programme, Interregional Project, INT/81/047, The World Bank, Washington.

Rivett-Carnac, JL (1989) Guidelines for ventilated improved pit latrines and alternative on-site sanitation systems, Appropriate Technology Information (Consulting Firm), Pietermaritzburg.

### 5.5.2 Water supply service level

The VIP latrine is not designed, *per se*, to dispose of waste water except that which is required to flush or clean the pedestal or latrine respectively. However, in many situations the soil drainage conditions are such that substantial quantities of waste water can be disposed of in the pit. Nevertheless, the level of water supply to the inhabitants is a factor when considering the VIP latrine option. For example, if a tap is supplied on every plot, increase in waste water can lead to unsanitary conditions around the home encouraging fly and mosquito breeding; to dispose of the waste water on-site would require construction of soakaways with an associated increase in capital and running costs and possible increase in plot size.

## 5.6 VIP CASE STUDY

The VIP latrine has been installed extensively in rural areas in Zimbabwe, Zambia, Botswana and Lesotho. There is little information on the use of VIPs in rural South Africa and it is very likely that only a few have been built. Jackson (1991) reports the installation of VIPs in urban Lesotho, where 20 percent of urban households in Lesotho are provided with VIP latrines. Installation of VIP latrines in urban South Africa as yet has not found favour - perhaps mainly because information on the favourable characteristics and behaviour of this latrine has not been disseminated sufficiently. Furthermore, until recently there has been no or only limited installation of VIP's in very high density housing areas so that there would be a natural reluctance by planners to propose the VIP option. However, two installation programs have been completed, one at Umlazi and the other at Bester's Camp, both in the

greater Durban metropolitan area. Both projects are in densely settled urban areas and provided valuable information on the use of the VIP in high density informal housing areas. The key findings and conclusions from the case study entitled "Evaluation of two VIP latrines" (Document B2, PDG/UCT, 1992) are reproduced here.

### **5.6.1 Umlazi in-fill scheme**

Umlazi is a large formal township situated 15 km south of the centre of Durban. Umlazi was first developed in the early 1960's by the Durban City Council acting as agents of the then Bantu Administration. Development came to a virtual standstill towards the end of the 1970's, at which time approximately 22 000 houses had been built. Umlazi, along with other towns in KwaZulu, was handed over to the KwaZulu Government in January 1988. The topography in the township is typical of many coastal areas of Natal/KwaZulu, comprising a plateau divided by steeply sloping valleys.

There are approximately 350 000 people currently living in the area, most (approximately 75 percent) of whom are housed in 26 000 formal houses with waterborne sanitation. Due to the acute housing shortage in Durban, and Umlazi's close proximity to the city centre, informal housing has grown rapidly in the undeveloped areas in and around Umlazi. An aerial survey conducted in July 1990 estimated the number of informal dwellings to be 5000. However, this number has increased substantially since then. The vast majority of these people use unimproved pit latrines.

In January 1991 a project called the Umlazi In-fill Scheme commenced, funded by the RSA-KwaZulu Development Project (RKDP). The project was conceptualized in July 1990 and thus the initial project design and planning was carried out fairly rapidly. The aim of the project was the formalization of already populated informal settlements through the provision of services to approximately 2500 sites. The services provided include the construction of roads, standpipes and VIP latrines using labour intensive methods. In addition, the project sought to identify and use local

Black sub-contractors, with the training of these sub-contractors carried out through the KwaZulu Training Trust. The scheme was implemented in consultation with the Town Councils in the area.

Consulting engineers, Van Wyk and Louw, have acted as the project managers for the project, Horne Glassen and Partners as the planning and engineering design consultants and Exter Construction as the contractors. The initial project value was R7.5 million. When this amount was budgeted the number of sites was unknown, but during the course of the project it was estimated that this money would fund the provision of 1600 serviced sites at a cost of approximately R4700 per site. The first phase of 500 sites was constructed exclusively by Exter Construction. Thereafter small local contractors were sub-contracted to do as much of the work as possible, with Exter Construction filling up the slack in the project. Five small sub-contractors were used on the project. The sub-contractors had the capacity to complete about 75 percent of the work. The small contractors were managed by Exter Construction.

The communities affected by the upgrade project did not have a say in the original upgrade concept drawn up. However, once the concept had been decided upon, the communities were consulted during the planning process with regard to the delimitation of sites, the need for relocation in certain circumstances and the positioning of standpipes and access roads. During the planning process, planners met with existing committees which represented the various informally settled areas. The primary concern in planning of the upgrade was to minimise the need for relocating people. During the meeting the following choices were explained to the community:

- Option 1: Provide water, VIPs, refuse collection, but no access roads and everybody (except those living on public land, servitudes, and within the 1:50 year flood plain) could remain on their own sites;

- Option 2: Provide water, VIPs, refuse collection, a mix of road and pedestrian access meaning that more people than in Option 1 would need to be moved;
- Option 3: The above, except with vehicular access to every property, requiring that many more people would need to be moved; and
- Option 4: Reproduce formal development (except no houses), requiring everybody to be moved.

All of the committees, with one exception, accepted the proposed Option 2 upgrade without question. One committee wanted to be represented by a professional person during meetings with Councillors and the KwaZulu government. This was, however, refused by the KwaZulu government. The committee also wanted their community (which straddled the KwaZulu/RSA border) to be treated as a whole, whereas KwaZulu was only prepared to upgrade areas within Umlazi proper. Isipingo (the neighbouring local authority) did not want anything to do with the informal residents but was prepared to sell the land (on which the informal residents had settled) to the KwaZulu government. As a result of the above factors, no upgrading in this area has taken place, even though preliminary plans have been drawn up and the area was one of the priority areas to be upgraded (both from the planners and community points of view).

It can be taken for granted that people will prefer waterborne sanitation if given the choice. A discussion of the social acceptance of VIPs should thus not focus on VIPs as a preferred choice, but rather on the adequate functioning of VIPs vis a vis meeting the immediate needs of the people.

Few problems have been reported concerning the installation and operation of the VIPs. Most of the people appreciate the facility because it is much better than that which they had had previously. Where VIPs were installed in as yet unoccupied areas, many of the wooden VIP doors were stolen. However, this has not been the

case in occupied areas. There have been only two complaints of bad odours. The causes of these were not ascertained.

### **5.6.2 Bester's Camp in-situ upgrade scheme**

In 1986 what is now known as Bester's Camp was cane-field situated between KwaMashu and Phoenix approximately 20 km north of Durban City centre. In the space of 4 years the area was settled by more than 8000 families and currently has a population of between 36 000 and 50 000 people.

Bester's Camp consists of three adjacent settlements:

Bester's "proper"	3837 households
Ezimazweni	3242 households
Nhlungwane	1021 households
Total	8100 households

An in-situ upgrade project commenced in Bester's Camp in early 1991. The project is community driven with the Urban Foundation acting as the development agency and providing the project management skills. The overall philosophy of the project is to maximize the welfare of the local residents. Full community participation and control together with community based labour intensive construction is being employed in an attempt to achieve this.

The project is funded primarily by the Independent Development Trust (IDT) which makes available a capital subsidy of R7500 per household which is paid to the developer on behalf of the household on transfer of the serviced stand to the household. The total project value is approximately R60 million.

The principles and standards decided upon in consultation with the community and used in the project are:

- relocate as few people as possible;
- no minimum stand size;
- VIP latrine on every site;
- 1 standpipe or water kiosk for every 150 households;
- refuse collection from hoppers;
- tarred access roads and concrete pedestrian pathways;
- stormwater channelling where necessary;
- no provision for on-site grey water disposal; and
- community based construction techniques using local contractors.

The upgrade project was initiated towards the end of 1989 with the Urban Foundation acting as the project managers/consultants to the Bester's Camp community. The preliminary work involved defining what needed to and could be done and which sanitation system to use. Initially the community was adamant in its demand for waterborne sanitation, or nothing at all. There were, however, three compelling reasons why waterborne sanitation was not feasible:

- no bulk sewers were situated nearby;
- installing a full waterborne sanitation system would involve massive upheaval in the community as almost all the residents would be required to move during its construction; and
- the cost would be prohibitive.

Even in the face of these factors, the residents were still adamant that they wanted full waterborne sanitation and nothing less. However, after almost two years of debate, the residents eventually had to face the cost implications of their demand, given the limited funds available for the upgrade. Funding for the Bester's Camp upgrade is coming predominantly from the IDT capital subsidy scheme. The basis of the IDT scheme is that R7500 is made available for the purchase of a serviced site with tenure. The community makes the decision as to what level of service it would like and it is faced with the actual cost of the options it chooses. If full waterborne sanitation was chosen by the community, this alone would have used up the full

amount of the subsidy to the exclusion of the provision of other services such as access roads and pathways. The total project budget is R60 million and it was estimated that it would cost R50 - R60 million just to put in sewer reticulation.

The community only accepted the installation of VIP latrines on the understanding that these would be upgraded.

A series of demonstration toilets were built including VIP latrines with concrete blocks, corrugated iron and fibreglass superstructures and various low flush, anaerobic digester and on-site soakaway systems. A series of community workshops were held and the concrete block VIP was selected, its selling point being its permanence, upgradability and "status".

An important principle in the negotiations was the fact that the installation of VIPs did not mean that the community was destined to have and use VIP latrines for life. Even though it was seen as the best solution under the circumstances, the community still aspired to waterborne sanitation in the medium to long term.

The first VIPs were installed in June/July 1991.

The project relies on the community to educate itself with regard to the correct operation of the VIP latrines. This is done through the established local community development committees as well as the health committee. A sticker was prepared which is stuck on the outside of the door of every VIP latrine in both English and Zulu.

The community has established local development committees, functional development committees and a co-ordinating development committee. Monthly meetings of these committees are held.

Initially, problems were experienced with the wooden doors. Subsequent to the replacement of the doors with steel doors, no problems or complaints have been reported by the community concerning the VIP toilets.

The fact that there have been no problems reported indicates:

- the VIPs have brought a significant improvement to community life; and
- the VIPs are well constructed and function adequately.

There is one deficiency in the design of the cubicle which should be kept in mind in future designs. The cubicle was built without any ventilation holes making the cubicle pitch dark when the door is closed. Users complain of a feeling of claustrophobia in the dark. This design appears to have originated from an over-reaction to the need to keep the cubicle in a semi-dark state to discourage flies. The pitch dark state has been found to be so inimical that there is a high incidence of holes chiselled out in the walls of the cubicles to let in some light. The requirement for some light in the closed cubicle also comes from the VIP being used frequently as a washroom. There is also a desire to have the latrine door open inwards and for more space in the latrine in order to use the latrine as a bathroom or washroom. With these functions, there would be the tendency to dispose of the wash water to the pit which may cause pits to fill where the infiltration of the soil is poor.

## **5.7 SOCIAL ACCEPTANCE**

Evidence from the Umlazi and Bester's camp projects suggest that where community participation in the selection of the sanitation system has taken place in a well co-ordinated program and where the communities are aware of the cost implications of other sanitation systems, the VIP is likely to meet with community approval. However, extensive VIP programmes in urban areas of South Africa are a recent phenomenon and the social acceptability of VIP latrines in urban areas on a broader scale must still be tested.

## 5.8 ECONOMIC COST

Capital costs are very much a function of materials used and method of construction. Direct construction costs at Umlazi and Bester's camp (Document B2, PDG/UCT, 1992) ranged from R2300 to R3300 per VIP. These prices were for well built concrete block superstructures. The higher figure was due to high labour rates and project overheads. The lower figure should be more typical for a well designed, good quality concrete block VIP latrine. If industrial material such as corrugated iron, glassfibre or roto-moulded plastic, is used for the superstructure, VIP latrines can be constructed more economically, possibly for as little as R800 to R1000 per completed VIP.

Operating and maintenance costs of VIP's are very low, comprising maintenance of the superstructure and periodic pit emptying and treatment and disposal of collected solids at an off-site treatment works. Typical costs are likely to be in the range R15 to R80 per VIP latrine per year.

## 5.9 ENVIRONMENTAL CONSIDERATIONS

The risk of pollution and contamination from on-site liquid disposal systems in general is dealt with in Chapter 3.4.

However, with regard to the disposal of sullage water, it must be noted that the ventilated improved pit latrine is traditionally not designed to accept this waste water. Separate soakaways can be designed and built when the pit can no longer dispose of the volume being applied, as might be the case when water usage increases with the upgrade from hand carried water (Level 1) to a plot connection (Level 2).

## 5.10 DEVELOPMENTS

The ventilated improved double pit (VIDP) latrine is an adaptation of the ventilated improved pit (VIP) latrine. Both versions are intended to function as dry pit latrines. With the VIDP two shallow pits are dug side by side and straddled by a single superstructure. A

prefabricated pedestal seat is provided over one pit, the other pit is capped with a prefabricated slab. When the first pit is full, the prefabricated pedestal seat is moved to the second pit and the first pit is capped. After capping, the full pit is left for further fermentation and decomposition for a minimum period of one year. The full pit can be emptied mechanically or manually, if this is socially acceptable. The pits are used alternately providing a permanent sanitation facility (De Villiers, 1984).

A common problem with the double pit latrine stems from lack of understanding of the working principles of the latrine: in many instances people have been observed to use both pits simultaneously (Makhetha, 1987) thus not allowing the full pit to rest for a year before manual emptying. A further problem which stems from the proximity of the two pits, is the movement of water from one pit to the other causing cross-contamination. As a consequence the solids removed from the full pit after a year or two of decomposition still contain active pathogens presenting a health risk in manually emptying or where the material is re-used as a soil conditioner. Where mechanical emptying is available, and the solids have no re-use potential, there is no advantage in building a double ventilated improved pit latrine (Makhetha, 1987).

## **5.11 CONCLUSION**

In evaluating the ventilated improved pit (VIP) latrine it is clear that this option can play an important role in both the upgrading of existing basic pit latrines as well as in the provision of new services. There is now substantive evidence that the VIP's can be used in urban areas with very high densities either for new site-and-service schemes or for community upliftment in established informal housing areas. Because the VIP latrine cannot be used to dispose sullage (except in minor quantities) the system finds its application in areas with a low level of water supply for example, in areas provided with communal stand pipes, where water is hand carried to the plot.

## CHAPTER 6

### BASIC AQUA-PRIVY SYSTEM

#### 6.1 INTRODUCTION

The origin of the aqua-privy system of excreta disposal is not clear but its use in Africa stems from Australian experience (Vincent, *et al.*, 1963). The first units were installed in Zambia in the late 1950's, in an attempt to provide sanitation for low cost high density areas. Since that time significant developments of the system have taken place, developments that have enhanced the opportunity to supply an acceptable form of sanitation to the urban poor, and a less costly sanitation service even for smaller affluent communities in certain situations. To set these developments in perspective this chapter will describe the basic aqua-privy system and its performance, and the next two chapters the developments and modifications of the system to suit various situations.

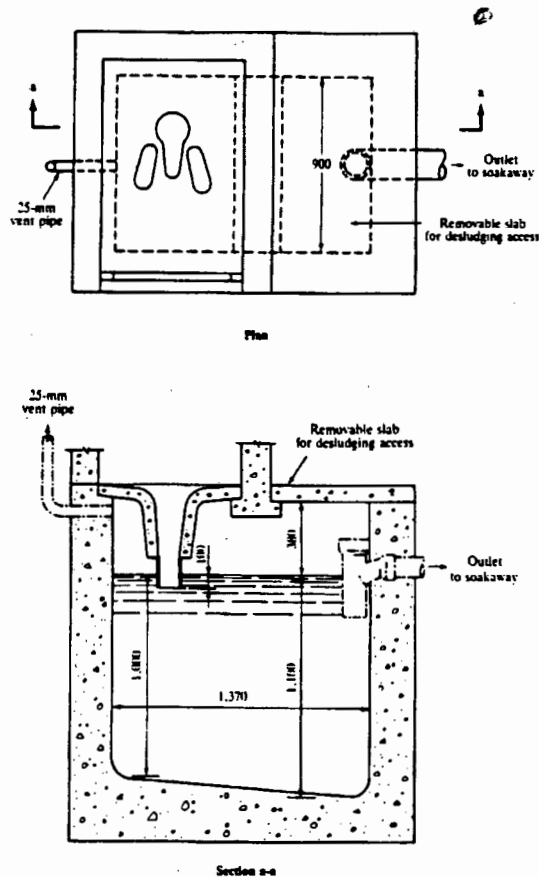
#### 6.2 SYSTEM DESCRIPTION

The original aqua-privy system was installed in areas served by waterpoints (Level 1 water provision).

A diagrammatic cross section of the basic aqua-privy is shown in Figure 6.1 (Kalbermatten *et al.*, 1982). It consists of the following:

- single chamber septic tank;
- squat or pedestal seat located directly on top of the septic tank;
- chute below the squat or pedestal seat to transfer the excreta and urine directly to the tank liquid;
- discharge point from the tank to the soakaway;
- soakaway; and
- superstructure.

**Figure 6.1 Basic aqua-privy**



Source: Adapted from Wagner and Lanois (1958).

## 6.3 COMPONENT PARTS

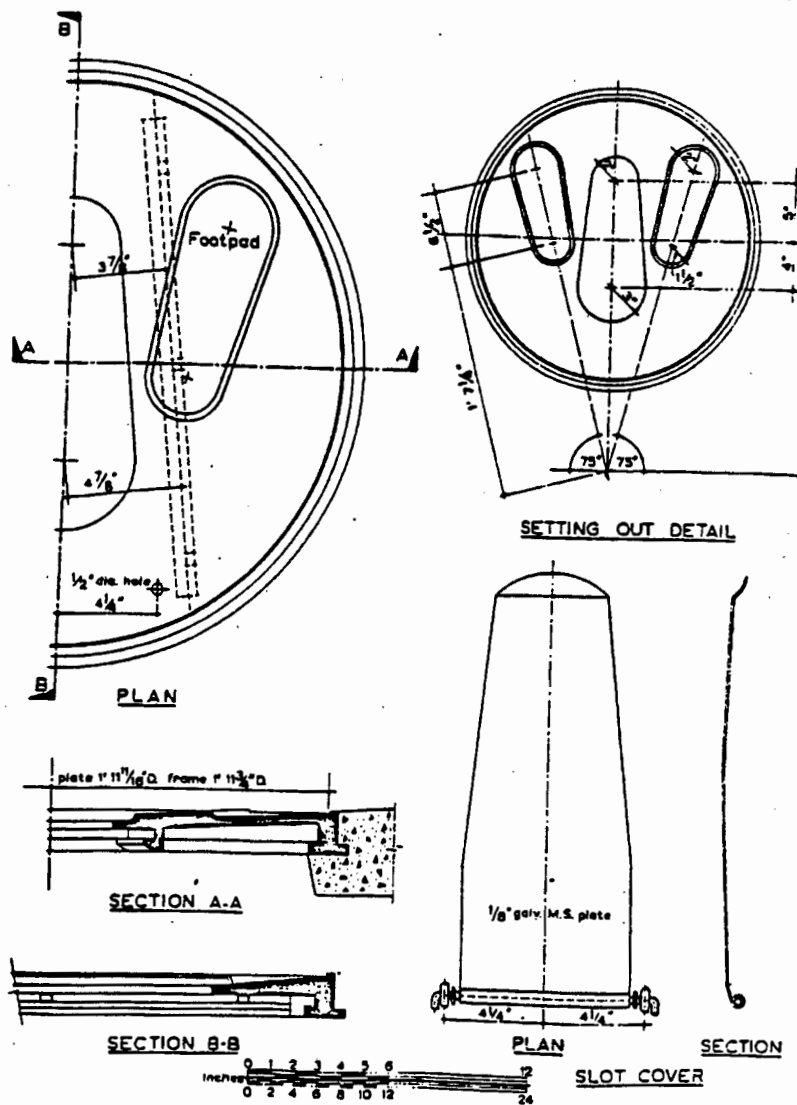
### 6.3.1 The single chamber septic tank

The tank walls were constructed of burnt clay or cement bricks, plastered on the inside. The slab on top of the tank was reinforced concrete either cast in-situ or precast and the base of cast concrete. At the time the volume of the tank was sized to provide adequate storage of sludge for an expected user number of 6, each person contributing  $0.03 \text{ m}^3$  of sludge per year, with provision for 8 to 10 year storage. The liquid volume of the tank was designed to be twice the sludge storage volume to give a total volume of about  $2.5 \text{ m}^3$ .

### 6.3.2 Squat or pedestal seat

A drawing of the chute/squat seat, the usual seat provided in Zambia, is given in Figure 6.2 . The squat seat unit fits into a manhole covering and the unit is lifted to obtain access to the tank. To prevent odour passing between the ring and the squat unit, the ring contact zone is sealed by a tar compound. The squat plate with feet location cast into it is graded inward to the squat hole to facilitate cleaning.

Figure 6.2 Squat seat



### **6.3.3 Chute**

The chute terminates 100 mm below the surface of the liquid to form a water seal to prevent the gases of decomposition from entering the cubicle above; only the material in the chute at the water surface can give off odour; as the diameter of the chute at the water surface is about 100 mm the source for odour production is very small.

### **6.3.4 Discharge Point**

The outflow from the tank is through a T piece with the centre of the T lying horizontal. The level of the water surface in the tank is set by the invert level of the horizontal leg of the T. To ensure 100 mm penetration of the end of the chute into the tank liquid (to maintain the water seal) requires the correct setting of the invert level of the horizontal leg of the T with regard to the chute bottom. In constructing aqua-privies using cement block or brickwork setting the invert level of the horizontal leg of the outlet correctly with regard to the bottom outlet of the chute proved to be a difficult operation.

### **6.3.5 Soakaway**

The effluent is discharged through the T piece into an empirically designed soakaway.

### **6.3.6 Superstructure**

In Zambia the superstructure was built of burnt brick or concrete block, plastered internally and externally. Each cubicle was provided with a door with clearance at the top and bottom to assist in ventilation and allow subdued illumination of the interior.

## 6.4 TANK FUNCTION

The excreta, urine and cleaning materials discharging to the tank (via the chute) consist of biodegradable and unbiodegradable fractions in particulate and soluble form. Particulate organic material and any inorganic solids (sand, grit and stone) that may enter the tank, sink to the bottom to form a sludge layer. In the sludge layer and in the liquid above, the biodegradable organic material (soluble and particulate) undergoes anaerobic digestion and is transformed to methane and carbon dioxide.

On the top of the liquid surface a floating scum layer forms composed of fats, oils and grease and light organic material.

Between the sludge and scum layers a "clear" water layer forms having a relatively low concentration of particulate and soluble organic materials. The vertical bottom inlet of the T outlet is located in this zone.

## 6.5 SYSTEM OPERATION AND BEHAVIOUR

The aqua-privy system, as described above, was installed at a number of Zambian townships. In operation the following were noted.

- The system was readily accepted by the users. Each family had its own aqua-privy and on the whole these were kept clean and were virtually odour free. Many families asked for a hasp and staple to be put on the door to allow locking of the door to prevent use by outsiders. Where doors had been designed with clearance above the floor of about 100 mm (to assist in ventilating the cubicle), this clearance was virtually always closed by tacking on a piece of cloth or a plank. Perhaps in the subdued light of the cubicle when the door was closed, the "sharp" light entering at the bottom of the door was irritating. Some complaints were made about the fact that with the squat seat the top water level was only about 200 mm below the top of the squat plate making the faeces in the chute clearly visible. This complaint was not encountered where a pedestal sanitary seat was provided.

- Paper for anal cleansing was not widely available. Consequently, other materials were used, principally stones but also grass, sticks, corn cobs, etc. These materials were discarded via the chute to the tank where they sank to the bottom and collected there. Their presence in the tank did not interfere with the quality of effluent discharged to the soakaway but the use of stones for anal cleansing was so widespread that some tanks became inoperative due to a cone of stones building up in the tank, eventually blocking the chute outlet.
- The tank walls, constructed of cement blocks or burnt brick cracked in many instances, and seepage through these cracks caused the water level in the tank to drop below the bottom outlet of the chute, thus breaking the water seal. This gave rise to odour nuisance in and around the aqua-privy and fly and mosquito breeding in the tank liquid. To maintain the seal the user had to add water manually through the chute. However, this was rarely done and in many instances the tank liquid drained out completely and the system, in effect, became a pit latrine. In order to maintain the liquid level sullage water, where wash basins were provided, was disposed of into the tank. Where no such wash basins were provided gangs of labourers were employed to add a 4 gallon (16 litre) paraffin tin of water every second day to each tank via the chute. However, these solutions were also largely unsuccessful in areas in which the soil was clayey; the quantities of water entering the tank and discharging to the soakaway exceeded the absorptive capacity of the soakaway and effluent came up in springs around the soakaway. This situation was exacerbated during the rainy season in areas where the water table rose close to the soil surface. However, where the water level in the tank was maintained and difficulties with the soakaway were not encountered, the system worked satisfactorily.

## 6.6 CONCLUSION

In principle the basic aqua-privy system provided a sound system of sanitation which was acceptable to the users. However, in operation two problems became evident that made it unacceptable in its basic form (Vincent, *et al.*, 1963).

- Seepage from the tank through the cracks caused the tank water level to drop below the bottom outlet of the chute, breaking the water seal. This then generated fly and mosquito breeding. This situation was widespread where the tank received only urine and faecal material.
- Failure of the soakaways took place where sullage was discharged to the tank to maintain the water seal. On many sites the consequential increase in discharge from the tank proved to be in excess of the absorptive capacity of the soakaways particularly where clayey soils, seasonally high water tables or shallow soils underlaid by rock were encountered.

The two problems are in a sense mutually exclusive. Resolution of one or other would provide a solution to the aqua-privy system.

- In Zambia the solution focused on an alternative to the soakaway: leakage from the tanks was accepted but the water level in the tank was maintained with sullage discharging to the tank. To deal with the increased flow the soakaway was replaced by a sewer conveying the liquid effluent off site. This solution gave rise to the "self topping aqua-privy system".
- In South Africa the solution centred on providing a watertight tank, limiting its discharge and retaining the soakaway. This solution gave rise to the "on-site low flush aqua-privy".

## CHAPTER 7

### THE SELF-TOPPING AQUA-PRIVY

#### 7.1 INTRODUCTION

In the previous chapter it was concluded that the basic aqua-privy had two problems;

- Seepage from the tank through the cracks caused the tank water level to drop below the bottom outlet of the chute, breaking the water seal. This led to fly and mosquito breeding. This situation was widespread where the tank received only urine and faecal material.
- Failure of the soakaways took place where sullage was discharged to the tank to maintain the water seal. On many sites the consequential increase in discharge from the tank proved to be in excess of the absorptive capacity of the soakaways particularly where clayey soils, seasonally high water tables or shallow soils underlaid by rock were encountered.

The two problems are in a sense mutually exclusive. Resolution of the one or other would provide a solution to the aqua-privy system. In Zambia the solution focused on an alternative to the soakaway: leakage from the tanks was accepted but the water level in the tank was to be maintained by the tank discharging sullage to the tank. To deal with the increased flow the soakaway was replaced by a sewer conveying the liquid effluent off site. This solution gave rise to the "self-topping aqua-privy system".

The self-topping aqua-privy system described here is the one developed in Zambia during the 1960's (Vincent, *et al.*, 1963). The system has found little application in South Africa in its original form. The description of the parts of the self-topping aqua-privy system are the same as those implemented in the 1960's. Implementation of the system today doubtless will

contain improved toilet design, sewer connection, etc, but the basic principles on which the system operates will still apply.

## 7.2 SYSTEM DESCRIPTION

The self-topping aqua-privy system comprises:

- an on-site partial treatment of the waste water in an aqua-privy; and
- transportation of the anaerobically treated effluent in a sewer to the disposal site where it is treated.

A water supply, not necessarily piped, is essential for the operation of the system. Figure 7.1 (Vincent, *et al.*, 1963) depicts the self-topping aqua-privy.

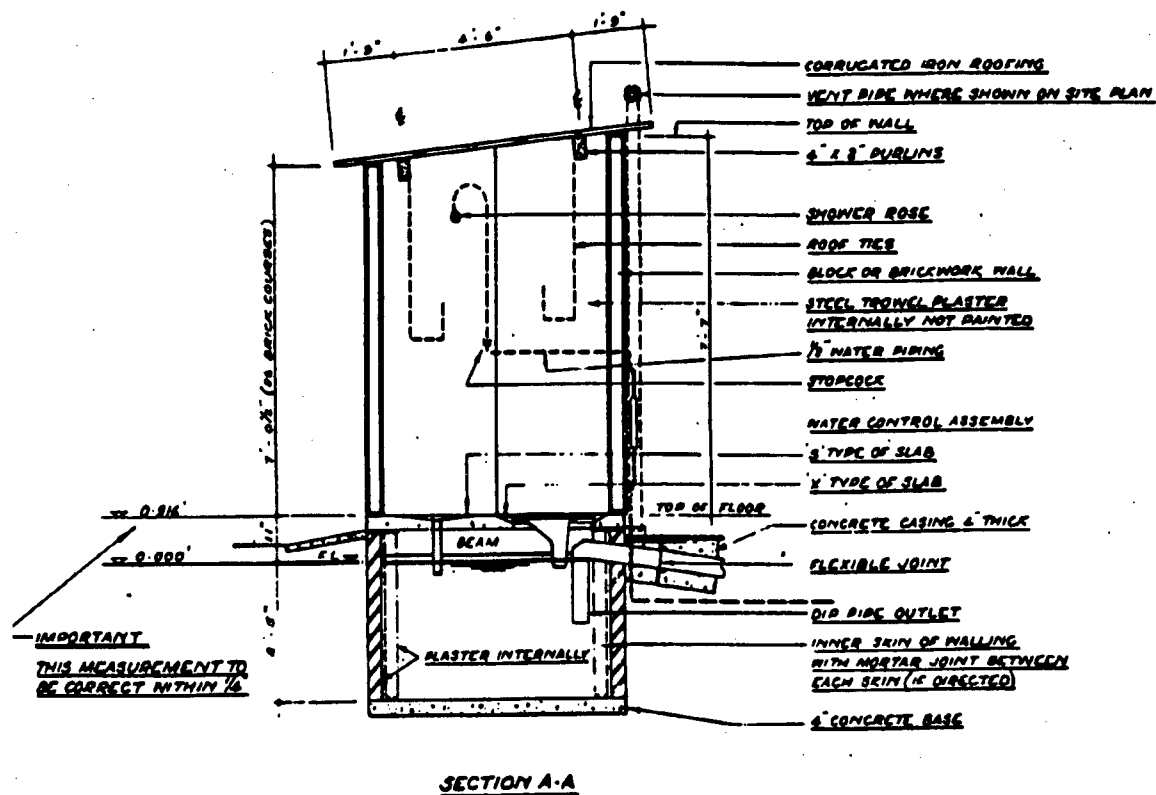
## 7.3 COMPONENT PARTS

### 7.3.1 Sanitation block

The sanitation block, see Figure 7.2 where it is designed to serve two families, is usually placed across the common boundary and where it serves three or four families on the corner junction of the plots. The building is located away from the house for the economic advantage gained by combining more than one unit and reducing the number of lengths of connections to the sewer.

The ablution and latrine cubicles have a common door and these cubicles are placed at right angles to each other. This arrangement avoids passing or squatting under a water drip if and when a shower is installed. The floors of the cubicles are laid to provide good falls towards the drainage pipe in the ablution cubicle and the squatting plate in the latrine cubicle. The waste water from the ablutions discharges into the aqua-privy tank through a vertical pipe terminating 100 mm below the surface of the

Figure 7.1 Self topping aqua-privy



tank liquor.

The washing facilities are under cover of the roof. Each family has its own wash trough screened from that of its neighbours. Again the waste water discharges directly through a vertical pipe into the tank below; should a blockage occur, it is easily removed by rodding. In designs where U - trapped waste pipes were used, these frequently blocked with organic material (principally maize porridge) and/or sand commonly used in pot scouring.



The top of the tank is covered with a concrete slab either cast insitu or precast into which is set the requisite number 61 cm diameter manhole frames receiving the squatting plates.

The squatting plate has an opening with two suitably located footpads cast into it. The footpads are raised above the surface of the plate and the plate is graded inwards towards the opening for drainage. To the underside of the squatting plate a chute of stainless steel or other corrosive resistant material is fixed by means of an airtight joint. To ensure odour free operation, it is essential that there is no gas leakage from the tank, and that the rim is sealed with a tar compound. The outlet from the tank to the sewer is located below one of the squatting plates. Should any blockages occur in the connection from the tank to the sewer, the squatting plate can be lifted and rodded through the opening. The squatting plate serves as a manhole cover giving access to the tank and eliminates the need for an external manhole. External manholes are not recommended unless fitted with medium heavy covers, as light covers are sometimes lifted, and the tank used for garbage disposal.

### **7.3.2 Tank**

The tank is placed below the building and its width is the same as that of the building, the longitudinal walls bearing directly on the walls of the tank. The tank extends beyond the end walls of the building so that waste water from washing troughs can drain into it directly from above.

The floor of the tank, which also forms a foundation for the whole superstructure, consists of concrete 100 mm thick. By making the tank an integral part of the building, the foundations are simplified and differential settlement is reduced. The volume of the tank was fixed by the larger volume required for either liquid retention or sludge accumulation. The criteria for design was :

- (1) retention time in the tank should not be less than 1 to 2 days - longer retention times bring about little improvement in BOD (COD) reduction.

- (2) in areas of low water consumption per capita, the retention time is an inadequate criterion for design as sludge accumulation makes the period too short between desludging.

It was measured that approximately 0,03 m<sup>3</sup> of sludge per person per year accumulates in the tank. In many instances, the period between desludging governs the design of the tank volume. The tank volume was determined by allowing at least twice the maximum sludge volume accumulation. The tank design shown here allows approximately 0,5 - 0,7 m<sup>3</sup> volume per person. This provides for about 10 years' service before desludging is necessary.

Self-topping aqua-privy tanks were operated successfully with a sludge volume space of 80 litres (0.08 m<sup>3</sup>) per person but desludging was required after two years' operation.

The outlet from the tank is a modified 100 mm ceramic T-junction, or a specially cast asbestos cement outlet. With the ceramic T, the top branch of the T is cut off; this allows the water level to come within 100 mm of the bottom of the roof slab of the tank. The centre leg of the tee lies horizontally and passes through the tank wall and connects with a 100 mm salt glazed connecting sewer. It is of the greatest importance that the invert level of the horizontal leg of the T-outlet be set at the correct level with regard to the outlet level of the aqua-privy chutes, as the T-invert level governs the level of the liquid surface in the tank. If it is set too low there will be no water seal around the chute outlet; if set too high the liquid level comes too near the top of the chute and there will be complaints about the unsightliness of the faeces in the chutes where units have squat seat toilets. In addition, it is also difficult to flush the faeces during cleaning. In construction the correct setting of the chute outlet in relation to the T invert proved to be a major problem.

As the tank vents through the sewer, it is doubtful whether ventilation pipes are necessary but until more research is carried out, it is perhaps advisable to install at

least a limited number: vents are placed in the aqua-privy tank at the head of the collecting sewer, and in tanks approximately 100 m apart thereafter.

The system can be adapted to operate with very little waste water flow. Where water supply is limited, a communal washing trough is placed at the head of the sewer and the aqua-privies connected in series. Such systems have operated satisfactorily with flows as low as 10-20 litres/person/day.

### 7.3.3 Sewer

The aqua-privy tank retains all sand, stones, etc.; most of the organic solids are decomposed to a finely divided state. The criteria valid for sewers carrying raw sewage therefore need no longer be adhered to and the sewer may be designed in conformity with the hydraulic requirements of flow. In Zambia the old Northern Rhodesian Housing Board (later the Zambian Housing Board), from about 1959, applied the following minimum criteria to design sewers transporting aqua-privy effluent:

- minimum velocity at half or full bore flow - 0,3 m/s; and
- minimum diameter of sewer - 100 mm.

The velocity of flow in the sewer is dependent on the roughness co-efficient of the internal sewer surface, the sewer slope and the depth of flow in the sewer. [Comparison of flows in sewers of different diameters by Marais (personal comment (1992)), indicated that for the same slope (S) the velocity of flow (V) in a sewer is virtually independent of the sewer diameter (up to 0.8 full) and is dependent only on the flow rate (Q) and friction factor (f), or generally,  $V = f(S, Q, f)$ ]. Usually at peak flow the sewer diameter will be selected such that the flow depth will be at least half full. As at this depth the sewer will have the same velocity as at full bore free flow (ie channel flow not pressure flow). The half bore velocity serves as a convenient reference value. For velocities of 0.3 m/s different diameter of pipes with

the Mannings co-efficient of friction of 0.012 will have slopes as given in Table 10.2. The minimum slopes will allow virtually any flat site to be sewerred without the need for lifting stations.

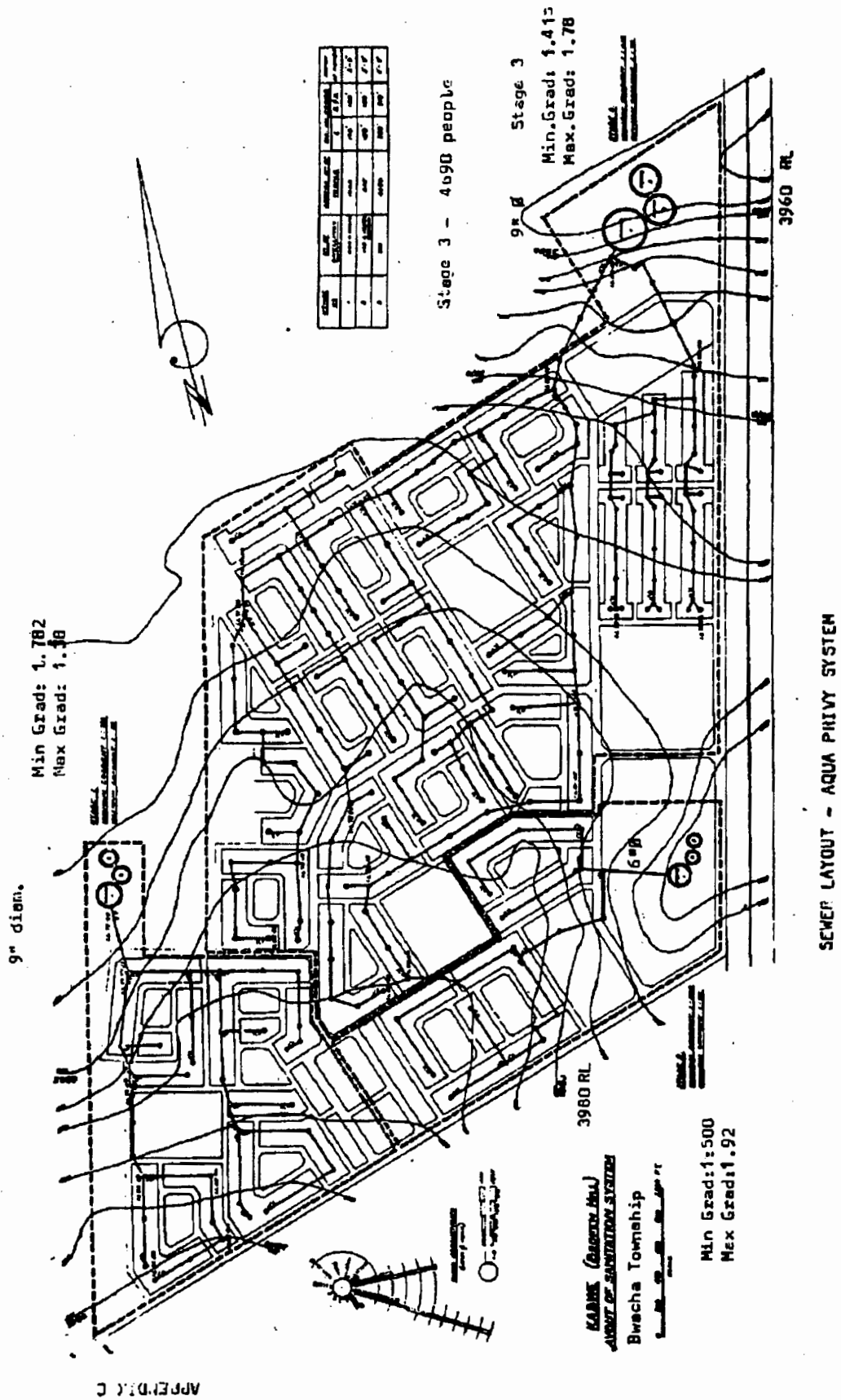
At flat minimum slopes it is impossible to ensure a smooth slope so that in some lengths the sewer may not be free flowing but flowing full bore through "dips" in the sewer line; this does not appear to effect the discharge of the sewer. Figure 7.3 shows a sewerage system conveying self-topping aqua-privy effluent in Kabwe, Zambia designed in the early 1960's. Note that the minimum slope is 1:782. The suburb was laid out originally for pit latrines and hence the layout did not take cognisance of the flat topography for future sewer design. Note that even with the these flat minimum sewer grades it was still necessary to divide the township into 3 drainage areas, each with its own sewerred self-topping aqua-privy system, discharging to the respective oxidation pond systems.

It should be noted that these minimum slopes would be employed only in exceptional circumstances and in unusually flat topography. Usually the slopes available will be greater and hence velocities higher than the minimum 0.3 m/s are usually attained.

In Zambia over 30 self-topping aqua-privy sewerred systems where installed by 1965. By providing solids free effluent, it became possible to install "water carriage" sewerage systems in very flat topographical areas without the need for pump stations. In not one of the schemes in Zambia was it necessary to provide lifting stations in the sewer systems (Vincent, *et al.*, 1963). Sewer blockages were rare events; sewer systems operated for 6 months or longer without blockages. Blockages noted were in the aqua-privy tank caused by plastic bags covering the T outlet.

In Zambia the minimum midblock sewer diameter - 100 mm - was selected because this was the smallest sewer diameter available. However, for sewer lines a minimum diameter of less than 100 mm does not appear to be a good option because of the increased difficulty of clearing blockages should these occur.

Figure 7.3 Kabwe, Zambia



With these flat sewers it is essential that the sewer system is "sealed" against entry of sand and other inorganic material. From experience with full waterborne systems, light manhole covers are readily lifted and garbage dumped into the manhole. Accordingly in the self-topping aqua-privy system heavy duty covers were obligatory from the start. Manhole covers with holes drilled through the cover to vent the sewer were not allowed; with such manholes, sand and pebbles fall through the holes, and children push reeds and sticks through the holes. Instead of manholes, some experimental sewer rodding eyes were substituted. However, the efficiency of these, for cleaning the sewer, were not tested effectively because of the rarity with which blockages occurred.

If at some future date it is intended to install a conventional flush water closet in the latrine cubicle, discharging into the tank, the effluent flow per person per day from the tank will increase and the sewers should be designed to take this future expected flow.

Where flat grades are present in sewers carrying aqua-privy or septic tank effluent **raw sewage or any waste water must never be discharged directly into the sewer but must always pass through a tank.**

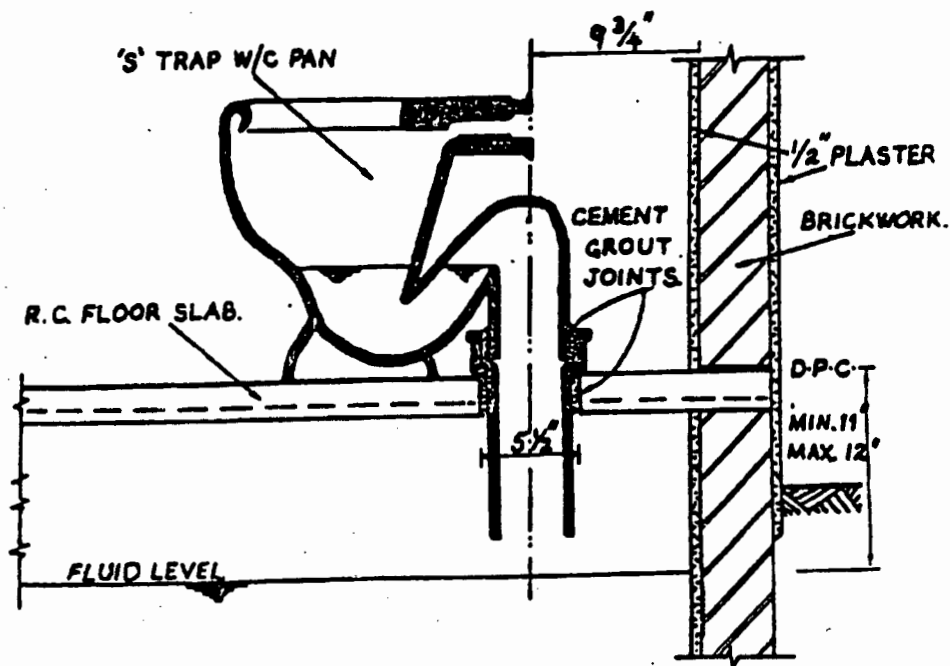
In the aqua-privy sewer systems flexible joints were installed to allow for differential movements in the sewer due to heaving clays and collapsing sands. Flexible joints at junctions in buildings and at manholes are also essential to accommodate differential settlement between the structure and the sewer. Indeed flexible joints throughout the sewer are advisable to reduce the risk of sewer breaks due to differential movements. With flat sewers sand entering through breaks in the sewer will not be carried down the sewer. Manholes were spaced 100 m apart because cleaning rods extended only to that length; with longer cleaning rod apparatus there appears good reason for spacing the manholes further apart.

In some instances curved sewers were employed instead of straight sewer sections with a manhole at every change in direction but too few of these were constructed to evaluate their efficiency.

### 7.3.4 Modifications

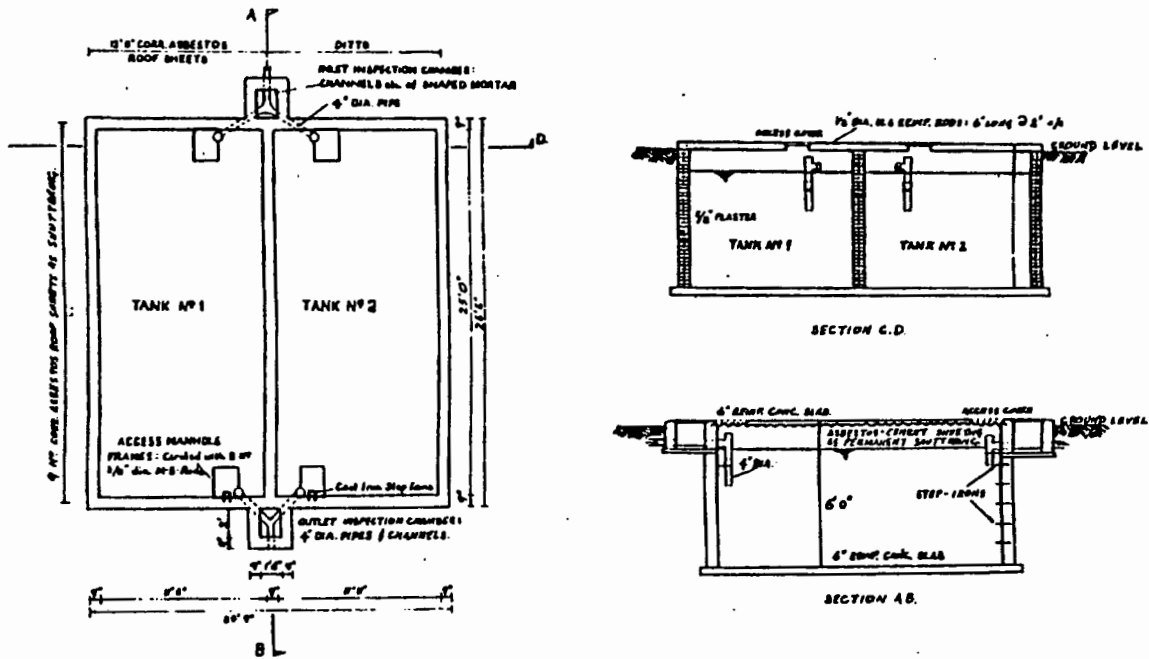
- Where flush sanitation units are specified the aqua-privy chute assembly may be replaced by a regular flush watercloset (WC) unit. The discharge from the flush unit must terminate **above** the tank water level otherwise the liquid in the water seal of the flush is syphoned into the tank, see Figure 7.4 (Apparently there are flush units discharging to the tank below which do not require the outlet to terminate above the water level because they have a bleed hole in the waterseal area).
- If internal sanitation is specified, the WC unit flushes to a small "pre-treatment" tank, a simple single chamber septic tank, outside the house, and from there to the sewer.
- Where a block of houses is fitted with internal WC units and the feeder sewers have sufficient fall to carry raw sewage but the slope of the main sewer is inadequate to give self-cleansing velocities (1 m/s), an anaerobic treatment tank (Figure 7.5 ) is placed in the feeder sewer line just before discharge to the main sewer.
- Where ground slopes are adequate throughout for self-cleansing raw sewage flows, and the effluent is treated in a oxidation pond system the anaerobic pre-treatment tank should be located at the outfall just before the primary oxidation pond.

Figure 7.4 Traditional flush water closet



A typical design of such a pre-treatment tank serving 200 families is shown in Figure 7.5. The distinguishing feature of the design is that the plan module is an asbestos cement corrugated sheet which serves as permanent shuttering for the cover slab. The sheets are placed over the tank with the appropriate reinforcing and the slab cast on top of the sheets. The walls are 225 mm reinforced brick internally plastered. Total depth below the slab is 200 mm with 150 mm water depth. Where the soil conditions allow, the total depth below the slab is increased to 250 mm. The size of the tanks depends on the number of families served, Table 7.1.

**Figure 7.5 Pretreatment tank serving 200 families**

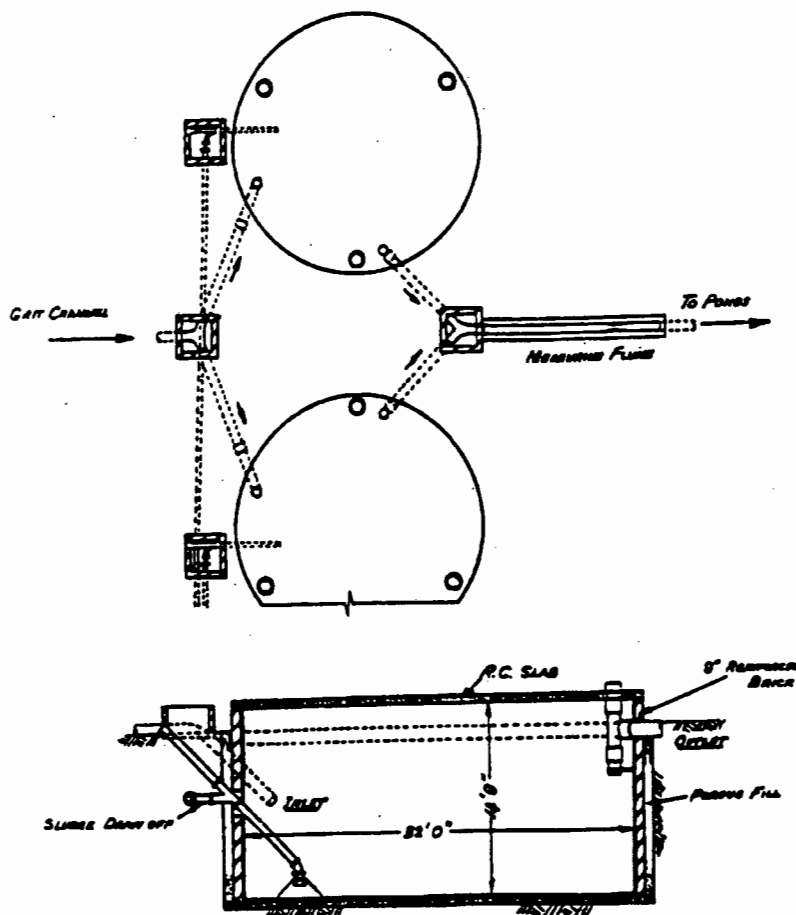


No. of Families	A.C. Sheets	No. of tanks	Overall Plan Dimension
5 - 10	7 x 1.80m	1	3.90m x 2.00m
10 - 20	7 x 2.70m	1	3.90m x 2.90m
20 - 50	4 x 3.60m	1	3.75m x 3.00m
50 - 100	7 x 3.60m	1	6.40m x 3.90m
100 - 200	9 x 3.60m	2	8.10m x 7.55m

Treatment tanks for larger communities, 6000 to 10 000 people, installed before discharge to stabilization ponds are usually in pairs and circular in design to reduce the cost of wall reinforcement. Retention times are reduced to 18 to 24 hours. At such short holding times, the relative mass of sludge and sand accumulation is significant. Grit channels are installed before discharge to the tanks. A design for 10 000 people is shown in Figure 7.6 . Degritting of the tanks is carried out at regular monthly intervals. Longer intervals tend to cause compaction of the sludge

and desludging may require prior rodding of the desludging pipe, or the use of compressed air.

Figure 7.6 Tank design for 10 000 people



By enclosing the anaerobic tanks, odour problems are reduced significantly so that the anaerobic tank and oxidation pond system can be quite close to the houses. In contrast, open anaerobic ponds are always liable to give rise to odour and fly problems at some time.

#### 7.4 EFFLUENT TREATMENT

Where the aqua-privy system is installed in areas served by activated sludge or trickling filters the effluent will very likely discharge to the outfall sewers feeding these works. The

influent BOD to the self-topping aqua-privy is reduced by 50 to 80 percent but the TKN remains the same. The effluent also contains no readily biodegradable substrate fraction, only slowly biodegradable and inert fractions. These factors mean that the TKN/COD (or TKN/BOD) ratio of the influent to the works will be raised, thereby increasing the difficulties in obtaining adequate denitrification and biological phosphorous removal. Significant increases in the TKN/COD ratio will require that provision for generation of additional readily biodegradable material be included in the works process if, in particular, phosphorus removal is a requirement.

Treatment by normal trickling filters can ensure nitrification but denitrification is not possible; phosphorous removal requires chemical precipitation.

With isolated systems, treatment of self-topping aqua-privy effluent by oxidation ponds is a viable and relatively inexpensive option. The size of the primary oxidation pond per person is reduced compared with that for raw sewage; a rule of thumb is 1 to 1.3 m<sup>2</sup>/person for the primary pond 1.6 m deep. With appropriate design of the secondary (maturation) ponds, effluent very low in faecal micro-organisms and complete elimination of helminths are attained; again a rule of thumb for sizing the ponds is 0.5 to 0.65 m<sup>2</sup>/person, for a pond 1.6 m deep, with two maturation ponds in series, Marais (1970).

With appropriate design, mosquito breeding will not take place in the ponds. The main, and virtually only, cause to give rise to mosquito breeding in ponds is emergent vegetation which provides a sheltered shadowed area on the pond surface. This is a condition favourable to mosquito breeding especially where the ponds have been kept free of emergent and peripheral water's edge vegetation. In Zambia bilharzia snails have never been found in the ponds. A major vegetation problem is growth at the water's edge at the sloping earth walls of the pond. **Concrete slabs from 150 mm above to 150 mm below the waters edge effectively control vegetation growth and hence mosquito breeding.** Phosphorous removal from the influent is poor but a certain measure of nitrogen removal takes place by gas exchange due to the high pH developed in the top layers.

Due to the fact that algal growth in the pond is facilitated by mixing due to wind, the behaviour of the pond is crucially influenced by mixing and stratification. Mixing promotes the growth of non motile algae which are good oxygen producers and the pond is aerobic throughout its depth. This condition is often dominant during the cooler weather with windy conditions. Stratification causes the non motile algae to die out leaving the motile forms. *Euglena* is the most prominent species. This alga is present in greatly reduced numbers and is a poor oxygen generator. Stratification occurs more readily in hot weather when the wind velocity is low. Generally the pond should show signs of anaerobic conditions in the summer. The beneficial effect of wind is important and hence no trees should be planted around oxidation ponds. The dynamic behaviour of ponds is extensively investigated by Marais (1970).

With self-topping aqua-privy influent the sludge layer formed in the pond reduces anaerobic fermentation potential and the sludge constitution is granular. In hot weather rising sludge tends to break up so that floating sludge layers tend to be significantly less than with raw sewage as the influent. In general anaerobic pre-treatment before discharge reduces operational problems.

The great deficiency in oxidation pond treatment is the high algal concentration in the effluent and the poor removal of nitrogen and phosphorous. Research into oxidation ponds has been virtually abandoned in South Africa over the past decade or two. Oxidation pond research should be revived, considering the potential of this system for waste water treatment in the present socio-economic climate in South Africa.

## **7.5 APPLICATION OF THE SELF-TOPPING AQUA-PRIVY**

### **7.5.1 Application overseas - the Australian experience**

In South Australia the use of anaerobic pre-treatment ("interceptor") tanks at each house before discharging to sewers is widely applied. The sewerage systems of 65 towns are based on this approach. State design standards have been promulgated. At the time of writing information on the design of these systems is still incomplete.

From information available, flow criteria in the sewers are much stricter than those employed in Zambia, only slightly less rigorous than those for raw sewage. However, for the purposes of this document, the important fact is that on-site pre-treatment of waste flows has found application in a country with a high standard of sanitation provision - this may assist in countering criticism that an inferior system is being imposed on the communities.

### **7.5.2 Application - Locally**

No "regular" self-topping aqua-privy system has been installed in South Africa. At Marseille, however, a low flush system has been installed, the effluent discharging to solids free sewers and then to oxidation ponds (see Chapter 8.9.2.).

## **7.6 CONCLUSION**

The self-topping aqua-privy system and its adaptations and extensions provides a versatile system of sanitation. Although the system may not find application in its entirety, the concept of on-site pre-treatment before discharge to sewers for off-site treatment allows total removal of waste water, both grey and black water, generated on-site, for virtually all levels of water supply.

For sanitary provision to poor communities combining 2, 3 or 4 units in a single building reduces cost. However, it is not a communal system because each site retains individual access and responsibility. Different levels of provision of water supply, washing and ablution facilities can be provided to suit the communities' requirements and financial affordability. The system can be upgraded as required.

Allowing only pre-treated effluent in the sewers can reduce the capital cost of sewerage, particularly in flat and rocky areas, and certainly reduces sewer maintenance costs. Furthermore, construction of some parts of the sanitation unit and the sewers can make use of local contractors and labour.

No cost figures can be given because systems, such as the one described in this chapter, have not been installed in South Africa. Cost information is not available for the systems in use in Zambia.

## CHAPTER 8

### ON-SITE LOW FLUSH AQUA-PRIVY

#### 8.1 INTRODUCTION

In Chapter 5, it was noted that one of the reasons the basic aqua-privy system was unsuccessful in Zambia was that the tank constructed of brick or concrete blocks often cracked. This caused a loss of liquid from the tank. If the liquid level was not maintained the tank became, in effect, a basic pit latrine with the attendant problems of short life and fly and mosquito breeding.

To overcome the problem of seepage from the basic aqua-privy (see chapter 6.5) in South Africa the tank was constructed using watertight materials. As with the basic aqua-privy the disposal of the effluent continued to be via a soakaway. In some designs the pedestal seat followed the design of the basic aqua-privy but in others the pedestal seat was modified to a flush system. In order to reduce the flow to the soakaway, low volume flush mechanisms were utilised to flush the pedestal units. This led to the aqua-privy system being known as the on-site low flush aqua-privy (OSLAP).

The designation "on-site low flush aqua-privy system" refers to low flushing (less than one litre per flush) or dry rodding sanitation systems in which the faeces/flush discharges to an anaerobic digester tank, the effluent from the tank in turn discharging to a soakaway. **The tank does not receive any sullage.**

To date over 20 000 OSLAP units have been installed in urban South Africa, the majority in the PWV area.

## 8.2 SYSTEM DESCRIPTION

The OSLAP sanitation system comprises the following basic components:

- toilet pedestal and flushing/rodding mechanism with water seal;
- anaerobic digester tank (watertight); and
- effluent disposal soakaway (with an option of solid free sewer to treatment works).

A number of variants of these sanitation units have been developed commercially (see section 8.6 for a description of three systems in use in Ivory Park in the Transvaal).

## 8.3 COMPONENT PARTS

### 8.3.1 Toilet pedestal and flushing/rodding mechanism with water seal

The pedestal toilet seat designs are generally more sophisticated than those used in the self topping aqua-privy design (indeed the self topping system can make use of these designs with advantage). In most instances there is a chute with a round or oval conical top and a circular bottom. The bottom of the chute is of restricted diameter (approximately 100 mm) to limit the size of balled paper or other extraneous material being forced into the tank.

In some instances the pedestal seat may have a hinged water trap (tipping tray) providing a second seal against odour emanating from the tank; this hinged trap ensures that the user can not see the contents of the tank when the pedestal lid is raised. Other designs have hinged chutes above the main chute, again to hide the faeces from view.

Some pedestal units have a cistern integral with the unit, some an external cistern discharging by gravity. These need to be filled manually and have sufficient volume

for about 20 flushes. Some units have no flushing mechanism and, if necessary, the faeces are rodded into the tank by means of a flexible rod provided for this purpose.

The pedestal seats are made from a variety of materials the more common being fibre glass, rotor moulded plastic or vitreous china.

### **8.3.2 Anaerobic digester tank (watertight)**

The tanks are either made of fibre-glass or rotor moulded plastic.

The important components of the tank are:

- inlet and outlet arrangements; and
- tank volume.

#### **Inlet**

The inlet must provide for free discharge to the tank of the faecal and anal cleansing material, and other extraneous material (such as stones, paper or rubbish). A variety of inlet arrangements have been designed; some have a direct vertical discharge similar to that in the basic and self topping aqua-privy design; others have discharge pipes of constant or expanding diameter curving from the pedestal to the tank and discharging at the side of the tank. It is also possible to have the pedestal inside the house and the tank outside, a design that has been used for schools and some houses.

#### **Outlet**

The outlet arrangement must ensure that minimal suspended solids or large solids discharge to the soakaway. A common design is a T piece with a horizontal centre piece. The one vertical leg of the T ends above the scum layer and vents the gases generated in the tank to the pipe draining to the soakaway. The other leg of the T penetrates into the liquid volume terminating at the level estimated to be above the

maximum sludge layer but below the scum layer. The outlet pipe diameters vary from less than 75 mm to 100 mm.

### **Tank**

Until recently tank volumes of commercially made OSLAP systems have ranged from approximately 142 litres to more than 1000 litres. The smaller tank volumes are overtly too small. There is no opportunity for the sludge to digest and eventually it is "washed" over into the soakaway (see this chapter, section 5). Tanks of 1000 litres or larger seem more appropriate but there are as yet no formal guidelines on minimum tank volume.

## **8.4 SYSTEM OPERATION AND BEHAVIOUR**

### **8.4.1 Tank**

The function of the tank is to retain the inorganic and organic solids in a fermenting sludge layer at the bottom, retain the build up of scum layer at the top, and by settlement separate out the organic particulate material from the liquid to leave a relatively clear water zone from which the discharge to the soakaway takes place.

Tests done on the aqua-privies in Ivory Park (Document EXT1, PDG/UCT, 1993) show that the smaller the tank the higher the solids carry-over to the soakaway.

### **8.4.2 The soakaway**

The function of a soakaway is to facilitate the infiltration of the effluent from the digester tank to the surrounding ground. It is unfortunately not easy to determine a soil's suitability for a soakaway (long and short term). In many areas site conditions, such as the following, may discourage or prohibit the use of soakaways:

- soils with low permeability;

- shallow infiltrative soils overlying a restrictive layer of impermeable soil or rock;
- high groundwater tables; and
- areas underlaid with dolomitic rock (rapid drainage of effluent to the groundwater and danger of sinkhole formation).

A fairly detailed site evaluation with soil profiles, and soakage tests are essential to size the soakaway (De Villiers, 1987). Because of the effort involved in a detailed infiltration investigation and the wide variation in soil properties over the housing area, an *ad hoc* decision empirically based on a suggested infiltration rate from an agency such as The World Bank may be the only practical solution (See Section 8.5.2).

## 8.5 TECHNICAL CONSIDERATIONS

### 8.5.1 Tank

In general the size of the self-topping aqua-privy or interceptor septic tanks have been based either on hydraulic retention time or storage volume for sludge accumulation. Tanks receive waste flows from domestic dwellings, where piped water is supplied to the house. The volume of water supplied is such that if the tank is designed to give 2 to 3 days hydraulic retention time, the volume of the tank would usually also provide adequate space for sludge accumulation of 6 to 10 years before sludge builds up to the discharge point to the soakaway. (The SABS building regulations require a minimum 1700 litre volume for septic tanks.)

With on-site low flow aqua-privy systems, the sizing of the tank using the hydraulic retention time criterion will result in inadequate volume provision for sludge storage, even if the hydraulic retention time is increased five fold due to the low volumes of water used per flush. Consequently with the low flow systems the sizing of the tank must be fixed by the sludge accumulation rate and the period between desludging.

The sludge accumulation rate in the digester tank is dependent on unbiodegradable organic solid residue from the faecal material, materials for anal cleansing, additional household waste water (kitchen and bathroom) and the number of users. Although the faecal material residue will differ somewhat with different diets, the effect of different anal cleansing and kitchen wastes (sullage) are more marked. De Villiers (1984) gives the following sludge accumulation rates in litres/person/year:

Table 8.1 Sludge accumulation rates

<b>Materials used for anal cleansing</b>	<b>litres/person/year without sullage</b>	<b>litres/person/year with sullage</b>
<b>Water and soft paper</b>	25	40
<b>Hard paper</b>	40	50
<b>Sand or stone</b>	55	70

With the above rates, and an estimate of the likely maximum number of users, it is possible to determine the sludge accumulation over a period. With OSLAP systems no sullage is received but the use of hard paper for anal cleansing can be expected. In terms of the table above, provision for sludge accumulation of at least 40 litres/person/year should be provided. The sludge volume that is provided should extend downward below the inlet of the discharge leg of the T. Volumes for the clear water zone, scum zone and air space above the liquid level, are then added to the volume reserved for sludge accumulation, to give the volume of the tank. Conversely, for any selected sludge storage volume, the period between desludging will be fixed by the accumulation rate of sludge.

A further difficulty arises in determining the period between desludging, in that the number of latrine users are statistically distributed quite widely about the mean number. So, for example, for a mean number per latrine of 4 the distribution may range from 1 to 8 - the desludging period should be based not on the 50 percentile, but, say, on the 80 or 90 percentile value.

### 8.5.2 Soakaways

Soakaway design needs to take cognisance of the following:

- The **infiltrative capacity** of a soakaway which is the rate at which liquid will pass through the soil-water interface; this measures the ability of a soil to accept liquid.
- The **percolative capacity** which is the rate at which a liquid moves through a soil once it has passed the interface; this measures the ability of a soil to transport the liquid.

There are approximate relationships between the percolative capacity of the soil (established from tests) and the application rate of effluent. However, the critical factor often is the infiltrative capacity which can decline significantly with time due to "clogging" at the water - soil interface.

#### **Clogging of percolating systems in soils**

Clogging causes many failures in soakaways and can be brought about by three main factors:

- physical;
- chemical; and
- biological.

**Physical factors in clogging** - these can be caused by the compaction of the soil due to superimposed loads, smearing of infiltrative soil surfaces by excavating equipment during construction or the migration of fines due to vibration or rainfall.

**Chemical factors in clogging** - this is caused principally by ion-exchange. This can occur by deflocculation of the clay colloids by sodium.

**Biological factors in clogging** - these are the most important causes of clogging. Generally it is a surface phenomenon caused by the development of an organic mat on the surface of the infiltration interface. Infiltrative capacity may recover if the surface is drained and oxygen is drawn in to induce high rate aerobic decomposition of the clogging mat.

The soil surface texture, and hence its infiltrative capacity, may be resuscitated by drying and subsequent cracking of the surface (Gilmore, 1970). These two effects can be achieved by cyclic loading and resting of the soakaway. This operational procedure will demand two soakaways, the soakaways being used alternately, one in use while the other rests.

With single soakaways under continuous use, anaerobic conditions may set in which can cause clogging due to growth of slimes in the organic mat and the deposition of ferrous sulphide, a black particulate matter, which gives the characteristic colour to clogged soakaways. Presence of ferrous sulphide in appreciable amounts indicates failure of the soakaway.

A technique which can extend the life of a soakaway is to provide the opportunity for the organic mat to develop "in depth" rather than as an intense layer on the soil interface. This is achieved by providing a sand layer between the soil and stone medium in the soakaway. However, incorporating a sand layer greatly increases the difficulty of construction but this can be reduced somewhat by sloping the sides of the soakaway.

Estimation of the long term seepage disposal rate is so fraught with uncertainty that different rules of thumb are sometimes substituted for experimentally based estimates of seepage rates. One such rule, for example, suggested by the World Bank, is an infiltration rate of 10 l/m<sup>2</sup>/day for septic tank effluent based on the surface area of the walls only, and excluding the bottom area of the soakaway (Kalbermatten *et al.*, 1982).

### 8.5.3 OSLAP latrines discharging to a soakaway

With on-site low flow aqua-privies, depending on the amount of flushing water used, the chemical oxygen demand (COD) of the discharge to the tank can range from 18 000 mg/l (4 litres of flush water /person/day) to 50 000 mg/l (1.5 litres of flush water/person/day).

These values can be estimated as follows: Vincent *et al.* (1963) measured the BOD contribution in townships at 0.0364 kg/person/day (0.081lb/person/day). COD is approximately 2 \* BOD to give  $0.0364 * 2 = 0.0727$  kg COD/person/day. For a range of water use ranging from 1.5 to 4 litres/person/day these would give an "influent" COD ranging from 48 500 to 18 200 mg COD/l. Measurements of the effluent from the tanks of low flow units have ranged from 2000 to 8000 mg COD/l giving reductions ranging from 80 to 90 percent. The effluent will contain an appreciable unbiodegradable soluble fraction but this has not yet been evaluated experimentally. Taking cognisance of the likely load of high inert COD in the influent to the soakaway, the biodegradable concentration can be expected to be very high; there appears to be no reported data on the effect of concentrated effluents on infiltration capacity in the soakaway. There is as yet no quantitative data on the expected "life" of the soakaways treating effluent from OSLAP systems. Noting that pit latrines in which the infiltration surface per person in the pit (say half full) is not significantly different from that provided in the "rule of thumb" for soakaways, a reasonable life is possible.

**It must be understood that no soakaway has an indefinite life. Information is still scarce on the response of soakaways to the high effluent CODs from OSLAP systems.**

## 8.6 CASE STUDY - IVORY PARK

Ivory Park is a Transvaal Provincial Administration "site-and-service" scheme situated in Midrand on the Witwatersrand. There are 14 690 sites which have been occupied since

1990. The basic services in the area are gravel roads, water supplied to communal standpipes and aqua-privies (on-site low flush anaerobic digesters). At present electricity is being installed by ESCOM.

Since installation commenced in November 1990, the toilets at Ivory Park have come under intensive scrutiny. A case study comprising both a social survey of users' views and a technical evaluation was undertaken by Palmer Development Group in association with the Water Research Group at the University of Cape Town. This section highlights the key findings and conclusions from the case study entitled "Technical evaluation of on-site low flush anaerobic digesters in Ivory Park and Duduza" (Document B3, PDG/UCT 1992).

#### **8.6.1 Description of toilets at Ivory Park**

Three different types of toilets were provided by the TPA, all being "on-site low flush anaerobic digesters". This definition refers to on-site low flush or dry rodding, anaerobic digester tanks. They comprise the following basic components which have to be integrated in order that the sanitation system functions as intended:

- toilet pedestal and flushing/rodding mechanism;
- anaerobic digester tank; and
- effluent disposal field (soakaway).

The three different systems that have been installed in Ivory Park are the Calcamite dry septic tank, the Atlas aqua-privy and the HS Sanitation System. The HS Sanitation System has two clones, the Waterloo and the Pennels system, which were also installed at Ivory Park.

2200 Calcamite units were installed in November 1990.

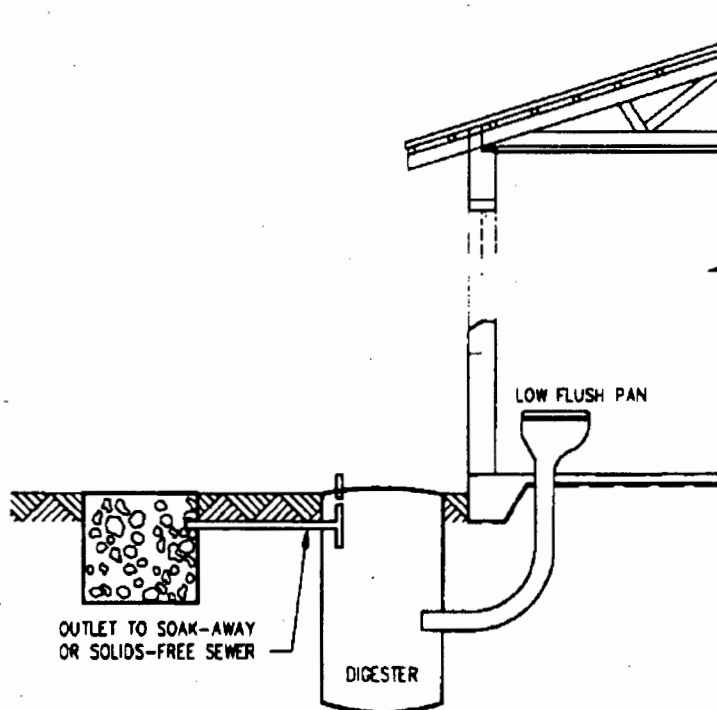
3000 Atlas systems were installed in September and October 1991.

9000 "HS type" sanitation systems were installed in Ivory Park, the last in March/April 1992. Modern Quality Homes, under license to HS, installed 1500 HS Waterslot units. Two clones, Waterloo and Pennels, were installed by a number of contractors; Elite (1500 Waterloo units), Reef (1500 Pennels units), Delanco (1500 Waterloo units), Leon's (1500 Pennels units) and Solfred (1500 Waterloo units).

### Calcamite sanitary disposal systems

The Calcamite tanks are made from rotor-moulded plastic. The liquid volume of the tanks installed at Ivory Park is 850 litres. The moulded polyethylene toilet pedestal is connected to the tank by a funnel. Faeces is transported to the tank by rodding the funnel. The outlet pipe removes the liquid to a soakaway. The Calcamite septic tanks have a removable man-hole cover for physical cleaning. A diagrammatic sketch of the Calcamite unit as installed at Ivory Park is shown in Figure 8.1 . The soakaway at Ivory Park for these units was elementary, of no indicated design.

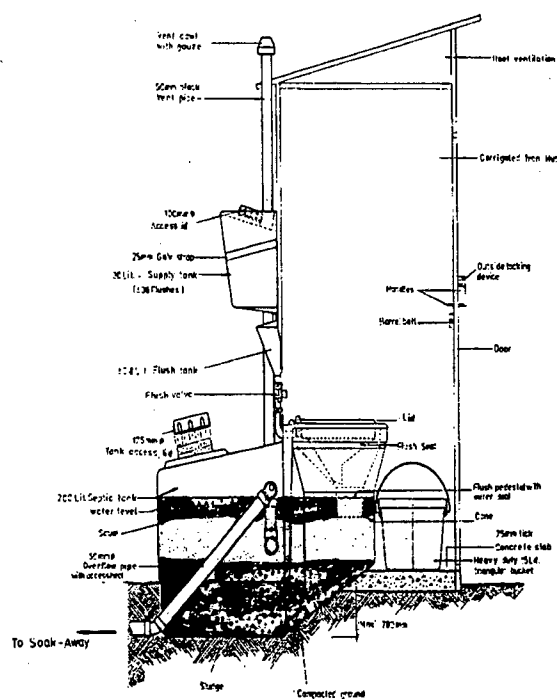
**Figure 8.1** Calcamite sanitation system



### The Atlas aqua-privy

The Atlas aqua-privy installed at Ivory Park has a 150 litre liquid capacity. It is designed so that the system can be installed with the minimum of excavation. The supply tank has a 30 litre flush water storage capacity with a 100 mm diameter access lid. The flush tank uses approximately 0.8 litres, therefore the supply tank can provide 36 flushes. The flush pedestal, septic tank and supply and flush tanks are made from black ultraviolet low density polyurethane. The discharge point is below the scum level and discharges through a 50 mm diameter overflow pipe to the soakaway. The soakaways at Ivory Park were approximately 600 mm x 600 mm x 600 mm. Figure 8.2 of an Atlas Aqua-privy is shown below.

**Figure 8.2 Atlas aqua-privy**



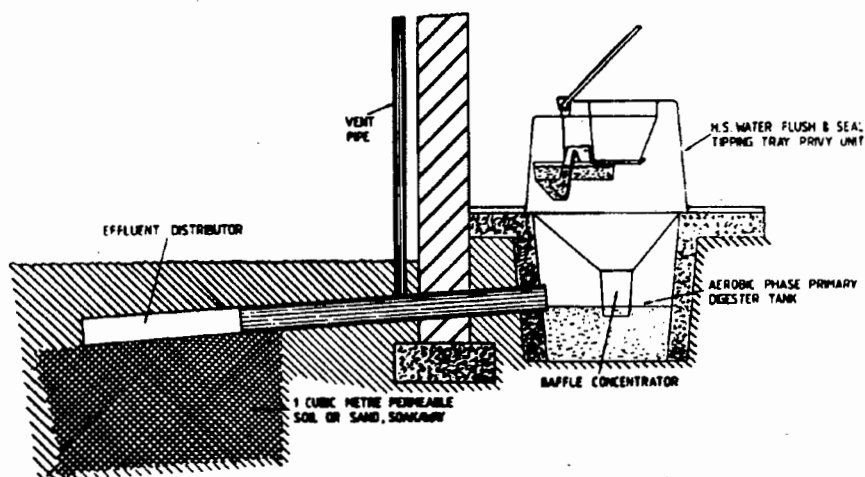
### H and S water flush tipping tray sanitation system

This sanitation system comprises an integrally mounted glass fibre pedestal and small volume primary digester tank. The pedestal has a built in storage reservoir of 12 litres. A hand operated tipping mechanism is used to tip and refill a water seal contained in the tipping tray with 0,5 litres of water per flush.

Excreta dropping from the tray passes through a chute which extends below the liquid level in the tank below. The excreta is retained in the primary digester tank directly below the seat. This tank has a liquid volume of approximately 140 litres and a depth of about 200 mm.

The effluent from the primary digester passes to a soakaway via a surface overflow. The soakaway size as installed at Ivory Park was estimated at approximately 600 mm \* 600 mm \* 600 mm deep. Figure 8.3 shows the HS sanitation system.

Figure 8.3 HS sanitation system



### **8.6.2 Technical survey**

The survey undertaken by the PDG/UCT Urban Sanitation Evaluation team in Ivory Park and Duduza covered 250 sites on which three commercial OSLAP systems had been installed, and had been in operation for about 12 to 18 months. The survey showed that where the systems have been in operation for a year or longer, there was widespread failure of the soakaways with both low flush and dry systems. The following possible causes for the failure were advanced:

- The soakaways of the low flush systems installed had totally inadequate infiltration capacity.
- The sludge storage volume in tanks of some of the commercial systems were inadequate giving rise to sludge discharge to the soakaway, thereby exacerbating the problem of soakaway failure.

The technical evaluation (PDG/UCT, Document B3, 1992) concluded:

- That inadequate volumes for sludge storage had been provided in some makes of the digester tanks causing sludge carry-over into the soakaway;
- That the infiltration surface of the soakaways was too small for the volume discharged.

### **8.6.3 Social Survey**

The social survey of users' views on low flush aqua-privies, in addition to highlighting the failure of so many soakaways, also quantified the disapproval of the system (Document B3.2, PDG/UCT, 1992). Of the respondents, 74 percent did not approve of the system because of the poor performance of the soakaways. 12 percent

stated that the system was "OK" while a few commented that it was better than either nothing or what they had had before.

In response to "is there anything you do not like about your toilet?":

- 31 percent said the system does not flush properly;
- 35 percent said it fills too quickly; and
- 44 percent said it smells.

It must be noted that the respondents were able to indicate more than one dislike.

The social survey concluded that general dissatisfaction with the sanitation system was widespread, but it is not clear whether the dissatisfaction stems from problems that have arisen due to inadequate design of the systems or from the system *per se*.

## 8.7 SOCIAL ACCEPTANCE

Using the case study as our principle source, one can conclude that the on-site low flush aqua-privy is at present not well accepted by the communities. This attitude may change once the deficiencies in the design are corrected.

## 8.8 ECONOMIC COST

Due to the inappropriateness of the Ivory Park designs actual cost figures cannot be used but rather costs estimated from recent tenders for 1000 litre tanks with 4 m<sup>2</sup> soakaways are used:

Capital Cost	R1200
Operating and Maintenance	R 102 per year

Using a projected life of 20 years, an interest rate of 19 percent and an inflation rate of 15 percent, one calculates the net present value to be R2653 and the total annual cost per household to be R186.

## 8.9 DEVELOPMENTS

### 8.9.1 OSLAP's discharging to solids free sewers

Taking cognisance of the following three factors:

- the width of the sites in high density housing areas range from 8 to 10 m approximately;
- the volume of excavation for soakaways per site; and
- the cost of stone and sand in constructing the soakaway,

the cost of the soakaways might not differ greatly from the cost of constructing a sewer across the plot.

From a cost aspect there is merit in considering the discharge of the tank to a solids free sewer. Such a sewer should be located on the mid block boundary (or in the servitude where this is provided in the layout) and the sanitary unit located near or next to the common midblock boundary. The sewer will need to be at a level that can drain the units from the sites on both sides of the sewer, a factor that will need to be taken into account in the layout of the township. Although minimum sewer diameters have been used as low as 75 mm, the minimum diameter of midblock sewers of 100 mm has operated very satisfactorily in Zambia, at very low gradients up to 1:1000. Once the sewer option is exercised, upgrading in the future, by supplying washing troughs and possible piped water to the site, would require that sewers be designed to take this future flow - the system in fact reverts to the self-topping aqua-privy. With provision for future upgrading the sizing of the tank

initially installed should take cognisance of the hydraulic retention time in the tank under future flows.

### **8.9.2 Application at Marselle**

The only application that could be found in South Africa of the OSLAP system draining to solids free sewers to oxidation ponds, is at Marselle. The sewer design, however, was in accordance with minimum criteria that are more strict than those set out for the self-topping aqua-privy effluent in Zambia. At present, the oxidation ponds receiving the effluent at Marselle are designed for a different purpose, that of the disposal of nightsoil and are oversized for the treatment of the Marselle effluent. Accordingly, the response of the oxidation ponds to the OSLAP effluent cannot be determined. The Marselle system is being evaluated at present by Water Technology of the CSIR.

### **8.9.3 Offsite treatment for OSLAP effluent**

#### **Treatment in waste water treatment plants**

Where the sewers from OSLAP systems can drain to the waste water treatment facilities of the town or city, this may be an option for treatment. However, from tests done at Ivory Park, we have noted that the effluents have a very high TKN concentration (1000 to 5000 mg N/l) and low COD (2000 to 8000 mg COD/l). Where such effluents form an appreciable fraction of the load on the treatment works, the effluents will have a very negative effect on nutrient removal activated sludge plants and the effect may be that no biological phosphorus removal can be achieved.

#### **Treatment in oxidation ponds**

Cognisance must be taken of the fact that the anaerobically pre-treated effluents from OSLAP systems have very high concentrations of TKN/Ammonia (TKN ranges from 1000 to 5000 mg N/l) without the associated high biodegradable COD of the raw sewage. There is no recorded experience of the treatment of these effluents in oxidation ponds. As a preliminary guide the surface areas of the primary and

secondary ponds in the oxidation pond system can be determined from the design values given for oxidation pond systems treating self-topping aqua-privy, septic tank and other anaerobic pre-treated tank effluents with high per person daily effluent flows - 1 m<sup>2</sup>/person for the primary pond, 0.5 m<sup>2</sup>/person for the secondary ponds (see chapter 7.4). There is the possibility that pond surfaces based on these dimensions may give daily evaporation and infiltration losses that exceed the daily influent flow rate. Until operational experience has been acquired it would be advisable to provide for discharge of the influent to the first of the secondary ponds as this pond has about half the surface area of the primary pond.

## 8.10 CONCLUSION

The design of on-site low flush aqua-privy units has, in the main, been dominated by the objective of reducing cost. The commercial companies have cut costs by reducing volumes, simplifying tank designs and building smaller soakaways. With no explicit guidelines on tank volumes, inlet and outlet arrangements and soakaway design available, township planners are without an instrument to adjudicate the most appropriate system.

The consequence of this set of circumstances has been the development of situations in which the systems are technically not operating satisfactorily. Users have in this scenario developed antagonism to their installation.

Based on the experience with OSLAP systems so far it is necessary to be extremely careful with future specification and implementation of OSLAP systems. Tank volumes, soakaway capacities as well as the possibilities for future upgrading to sewer discharge instead of soakaways, all require indepth consideration.

Based on the experince with OSLAP systems so far great care will be necessary in future specification and installation of OSLAP systems in order to give a technically satisfactory service and achieve social acceptance.

## **CHAPTER 9**

### **BUCKET SYSTEM**

#### **9.1 INTRODUCTION**

The bucket latrine system serves about 1.9 million people living in the urban areas of South Africa.

#### **9.2 SYSTEM DESCRIPTION**

The traditional bucket latrine consists of either a squatting plate or pedestal seat with a metal or plastic bucket located in a small compartment immediately below the squat or pedestal seat. Removing and replacing the bucket takes place at the rear of the latrine. The bucket must be totally isolated by a fly-proof trapdoor at the rear when the latrine is not being used, and by a lid over the hole in the pedestal/squat seat.

Excreta, urine and anal cleansing material are deposited and stored in the bucket which is periodically collected and emptied into a "nightsoil" tanker by collectors. The dirty buckets are stored on the tanker which also carries a stock of clean buckets for replacement in the bucket compartment in the latrine.

The nightsoil is conveyed by the tanker to the disposal site. Disposal may be either by trenching and burial, treatment in specialised nightsoil treatment plants, or discharge to a main sewer for treatment at a conventional waste water treatment plant.

#### **9.3 SYSTEM OPERATION AND BEHAVIOUR**

A bucket system can rapidly be put into operation. It is labour intensive and requires minimal capital equipment.

Successful operation of a bucket latrine system depends on the following requirements:

- The design of the latrine must provide for the exclusion of flies from the excreta when the latrine is not in use.
- The interval between collections must be sufficiently short so that buckets serving sites with high occupancy will not overflow. Collection frequency must not be based on the average number of users per bucket but on the expected maximum or near maximum numbers.
- Each site must have its own latrine to alleviate divisions of responsibility between occupants of the adjoining sites to keep the unit clean. Each latrine must have a locking device to control access of unauthorized users. The location of the latrine must take into account the need for privacy of the user.
- Collection of the bucket, cleaning the bucket space and the bucket itself, and returning the bucket should be the task of the bucket collectors. These tasks must be performed reliably and regularly.

Common difficulties with the system arise from:

- **Inappropriate design** - the bucket is not isolated; there are no flyproof trapdoors; no lid over the hole; and no locks on doors.
- **Inadequate frequency of collection** - at collection time some of the buckets are always overfull at sites with a high occupancy rate.
- **Short periods between collections (3 to 7 days)** - this makes the system a very critical one in which failure of the collection system through strikes, tanker breakdown or any other reason, rapidly gives rise to unsanitary conditions with attendant health risks.

- **Poor bucket removal service** - buckets removed by collectors are often neither cleaned nor replaced in the pedestal with the result that replacement must be performed by the users.
- **Difficulty in cleaning the bucket compartment in the latrine** - this gives rise to faecal odours in and around the latrine resulting in an infestation of flies in the area of the latrine and houses.
- **Bucket spillage** - with bucket removal, spillage from overfull buckets onto the ground outside the latrine often occurs. Spillage of faeces on the ground also leads to flies and odours and to a contamination of the soil with micro-organisms, helminths (worms) and their ova, and pathogenic material.
- **Inadequate supervision and operational control** - although it is possible to run an efficient, hygienic bucket system, in practice it is difficult to ensure that the system is operated satisfactorily on a continuous basis. Supervision must be of a high quality; operation must adhere strictly to standards set for removal of buckets from the latrine, transfer of faecal material, cleaning and disinfection of buckets, disposal of bucket contents and returning of cleaned buckets to the latrine. In this chain of operations human involvement is necessary at every stage and disruption at any stage leads to failure of the system to some degree.

#### 9.4 CASE STUDY - SILVERTOWN

The study area selected was Silvertown and Site C, suburbs of Khayelitsha township. Khayelitsha is situated in the greater Cape Town metropolitan area. The case study is published in full under the title "Bucket collection in Silvertown in Khayelitsha - in Cape Town's metropolitan area" (Document B4, PDG/UCT, 1992).

Silvertown and Site C are served by a bucket system of sanitation operated by the Lingeletu West Town Council. In both areas the social conditions appeared to be similar but the social survey was restricted to Silvertown because Site C has a reputation for being unsafe - all the

interviewers expressed an unwillingness to conduct interviews in Site C. However, for the evaluation of the costs of running the bucket system both areas are included, as these two areas are the only ones served by buckets and are under a single operation of the Lingeletu West Town Council.

Silvertown was established in 1989. It functions as a transit camp and groups of residents occupy it until they are allocated sites in newly developed site-and-service areas in Khayelitsha. When a group moves from Silvertown they completely or partly demolish their shacks for transfer to their newly allocated sites. Discarded materials and other remnants are then removed from the sites by the Lingeletu West Town Council to provide "clean" sites for the next group of residents.

The first of the present group of residents moved into Silvertown in June 1991. They originated from various other areas in the Western Cape, including other temporary informal housing areas and from backyard shacks in older formal housing areas.

Silvertown comprises about 1200 pegged 8 m by 9 m sites which are rented from the Lingeletu West Town Council. At the time the study was undertaken (April/May 1992) a block of 854 numbered sites were occupied.

The roads are unpaved but are gravel surfaced. An oval ring road encircles the layout, with short parallel streets at right angles to the longer leg of the oval. Midway in every second or third road a standpipe for water supply is provided. There is no electrical reticulation or highmast street lighting.

The sites were pegged but are neither surveyed nor mapped.

One bucket latrine is provided for every two sites. The latrine is located on the common boundary of two sites, on the road's edge. The placing and positioning of the latrines was done by the Town Council in June 1991, as part of the upgrading of the Silvertown area. The projected sanitary provision by the Lingeletu West Town Council is to provide a twice

weekly collection of buckets. The cleaning, disinfecting and replacing of the buckets is to be done by the collection teams.

A number of sites in the area provide bases for informal income-generating activities, such as spazas (cafes), shebeens, shoe-repair shops, a panel-beating and spray-painting shop, etc. These sites have not been designated for business activities and no special provision for increased sanitary use or effluent disposal is provided.

#### **9.4.1 The latrine**

The bucket latrine cubicle comprises a precast concrete superstructure, a corrugated iron door hinged on a vertical aluminium post, a wooden plank seat with a hole through it, and a 18 litre bucket placed below the hole. The door opens outwards. There is a horizontal gap of 170 mm above the door, allowing direct sunlight into the cubicle, and a gap of 120 mm between the bottom of the door and the floor. The superstructure is not specific for a bucket latrine; it was designed for a waterborne flush unit, but is serving temporarily to house a bucket. Not being built specifically for the bucket system, the cubicle has a number of limitations in serving as a bucket latrine: In a standard bucket latrine, access for removal of the bucket is provided at the back of the cubicle. There not being such access, by necessity, the bucket must be removed from the front of the seat by opening the door of the cubicle. The front vertical section of the seat is not covered by a flyproof trapdoor but is open leaving the bucket exposed. No lid is provided to cover the hole when the latrine is not in use.

The door of the latrine faces the road, apparently to facilitate the twice weekly collection of the bucket. Buckets are collected at 3 and 4 day intervals, the 4 day interval being over the weekend.

#### **9.4.2 Survey methodology**

A survey was conducted among residents of 100 sites in Silvertown. The survey was conducted during working hours on week days, with the consequence that on many sites no residents were present at the time of interviewing. The sites, therefore, were selected on a non-random availability basis. For each interview an adult respondent, who was a resident on the site, was asked to answer a short questionnaire (see Table 9.1). Of the 100 people interviewed, 60 were women and 40 were men.

The questionnaire was compiled by members of the sanitation project team with assistance from members of the University of Cape Town's Department of Social Anthropology. It was designed to generate quantitative physical data on latrine use as well as qualitative data on social acceptability of the bucket latrine system. The social acceptability aspect was of particular interest and accordingly information pertaining to this aspect was elicited through a variety of questions, many of them providing for open-ended responses.

The survey was conducted by two senior undergraduate Social Anthropology students both of whom spoke Xhosa as their first language, one of whom resides in a nearby formal housing area in Khayelitsha. The third interviewer was an off-duty bank clerk who also lives in Khayelitsha.

In conducting the survey most respondents were willing to answer the questionnaire; a few felt threatened by, or uneasy about, the interview process, expressing fears that the interviewers were employees of the local authority (Lingeletu West Town Council).

Table 9.1 Silvertown bucket collection social survey

Date...	Interviewer's name... Questionnaire No...
Interviewee's address...	
	Distance to nearest bucket latrine...
	Distance to nearest tap...
Estimate age...M / F	Relationship to head of household...
Q1	No. of people including children using the bucket facilities?
Q2	No. of people including children living on the site?
Q3	What type of toilet facilities did you have before moving here?
Q4	Are you prepared to share bucket facilities with other families?
	Yes / No...because...
Q5	Is there somebody here who cleans your toilet? If Yes...who?
Q6	How often is the bucket collected by the local authority?
Q7	What do members of the household use at night?
Q8	Is there anything you like or don't like about the bucket toilet?
	LIKE...
	DON'T LIKE...
Q9	How can the bucket system be improved?
Q10	Is there any other toilet you use to avoid using the toilet at home?
Q11	What alternative toilet system would you prefer?
Q12	Would you pay for this upgrade?
	Note respondent's attitude toward interview...
	Other comments...

### 9.4.3 Survey results

#### Site occupation and latrine use

In Figure 9.1 the frequency distribution and in Figure 9.2 the cumulative log probability of the number of residents (including children) per site are depicted.

Figure 9.1 Frequency distribution of site occupation

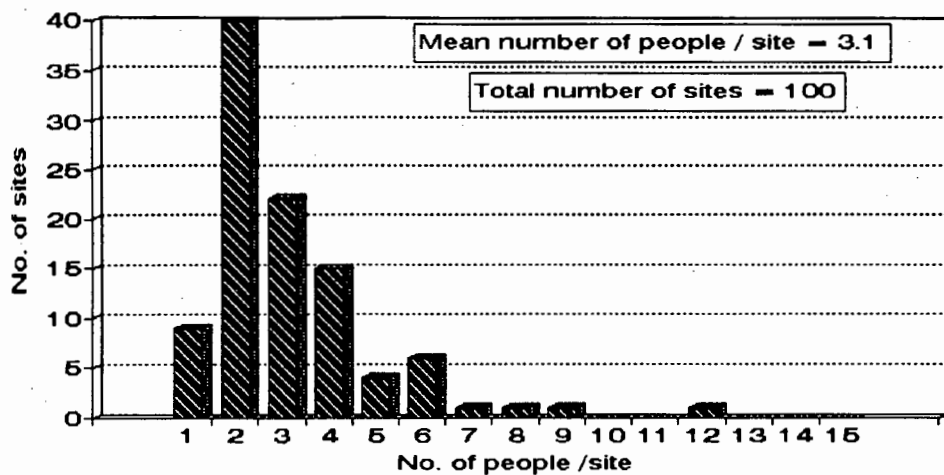
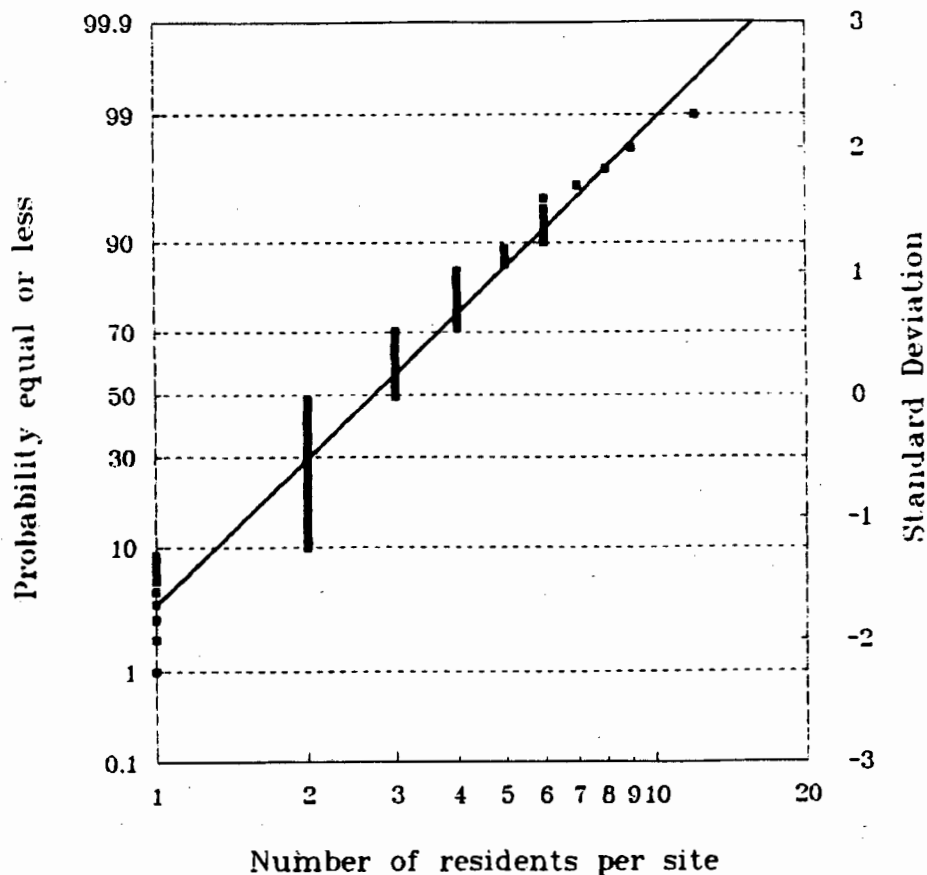


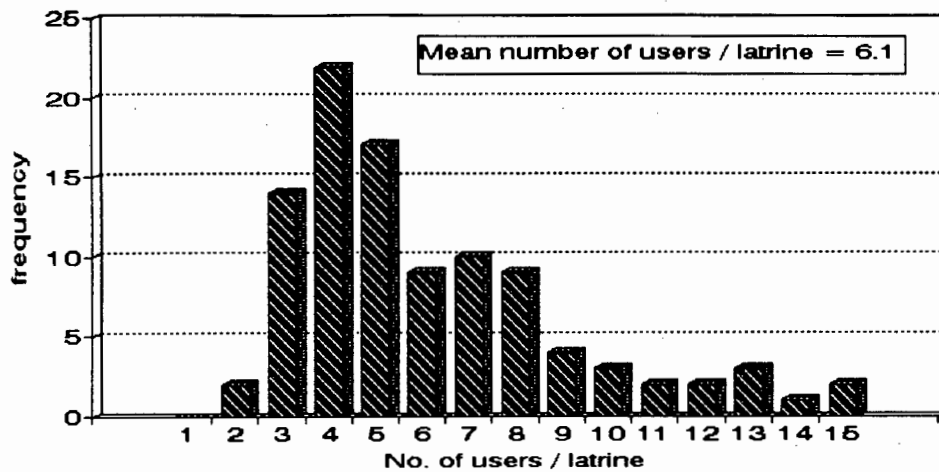
Figure 9.2 Cumulative log probability of site occupation



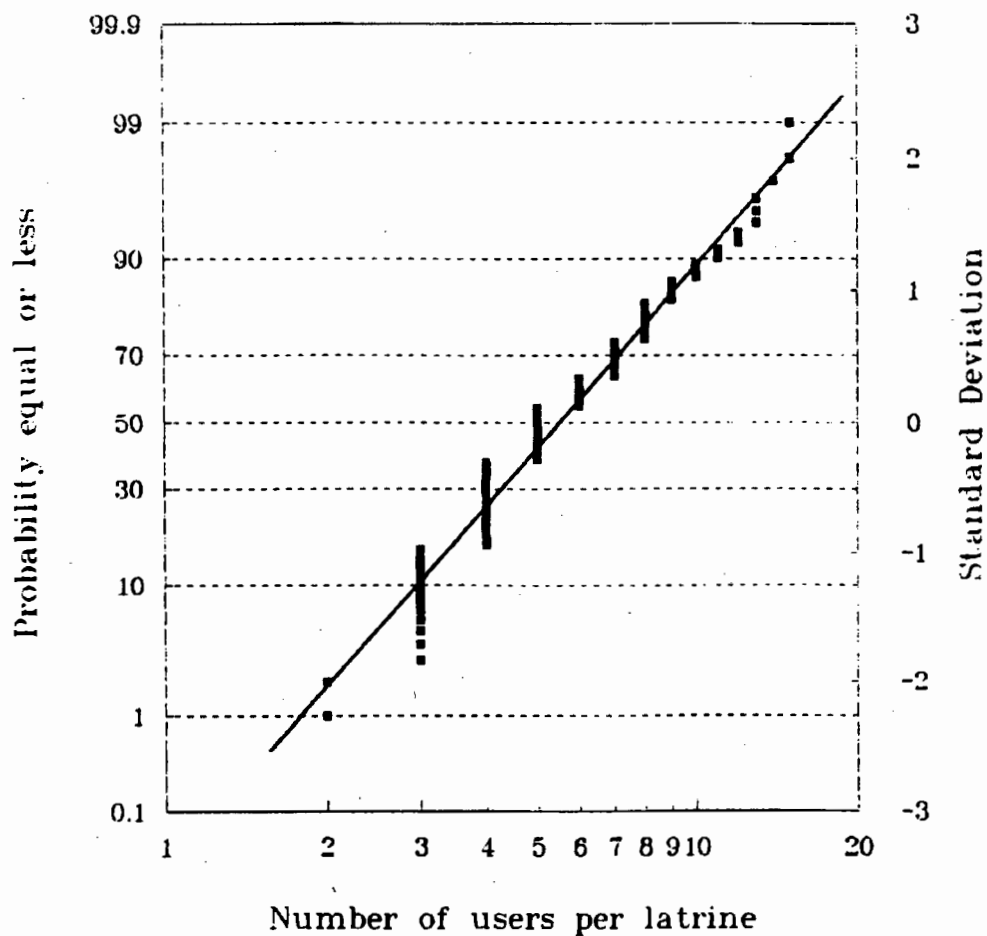
Referring to Figure 9.1 the distribution of the number of residents per site is skew to the right. The distribution is approximately log normal. The arithmetic mean is 3.1 residents per site. The geometric mean is 2.8 residents per site and the geometric standard deviation is 1.73 residents. 71 percent of the sites have an occupancy equal or less than the arithmetic mean; 10 percent have an occupancy of 6 or more per site.

In Figure 9.3 the frequency distribution and in Figure 9.4 the cumulative log probability of the number of users (including children) per latrine are depicted.

**Figure 9.3** Frequency distribution of latrine use



**Figure 9.4** Cumulative log probability of latrine use



Referring to Figure 9.3 and Figure 9.4 the distribution of the number of users per latrine is also skewed to the right and log normally distributed. The arithmetic mean is 6,1 users per latrine. The geometric mean is 5,5 users per latrine and geometric standard deviation is 6,3 users per latrine. 64 percent of the latrines have user numbers equal or less than the mean; 10 percent have 11 or more users per latrine; 2 percent have 15 users, the maximum number per latrine.

#### **9.4.4 Respondents' responses to the bucket system**

##### **Sharing of bucket latrines**

Of the 100 respondents, all indicated that they shared the latrine only because they have no alternative; 53 percent cite sharing toilets as leading to conflict with their neighbours over cleaning the latrine - women do not talk to each other and their menfolk are drawn in to attempt to resolve latrine-cleaning disputes. 10 percent complain that sharing causes the latrine to become dirty quickly; 9 percent stated that sharing causes the buckets to fill before the next collection; and 7 percent believe that the sharing of latrines spreads diseases.

##### **Odour**

76 percent of respondents complain about the odour emanating from the bucket latrines; 14 percent complain that the odour is so bad that on hot days it can be smelt from their homes; and 2 percent link the bad odour to poor ventilation of the latrine cubicle.

##### **Flies**

72 percent of respondents complain of flies with 2 percent explicitly stating that the bucket latrines increase the number of flies in the area.

##### **Health hazard**

22 percent of respondents describe the bucket latrines as a health hazard; some respond that the health hazard is due to flies coming from the latrine into the home and onto the food.

**Bucket cleaning and replacement**

17 percent of respondents state that the buckets are always dirty; some state that the buckets are not cleaned by the collectors and have to be cleaned and replaced in the latrine by the users themselves. Faeces from overfull buckets is left inside the latrine cubicle and is spilled onto the gravel while the buckets are being carried to the tanker.

**Aggressive attitude of collectors**

Respondents complain that the collectors are, at times, aggressive; if they happen to be using the latrine at the time of collection, the collector opens the latrine door and forcibly drags out the occupant in order to collect the bucket; respondents claim that the collectors prohibit urination in the buckets - when breaking this rule the contents of buckets with urine are emptied in front of the offending household's home as punishment.

**Frequency of bucket collection**

Collection is scheduled for twice a week. Respondents state that this is not always adhered to - for instance strikes by the collectors results in no collection.

**Lack of privacy**

4 percent of the respondents stressed the lack of privacy; the doors do not shut properly, there is no locking facility; latrines are used by passersby who often foul them; the entrance to the latrines face the street so that users entering and leaving are in full view of passersby.

**9.4.5 Respondents' suggested improvements to the service**

Respondents were asked for their views on improving the bucket sanitation system. The majority (80 respondents) state that the only improvement would be to upgrade to a waterborne system. The remaining 20 suggest improvements listed in Table 9.2.

Table 9.2 Ways of improving the bucket sanitation system

Way of improving system	Number of respondents
No sharing of buckets	7 respondents
More frequent collection	4 respondents
Bucket should have a lid	4 respondents
Lockable doors	1 respondent
Supply deodorizing fresheners	1 respondent

#### 9.4.6 Respondents' motivations for wanting to upgrade to a waterborne system

With so many respondents wanting a waterborne system, they were asked what would motivate them to pay more for this system. Their answers are listed in Table 9.3.

Table 9.3 Motivation to pay for upgrading to a waterborne system

Motivation	Number of respondents
Easier to clean / keep clean	47
Health risks diminished	24
Better facility / best system	11
Brings water on to site	7
More privacy having own latrine	5

### **9.4.7 Economic cost**

Information on operating and maintenance costs were supplied by the Lingeletu West Town Council. The information on operating and maintenance cannot be taken to include all hidden costs, and so are therefore likely to be underestimates.

#### **Capital costs**

The latrine superstructures in Silvertown are second-hand and as such no capital cost could be ascertained. The capital cost of a prefabricated bucket latrine superstructure was supplied by a manufacturer and includes a pedestal with closing lid and two buckets. The cost was R600 - very low.

#### **Operating and maintenance costs**

To estimate the cost of operating a bucket system, the cost was broken down into labour and plant. Labour costs include benefits such as housing subsidies and medical aid for the workers plus supervision and overheads. The labour cost per bucket collected is estimated by dividing the cost of one shift by the number of buckets collected in one shift. A labour team comprises a driver and ten workers. The team works a nominal eight hour shift but usually completes the work in four hours. Collections are twice weekly either on a Monday and Thursday or Tuesday and Friday.

The plant available to the bucket collection team is a Leyland nightsoil tanker or a tractor and trailer. To obtain the plant cost per bucket collected, the plant costs for the current year including interest and redemption, fuel and oil, workshop levy, etc were divided by the total number of buckets collected in a year. Maintenance of plant is included in this estimate but maintenance of the latrine superstructures is not included.

Treatment costs are not included. Bucket contents are dumped at the head of the Zandvliet Works that treats the daily sewage flows from the areas in Khayelitsha

served by waterborne sanitation. The Lingelethu West Town Council is not charged separately for the treatment of the bucket contents.

Table 9.4 Sivertown bucket operating and maintenance cost summary

Operating and Maintenance - Labour	R 3.06 per bucket collected
- Plant	R 0.45 per bucket collected
<b>TOTAL</b>	<b>R 3.51 per bucket collected</b>

#### 9.4.8 Evaluation of Silvertown / Site C Bucket System

The bucket system at Silvertown / Site C shows the following deficiencies:

##### **Inappropriate latrine design**

The design of a bucket latrine should provide the following:

- Access at the rear for the removal and replacement of the bucket.
- Prevention of access of flies to the faeces in the bucket when the unit is not in use - a seat/platform that isolates the bucket from the cubicle, a trapdoor that closes over the rear access opening, and a lid that covers the hole in the seat.
- Control of odour in and around the latrine which attracts flies - a vent pipe similar to that used in VIP latrine designs.
- Privacy and prevention of unauthorized use - a door with a lock.
- Discouragement of flies from entering the interior of the cubicle - direct sunlight must not shine into the cubicle which must be in semi-darkness when the door is closed.

The latrines in Silvertown do not satisfy certain of these basic design guidelines because:

- Removal and replacement of buckets is via the latrine door.
- The bucket is not isolated from the cubicle - there is no enclosing seat and no cover lid over the hole; free access of flies to faeces.
- There is no lock on the door and the doors do not close properly.
- There is no vent pipe.
- Direct sunlight enters into the latrine via the gap above the door.

### **Inadequate sanitary provision**

From the frequency distribution of users per latrine in Figure 9.3, the number of users per latrine ranges from 2 to 15; 10 percent of the latrines will have 11 or more users. The volume of excreta per person per day is approximately 1.5 litres; some residents would use latrines at places of employment so that on average the excreta volume will be less. For the purpose of illustration assume that the volume of excreta and cleaning material per person per day is half the normal, ie 0.75 litres. With 11 users per latrine the daily storage volume required is 8.25 litres, in 3 days 24.75 litres. The bucket volume is 18 litres and removal is alternatively at 3 or 4 day intervals with the longer period extending over the weekend when higher latrine usage is expected. Consequently, an appreciable percentage of the buckets must overflow between every collection. Clearly in estimating the frequency of collection the distribution of the user per latrine must be taken into account. As evident in Silvertown the maximum number of users per latrine is 15 whereas the mean number per latrine is 6. As such it is unlikely that a bucket system can be designed that will cause some buckets not to overflow.

### **Sharing facilities**

Sharing of latrines gives rise to the problems of divided responsibility for cleaning the latrine and controlling access: These problems inevitably lead to conflict between the occupants of the sites sharing the facility, irrespective of whether the bucket is,

or is not, adequate for the number of users in the interval between collections. In Silvertown sharing of latrines is a significant source of conflict between households.

### **Service planning is inadequate and control is poor**

A large percentage of the buckets are estimated to be full or overflowing at collection time. The collectors attempt to cope with this by intimidating or telling the users not to urinate in the buckets in order to reduce spillage. This solution does not improve the quality of service and increases health hazards due to flies and worm infections. Buckets are neither cleaned nor disinfected by the removal service and buckets must be replaced by the residents. These actions impose a function on the user which is repugnant to them and a health hazard which they are not equipped to handle. The operation was designed to make provision for cleaning, disinfecting and replacing of buckets by the collection teams. These functions are not performed at all times due to poor supervision of the teams: the collecting teams complete their task within 4 hours of the 8 hour shift; this would imply that the labour provided is adequate but that the supervision or operational control is not.

### **9.4.9 Conclusions**

The following conclusions are made in the case study of the bucket sanitation system in Silvertown:

- The design of the latrine cubicles is inappropriate - the units are modified water flush units, and incorporate none of the provisions to control flies, prevent contact of flies with faeces and avoid bad odours.
- Sanitary provision is inadequate - an appreciable percentage of latrines' buckets are full to overflowing due to the number of users per latrine. Intervals between collections are 3 to 4 days. This situation may have arisen in part due to frequency of collection - twice per week.

- Sharing of a latrine by two households is a cause of social stress - provision of one latrine for two sites results in a division of responsibility in keeping the latrine clean and conflict between households sharing the latrine.
- Collection supervision and control is inadequate.

## **9.5 SOCIAL ACCEPTANCE**

Social opposition to the bucket system is common knowledge. The case study at Silvertown quantified this opposition. While not all bucket systems have as many problems as those operating at Silverown, it is clear that the system has no future where the community is involved in the decision making process.

## **9.6 ECONOMIC COST**

Bucket systems investigated give an on-site capital cost of between R500 - R1000. The operating and maintenance costs range from R175 to R385 per annum. The operating and maintenance costs include on-site maintenance, collection and emptying of the buckets and treatment of the effluent.

For a typical household using its own bucket latrine, the total annual cost per household (TACH) would be R310. This is calculated on a capital cost of R600, operating and maintenance of R268 per year and taking a 20 year life span with the interest rate of 19 percent and inflation rate of 15 percent.

## **9.7 ENVIRONMENTAL AND HEALTH CONSIDERATIONS**

One of the issues raised by a bucket collection service is that the system does not provide a means of removing the sullage water. This is usually thrown on the ground or in the road. For a system that is serviced by a hand carried water supply (Level 1) this might not lead to unsanitary conditions but for any higher level, such as where each plot has a water connection, unsanitary conditions will prevail.

A further health issue which the case study at Silvertown raised was the fact that the operators and collectors of the bucket system do not allow the users to urinate in the buckets and as a result urine is thrown onto the open ground or in the road.

Because the bucket system has no "storage capacity" it is very susceptible to a breakdown in the collection process. When collection is delayed or interrupted buckets overflow, causing spillage in the cubicle and on their way to the cart or tanker.

Buckets which are not cleaned and sanitized before their return to the users are unhygienic and control on this aspect of the collection system is important.

## **9.8 CONCLUSION**

In many situations the bucket system provides an extremely poor level of sanitation, often only slightly better than no sanitation at all. Taking into account the difficulties with running the system, the immediate creation of health hazards when any breakdown or poor operation occurs, and the high cost, the bucket system should not be considered as a viable and acceptable sanitation option in urban areas in South Africa.

## **CHAPTER 10**

### **FULL WATERBORNE SANITATION**

#### **10.1 INTRODUCTION**

Classic full waterborne sanitation is provided for 15,7 million urban South Africans. This number includes the provision for both the poorer and more affluent communities. In this chapter the discussion will focus on waterborne sanitation as provided to the poorer section of the community.

The design of waterborne systems, in township housing for low income groups of the urban community, is mostly done in accordance with "Guidelines for the provision of engineering services for residential townships" called the "Blue book". These guidelines were prepared by the Department of Community Development in Pretoria in 1983. Some municipalities/consulting engineers have in-house guidelines to supplement those of the "Blue book".

#### **10.2 SYSTEM DESCRIPTION**

A full waterborne sanitation system to low income areas comprises the following:

- piped potable water supply to every house or toilet and wash superstructure depending on the nature of the development;
- a flushing pedestal (water closet-WC) either in the house or in a separate superstructure (privy), including taps, pipes and fittings associated with the pedestal;
- washing facilities either in the house or at the toilet and wash superstructure;

- drains (plot sewers) to receive the washing water, kitchen and toilet waste water and transport this effluent to the feeder sewer;
- sewer network, outfall sewer to treatment works; and
- treatment works.

### 10.3 COMPONENT PARTS

#### 10.3.1 Water supply

Where a full waterborne sanitation system is installed, drinking water is supplied to every site. This is a minimum requirement because the sanitation system requires water for the conveyance of the wastes from the site to the treatment works.

#### 10.3.2 Flush cistern

Conventional water cisterns for the flush pedestal units have a volume of 15 litres however cistern flushes with less than 10 litres per flush have been developed but have yet to gain widespread usage. Rivett-Carnac (1991) reports that newer close coupled toilets use 9 litre cistern volumes. The flush pedestal should have a large diameter water trap (S or P) to flush balls of paper or other large sized extraneous anal cleansing material. Many of the "sophisticated" flush pedestal designs have small diameter flushing traps, which promote a self-cleansing action but are readily blocked by anal cleansing material other than standard toilet paper.

Recently 4 litre flush units have been developed and tested. These units are being put into operation in various parts of the world (Boccaro, 1992).

### **10.3.3 Washing facilities**

Houses have either internal or external washing basins and kitchen water facilities. A waterborne system removes all waste water from the site, ie the waste water from the kitchen, bath and/or shower.

### **10.3.4 Effluent treatment**

In South Africa the three most common forms of off-site treatment of waterborne sewage are; (1) Activated sludge, in terms of the volume treated, (2) Biofilters in terms of the number of units and, (3) Oxidation ponds, for smaller communities.

With all these systems screens to remove rags, etc, and grit channels to remove grit, sand and stones are necessary. With bio-filters primary settlement is required prior to filtration. With activated sludge and stabilization ponds the raw sewage can be treated unsettled or settled. With settled influent provision for treatment of the primary sludge is necessary. Furthermore, for activated sludge and bio-filters, the waste sludge generated by the process must also be treated, usually together with the primary sludge. The activated sludge system always removes carbonaceous material in the influent very efficiently. The design can be modified to give nitrification (N), nitrification - denitrification (ND) or nitrification - denitrification biological excess phosphorous removal (NDBEPR).

#### **Nitrification (N) activated sludge systems**

In nitrification systems the ammonia, both that in the influent and that converted from the organic nitrogen in the system, are converted to nitrate. Nitrification plants are designed to give a low ammonia concentration in the effluent, important because ammonia is toxic to higher aquatic life above threshold concentrations. Nitrification systems are completely aerobic. Nitrification removes alkalinity from the wasteflows and in areas where the alkalinity in the influent is low, as in the Table Mountain sandstone regions, the removal of alkalinity causes the pH of the effluent to be very low,  $\text{pH} < 5$ . This can give rise to poor settling sludges. Alkalinity (lime) may

have to be added to maintain the pH near neutral in the system. Nitrification requires a significant increase in the oxygen that needs to be supplied per unit influent COD. Virtually no phosphorous is removed biologically; phosphorous removal would require chemical addition.

Nitrification system effluents still contain high concentrations of faecal organisms and must be chlorinated or passed through a series of maturation ponds to reduce the faecal organisms' concentration to acceptably low levels.

#### **Nitrification - denitrification (ND) activated sludge systems**

Once nitrification is required, denitrification should also be built into the plant. Denitrification recovers in part the alkalinity lost by nitrification, and almost invariably, the pH is maintained near neutrality, so that pH adjustment by lime addition is not required. Also some of the oxygen required for nitrification is recovered so that the aeration costs are reduced. A problem with ND plants is that they are prone to produce bulking sludges and hence require relatively large settling tanks. However, from recent research Casey *et al.* (1992) has proposed a hypothesis for the main causes of bulking in nitrification - denitrification activated sludge systems and corrective design guides are in the process of being developed. Virtually no phosphorous is removed biologically and, therefore, phosphorous removal would require chemical addition. As with nitrification systems effluent from the ND systems still contains high concentrations of faecal organisms and must be chlorinated or passed through a series of maturation ponds to reduce the faecal organisms concentration to acceptably low levels.

The level of supervision required in ND systems is higher than that for nitrification only systems.

#### **Nitrification - denitrification biological excess phosphorous removal (NDBEPR) systems (nutrient removal systems)**

Nitrification - denitrification systems can be modified to remove phosphorous biologically. Imposing appropriate environmental conditions on the activated sludge

induces the micro-organism Acinetobacter sp. to take up phosphorous from the influent in excess of metabolic requirements. The phosphorous is removed from the system by daily wasting of the activated sludge from the aerobic zone. Biological phosphorous removal requires a readily biodegradable COD (RBCOD) fraction in the influent which may not always be present in sufficient concentration, in which event poor phosphorous removal will be obtained. Nitrification-denitrification biological excess phosphorus removal systems are prone to produce bulking sludges, requiring relatively large settling tanks but as stated above for ND systems the problem should be ameliorated in future plants by appropriate design. Treatment of the excess activated sludge wasted daily, requires specific handling procedures so as not to reintroduce phosphorous into the waste flows. As with the other activated sludge systems effluent from the NDBEPR systems still contains high concentrations of faecal organisms and must be chlorinated or passed through a series of maturation ponds to reduce the faecal organisms concentration to acceptably low levels.

The level of supervision and technology required in nitrification-denitrification biological excess phosphorous removal systems is highest for any of the activated sludge systems.

### **Bio-filters**

Trickling filtration is an attached growth system of biological treatment of sewage. The filter consists of a bed of selected crushed rock aggregate or stone placed within a cylindrical perimetric wall of depth 1 - 3 m depending on design. A mobile or fixed distribution system sprays previously clarified sewage over the bed. The sewage percolates through the bed to a system of drainage channels. Air passes up, or down, the filter to supply oxygen to the attached organisms.

Trickling filters can be designed to nitrify the ammonia/TKN in the waste stream but "normal" filters have very little denitrification capability. Phosphorous removal is also minimal and chemical addition is necessary if this element is to be removed. As with the activated sludge system, the treated effluent must be either chlorinated or

passed through maturation ponds to reduce the concentrations of faecal organisms to acceptable levels. The plants require reasonably high levels of technology control.

### **Oxidation ponds**

In South Africa oxidation ponds (also called stabilisation ponds) are installed for treating raw or anaerobically pretreated sewage from small communities where activated sludge or trickling filter systems are too expensive to build and run (capital plus operating costs) or the technological infrastructure for running activated sludge and trickling filters is not available.

Oxidation pond systems consist of a primary pond and secondary ponds in series. The primary pond removes carbonaceous material in the influent and the secondary ponds reduce the faecal bacterial concentrations.

When a raw sewage flow enters a pond the particulate material settles as a distinct sludge layer on the bottom of the pond. In this layer a fraction of the organic material is anaerobically fermented to methane and soluble organic products. The methane leaves the system as a gas thereby reducing the influent load by about 30 percent. The rate of biodegradation is very temperature dependent giving little degradation below 17°C and such intense degradation above 22°C that the sludge layer may be brought to the surface by the trapped gases and form a surface sludge layer.

The soluble fraction of the raw influent mixes with the liquid above the sludge layer. The liquid also receives the solubilized byproducts from the fermentation of the sludge layer. Degradation takes place principally aerobically. Algae are the sole suppliers of oxygen via photosynthesis. The algal types that develop depend on the mixing conditions in the pond and the temperature. Mixing is induced primarily by wind action but for the same wind velocity mixing is more intense in cold than in hot weather. In summer, long periods of stratification (no mixing) may develop. Stratification acts most adversely on re-oxygenation by the algae - during stratification the algae die off and reduce the oxygenation of the liquid. At the same time, in

summer, the high rate of feedback of COD from the sludge layer adds to the oxygen needs and the pond may turn anaerobic. In Southern Africa anaerobic conditions throughout the pond (ie failure of the pond) are most likely to take place in the summer. Problems with floating sludge will almost always be encountered at this time (Marais GvR, 1970).

Anaerobic pre-treatment of the influent significantly reduces the fermentation potential of the sludge layer in the pond and greatly reduces the problem of rising sludge and the advent of pond failure. The reduction is so significant that if at all possible raw sewage should not be discharged to oxidation ponds but always pretreated anaerobically.

Anaerobic pre-treatment can be done either in closed tanks or in open anaerobic lagoons. For small communities, up to about 10 000 people, closed pre-treatment tanks are probably the most convenient. With pre-treatment tanks the ponds can be located close to the households. For larger communities open anaerobic lagoons are probably the cheapest. With open lagoons the problem of odour development is always potentially there and as such the lagoon and pond system should be located away from the housing area. It has been shown that recycling from the primary or secondary oxidation pond to the influent to the anaerobic lagoon reduces odour development to such a degree that recycling of half to one times the mean influent flow should always be considered in an anaerobic oxidation pond system.

The oxidation pond series system, if appropriately designed, is very efficient in reducing faecal bacterial concentrations, and reductions of 99.99 percent can be readily achieved (Marais GvR, 1974). The ammonia/TKN in the influent is partly lost through gas exchange due to the high pH that develops in the top layer of the pond due to photosynthesis. The balance of the ammonia/TKN is incorporated in the algal growth in the pond. The organic material discharged in the form of algae can be high but organic material in algal form has a very much reduced adverse effect on the receiving waters than normal organic material. Phosphorous in the influent to

these plants is not significantly reduced and consequently remains as a source of eutrophication in the receiving waters.

#### **10.4 OPERATION AND BEHAVIOUR**

Maintenance personnel report that many problems are encountered with waterborne networks in low income areas. It is often not possible to identify the causes that gave rise to these problems, whether they arise from deficiency in design or are due to the behaviour of the users. For example, blockages may be more frequent due to the minimum self cleansing velocity specified in design - 0.7 m/s, or may be because of the minimum sewer diameter of 100 mm. An important cause of blockages is the introduction of extraneous material such as bicycle parts, bottles, bricks, stones, rags, etc into the sewer either at the home or at manholes. Clothing, rags, stockings can cause blockages due to balling and entangling other solid objects. Sand and soil used for pot scouring increases the sand and grit load in the sewer - some designers are proposing the installation of screens and sand traps in sewer lines to reduce these problems. There may be widespread removal of manhole covers, a problem which has led to the installation of locking devices on the covers or extra heavy duty covers.

Problems with treatment works tend to be case specific and no general trend with a particular technology could be found in the PDG/UCT Urban Sanitation Evaluation database.

#### **10.5 TECHNICAL CONSIDERATIONS**

##### **10.5.1 Sewer flows**

The "Blue book" gives the average daily waste water flow figures per single family as follows:

Table 10.1 Average daily waste water flow per household

Income group	Lower	Middle	Higher
Litres per house per day	500	750	1 000
Average total persons per house	7	6	5

For urban sites zoned as general residential, the "Blue book" suggests an average daily flow of 600 litres per day for every 100 m<sup>2</sup>. Rivett-Carnac (1991) reports middle to high income residential sites with metered water supply and full waterborne sewerage as;

2 to 3 bedroom house	840 litres per house per day
4 to 6 bedroom house	1600 litres per house per day

### 10.5.2 Sewer reticulation network

Sanitary sewer pipes are manufactured from concrete, asbestos cement, vitrified clay, polyvinyl chloride (PVC) or pitch fibre.

#### Minimum depth and cover

For conventional reticulation systems the minimum depth and cover are ("Blue book"):

- in servitudes, 600 mm below ground level;
- in sidewalks, 1.4 m below final kerb level; and
- in road carriageways, 1.4 m below final road level

Exceptions to these guidelines are allowed if protective collars are used.

**Manholes**

Manholes must be provided at all changes in direction or slope. On straight sections manholes must be provided at a spacing of 150 m if the local authority has power rodding machines or alternatively at 100 m if the local authority has only hand operated equipment ("Blue book").

**Minimum sewer diameter**

For raw sewage reticulation the minimum sewer diameter is 100 mm ("Blue book").

**Sewer gradients**

The slopes or gradients of a sewer must be such that they achieve a "**self cleansing**" or scouring velocity over some period during the daily flow cycle. This velocity is required to re-suspend and transport solid material that may have settled during periods of lower flows and lower velocities (Kalbermatten *et al*, 1982). A convenient way of defining the self-cleansing velocity is that the velocity to scour a sewer when it is flowing either at half bore or at full bore. These two velocities are approximately the same provided that the full bore flow is still free, that is to say, not flowing under pressure. The sewer gradients to give these self-cleansing velocities depend on the roughness of the sewer (internal) and its diameter. The higher the roughness and the smaller the diameter the greater the gradient necessary to give the self-cleansing velocity. A range of self-cleansing velocities have been proposed, empirically developed from experience with sewer networks or as a compromise between (1) higher capital cost in installing sewers with steeper gradients in which the higher self-cleansing velocities reduce the chance of blockages and (2) higher operating costs by installing sewers with flatter gradients in which the lower velocities increase the risk of blockages.

Sewer systems for low income housing areas tend to carry much larger quantities of grit and extraneous large solids such as broken bricks, bottles, metal parts, rags, etc. than sewers from higher income areas. Accordingly the incidence of blockages in sewers are also higher. Kalbermatten *et al* (1984) suggest that sewers should be designed for velocities of 0.6 to 1 m/s at mean daily flow, but in areas where bulky

anal cleansing materials are used or where sand is used for scouring kitchen utensils, these velocities should not be less than 1 m/s.

The "Blue book" recommends a velocity 0.7 m/s at full (or half) bore, a guide followed by many designers.

The guide for sewers carrying raw sewage from low cost housing areas, followed by the Zambian Housing Board (circa 1959 to 1970) were:

- minimum gradient at head of sewer 1:60;
- minimum velocity at full (or half) bore 3 feet/s (0.91 m/s);
- minimum diameter of sewer 150 mm; and
- peak flow three times mean flow.

These guidelines are to ensure that at the head of the sewer where the depth of flow is small, the velocity will be sufficient to transport organic and inorganic solids. Elsewhere the velocity of 0.91 m/s would ensure that sand and gravel will be transported. The minimum diameter of 150 mm ensured that the sewer diameter will not easily become blocked by organic and inorganic solids - grit and stones.

Different minimum self-cleansing velocities have a significant effect on the minimum sewer gradients, (See Table 10.2), and accordingly may have a significant influence on the costs, particularly in areas with flat topography where the depth the sewers may attain with high gradients over short distances, make lifting stations necessary.

In general the cost of sewage reticulation is critically influenced by the topography of the site and the subsoil conditions.

Table 10.2 Limiting grades for different flow velocities and pipe diameters flowing half full for Mannings'  $n=0.012$

Sewer Size [mm]	Slope 1 in: -		
	1 m/s flow velocity	0.7 m/s flow velocity	0.3 m/s flow velocity
100	1: 50	1:120	1: 600
150	1: 90	1:200	1:1000
200	1:130	1:300	1:1500
250	1:180	1:400	----
300	1:220	1:500	----

## 10.6 MDANTSANE CASE STUDY

The key findings and conclusions of the case study undertaken on Mdantsane entitled "The Mdantsane waterborne system" (Document B1, PDG/UCT, 1992) is presented in this section and serves as an example of a sewer reticulation system serving a low income community.

Mdantsane, with a population of approximately 220 000 people, is located almost 25 km from East London in a strip of land approximately 5 km wide between the Buffalo River and the national road between East London and King Williamstown. The national road lies approximately astride the watershed between the Nahoon and the Buffalo Rivers, and the natural drainage from Mdantsane is towards the Buffalo River. Mdantsane is located partly upstream of the Bridle Drift Dam so that any spill from the sewer system drains into the dam, or into the diversion weir below the dam from which East London draws its water supply.

Mdantsane is served principally by a waterborne sewerage system. The waste water is predominantly domestic in origin; there is very little industry in the area. The effluent is

treated by two sewage treatment works which receive most of their flow under gravity. There are three pump stations which lift sewage from three sub-catchments to the main interceptor sewers.

The two waste water treatment works are the Mdantsane and Potsdam (Mdantsane West) Treatment Works. Both works are biological double filtration plants. The effluent from these works is discharged downstream of the Bridle Drift Dam and the diversion weir.

Numerous problems have been experienced in effectively operating and maintaining the system. The most important problems are the large number of sewer blockages and the mechanical failures at the pumping stations and Mdantsane waste water treatment works. These cause the sewage to spill out of the sewers at manholes and the pump stations onto the surface, and drain into the Bridle Drift Dam or below the dam but upstream of the diversion way. This has major consequences; the dam receives an appreciable fraction of raw sewage which affects the oxygen content and increases the faecal bacterial concentration; phosphorus and nitrogen in the spill cause algal blooms in the dam greatly increasing the difficulties in treating the water for potable use. Mechanical failures at the older works also cause a substandard effluent to be discharged to the Buffalo River downstream of the weir.

The reasons for these failures are numerous. Resource constraints, however, form a common linking thread:

- Poor construction, possibly as the result of a need to cut costs, has resulted in instances of poor pipe laying and negative gradients. These problems are compounded by the use of pitch-fibre pipes which are susceptible to collapse (for example through inadequate pipe support during pipe laying) and holing (during pipe unblocking).
- The poor economic position of the residents has meant that many do not use toilet paper resulting in high loads of newspaper, rags, stones and other materials being used as substitutes.

- There is inadequate financial support for maintenance from the residents. Cost recovery (by the Ciskei government) is approximately 50 percent of the maintenance cost placing a real constraint on the money available to spend on system maintenance. It is estimated that maintenance expenditure is only a third of what it should be. This has meant that maintenance has historically been reactive, leading to a deterioration of the capital asset and increased maintenance requirements and costs.

Over and above these financially limiting constraints is the abuse of the system by the users, by introducing foreign objects into the sewer, ranging from bricks to bicycle parts.

## **10.7 USER PERCEPTION**

Often the perception of the user in low income areas is that full waterborne systems offer the highest level of convenience and health benefits. The system is widely regarded as the only adequate one. However, there is general lack of understanding of the function of the system and the constraints that must be exercised in its utilization to maintain the highest efficiency with least possible disruption. There is often also an apathetic attitude towards the reticulation system. Problems are only reported when they directly affect a resident otherwise little is done. For example, an outfall blockage that occurs below the line of the housing development may often go unreported.

## **10.8 ECONOMIC COST**

### **10.8.1 Capital costs for waterborne sanitation**

#### **Toilet superstructure and plumbing**

The cost of the toilet superstructure is highly dependent on the design and the materials used. Plumbing costs including on-site sewer, pedestal and related plumbing are estimated from the Independent Development Trust data base (100 projects):

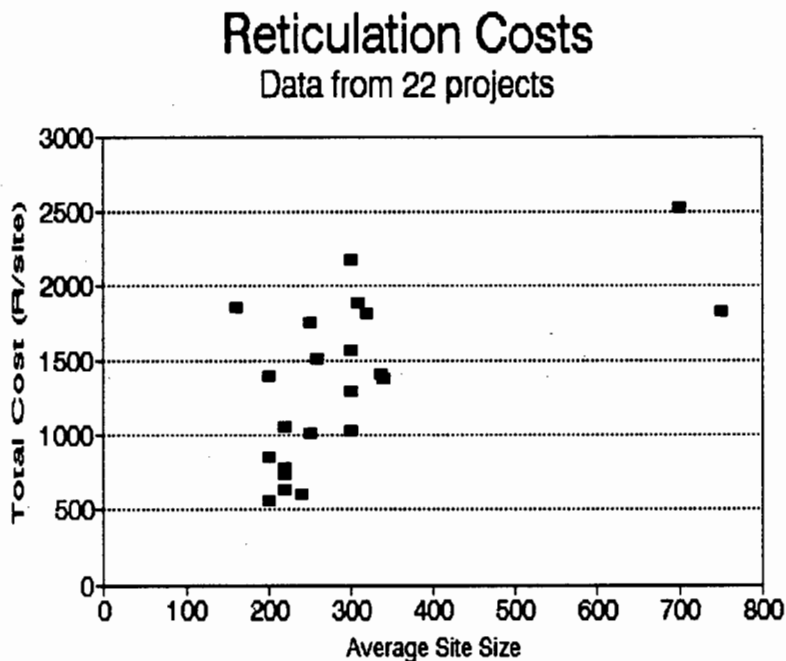
- Average cost R1100 per site
- Range R 500 - R2000 per site

### Reticulation

From a survey of 100 projects financed by the Independent Development Trust (1991 prices escalated by 15 percent) and the CSIR level of service matrix, the average cost per site for sewer reticulation is R1400, ranging from R600 to R2500. From a survey of 28 projects (data supplied by consultants from tender documents; all projects less than 3 years old) plots of the total cost per site vs the plot size, and pipe length per plot, are shown in Figure 10.1 and Figure 10.2 respectively. The plot sizes range from about 180 to 320 m<sup>2</sup> with two projects having sizes in excess of 700 m<sup>2</sup> (Figure 10.1). The pipe length per plot ranges from about 7 m to 17 m with two projects having lengths of greater than 17 m.

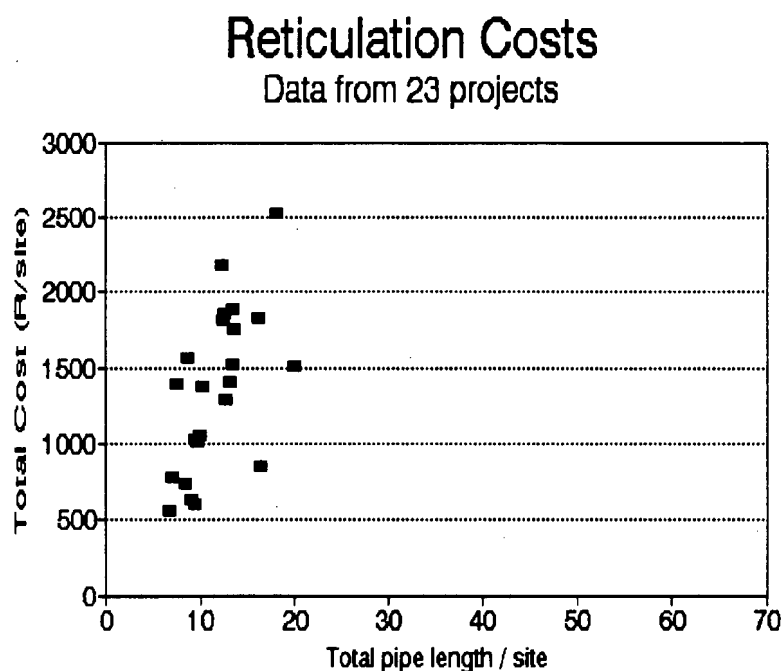
Figure 10.1 shows the correlation between total sewer reticulation cost with plot size.

**Figure 10.1 Reticulation costs vs site size**



The plot in Figure 10.2 shows a fairly strong relationship between total sewer reticulation cost and pipe length per plot. The mean relationship is linear but does not pass through the origin. For each pipe length per plot the total cost can range from about 0.5 to 1.7 times the mean cost for that pipe length.

**Figure 10.2 Reticulation cost vs pipe length**



The following comments are relevant:

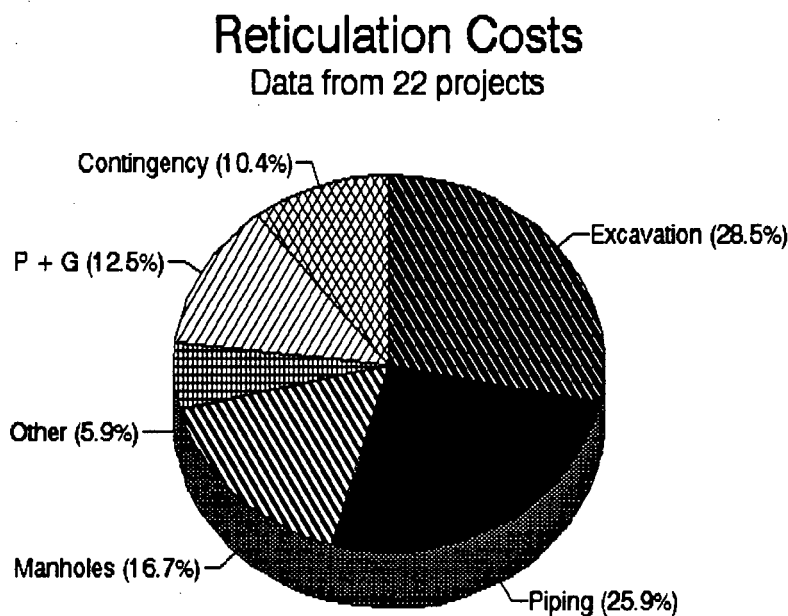
- For economical design the plots should have a narrow frontage as this would accordingly reduce the length of the receiving sewer per plot. (This also would apply to other services, such as water supply reticulation, electrical supply lines, roads.) Plot size should be achieved rather by increasing the depth of the plot, that is, deep narrow plots should be provided.
- To reduce the length of the sullage and sanitary drains, washing and sanitation facilities should be sited as near to the sewer as possible. Midblock sewers are a solution; with the washing and latrine facilities sited at the back of the

plot next to the sewer line. The house or shelter will then also tend to be located toward the back of the plot with open plot space provided at the front of the house.

Principle variations in the cost per pipe length would arise from the plot layout, deep midblock sewer excavation to relieve drainage from both plots to the sewer on steeply sloping sites, and subsurface conditions such as shallow rock and loose sands.

With regard to the relative cost of specific items in providing a waterborne sanitation system, a percentage breakdown for the 22 projects is shown in Figure 10.3 . On average, excavation, pipes and manholes account for 29 percent, 26 percent and 17 percent respectively, that is for 72 percent of the total cost. Preliminary and general costs averaged at 12.5 percent.

**Figure 10.3 Breakdown of reticulation costs**



### Outfall sewer

The cost of the outfall sewer is site-specific, depending primarily on the distance of the township from the treatment works. The PDG/UCT investigation (PDG/UCT, Document B6, 1992) found that the cost of the outfall sewer ranged from R100 to R1000 per site. More relevant figures would possibly have been obtained by comparing the cost per site for a unit sewer length of the different projects if this information had been available.

### Treatment works

The cost of a treatment works varies widely depending on the technology employed, the size of the treatment works and the site conditions. The table below provides a reasonable estimate of treatment works costs as a function of population size and complexity. This table is based on costs presented in the UCT/PDG Document B6, 1992, for activated sludge works. In general capital costs for biofilter works would be higher than for activated sludge whilst oxidation ponds may offer substantial cost savings.

Table 10.3 Treatment works costs for various hydraulic capacities

Hydraulic capacity [Ml/day]	Population equivalent	Cost Range [R per site]
1.5	10 000	1180 - 1930
7.5	50 000	750 - 1030
15.0	100 000	625 - 870
22.5	150 000	500 - 710
60.0	400 000	320 - 550

- Average sewage treatment cost R720 per site
- Range R320 to R1500

These figures were based on the following assumptions:

- an average treatment capacity of 100 000 population equivalents (p.e.'s) in the urban areas of South Africa.
- complex treatment works are not used for small population equivalents (hence reducing the maximum cost from R1900 to R1500).

Table 10.4 Summary of capital costs for waterborne sanitation

Item	Average cost [Rands]	Cost Range [Rands per site]
Superstructure	R1100	R 500 - R2000
Reticulation	R1400	R 600 - R2500
Outfall sewer	R 500	R 100 - R1000
Treatment works	R 700	R 300 - R1500
<b>TOTAL</b>	<b>R3700</b>	<b>R1500 - R7000</b>

### 10.8.2 Operation and maintenance costs

The average operation and maintenance costs and the typical range in these costs that can be expected in maintaining and operating full waterborne sanitation systems are summarised in the table below (source PDG/UCT Document B6, 1992).

Table 10.5 Summary of operating and maintenance costs for waterborne sanitation

	Average Cost [Rands/site/year]	Cost Range [Rands/site/year]
On-site	R 45	R 15 - R 60
Water	R130	R 80 - R240
Reticulation	R 80	R 20 - R120
Outfall	R 15	R 1 - R 30
Treatment	R 33	R 13 - R106
<b>TOTAL</b>	<b>R303</b>	<b>R129 - R556</b>

The survey of local authorities conducted in the first phase of the PDG/UCT Urban Sanitation Evaluation project gave the following average and range for the operation and maintenance of waterborne sanitation:

- average R335 per household per year; and
- range R115 to R500 per household per year.

These figures exclude water consumption and on-site maintenance costs and some may include water supply operation and maintenance costs. A direct comparison between the two sets of figures is therefore difficult, but nevertheless does indicate that the derived figures are approximately correct.

### **10.8.3 Total annual cost per household**

Using an assumed project life,  $N = 20$  years, interest rate of 19 percent and inflation rate of 15 percent, the TACH for a waterborne system using the average capital, operating and maintenance costs listed above will be R563.

## **10.9 ENVIRONMENTAL AND HEALTH CONSIDERATIONS**

When a full waterborne system operates as designed the impact on the environment is quantified and managed. However, when a part of the system or the whole system fails, it poses a serious threat to the environment and to the health of the community. Partial failure can occur in three ways:

- reticulation - pipe blockages;
- pump stations - pump blockages, pump failures or power failures; and
- treatment works - over capacity and/or incorrectly operated and maintained.

Complete failure occurs with:

- failure of the water supply.

In the first three instances the failures may give rise to significant point source organic and nutrient pollution and viral and bacteriological contamination with consequent health risks.

In the fourth instance ie failure of the water supply, the system ceases to function totally and causes an immediate health risk to the community.

**10.10 CONCLUSION**

Waterborne sanitation is designed to satisfy user convenience and at the same time health requirements. Almost sixteen million urban South Africans enjoy the advantages of this system. Waterborne sanitation is a goal for many communities that presently have alternative forms of sanitation or who lack a sanitation system. The cost of waterborne sanitation is, however, too expensive for many communities. Capital subsidies can help make the system more affordable but international experience warns that the operating and maintenance costs must be borne by the community to ensure sustainability.

## CHAPTER 11

### CONCLUSIONS

The sanitary state of 24.5 million urban South Africans was assessed by the PDG/UCT Urban Sanitation Evaluation. While almost 16 million (65 percent) are served by full waterborne sanitation, over 7.6 million (31 percent) are served by bucket latrines, unimproved basic pit latrines or they lack any kind of facility. Numerous systems that offer full health benefits are available for developing communities. The range of options accommodates various water supply levels in both formal and informal housing even at the high densities usually associated with these settlements.

This thesis looked at the factors affecting implementation, operation and sustainability of sanitation systems for developing communities. Key factors were divided into four categories; namely technical, social, economic and environmental.

**Technical factors** in sanitation are usually site-specific. Soil type, topography, surface and groundwater are constraints that are investigated with a site investigation. In addition, the level of water supply available, or planned, is a key factor in determining which sanitation system can be used. Supporting institutional, technical and educational infrastructure is a constraint at a broader community level. Without an appropriate infrastructure international experience suggests that sustainability of any sanitation system is unlikely.

**Social and cultural factors** are shown in nearly all studies addressing the sanitation problems of the urban poor in developing countries to be of great importance in the provision of appropriate technology. This can be done through a community support program. Community acceptance and co-operation and with the information gained from such a program is likely to make the difference between a system that fails and one that succeeds.

**Economic factors** raise two issues when affecting sanitation. The first is the cost of the system to the economy, regardless of who incurs the cost. This is calculated through economic costing principles to give a total annual cost per household. This cost includes

both investment and recurrent costs, properly adjusted to reflect real opportunity costs. The total annualised cost per household is a useful measure of one system against another as different project life spans can still be compared on an equal basis. The second issue raised is the financial cost of the system; that is the actual cost to be borne by the household. Here international experience teaches us that, even if the capital cost of a system is subsidized, the household must be in a position to pay the operating and maintenance costs.

This ensures that the community can afford regular and preventative operating and maintenance costs.

**Environmental and health factors** affecting sanitation are dominated by the consequences of providing on-site sanitation on the health of local and other communities. Pollution and contamination of groundwater is a main concern. In areas where the groundwater is used as a drinking water source, this issue must be investigated with special attention given to groundwaters with high nitrate levels.

The selected sanitation systems evaluated include the basic pit latrine, VIP, basic aqua-privy, self-topping aqua-privy, on-site low flush aqua-privy, bucket system and full waterborne sanitation.

The **basic pit latrine** has been superseded by the ventilated improved pit latrine for reasons of better health and safety and as such the basic pit latrine is not considered as an option in future urban development.

The **ventilated improved pit latrine**, on the other hand, has shown great success nationally and internationally in both low and high density urban developments. The addition of the vent pipe with a fly screen at the top controls odour and fly problems. The low capital and operating and maintenance cost makes it the most affordable of all the sanitation systems reviewed for the urban poor.

The **basic aqua-privy**, like the basic pit latrine, has been superseded by the self topping aqua-privy and the on-site low flush aqua-privy. The **self-topping aqua-privy** and its adaptations and extensions provide a versatile system of sanitation. The system allows total

removal of waste water (both black and grey) generated on-site, for all levels of water supply. Due to a lack of cost data the cost of the system could not be compared to the others evaluated. The **on-site low flush aqua-privy** has been inadequately designed and implemented. This has led to a situation of technical failure and social unacceptance. Guidelines presently being developed will attempt to reverse this situation.

The **bucket system** provides, in many situations, an extremely poor level of sanitation, often only slightly better than no sanitation at all. Taking into account the difficulties with running the system, the immediacy with which health hazards are created with any breakdown or poor operation, and the high cost of providing the system, the bucket system should not be considered as a viable and acceptable sanitation option in urban areas.

**Full waterborne sanitation** is the most extensively used sanitation system in South Africa. It is also the most expensive. Although waterborne sanitation is a goal for many communities it should only become a reality for those that can afford the full operating and maintenance costs. If this policy is not adopted the lack of maintenance will cause a system failure. Government subsidies used to fund operating and maintenance costs are usually inadequate and again the system will inevitably fail. The key issue is to provide a system that is sustainable in the community it is installed to serve and this is best done with a system that the community can afford to have.

In conclusion, only through continued research will new development projects be able to avoid the mistakes of the past and learn from the successful experiences. This research will guide the successful implementation, operation and sustainability of sanitation provision.

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